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16. Abstract

Storm water management issues facing the Texas Department of Transportation (TxDOT) in the late 1980's led to the development of a coordinated research program. The researchers developed methodologies for evaluating the field performance of the Department's most pressing needs that included: erosion-control blankets, channel lining materials, and mulches. From these methodologies, the Hydraulics and Erosion Control Laboratory was designed and constructed.

The objectives of the erosion control research are to determine the effectiveness of erosion control products on various application areas typically located in the highway environment such as slopes and channels. The researchers collect data on the effectiveness or field performance characteristics during one growing season (March - November) and statistically analyze the data. Product effectiveness data include vegetative density coverage and sediment loss measurements based upon soil type and slope condition. Results for the current year support the Texas Department of Transportation's Standard Specifications for Soil Retention Blankets (Erosion-control Blankets and Channel Liners) and Hydraulic Mulches with an *Annual List of Approved Materials*. As an additional level of analysis, the researchers compare previous years' findings with the current year's results and include these results in the interim report(s).

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THE 1994 PERFORMANCE RESULTS FOR EROSION-CONTROL BLANKETS, MULCHES, AND CHANNEL LINERS

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Research Report 1914-4
Research Study Number 7-1914
Research Study Title: Roadside Development and Management Field Laboratory: Erosion Control Material Testing

Sponsored by the
Texas Department of Transportation

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IMPLEMENTATION STATEMENT

The findings from this work have immediate application in the planning, design, construction, and maintenance of highway sites requiring erosion control or vegetation establishment. Research methods used to evaluate the field performance of erosion-control blankets and channel liners (soil retention blankets) should provide engineers and landscape architects with realistic performance characteristics for slopes and channels. Different vegetation management techniques (mulches) are studied in typical roadside environments to provide a basis for specification recommendations.

Results from the study support TxDOT's Annual Approved Materials List included in the Standard Specifications for the Construction of Highways, Streets, and Bridges. Benefits to be recognized include an annually updated listing of the best performing erosion control products and mulches for highway use that will meet minimum performance standards and encourage competitive marketing within the State of Texas. Associated products supported by these research results, such as TxDOT's Standard Specification Details and Specification inserts, will continue to keep TxDOT as a pro-active leader in highway-related environmental concerns.

DISCLAIMER

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LIST OF ABBREVIATIONS AND SYMBOLS

Hydraulics

I	=	Rainfall Intensity in inches per hour
t_c	=	Time of Concentration in minutes
τ_d	=	Shear Stress Force per unit area
γ	=	Unit Weight of Water
d	=	Depth of Flow
S	=	Average Slope of Channel Bottom, Energy Gradient
Pa	=	Pascal (Metric Unit) for Pound-force per Square Foot Conversion
n	=	Manning's Roughness Coefficient

General

K	=	Soil Erodibility Factor
VM	=	Effectiveness Factor (Typically for Vegetative Measures in Erosion Control IE. Non-structural Measures)

SUMMARY

The erosion control industry and the Federal Highway Administration (FHWA) recognize a wide variety of generic materials that may be used as erosion control protection. Erosion-control blankets (referred to by TxDOT as soil retention blankets) that met the Texas Department of Transportation's (TxDOT's) standard specifications for the past twenty years consisted of two products. Technically, products that did not meet the material-based specification were excluded from the specification and bidding process. In response to this practice, TxDOT searched for alternatives that would provide a fair system of selecting and specifying erosion control products based upon their performance. TxDOT and the Texas Transportation Institute (TTI) initiated a cooperative research study in 1989 to help further this initiative.

Once the researchers determined TxDOT's needs and reviewed the current state-of-practice in erosion control, they recommended evaluating erosion control materials based upon their field performance rather than traditional laboratory testing. Since the textile industry developed erosion-control blankets and mats, a variety of laboratory tests were developed to describe standard strength properties such as tensile and shear strength, heat resistance, etc. These tests did not adequately describe or test field performance. Laboratory tests and field observations suggest that there are great variations in strength, durability, soil-blanket interaction, and vegetation response between generic material classifications and manufactured brands of similar materials. Soil-fabric interaction, vegetation establishment, and installation methods are critical factors to consider in figuring out field performance characteristics.

The researchers developed evaluation methodologies for the Department's most pressing needs: erosion-control blankets in varying slope applications, flexible channel liners in varying shear stresses, and hydraulic mulches for vegetation establishment. A state-of-the-art facility was designed and constructed during a two year period to accommodate these application areas and more. Today, the facility is a nine-hectare site that includes approximately three hundred linear meters by six vertical meters of fill embankment, ten at-grade channels, two reservoirs, pumping stations, rainfall simulators, and various instrumentation. The erosion control industry and other state departments of transportation support research methodology as acceptable test methods for highway-related erosion control measures.

Since 1991, an annual evaluation of erosion control products has been studied at the Hydraulics and Erosion Control Laboratory. Data on specific field performance characteristics such as apparent vegetation coverage and sediment loss are collected and analyzed. Vegetation coverage is collected and analyzed by a video/image capture, and interactive, color analysis process. Artificial rainfall simulations provide the researchers with sediment loss ratios. TxDOT uses the data to support their Annual List of Approved Materials and develop standard installation detail sheets as construction document inserts.

Private industry, TxDOT, and TTI cooperatively work to further this important area of environmental research and development.

INTRODUCTION

Storm water management issues facing the Texas Department of Transportation (TxDOT) in the late 1980s led to the development of a coordinated research program with the Texas Transportation Institute (TTI) to research the effectiveness of erosion control materials. The researchers developed methodologies for evaluating field performance of the most widely used erosion control products within the Department's construction and maintenance operations. From these methodologies, the Hydraulics and Erosion Control Laboratory was designed and constructed in two phases during 1990 and 1992. Results from these studies provide the Department with current performance data for erosion control products applied on slopes and in roadside channels. Currently, participants include manufacturers of erosion-control blankets, mulches, and flexible channel lining materials.

As a part of the research program, the researchers established a timely and fair program through which manufacturers' erosion control related materials are evaluated for use in TxDOT's construction and maintenance activities. The research objectives set forth include the following:

- Determine the acceptable performance level in fostering the establishment of vegetative cover and sediment retention for slope and channel application areas within highway rights-of-way.

- Determine acceptable application methods for hydraulically-applied mulch products used for vegetation establishment within highway rights-of-way.

Since beginning the research at TTI, the International Erosion Control Association (IECA) has begun their program of developing industry standards for erosion control-related products. The IECA is an international organization serving as *"a global resource for people who share a common responsibility for the cause, prevention, and control of erosion."* TTI is an internationally recognized transportation institute recognized for its dedication to transportation-related research. The research program conducted at the Hydraulics and Erosion Control Laboratory is nationally recognized as a full-scale highway-related laboratory and program devoted to the better understanding of erosion control product performance. Because of this approach, the researchers consider their work to parallel the IECA's efforts to establish standards for the erosion industry and welcome their participation.

With TxDOT's commitment to specifying erosion control products based upon their field performance, the Department changed its standard specification for *Item 169 - Soil Retention Blanket* (erosion-control blanket) for the Standard Specifications for Construction of Highways, Streets, and Bridges, 1993. Item 169, "Soil Retention Blanket," contains the following requirements:

"Soil Retention Blanket" shall meet the requirements of and be approved by the Chief Engineer of Maintenance and Operations. A list of pretested and approved soil retention blankets will be maintained, and can be obtained by writing the Chief Engineer of Maintenance and Operations, 125 East 11th Street, Austin, Texas, 78701-2483.

In addition, TxDOT changed its standard specification for *Item 164.2(b) - Seeding for Erosion Control, Cellulose Fiber Mulch* (hydraulic mulches) to meet the following requirements:

> *164.2(b) - Cellulose Fiber Mulch. It shall meet the requirements of and be approved by the Director of Maintenance and Operations. A list of pretested and approved materials will be maintained and can be obtained by writing the Director of Maintenance and Operations, 125 East 11th Street, Austin, Texas 78701-2483.*

The results presented within this final report reflect the results from 1994 and the combined results from previous study years. For each study area, multiple statistical analyses indicate product performance levels. This document describes the Hydraulics and Erosion Control Laboratory, provides general background on the research methods, and presents the study results. The results include the following: (1) erosion-control blankets (soil retention blankets) for 1994 and combined with 1991 and 1992; (2) hydraulic mulches for 1994 and combined with 1992 and 1994; and (3) flexible channel liners for 1994.

HYDRAULICS AND EROSION CONTROL LABORATORY

LOCATION

The Hydraulics and Erosion Control Laboratory (formerly the Roadside and Development and Management Field Laboratory) is part of the Texas Transportation Institute's proving grounds. The proving grounds are at the Texas A&M University Riverside Campus, 6.5 km (4 mi) west of Bryan, Texas. The laboratory site is bounded on the north, east, and west sides by runways and an open field to the south. Because the site (originally a military airport facility) is on a ridge just above the Brazos River, harsh climatic conditions exist. The soils are generally low in organic content, and the site is influenced by heat energy stored in, or reflected from the surrounding pavement. These unique physical conditions provide the most realistic conditions possible for conducting controlled experiments related to the roadside environment.

PHASE I CONSTRUCTION: EARTH EMBANKMENT

The first construction phase occurred on TTI's five hectare tract (12.5 acres) in 1990. The researchers built an earthen fill embankment constructed with density control as the compaction method. The Texas State Department of Highways and Public Transportation 1982 Standard Specifications for Construction of Highways, Streets and Bridges governed construction. The density control method was by test method Tex-114-E, and test method Tex-115-E was the compaction control. The Texas Department of Transportation District 17 laboratory in Bryan and the TTI Field Laboratory manager performed field testing.

Nominal dimensions for the "L"-shaped embankment measure 6.75 m (22 ft) vertical height, 267 m (876 ft) in length, 1:2 sloped condition on the west side, and 3:1 sloped condition on the east side. Treatment plots are 6 m (20 ft) across and 15 m (50 ft) or 21 m (70 ft) lengthwise, depending upon the slope condition. The embankment design provides a total of seventy treatment plots, each being 6.2 m (20 ft) wide. One-half of the treatment plots are sandy loam soils (SL)[1] (K=0.38),[2] and the other half are clay soils ©[3] (K=0.20).[4] For the hydraulic mulch evaluations, each treatment plot, "sand" and "clay," is divided into two subplots to collect data on application processes rather than sediment retention characteristics (see figure 1).

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[1]Post-construction soil sample analyzed by SASI, Inc., with reference made to the National Soils Handbook, July 1983, Figure 603-1, "Soil Texture Triangle."

[2]K value determined on post-construction soil sample following the SCS soil erodibility nomograph Predicting Rainfall Erosion Losses-- A Guide to Conservation Planning.

[3]Post-construction soil sample analyzed by SASI, Inc., with reference made to the National Soils Handbook, July 1983, Figure 603-1, "Soil Texture Triangle."

[4]K value determined on post-construction soil sample following the SCS soil erodibility nomograph Predicting Rainfall Erosion Losses -- A Guide to Conservation Planning.

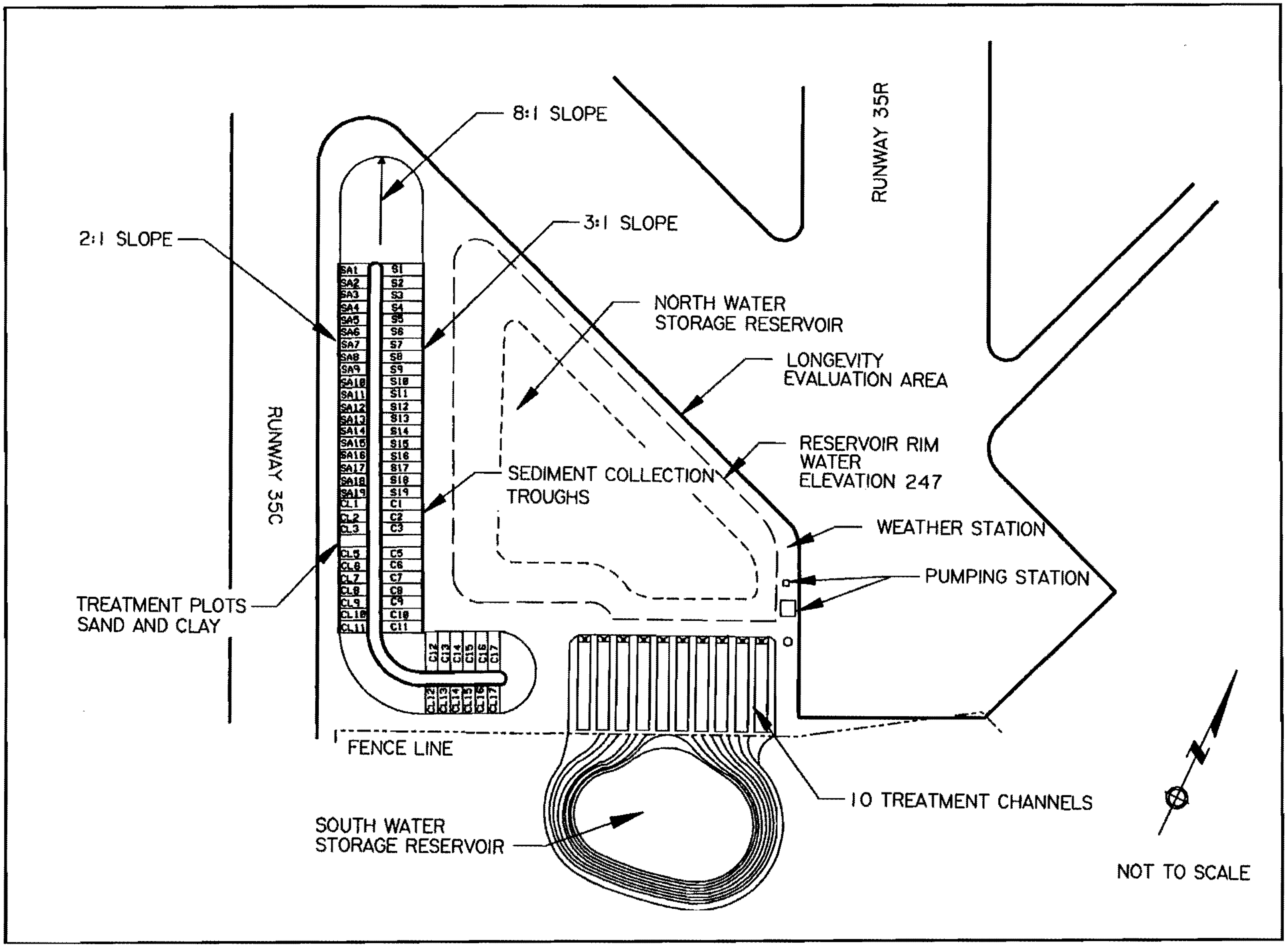

Figure 1. Plan of the Hydraulics and Erosion Control Laboratory.

Sediment collection boxes are at the base of each treatment plot. These boxes are precast concrete sections that were set in the field. Physical dimensions of each box are 607 cm (20 ft) by 46 cm (1.5 ft) wide by 15 cm (0.5 ft) depth. The flow line is "V" shaped giving the box a holding capacity of approximately 418 liters (110 gallons). Removable plywood dividers separate the boxes (see Figure 2).

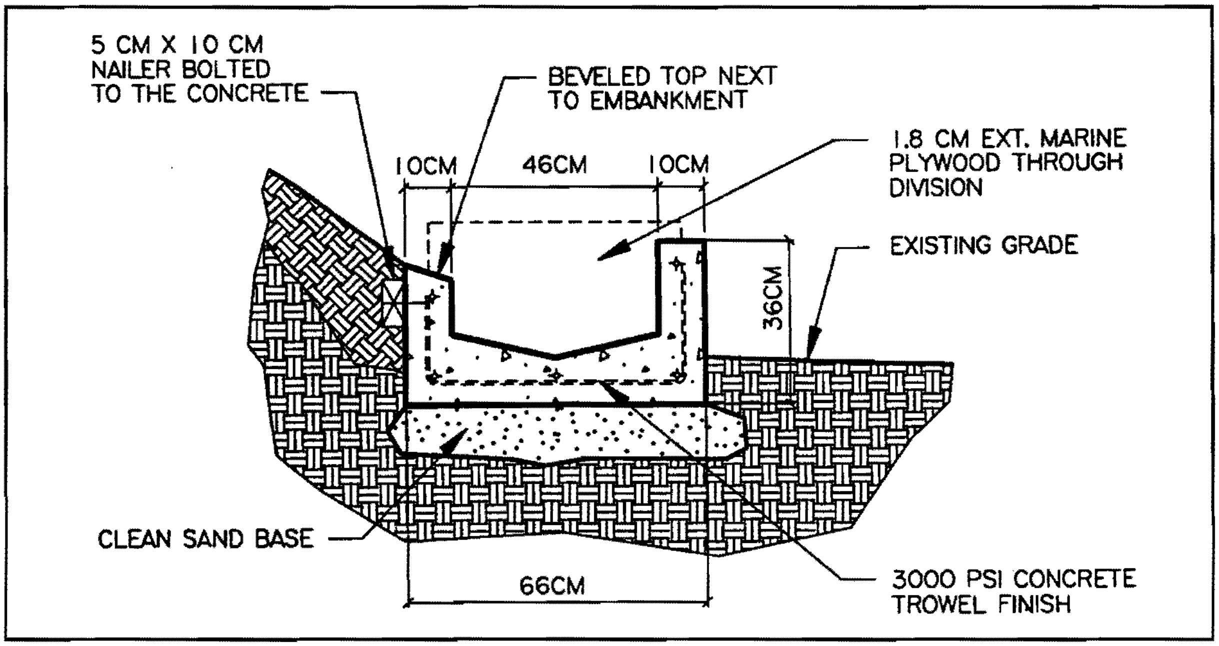

Figure 2. Section through Sediment Collection Trough

Two reservoirs created as the result of the embankment and channel construction have a vertical elevation difference of approximately 1-1/2 m (5 ft). The upper reservoir surface area is 2.43 ha (6.5 ac). This reservoir is the primary water supply source for all of the experimental work. An underground water supply system located along the top of the embankment for the slope treatment plots provides water for simulated rainfall events.

A ten-horsepower centrifugal pump supplies one of four rainfall simulation machines stationed on the embankment. Each simulator unit consists of a series of arms spaced, 1-1/2 m (5 ft) apart mounted on a steel frame and set approximately 0.60 meters (2 feet) above the ground plane. Pressure gauges located on the arms control water flow through the coarse spray, adjustable, irrigation nozzles. The nozzles spray upwards away from the slope face approximately 1 to 1-1/2 m (3-5 ft) to provide greater drop velocity. Each unit may provide 25 - 300 mm (1-11.8 inches) of precipitation per hour as calibrated. Drop size is generally representative of natural rainfall.

The recording weather station equipment was installed at this time and is positioned on-site to provide continuous and accurate climatic conditions. Features of the weather station include a tipping-bucket rain gauge, hygrothermograph, barograph, recording anemometer, and pyronometer.

PHASE II CONSTRUCTION: EARTH CHANNELS

The second construction phase occurred in 1992. Construction consisted of placing a water distribution system (pumping stations, corrugated metal piping, and release structures) and ten at-grade channels (six 7% grade and four 3% grade). An earth embankment built between the two reservoirs provided a base for the excavated channels. Soil analysis for the treatment channels indicated the soil class to be clay ©[5] with a soil erodibility factor of (K = 0.27).[6] Each open channel has a trapezoidal cross section that includes a 0.30 m (1 ft) bottom, 1:1 side slopes, and a typical 0.91 m (3 ft) depth beginning 4.5 m (15 ft) downstream of the channel release. Total length of the test channel section equals 26 m (85 ft) as shown in figure 3. Maximum test flow capacity was provided by modifying the existing south water reservoir and installing a return pumping station to aid in the reuse of test water. Water supplied by an industrial grade, high volume, low head, axial flow pump is capable of producing 136,260 liters per minute (36,000 gallons per minute).

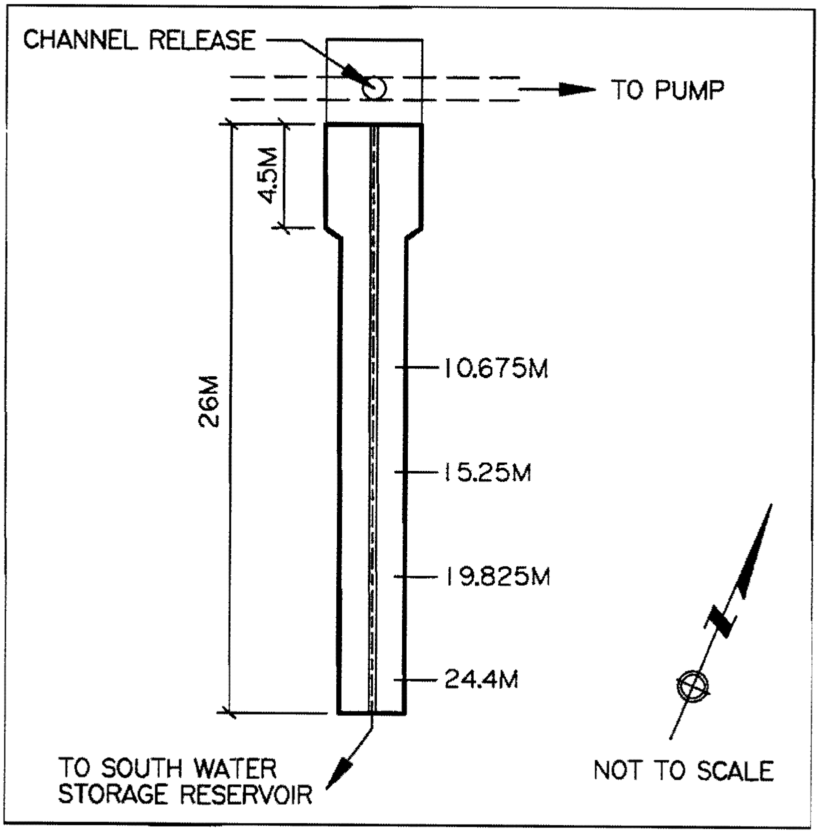

Figure 3. Plan of Treatment Channel and Station Locations.

[5]Post-construction soil sample analyzed by SASI, Inc., with reference made to the National Soils Handbook, July 1983, Figure 603-1, "Soil Texture Triangle."

[6]K value determined on post-construction soil sample following the SCS soil erodibility nomograph Predicting Rainfall Erosion Losses -- A Guide to Conservation Planning.

STUDY OBJECTIVES

OBJECTIVES

The objectives for the research program at the Texas Transportation Institute, Hydraulics and Erosion Control Laboratory are as follows:

- Determine the field performance of erosion-control blankets and flexible channel liners for use in highway rights-of-way based upon field performance evaluations conducted in a simulated highway environment.

- Determine the field performance of hydraulic mulches for use in highway rights-of-way based upon field performance evaluations conducted in a simulated highway environment.

METHODOLOGY

The methods adopted for use in the research program provide a reproducible, defensible experiment for surficial erosion control products. The design and construction of each study area, slope and channel, is at a scale that adequately represents the highway environment. Experimental designs were completely randomized.

EROSION-CONTROL BLANKET STUDY

For the erosion control products on a slope condition, there are treatment and control plots of two replicates, one for each soil type (sand or clay) by slope. Treatments consist of an erosion-control blanket (soil retention blanket) overlaying seeded soil (clay and sandy loam) in a 1:2 and/or 1:3 slope condition. Experimental control consists of four plots receiving the same vegetative treatment for each soil type with no erosion-control blanket in place. Researchers collect and statistically analyze treatment plot data relative to each product's sediment retention performance and apparent vegetative density coverage with respect to soil type and slope condition.

Erosion control criteria are as follows:

- Acceptable erosion-control blankets should reduce the sediment loss from the protected treatment area significantly greater than from bare ground (Control).

- Erosion-control blankets should effectively protect the seed bed from a short duration and one-year return frequency (99% probability of occurrence within a given year) within the first month after installation.

- Erosion-control blankets should effectively protect the seed bed from a short duration and two-year return frequency (50% probability) within the first three months of installation.

- Erosion-control blankets should effectively protect the seed bed from a short duration and five-year return frequency (20% probability of occurrence within a given year) within the first six months of installation.

- In cohesive soils (clay) and a slope condition, sediment loss should be no greater than 0.34 kg/10 m^2 (0.70 lbs/100 sf) during the first six months after installation.

- In non-cohesive soils (sandy) and slopes steeper than 1:3, sediment loss should be no greater than 26.85 kg/10 m^2 (55 lbs/100 sf) during the first six months after installation.

- In non-cohesive soils (sandy) and slopes flatter than 1:3, sediment loss should be no greater than 12.21 kg/10 m^2 (25 lbs/100 sf) during the first six months after installation.

Vegetation establishment criteria will be as follows:

- Acceptable erosion-control blankets should promote significantly greater vegetative cover on the protected treatment area as compared with the bare ground (Control).

- Acceptable erosion-control blankets should promote a vegetative cover within the first six months after installation by protecting the seed bed from the impacts of rain splash and preventing damaging rill formations.

- In cohesive soils (clay) and sloped conditions, vegetation density should reach a minimum coverage of 80% during the first six months after installation.

- In non-cohesive soils (sandy) and sloped conditions, vegetation density should reach a minimum coverage of 70% during the first six months after installation.

Material (natural or synthetic) performance criteria will be as follows:

- Acceptable erosion-control blankets, installed in accordance with the manufacturer's published guidelines, should be able to retain their physical properties during the first six months after installation without developing major rips, sags, tears, joint gaps, or become undermined by excessive rill formations.

- Acceptable erosion-control blankets should provide protection for the seed bed until a sufficient stand of vegetation is established or six months after installation.

Rainfall Simulation

To maintain uniformity throughout a multi-year testing program, all results are based on artificially generated rainfall. The researchers realize there is no way of controlling natural rainfall over the course of the study. All results include a profile of the on-site weather conditions, and the analysis notes and considers any unusual or mitigating events.

Rainfall intensity determination was based upon rainfall intensities of anticipated storms during a typical vegetation establishment period. To adequately model the rainfall simulations for the State of Texas, the researchers chose to derive the rainfall intensity values from a thirty-six-county area that extends between Houston, Dallas, and Austin. This area was chosen since it contains the highest percentage of state maintained highways. The method used to derive the intensity values was the *modified Steel Formula* (7) as shown below:

$$i = \frac{b}{(t_c + d)^e}$$

Where: b, d, and e are constants

The values of the constants b, d and e are from the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) Technical Paper No. 40, "Rainfall Frequency Atlas of the United States." Table 6 of the SDHPT (TxDOT) Hydraulics Manual contains the *I* values for each county. The researchers derived the intensity values for the erosion-control blanket study by computing the values of *I* for the thirty-six county area based upon a short storm duration. The researchers assumed that more damage occurs by the impacts of rain splash in a steep slope situation (3:1 or greater) subjected to short duration, high probability design storms than from a moderate slope situation (4:1 or less) with a larger runoff area. Therefore, the storm duration, t_c, was ten minutes since the majority of disturbed slopes (cut slopes and embankments) are at the upper limit of the micro-watershed.

Vegetation Coverage

The seeding mixtures selected by the research team are from TxDOT's standard seeding specification, *Item 164 - Seeding for Erosion Control* published in the 1993 TxDOT Standard Specifications for Construction of Highways, Streets, and Bridges (8). Since the laboratory is located in the Bryan District, the rural area species for warm-season perennial vegetation were hydraulically applied in a one-step application process. A one-step process, where seed and fertilizer are in a water slurry and sprayed by a hydro seeder, is the most typical application method used by TxDOT. Specific mixtures selected included a mixture for clay or tight soils and a mixture for sand or sandy soils. In clay or tight soils, the recommended seed mixture includes the following species and rates given in kilograms (pounds) of pure live seed per 0.405 hectare (1 acre):

- Green Sprangletop 0.2724 kg/0.405 ha (0.60 lbs/ac)
- Bermudagrass 0.3632 kg/0.405 ha (0.80 lbs/ac)
- Little Bluestem 0.4994 kg/0.405 ha (1.10 lbs/ac)

- Indian grass (Lometa) 0.6810 kg/0.405 ha (1.50 lbs/ac)
- K-R Bluestem 0.3178 kg/0.405 ha (0.70 lbs/ac)
- Switch grass (Alamo) 0.5448 kg/0.405 ha (1.20 lbs/ac)

In sand or sandy soils, the recommended seed mixture includes the following species and rates given in kilograms (pounds) of pure live seed per 0.405 hectares (1 acre):

- Green Sprangletop 0.4994 kg/0.405 ha (1.10 lbs/ac)
- Bermuda grass 0.6810 kg/0.405 ha (1.50 lbs/ac)
- Bahia grass (Pensacola) 3.0418 kg/0.405 ha (6.70 lbs/ac)

The research team needed data that would accurately depict the vegetative density or apparent vegetative cover for the first growing season. After experimenting with several data collecting methods, the researchers chose a computer-based process, *VeCAP,* to analyze the samples. The process selected is reproducible and is a cost efficient data collection method. *VeCAP* or Vegetation Coverage Analysis Program, calculates the percentage of pixels in a sample image by color. Sample images recorded in the field are converted to single digital images using a TARGA 16 board and TIPS software, and imported into the *VeCAP* program (see figures 4, 5). The researcher records the percentage of vegetation for each analyzed image.

Figure 4. Researcher Recording VeCAP Samples in the Field.

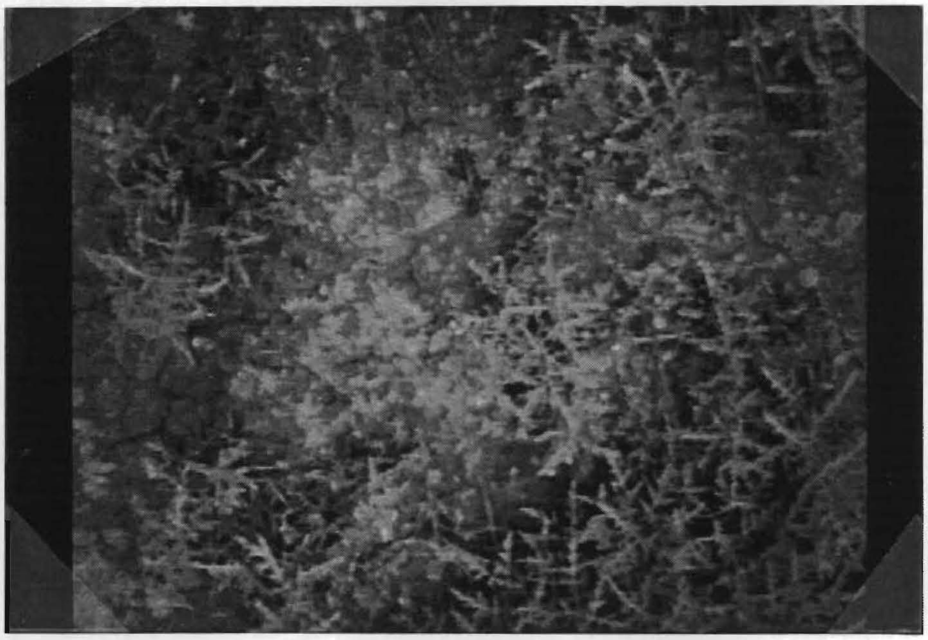

Figure 5. A VeCAP Sample Image Used in the Vegetation Analysis.

The sediment retention and vegetation density data were analyzed by the Statistical Analysis System, SAS, and Duncan's Multiple Range Test ($P<0.05$) which separates sample means into similar groupings. Material performance is documented, but no data is included in the Duncan's Multiple Range test.

HYDRAULIC MULCH STUDY

The Texas Department of Transportation hydraulic mulch specification, originally written in 1982 and slightly modified in 1993, adopted the methodology that a two-step application process was better for vegetation establishment than a one-step application process (6). The research team did not find sufficient knowledge to support this assumption. Based upon these findings, the researchers recommended that these past assumptions be validated through the research program for the potential economical benefits to the Department. Cost savings found would include reduced labor costs directly related to a faster application process by the contractor. Once this information becomes known, the Department may change their recommendations for hydraulic mulch application.

Vegetation establishment criterion is as follows:

- Acceptable hydraulic mulch products should promote significantly greater vegetative cover on the protected treatment area as compared with the bare ground (Control).

- Acceptable hydraulic mulches should promote a vegetative cover within the first six months after installation by protecting the seed bed from the impacts of rain splash.

- In cohesive soils (clay) and sloped conditions, vegetation density should reach a minimum coverage of 50% during the first six months after installation.

- In non-cohesive soils (sandy) and sloped conditions, vegetation density should reach a minimum coverage of 50% during the first six months after installation.

The vegetation density data are statistically analyzed by the Statistical Analysis System, SAS, and Duncan's Multiple Range Test ($P<0.05$) which separates sample means into similar groupings.

FLEXIBLE CHANNEL LINER STUDY

For the erosion control products in a channel condition, there are treatment plots and a control plot of one replicate on a cohesive (clay) soil in either a 7% or 3% gradient. Treatments consist of flexible channel liners (erosion-control blanket) overlaying seeded soil. Experimental control consists of one channel receiving the same vegetative treatment with no erosion-control blanket in place. Treatment plots are analyzed for their sediment retention performances (channel deformation) and apparent vegetative density coverage with respect to shear stress capacity range. The researchers documented material performance, but the analysis does not include statistical data.

Erosion control criteria are as follows:

- Acceptable flexible channel liners should reduce the sediment loss and channel degradation from the protected treatment area significantly greater than from bare ground (Control).

- Flexible channel liners should effectively protect the seed bed from a short duration flow that produces less than 95.76 Pa (2 lbs/ft^2)[7] shear stress on the channel bottom within the first 90 days after installation.

- Flexible channel liners should effectively protect the channel surface within the maximum permissible tractive force category, Pa, (lbs/ft^2) as published by the manufacturer for product use and conditions.

[7]Based upon FHWA, Hydraulic Engineering Circular No. 15.

Vegetation establishment criteria are as follows:

- Acceptable flexible channel liners should promote significantly greater vegetative cover on the protected treatment area as compared with bare ground (Control).

- Acceptable flexible channel liners should promote a vegetative cover within the first six months after installation by protecting the seed bed from the impacts of shear stress from water flow and rain splash from raindrop velocity.

- In cohesive soils (clay), vegetation density should reach and maintain a minimum coverage of 70% during the first six months after installation.

Shear Stress Data
In straight line channels, the maximum tractive force occurs on the bottom and near the center of the channel. The force generated at this point is a function of *Y*, the unit weight of water; *d*, the depth of flow; and *S*, the average slope of the channel bottom (energy gradient). This relationship allows the designer to estimate the maximum permissible tractive force with a single calculation as follows:

$$\tau_d = YdS$$

In Hydraulic Engineering Circular No. 15, the maximum recommended shear stress values for flexible channel liners were 95.76 Pa (2 lbs/ft^2). The research work accomplished at TTI continues the Federal Highway Administration's work cited in the Federal Highway Administration's Hydraulic Engineering Circular 15. Possible maximum working shear stresses generated are approximately 191.52 Pa (4 lbs/ft^2) in the 3% sloped channels and 431.10 Pa (9 lbs/ft^2) in the 7% sloped channels at the Hydraulics and Erosion Control Laboratory. The data collected should suggest breakdown points in field performance under an incremental level of shear stress.

Flow simulations conducted to emulate field conditions after short duration, micro-watershed area, drainage ditch flow is the primary data generator. At the beginning of a flow, the water slowly leaves the vertically-piped opening and travels down the channel reaching uniform flow after 15 m (50 ft). The water level rises until achieving the desired depth. Velocity and depth measurements are taken at different locations along the channel during the flow. Once the flow has reached the benchmarks for the shear stress level, the flow continues for twenty minutes. When twenty minutes have passed, the researchers turn the pump off and the water subsides quickly.

Vegetation Coverage
The seeding mixtures selected by the research team are from TxDOT's standard seeding specification, *Item 164 - Seeding for Erosion Control* published in the 1993 TxDOT Standard

Specifications for Construction of Highways, Streets, and Bridges (8). Since the laboratory is located in the Bryan District, the rural area species for warm-season perennial vegetation were hydraulically applied in a one-step application process. A one-step process, where seed and fertilizer are in a water slurry and sprayed by a hydro seeder, is the most typical application method used by TxDOT. Specific mixtures selected included a mixture for clay or tight soils and a mixture for sand or sandy soils.

In clay or tight soils, the recommended seed mixture includes the following species and rates given in kilograms (pounds) of pure live seed per 0.405 hectares (1 acre):

- Green Sprangletop 0.2724 kg/0.405 ha (0.60 lbs/ac)
- Bermuda grass 0.3632 kg/0.405 ha (0.80 lbs/ac)
- Little Bluestem 0.4994 kg/0.405 ha (1.10 lbs/ac)

- Indian grass (Lometa) 0.6810 kg/0.405 ha (1.50 lbs/ac)
- K-R Bluestem 0.3178 kg/0.405 ha (0.70 lbs/ac)
- Switch grass (Alamo) 0.5448 kg/0.405 ha (1.20 lbs/ac)

The sediment retention and vegetation density data are analyzed by the Statistical Analysis System, SAS, and Duncan's Multiple Range Test ($P<0.05$), which separates sample means into similar groupings. Material performance is documented, but no data is included in the Duncan's Multiple Range test.

DESCRIPTION OF MATERIALS FOR THE 1994 CYCLE

The erosion control products were categorized into three varying degrees of definition by the researchers. Generic material type, primary material classification, and trade or brand names are shown in the first three columns of tables A, B, and C. The last column documents steepness of the slope condition or channel gradient as requested by the manufacturer for the 1994 cycle.

Table A. Description of Erosion-control Blankets for the 1994 Cycle.

Generic Classification	Material Classification	Brand Name of Material Evaluated	Slope or Channel Condition
Organic	Coir	GEOCOIR®/DEKOWE® 700	1:2
	Excelsior	American Excelsior Curlex®	1:2 & 1:3
	Gypsum	AIRTROL® Plaster	1:2 & 1:3
	Jute	GEOJUTE PLUS®	1:2
	Wood Fiber/Natural Binder	Soil Guard™	1:2
Synthetic	Polypropylene composite	SuperGro®	1:2 & 1:3
	Polypropylene or PVC monofilaments	MIRAMAT™ 1000	1:2

Table B. Description of Hydraulic Mulches for the 1994 Cycle.

Generic Classification	Material Classification	Brand Name of Material Evaluated	Slope Condition
Organic	Recycled Cellulose Wood Fiber	PRO MAT	1:3
	Recycled Cellulose Wood Fiber (long fibers)	PRO MAT XL	1:3
	Recycled Cellulose Wood Fiber with RMB Plus (tackifier)	PRO MAT w/ RMB Plus	1:3
	Recycled Paper	American Fiber Mulch®	1:3
	Virgin Wood Fiber with 3% Tackifier	Silva-Fiber® Plus	1:3

Table C. Description of Flexible Channel Lining Materials for the 1994 Cycle.

Generic Classification	Material Classification	Brand Name of Material Evaluated	Channel Condition
Organic	Coir	GEOCOIR®/DEKOWE® 900	3%
	Excelsior	XCEL Super Duty	3%
		Hi-Velocity Curlex® Blanket	3%
Synthetic	Polypropylene	MIRAMAT™ 1000	7%
		North American Green P300P	7%
	PVC	GREENSTREAK® PEC-MAT®	7%
	Polyolefin Fibers	TENSAR® Erosion Blanket TB-1000	7%
		LANDLOK® ECRM 450	7%
	Nylon Net	ENKAMAT® 7020	7%

For each study area, there were bare ground treatment plots (Controls) replicated on the 1:2, 1:3, and channel application areas for each soil type. The Controls were prepared in the same manner as the product treatment plots or channels. All erosion-control blanket treatment controls were subjected to the identical rainfall simulations and vegetative density measurements as the product treatment plots. The set of mulch treatment controls had vegetative density measurements taken throughout the growing season. A leaking pipe damaged the channel control for the 1994 season.

MANUFACTURER MATERIAL DESCRIPTIONS

The researchers evaluated seven erosion-control blankets, five mulches, and nine flexible channel lining materials for the 1994 cycle. These results include material description to document the product information as provided by the manufacturer. When applicable, a photograph is included for reference. The first seven descriptions are *erosion-control blanket material descriptions.*

Erosion-control Blanket 1 - AIRTROL® Plaster. AIRTROL® Plaster is made by the U.S. Gypsum Company, a subsidiary of USG Corporation, based in Chicago, Illinois. AIRTROL® Plaster is a cementitious binder which, when mixed with water and mulch, sets in a controlled way to form a crust. It is produced from high purity gypsum deposits. AIRTROL® Plaster is nontoxic, noncombustible, and harmless to fish, birds, plants, and animals. AIRTROL® Plaster is applied as a single application using conventional hydro seeding equipment.

Erosion-control Blanket 2 - American Excelsior Curlex®. American Excelsior Curlex® is manufactured by the American Excelsior Company based in Arlington, Texas. Curlex is made from curled and seasoned Aspen wood excelsior reinforced with Polypropylene netting. The top side is covered with a photo degradable extruded plastic mesh adhered to the wood excelsior. The blanket is smolder-resistant without the use of chemical additives.

Table D. American Excelsior Curlex® Product Specifications.

MATERIAL SPECIFICATIONS	
Wood Excelsior	80% 152.4 mm (6 in) or longer
Weight	0.44 kg/0.83 m^2, (0.98 lbs/yd^2)
Mesh	Black Plastic
ROLL SPECIFICATIONS	
Width	1.22 m (4 ft)
Length	54.90 m (180 ft)
Weight	35.41 kg (78 lbs)
Area	66.88 m^2, (80 yd^2)

Source: American Excelsior Curlex® product installation guidelines, 1993. Metric conversions are shown to comply with metrication reporting procedures.

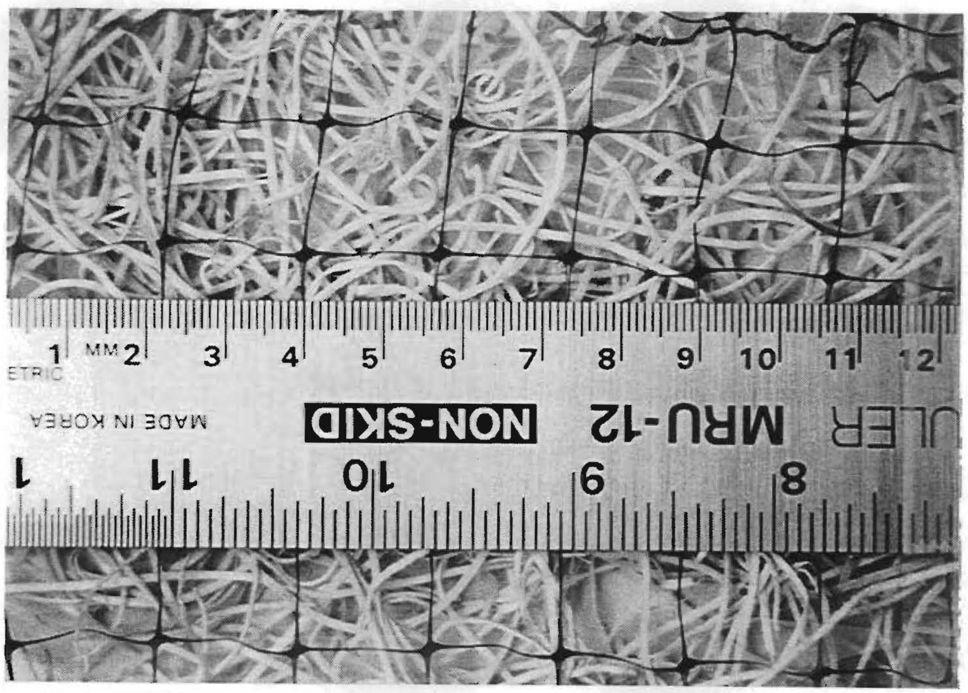

Figure 6. American Excelsior Curlex® Photograph.

Erosion-control Blanket 3 - GEOJUTE® PLUS. GEOJUTE PLUS® is manufactured by Belton Industries, Inc. Based in Atlanta, Georgia. GEOJUTE PLUS® is made from non-toxic natural jute fibers that are undyed and unbleached. At least 78 per width, warp, and 42 per linear yard, weft, are the yarn counts. GEOJUTE® PLUS decomposes within two years after installation.

Table E. Belton Industries GEOJUTE® PLUS Product Specifications.

MATERIAL SPECIFICATIONS	
100% Woven Jute	
Weight	0.42 kg/0.83 m², (0.92 lbs/yd²)
Yarn Count	Warp - 78, Weft - 42
Grab Tensile - Dry	136.2 kg/0.305 m (300 lbs/ft)
Grab Tensile - Wet	56.75 kg/0.305 m (125 lbs/ft)
Elongation at Break	10%
ROLL SPECIFICATIONS	
Width	1.22 m (4 ft)
Standard Lengths	68.63 m (225 ft), 44.84 m (147 ft)
Weight varies with Roll Length	41.77 kg (92 lbs), 27.24 kg (60 lbs)
Area varies with Roll Length	83.6 m² (100 yd²), 54.34 m² (65 yd²)

Source: Belton Industries, Inc., GEOJUTE® PLUS product installation guidelines, 1993. Metric conversions are shown to comply with metrication reporting procedures.

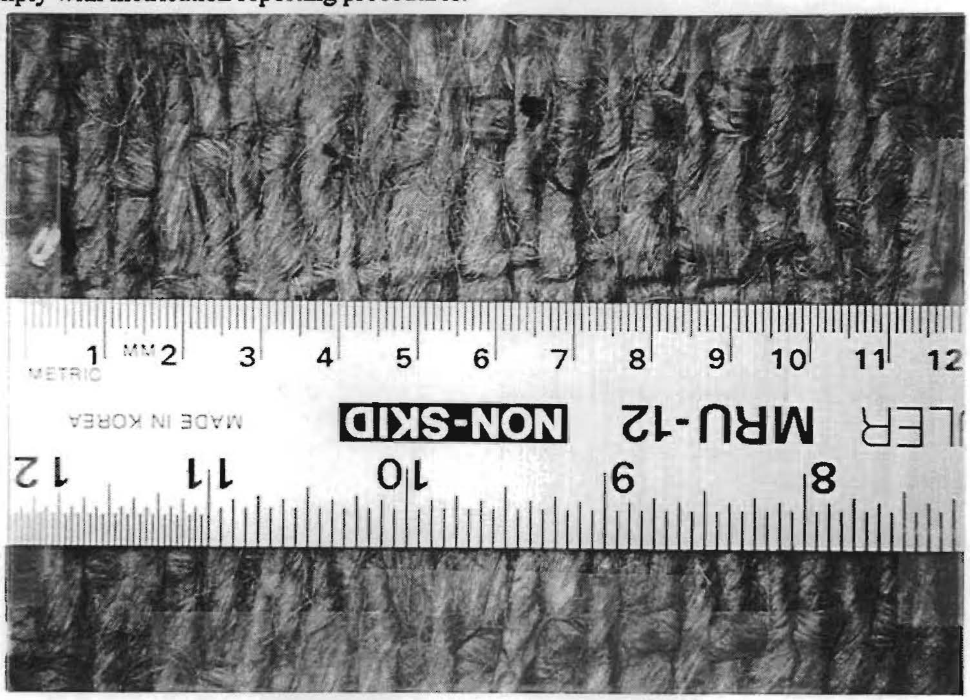

Figure 7. GEOJUTE® PLUS Photograph.

Erosion-control Blanket 4 - DEKOWE® 700. DEKOWE® 700, also marketed as GEOCOIR®, is manufactured by Belton Industries, Inc., based in Atlanta, Georgia. DEKOWE® 700 is made from Coir fibers that come from coconut husks. The composition of coir fibers is about 45% lignin that gives it a high tensile strength and provides resistance to rotting.

Table F. Belton Industries DEKOWE® 700 Product Specifications.

MATERIAL SPECIFICATIONS	
Composition	100% Spun Coir
Weight	700 g/m^2, (1.25 lbs/yd^2)
Yarn Count	Warp - 88, Weft - 64
Grab Tensile - Dry	24.97 kg (55 lbs)
Grab Tensile - Wet	18.16 kg (40 lbs/ft)
Elongation - Dry, Wet	29%, 35%
ROLL SPECIFICATIONS	
Standard Widths	1,2,3,4 m (39.3, 78.7, 118.1, 157.5 in)
Standard Length	50 m (55 yds)
Weight varies with Roll Width	34.96, 69.92, 104.87, 140.29 kg
Area Varies with Roll Width	50, 100, 150, 200 m^2

Source: Belton Industries, Inc., DEKOWE® 700 product installation guidelines, 1994. Metric conversions are shown to comply with metrication reporting procedures.

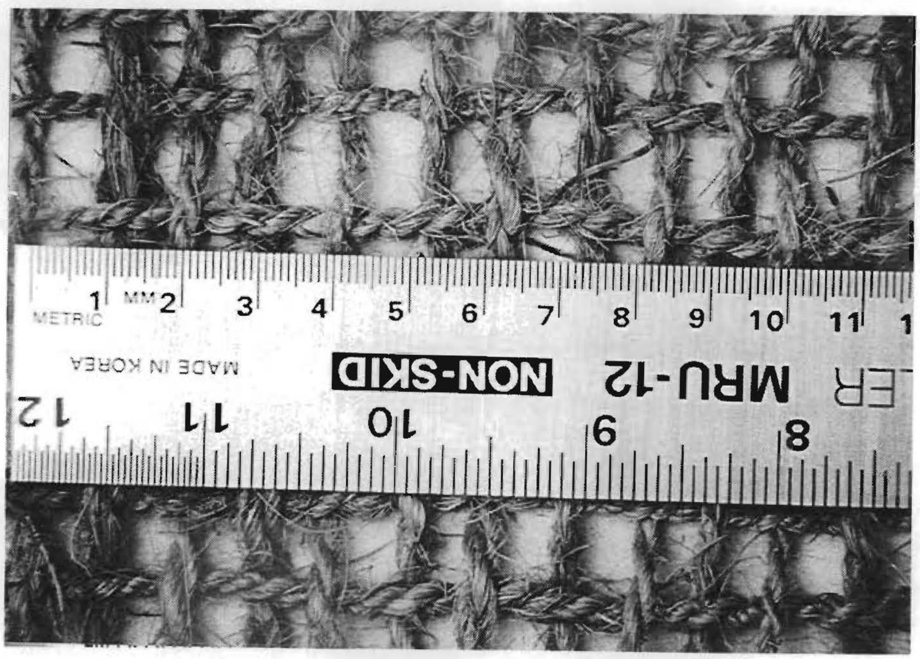

Figure 8. Belton DEKOWE® 700 Photograph.

Erosion-control Blanket 5 - MIRAMAT™ 1000. MIRAMAT™ 1000 was developed by the engineers at Mirafi® in cooperation with the 3M Company. The Nicolon Corporation owns the trademarks Mirafi® and MIRAMAT™. The manufacturers of Mirafi® include the Nicolon Corporation/Mirafi® based in Norcross, Georgia and the 3M Corporation based in St. Paul, Minnesota. MIRAMAT™ 1000 is a three-dimensional web of bonded Polypropylene created for light-to-moderate installation environments.

Table G. Nicolon Corporation/Mirafi® MIRAMAT™ 1000 Specifications.

MATERIAL SPECIFICATIONS	
Composition	Polypropylene
Weight	272.16 g/0.83 m², (9.6 oz/yd²)
Thickness	2.44 mm (0.31 in)
Tensile Strength - Machine Direction	9.99 kg (22 lbs)
Tensile Strength - Cross Direction	5.45 kg (12 lbs/ft)
Elongation - Machine, Cross	40%, 35%
ROLL SPECIFICATIONS	
Width	1.31 m (4.3 ft)
Length	64.05 m (210 yds)
Weight	29.51 kg (65 lbs)
Area	83.6 m² (100 yd²)

Source: Mirafi®, MIRAMAT™ 1000 product installation guidelines, 1993. Metric conversions are shown to comply with metrication reporting procedures.

Figure 9. MIRAMAT™ 1000 Photograph.

Erosion-control Blankets 6 - SuperGro®. SuperGro® is made by Amoco Fabrics and Fibers Company based in Austell, Georgia. A flexible composite, SuperGro® consists of a non-woven Polypropylene fiber blanket reinforced with Polypropylene netting.

Table H. Amoco Fabrics and Fibers Company, SuperGro® Specifications.

MATERIAL SPECIFICATIONS	
Composition	Polypropylene
Weight	28.35 g/0.83 m², (1 oz/yd²)
Flammability Test	CS191-93
ROLL SPECIFICATIONS	
Width	2.44 m (8 ft)
Length	228.75 m (750 yds)
Weight	20.43 kg (45 lbs)
Area	558 m² (667 yd²)

Source: Amoco Fabrics and Fibers Company, SuperGro® product installation guidelines, 1994. Metric conversions are shown to comply with metrication reporting procedures.

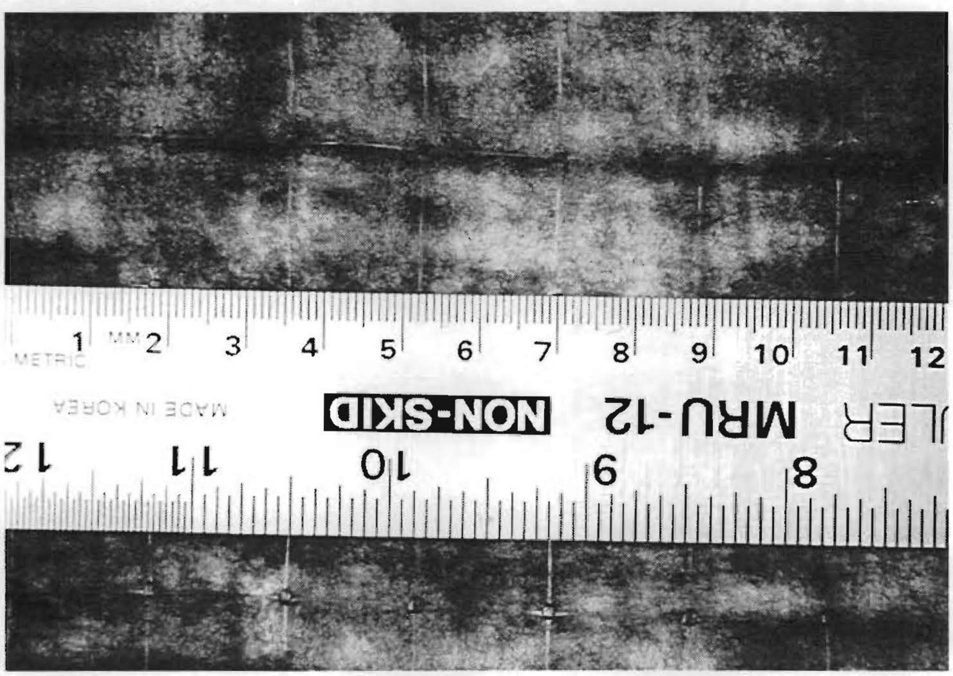

Figure 10. SuperGro® Photograph.

Erosion-control Blanket 7 - Soil Guard™. Soil Guard™ is made by the Weyerhauser Company based in Tacoma, Washington. Soil Guard™ is a bonded fiver matrix produced from 100% wood fiber with an added binder for increased erosion control. The product disperses rapidly in water and remains in uniform suspension under agitation and may be applied with hydraulic planting equipment. Soil Guard™ is biodegradable and non-toxic.

Table I. Weyerhauser Company Soil Guard™ Specifications.

MATERIAL SPECIFICATIONS	
Composition	90% Wood Fiber, 9% Natural Binder, 1% Organic and Mineral Activators
Moisture Content	12 (+/- 3)% by Weight
Mixing Specification	22.7 kg (50 lbs) Soil Guard™ to 473.13 l (125 gal) water
Application Method	Approved for Bowie Hydro-Mulchers® and Finn Hydroseeders®
Application Rate	1,362 - 1,816 kg (3,000 - 4,000 lbs), dry per 0.405 ha (1 acre)
Surface Thickness	3.175 - 4.763 mm (1/8 - 3/16 in)
Color	Yellow
Water Resistance	More than 99% by Weight after Dried

Source: Weyerhauser Company, Soil Guard™ product installation guidelines, 1994. Metric conversions are shown to comply with metrication reporting procedures.

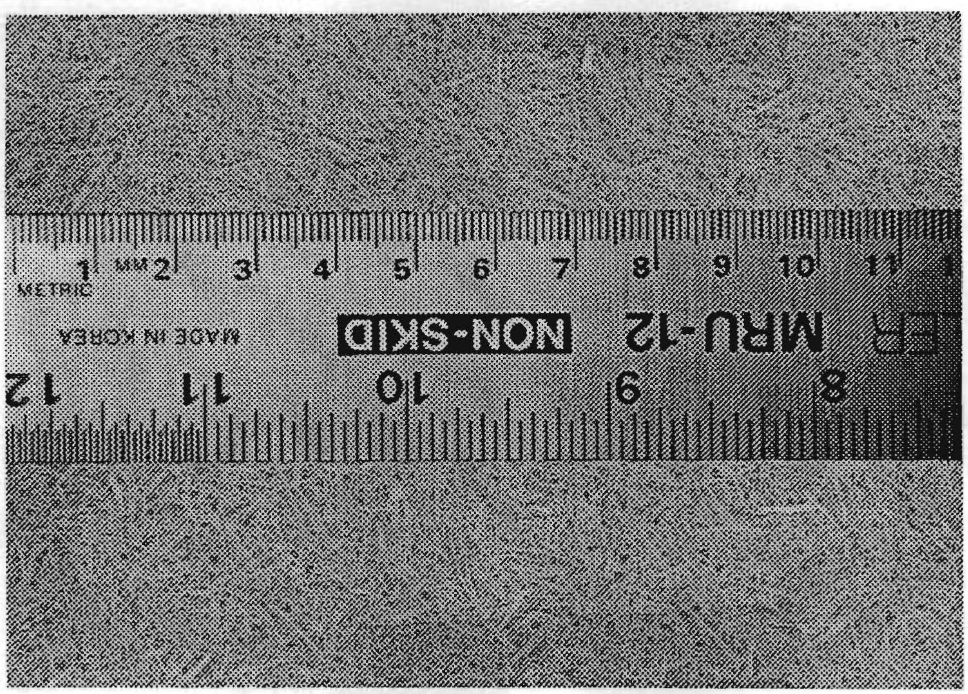

Figure 11. Weyerhauser Soil Guard™ Photograph.

The following five descriptions are *hydraulic mulch descriptions.*

Hydraulic Mulch 1 (Clay Soil) - American Fiber Mulch® with HYDRO-STIK. American Fiber Mulch® is made by American Fiber Manufacturing, Inc., based in Austin, Texas. HYDRO-STIK is a special gum-based tackifier made by the Finn® Corporation based in Fairfield, Ohio. American Fiber Mulch® is produced from recycled paper. The manufacturer does not have any published literature for further product information. The Finn® Corporation literature recommends the product application rate to be 18.16 - 27.24 kg (40-60 lbs) in 5,677.5 l (1,500 gal) of water per 0.405 ha (1 ac).[8]

Hydraulic Mulch 1 (Sand Soil) - American Fiber Mulch® with FIBER-PLUS. American Fiber Mulch® is made by American Fiber Manufacturing, Inc., based in Austin, Texas. FIBER-PLUS is a specially coated synthetic fiber to improve the tenacity and bonding of all fiber mulches made by the Finn® Corporation based in Fairfield, Ohio. American Fiber Mulch® is produced from recycled paper. The manufacturer does not have any published literature for further product information. The Finn® Corporation literature recommends the product application rate to be 1.362 kg (3 lbs) for a 1,892.5 l (500 gal) hydro seeder.[9]

Hydraulic Mulch 2 - PRO MAT. PRO MAT is made by Tascon, Inc., based in Houston, Texas. PRO MAT is a natural cellulose wood fiber hydro-mulch material manufactured from 85% recycled newspaper and milled into mulch under a strict quality control program. PRO MAT meets or exceeds the requirements for virgin wood cellulose mulch. It contains less than 1.6% ash (dust) content, has a moisture content of not more than 15%, a pH of 6.5 +/- 1, and a minimum 90% water holding capacity.[10]

Hydraulic Mulch 3 - PRO MAT XL. PRO MAT XL is made by Tascon, Inc., based in Houston, Texas. PRO MAT XL is a natural cellulose wood fiber hydro-mulch material manufactured from 85% recycled newspaper and milled into mulch under a strict quality control program. PRO MAT XL meets or exceeds the requirements for virgin wood cellulose mulch. It contains less than 1.6% ash (dust) content, has a moisture content of not more than 15%, a pH of 6.5 +/- 1, and a minimum 90% water holding capacity. PRO MAT XL is produced from extra long corrugated fibers for applications when increased density is desirable.[11]

Hydraulic Mulch 4 - PRO MAT with RMB Plus. The PRO MAT product is the same product described above, Hydraulic Mulch 2 made by Tascon Inc. RMB Plus is a tackifier made by Reinco Mulch Binder Corporation based in Plainfield, New Jersey. RMB Plus is a nonflammable, nonasphaltic, naturally occurring beige powder blended from a hydrophilic

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[8]Source: American Fiber Manufacturing, Inc. and Finn® Corporation product literature, 1994.

[9]Source: American Fiber Manufacturing, Inc. and Finn® Corporation product literature, 1994.

[10]Source: Tascon Inc. product literature, 1994.

[11]Source: Tascon Inc. product literature, 1994.

colloidal clay compound mixed with special gelling agents and growth stimulants. The application rates recommended by the manufacturer are 45.4 kg (100 lbs) per 0.405 ha (1 ac) for a slope steepness less than 1:2.[12]

Hydraulic Mulch 5 - Silva-Fiber® Plus. Silva-Fiber® Plus is made by the Weyerhauser Company based in Tacoma, Washington. Silva-Fiber® Plus is 100% virgin wood fiber with 3% tackifier. Table J shows the product specifications.

Table J. Weyerhauser Company Silva-Fiber® Specifications.

MATERIAL SPECIFICATIONS	
Composition	100% Virgin Wood Fiber with 3% Tackifier
Moisture Content	12 (+/- 3)% by Weight
Organic Matter (oven-dried weight basis, min.)	99.0%
Inorganic (ash) content (oven-dried weight basis, max.)	1.0%
pH at 3% consistency in water	4.7
Water-holding Capacity	1,000 g/100g (1.2 gal/lb fiber)
Tackifier Content (Weight Basis)	3%

Source: Weyerhauser Company, Silva-Fiber® Plus product installation guidelines, 1994. Metric conversions are shown to comply with metrication reporting procedures.

[12]Source: Tascon Inc. product literature, 1994 and Reinco Mulch Binder Corporation product literature, 1994.

The following nine descriptions are *flexible channel lining materials.*

Flexible Channel Liner 1 - ENKAMAT® 7020. ENKAMAT® 7020 is made by AKZO Industrial Systems Company based in Asheville, North Carolina. ENKAMAT® 7020 is a three-dimensional geomatrix of heavy nylon monofilaments fused at their intersections.

Table K. AKZO Industrial Systems Company ENKAMAT® 7020 Specifications.

MATERIAL SPECIFICATIONS	
Composition	Nylon 6 plus 2% by Weight of Carbon Black
Weight	340.2 g/0.836 m^2 (12.0 oz/yd^2)
Thickness	19.05 mm (0.75 in)
Tensile Strength - Length	113.5 kg/0.305 m (250 lbs/ft)
Tensile Strength - Width	54.48 kg/0.305 m (120 lbs/ft)
Elongation - Length, Width	75%, 75%
ROLL SPECIFICATIONS	
Width	0.99 m (3.25 ft)
Length	84.49 m (277 yds)
Weight	34.96 kg (77 lbs)
Area	83.6 m^2 (100 yd^2)

Source: AKZO Industrial Systems Company, ENKAMAT® 7020 product installation guidelines, 1993. Metric conversions are shown to comply with metrication reporting procedures.

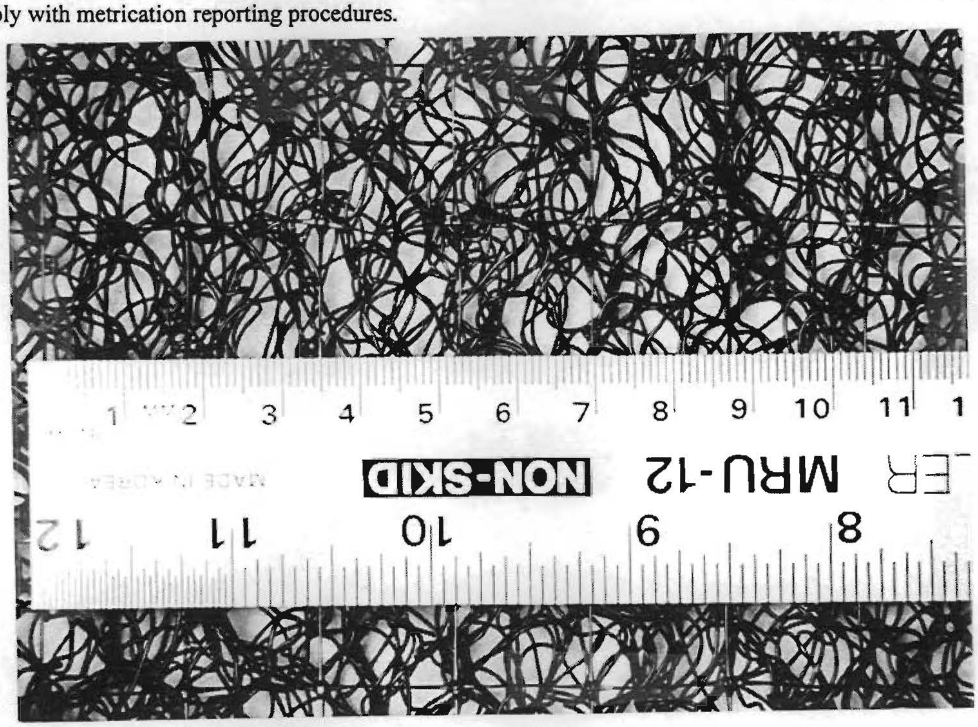


Figure 12. ENKAMAT® 7020 Photograph.

Flexible Channel Liner 2 - American Excelsior Hi-Velocity Curlex®. American Excelsior Hi-Velocity Curlex® is made by the American Excelsior Company based in Arlington, Texas. Hi-Velocity Curlex® is a machine-produced mat of curled wood excelsior of 80%, 152.4 mm (6 in) or longer fiber evenly distributed over its entire area. Each side is covered with black, extra heavy-duty extruded plastic mesh netting designed to last for years.

Table L. American Excelsior Hi-Velocity Curlex® Specifications.

MATERIAL SPECIFICATIONS	
Composition	Wood Excelsior and Plastic Netting
ROLL SPECIFICATIONS	
Width	1.22 m (4.0 ft)
Length	30.5 m (100 ft) minimum
Weight	32.69 kg (72 lbs)
Area	37.2 m^2 (400 ft^2)

Source: American Excelsior Hi-Velocity Curlex® product installation guidelines, 1993. Metric conversions are shown to comply with metrication reporting procedures.

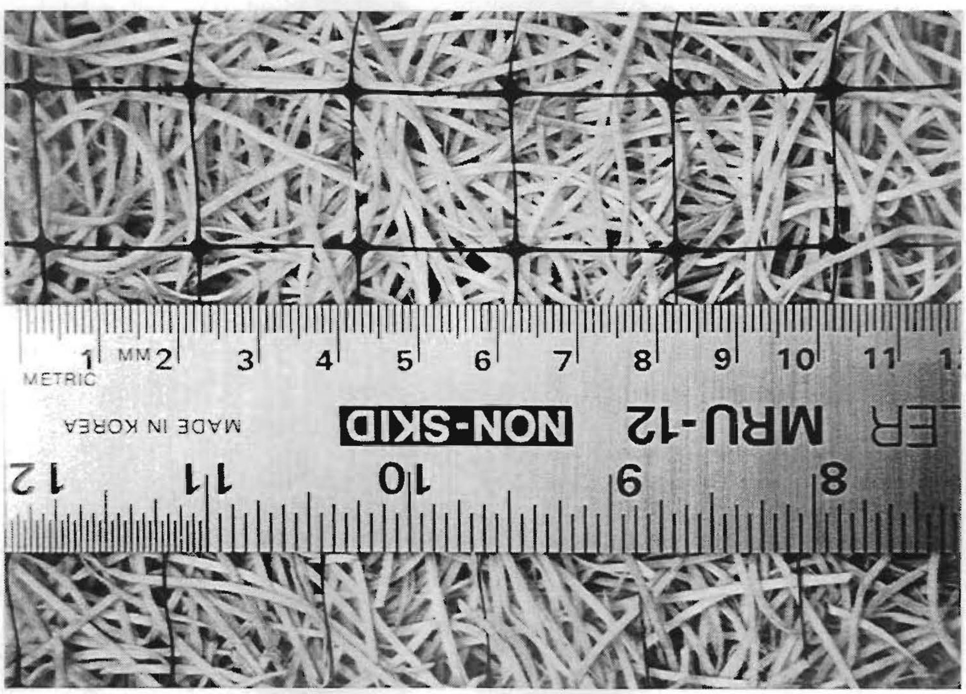


Figure 13. American Excelsior Hi-Velocity Curlex® Photograph.

Flexible Channel Liner 3 - DEKOWE® 900. DEKOWE® 900, also marketed as GEOCOIR®, is manufactured by Belton Industries, Inc., based in Atlanta, Georgia. DEKOWE® 900 is made from fibers that come from coconut husks. The composition of coir fibers is about 45% lignin which gives it a high tensile strength and provides resistance to rotting. DEKOWE® 900 is woven from spun yarns of 100% biodegradable coir fibers.

Table M. Belton Industries DEKOWE® 900 Product Specifications.

MATERIAL SPECIFICATIONS	
Composition	ANJENGO; 100% Spun Coir
Weight	900 g/m^2, (1.63 lbs/yd^2)
Open Area	39%
Chezy-Manning Coefficient of Roughness	(0.028-0.016)
Water Flow Velocity	4.575 mps (15 fps)
Elongation - Dry, Wet	29%, 35%
ROLL SPECIFICATIONS	
Standard Widths	1, 2, 3, 4 m (39.3, 78.7, 118.1, 157.5 in)
Standard Length	50 m (55 yds)
Weight varies with Roll Width	44.95, 89.89, 135.29, 180.24 kg (99, 198, 298, 397 lbs)
Area varies with Roll Width	50, 100, 150, 200 m^2 (60, 120, 180, 240 yd^2)

Source: Belton Industries, Inc., DEKOWE® 900 product installation guidelines, 1994. Metric conversions are shown to comply with metrication reporting procedures.

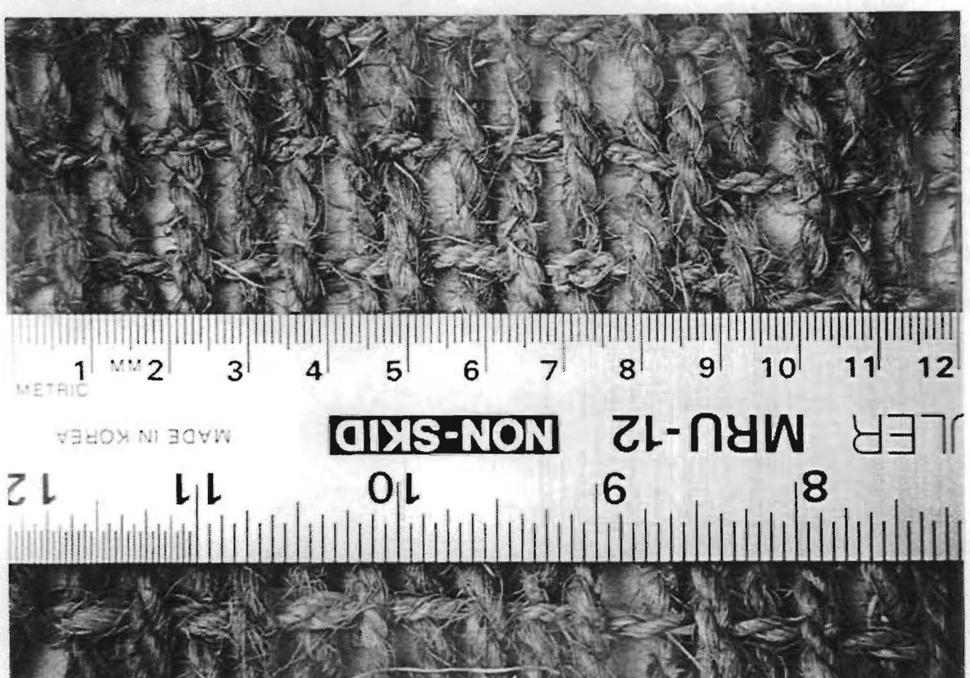


Figure 14. Belton Industries DEKOWE® 900 Photograph.

Flexible Channel Liner 4 - GREENSTREAK® PEC-MAT®. GREENSTREAK® PEC-MAT® is made by GREENSTREAK®, Inc., based in St. Louis, Missouri. PEC-MAT® is a dense web of extra-thick PVC monofilaments thermally welded together to create a long-lasting, flexible mat.

Table N. GREENSTREAK® Inc., PEC-MAT® Product Specifications.

MATERIAL SPECIFICATIONS	
Composition	Polyvinyl chloride (PVC)
Weight	0.95 kg/m^2, (28 oz/yd^2)
Tear Strength - Length, Width	640 n/m, 373 n/m (12 lb/in, 7 lb/in)
Elongation - Length, Width	75%, 75%
Water Flow Velocity	6.1+ mps (20 fps)
Maximum Shear Stress	240 pa (5 lb/sf)
ROLL SPECIFICATIONS	
Standard Width	1.83 m (6 ft)
Standard Length	45.7 m (150 ft)
Weight	80 kg (175 lbs)
Area	83.6 m^2 (100 yd^2)

Source: GREENSTREAK® PEC-MAT® product installation guidelines, 1993. Metric conversions are shown to comply with metrication reporting procedures.

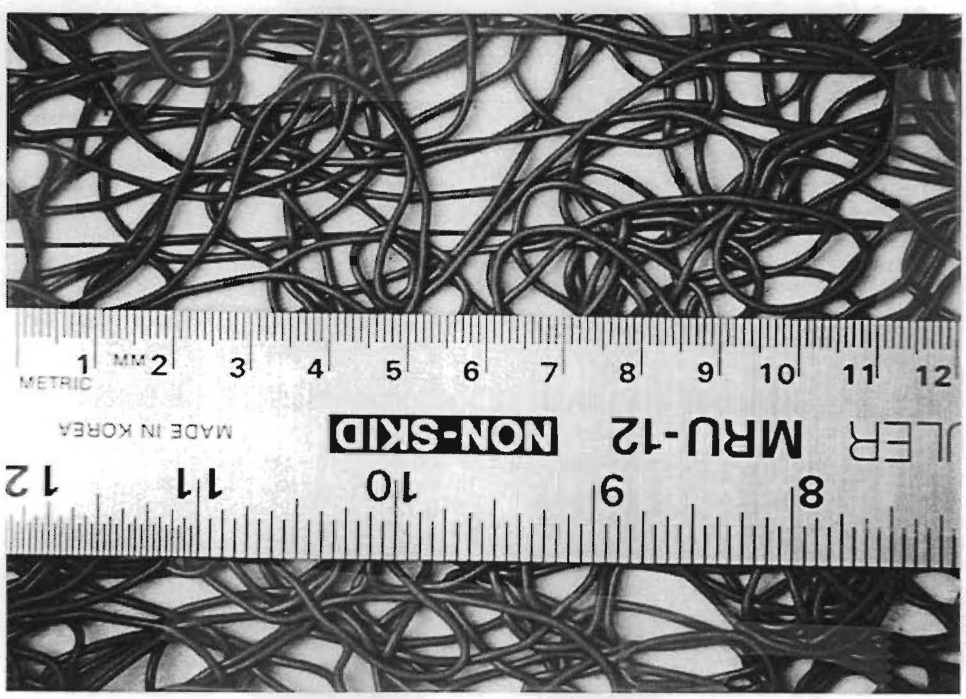


Figure 15. GREENSTREAK® PEC-MAT® Photograph.

Flexible Channel Liner 5 - North American Green® P300P. North American Green® P300P is made by North American Green® based in Evansville, Indiana. P300P is a stabilized Polypropylene fiber matrix sewn between an extra heavy duty UV stabilized top net and heavy UV stable bottom net.

Table O. North American Green® P300p Product Specifications.

MATERIAL SPECIFICATIONS	
Composition	Polypropylene
Weight	0.38 kg/m^2, (0.7 lbs/yd^2)
"C" or "VM" Factor	0.009
Maximum Flow Depth	(~0.97 ft)
Water Flow Velocity	~2.36 mps (~7.75 fps)
Maximum Shear Stress	~0.908/0.093 kg/m^2 (~2 lb/sf)
ROLL SPECIFICATIONS	
Standard Width	2 m (6.5 ft)
Standard Length	25.4 m (83.5 ft)
Weight	19.1 kg (42 lbs)
Area	50 m^2 (60 yd^2)

Source: North American Green® P300P product installation guidelines, 1993. Metric conversions are shown to comply with metrication reporting procedures.

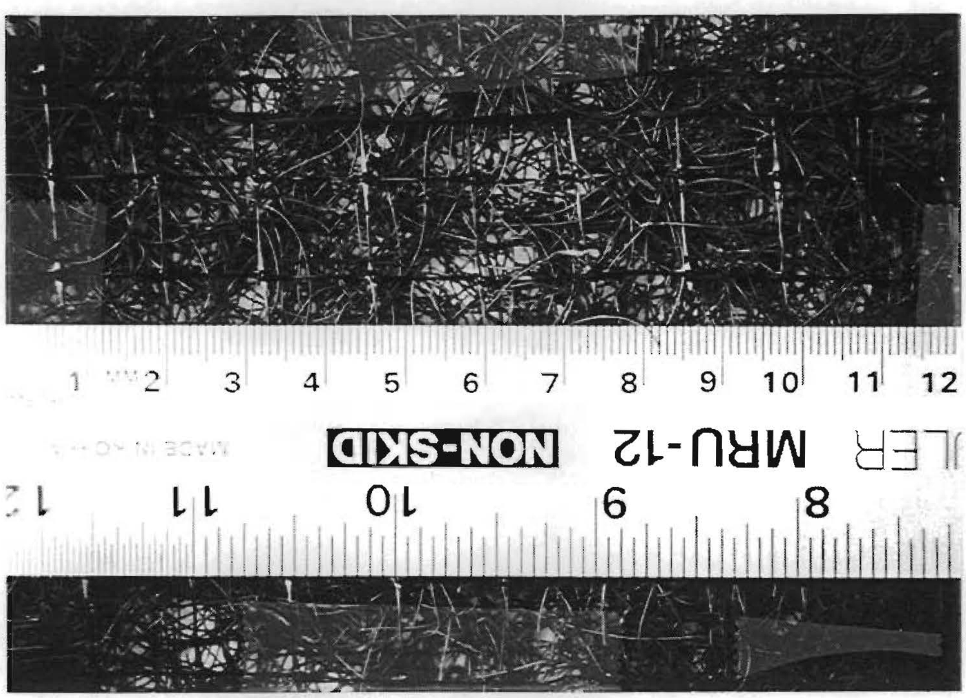


Figure 16. North American Green® P300P Photograph.

Flexible Channel Liner 6 - MIRAMAT™ 1000. MIRAMAT™ 1000 was developed by the engineers at Mirafi® in cooperation with the 3M Company. The Nicolon Corporation owns the trademarks, Mirafi® and MIRAMAT™. The manufacturers of Mirafi® include the Nicolon Corporation/Mirafi® based in Norcross, Georgia and the 3M Corporation based in St. Paul, Minnesota. MIRAMAT™ 1000 is a three-dimensional web of bonded Polypropylene created for light-to-moderate installation environments.

Table P. Nicolon Corporation/Mirafi® MIRAMAT™ 1000 Specifications.

MATERIAL SPECIFICATIONS	
Composition	Polypropylene
Weight	272.16 g/0.83 m^2, (9.6 oz/yd^2)
Thickness	2.44 mm (0.31 in)
Tensile Strength - Machine Direction	9.99 kg (22 lbs)
Tensile Strength - Cross Direction	5.45 kg (12 lbs/ft)
Elongation - Machine, Cross	40%, 35%
ROLL SPECIFICATIONS	
Width	1.31 m (4.3 ft)
Length	64.05 m (210 yds)
Weight	29.51 kg (65 lbs)
Area	83.6 m^2 (100 yd^2)

Source: Mirafi®, MIRAMAT™ 1000 product installation guidelines, 1993. Metric conversions are shown to comply with metrication reporting procedures.

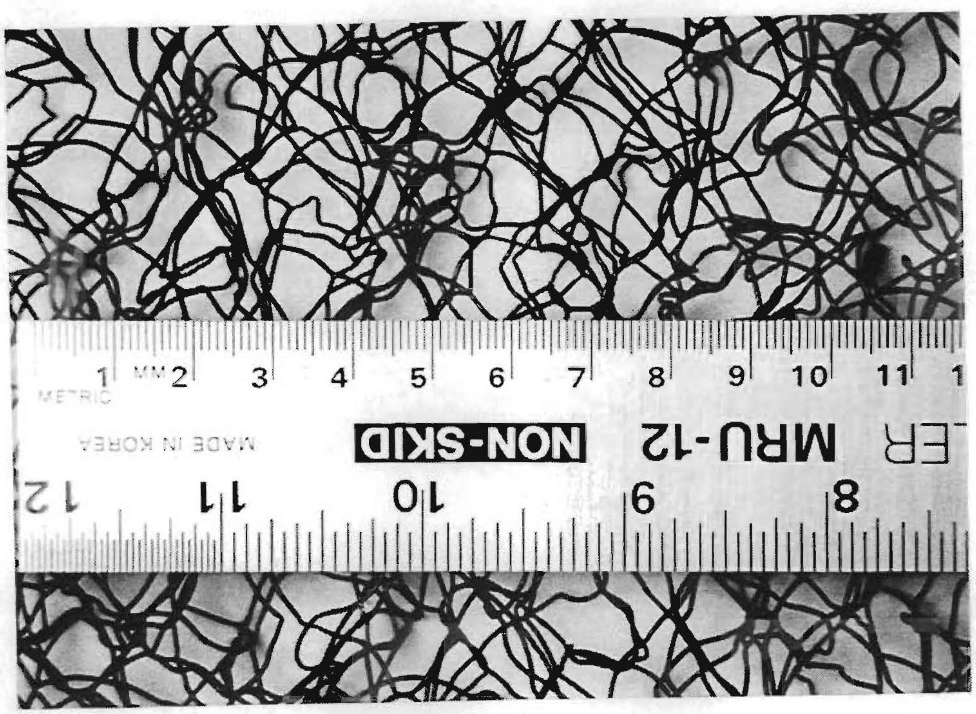


Figure 17. MIRAMAT™ 1000 Photograph.

Flexible Channel Liner 7 - XCEL Super Duty. XCEL Super Duty is made by PPS Packaging Company based in Fowler, California. XCEL Super Duty is a machine-produced mat of wood excelsior fibers with a photo degradable extruded plastic netting which covers the top, bottom, and sides. The netting is secured to the wood excelsior by PPS's PLASTISTITCH process which continuously applies extra heavy lines of plastic onto the width of each blanket.

Table Q. PPS Packaging Company, XCEL Super Duty Specifications.

MATERIAL SPECIFICATIONS	
Composition	Wood Excelsior, 80% are 152.4+ mm (6+ in)
Weight	0.74 kg/0.83 m^2, (1.62 lbs/yd^2)
Estimated Maximum Velocities	3 - 3.66 mps (10 - 12 fps)
Flow Depths	152.4+ mm (6+ in)
Channel Grade	6% and greater
ROLL SPECIFICATIONS	
Width	1.22 m (4 ft)
Length	30.5 m (100 ft)
Weight	32.69 kg (72 lbs)
Area	36.78 m^2 (44 yd^2)

Source: PPS Packaging Company, XCEL Super Duty product installation guidelines, 1993. Metric conversions are shown to comply with metrication reporting procedures.

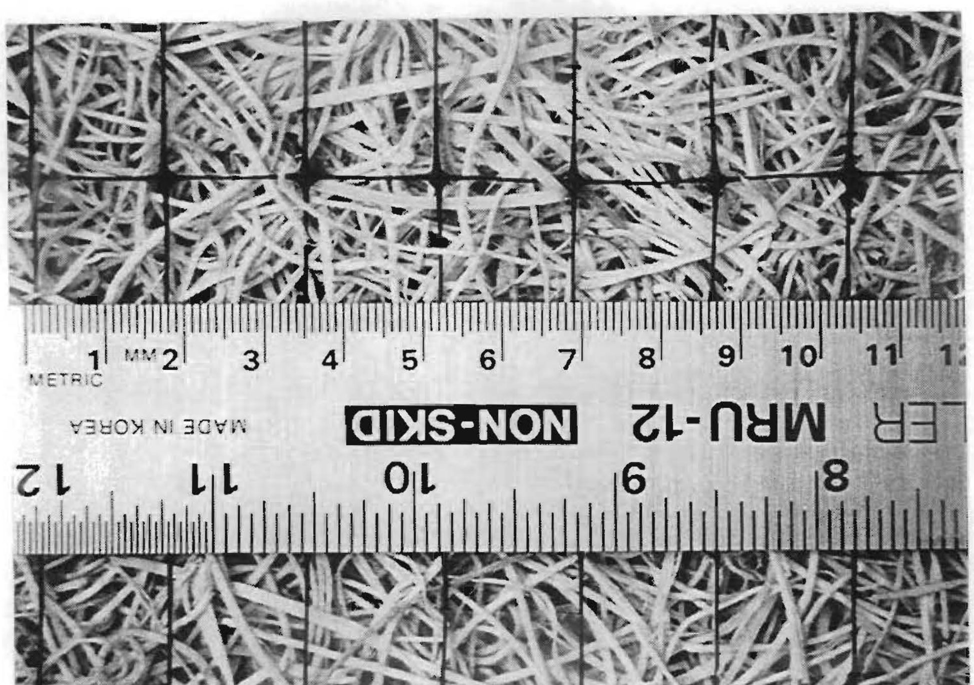


Figure 18. XCEL Super Duty Photograph.

Flexible Channel Liner 8 - LANDLOK® ECRM 450. LANDLOK® ECRM 450 is made by Synthetic Industries, Construction Products Division based in Chattanooga, Tennessee. LANDLOK® ECRM 450 is a dense, three-dimensional web of green Polyolefin fibers oriented and mechanically bonded between two nets.

Table R. Synthetic Industries, LANDLOK® ECRM 450 Product Specifications.

MATERIAL SPECIFICATIONS	
Composition	Polyolefin
Weight	283.5 g/0.836 m^2, (10 oz/yd^2)
Tensile Strength - Dry, Wet	65.83 x 49.94 kg/0.305 m (145 x 110 lb/ft)
Tensile Elongation - Dry, Wet	10% min, 50% max
Water Flow Velocity	mps (18 fps)
Maximum Shear Stress	3.178 kg/0.093m^2 (7 lbs/sf)
ROLL SPECIFICATIONS	
Standard Width	2 m (6.5 ft)
Standard Length	42.24 m (138.5 ft)
Weight	31.78 kg (70 lbs)
Area	83.6 m^2 (100 yd^2)

Source: Synthetic Industries, LANDLOK® ECRM 450 product installation guidelines, 1993. Metric conversions are shown to comply with metrication reporting procedures.

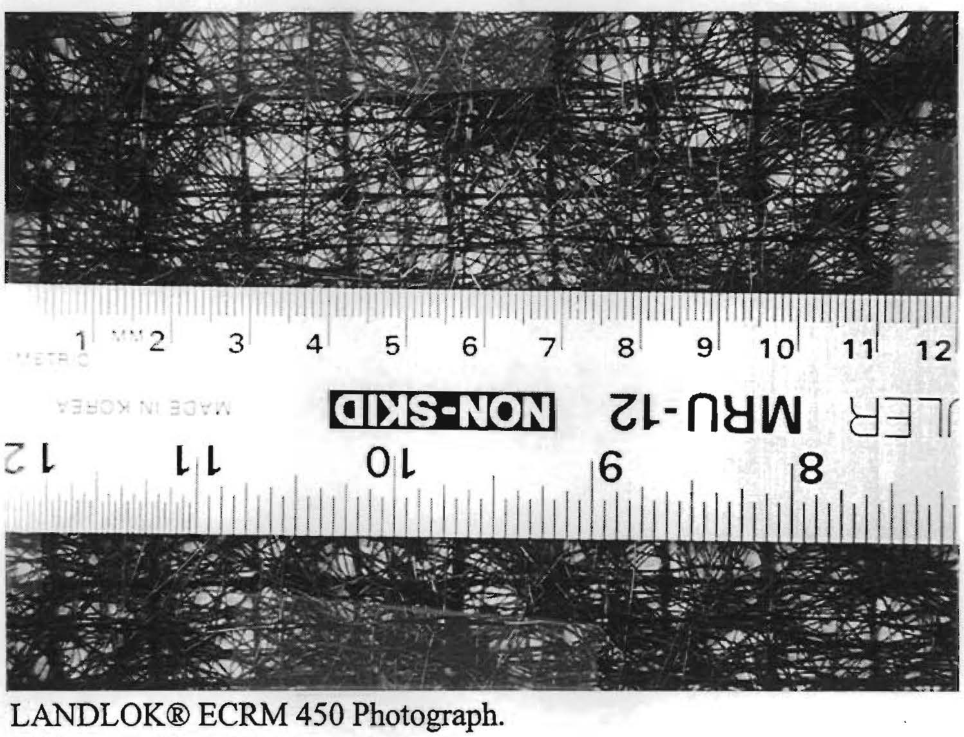


Figure 19. LANDLOK® ECRM 450 Photograph.

Flexible Channel Liner 9 - TENSAR® Erosion Blanket TB1000. TENSAR® Erosion Blanket TB1000 is made by Bon Terra America based in Moscow, Idaho with TENSAR® Earth Technologies as the distributor. TENSAR® Erosion Blanket TB1000 is a flexible, three-dimensional mat composed of polyethelene that is UV stabilized.

Table S. TENSAR® Earth Technologies, TENSAR® Erosion Blanket TB1000 Product Specifications.

MATERIAL SPECIFICATIONS	
Composition	Polyolefin
Weight	283.5 g/0.836 m^2, (10 oz/yd^2)
Tensile Strength - ASTM D-1682	79.45 x 49.94 kg/0.305 m (175 x 110 lb/ft)
Tensile Elongation - Machine, Cross-machine	40% x 22%
UV Stability - ASTM D-4355	80%
Thickness - ASTM D-1777	10.16 mm (0.40 in)
ROLL SPECIFICATIONS	
Standard Width	2 m (6.5 ft)
Standard Length	30.5 m (100 ft)
Weight	20.43 kg (45 lbs)
Area	60.37 m^2 (72 yd^2)

Source: TENSAR® Earth Technologies, TENSAR® Erosion Blanket TB1000 installation guidelines, 1993. Metric conversions are shown to comply with metrication reporting procedures.

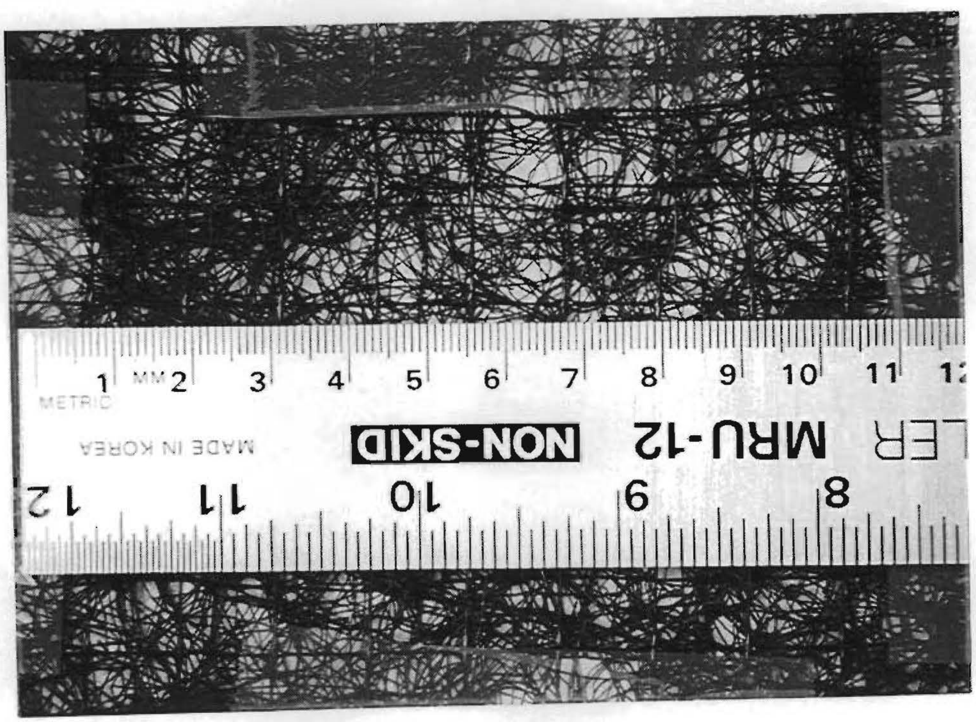


Figure 20. TENSAR® Erosion Blanket TB1000 Photograph.

INSTALLATION PROCEDURES

The researchers prepared each of the study areas in a similar manner by soil preparation and seeding application followed by material installation. The soil preparation consisted of the following steps:

- For the sloped study plots located on the embankment, an experienced roadway contractor performed the major earthwork operations that included stripping the previous year's materials, providing replacement soil, and rough grading. For the channel study plots, the contractor provided the same services except the grading operation was accomplished with a specialized tool shaped like the channel profile.

- Once the treatment plots were rough graded, the researchers sterilized the soil with a fumigant according the manufacturer's directions.

- The contractor then returned to the site and fine graded the plots with the research team hand-raking each plot prior to installation.

A soil analysis is performed prior to each evaluation cycle by an independent soil laboratory to verify the soil class and provide the information necessary to determine a soil erodibility factor or "K" value. For 1994, the sloped treatment plot's soil was predominantly classified as either a clay, C, with a "K" value of 0.19 or a loamy sand (LS) with a "K" value of 0.24. The treatment channels were a clay, C, with a "K" value of 0.20. Appendix D diagrams this information.

Once the plots were prepared to receive the erosion control products, the researchers began the installation operations that consisted of seeding the plot and installing the material. Thus far, all of the treatment plots have received seeding prior to the material installation. The researchers used the seeding mixture from *Item 164, Seeding for Erosion Control (Appendix B)* for the Bryan District as recommended by TxDOT. The seeding mixtures were consistent for each study, but the application process differed in the hydraulic mulch installations. The following descriptions describe the seeding mixture and application process.

EROSION-CONTROL BLANKET SEEDING

Since the laboratory is located in the Bryan District, the rural area species for warm-season perennial vegetation was hydraulically applied in a one-step application process in the erosion-control blanket study. Specific mixtures selected included a mixture for clay or tight soils and a mixture for sand or sandy soils. In clay or tight soils, the recommended seed mixture includes the following species and rates given in kilograms (pounds) of pure live seed per 0.405 hectares (1 acre):

- Green Sprangletop 0.2724 kg/0.405 ha (0.60 lbs/ac)
- Bermuda grass 0.3632 kg/0.405 ha (0.80 lbs/ac)
- Little Bluestem 0.4994 kg/0.405 ha (1.10 lbs/ac)
- Indian grass (Lometa) 0.681 kg/0.405 ha (1.50 lbs/ac)
- K-R Bluestem 0.3178 kg/0.405 ha (0.70 lbs/ac)
- Switch grass (Alamo) 0.5448 kg/0.405 ha (1.20 lbs/ac)

In sand or sandy soils, the recommended seed mixture includes the following species and rates given in kilograms (pounds) of pure live seed per 0.405 hectares (acre):

- Green Sprangletop 0.4994 kg/0.405 ha (1.10 lbs/ac)
- Bermuda grass 0.681 kg/0.405 ha (1.50 lbs/ac)
- Bahia grass (Pensacola) 3.0418 kg/0.405 ha (6.70 lbs/ac)

HYDRAULIC MULCH SEEDING

The seed mixture and rates were the same for the hydraulic mulch study as noted in the previous section. However, the researchers applied the seeding mixture in two different application techniques as required by the study objectives. According to current TxDOT standard specifications, a two-step application process is the recommended procedure. A two-step application process is performed as its name indicates. First, the seed and fertilizer are combined in a water slurry and sprayed on the treatment plot with a hydro seeder. Second, the mulch is combined with water and sprayed over the seed bed with a hydro seeder. The second step is completed within thirty minutes of finishing the first step. As a comparison, the researchers applied the hydraulic mulches in a one-step process. A one-step process is performed by mixing the seed, fertilizer, mulch, and water and applying the slurry in a single application.

CHANNEL LINER SEEDING

The researchers applied the seeding mixture for clay or tight soils according to the TxDOT standards as shown in the erosion-control blanket description.

MATERIAL INSTALLATIONS

Once the treatment plots had received their seed and fertilizer application, the researchers began the installation process. The Hydraulics and Erosion Control Laboratory manager supervised all of the product and control installations. Typically, the researchers install two erosion-control blanket products per day, between one and three hydraulic mulches per day, and one channel liner product per day. This allows the research team and manufacturer sufficient time to ensure proper installation procedures have been completed. Each manufacturer was encouraged to attend their product installation. The following descriptions are provided for each product installation per treatment plot.

Erosion-control Blanket 1 - AIRTROL® Plaster, 1:2 Sand

The manufacturer's representative installed the AIRTROL® Plaster on May 16, 1994. This installation was accomplished with a two-step application process. First, a seed, fertilizer, and water slurry was sprayed on the treatment plot. Second, the researchers mixed the AIRTROL® Plaster with American Fiber Mulch® and applied this onto the seed bed. At the crest of the slope, the product installation extended a minimum of 0.46 m (18 in) beyond this point. The application rate for the AIRTROL® Plaster product was as follows:

American Fiber Mulch® - 1,794 kg/ha (1600 lbs/ac)

AIRTROL® Plaster - 6.72 Mg/ha (3 T/ac)

Erosion-control Blanket 1 - AIRTROL® Plaster, 1:3 Sand
The manufacturer's representative installed the AIRTROL® Plaster on May 16, 1994. This installation was accomplished with a two-step application process. First, a seed, fertilizer, and water slurry was sprayed on the treatment plot. Second, the researchers mixed the AIRTROL® Plaster with American Fiber Mulch® and applied this onto the seed bed. At the crest of the slope, the product installation extended a minimum of 0.46 m (18 in) beyond this point. The application rate for the AIRTROL® Plaster product was as follows:

American Fiber Mulch® - 1,794 kg/ha (1600 lbs/ac)
AIRTROL® Plaster - 6.72 Mg/ha (3 T/ac)

This installation was substantially damaged by above normal rainstorms, and the installation process was redone. The second installation date was June 9, 1994, and was completed in the same manner as the first installation.

Erosion-control Blanket 2 - American Excelsior Curlex®, 1:2 Sand
The researchers installed the American Excelsior Curlex® on May 11, 1994, with a manufacturer's representative present. The material extended a minimum 0.915 m (3 ft) beyond the crest of the slope, and staples anchored the material every 304.8 mm (12 in) on center. The researchers installed the blanket by rolling it downhill in the direction of water flow. Edges of parallel blankets were butted together and stapled with a common row of staples. Ends of blankets were butted snugly together and stapled with a common row of staples. The staple pattern was a 1.83 m x 0.915 m (6 ft x 3 ft) pattern. Staple size was 203.2 mm x 50.8 mm x 203.2 mm (8 in x 2 in x 8 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 21 graphically depicts the installation of the Curlex® blanket.

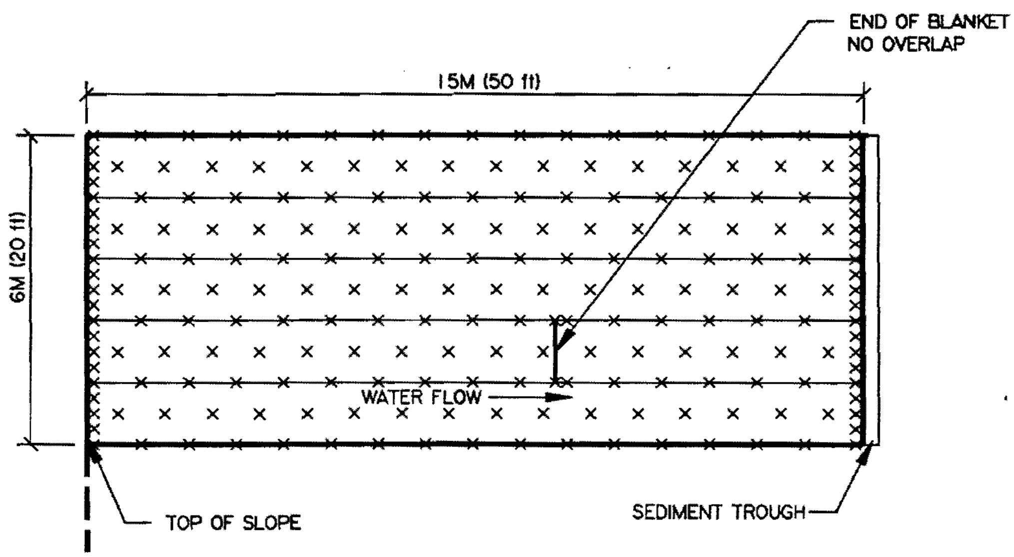


Figure 21. American Excelsior Curlex® 1:2 Installation Plan

Erosion-control Blanket 2 - American Excelsior Curlex®, 1:3 Sand

The researchers installed the American Excelsior Curlex® product on May 11, 1994, with a manufacturer's representative present. The material extended a minimum 0.915 m (3 ft) beyond the crest of the slope, and staples anchored the material every 304.8 mm (12 in) on center. The researchers installed the blanket by rolling it downhill in the direction of water flow. Edges of parallel blankets were butted together and stapled with a common row of staples. Ends of blankets were butted snugly together and stapled with a common row of staples. The staple pattern was a 1.83 m x 0.915 m (6 ft x 3 ft) pattern. Staple size was 203.2 mm x 50.8 mm x 203.2 mm (8 in x 2 in x 8 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 22 graphically depicts the installation of the Curlex® blanket.

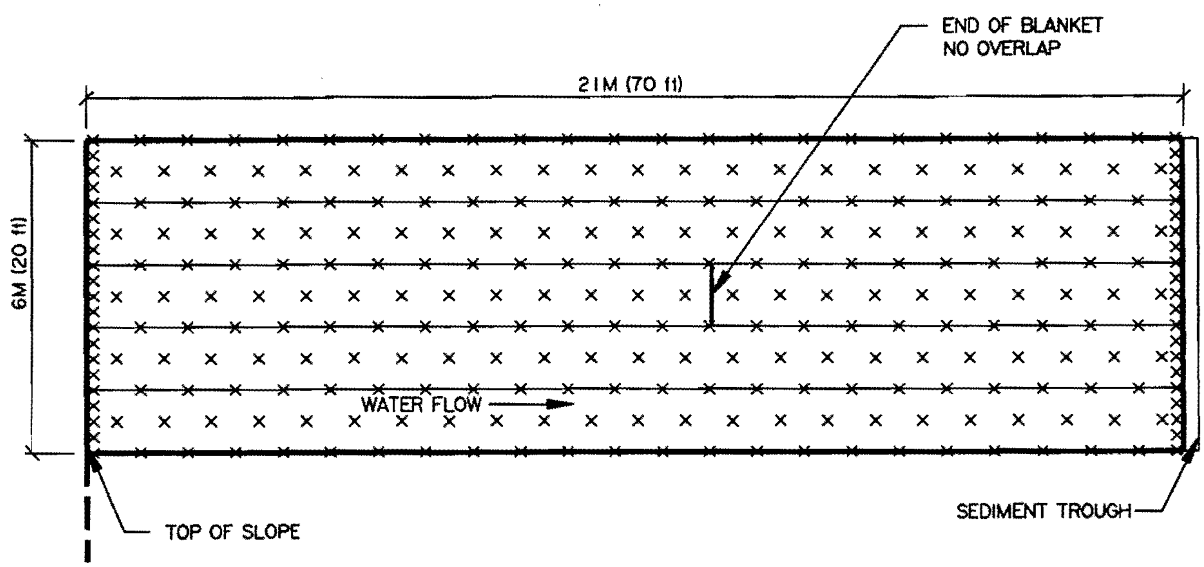


Figure 22. American Excelsior Curlex® 1:3 Installation Plan.

Erosion-control Blanket 3 - SuperGro®, 1:2 Sand

Amoco's SuperGro® was installed on May 12, 1994, by the manufacturer's representatives. The installers unrolled the material with the netting side on top, making sure not to stretch the blanket in the direction of water flow. They anchored the mat by placing pins at 1.22 m (4 ft) intervals at the crest and bottom of the slope. Edges of parallel blankets were overlapped a minimum of 76 mm (3 in) and anchored with pins every 1.22 m (4 ft) on center. Ends of blankets were overlapped a minimum of 76 mm (3 in) with the up slope mat on top, i.e., shingle style. The staple pattern was a 1.22 m (4 ft) pattern, and the staple size was 152.4 mm x 25.4 mm x 152.4 mm (6 in x 1 in x 6 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 23 graphically depicts the installation of Amoco's SuperGro®.

Erosion-control Blanket 3 - SuperGro®, 1:2 Clay
Amoco's SuperGro® was installed on May 12, 1994, by the manufacturer's representatives. The installers unrolled the material with the netting side on top, making sure not to stretch the blanket in the direction of water flow. They anchored the mat by placing pins at 1.22 m (4 ft) intervals at the crest and bottom of the slope. Edges of parallel blankets were overlapped a minimum of 76 mm (3 in) and anchored with pins every 1.22 m (4 ft) on center. Ends of blankets were overlapped a minimum of 76 mm (3 in) with the up slope mat on top, i.e., shingle style. The staple pattern was a 1.22 m (4 ft) pattern, and the staple size was 152.4 mm x 25.4 mm x 152.4 mm (6 in x 1 in x 6 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 23 graphically depicts the installation of Amoco's SuperGro®.

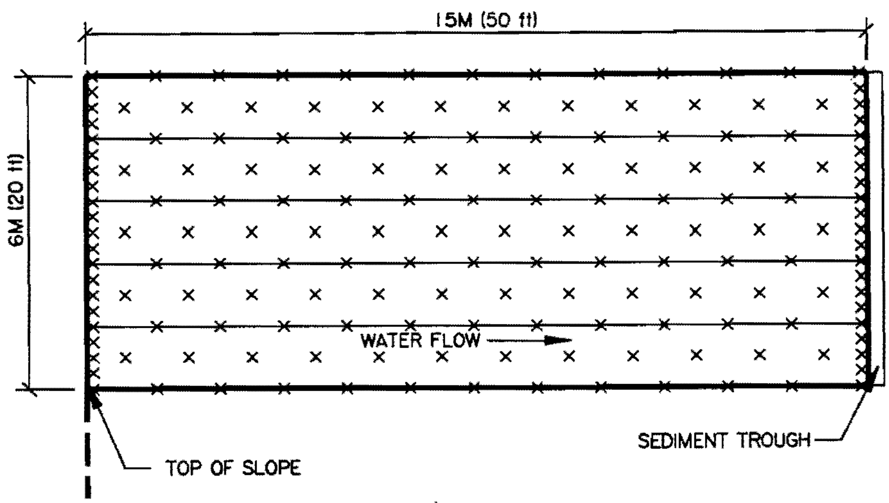


Figure 23. SuperGro® 1:2 Installation Plan.

Erosion-control Blanket 3 - SuperGro®, 1:3 Sand
Amoco's SuperGro® was installed on May 12, 1994, by the manufacturer's representatives. The installers unrolled the material with the netting side on top, making sure not to stretch the blanket in the direction of water flow. They anchored the mat by placing pins at 1.22 m (4 ft) intervals at the crest and bottom of the slope. Edges of parallel blankets were overlapped a minimum of 76 mm (3 in) and anchored with pins every 1.22 m (4 ft) on center. Ends of blankets were overlapped a minimum of 76 mm (3 in) with the up slope mat on top, i.e., shingle style. The staple pattern was a 1.22 m (4 ft) pattern, and the staple size was 152.4 mm x 25.4 mm x 152.4 mm (6 in x 1 in x 6 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 24 graphically depicts the installation of Amoco's SuperGro®.

Erosion-control Blanket 3 - SuperGro®, 1:3 Clay
Amoco's SuperGro® was installed on May 12, 1994, by the manufacturer's representatives. The installers unrolled the material with the netting side on top, making sure not to stretch the blanket in the direction of water flow. They anchored the mat by placing pins at 1.22 m (4 ft) intervals at the crest and bottom of the slope. Edges of parallel blankets were overlapped a minimum of 76 mm (3 in) and anchored with pins every 1.22 m (4 ft) on center. Ends of blankets were overlapped a minimum of 76 mm (3 in) with the up slope mat on top, i.e., shingle style. The staple pattern was a 1.22 m (4 ft) pattern, and the staple size was 152.4 mm x 25.4 mm x 152.4 mm (6 in x 1 in x 6 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 24 graphically depicts the installation of Amoco's SuperGro®.

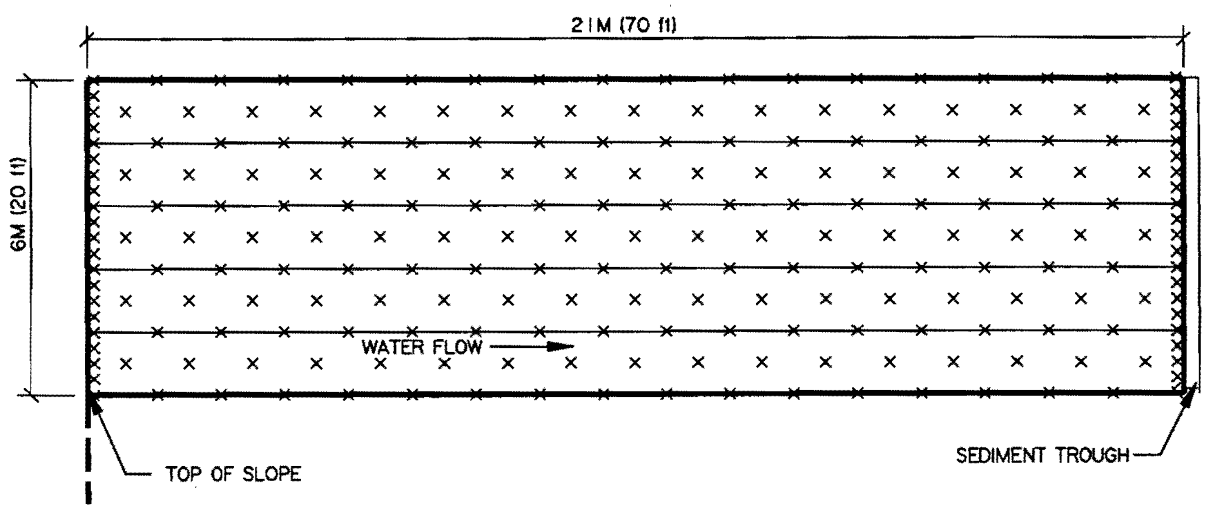


Figure 24. SuperGro® 1:3 Installation Plan.

Erosion-control Blanket 4 - GEOJUTE® PLUS, 1:2 Clay
The researchers installed the GEOJUTE® PLUS product on May 13, 1994, with a manufacturer's representative present. To secure the material at the top of the slope, the GEOJUTE® PLUS was toed in a minimum of 152.4 mm (6 in) and reinforced with a row of five staples per blanket. The researchers installed the blanket by rolling it downhill in the direction of water flow. Edges of parallel blankets were overlapped between 50 mm (2 in) and 152 mm (6 in). Ends of blankets were folded back between 101 mm and 203 mm (4 in - 8 in), and the next blanket overlapped this area and was secured with staples. The staple pattern was a 0.46 m x 0.60 m (18 in - 2 ft) pattern throughout the treatment plot. Staple size was 152.4 mm x 25.4 mm x 152.4 mm (6 in x 1 in x 6 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 25 graphically depicts the installation of the GEOJUTE® PLUS blanket.

Erosion-control Blanket 4 - GEOJUTE® PLUS, 1:2 Sand
The researchers installed the GEOJUTE® PLUS product on May 13, 1994, with a manufacturer's representative present. To secure the material at the top of the slope, the GEOJUTE® PLUS was toed in a minimum of 152.4 mm (6 in) and reinforced with a row of five staples per blanket. The researchers installed the blanket by rolling it downhill in the direction of water flow. Edges of parallel blankets were overlapped between 50 mm (2 in) and 152 mm (6 in). Ends of blankets were folded back between 101 mm and 203 mm (4 in - 8 in), and the next blanket overlapped this area and was secured with staples. The staple pattern was a 0.46 m x 0.60 m (18 in - 2 ft) pattern throughout the treatment plot. Staple size was 203.2 mm x 50.8 mm x 203.2 mm (8 in x 2 in x 8 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 25 graphically depicts the installation of the GEOJUTE® PLUS blanket.

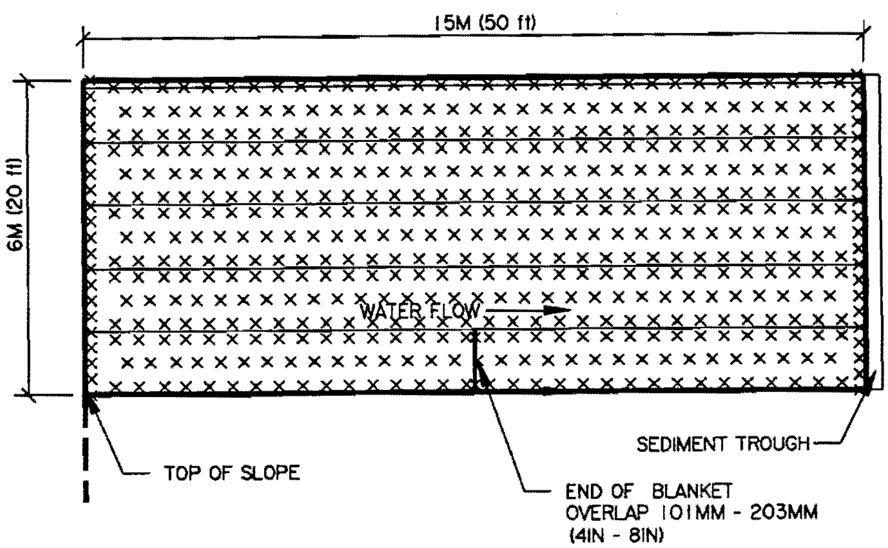


Figure 25. GEOJUTE® PLUS 1:2 Installation Plan.

Erosion-control Blanket 5 - DEKOWE® 700, 1:2 Sand
Belton's DEKOWE® 700 blanket was installed on May 13, 1994, with a manufacturer's representative present. The researchers buried the material in a 254 mm (10 in) deep anchor trench located at the crest of the slope. At the bottom of the slope, the material was secured with a row of staples placed every 304.8 mm (12 in) on center. The researchers installed the blanket by rolling it downhill in the direction of water flow. Edges of parallel blankets were overlapped a minimum of 127 mm (5 in) and stapled with a common row of staples placed 304.8 mm (12 in) on center. Ends of blankets were overlapped a minimum of 0.51 m (20 in). The staple pattern was a 0.915 m x 0.915 m (3 ft x 3 ft) pattern, and staple size was 254 mm x 50.8 mm x 254 mm (10 in x 2 in x 10 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 26 graphically depicts the installation of Belton's DEKOWE® 700 blanket.

Erosion-control Blanket 5 - DEKOWE® 700, 1:2 Clay

Belton's DEKOWE® 700 blanket was installed on May 13, 1994, with a manufacturer's representative present. The researchers buried the material in a 254 mm (10 in) deep anchor trench located at the crest of the slope. At the bottom of the slope, the material was secured with a row of staples placed every 304.8 mm (12 in) on center. The researchers installed the blanket by rolling it downhill in the direction of water flow. Edges of parallel blankets were overlapped a minimum of 127 mm (5 in) and stapled with a common row of staples placed 304.8 mm (12 in) on center. Ends of blankets were overlapped a minimum of 0.51 m (20 in). The staple pattern was a 0.915 m x 0.915 m (3 ft x 3 ft) pattern, and staple size was 254 mm x 50.8 mm x 254 mm (10 in x 2 in x 10 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 26 graphically depicts the installation of Belton's DEKOWE® 700 blanket.

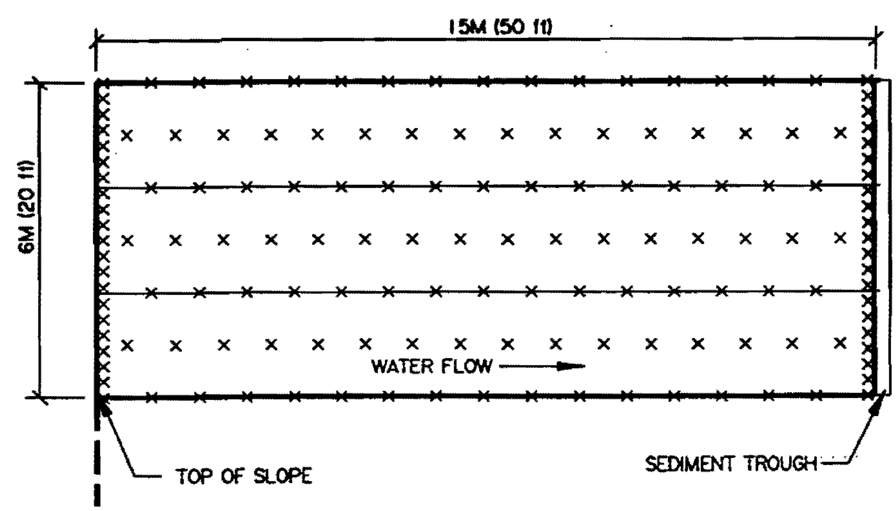


Figure 26. DEKOWE® 700 1:2 Installation Plan.

Erosion-control Blanket 6 - MIRAMAT™ 1000, 1:2 Sand

Nicolon's MIRAMAT™ 1000 was installed on May 16, 1994. The researchers buried the material in a 0.305 m (1 ft) deep terminal trench at the crest and bottom of the slope. Staples spaced every 0.915 m (3') on center were installed in the terminal trenches. After anchoring the material, the researchers rolled the material in the direction of water flow with the mat laying flat, not stretched. Transverse check slots, 152 mm deep and wide (6 in) were installed every 7.6 m (25 ft) on center as noted in the manufacturer's installation guidelines. Edges of parallel blankets were overlapped a minimum of 76 mm (3 in) and staked with a common row of staples. Ends of blankets were overlapped a minimum of 0.305 m (1 ft) with the up slope mat on top, i.e., shingle style. The staple pattern was a 1.22 m pattern that looks like a five on a die, and staple size was 152.4 mm x 25.4 mm x 152.4 mm (6 in x 1 in x 6 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 27 graphically depicts the installation of Nicolon's MIRAMAT™ 1000.

Erosion-control Blanket 6 - MIRAMAT™ 1000, 1:2 Clay
Nicolon's MIRAMAT™ 1000 was installed on May 16, 1994. The researchers buried the material in a 0.305 m (1 ft) deep terminal trench at the crest and bottom of the slope. Staples spaced every 0.915 m (3ft) on center were installed in the terminal trenches. After anchoring the material, the researchers rolled the material in the direction of water flow with the mat laying flat, not stretched. Transverse check slots, 152 mm deep and wide (6 in) were installed every 7.6 m (25 ft) on center as noted in the manufacturer's installation guidelines. Edges of parallel blankets were overlapped a minimum of 76 mm (3 in) and staked with a common row of staples. Ends of blankets were overlapped a minimum of 0.305 m (1 ft) with the up slope mat on top, i.e., shingle style. The staple pattern was a 1.22 m (4 ft) that looks like a five on a die, and staple size was 152.4 mm x 25.4 mm x 152.4 mm (6 in x 1 in x 6 in). During the installation, there were no visible signs of punctures, tears, or other physical damage. Figure 27 graphically depicts the installation of Nicolon's MIRAMAT™ 1000.

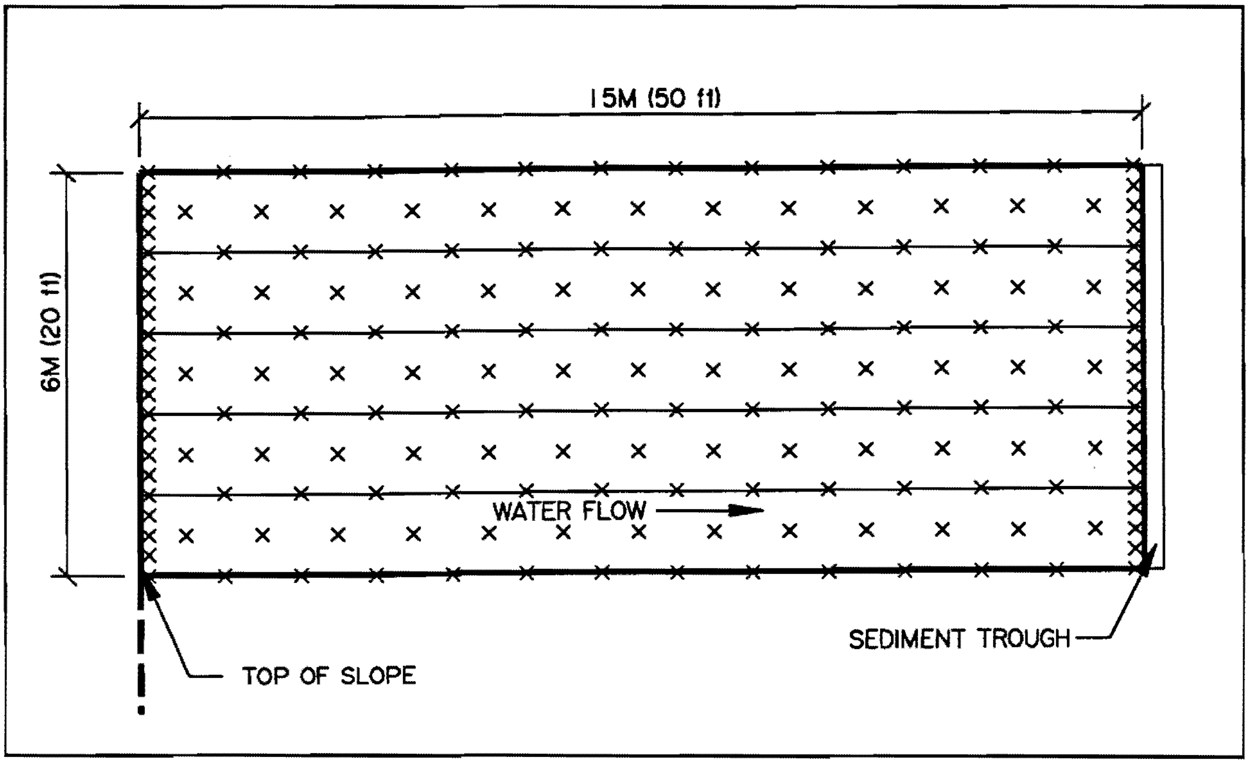


Figure 27. MIRAMAT™ 1000 1:2 Installation Plan.

Erosion-control Blanket 7 - Soil Guard™, 1:2 Sand
Weyerhauser's Soil Guard™ was installed on May 9, 1994, with a manufacturer's representative present. The researchers mixed the seed, fertilizer, Soil Guard™, and water to make a thick slurry that was hydraulically applied to the sloped surface. The rate for the Soil Guard™ was 1.36 Mg per 0.405 ha (1.5 T/ ac). The slurry was sprayed evenly on the sloped surface and did not receive any natural or simulated rainfall during the curing process that is typically 24 hours.

Erosion-control Blanket 7 - Soil Guard™, 1:2 Clay

Weyerhauser's Soil Guard™ was installed on May 9, 1994, with a manufacturer's representative present. The researchers mixed the seed, fertilizer, Soil Guard™, and water to make a thick slurry that was hydraulically applied to the sloped surface. The rate for the Soil Guard™ was 1.36 Mg per 0.405 ha (1.5 T/ ac). The slurry was sprayed evenly on the sloped surface and did not receive any natural or simulated rainfall during the curing process that is typically 24 hours.

HYDRAULIC MULCH INSTALLATIONS

The researchers installed the hydraulic mulches according to TxDOT's recommendations for the rate of application in clay or tight soils and sand or sandy soils in a sloped condition. Each product was replicated twice for each application method, one-step and two-step, in clay and sandy soils. Plot size for the evaluations was 3.05 m x 21.35 m (10 ft x 70 ft) to accommodate the replication of application methods. To compensate for transition areas at the edges and slope crest, an additional 8.56 m^2 (92 ft^2) was calculated in the mixture proportions. The researchers used the following application rates for the mulch treatment plots.

1:3 Sandy Plots - 2.84 Mg/ha (1.15 T/ac) or 21 kg (46 lbs) of mulch per plot
1:3 Clay Plots - 3.71 Mg/ha (1.5 T/ac) or 27 kg (60 lbs) of mulch per plot

An installation schedule is provided to show the product and its installation date(s). As stated previously, the 1:3 Sand hydraulic mulch plots sustained substantial damage shortly after their initial installation. The research team recommended that these treatment plots be installed again to provide a fair evaluation of product performance. Table T shows the installation schedule.

Table T. Installation Dates for Hydraulic Mulch Products.

Mulch Reference	Mulch Material	Installation Dates	1:3 Plot
Hydraulic Mulch 1	American Fiber Mulch® with HYDRO-STIK	11 May	Clay
Hydraulic Mulch 1	American Fiber Mulch® with FIBER-PLUS	11 May	Sand
Hydraulic Mulch 1	American Fiber Mulch® with FIBER-PLUS	11 May	Sand
Hydraulic Mulch 2	PRO MAT	10 May	Clay & Sand
Hydraulic Mulch 2	PRO MAT	10 June	Sand
Hydraulic Mulch 3	PRO MAT XL	10 May	Clay & Sand
Hydraulic Mulch 3	PRO MAT XL	10 June	Sand
Hydraulic Mulch 4	PRO MAT with RMB Plus	10 May	Clay & Sand
Hydraulic Mulch 4	PRO MAT with RMB Plus	10 June	Sand
Hydraulic Mulch 5	Silva-Fiber® Plus	9 May	Clay & Sand
Hydraulic Mulch 5	Silva-Fiber® Plus	13 June	Sand

FLEXIBLE CHANNEL LINER INSTALLATIONS

Flexible Channel Liner 1 - ENKAMAT® 7020, 7% Channel

AKZO, Inc., ENKAMAT® 7020 was installed on June 14, 1994, with the manufacturer's representative present. The researchers buried the material in a 0.305 m (1 ft) deep transverse terminal trench at the top of the channel and anchored it with 0.25 m (10 in) wood diagonal survey stakes. The material was rolled in the direction of water flow with the peaked side down. Check slots measuring a minimum 0.15 m (6 in) deep were located every 7.6 m (25 ft) along the channel. Side strips or edges of blankets were overlapped 101.6 mm (4 in) and staked a minimum of 1 m (3 ft) intervals. At the side slope top, the researchers extended ENKAMAT® a minimum of 101.6 mm (4 in) and staked the material at 1 m (3 ft) intervals. The end of the roll was overlapped 1 m (3 ft). At the terminal end of the channel, the researchers buried the material in a 0.305 m (1 ft) terminal trench. All check slots and trenches were backfilled and tamped. The anchor pattern was every 1 m (3 ft) on center, and the anchors were 0.25 m (10 in) wood diagonal stakes.

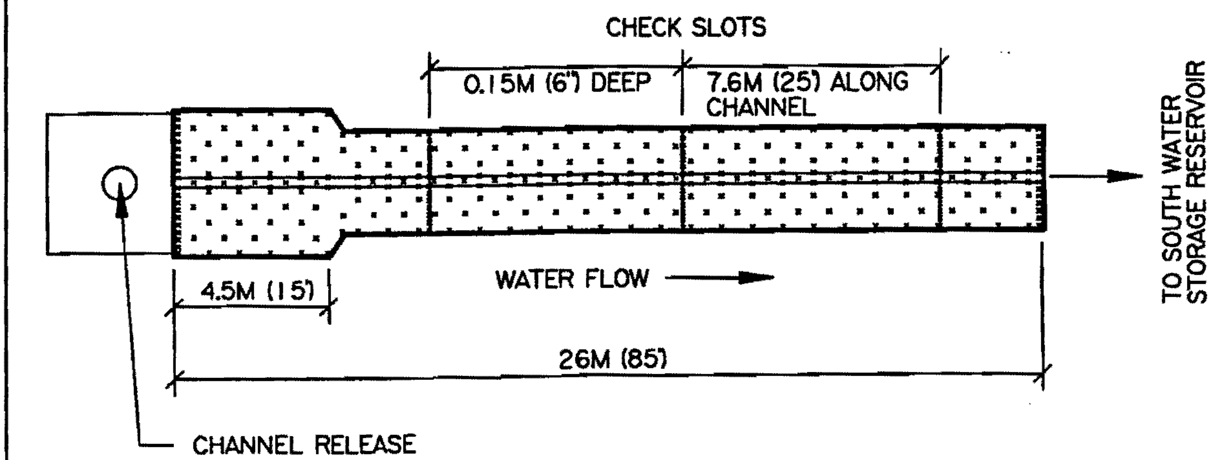


Figure 28. ENKAMAT® 7020 Installation Plan.

Flexible Channel Liner 2 - American Excelsior Hi-Velocity Curlex®, 3% Channel

American Excelsior's Hi-Velocity Curlex® was installed on June 8, 1994, with the manufacturer's representative present. The researchers buried the material in a 0.15 m (6 in) deep terminal trench at the top of the channel and anchored it with 203.2 mm x 50.8 mm x 203.2 mm (8 in x 2 in x 8 in) staples every 0.305 m (1 ft) interval as shown in figure 29. The material was rolled in the direction of water flow. Edges of blankets were overlapped 50 - 76 mm (2 - 3 in) and stapled with a common row of staples. The end of the roll was overlapped 0.15 m (6 in) in a shingle-style and stapled with two rows of common staples. There were no check slots or perimeter slots. The staple pattern was 0.61 m (2 ft) on center throughout the blanket, and staple size was 0.15 m x 0.03 m x 0.15 m (6 in x 1 in x 6 in).

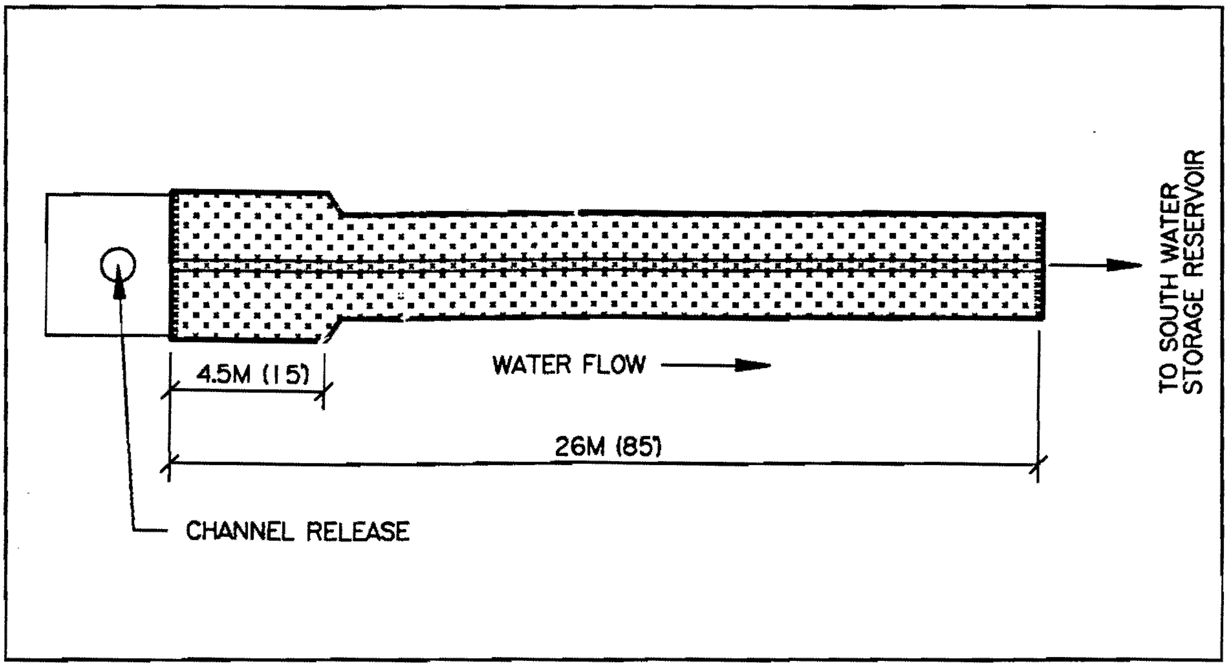


Figure 29. American Excelsior Hi-Velocity Curlex® Installation Plan.

Flexible Channel Liner 3 - DEKOWE® 900, 3% Channel
Belton Industries, DEKOWE® 900 was installed on June 13, 1994, with the manufacturer's representative present. The researchers buried the material in a 0.25 m (10 in) deep by 0.15 m (6 in) wide trench located at the top of the channel and anchored the material on top of the trench. The material was rolled in the direction of water flow. Check slots measuring a minimum of 0.15 m (6 in) wide and deep were located every 7.6 m (25 ft) along the channel as shown in figure 30. The material was overlapped, anchored with staples in the trench, and backfilled and compacted. In the channel, edges of blankets were overlapped a minimum of 0.20 m (8 in) in a shingle style and anchored through the centerline of the overlap. The blanket was extended to the top of the channel side and anchored with staples every 0.31 m (1 ft) on center. The end of the roll was overlapped a minimum of 0.46 m (18 in) and anchored with a double row of staples. At the terminal end of the channel, the researchers buried the material in a 0.25 m (10 in) deep by 0.15 m (6 in) wide trench and stapled on top of the trench. Anchor pattern was every 1 m (3 ft) on center in a domino pattern with 0.20 m x 0.05 m x 0.20 m (8 in x 2 in x 8 in) staples.

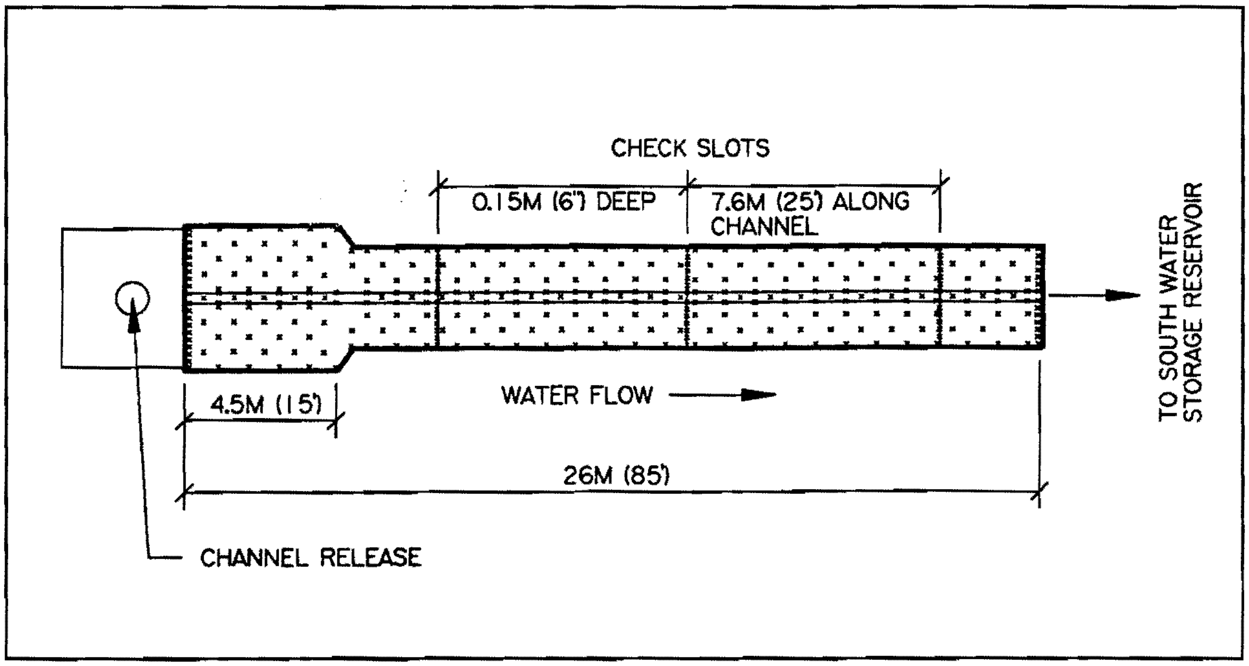


Figure 30. DEKOWE® 900 Installation Plan.

Flexible Channel Liner 4 - GREENSTREAK® PEC-MAT®, 7% Channel
GREENSTREAK®'s PEC-MAT® was installed on June 10, 1994, with a manufacturer's representative present. The researchers buried the material in a 0.31 m deep x 0.15 m wide (12 in x 6 in) trench located at the top of the channel. The material was placed downstream of the trench, rolled uphill over the cross-section of the trench, and overlapped the top once it was anchored and backfilled. The PEC-MAT® product was rolled in the direction of water flow and not placed in tension. Check slots (transverse check slots) measuring a minimum of 0.31 m deep x 0.15 wide (12 in x 6 in) were located every 7.6 m (25 ft) along the channel as shown in figure 31. The material was overlapped, anchored with staples in the trench, backfilled and compacted, and stapled on the downhill side of the check slot. In the channel, edges of blankets were overlapped a minimum of 0.15 m (6 in) and stapled with a common row of staples. The blanket was extended to the top of the channel side and anchored in a perimeter slot measuring 0.31 m deep x 0.15 m wide (12 in x 6 in). The end of the roll was overlapped a minimum of 0.61 m (2 ft) in a shingle style and anchored with two rows of common staples. At the terminal end of the channel, the researchers buried the material in a 0.31 m deep x 0.15 m wide (12 in x 6 in) trench and stapled before the trench, in the trench, and after the trench. The anchor pattern was every 0.61 m (2 ft) on center in a square pattern with 0.20 m x 0.05 m x 0.20 m (8 in x 2 in x 8 in) staples.

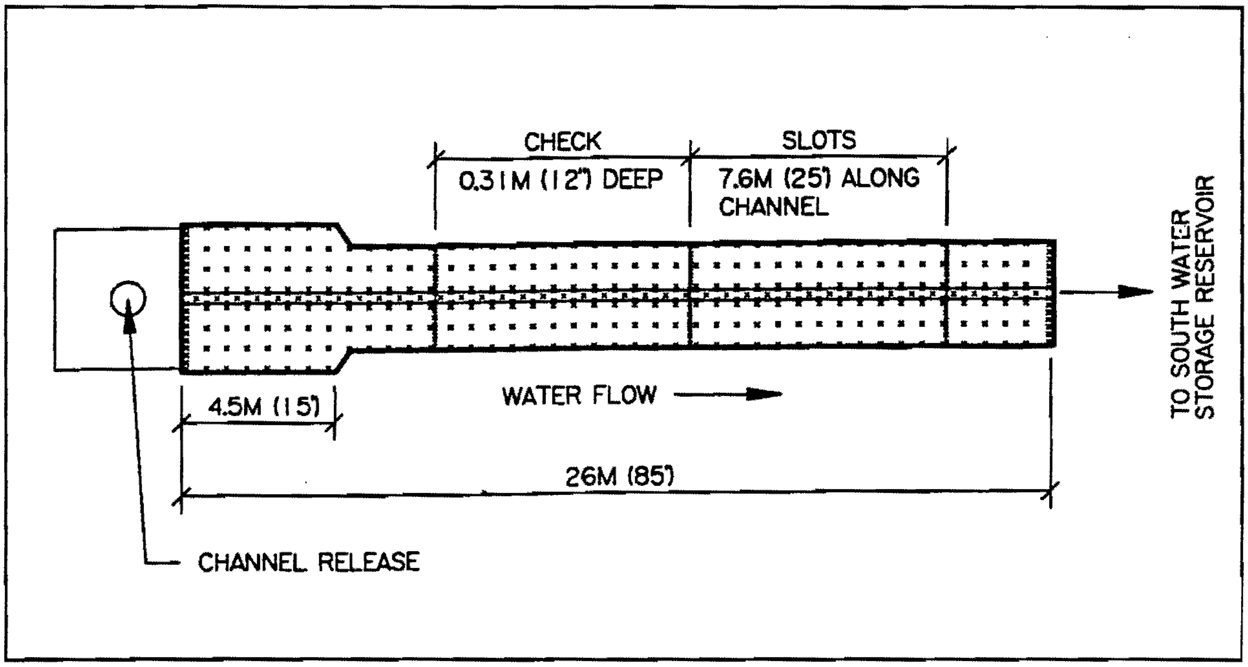


Figure 31. GREENSTREAK® PEC-MAT® Installation Plan.

Flexible Channel Liner 5 - North American Green® P300P, 7% Channel

North American Green®'s P300P was installed on June 2, 1994 with a manufacturer's representative present. The researchers buried the material in a 0.15 m deep x 0.15 m wide (6 in x 6 in) trench located at the top of the channel. The material was rolled in the direction of water flow. Staple check slots were located every 12.2 m (40 ft) where double rows of staples were placed to anchor the blanket as shown in figure 32. In the channel, edges of blankets were overlapped a minimum of 0.10 m (4 in) in a shingle style and anchored with a common row of staples. The blanket was extended to the top of the channel sides and anchored in a perimeter slot measuring 0.15 m deep x 0.15 m wide (6 in x 6 in) trench. Staples placed prior to the trench and within the trench anchor the material in this location. The end of the roll was overlapped a minimum of 0.15 m (6 in) and anchored with staples placed 0.10 m (4 in) on center. At the terminal end of the channel, the researchers buried the material in a 0.15 m deep x 0.15 m wide (6 in x 6 in) trench and anchored it in the trench. The anchor pattern was every 0.61 m (2 ft) on center in a square pattern and anchored the critical points within the channel. Staple size was 0.15 m x 0.03 m x 0.15 m (6 in x 1 in x 6 in).

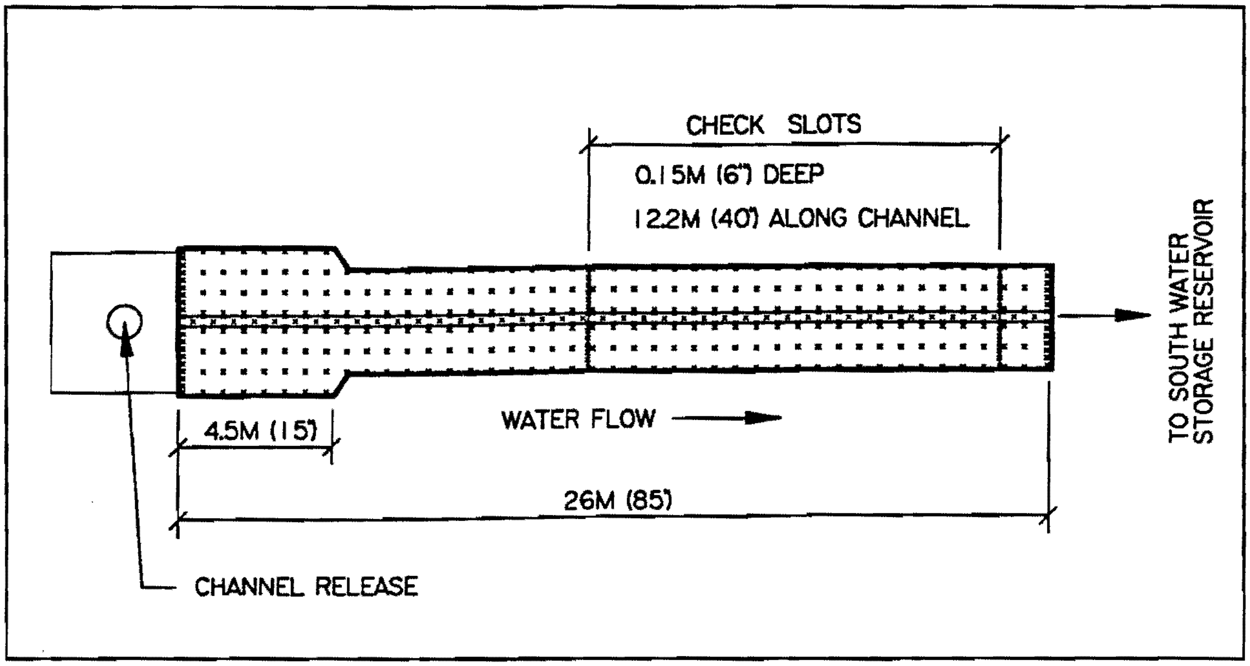


Figure 32. North American Green® P300P Installation Plan.

Flexible Channel Liner 6 - MIRAMAT™ 1000, 7% Channel

Nicolon's MIRAMAT™ 1000 was installed on June 9, 1994, with a manufacturer's representative present. The researchers buried the material in a 0.31 m deep x 0.15 m wide (12 in x 6 in) trench located at the top of the channel and anchored in the trench and on the downstream side of the trench. The material was rolled in the direction of water flow and was not stretched during installation. Check slots (transverse check slots) measuring 0.15 m deep x 0.15 m deep (6 in x 6 in) were located every 7.6 m (25 ft) along the channel. In the check slots, the material was overlapped and stapled in the trench, backfilled, compacted and rolled downstream. In the channel, edges of blankets were overlapped a minimum of 0.08 m (3 in) and anchored a minimum of 1 m (3 ft) longitudinally. The blankets were extended to the top of the channel sides and anchored in a perimeter slot measuring 0.31 m deep x 0.15 m wide (12 in x 6 in) trench with staples anchoring the blanket in the trench. The end of the roll was overlapped a minimum of 1 m (3 ft) and anchored with a double row of common staples. At the terminal end of the channel, the researchers buried the material in a 0.31 m deep x 0.15 m wide (12 in x 6 in) trench. The blanket covered the perimeter of the slot and extended upstream underneath the blanket with a common row of staples upstream and within the slot. The anchor pattern was every 1 m (3 ft) on center as shown figure 33. Staple size was 0.15 m x 0.03 m x 0.15 m (6 in x 1 in x 6 in).

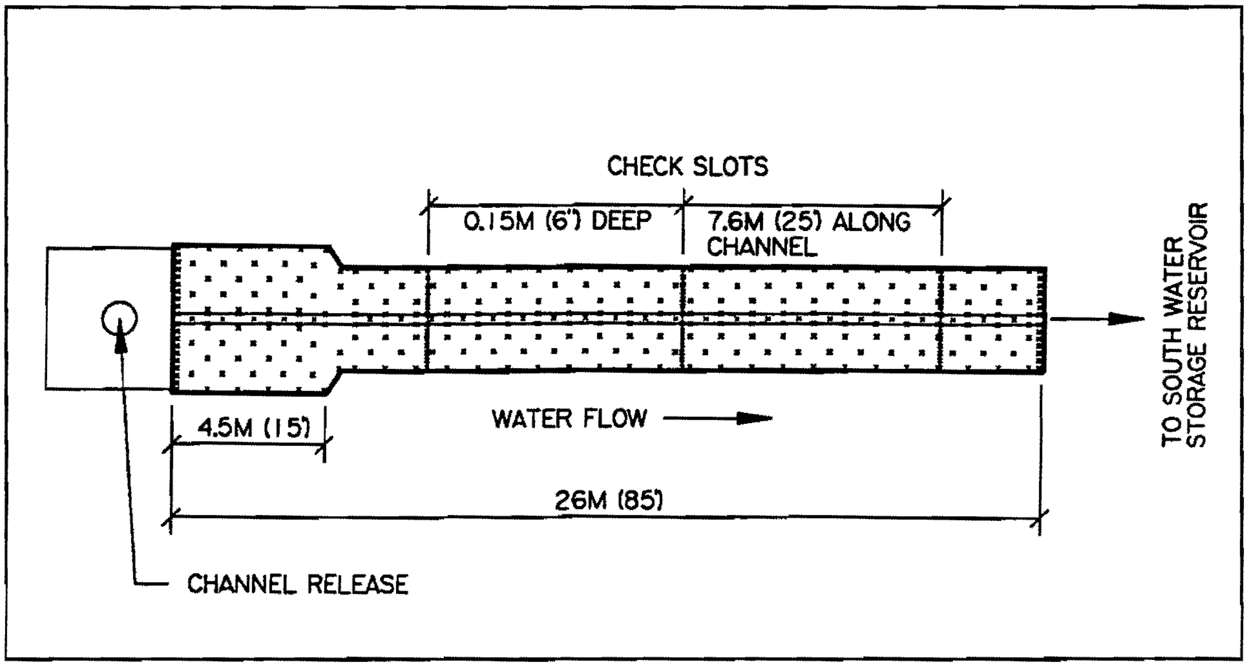


Figure 33. MIRAMAT™ 1000 Installation Plan.

Flexible Channel Liner 7 - XCEL Super Duty, 3% Channel

PPS Packaging Company's XCEL Super Duty was installed on June 3, 1994, with a manufacturer's representative present. The researchers buried the material in a 0.15 m deep x 0.15 m wide (6 in x 6 in) trench located at the top of the channel and anchored in the trench. The material was rolled in the direction of water flow. Check slots measuring 0.15 m deep x 0.15 m wide (6 in x 6 in) were located every 7.6 m (25 ft) along the channel. In the check slots, the material covered the perimeter of the slot and was anchored at the bottom with staples. In the channel, edges of blankets were overlapped a minimum of 0.08 m (3 in). The blankets were extended to the top of the channel sides and anchored with a row of staples. The ends of the blankets were overlapped a minimum of 0.15 m (6 in) and anchored with a common row of staples. At the terminal end of the channel, the researchers buried the material in a 0.15 m deep x 0.15 m wide trench. The anchor pattern was every 0.61 m (2 ft) on center as shown in figure 34. Staple size was 0.20 m x 0.05 m x 0.20 m (8 in x 2 in 8 in).

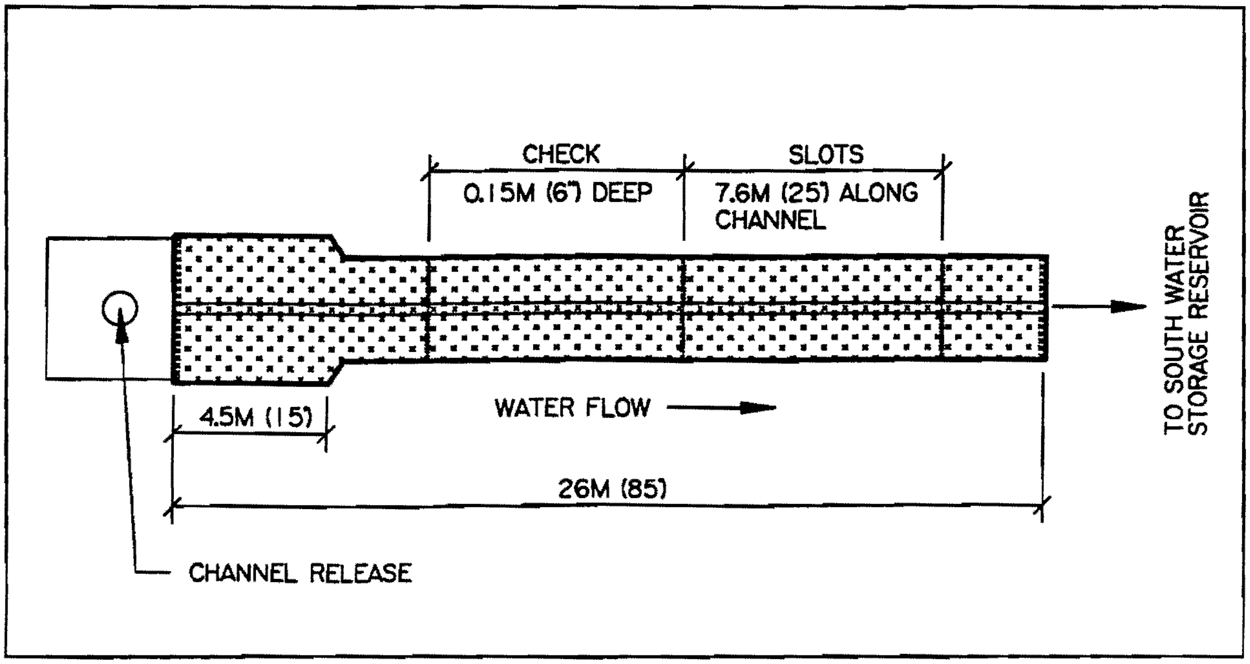


Figure 34. XCEL Super Duty Installation Plan.

Flexible Channel Liner 8 - LANDLOK® ECRM 450, 7% Channel

Synthetic Industries LANDLOK® ECRM 450 was installed on June 7, 1994, with a manufacturer's representative present. The researchers buried the material in a 0.31 m deep x 0.15 m wide (12 in x 6 in) trench at the terminal end of the channel. The roll was laid 0.31 m prior to the trench, around the perimeter of the trench, and over the top of the trench with anchors on the upstream side and within the trench. The material was rolled in an upstream direction against water flow. Check slots measuring 0.15 m deep x 0.15 m wide (6 in x 6 in) were located every 9.15 m (30 ft) along the channel. In the check slots, the material was overlapped and stapled on the bottom of the trench, backfilled and compacted, and rolled over the compacted trench. In the channel, edges of blankets were overlapped a minimum of 0.08 m (3 in) and anchored with a common row of staples. The blankets were extended to the top of the channel sides and anchored in longitudinal slots measuring 0.10 m deep x 0.10 wide (4 in x 4 in). The researchers anchored the blanket with two rows of staples prior to the longitudinal slot and on the bottom of the slot with staples. The end of the blanket was overlapped a minimum of 0.31 m (1 ft) in a shingle style with two rows of common staples. At the top of the channel, the LANDLOK® ECRM 450 was anchored in a 0.31 m deep x 0.15 m wide (12 in x 6 in) trench. The material was laid in the trench and overlapped a minimum of 1 m (3 ft) with staples placed on the overlapped portion and the bottom of the trench. The anchor pattern was every 1 m x 0.5 m (3 ft x 1.5 ft) in a domino pattern as shown in figure 35. Staple size was 0.20 m x 0.05 m x 0.20 m (8 in x 2 in x 8 in).

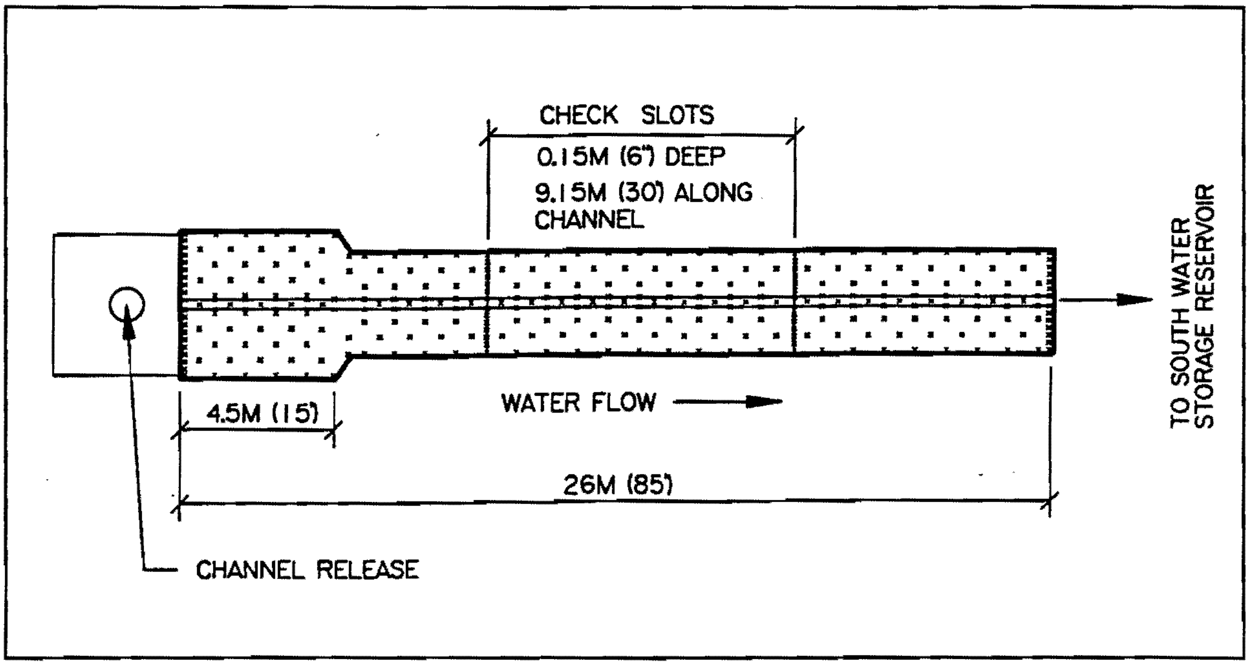


Figure 35. LANDLOK® ECRM 450 Installation Plan.

Flexible Channel Liner 9 - TENSAR® Erosion Blanket TB1000, 7% Channel
TENSAR®'s Erosion Blanket TB1000 was installed on June 6, 1994, with a manufacturer's representative present. The researchers buried the material in a 0.31 m deep x 0.15 m wide (12 in x 6 in) trench located at the top of the channel. The roll was laid a minimum of 0.31 m (12 in) downstream of the trench, rolled to cover the trench perimeter, stapled on the bottom, backfilled and compacted, and rolled the material over the compacted trench in the downstream direction. A row of common staples anchor the material on the 0.31 m (12 in) overlapped portion of this trench. The material was rolled in a downstream direction with check slots (transverse check slots) measuring 0.15 m x 0.15 m (6 in x 6 in) located every 9.15 m (30 ft) along the channel. In the check slots, the material was overlapped and stapled upstream, in the trench bottom, and downstream of the trench. In the channel, edges of blankets were overlapped a minimum of 0.08 m (3 in) and anchored with a common row of staples. The blankets were extended to the top of the channel sides and anchored in a 0.10 m deep x 0.10 m wide trench. Two rows of staples placed prior to this longitudinal trench and one row on the bottom of the trench anchor the material. The end of the blanket was overlapped a minimum of 0.61 m (2 ft) in a shingle style with two rows of common staples. At the terminal end of the channel, the TB1000 was buried in a 0.31 m deep x 0.15 m wide (12 in x 6 in) trench with staples placed prior to the trench and on the trench bottom. The anchor pattern was every 1.22 m x 0.61 m (4 ft x 2 ft) with the alternating rows of staples starting 0.46 m (1.5 ft) from the blanket edge as shown in figure 36. Staple size was 0.20 m x 0.05 m x 0.20 m (8 in x 2 in x 8 in).

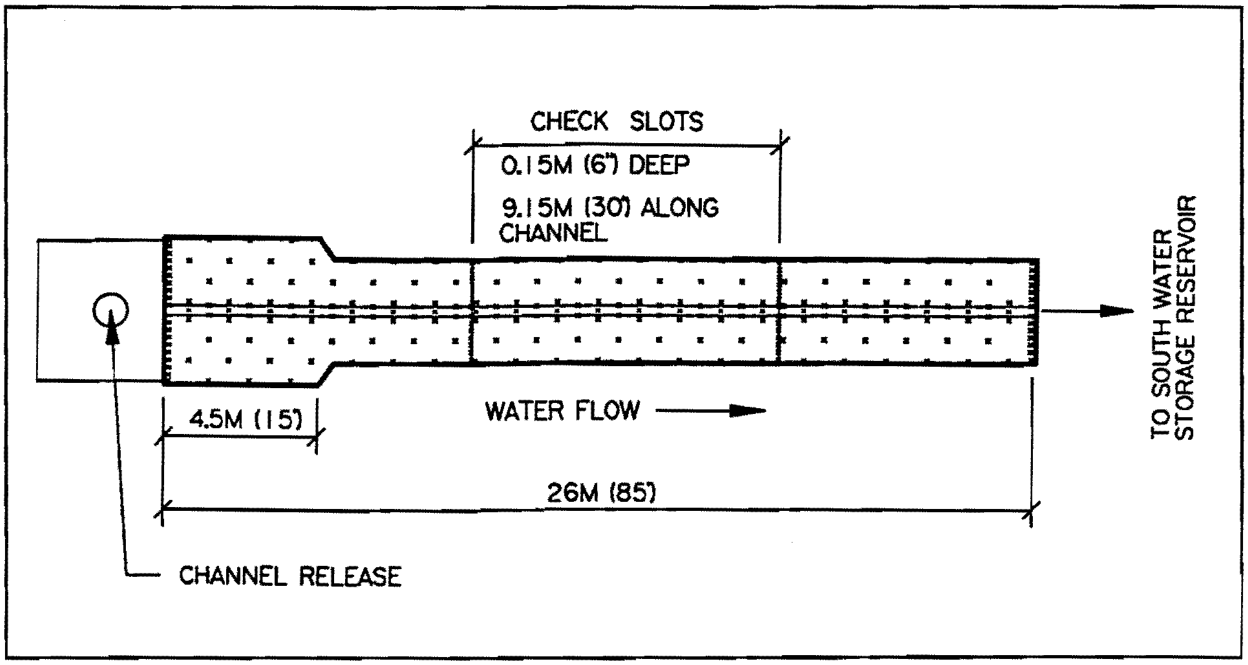


Figure 36. TENSAR® Erosion Blanket TB1000.

DATA COLLECTION

The researchers collected similar data for each study area regarding sediment retention performance and vegetation establishment performance in the field as shown in table U. The manner in which the data was collected varied depending upon the application area.

Table U. Data Collection for Each Study Area

Application Area	Material Type	Data Collected			
		Sediment	Shear Stress	Vegetation	Weather
Slope, 1:3 and 1:2	Erosion-control Blankets	✔		✔	✔
Slope, 1:3	Hydraulic Mulches			✔	✔
Channel, 3% and 7%	Flexible Channel Liners	✔	✔	✔	✔

WEATHER DATA

The researchers collected weather data on a daily basis during the evaluation period. The on-site weather station provided weather data. In case of a malfunction, weather data obtained from Easterwood Airport located 10.5 km (6.5 mi) away provided the research team with adequate information.

SEDIMENT DATA FOR THE EROSION-CONTROL BLANKET STUDY

The researchers began the rainfall simulation events within four weeks after a blanket was installed. As described earlier in this document, the erosion-control blankets and control plots received a series of rainfall simulations for the 1-year, 2-year, and 5-year design storms. The following description details how the data was collected for each storm event to determine the sediment retention performance.

After each simulated rainfall event, the sediment and water were vacuumed with a wet-dry vacuum into buckets, then labeled, covered, and temporarily stored. The sediment was allowed to settle for at least twenty-four hours before the top layer of water was vacuumed off and discarded. Soil samples collected from each bucket were capped, labeled, and stored in the lab trailer. The remaining soil in the buckets was weighed, recorded, and discarded at this time. To determine the moisture-to-sediment ratio, the researchers used soil samples to calculate the total dry weight of sediment.

Each soil sample went through a drying process to arrive at the wet/dry ratio. First, the soil sample was weighed, recorded, and emptied onto a microwave cooking dish. Any material left in the sample bottle was rinsed with water and added to the cooking dish. The researcher dried the soil for several minutes followed by another weight measurement. Until three consecutive weighings were equal, this process continued. The dry sample weight was recorded and averaged with the other samples to determine an average wet/dry ratio. This ratio was divided into the total weight of sediment to obtain the dry weight of the collected sediment. Finally, the dry sediment weight total was divided by the number of 10 square meters (107.64 sf) for each plot to figure total sediment loss. Table V shows the rainfall simulation schedule for the 1994 product evaluations.

Table V. 1994 Rainfall Simulations, 1:2 Slope

1:2 Sand Study Treatment Plots						
Product Brand Name	Install	1-Year #1	1-Year #2	2-Year #1	2-Year #2	5-Year #1
Airtrol® Plaster	05/16/94	06/27/94	07/06/94	08/12/94	09/06/94	10/13/94
American Excelsior Curlex®	05/11/94	06/06/94	07/11/94	07/26/94	09/21/94	10/07/94
SuperGro®	05/12/94	06/11/94	06/16/94	07/28/94	09/19/94	10/06/94
GEOJUTE® PLUS	05/13/94	06/27/94	07/08/94	08/10/94	09/15/94	10/11/94
DEKOWE® 700	05/13/94	06/27/94	07/07/94	08/12/94	09/12/94	10/12/94
MIRAMAT™ 1000	05/16/94	06/22/94	07/08/94	08/04/94	09/16/94	10/10/94
SoilGuard™	05/09/94	06/02/94	07/11/94	07/25/94	09/21/94	10/07/94
Control	05/19/94	06/27/94	07/06/94	08/18/94	08/31/94	10/13/94
1:2 Clay Study Treatment Plots						
SuperGro®	05/12/94	05/26/94	06/27/94	08/04/94	09/06/94	10/10/94
GEOJUTE® PLUS	05/13/94	05/27/94	07/06/94	07/25/94	09/12/94	10/05/94
MIRAMAT™ 1000	05/16/94	06/02/94	06/29/94	07/28/94	09/07/94	10/06/94
SoilGuard™	05/09/94	06/06/94	06/27/94	08/11/94	08/18/94	10/11/94
Control	05/19/94	05/27/94	07/06/94	07/25/94	09/15/94	10/05/94
1:3 Sand Study Treatment Plots						
Product Brand Name	Install	1-Year #1	1-Year #2	2-Year #1	2-Year #2	5-Year #1
Airtrol® Plaster	05/16/94	06/17/94	06/28/94	07/20/94	08/15/94	10/04/94
American Excelsior Curlex®	05/11/94	06/16/94	06/28/94	07/18/94	08/29/94	09/28/94
SuperGro®	05/12/94	06/17/94	06/28/94	07/19/94	08/26/94	09/30/94
Control	06/13/94	06/16/94	06/29/94	07/13/94	08/31/94	09/26/94
1:3 Clay Study Treatment Plots						
SuperGro®	05/12/94	05/26/94	06/28/94	07/18/94	08/26/94	09/27/94
Control	05/19/94	05/27/94	06/27/94	07/19/94	08/15/94	09/29/94

For simulating rainfall events, the researchers adhered to the following criteria: (1) Rainfall simulations did not occur within 24 hours of a natural rainfall or during any natural precipitation; (2) Simulations were not done when the wind conditions were such that most of the water blew onto the adjacent plots. If the wind was calm, the plots adjacent to the treatment plot were covered with a plastic film immediately before the rain simulation was started; (3) Once the material was "rained" upon, the researchers removed the plastic film and collected the sediment and runoff from the trough(s).

CHANNEL DEGRADATION (SEDIMENT) DATA FOR THE CHANNEL LINERS

The researchers used flow simulations to generate the channel degradation or sediment retention data and the shear stress data for determining maximum permissible tractive force. Prior to all flow simulations, the researchers pre-wetted the channels as this would occur with natural rainfall before flow begins. Once the channel surface was "rained" upon, the technician activated the pumping station to deliver the pre-determined volume of water. Similar to natural flows seen along roadside drainage ditches, the water rises within the system and begins to flow out of the treatment channel opening, gradually. Within three to four minutes, water flowed at the desired depth and continued for ten minutes until the pump stopped. Tables W and X show the flow simulation schedule for 1994.

Before and after each simulated flow, the researchers surveyed the channel profile to record deformation. To collect this data, the researchers used a point gauge to take section profiles at four stations located longitudinally along the treatment channel. These stations were at 10.675 m (35 ft), 15.25 m (50 ft), 19.825 m (65 ft), and 24.4 m (80 ft) from the upper end of the channel as shown in figure 37. Each individual profile sample consisted of seven readings taken at each station as shown in figure 37. This procedure enabled the researchers to quantify sediment retention and sediment bed load migration.

Table W. 1994 Flexible Channel Liner Flow Simulations for 7% Channels

7% Channel Flow Simulations

Product	Shear Stress Generated (lbs/ft^2)												
	2.66a	2.66b	3a	3b	4a	4b	5a	5b	6a	6b	7a	7b	8a
ENKAMAT® 7020	06/22	07/08	07/12	07/18	08/03	08/10	08/19	08/30	09/08	09/27	10/04	10/12	-
GREENSTREAK® PEC-MAT®	06/16	07/07	07/13	07/19	08/03	08/15	08/24	08/31	09/13	09/27	10/10	-	-
North American Green® P300P	06/08	06/23	07/12	07/18	08/02	08/11	08/23	08/30	09/08	-	-	-	-
MIRAMAT™ 1000	06/15	07/06	07/14	07/20	08/04	08/16	08/24	-	-	-	-	-	-
LANDLOK® ECRM 450	06/10	07/07	07/14	07/19	08/04	08/16	08/24	09/01	09/13	09/26	10/11	-	-
TENSAR® TB 1000	06/13	06/29	07/13	07/19	08/01	08/12	08/23	08/31	09/12	-	-	-	-

Table X. 1994 Flexible Channel Liner Flow Simulations for 3% Channels

3% Channel Flow Simulations

Product	Shear Stress Generated (lbs/ft^2)									
	1.66a	1.66b	2a	2b	3a	3b	4a	4b	5a	5b
American Excelsior Hi-Velocity Curlex®	07/05	07/11	07/15	07/21	08/10	08/18	08/26	09/07	-	-
DEKOWE® 900	06/21	07/06	07/15	07/20	08/05	08/17	08/25	09/06	09/14	09/22
XCEL Super Duty	06/30	07/11	07/15	07/21	08/05	08/18	08/25	09/06	-	-

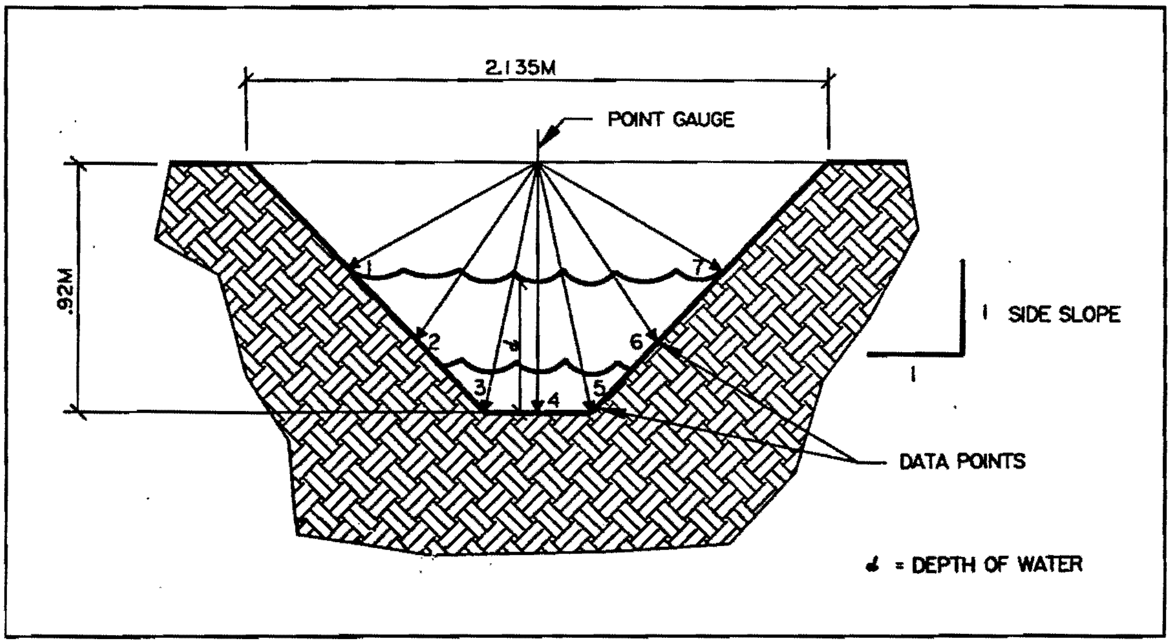


Figure 37. Channel Profile Station Points.

SHEAR STRESS (MATERIAL PERFORMANCE) DATA FOR FLEXIBLE CHANNEL LINERS

Before and after flow simulation, researchers visually inspected each treatment channel for any damage or undermining of the material. Significant rips, tears, pulling away at the seams or loss of material, etc., were recorded on a channel diagram and photographed. Since the researchers incrementally increase the shear stresses placed upon the flexible channel liners, these visual inspections help to determine if the liner should receive the next level of shear stress.

If a flexible liner has reached its maximum permissible tractive force capability, it has reached its "failure" point. "Failure" in this context refers to the amount of bare ground exposed due to the failure of the material to withstand the shear stresses generated upon them. One obvious failure point is the material physically pulls away from the surface and is transported downstream, thereby no longer providing protection to the channel surface. Minor migration of material components within the flexible channel liner, such as excelsior or straw materials, would not constitute a failure as described here. No repairs were made to the flexible channel liners when damage resulted from a simulated flow event.

VEGETATION DENSITY DATA FOR EROSION-CONTROL BLANKETS AND HYDRAULIC MULCHES

The research team began collecting vegetation density data four weeks after installation and continued at approximately five to seven week intervals until the end of the growing season (before the first frost) as shown in Table Y. In order to determine the apparent vegetation density or establishment, the research team modified an existing software package developed by Texas A&M University. *VeCAP* or *V*egetation *C*overage *A*nalysis *P*rogram became the researchers' data analysis method after several modifications. For each round of data collection, the researchers followed this process.

Each plot was subdivided on a graph into a grid of 0.50 m^2 (5.38 ft^2) sections. A random sampling pattern established with a random numbers table was used to set the sample locations. The researchers recorded thirty samples from the 1:3 sloped treatment plots and twenty samples from the 1:2 sloped treatment plots with an 8 mm camera positioned perpendicular to the sloped surface. The video analog images were converted to digital images using a TARGA 16 board and TIPS software. The researchers processed each image (sample) with the VeCAP program to determine the percentage of apparent vegetation coverage. Total cover value was based on the average of the observations for each round of data collection

Table Y. VeCAP Data Collection Schedule for Erosion-control Blankets and Mulches.

Round	Date	Length of Videotaping	Interval Between Videotaping
1	21 June - 28 June	7 Days	Start*
2	29 July - 30 July	2 Days	5.4 Weeks Average
3	16 Sept - 18 Sept	2 Days	7 Weeks Average
4	14 Nov - 30 Nov	16 Days	7 Weeks Average

*The four 1:3 Sand Treatment plots redone due to significant damage had VeCAP dates that corresponded to their installation schedule with the last VeCAP taping occurring before the first freeze date.

VEGETATION DENSITY DATA FOR FLEXIBLE CHANNEL LINERS

Vegetation establishment observations were scheduled to begin in the fourth week after material installation and to continue at approximately six week intervals until the end of the growing season (November 15). However, upon visual inspection, there was not sufficient growth that occurred until ninety days passed. At this time, the researchers began the vegetation density data collection as shown in table Z.

Table Z. VeCAP Data Collection Schedule for Flexible Channel Liners

Round	Date	Length of Videotaping	Interval Between Videotap
1	5 Oct	1 Day	Start
2	1 Nov - 5 Nov	4 Days	4 Weeks Average

The researchers used random patterns, established with a random numbers table, for the bottom and sides of the channel to collect thirty-six samples for each round of data collection. With an 8 mm camera positioned perpendicular to the channel surface, the researchers recorded their observations. From the video tape, single images were captured using a TARGA 16 and TIPS software with the center of the image equal to 0.50 m^2. The researchers processed each image (sample) with the VeCAP program to determine the percentage of apparent vegetation coverage. Total coverage value was based on the average of the observations for each round of data collection.

LABORATORY INDEX TESTS

Manning's *n* value for Flexible Channel Liner Research

For the flexible channel liner study, the researchers determined Manning's *n* value to simulate flows of equal shear stress upon the liner's bottom. To determine Manning's *n* or roughness coefficient for each flexible channel liner, researchers used an indoor flume facility located at the College of Ocean Engineering, Texas A&M University. Physical dimensions of the box-shaped flume are approximately 0.46 m (18 in) in width, 1.22 m (4 ft) in height, and 21 m (70 ft) in length. The energy gradient is 2% longitudinally along the flume bottom. Researchers view the flows through the plexiglass sides of the flume.

The researchers attached the product to the plywood flume bottom with carriage bolts and washers placed 0.46 m (18 in) on center. At a predetermined rate of flow (Q), the researchers simulated a series of flows to collect velocity and depth measurements. Using a digital flow meter, the researchers recorded velocity at two different depths, 60.96 mm (0.20 ft) and 243.84 mm (0.80 ft), to calculate the average velocity during uniform flow.[13] The researchers used a point-gauge instrument to calculate depth of flow. Flow duration was for twenty minutes with data recording every four minutes. Manning's *n* may be determined since rate of flow (Q), channel geometry and slope, measured resultant mean water velocity and depth of flow, are known. With this data, the research team figured a minimum, normal, and maximum Manning's *n* for each product prior to any flow simulations in the field.

Baseline Index Testing for Erosion-control Blankets and Flexible Channel Liner Research

TxDOT's Materials and Tests Division performed laboratory index tests for the erosion-control blankets and flexible channel liners as a baseline product description. The Industry Advisory Council, TxDOT, and TTI selected these particular tests to describe basic physical properties used to identify a product once it has been placed on TxDOT's approved materials list. Table AA lists the index tests for erosion-control blankets and flexible channel liners.

[13] Based on Chow's *Open-Channel Hydraulics,* 1959.

Table AA. Laboratory Index Tests Conducted by TxDOT.

Material Property	Test Method
Synthetic Products	
Polymer Type(s)	ASTM E 1252
Weight	ASTM D 3776
Thickness	ASTM D 1777
Tensile Strength	ASTM D 1682, Grab Method G
Elongation, ultimate	ASTM D 1682, Grab Method G
Tensile Modulus	ASTM D 1682, at 10% Elongation
UV Resistance	ASTM D 4355, Tensile D 1682
Flexibility	ASTM D 1388-64
Biodegradable Products	
Weight	ASTM D 3776 (Total Roll Only)
Netting: Composition	ASTM E 1252
Aperture Size	Direct Measure
Placement	Visual
Weight	ASTM D 3776
Color	Tex-839-B
Number of Nets	Visual
Net/Matrix Binding Method	Visual/Direct Measure
Jute Products	
Fabric Weave/Yarn Count	Threads/Foot
Weight	ASTM D 3776

ANALYSIS LEVELS AND RESULTS

The research team formatted a statistical analysis to answer a range of questions for each study area based upon TxDOT's needs. All research data necessary for analysis was processed by variance tests for significance with the Statistical Analysis System (SAS). Means were separated by Duncan's Multiple Range test ($P < 0.05$), with the sampling sizes equal to the following; $n = 30$ (1:3 sloped plots), $n = 20$ (1:2 sloped plots), and $n = 36$ (channels).

ANALYSIS LEVEL DESCRIPTION FOR EROSION-CONTROL BLANKETS

The research team conducted statistical analysis for eight levels to ascertain how a product performed from a generic manner increasingly to a specific field situation. These levels are described in the following text with Level 5 results included in the body of this report. All other level results may be obtained from the Texas Department of Transportation.

Level 1

Analyzed the product's *overall performance* without separating performance with respect to steepness of slope, type of soil, or design storm level. (Final vegetation density measurements for round 4 used.)

Level 2

Analyzed the product's performance with respect to *steepness of slope only*, without separating performance into clay or sandy soils, or design storm level. (Final vegetation density measurements for round 4 used.)

Level 3

Analyzed the product's performance with respect to *soil conditions only*, without separating performance into 1:2 or 1:3 slopes, or design storm level. (Final vegetation density measurements for round 4 used.)

Level 4

Analyzed the average sediment loss for each product within *each of the three simulated design storms*. The vegetative density achieved by each product at each round of measurement was determined.

Level 5

Analyzed the product's performance with respect to *both steepness of slope and soil condition.* This level averages the sediment loss determined within each of the three simulated design storms and final vegetative density measurements. TxDOT uses this performance level to support their Annual Approved Products List.

Level 6

Analyzed the average sediment loss for each product within *each of the simulated design storms and by the 1:2 and 1:3 slopes*. The data collected from the vegetative densities achieved by each product at each measurement stage within the 1:2 and 1:3 slopes were used for this analysis level.

Level 7
Analyzed the average sediment loss for each product within *each of the simulated design storms and by the clay and sandy soils*. The data collected from the vegetative densities achieved by each product at each measurement stage within the clay and sandy soils were used for this analysis level.

Level 8
Analyzed the sediment loss by each product within *each of the simulated design storms, within the clay and sandy soils, and within the 1:2 and 1:3 slopes*. The data collected from the vegetative densities produced by each product at each measurement stage within the clay and sandy soils and within the 1:2 and 1:3 slopes were used for this analysis level.

ANALYSIS LEVEL DESCRIPTION FOR HYDRAULIC MULCHES

The researchers identified four logical analysis levels that provided answers to how a particular product performed. Generally, this analysis approach starts "broad-brush" then isolates different variables on an increasingly specific manner.

Level 1
Analyzed the product's *overall performance* without separating performance with respect to type of soil or application method.

Level 2
Analyzed the product's performance with respect to *soil type only*, without separating performance by application method.

Level 3
Analyzed the product's performance with respect to *application methods only*, without separating performance by soil type.

Level 4
Analyzed the product's performance with respect to *soil type and application method.*

MINIMUM PERFORMANCE STANDARDS

TxDOT established minimum performance standards for erosion-control blankets and hydraulic mulches prior to the 1994 research. Each product must meet the appropriate standards as a minimum for recommendation to the approved materials list for TxDOT standard specification Item 169 and Item 164.2. Manufacturer's products that fail to meet these criteria have the first opportunity to submit their product for re-evaluation in the next cycle. TxDOT has reserved the right to refine the minimum acceptable performance standards based upon additional data collected through the research program. Tables BB and CC show the minimum performance standards for erosion-control blankets and hydraulic mulches.

Table BB. Performance Standards for Erosion-control Blankets.

Vegetation Density		
Application	**Cohesive Soils (Clay or Tight)**	**Non-cohesive Soils (Sand or Sandy)**
1:3 or Flatter	80%	70%
Steeper than 1:3	80%	70%
Sediment Loss		
1:3 or Flatter	0.34 kg/10 m^2 (0.70 lbs/100 ft^2)	12.21 kg/10 m^2 (25 lbs/100 ft^2)
Steeper than 1:3	0.34 kg/10 m^2 (0.70 lbs/100 ft^2)	26.85 kg/10 m^2 (55 lbs/100 ft^2)

Table CC. Performance Standards for Hydraulic Mulches.

Vegetation Density	
Application	**Combined Soil Type**
1:3 or Flatter	50%*

*TxDOT has reserved the right to not recommend hydraulic mulches for steep sand and sandy soil slopes based upon the poor performance results achieved through the research program.

TxDOT established minimum performance standards for flexible channel liners for the 1994 research. As this applies with other erosion control products, these standards reflect the minimum performance allowable for recommendation to TxDOT's approved materials list. Since the laboratory research is aimed at continuing the research started by the FHWA in open-channel hydraulics, a key component is vegetation growth. The soil-fabric interaction and changes in material performance under increasingly greater shear stress depend, in part, on the vegetation density present during flow simulations. For the 1994 cycle, the researchers recommended that the products be re-evaluated in 1995 due to the lack of vegetation density achieved during the 1994 growing season. In response to the research team's recommendations, TxDOT agreed to re-evaluate the materials in 1995 and to refine the standards based upon sufficient data analysis.

RESULTS AND DISCUSSION

1994 EROSION-CONTROL BLANKET RESULTS

Vegetative Density

Table DD and figures 38-44 show the material performance and Level 5 analysis for each product evaluated in 1994. In the vegetation study, the erosion-control blankets protected the 1:2 sloped, sandy soils significantly better when compared to the Control treatment results. American Excelsior Curlex®, Soil Guard™, and MIRAMAT™ 1000 supported 93% more vegetation than the Control treatment. Interestingly, the best performing erosion-control blanket for the 1:2 sloped, clay soils, SuperGro® (96.353), supported 26% more vegetation than the Control treatment (71.628). All of the results for the 1:3 sandy sloped treatments were below the minimum standards established by TxDOT, although American Excelsior Curlex® gave the best performance by supporting 77% more vegetation than the Control treatment.

Table DD. Performance Assesment of Erosion-control Blankets for the 1994 Cycle.

Treatment	**Vegetative Density(%)**	**Vegetative Density (%)**
1:2 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
SuperGro®	96.353 a	69.570 b
Soil Guard™	83.987 ab	86.735 a
GEOJUTE PLUS®	72.647 bc	3.883 d
MIRAMAT™ 1000	65.814 c	81.466 ab
American Excelsior Curlex®	n/a	89.461 a
GEOCOIR®/DEKOWE® 700	n/a	49.623 c
Airtrol® Plaster	n/a	17.614 d
CONTROL	71.628 bc	6.073 d
Treatment	**Vegetative Density (%)**	**Vegetative Density (%)**
1:3 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
SuperGro®	70.378 b	17.585 c
American Excelsior Curlex®	n/a	48.632 a
Airtrol® Plaster	n/a	33.638 b
CONTROL	88.437 a	11.147 c

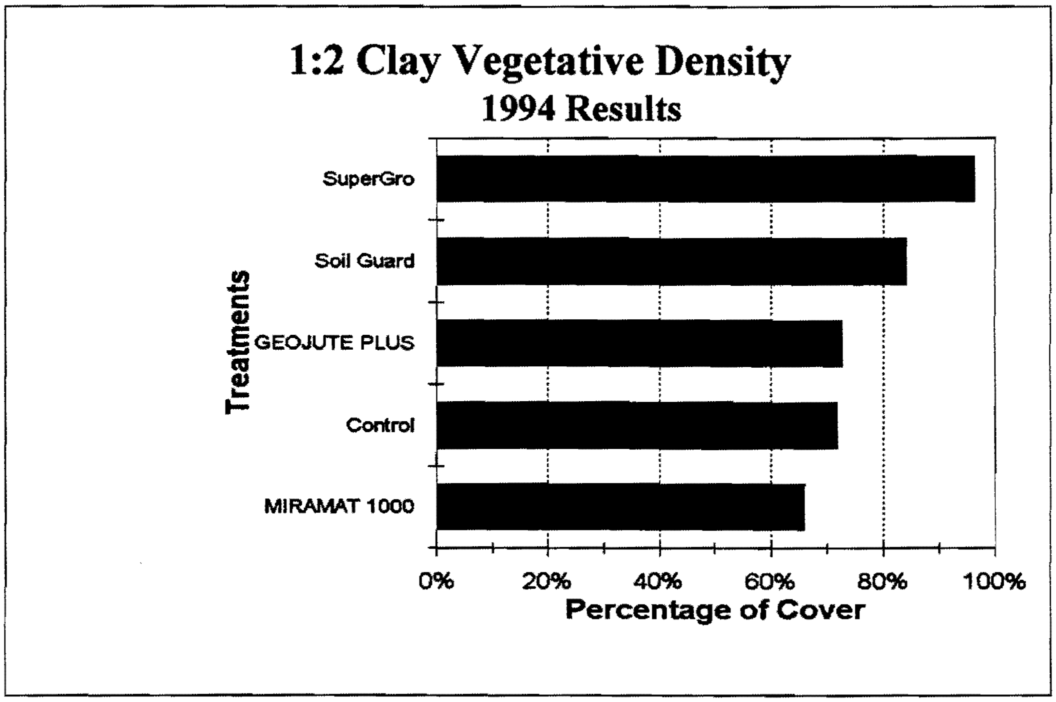


Figure 38. 1:2 Clay Vegetative Density Results.

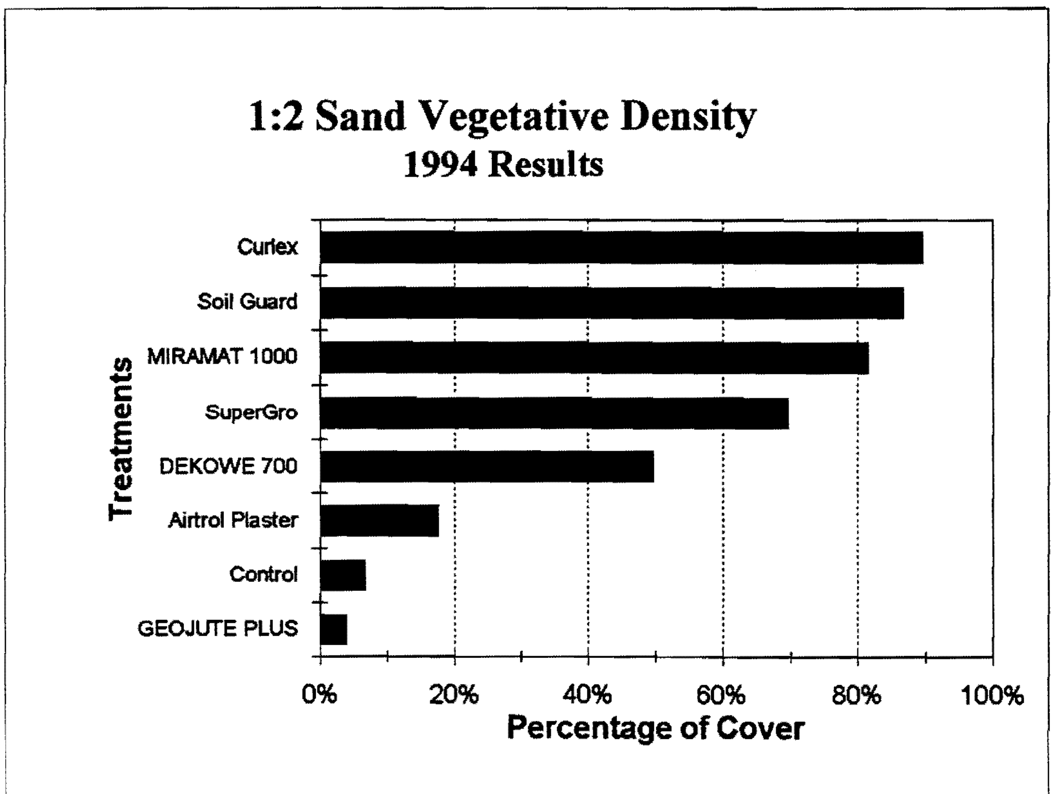


Figure 39. 1:2 Sand Vegetative Density Results.

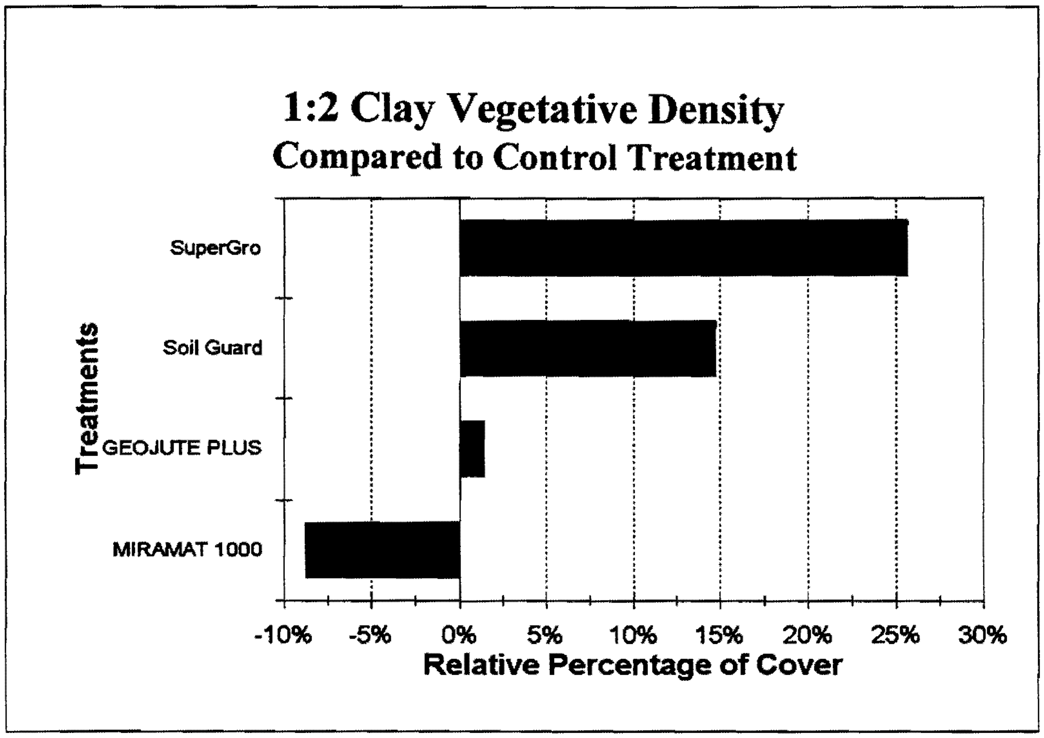


Figure 40. 1:2 Clay Vegetative Density Compared to Control Treatment.

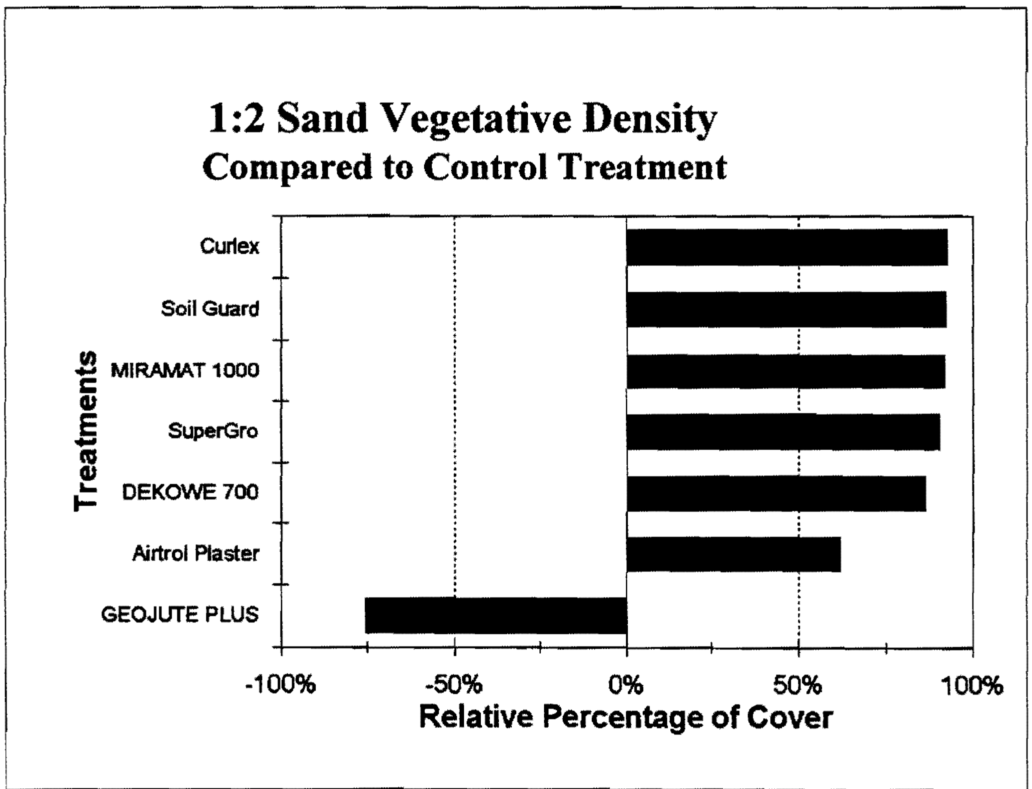


Figure 41. 1:2 Sand Vegetative Density Compared to Control Treatment.

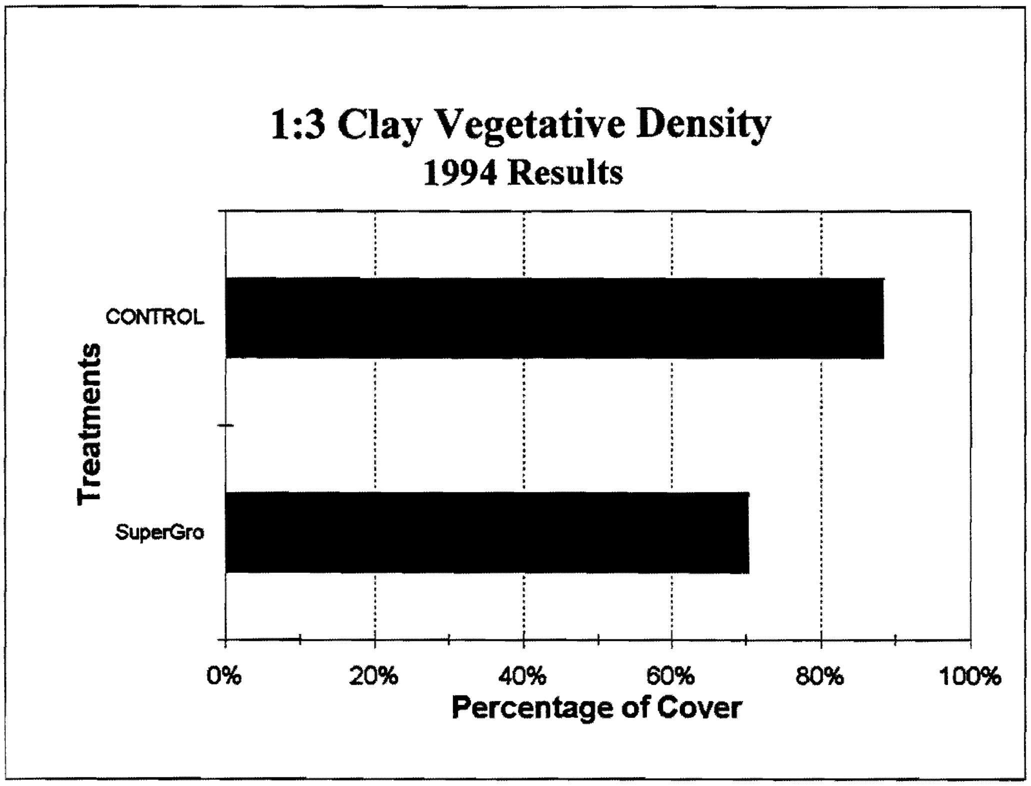


Figure 42. 1:3 Clay Vegetative Density.

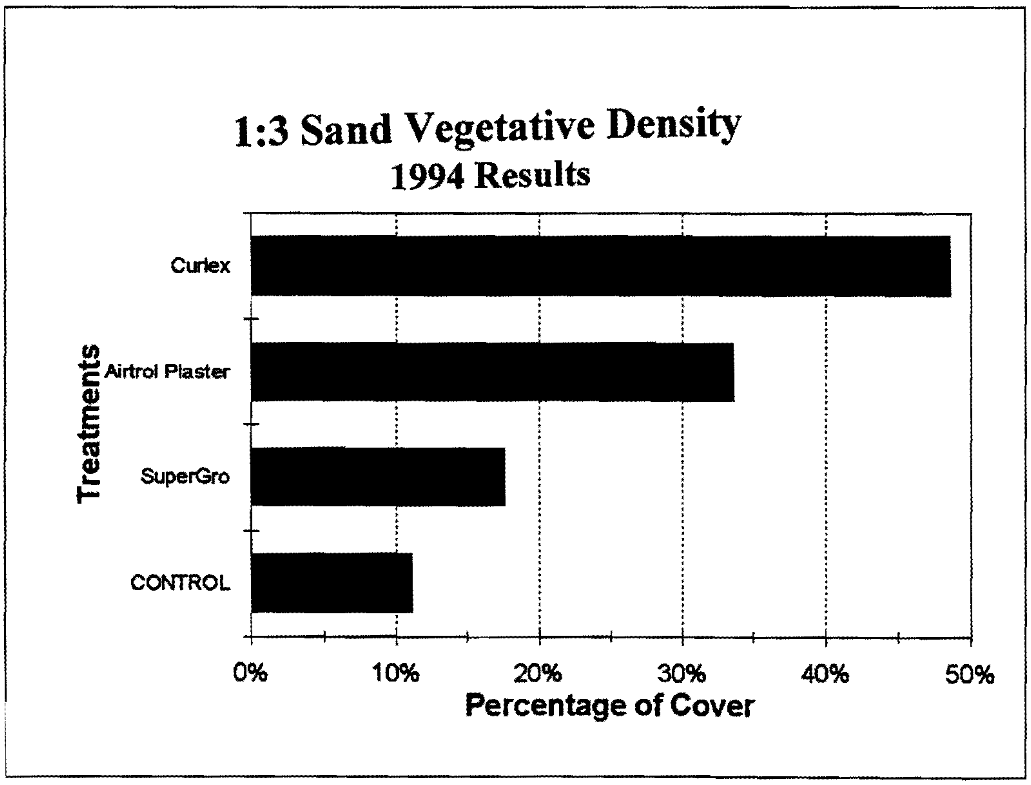


Figure 43. 1:3 Sand Vegetative Density.

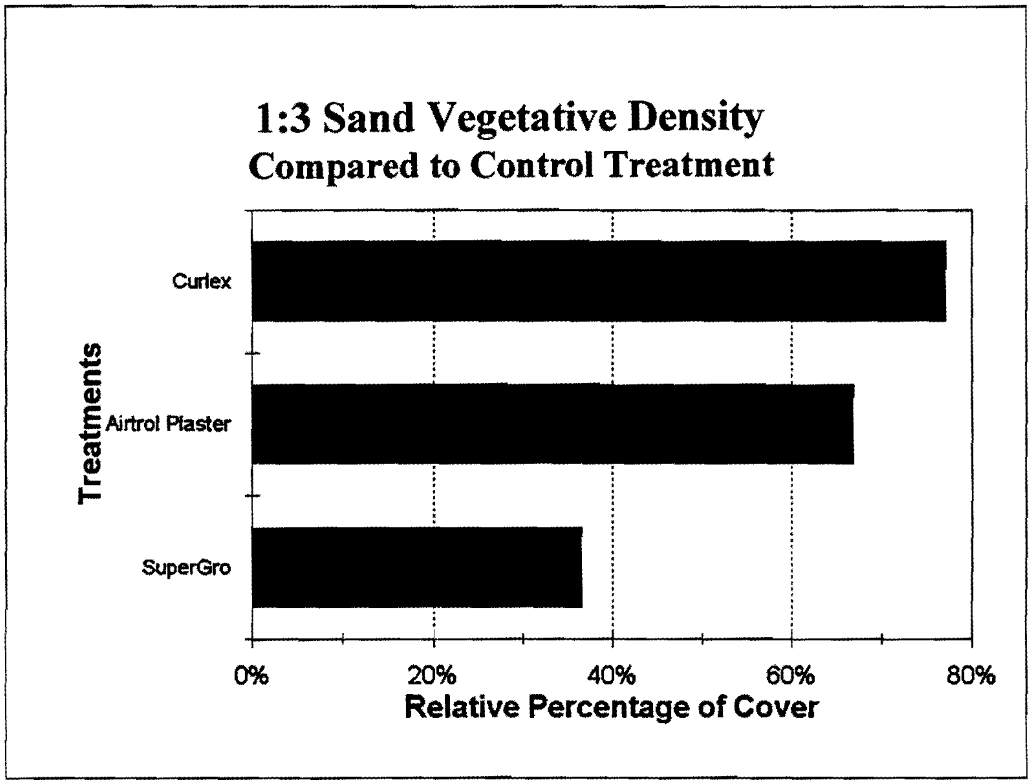


Figure 44. 1:3 Sand Vegetative Density Compared to Control Treatment.

Sediment Retention

The researchers evaluated the sediment retention performance with the following results from the 1994 study as shown in Table EE and Tables 45-51. As expected, the Control treatment plots yielded significantly greater sediment loss than all other treatments within each of the soil and sloped conditions. Surprisingly, there were significant differences in performance for erosion-control blankets on the 1:2 sloped clay soils but no significant differences in blanket performance on the 1:2 sandy soils. When comparing sediment retention performance to the control treatment, all of the treatments performed 45% better than the control for the 1:2 clay plots. Soil Guard™ on the 1:2 clay slope was the top performer with 80% better sediment retention compared to the Control treatment. For the 1:2 sandy plots, all of the blankets performed 60% or higher on their sediment retention evaluation when compared to the Control treatment, with Soil Guard™ as the best performer reaching nearly 80% more retention. SuperGro® (-0.0819 kg/10 sq m) on the 1:3 clay slope performed well when compared to the Control treatment (-1.1362 kg/10 sq m). For the 1:3 sandy slope, American Excelsior Curlex® and SuperGro® performed significantly better than Airtrol® Plaster and the Control. The researchers compared the 1:3 sandy treatments to the Control and found that each of the treatments performed at least 55% better than the Control for sediment retention.

Table EE. 1994 Sediment Retention Results.

Treatment	Sediment Loss (kg/10 sm)	Sediment Loss (kg/10 sm)
1:2 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
Soil Guard™	-0.2712 a	-8.042 a
SuperGro®	-0.3342 a	-8.967 a
MIRAMAT™ 1000	-0.4199 ab	-11.824 a
GEOJUTE PLUS®	-0.6942 b	-8.157 a
American Excelsior Curlex®	n/a	-9.124 a
GEOCOIR®/DEKOWE® 700	n/a	-10.389 a
Airtrol® Plaster	n/a	-13.417 a
CONTROL	-1.5318 c	-38.444 b
Treatment	**Sediment Loss (kg/10 sm)**	**Sediment Loss (kg/10 sm)**
1:3 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
SuperGro®	-0.0819 a	-3.002 a
American Excelsior Curlex®	n/a	-2.936 a
Airtrol® Plaster	n/a	-9.261 b
CONTROL	-1.1362 b	-22.063 c

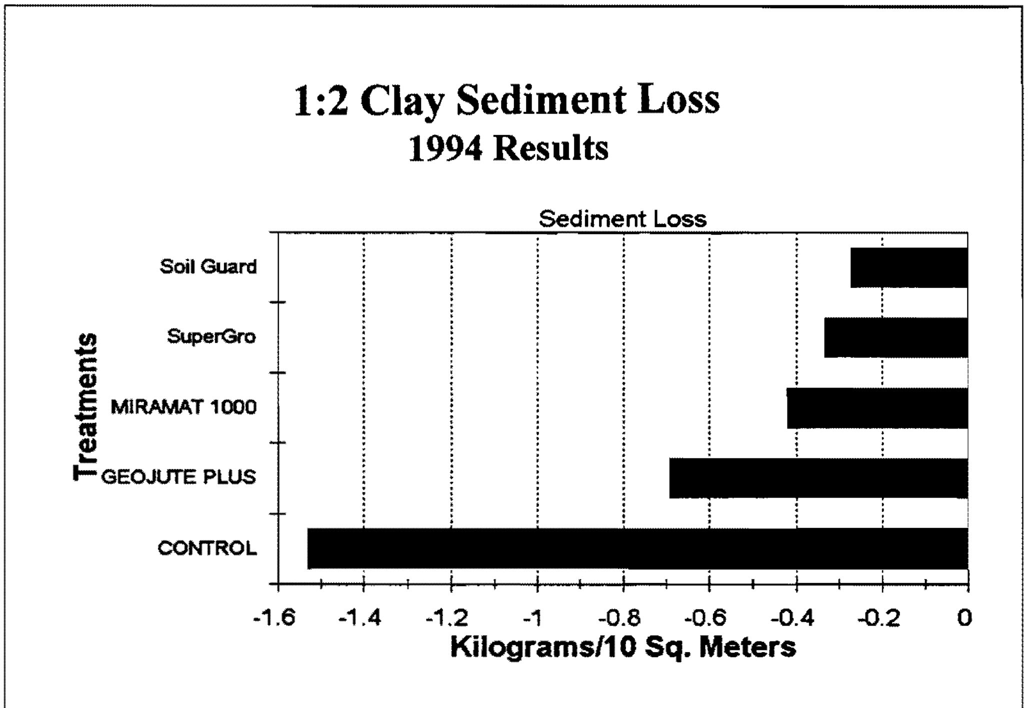


Figure 45. 1:2 Clay Sediment Loss.

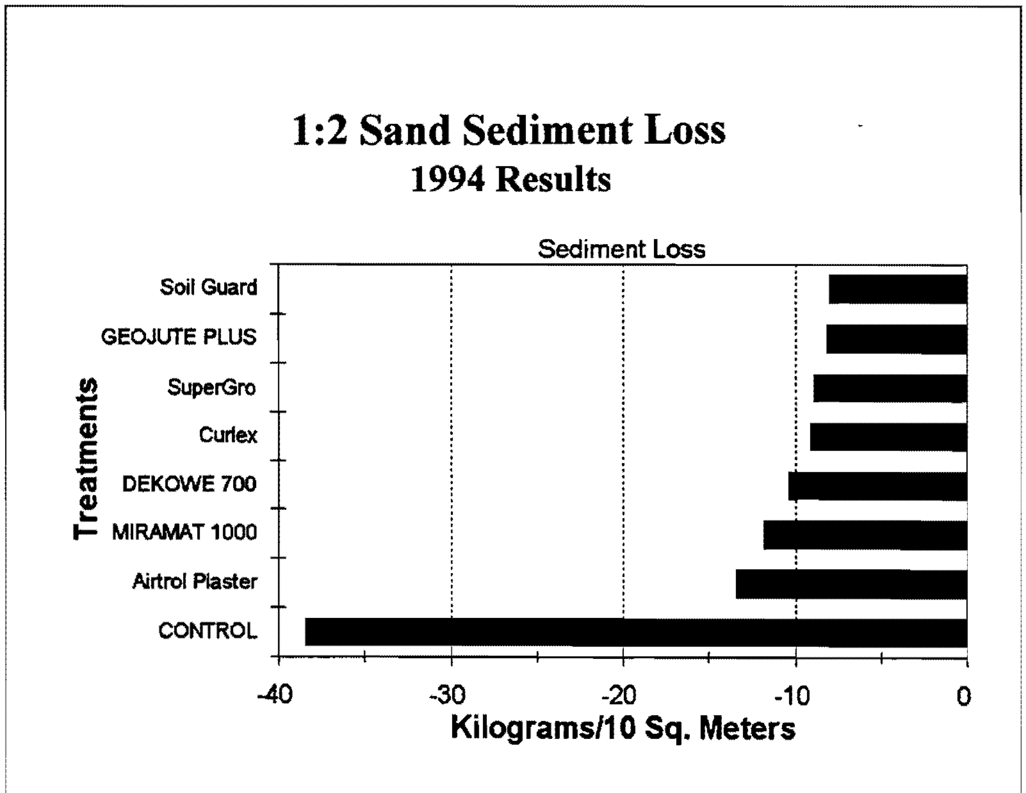


Figure 46. 1:2 Sand Sediment Loss.

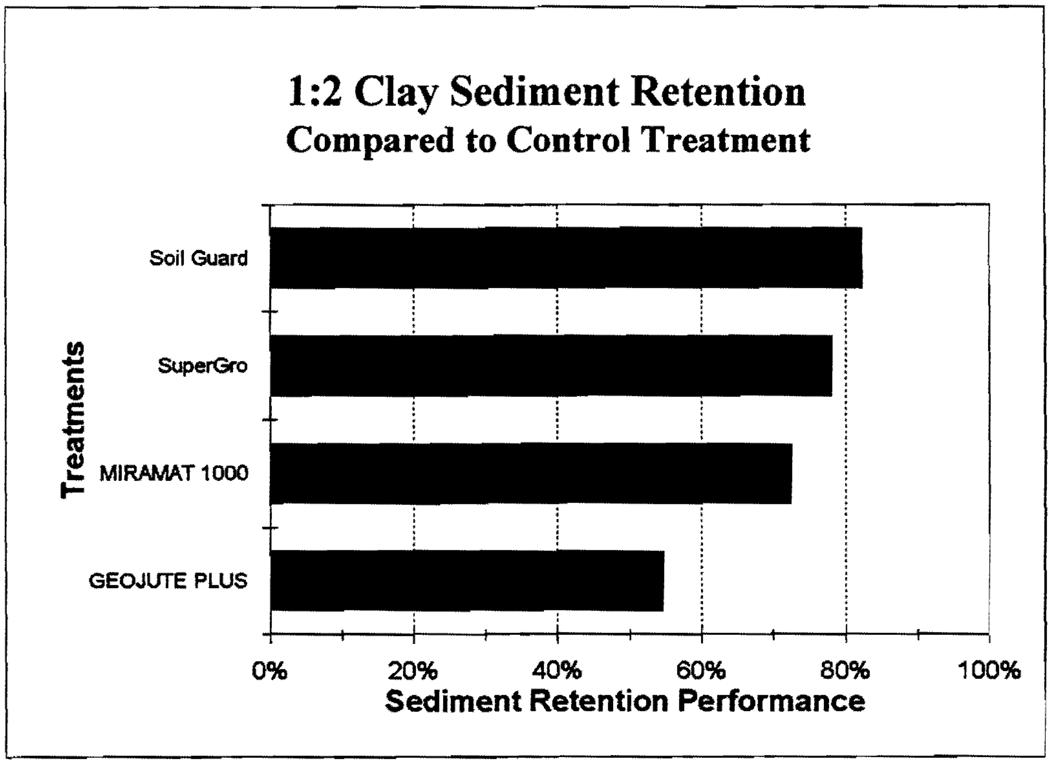


Figure 47. 1:2 Clay Sediment Retention Compared to Control Treatment.

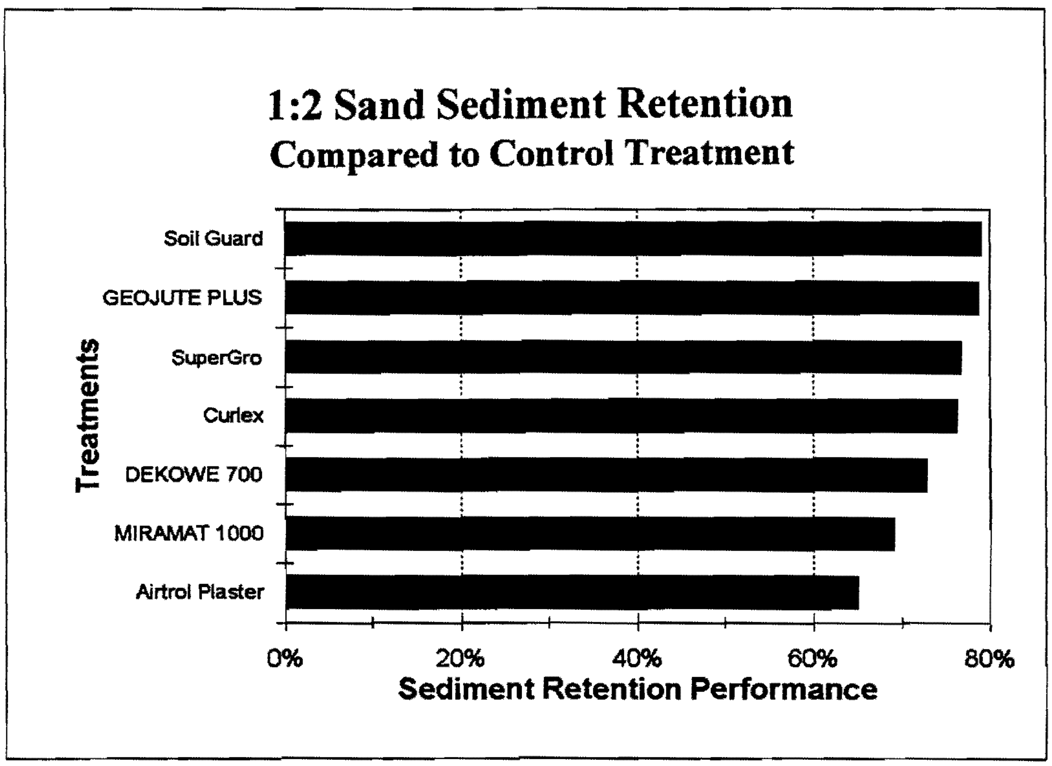


Figure 48. 1:2 Sand Sediment Retention Compared to Control Treatment.

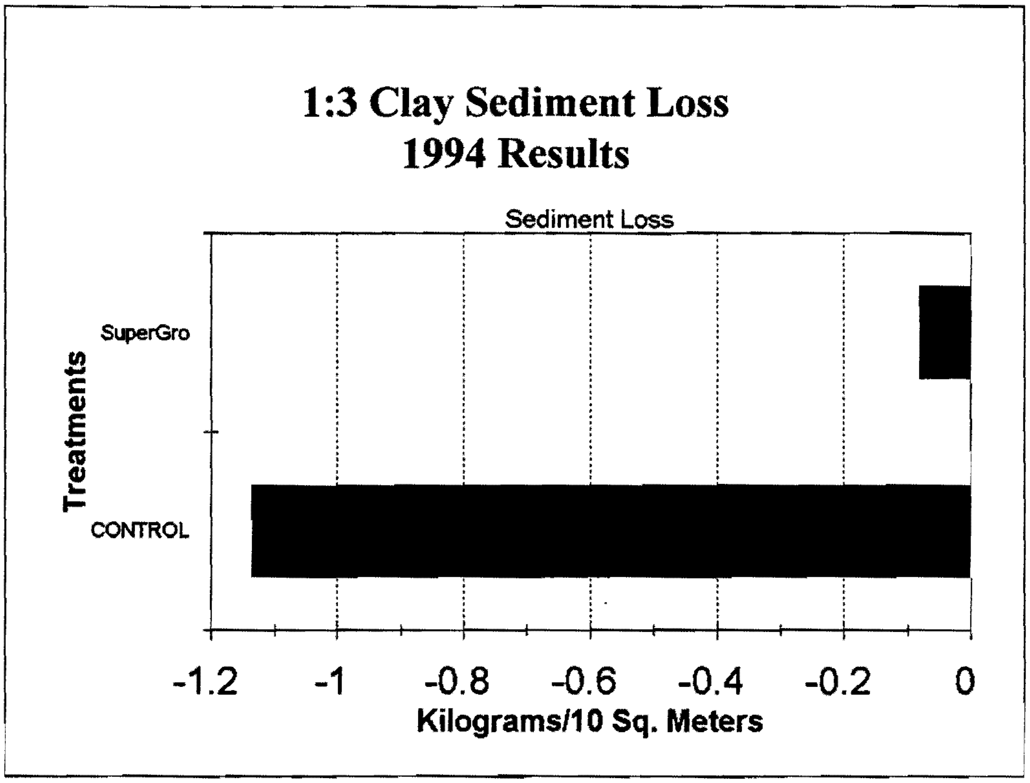


Figure 49. 1:3 Clay Sediment Loss.

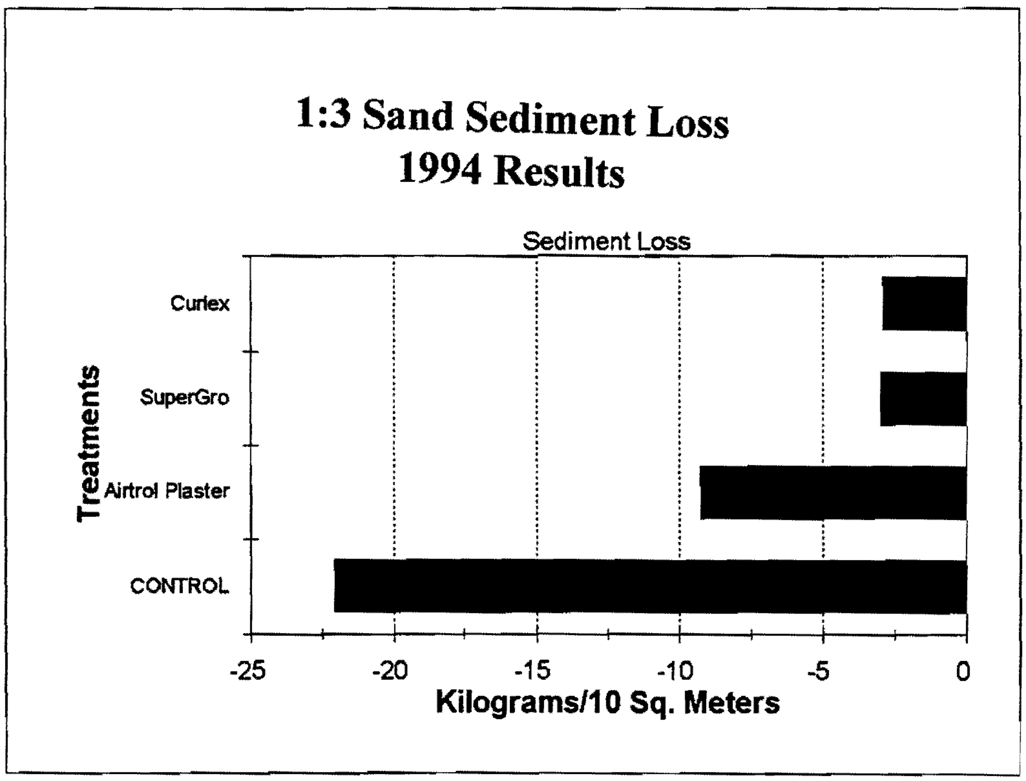


Figure 50. 1:3 Sand Sediment Loss.

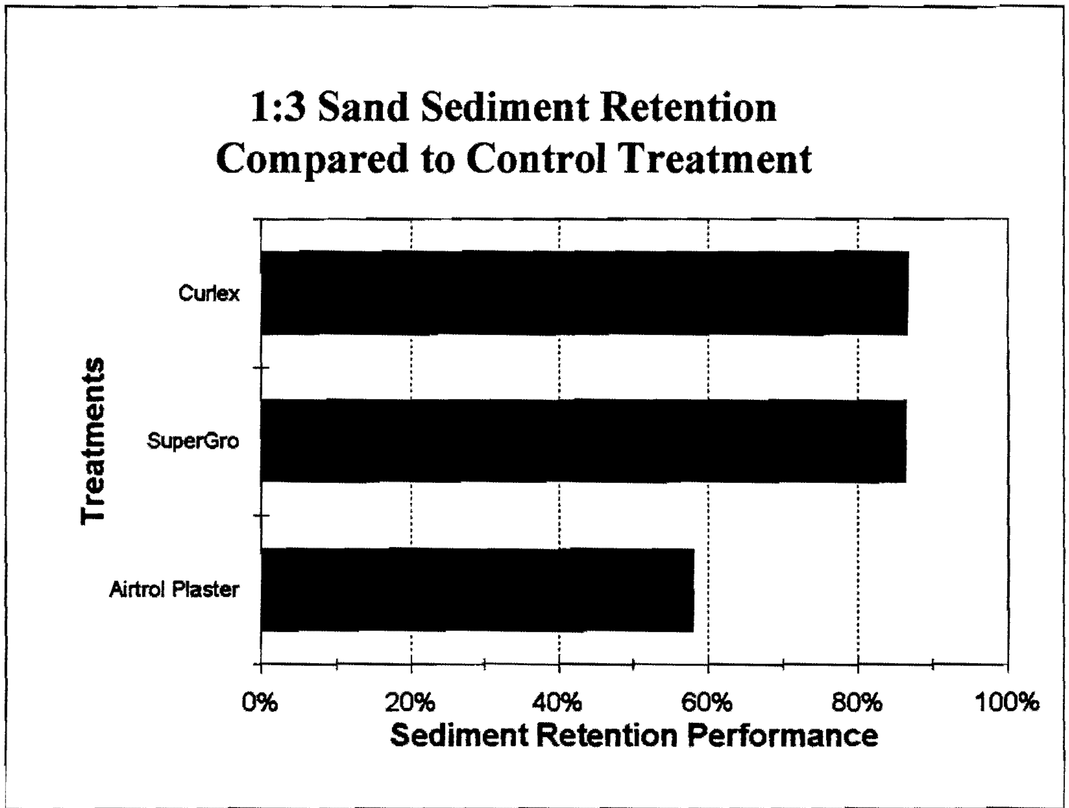


Figure 51. 1:3 Sand Sediment Retention Compared to Control Treatment.

1994

HYDRAULIC MULCHES RESULTS

Vegetative Density

The results for hydraulic mulches showed that the mulches performed significantly different in comparison to the Control treatment for each soil type. For the 1:3 clay mulch treatments, Silva-Fiber® Plus was the top performer with 24% more vegetation than the Control, while all of the other treatments on the 1:3 clay produced a minimum of 15% more vegetation than the Control. In contrast, PROMAT was the best performer for the 1:3 sandy treatments with 42% *less* vegetative growth than the Control treatment. Baseline results showed that all of the products evaluated on the cohesive soil, clay, produced a minimum vegetative density of 80%. Data for the non-cohesive soils, sandy, showed that the products produced a minimum vegetative density of 22%. These results indicate the inherent problems associated with mulches placed on steep slopes with sandy soils as specified in the TxDOT standard specifications. The researchers analyzed the data with soil types combined that show all of the product treatments producing a minimum vegetative density of 52%. When analyzed in this manner, the mulches did not perform significantly different than the Control treatments. Table FF and figures 52-57 show the researchers' results.

Table FF. 1994 Hydraulic Mulch Results.

Treatment	Vegetation Density (%)	Vegetation Density (%)
1:3 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
Silva-Fiber® Plus	91.983 a	24.833 b
PROMAT XL	86.245 a	24.615 b
PROMAT	84.154 a	25.070 b
American Fiber Mulch®	83.568 a	22.518 b
PROMAT XL w/tack	82.960 a	23.045 b
CONTROL	70.034 b	35.676 a

Treatment	Vegetation Density (%)
1:3 Slope	**Combined Soil Types Mean/Grouping**
Silva-Fiber® Plus	58.408 a
PROMAT XL	55.430 a
PROMAT	54.612 a
American Fiber Mulch®	53.043 a
PROMAT XL w/tack	53.002 a
CONTROL	52.855 a

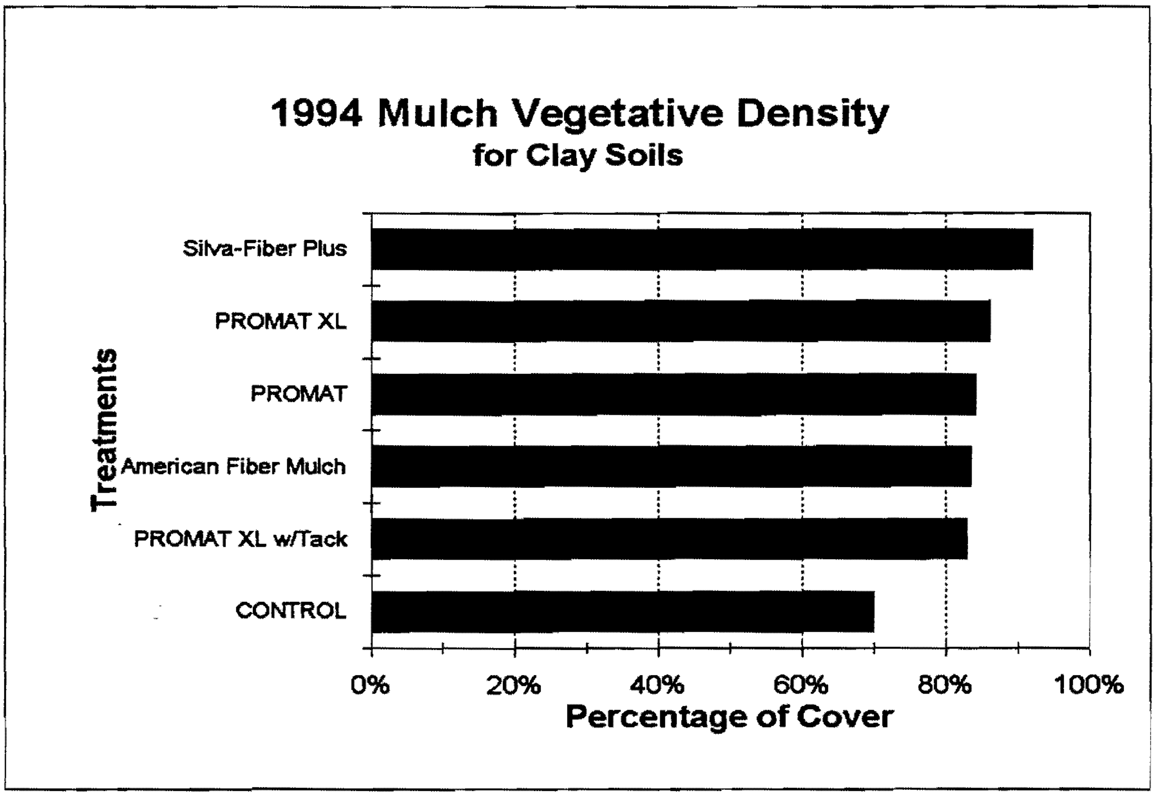


Figure 52. Mulch Vegetative Density for Clay Soils.

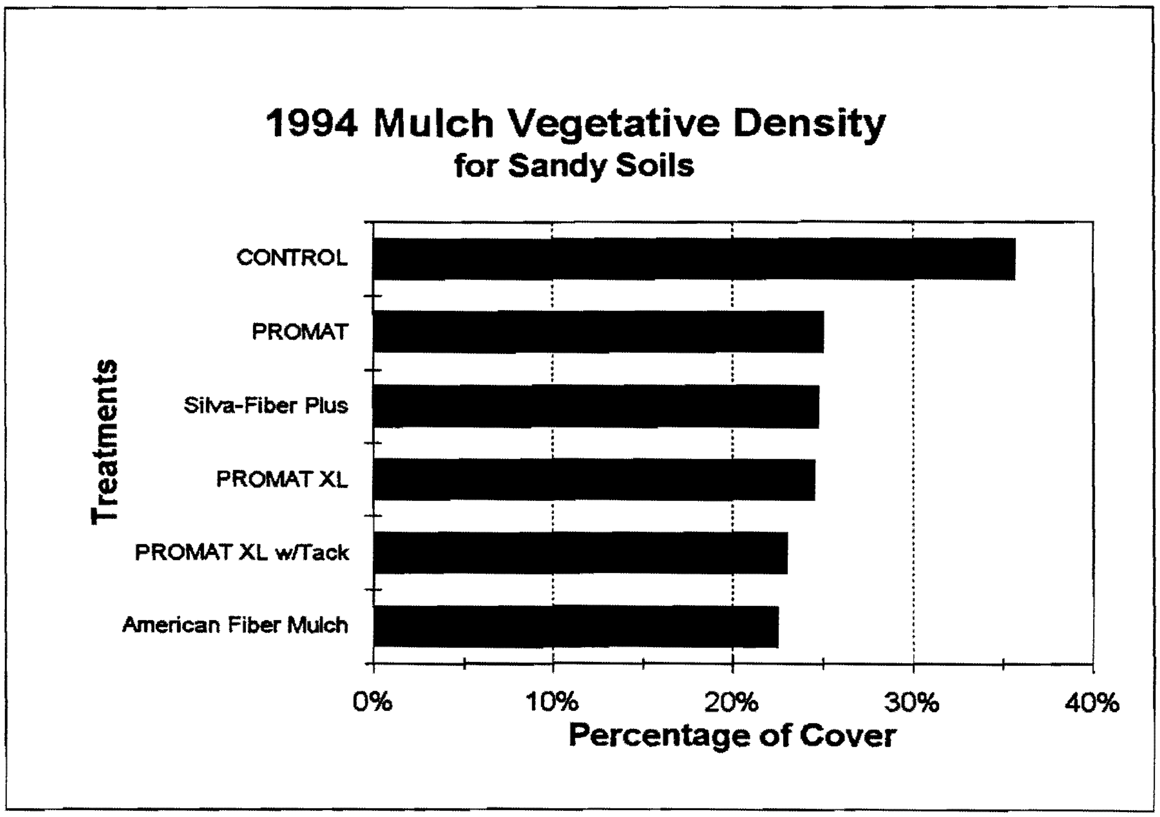


Figure 53. Mulch Vegetative Density for Sandy Soils.

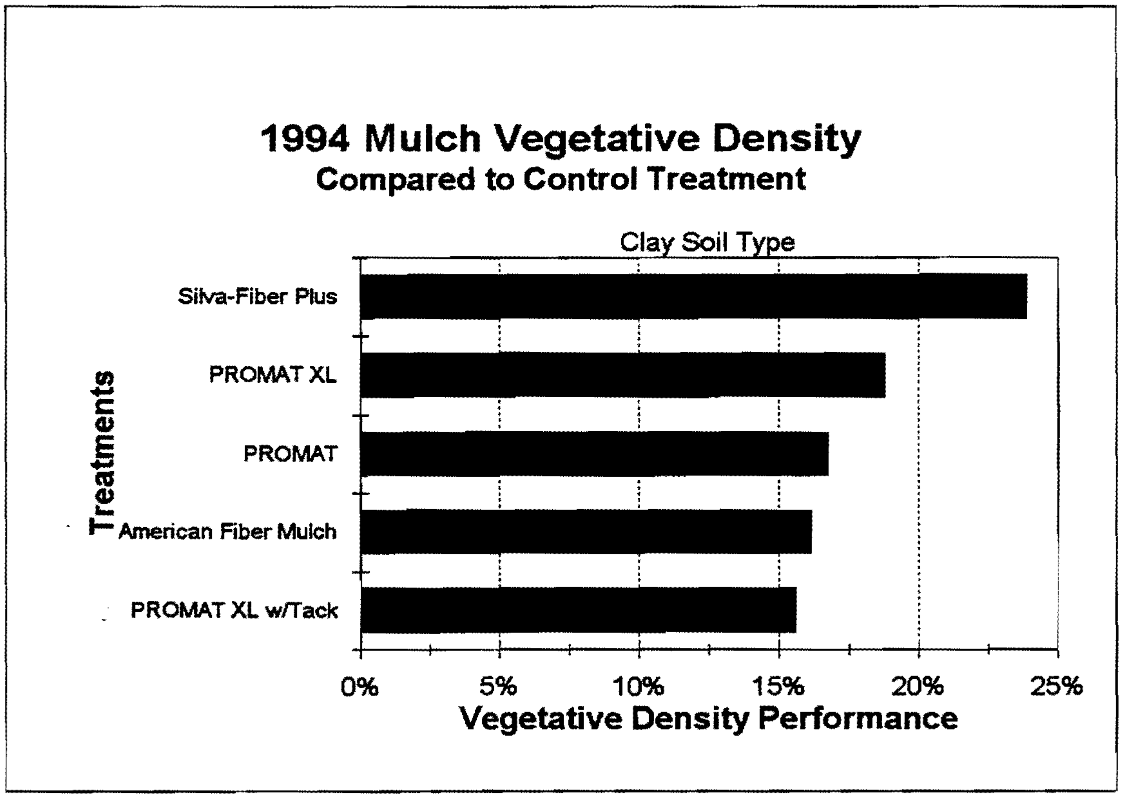


Figure 54. Mulch Vegetative Density Compared to Control Treatment.

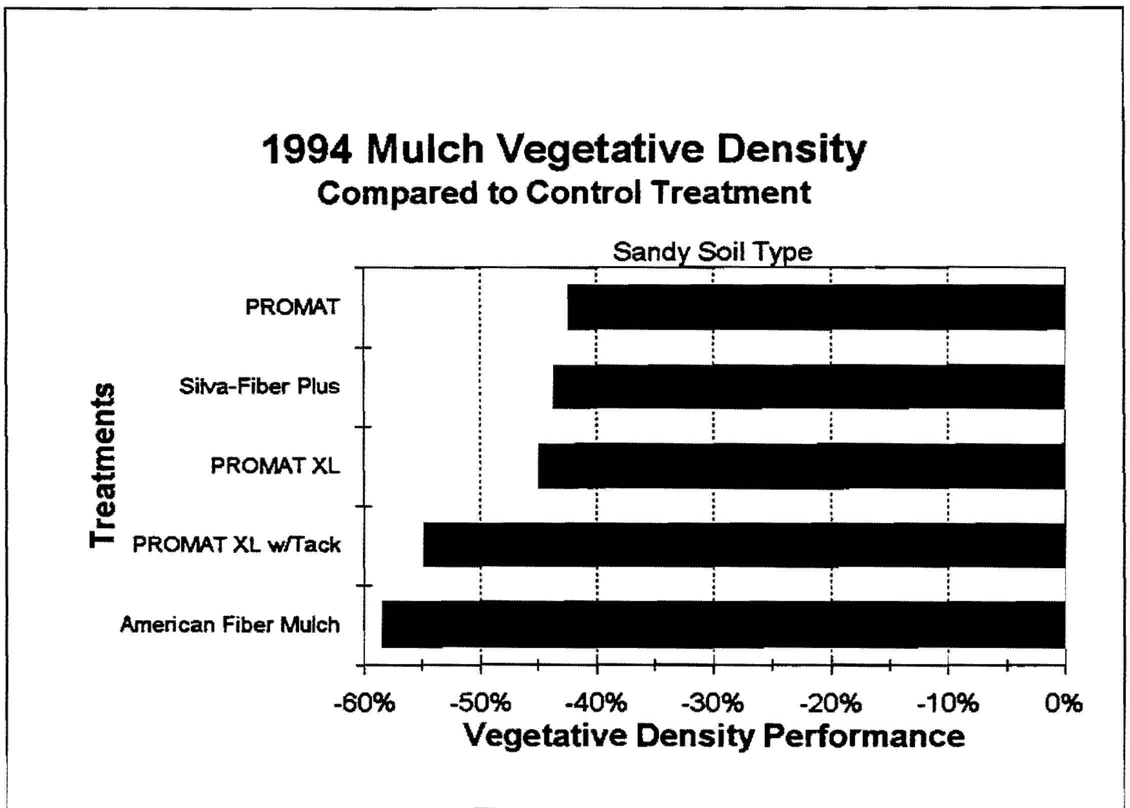


Figure 55. Mulch Vegetative Density Compared to Control Treatment on Sandy Soils.

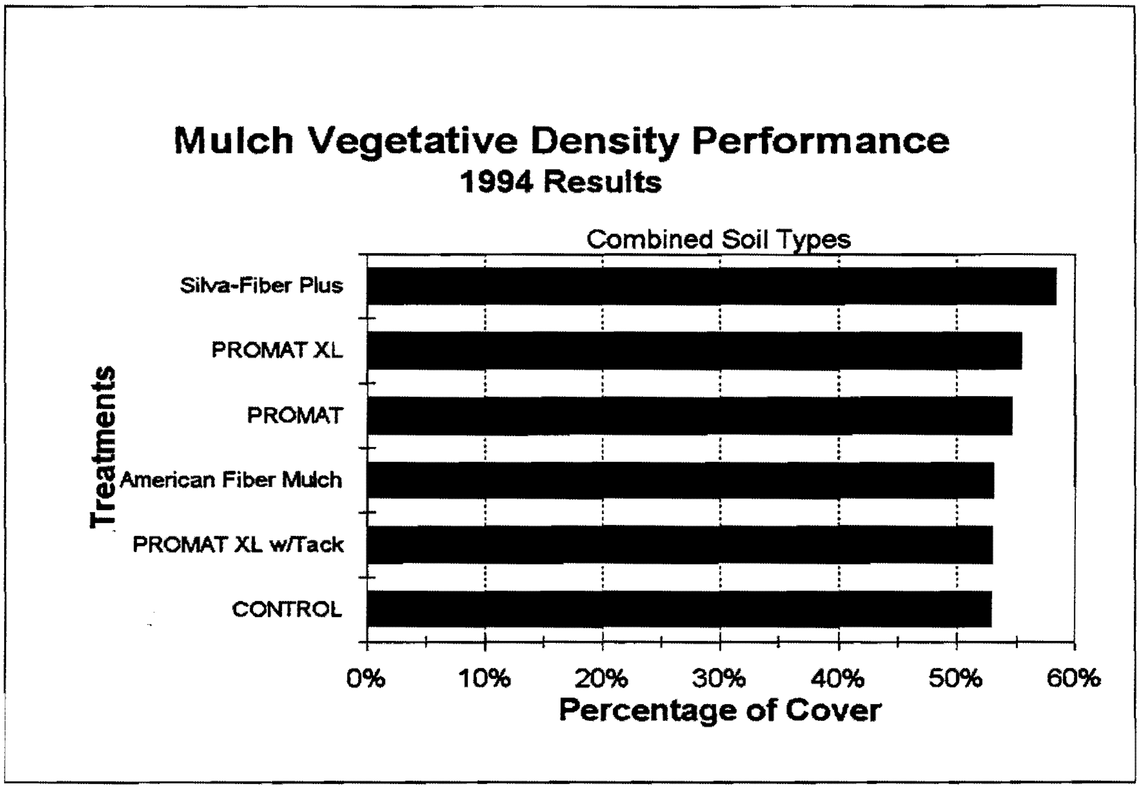


Figure 56. Mulch Vegetative Density Performance with Combined Soil Types.

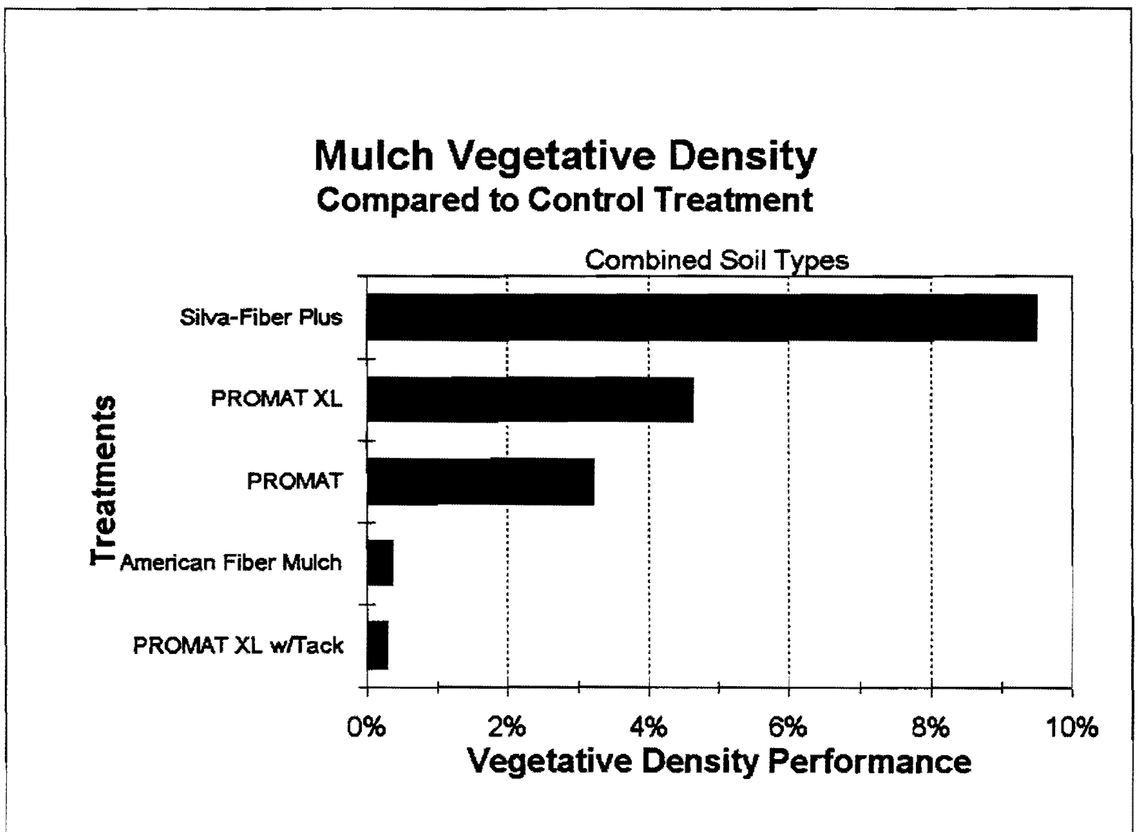


Figure 57. Mulch Vegetative Density Compared to Control Treatment.

SUMMARY OF THE COMBINED RESULTS FOR EROSION-CONTROL BLANKETS: 1991, 1992, AND 1994 STUDY YEARS

Vegetative Density

The researchers combined the data from the previous two years (1991,1992) with the 1994 results to evaluate the field performance of ersion-control blankets as shown in Table GG and Figuress 58-61. In the vegetation study on the 1:2 clay slope, the best five performers out of fourteen total product treatments were Xcel Superior®, American Excelsior Curlex®, SuperGro®, POLYJUTE™ 407GT, and North American Green® S150. Each of these products produced a minimum of 10% more vegetation than the Control treatment. In contrast, the results for the 1:2 sandy slope were more varied. The top five performers were composed of Excelsior, Wood Fiber with Natural Binders, Straw, and Polypropylene, with each of these products producing a minimum of 40% more vegetation. The results for the 1:3 clay treatments were less varied than for the 1:3 sand treatments. The best four performers, American Excelsior Curlex®, North American Green® S75, GREENSTREAK® PEC-MAT™, and Xcel Regular®, promoted a minimum of 90% vegetative cover but only performed a minimum of 14% better than the control. The blankets installed on sand promoted more vegetation growth when compared to the control treatment. The top three performers, North American Green® S75, verdyol® ERO-MAT®, and Xcel Regular®, had 70% more vegetation established than the control.

Table GG. Performance Assesment of Erosion-control Blankets for the 1994 Cycle.

Treatment	**Vegetative Density(%)**	**Vegetative Density (%)**
1:2 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
Xcel Superior®	98.814 a	85.805 a
American Excelsior Curlex® (91)	97.834 a	52.674 bc
American Excelsior Curlex® (92)	n/a	47.335 c
American Excelsior Curlex® (94)	n/a	89.461 a
SuperGro®	96.353 ab	69.570 ab
POLYJUTE™ 407GT	96.151 ab	74.302 a
North American Green® S150	92.014 ab	84.746 a
ANTI-WASH®/GEOJUTE®	90.058 ab	51.372 bc
North American Green® SC150	89.979 ab	76.409 a
GREENSTREAK® PEC-MAT™	87.580 abc	38.863 cd
Airtrol® Plaster (92)	86.094 abc	41.882 cd

Table GG. Performance Assessment of Erosion-control Blankets for the 1994 Cycle.

Treatment	Vegetative Density (%)	Vegetative Density (%)
1:2 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
Airtrol® Plaster (94)	n/a	17.614 e
Soil Guard™	83.987 abc	86.735 a
GEOCOIR®/DEKOWE® 700	73.717 cd	38.716 cd
GEOJUTE PLUS®	72.647 cd	3.883 e
MIRAMAT™ 1000	65.814 d	81.466 a
Polyfelt® TS22	35.909 e	46.051 cd
CONTROL	79.014 bcd	23.098 d
Treatment	**Vegetative Density (%)**	**Vegetative Density (%)**
1:3 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
American Excelsior Curlex® (94)	n/a	48.632 c
American Excelsior Curlex® (92)	98.125 a	33.232 d
North American Green® S75	96.187 a	77.904 a
GREENSTREAK® PEC-MAT™	90.524 a	63.385 bc
Xcel Regular®	90.166 a	72.263 ab
verdyol ERO-MAT®	87.808 ab	73.202 ab
Airtrol® Plaster (92)	86.444 ab	68.749 ab
Airtrol® Plaster (94)	n/a	33.638 d
SuperGro®	70.378 c	17.585 e
American Excelsior Curlex® (91)	63.230 c	60.937 bc
CONTROL	77.862 bc	29.350 d

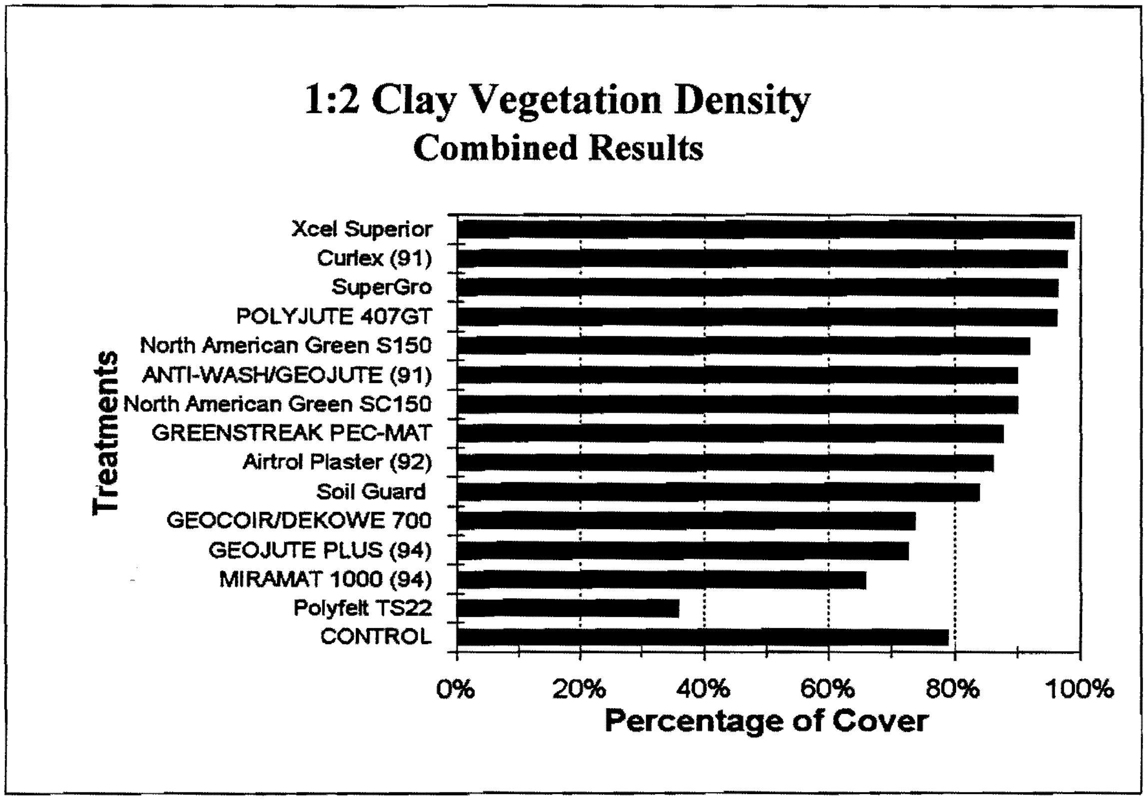


Figure 58. 2:1 Clay Vegetative Density, Combined Results

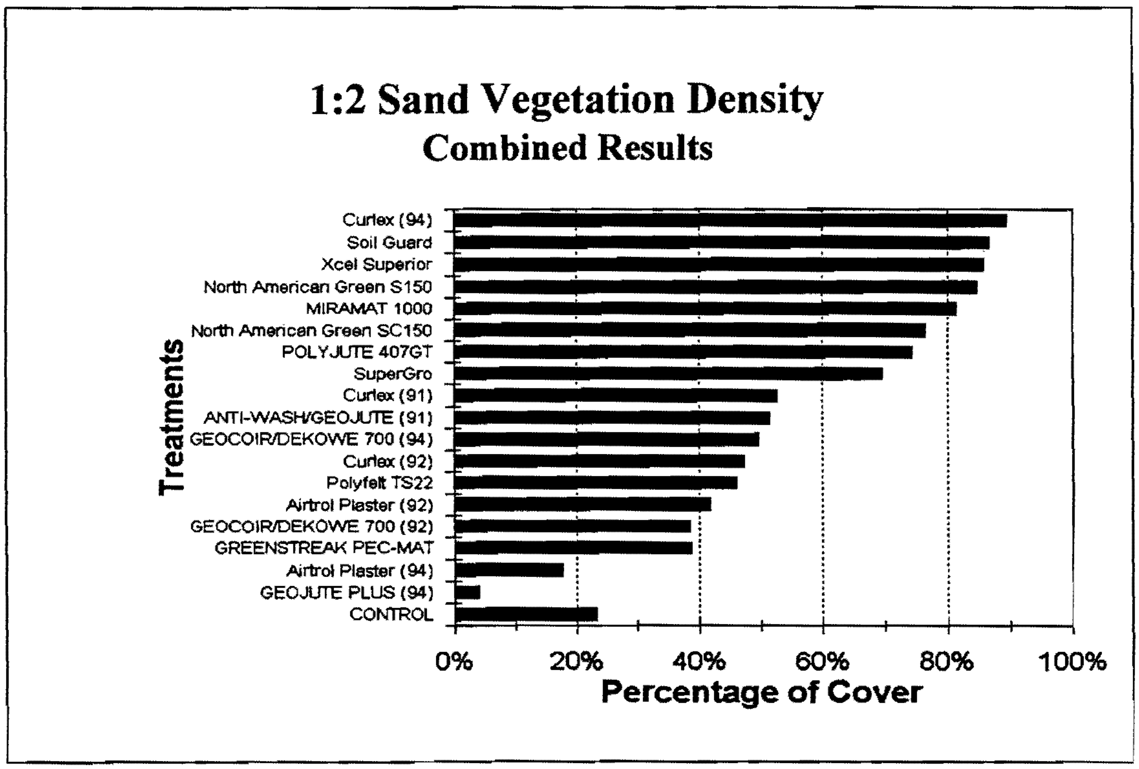


Figure 59. 2:1 Sand Vegetative Density, Combined Results

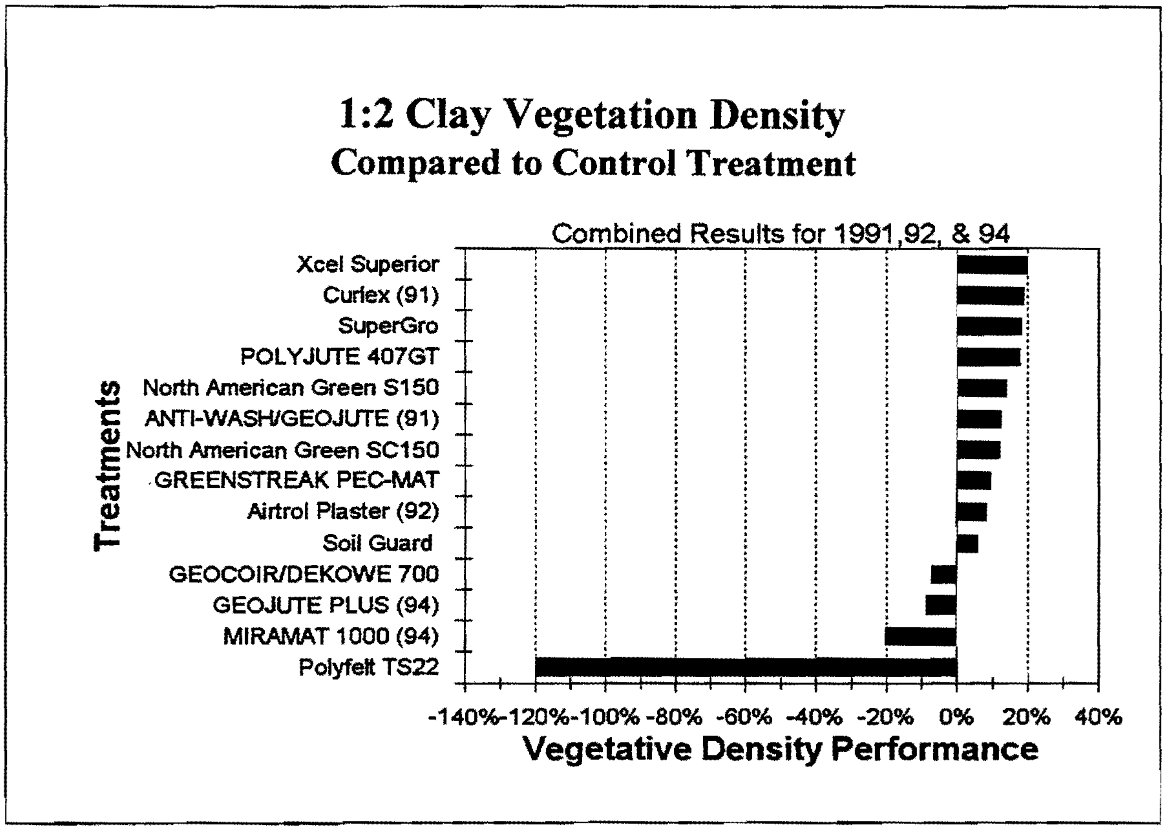


Figure 60. 2:1 Clay Vegetative Density Compared to Control Treatment

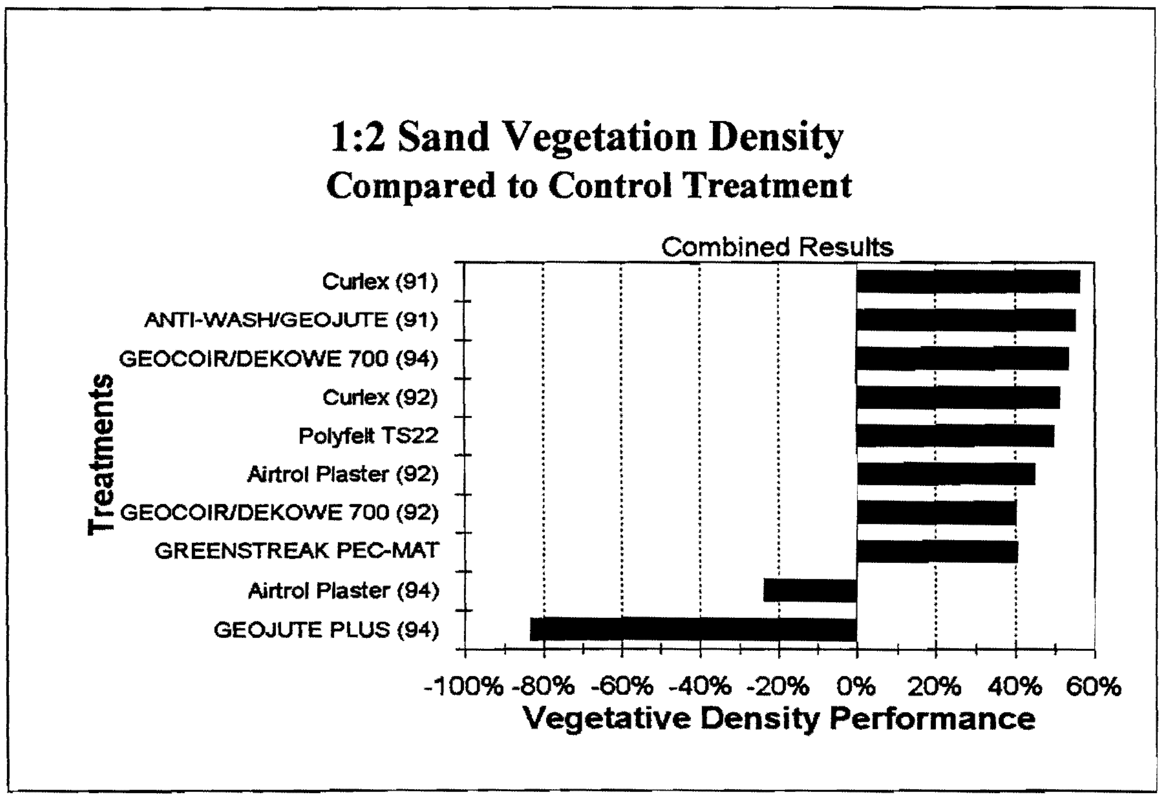


Figure 61. 2:1 Sand Vegetative Density Compared to Control Treatment

Sediment Retention

The researchers combined the data from the previous two years (1991,1992) with the 1994 results to evaluate the field performance of erosion-control blankets. In the sediment retention study on the 1:2 clay slope, the means were not spread, indicating similar performance for 10 of of 14 blanket trials (Table HH, Figure 62,64). Natural fiber products such as American Excelsior Curlex®, North American Green® SC150 and S150, and GEOCOIR®/DEKOWE® 700 performed in the same statistical grouping as the synthetic blends such as POLYJUTE™ 407GT, Airtrol® Plaster, and GREENSTREAK® PEC-MAT™. A (pleasing) indicator of sediment retention shown in the results was that the top ten performers retained a minimum of 80% more sediment when compared to the Control treatment on the 1:2 slope. On the 1:2 sand slope, the means were spread, indicating a wide variety in field performance (Table HH, Figure 63,65). The top five performers included Soil Guard™, GEOJUTE PLUS® (94), SuperGro®, American Excelsior Curlex® (94), and GEOCOIR®/DEKOWE® 700. These products performed signficantly better than the remaining 11 blanket trials and the Control. When compared to the Control treatment, these products retained a minimum of 80% more sediment with the top ten products retaining a minimum of 55% more sediment. The results for the 1:3 clay treatments were less varied than for the 1:3 sand treatments. The top four performers on 1:3 clay were SuperGro®, American Excelsior Curlex® (92), American Excelsior Curlex® (91), and verdyol ERO-MAT® (Table HH, Figure 66,68). These four products retained a minimum of 85% more sediment than the Control treatment. For the 1:3 sand treatments, the top five performers were predominantly natural fiber products. American Excelsior Curlex® remained as one of the best blankets in sediment retention each time it was evaluated (Table HH, Figuress 67-69). The other two top performers included SuperGro® and Xcel Regular®. These five products retained a minimum of 80% more sediment than the Control treatment.

Table HH. Sediment Retention Combined Results.

Treatment	Sediment Loss (kg/10 sm)	Sediment Loss (kg/10 sm)
1:2 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
American Excelsior Curlex® (91)	-0.191	-40.142
American Excelsior Curlex® (92)	n/a	-29.375
American Excelsior Curlex® (94)	n/a	-9.124
North American Green® SC150	-0.212	-28.048
Polyfelt® TS22	-0.217	-33.844
GEOCOIR®/DEKOWE® 700	-0.219	-10.389
North American Green® S150	-0.225	-32.220
POLYJUTE™ 407GT	-0.237	-25.282
Airtrol® Plaster (92)	-0.242	-51.040

Table HH. Sediment Retention Combined Results (continued).

Treatment	Sediment Loss (kg/10 sm)	Sediment Loss (kg/10 sm)
1:2 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
Airtrol® Plaster (94)	n/a	-13.417
GREENSTREAK® PEC-MAT™	-0.249	-41.957
Soil Guard™	-0.271	-8.042
ANTI-WASH®/GEOJUTE® (92)	-0.272	-40.815
Xcel Superior®	-0.320	-
SuperGro®	-0.334	-8.967
MIRAMAT™ 1000	-0.420	-11.824
GEOJUTE PLUS® (94)	-0.694	-8.157
CONTROL	-1.499	-63.569
Treatment	**Sediment Loss (kg/10 sm)**	**Sediment Loss (kg/10 sm)**
1:3 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
SuperGro®	-0.0819	-3.002
American Excelsior Curlex® (91)	-0.147	-4.415
American Excelsior Curlex® (92)	-0.116	-4.127
American Excelsior Curlex® (94)	n/a	-2.936
verdyol ERO-MAT®	-0.153	-9.097
GREENSTREAK® PEC-MAT™	-0.201	-16.436
Airtrol® Plaster (92)	-0.245	-12.415
Airtrol® Plaster (94)	n/a	-9.261
North American Green® S75	-0.273	-8.116
Xcel Regular®	-0.320	-4.722
CONTROL	-1.299	-2.936

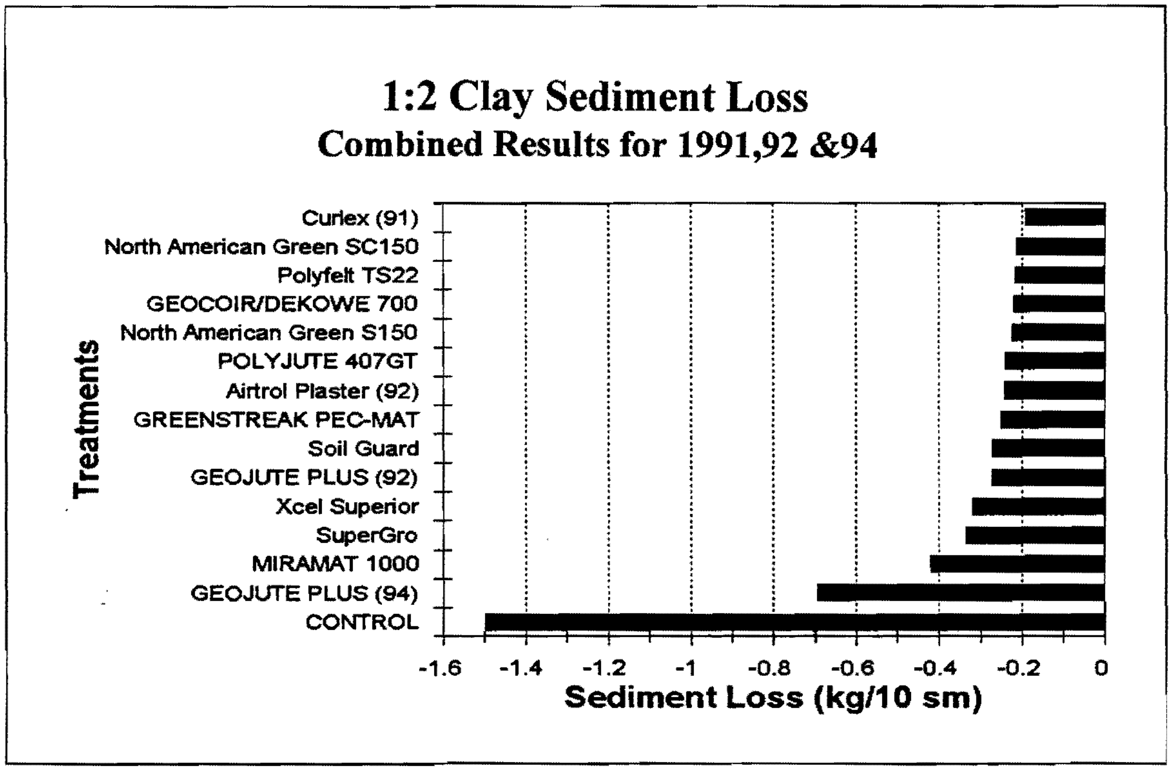


Figure 62. 1:2 Clay Sediment Loss Combined Results.

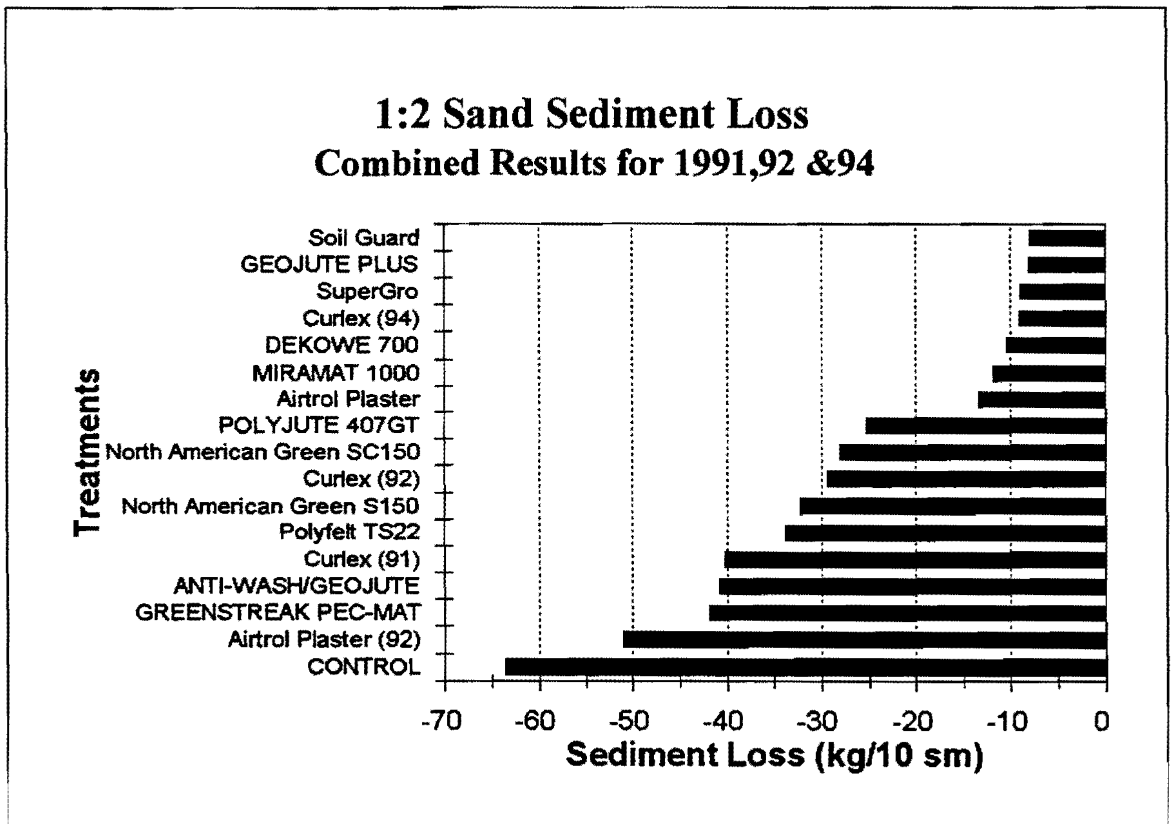


Figure 63. 1:2 Sand Sediment Loss Combined Results.

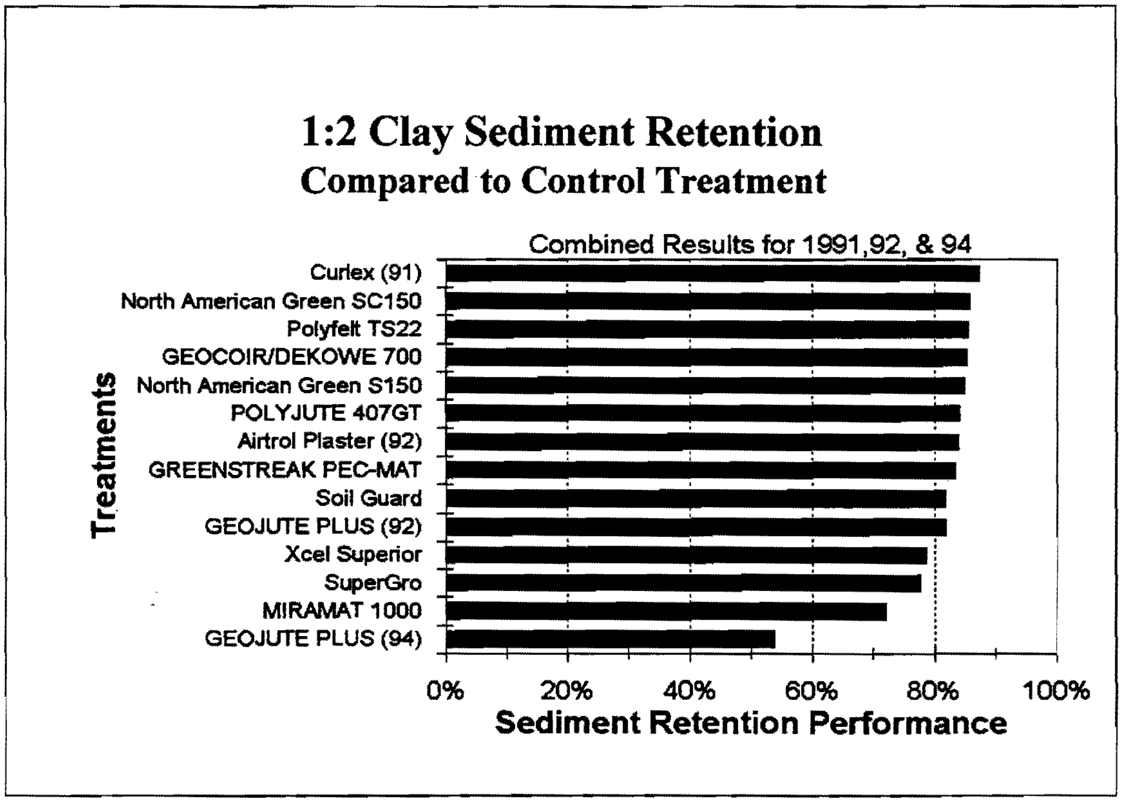


Figure 64. 1:2 Clay Sediment Retention (Combined Results) Compared to Control Treatment.

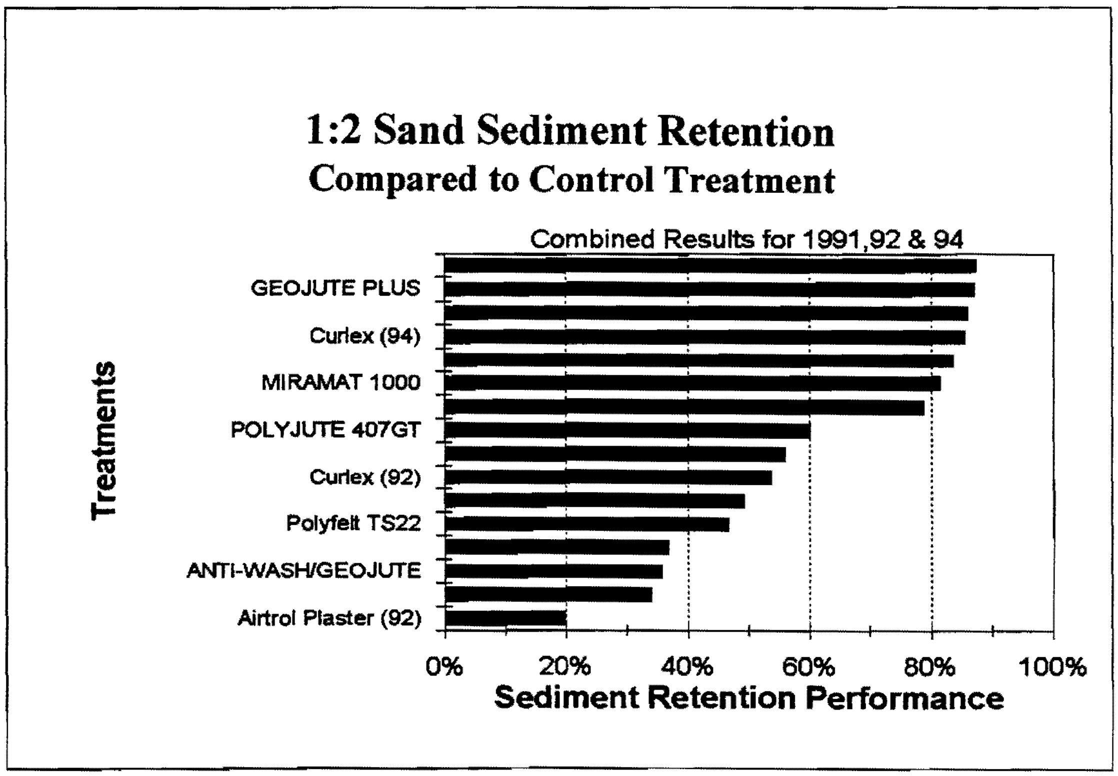


Figure 65. 1:2 Sand Sediment Retention (Combined Results) Compared to Control Treatment.

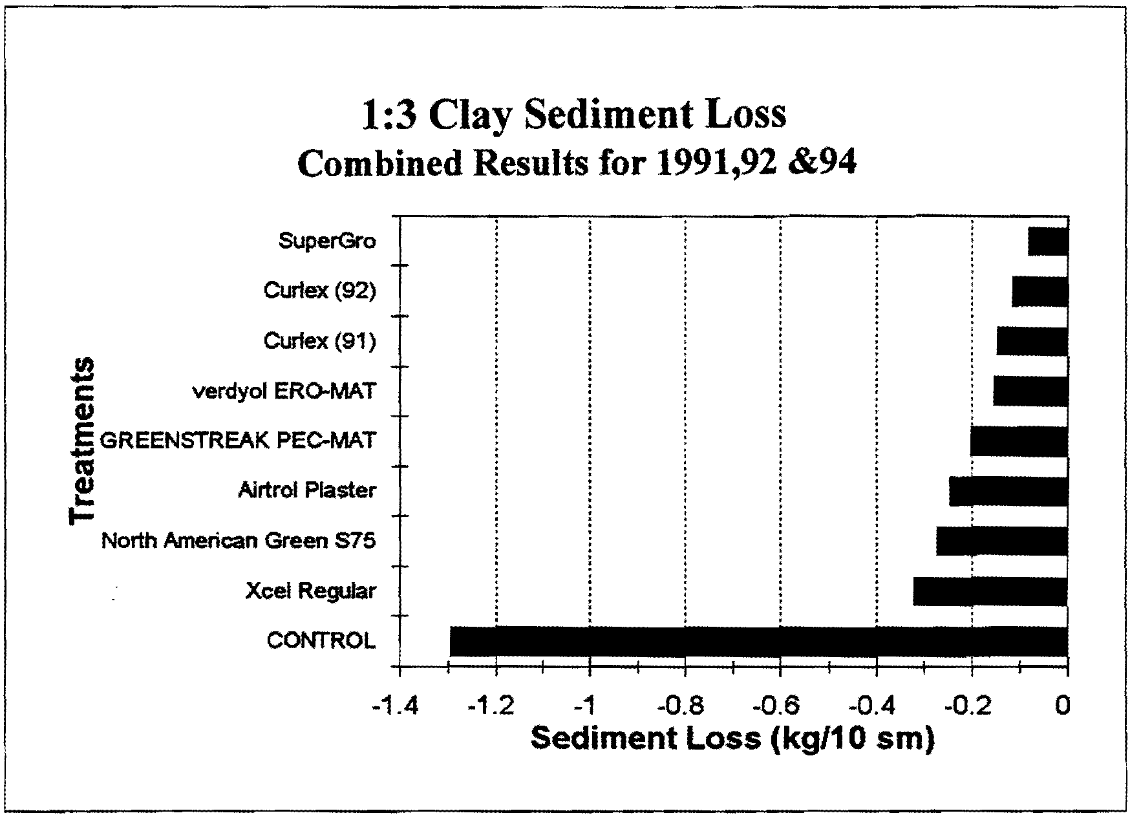


Figure 66. 1:3 Clay Sediment Loss Combined Results.

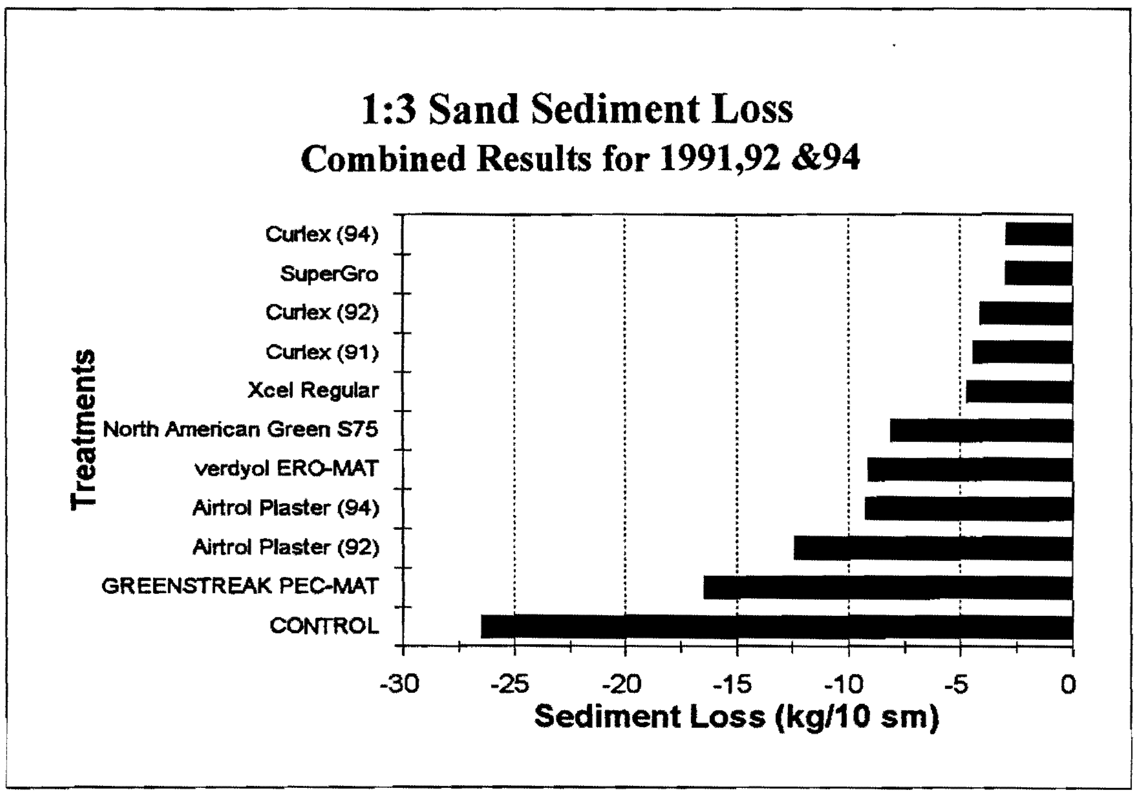


Figure 67. 1:3 Sand Sediment Loss Combined Results.

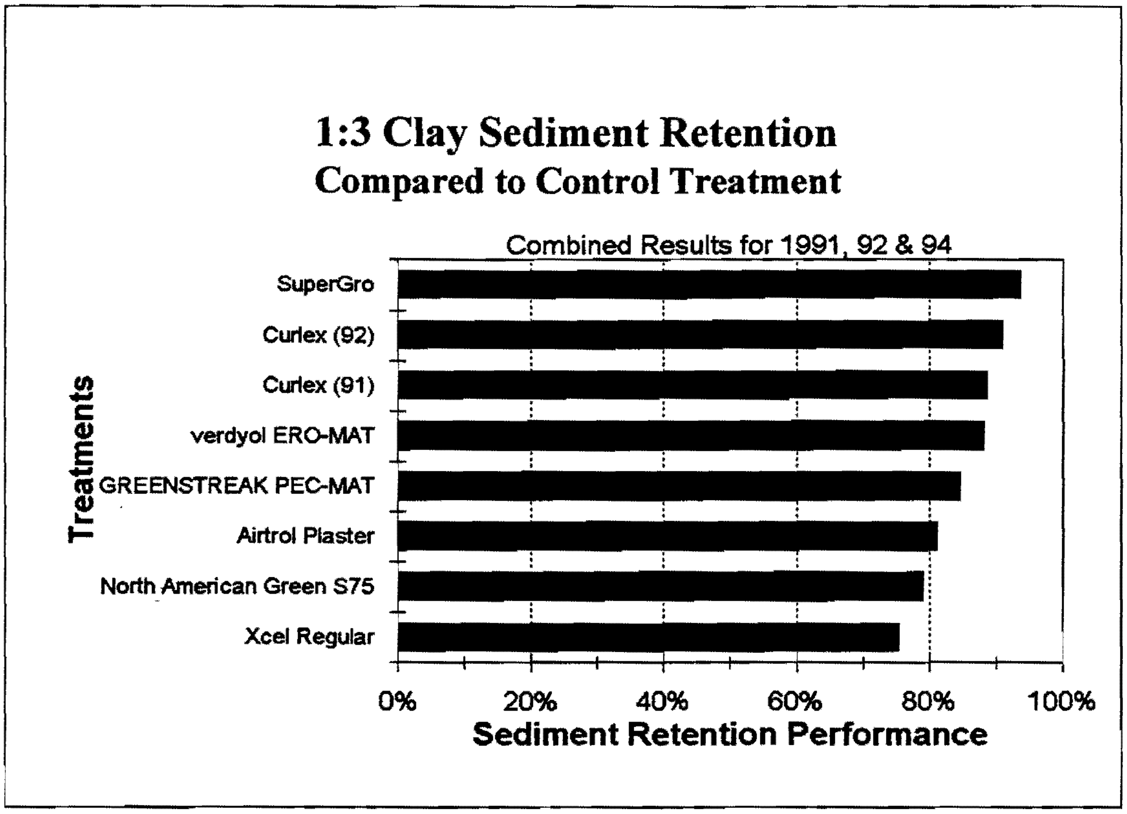


Figure 68. 1:3 Clay Sediment Retention (Combined Results) Compared to Control.

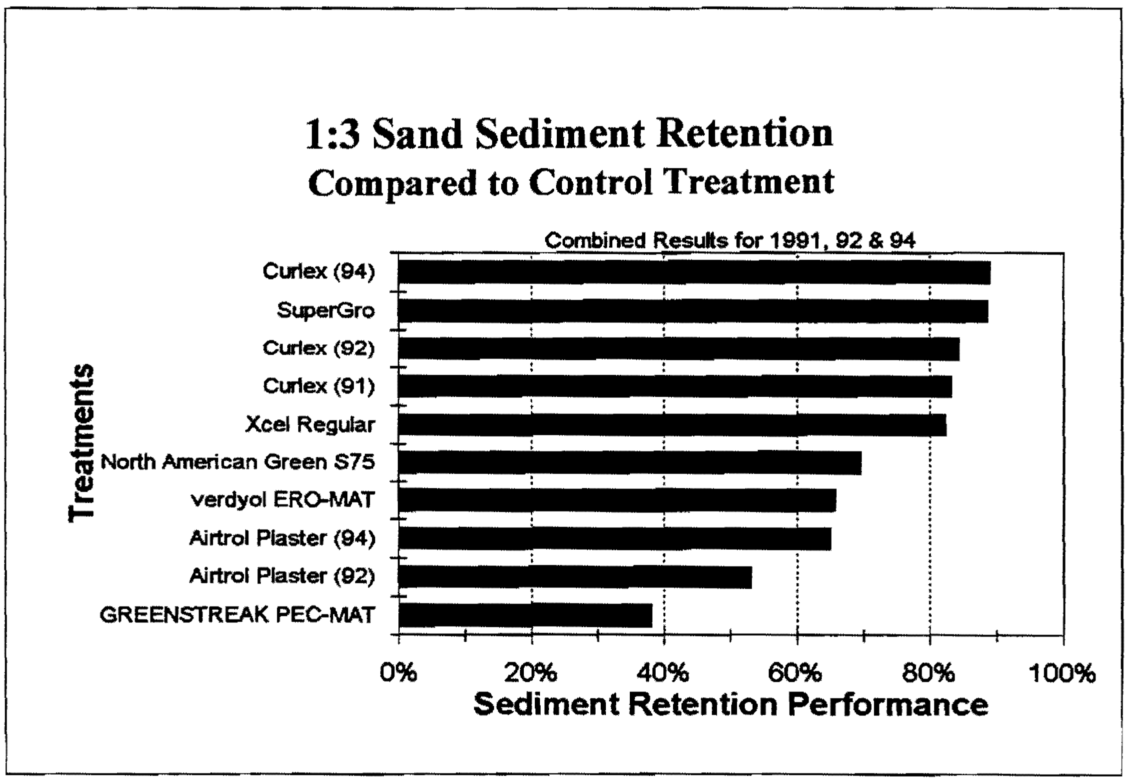


Figure 69. 1:3 Sand Sediment Retention (Combined Results) Compared to Control.

SUMMARY OF COMBINED RESULTS FROM THE HYDRAULIC MULCH STUDY: STUDY YEARS 1992 AND 1994

The researchers combined the results from the previous study year (1992) with the 1994 results to compare performance results as shown in table II and figures 70-75. By current TxDOT standards, the overall field performance results support their *Approved Materials List.* For this analysis level, the means were not spread, indicating similar performance among the mulch products. Some products did not perform as well as the Control treatments that included PROMAT, American Fiber Mulch, American Fiber Mulch with tackifier, and PROMAT XL with tackifier. However, if the analysis is by soil type, the results are different, indicating that soil type is an important factor when considering the use of mulches. For the 1:3 clay treatments, all of the products produced a minimum vegetative cover of 65% as compared to the 1:3 sand treatments with a minimum of 22% vegetative cover. American Fiber Mulch and Second Nature Wood Fiber performed signficantly better than the other mulch products on the sand plots by establishing a minimum cover of 40%.

Table II. Mulch Vegetative Density Results for 1992 and 1994.

Treatment	**Vegetative Density (%)**	**Vegetative Density (%)**
1:3 Slope	**Clay Soil Mean/Grouping**	**Sandy Soil Mean/Grouping**
Silva-Fiber® Plus	91.983	24.833
PROMAT XL	86.245	24.615
PROMAT	84.154	25.070
American Fiber Mulch® w/tack	83.568	22.518
PROMAT XL w/tack	82.960	23.045
Conwed Hydro Fiber Mulch	82.169	31.551
Second Nature Wood Fiber	77.968	40.272
American Fiber Mulch®	66.611	40.987
CONTROL	70.034	35.676

Treatment	**Vegetative Density (%)**
1:3 Slope	**Combined Soil Types Mean/Grouping**
Second Nature Wood Fiber	59.120
Silva-Fiber® Plus	58.408
Conwed Hydro Fiber Mulch	56.860

Table II. Mulch Vegetative Density Results for 1992 and 1994 (continued).

Treatment	Vegetative Density (%)
1:3 Slope	**Combined Soil Types**
PROMAT XL	55.430
PROMAT	54.612
American Fiber Mulch®	53.043
PROMAT XL w/tack	53.002
CONTROL	52.855

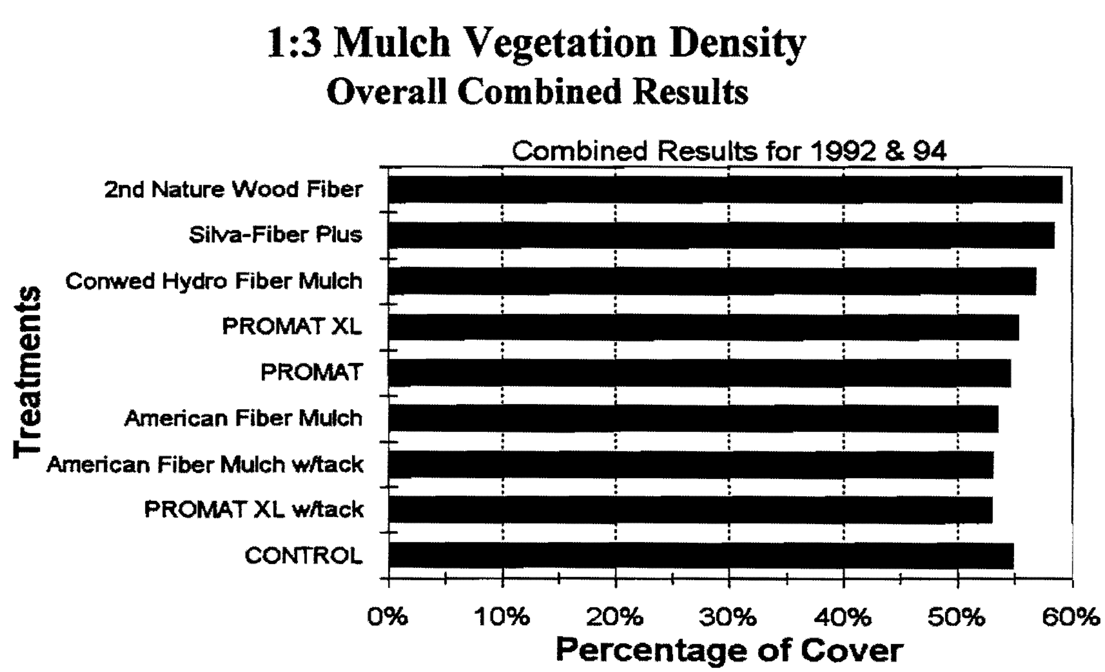


Figure 70. 1:3 Mulch Vegetative Density Overall Combined Results.

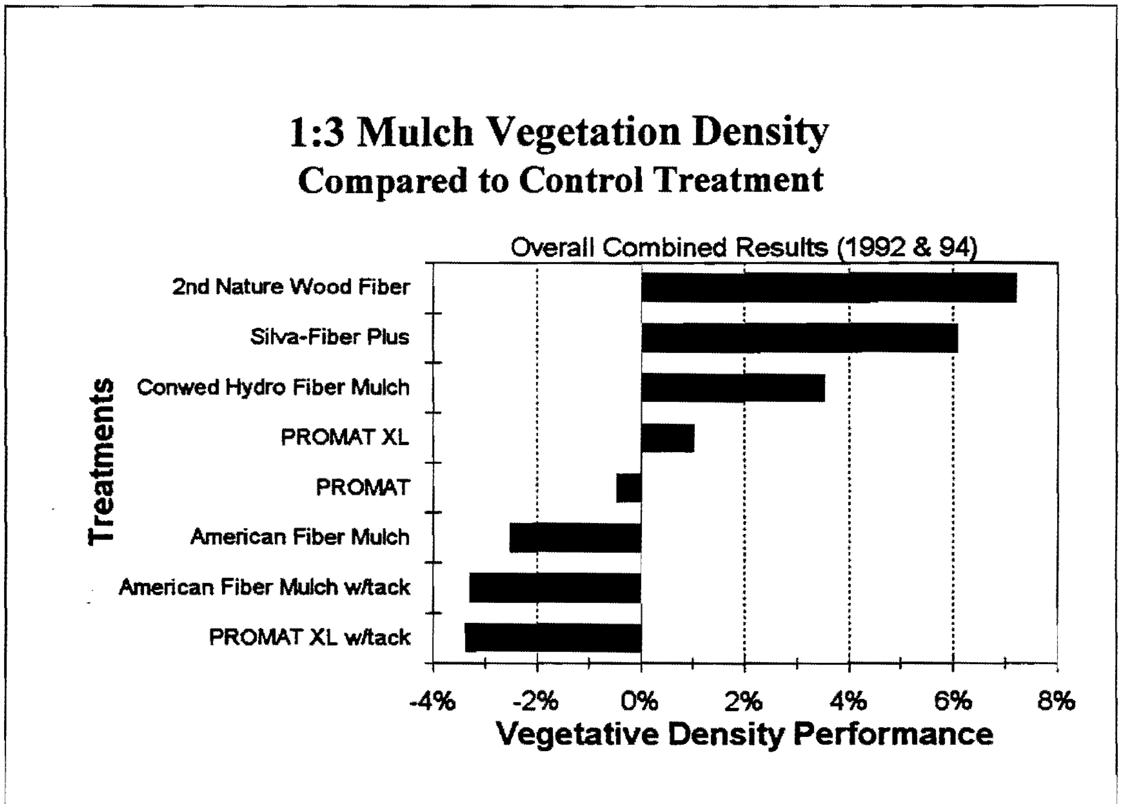


Figure 71. 1:3 Mulch Vegetative Density (Combined Results) Compared to Control.

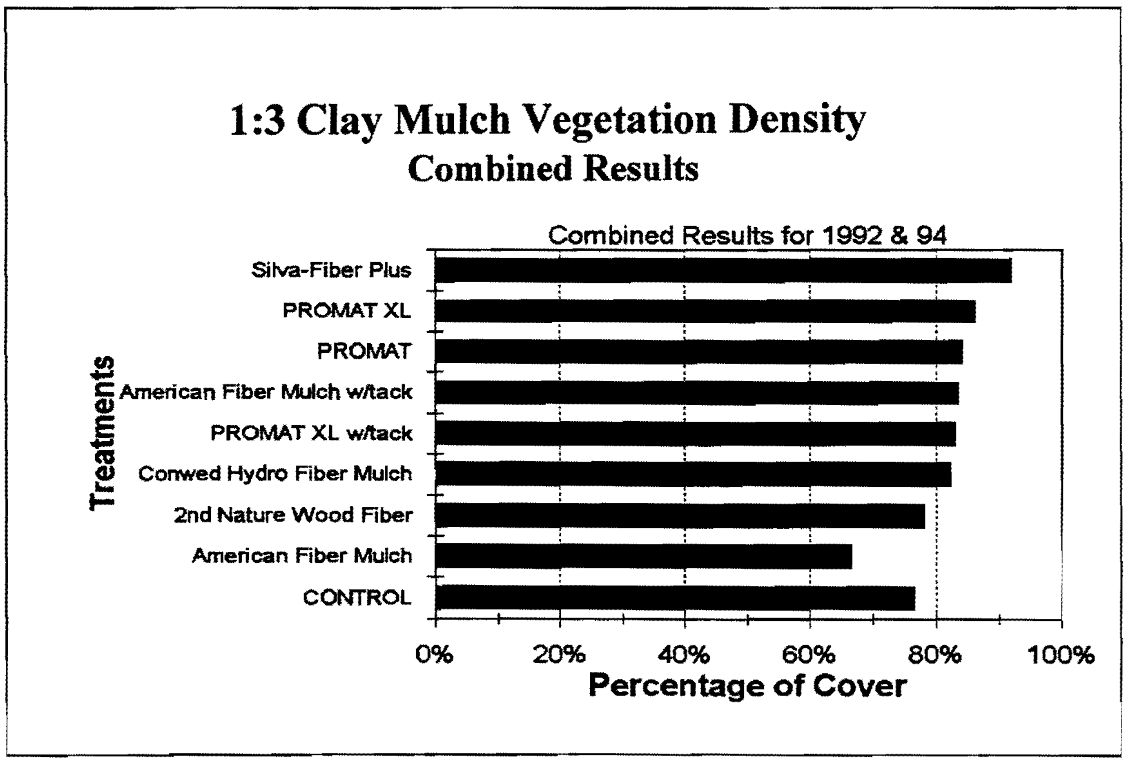


Figure 72. 1:3 Clay Mulch Vegetative Density Combined Results.

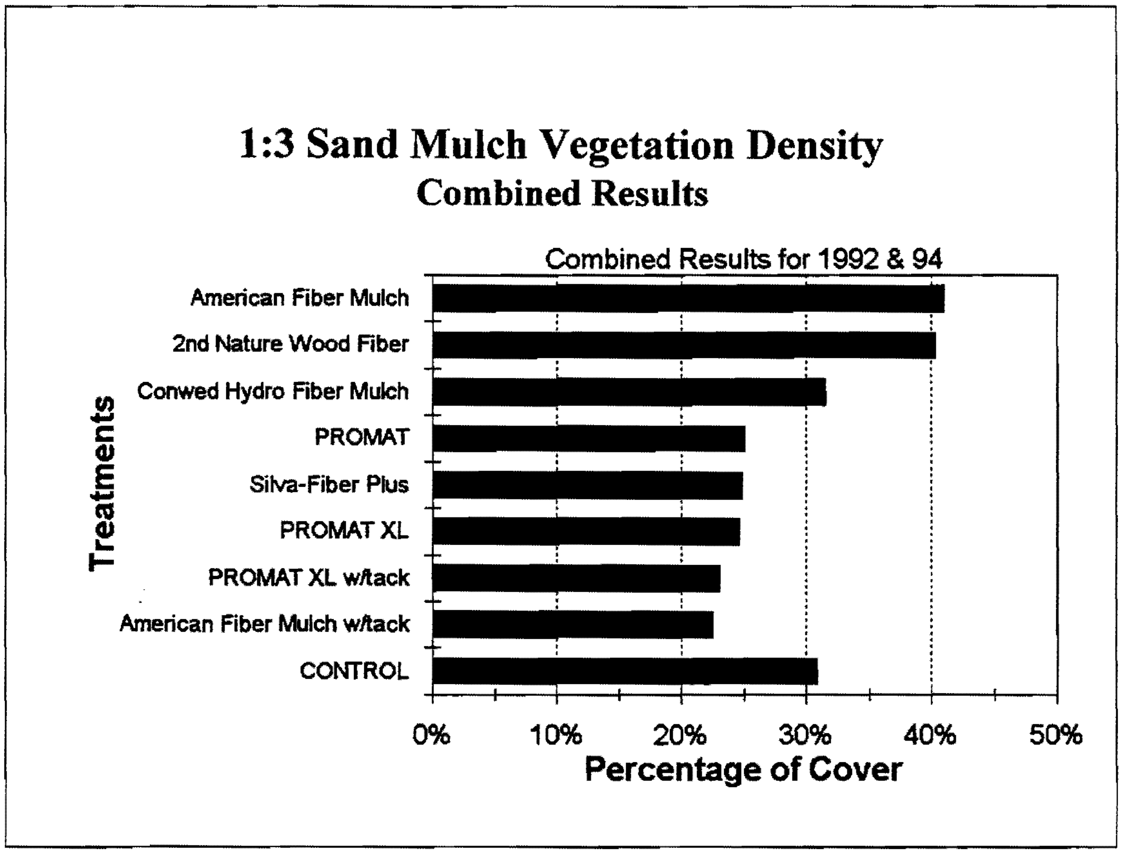


Figure 73. 1:3 Sand Mulch Vegetative Density Combined Results.

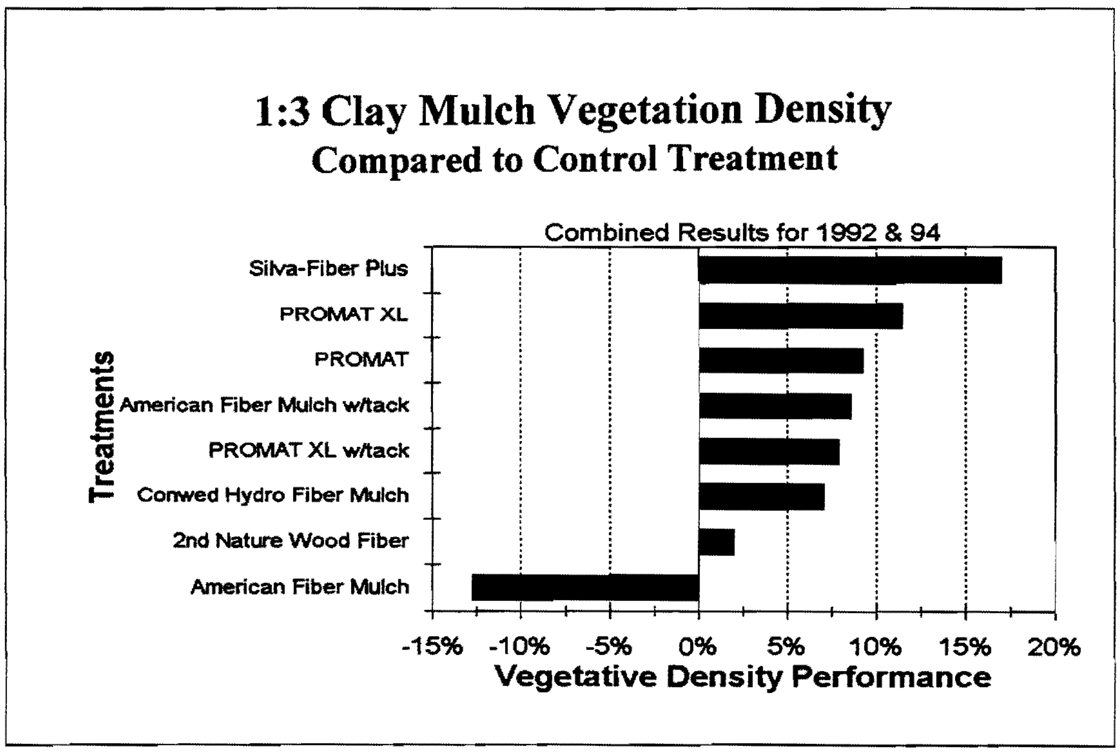


Figure 74. Clay Mulch Vegetative Density (Combined Results) Compared to Treatment.

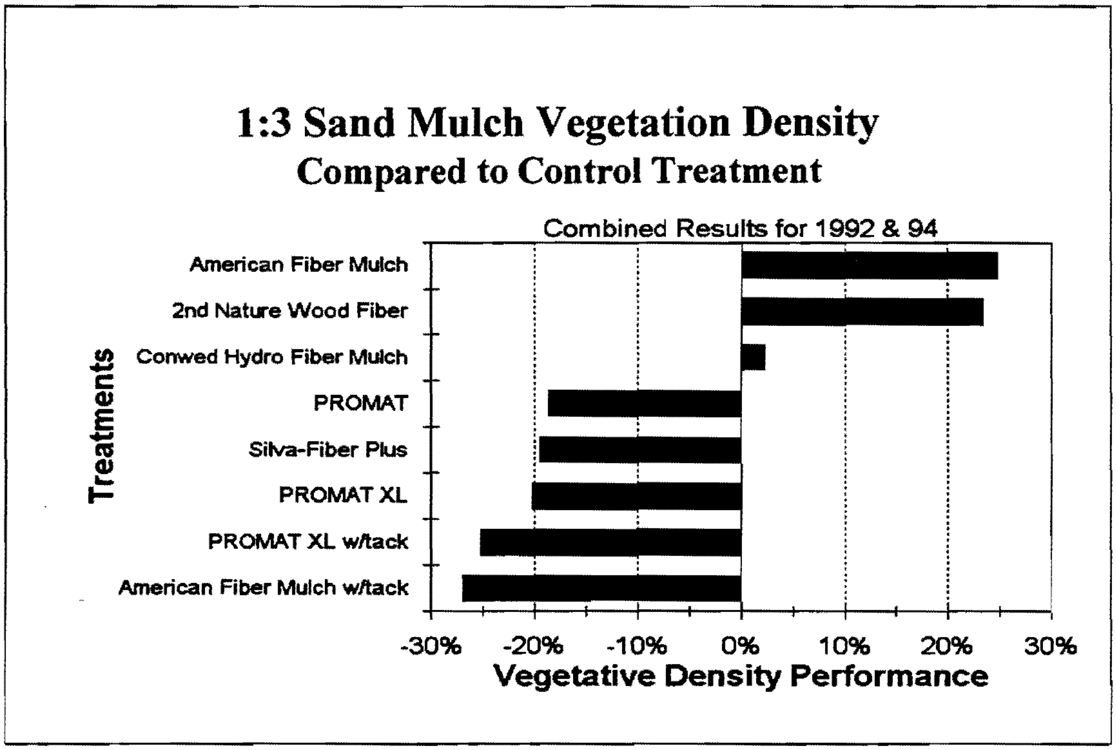


Figure 75. Sand Mulch Vegetative Density (Combined Results) Compared to Control Treatment.

CONCLUSIONS FROM THE RESULTS

The researchers recognize the importance of understanding materials and their field performance characteristics when installed according to a manufacturer's recommendations, whether a designer is specifying concrete pavement or erosion-control blankets. The field evaluations performed by the Texas Transportation Institute begin to provide answers to the engineers and designers at TxDOT for the selection, specifying, and installation of the best products available for erosion control. Many environmental factors can influence the actual results when a product is installed on a project, but through multiple years of testing and duplication of product results, the researchers are confident that a minimum field performance is a viable standard.

The research team feels that TxDOT's standards for erosion-control blankets are reasonable for field performance evaluations where highway-related environmental factors influence the results similar to an actual installation. Over the three years of testing, the products evaluated on the most severe slope have generally performed better than the products evaluated on the less severe 1:3 slope. On the the 1:2 slope, clay soil, 64% of the products have successfully passed TxDOT's minimum performance criteria and 59% have passed on the 1:2 sandy soils. For the 1:3 slope, clay soil condition, 75% of the products have successfully passed, but only 30% of the products on the sandy soil have met the minimum criteria.

While the minimums are fair, the highway environment is a unique envirnoment with tough vegetation establishment conditions such as severe slopes, poor or compacted soils, and either too dry or wet much of the time. The products evaluated on the 1:2 slope tended to have more of an engineered structure (bonded nettings), more contact points required (staples), or more surface contact (natural binding with the soil) that enhanced their performance range for a variety of environmental conditions. Also, to promote permenant warm-season perennial grasses, as specified by TxDOT, the blankets must be capable of controlling surficial erosion damage during an *extended* establishment phase. Several of the species included in the mixtures develop their root systems for a substantial length of time before vegetation breaks the surface. Without the vegetation above ground, the soil is exposed to the erosive effects of rainsplash. Nurse grasses and other grasses present in the mixture help to counter this problem, but an erosion-control blanket that provides this type of protection during the establishment phase is beneficial.

The focus of this research is permenant erosion control, but many of these same products are being used for *temporary* erosion control on construction sites. When determining what type of non-structural practice, such as a mulch covering or erosion-control blanket, the designer needs to consider the effectiveness of the practice. From previous research completed by the research team, the effectiveness of non-structural controls is not well documented. Therefore, the research team determined the effectiveness value or "VM" value based upon the results achieved through this study. From the erosion-control blankets that successfully controlled erosion and produced vegetation, the following VM factors were calculated and are in Table JJ.

Table JJ. Effectiveness Factors for Erosion-control Blankets.

Erosion-control Blankets	VM Factor 90+ days Average	% Effectiveness vs. Control
Clay Soils	0.10-0.05	90-95%
Sandy Soils	0.13-0.06	87-94%

These performance ranges are generally below other published effectiveness factors most likely due to the specific testing parameters such as soil type and simulated rainfall events. From the literature review, the researchers noticed that most sources do not distinguish between soil type and generally reference the "generic" nature of their values. Enhancement of product effectiveness may be possible by combining erosion and *sediment* control practices to reduce the amount of runoff across steep slope faces where these products are installed.

The researchers completed a series of tests on hydraulic mulches during 1993 after the normal testing cycle was cancelled due to natural flood damage. A variety of mulches and tackifiers were installed and subjected to a one year design storm. Vegetation establishment data was not collected due to the shortened time-frame. The researchers used the results from these trials to calculate the VM factors as shown below in Table KK.

Table KK. Effectiveness Factors for Hydraulic Mulches.

Hydraulic Mulches	VM Factor 1-yr Design Storm Average	% Effectiveness vs. Control
Clay Soils	0.39-0.13	61-87%
Sandy Soils	0.09-0.03	91-97%

The hydraulic mulch results from the 1993 trials seem to contradict the results from 1992 and 1994 with the difference being in the type of data collected to determine field performance. With the vegetative density data collection studies, the researchers anticipated a reasonable amount of vegetative cover to be between 50-60%. From two years results, the performance range for mulches on erosive soils and steep slopes (1:3) has not met the researchers' expectations. In comparison to the 1993 investigative work, initially the mulches applied on sandy soils performed better than the mulches on clay soils. The researchers believe the data indicate a range of performance characteristics for hydraulically-applied mulches and that there must be a logical breakdown point where their capacity to withstand the erosive forces of rainfall during the initial growing season are diminished. A better understanding of the effectiveness of these materials needs to be addressed through the research program.

APPENDIX A
GLOSSARY

Definitions of terms as approved by the International Standards Organization (ISO), related to geo-textiles and erosion control.

Drainage: The collecting and carrying of precipitation, groundwater, and/or other fluids in the plane of a geotextile.

Filtration: The restraining of soil or other particles subjected to hydrodynamic forces while allowing the passage of fluids.

Geocomposite: An assembled material using at least one geotextile or geotextile-related product among the components.

Geogrid: A polymeric, planar structure consisting of a regular open network of integrally connected tensile elements used in geotechnical and civil engineering applications.

Geonet: A polymeric, planar structure, used in geotechnical applications, whose openings are much larger than the constituents and in which the mesh is linked by knots.

Geotextile: A permeable, polymeric, woven, nonwoven, or knitted material used in geotechnical and civil engineering applications.

Geotextile-related products: Permeable, polymeric, sheet or strip-like construction materials used in geotechnical and civil engineering applications.

Knitted geotextile (Geoknitted): A geotextile produced by interlooping one or more yarns, fibers, filaments, or other elements.

Nonwoven geotextile (Geononwoven): A geotextile in the form of a manufactured sheet, web or batt of directionally or randomly orientated fibers, bonded by friction, and/or cohesion and/or adhesion (See ISO 9092:1988.)

Protection: The limiting or preventing with a geotextile of local damage to a geotechnical system.

Reinforcement: The use of the tensile properties of a geotextile to improve the mechanical properties of a soil layer.

Separation: The preventing from intermixing of dissimilar soils and/or fill materials.

Woven geotextile (Geowoven): A geotextile produced by interlacing, usually at right angle, two or more sets of yarns, fibers, filaments, tapes, or other elements. (Knitted fabrics are excluded.)

APPENDIX B
ITEM 164
SEEDING FOR EROSION CONTROL
(PARTIAL SPECIFICATIONS)

ITEM 164
SEEDING FOR EROSION CONTROL
(partial specifications)

164.1. Description. This Item shall govern for preparing ground, providing for sowing of seeds, mulching with straw, hay, or cellulose fiber and other management practices on areas shown on the plans and in accordance with this Item.

It includes seeding for permanent erosion control and seeding for temporary erosion control during the initial winter season.

164.2. Materials.

(1) Seed. All seed must meet the requirements of the Texas Seed Law including the labeling requirements for showing pure live seed (PLS = purity x germination), name and type of seed. Seed furnished shall be of the previous season's crop and the date of analysis shown on each bag shall be within nine months of the time of use on the project. Each variety of seed shall be furnished and delivered in separate bags or containers. A sample of each variety of seed shall be furnished for analysis and testing when directed by the Engineer. Buffalograss shall be treated with a dormancy method approved by the Engineer. The species and varieties of seed shall be from among the types specified in table 1A.

Table 1A.
List of Selected Grass Species
with Their Scientific and Common Names

Scientific Name Introduced	Common Name (Acceptable Varieties)	Season Warm/Cool	Native
Agropyron smithii	Western Wheatgrass	C	N
Andropogon hallii	Sand Bluestem	W	N
Avena sativa	Oats	C	I
Bothriochloa ischaemum	K-R Bluestem	W	I
Bouteloua curtipendula	Sideoats Grama (see seed mix table for	W	N

	appropriate varieties)		
Bouteloua eriopoda	Black Grama	W	N
Boutloua gracilis	Blue Grama (see seed mix table for appropriate varieties)	W	N
Buchloe dactyloides	Buffalograss	W	N
Cenchrus ciliaris	Buffelgrass	W	I
Chloris guyana	Rhodesgrass	W	I
Cynodon dactylon	Bermudagrass	W	I
Eragrostis trichodes	Sand Lovegrass (see seed mix table for appropriate varieties)	W	N
Festuca arundinaceae	Tall Fescue	C	N
Hordeum vulgare	Barley	C	I
Leptochloa dubia	Green Sprangletop	W	N
Panicum virgatum	Switchgrass (see seed mix table for appropriate varieties)	W	N
Paspalum notatum	Bahiagrass (Pensacola variety)	W	I
Schizachyrium scoparium	Little Bluestem (Texas origin only)	W	N
Setaria italica	Foxtail Millet	W	I
Setaria macrostachya	Plains Bristlegrass	W	N
Sorghastrum avenaceum	Indiangrass (see seed mix table for appropriate varieties)	W	N

Sporobolus cryptandrus	Sand Dropseed	W	N
Triticum aestivum	Wheat (Red, Winter)	C	I

(2) Fertilizer. Fertilizer shall conform to the requirements of Item 166, "Fertilizer." The fertilizer used shall have the analysis as shown on the plans.

(3) Water. Water shall conform to the requirements of Item 168, "Vegetative Watering."

(4) Mulch.

(a) Straw Mulch or Hay Mulch. Straw mulch shall be oat, wheat or rice straw. Hay mulch shall be prairie grass, bermudagrass or other hay as approved by the Engineer. The straw mulch or hay mulch shall be free of Johnson grass or other noxious weeds and foreign materials. It shall be kept in a dry condition and shall not be molded or rotted.

(b) Cellulose Fiber Mulch. It shall meet the requirements of and be approved by the Director of Maintenance and Operations. A list of pretested and approved materials will be maintained and can be obtained by writing the Director of Maintenance and Operations, 125 East 11th Street, Austin, Texas 78701-2483.

The mulch shall be designed for use in conventional mechanical planting, hydraulic planting of seed or hydraulic mulching of grass seed, either alone or with fertilizers and other additives. The mulch shall be such that, when applied, the material shall form a strong, moisture-retaining mat without the need of an asphalt binder. It shall be kept in a dry condition until applied and shall not be molded or rotted.

(5) Soil Retention Blanket. Soil retention blanket shall meet the requirements of Item 169, "Soil Retention Blanket."

(6) Tacking Agents. Tacking agents for straw or hay mulch shall be SS-1, unless otherwise shown on the plans. A biodegradable tacking agent may be used in lieu of the SS-1 tacking agent when approved by the Engineer. Asphaltic material shall conform to the requirements of Item 300, "Asphalt, Oils and Emulsions."

164.3. Construction Methods. After designated areas have been completed to the lines, grades and cross sections shown on the plans and as provided for in other items of this contract, seeding shall be performed in accordance with the requirements hereinafter described. Unless otherwise approved by the Engineer, all areas to be seeded shall be cultivated to a depth of at least 100 mm (four inches), except where seeding is to be done using a seed drill suitable for seeding into untilled soil. The seedbeds shall be cultivated sufficiently to reduce the soil to a state of good tilth when the soil particles on the surface are small enough and lie closely enough together to prevent the seed from being covered too deeply for optimum germination. Cultivation of the seedbed will not be required in loose sand where depth of sand is 100 mm (four inches) or more.

The cross section previously established shall be maintained throughout the process of cultivation. Any necessary reshaping shall be done prior to any planting of seed.

(1) Planting Season and Seed Mixes. All planting shall be done between the dates specified for each highway district except as specifically authorized in writing by the Engineer.

The pure live seed planted per acre shall be of the type specified in table 2 for rural areas (warm season).

Table 2.
Rural Area Species-Specific Warm-Season Seeding Mixtures in Pounds of Pure Live Seed Per Acre, by District.

District and Planting Dates*	Mixture for Use in Clay or Tight Soils		Mixture for Use in Sand or Sandy Soils	
17 (Bryan)	(All Sections)		(All Sections)	
Feb 1	Green Sprangletop	0.6	Green Sprangletop	1.1
May 15	Bermudagrass	0.8	Bermudagrass	1.5
	Little Bluestem	1.1	Bahiagrass	6.7
	Indiangrass (Lometa)	1.5	(Pensacola)	
	K-R Bluestem	0.7		
	Switchgrass (Alamo)	1.2		

(2) Broadcast Seeding. The seed or seed mixture, in the quantity specified, shall be uniformly distributed over the areas shown on the plans or where directed by the Engineer. If the sowing of seed is by hand, rather than by mechanical methods, the seed shall be sown in two directions at right angles to each other. If mechanical equipment is used, all varieties of seed as well as fertilizer, may be distributed simultaneously provided that each component is uniformly applied at the specified rate. When seed and fertilizer are to be distributed as a water slurry, the mixture shall be applied to the area to be seeded within 30 minutes after components are placed in the equipment. After planting, the planted area shall be rolled with a light corrugated drum roller or another type of roller approved by the Engineer. All rolling of the sloped areas shall be along the contour of the slopes.

(3) Cellulose Fiber Mulch Seeding. The seed or seed mixture, in the quantity specified, shall be uniformly distributed over the areas shown on the plans or where directed by the Engineer. If the sowing of seed is by hand, rather than by mechanical methods, the seed shall be sown in two directions at right angles to each other. If mechanical equipment is used, all varieties of seed, as well as fertilizer, may be distributed simultaneously, provided that each component is uniformly applied at the specified rate. When seed and fertilizer are to be distributed as a water slurry, the mixture shall be applied to that area to be seeded within 30 minutes after all components are placed in the equipment.

Immediately upon completion of planting of the seed, cellulose fiber mulch shall be spread uniformly over the seeded area at the following rates:

Sandy soils with 3:1 slope or less - min. 2000 lbs./acre
Sandy soils with greater than 3:1 slope - min. 2300 lbs./acre
Clay soils with 3:1 slope or less - min. 2500 lbs./acre
Clay soils with greater than 3:1 slope - min. 3000 lbs./acre

Cellulose fiber mulch rates are based on dry weight of mulch per acre. When used, a mulching machine, approved by the Engineer, shall be equipped to eject the thoroughly wet mulch material at a uniform rate to provide the mulch coverage specified.

APPENDIX C
ITEM 169
SOIL RETENTION BLANKET

ITEM 169
SOIL RETENTION BLANKET

169.1. Description. This Item shall govern for providing and placing wood, straw or coconut fiber mat, synthetic mat, paper mat, jute mesh or other material as a soil retention blanket for erosion control on slopes or ditches or for short-term or long-term protection of seeded or sodded areas as shown on the plans or as specified by the Engineer.

169.2. Materials.

(1) Soil Retention Blankets. All soil retention blankets must be prequalified by the Director of Maintenance and Operations prior to use.

Prequalification procedures and a current list of prequalified materials may be obtained by writing to the Director of Maintenance and Operations, 125 East 11th Street, Austin, Texas 78701-2483. A 12" X 12" sample of the material may be required by the Engineer in order to verify prequalification. Samples taken, accompanied by the manufacturer's literature, will be sent, properly wrapped and identified, to the Division of Maintenance and Operations for verification.

The soil retention blanket shall be one (1) of the following classes and types as shown on plans:

(a) Class 1. "Slope Protection"

- **(i) Type A.** Slopes 3:1 or flatter - Clay soils
- **(ii) Type B.** Slopes 3:1 or flatter - Sandy soils
- **(iii) Type C.** Slopes steeper than 3:1 - Clay soils
- **(iv) Type D.** Slopes steeper than 3:1 - Sandy soils

(b) Class 2. "Flexible Channel Liner"

- **(i) Type E.** Short-term duration (Up to 2 years)
  Shear Stress (t_d) < 1.0 lb./sq. ft.
- **(ii) Type F.** Short-term duration (Up to 2 years)
  Shear Stress (t_d) 1.0 to 2.0 lb./sq. ft.
- **(iii) Type G.** Long-term duration (Longer than 2 years)
  Shear Stress (t_d) > 2.0 to < 5.0 lb./sq. ft.

(iv) **Type H.** Long-term duration (Longer than 2 years)
Shear Stress (t_d) $\geq$ 5.0 lb./sq. ft.

(2) Fasteners. Fasteners shall conform to the requirements shown on Standard Detail sheet "Soil Retention Blanket (SRB)".

169.3. Construction Methods.

(1) General. The soil retention blanket shall conform to the class and type shown on the plans. The Contractor has the option of selecting an approved soil retention blanket conforming to the class and type shown on the plans and according to the current approved material list.

(2) Installation. The soil retention blanket, whether installed as slope protection or as flexible channel liner in accordance with the approved materials list, shall be placed within 24 hours after seeding or sodding operations have been completed, or as approved by the Engineer. Prior to placing the blanket, the area to be covered shall be relatively free of all rocks or clods over 1-1/2 inches in maximum dimension and all sticks or other foreign material which will prevent the close contact of the blanket with the soil. The area shall be smooth and free of ruts and other depressions. If as a result of rain, the prepared bed becomes crusted or eroded or if any eroded places, ruts or depressions exist for any reason, the contractor shall be required to rework the soil until it is smooth and to reseed or resod the area at the Contractor's expense.

Installation and anchorage of the soil retention blanket shall be in accordance with the Manufacturer's recommendations and the Standard Detail Sheet "Soil Retention Blanket (SRB)".

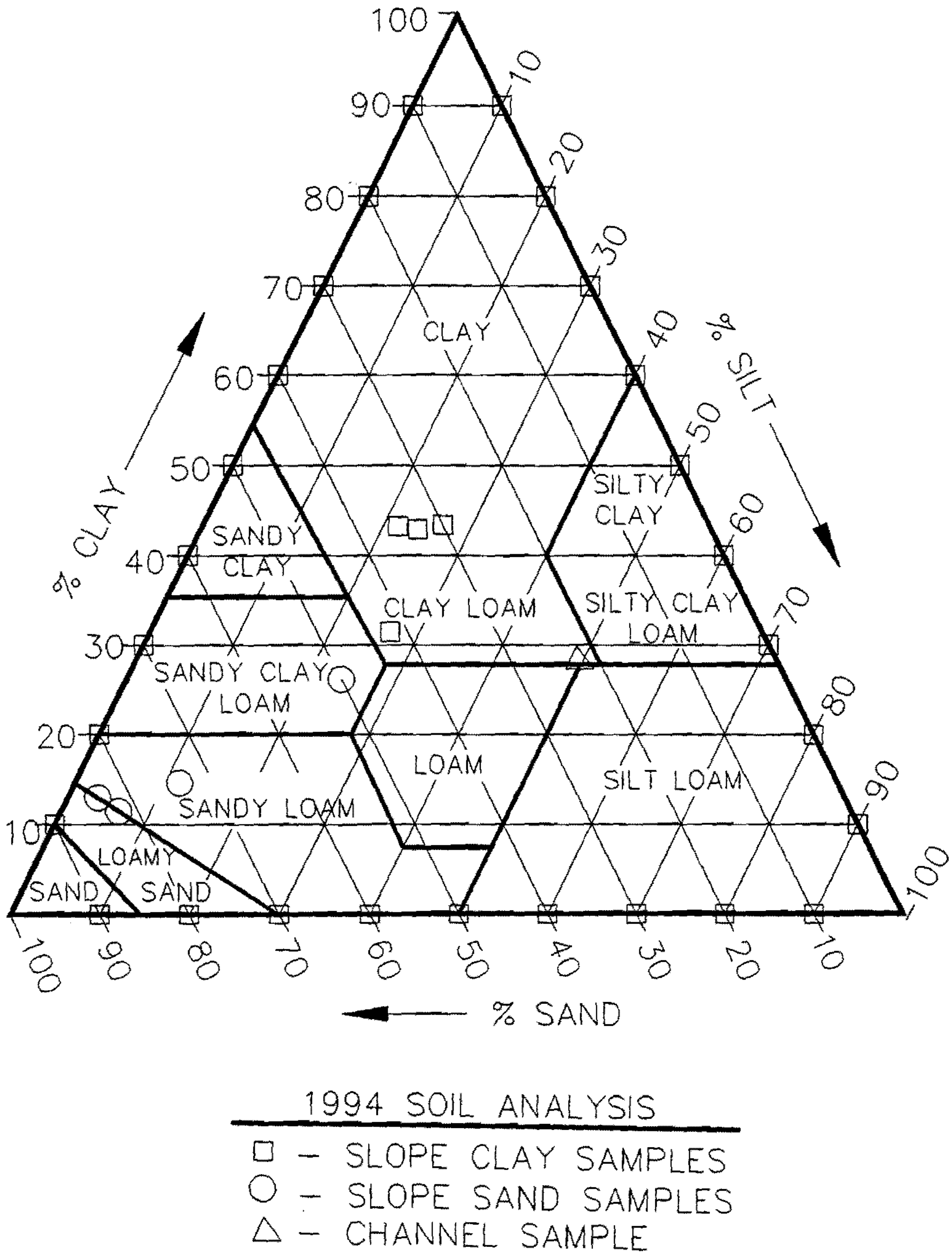
(3) Literature. The Contractor shall submit one (1) full set of manufacturer's literature and manufacturer's installation recommendations for the soil retention blanket selected in accordance with the approved material list.

169.4. Measurement. This Item will be measured by the square yard of surface area covered.

169.5. Payment. The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Soil Retention Blanket" of the class and type shown on the plans. This price shall be full compensation for furnishing all materials, labor, tools, equipment and incidentals necessary to complete the work. Anchors, checks, terminals or junction slots, and wire staples or wood stakes will not be paid for directly but will be considered subsidiary to this item.

APPENDIX D
SOIL TEXTURE TRIANGLE

The soil texture triangle is from the National Soils Handbook, Figure 603-1, which shows the two soil types used in the 1994 evaluations of erosion control materials at the Hydraulics and Erosion Control Field Laboratory, Bryan, TX.



APPENDIX E
WEATHER - RAINFALL DATA

Table E1. 1994 Weather - Rainfall Data

DATE	TEMPERATURE		PRECIPITATION
	MAXIMUM	MINIMUM	
01-01-94	20 °C (68 °F)	6 °C (43 °F)	---
01-02-94	22 °C (73 °F)	2 °C (37 °F)	---
01-03-94	14 °C (58 °F)	4 °C (40 °F)	---
01-04-94	19 °C (59 °F)	2 °C (36 °F)	---
01-05-94	21 °C (70 °F)	1 °C (35 °F)	---
01-06-94	25 °C (77 °F)	13 °C (56 °F)	T
01-07-94	13 °C (56 °F)	0 °C (33 °F)	---
01-08-94	14 °C (58 °F)	-2 °C (28 °F)	---
01-09-94	16 °C (61 °F)	1 °C (34 °F)	---
01-10-94	18 °C (66 °F)	12 °C (55 °F)	0 mm (0.03 in.)
01-11-94	21 °C (70 °F)	10 °C (51 °F)	T
01-12-94	13 °C (56 °F)	10 °C (51 °F)	T
01-13-94	15 °C (60 °F)	7 °C (45 °F)	0 mm (0.02 in.)
01-14-94	21 °C (71 °F)	0 °C (32 °F)	---
01-15-94	17 °C (63 °F)	4 °C (40 °F)	---
01-16-94	19 °C (67 °F)	9 °C (49 °F)	T
01-17-94	11 °C (53 °F)	2 °C (36 °F)	---
01-18-94	2 °C (37 °F)	-1 °C (29 °F)	---
01-19-94	12 °C (55 °F)	-3 °C (26 °F)	---
01-20-94	11 °C (53 °F)	6 °C (44 °F)	0 mm (0.01 in.)
01-21-94	12 ° C (55 °F)	6 °C (44 °F)	0 mm (0.01 in.)
01-22-94	11 °C (52 °F)	6 °C (43 °F)	0 mm (0.02 in.)
01-23-94	13 °C (57 °F)	8 °C (47 °F)	3 mm (0.13 in.)
01-24-94	20 °C (68 °F)	13 °C (56 °F)	---
01-25-94	22 °C (72 °F)	17 °C (63 °F)	0 mm (0.02 in.)
01-26-94	21 °C (71 °F)	19 °C (67 °F)	44 mm (1.76 in.)
01-27-94	20 °C (69 °F)	6 °C (43 °F)	8 mm (0.33 in.)
01-28-94	6 °C (43 °F)	3 °C (38 °F)	1 mm (0.04 in.)
01-29-94	10 °C (50 °F)	2 °C (37 °F)	0 mm (0.01 in.)
01-30-94	11 °C (53 °F)	-0 °C (31 °F)	---
01-31-94	6 °C (44 °F)	2 °C (37 °F)	T

Table E2. 1994 Weather - Rainfall Data

02-01-94	6 °C (44 °F)	-3 °C (26 °F)	T
02-02-94	12 °C (55 °F)	9 °C (22 °F)	---
02-03-94	11 °C (52 °F)	1 °C (34 °F)	---
02-04-94	21 °C (71 °F)	10 °C (51 °F)	T
02-05-94	26 °C (79 °F)	11 °C (52 °F)	---
02-06-94	23 °C (74 °F)	5 °C (42 °F)	---
02-07-94	25 °C (78 °F)	10 °C (51 °F)	---
02-08-94	27 °C (82 °F)	20 °C (68 °F)	---
02-09-94	21 °C (71 °F)	-3 °C (25 °F)	0 mm (0.02 in.)
02-10-94	0 °C (32 °F)	-3 °C (25 °F)	16 mm (0.65 in.)
02-11-94	11 °C (53 °F)	-3 °C (26 °F)	---
02-12-94	18 °C (65 °F)	6 °C (43 °F)	T
02-13-94	14 °C (58 °F)	2 °C (37 °F)	---
02-14-94	17 °C (63 °F)	0 °C (32 °F)	---
02-15-94	18 °C (66 °F)	7 °C (45 °F)	T
02-16-94	21 °C (70 °F)	7 °C (46 °F)	---
02-17-94	21 °C (70 °F)	5 °C (41 °F)	---
02-18-94	23 °C (74 °F)	8 °C (48 °F)	---
02-19-94	22 °C (73 °F)	17 °C (64 °F)	0 mm (0.01 in.)
02-20-94	22 °C (72 °F)	16 °C (61 °F)	20 mm (0.81 in.)
02-21-94	21 °C (71 °F)	15 °C (60 °F)	4 mm (0.18 in.)
02-22-94	21 °C (70 °F)	12 °C (54 °F)	24 mm (0.95 in.)
02-23-94	13 °C (56 °F)	3 °C (39 °F)	---
02-24-94	16 °C (62 °F)	0 °C (32 °F)	---
02-25-94	23 °C (74 °F)	3 °C (39 °F)	---
02-26-94	10 °C (51 °F)	2 °C (37 °F)	---
02-27-94	16 °C (61 °F)	6 °C (44 °F)	---
02-28-94	19 °C (67 °F)	10 °C (50 °F)	1 mm (0.07 in.)

Table E3. 1994 Weather - Rainfall Data

03-01-94	15 °C (60 °F)	7 °C (45 °F)	29 mm (1.17 in.)
03-02-94	18 °C (65 °F)	4 °C (40 °F)	---
03-03-94	20 °C (68 °F)	1 °C (35 °F)	---
03-04-94	25 °C (78 °F)	7 °C (46 °F)	---
03-05-94	26 °C (80 °F)	15 °C (60 °F)	---
03-06-94	25 °C (78 °F)	17 °C (63 °F)	T
03-07-94	26 °C (80 °F)	18 °C (65 °F)	T
03-08-94	25 °C (78 °F)	8 °C (47 °F)	3 mm (0.12 in.)
03-09-94	8 °C (47 °F)	2 °C (36 °F)	16 mm (0.64 in.)
03-10-94	15 °C (60 °F)	-0 °C (31 °F)	---
03-11-94	18 °C (65 °F)	2 °C (37 °F)	---
03-12-94	16 °C (61 °F)	11 °C (53 °F)	0 mm (0.01 in.)
03-13-94	17 °C (64 °F)	12 °C (54 °F)	---
03-14-94	23 °C (74 °F)	6 °C (44 °F)	---
03-15-94	21 °C (70 °F)	13 °C (57 °F)	7 mm (0.30 in.)
03-16-94	23 °C (74 °F)	13 °C (56 °F)	---
03-17-94	25 °C (77 °F)	8 °C (47 °F)	---
03-18-94	28 °C (83 °F)	13 °C (57 °F)	---
03-19-94	27 °C (81 °F)	14 °C (58 °F)	---
03-20-94	27 °C (81 °F)	18 °C (65 °F)	---
03-21-94	25 °C (77 °F)	12 °C (54 °F)	---
03-22-94	26 °C (79 °F)	11 °C (52 °F)	T
03-23-94	25 °C (78 °F)	18 °C (65 °F)	0 mm (0.01 in.)
03-24-94	24 °C (76 °F)	14 °C (58 °F)	T
03-25-94	24 °C (76 °F)	10 °C (50 °F)	---
03-26-94	23 °C (74 °F)	17 °C (63 °F)	T
03-27-94	21 °C (71 °F)	10 °C (50 °F)	0 mm (0.03 in.)
03-28-94	15 °C (60 °F)	6 °C (43 °F)	---
03-29-94	22 °C (73 °F)	2 °C (37 °F)	---
03-30-94	19 °C (67 °F)	6 °C (43 °F)	---
03-31-94	21 °C (71 °F)	4 °C (40 °F)	---

Table E4. 1994 Weather - Rainfall Data

04-01-94	23 ° C (75 °F)	6 °C (44 °F)	---
04-02-94	25 °C (78 °F)	8 °C (48 °F)	---
04-03-94	22 °C (73 °F)	9 °C (49 °F)	1 mm (0.07 in.)
04-04-94	25 °C (78 °F)	7 °C (46 °F)	T
04-05-94	27 °C (81 °F)	8 °C (47 °F)	12 mm (0.50 in.)
04-06-94	17 °C (63 °F)	4 °C (40 °F)	T
04-07-94	20 °C (69 °F)	3 °C (39 °F)	---
04-08-94	25 °C (78 °F)	8 °C (47 °F)	---
04-09-94	28 °C (84 °F)	18 °C (65 °F)	0 mm (0.01 in.)
04-10-94	28 °C (84 °F)	21 °C (70 °F)	T
04-11-94	26 °C (79 °F)	18 °C (66 °F)	3 mm (0.13 in.)
04-12-94	20 °C (69 °F)	10 °C (50 °F)	---
04-13-94	28 °C (84 °F)	8 °C (48 °F)	---
04-14-94	29 °C (85 °F)	18 °C (66 °F)	T
04-15-94	24 °C (76 °F)	17 °C (63 °F)	14 mm (0.58 in.)
04-16-94	24 °C (76 °F)	13 °C (56 °F)	---
04-17-94	25 °C (77 °F)	8 °C (47 °F)	---
04-18-94	26 °C (79 °F)	11 °C (53 °F)	---
04-19-94	25 °C (84 °F)	16 °C (62 °F)	10 mm (0.40 in.)
04-20-94	26 °C (79 °F)	17 °C (63 °F)	T
04-21-94	28 °C (84 °F)	16 °C (61 °F)	---
04-22-94	28 °C (84 °F)	17 °C (64 °F)	T
04-23-94	28 °C (84 °F)	16 °C (62 °F)	T
04-24-94	29 °C (85 °F)	17 °C (64 °F)	---
04-25-94	28 °C (83 °F)	21 °C (70 °F)	---
04-26-94	30 °C (87 °F)	22 °C (72 °F)	---
04-27-94	31 °C (89 °F)	23 °C (75 °F)	---
04-28-94	28 °C (83 °F)	18 °C (65 °F)	T
04-29-94	30 °C (87 °F)	21 °C (71 °F)	1 mm (0.05 in.)
04-30-94	22 °C (72 °F)	11 °C (53 °F)	T

Table E5. 1994 Weather - Rainfall Data

05-01-94	18 °C (66 °F)	9 °C (49 °F)	0 mm (0.03 in.)
05-02-94	22 °C (72 °F)	15 °C (59 °F)	24 mm (0.98 in.)
05-03-94	20 °C (68 °F)	13 °C (56 °F)	T
05-04-94	26 °C (79 °F)	13 °C (57 °F)	---
05-05-94	28 °C (84 °F)	16 °C (62 °F)	---
05-06-94	29 °C (85 °F)	16 °C (62 °F)	---
05-07-94	30 °C (87 °F)	22 °C (73 °F)	T
05-08-94	29 °C (85 °F)	19 °C (67 °F)	T
05-09-94	30 °C (86 °F)	21 °C (71 °F)	T
05-10-94	30 °C (87 °F)	21 °C (70 °F)	1 mm (0.07 in.)
05-11-94	31 °C (88 °F)	20 °C (69 °F)	---
05-12-94	29 °C (85 °F)	21 °C (70 °F)	---
05-13-94	29 °C (85 °F)	17 °C (64 °F)	55 mm (2.19 in.)
05-14-94	30 °C (86 °F)	17 °C (63 °F)	1 mm (0.05 in.)
05-15-94	26 °C (79 °F)	19 °C (67 °F)	2 mm (0.11 in.)
05-16-94	30 °C (86 °F)	19 °C (67 °F)	25 mm (1.02 in.)
05-17-94	30 °C (86 °F)	21 °C (70 °F)	1 mm (0.04 in.)
05-18-94	30 °C (86 °F)	20 °C (68 °F)	---
05-19-94	29 °C (85 °F)	16 °C (62 °F)	---
05-20-94	28 °C (84 °F)	15 °C (60 °F)	---
05-21-94	28 °C (84 °F)	14 °C (58 °F)	---
05-22-94	29 °C (85 °F)	16 °C (62 °F)	---
05-23-94	29 °C (85 °F)	15 °C (60 °F)	---
05-24-94	30 °C (87 °F)	16 °C (62 °F)	---
05-25-94	31 °C (88 °F)	20 °C (68 °F)	---
05-26-94	29 °C (85 °F)	19 °C (67 °F)	---
05-27-94	31 °C (89 °F)	18 °C (65 °F)	T
05-28-94	33 °C (92 °F)	20 °C (69 °F)	15 mm (0.62 in.)
05-29-94	33 °C (92 °F)	19 °C (67 °F)	9 mm (0.37 in.)
05-30-94	32 °C (91 °F)	19 °C (67 °F)	T
05-31-94	33 °C (93 °F)	21 °C (71 °F)	T

Table E6. 1994 Weather - Rainfall Data

06-01-94	30 °C (87 °F)	21 °C (71 °F)	---
06-02-94	31 °C (88 °F)	21 °C (70 °F)	24 mm (0.98 in.)
06-03-94	30 °C (86 °F)	22 °C (72 °F)	4 mm (0.17 in.)
06-04-94	32 °C (91 °F)	21 °C (70 °F)	---
06-05-94	32 °C (91 °F)	22 °C (73 °F)	---
06-06-94	33 °C (93 °F)	22 °C (73 °F)	---
06-07-94	34 °C (94 °F)	24 °C (76 °F)	---
06-08-94	34 °C (94 °F)	23 °C (75 °F)	---
06-09-94	35 °C (96 °F)	25 °C (77 °F)	---
06-10-94	31 °C (88 °F)	21 °C (70 °F)	9 mm (0.38 in.)
06-11-94	34 °C (94 °F)	20 °C (68 °F)	29 mm (1.17 in.)
06-12-94	33 °C (92 °F)	21 °C (71 °F)	---
06-13-94	31 °C (88 °F)	23 °C (74 °F)	---
06-14-94	31 °C (88 °F)	25 °C (77 °F)	T
06-15-94	32 °C (91 °F)	24 °C (76 °F)	1 mm (0.05 in.)
06-16-94	32 °C (91 °F)	23 °C (75 °F)	T
06-17-94	34 °C (94 °F)	22 °C (73 °F)	---
06-18-94	35 °C (96 °F)	22 °C (72 °F)	8 mm (0.33 in.)
06-19-94	33 °C (92 °F)	21 °C (70 °F)	---
06-20-94	34 °C (94 °F)	22 °C (72 °F)	1 mm (0.05 in.)
06-21-94	32 °C (91 °F)	20 °C (69 °F)	---
06-22-94	32 °C (91 °F)	21 °C (71 °F)	---
06-23-94	35 °C (95 °F)	21 °C (71 °F)	11 mm (0.46 in.)
06-24-94	35 °C (95 °F)	22 °C (72 °F)	1 mm (0.07 in.)
06-25-94	35 °C (95 °F)	23 °C (74 °F)	---
06-26-94	35 °C (95 °F)	25 °C (77 °F)	---
06-27-94	35 °C (95 °F)	24 °C (76 °F)	---
06-28-94	35 °C (96 °F)	23 °C (75 °F)	---
06-29-94	33 °C (92 °F)	23 °C (75 °F)	---
06-30-94	32 °C (90 °F)	23 °C (75 °F)	---

Table E7. 1994 Weather - Rainfall Data

07-01-94	34 °C (94 °F)	22 °C (73 °F)	---
07-02-94	33 °C (92 °F)	23 °C (74 °F)	---
07-03-94	34 °C (94 °F)	23 °C (74 °F)	---
07-04-94	34 °C (94 °F)	21 °C (71 °F)	T
07-05-94	34 °C (94 °F)	23 °C (74 °F)	T
07-06-94	35 °C (96 °F)	23 °C (75 °F)	---
07-07-94	36 °C (97 °F)	24 °C (76 °F)	---
07-08-94	36 °C (98 °F)	25 °C (78 °F)	T
07-09-94	35 °C (96 °F)	22 °C (73 °F)	0 mm (0.03 in.)
07-10-94	33 °C (93 °F)	23 °C (74 °F)	---
07-11-94	35 °C (96 °F)	23 °C (74 °F)	---
07-12-94	36 °C (98 °F)	23 °C (75 °F)	---
07-13-94	36 °C (98 °F)	23 °C (75 °F)	T
07-14-94	35 °C (95 °F)	25 °C (77 °F)	1 mm (0.07 in.)
07-15-94	36 °C (97 °F)	25 °C (77 °F)	---
07-16-94	37 °C (99 °F)	23 °C (75 °F)	---
07-17-94	36 °C (98 °F)	23 °C (74 °F)	---
07-18-94	36 °C (98 °F)	22 °C (73 °F)	---
07-19-94	36 °C (98 °F)	22 °C (73 °F)	---
07-20-94	37 °C (99 °F)	23 °C (74 °F)	---
07-21-94	37 °C (99 °F)	22 °C (73 °F)	0 mm (0.01 in.)
07-22-94	37 °C (100 °F)	23 °C (75 °F)	T
07-23-94	38 °C (102 °F)	23 °C (75 °F)	---
07-24-94	38 °C (101 °F)	22 °C (73 °F)	---
07-25-94	37 °C (99 °F)	23 °C (74 °F)	---
07-26-94	38 °C (101 °F)	24 °C (76 °F)	---
07-27-94	34 °C (94 °F)	23 °C (74 °F)	---
07-28-94	34 °C (94 °F)	17 °C (64 °F)	---
07-29-94	35 °C (95 °F)	18 °C (65 °F)	---
07-30-94	33 °C (92 °F)	20 °C (69 °F)	---
07-31-94	34 °C (94 °F)	22 °C (72 °F)	T

Table E8. 1994 Weather - Rainfall Data

08-01-94	35 °C (95 °F)	20 °C (68 °F)	---
08-02-94	35 °C (95 °F)	20 °C (68 °F)	---
08-03-94	35 °C (95 °F)	21 °C (70 °F)	---
08-04-94	33 °C (92 °F)	23 °C (74 °F)	6 mm (0.26 in.)
08-05-94	34 °C (94 °F)	22 °C (73 °F)	T
08-06-94	35 °C (96 °F)	21 °C (70 °F)	---
08-07-94	36 °C (98 °F)	22 °C (73 °F)	---
08-08-94	32 °C (90 °F)	22 °C (73 °F)	11 mm (0.45 in.)
08-09-94	31 °C (88 °F)	21 °C (71 °F)	10 mm (0.42 in.)
08-10-94	33 °C (93 °F)	21 °C (70 °F)	10 mm (0.41 in.)
08-11-94	35 °C (96 °F)	21 °C (71 °F)	---
08-12-94	35 °C (95 °F)	24 °C (76 °F)	---
08-13-94	35 °C (95 °F)	22 °C (72 °F)	---
08-14-94	36 °C (98 °F)	22 °C (73 °F)	---
08-15-94	36 °C (98 °F)	23 ° (74 °F)	33 mm (1.33 in.)
08-16-94	33 °C (92 °F)	22 ° (73 °F)	7 mm (0.31 in.)
08-17-94	35 °C (96 °F)	22 °C (72 °F)	---
08-18-94	35 °C (96 °F)	23 °C (75 °F)	---
08-19-94	35 °C (95 °F)	23 °C (75 °F)	---
08-20-94	35 °C (96 °F)	24 °C (76 °F)	---
08-21-94	27 °C (82 °F)	21 °C (71 °F)	40 mm (1.61 in.)
08-22-94	31 °C (89 °F)	23 °C (74 °F)	2 mm (0.08 in.)
08-23-94	31 °C (89 °F)	22 °C (72 °F)	0 mm (0.01 in.)
08-24-94	32 °C (91 °F)	23 °C (74 °F)	T
08-25-94	34 °C (94 °F)	22 °C (72 °F)	---
08-26-94	33 °C (93 °F)	22 °C (73 °F)	3 mm (0.12 in.)
08-27-94	33 °C (93 °F)	22 °C (73 °F)	---
08-28-94	35 °C (96 °F)	22 °C (72 °F)	---
08-29-94	33 °C (93 °F)	22 °C (73 °F)	---
08-30-94	31 °C (89 °F)	22 °C (73 °F)	---
08-31-94	32 °C (91 °F)	23 °C (75 °F)	0 mm (0.01 in.)

Table E9. 1994 Weather - Rainfall Data

09-01-94	32 °C (90 °F)	21 °C (71 °F)	21 mm (0.86 in.)
09-02-94	32 °C (91 °F)	21 °C (71 °F)	11 mm (0.44 in.)
09-03-94	33 °C (92 °F)	22 °C (73 °F)	---
09-04-94	33 °C (92 °F)	21 °C (71 °F)	---
09-05-94	33 °C (92 °F)	21 °C (71 °F)	---
09-06-94	35 °C (96 °F)	22 °C (73 °F)	---
09-07-94	34 °C (94 °F)	23 °C (74 °F)	---
09-08-94	32 °C (91 °F)	22 °C (72 °F)	0 mm (0.02 in.)
09-09-94	27 °C (82 °F)	20 °C (68 °F)	34 mm (1.37 in.)
09-10-94	32 °C (90 °F)	21 °C (70 °F)	26 mm (1.05 in.)
09-11-94	30 °C (86 °F)	20 °C (69 °F)	T
09-12-94	32 °C (91 °F)	21 °C (71 °F)	T
09-13-94	32 °C (90 °F)	22 °C (72 °F)	T
09-14-94	33 °C (92 °F)	22 °C (73 °F)	---
09-15-94	32 °C (91 °F)	22 °C (72 °F)	---
09-16-94	32 °C (91 °F)	20 °C (68 °F)	---
09-17-94	31 °C (89 °F)	20 °C (68 °F)	---
09-18-94	31 °C (88 °F)	16 °C (62 °F)	---
09-19-94	31 °C (88 °F)	15 °C (59 °F)	---
09-20-94	30 °C (87 °F)	15 °C (59 °F)	---
09-21-94	31 °C (88 °F)	15 °C (59 °F)	---
09-22-94	27 °C (82 °F)	11 °C (53 °F)	---
09-23-94	27 °C (81 °F)	8 °C (47 °F)	---
09-24-94	25 °C (78 °F)	12 °C (54 °F)	---
09-25-94	28 °C (83 °F)	8 °C (48 °F)	---
09-26-94	32 °C (90 °F)	12 °C (54 °F)	---
09-27-94	33 °C (92 °F)	16 °C (61 °F)	---
09-28-94	33 °C (93 °F)	17 °C (63 °F)	---
09-29-94	33 °C (92 °F)	15 °C (59 °F)	---
09-30-94	30 °C (86 °F)	17 °C (64 °F)	---

Table E10. 1994 Weather - Rainfall Data

10-01-94	32 °C (90 °F)	21 °C (71 °F)	---
10-02-94	33 °C (93 °F)	17 °C (63 °F)	---
10-03-94	34 °C (94 °F)	19 °C (67 °F)	---
10-04-94	33 °C (92 °F)	21 °C (70 °F)	---
10-05-94	32 °C (91 °F)	17 °C (63 °F)	---
10-06-94	32 °C (90 °F)	18 °C (65 °F)	---
10-07-94	33 °C (92 °F)	22 °C (73 °F)	1 mm (0.04 in.)
10-08-94	23 °C (74 °F)	14 °C (58 °F)	41 mm (1.64 in.)
10-09-94	23 °C (74 °F)	11 °C (53 °F)	---
10-10-94	23 °C (75 °F)	9 °C (49 °F)	---
10-11-94	23 °C (75 °F)	7 °C (45 °F)	---
10-12-94	25 °C (77 °F)	7 °C (46 °F)	---
10-13-94	21 °C (70 °F)	11 °C (53 °F)	---
10-14-94	21 °C (70 °F)	15 °C (60 °F)	2 mm (0.08 in.)
10-15-94	22 °C (72 °F)	15 °C (60 °F)	9 mm (0.38 in.)
10-16-94	26 °C (79 °F)	20 °C (69 °F)	340 mm (13.39 in.)
10-17-94	23 °C (74 °F)	20 °C (69 °F)	53 mm (2.10 in.)
10-18-94	25 °C (77 °F)	20 °C (69 °F)	26 mm (1.04 in.)
10-19-94	28 °C (83 °F)	18 °C (65 °F)	---
10-20-94	31 °C (88 °F)	22 °C (72 °F)	T
10-21-94	30 °C (87 °F)	22 °C (72 °F)	---
10-22-94	31 °C (89 °F)	21 °C (71 °F)	---
10-23-94	29 °C (85 °F)	18 °C (66 °F)	---
10-24-94	27 °C (81 °F)	17 °C (63 °F)	1 mm (0.04 in.)
10-25-94	22 °C (73 °F)	12 °C (55 °F)	1 mm (0.05 in.)
10-26-94	19 °C (67 °F)	10 °C (50 °F)	---
10-27-94	16 °C (61 °F)	9 °C (49 °F)	0 mm (0.01 in.)
10-28-94	22 °C (73 °F)	9 °C (49 °F)	---
10-29-94	26 °C (80 °F)	9 °C (49 °F)	---
10-30-94	26 °C (80 °F)	12 °C (55 °F)	---
10-31-94	25 °C (77 °F)	11 °C (52 °F)	---

Table E11. 1994 Weather - Rainfall Data

11-01-94	21 °C (71 °F)	8 °C (47 °F)	---
11-02-94	30 °C (86 °F)	10 °C (51 °F)	---
11-03-94	30 °C (86 °F)	23 °C (74 °F)	0 mm (0.01 in.)
11-04-94	29 °C (85 °F)	23 °C (75 °F)	T
11-05-94	25 °C (78 °F)	13 °C (56 °F)	16 mm (0.63 in.)
11-06-94	23 °C (75 °F)	11 °C (53 °F)	---
11-07-94	25 °C (78 °F)	11 °C (52 °F)	---
11-08-94	30 °C (86 °F)	17 °C (63 °F)	---
11-09-94	28 °C (83 °F)	10 °C (50 °F)	T
11-10-94	13 °C (56 °F)	8 °C (48 °F)	---
11-11-94	18 °C (66 °F)	9 °C (49 °F)	---
11-12-94	22 °C (72 °F)	7 °C (46 °F)	---
11-13-94	26 °C (80 °F)	15 °C (59 °F)	---
11-14-94	26 °C (79 °F)	17 °C (64 °F)	---
11-15-94	18 °C (66 °F)	13 °C (56 °F)	1 mm (0.05 in.)
11-16-94	17 °C (63 °F)	11 °C (53 °F)	T
11-17-94	21 °C (71 °F)	11 °C (52 °F)	---
11-18-94	23 °C (74 °F)	15 °C (59 °F)	0 mm (0.03 in.)
11-19-94	22 °C (72 °F)	18 °C (65 °F)	T
11-20-94	23 °C (74 °F)	9 °C (49 °F)	1 mm (0.07 in.)
11-21-94	25 °C (77 °F)	6 °C (43 °F)	---
11-22-94	23 °C (74 °F)	10 °C (50 °F)	---
11-23-94	16 °C (61 °F)	8 °C (48 °F)	0 mm (0.01 in.)
11-24-94	12 °C (54 °F)	8 °C (48 °F)	---
11-25-94	19 °C (67 °F)	11 °C (53 °F)	1 mm (0.06 in.)
11-26-94	27 °C (82 °F)	13 °C (57 °F)	---
11-27-94	28 °C (83 °F)	13 °C (56 °F)	---
11-28-94	19 °C (67 °F)	5 °C (42 °F)	---
11-29-94	21 °C (71 °F)	8 °C (47 °F)	---
11-30-94	17 °C (64 °F)	3 °C (39 °F)	---

Table E12. 1994 Weather - Rainfall Data

12-01-94	18 °C (66 °F)	1 °C (35 °F)	---
12-02-94	16 °C (61 °F)	10 °C (51 °F)	21 mm (0.84 in.)
12-03-94	22 °C (72 °F)	16 °C (61 °F)	---
12-04-94	22 °C (73 °F)	13 °C (56 °F)	---
12-05-94	23 °C (75 °F)	12 °C (55 °F)	T
12-06-94	26 °C (80 °F)	17 °C (63 °F)	T
12-07-94	25 °C (78 °F)	15 °C (59 °F)	26 mm (1.03 in.)
12-08-94	27 °C (82 °F)	15 °C (60 °F)	
12-09-94	19 °C (67 °F)	4 °C (40 °F)	13 mm (0.54 in.)
12-10-94	12 °C (55 °F)	2 °C (37 °F)	3 mm (.012 in.)
12-11-94	10 °C (50 °F)	0 °C (33 °F)	---
12-12-94	17 °C (63 °F)	1 °C (35 °F)	---
12-13-94	15 °C (59 °F)	7 °C (46 °F)	3 mm (0.15 in.)
12-14-94	20 °C (68 °F)	12 °C (54 °F)	16 mm (0.64 in.)
12-15-94	18 °C (66 °F)	15 °C (59 °F)	147 mm (5.79 in.)
12-16-94	18 °C (66 °F)	7 °C (46 °F)	11 mm (.045 in.)
12-17-94	14 °C (58 °F)	6 °C (43 °F)	---
12-18-94	20 °C (68 °F)	3 °C (39 °F)	---
12-19-94	18 °C (66 °F)	5 °C (41 °F)	---
12-20-94	15 °C (60 °F)	9 °C (49 °F)	T
12-21-94	20 °C (68 °F)	6 °C (44 °F)	---
12-22-94	15 °C (60 °F)	4 °C (40 °F)	---
12-23-94	18 °C (65 °F)	2 °C (37 °F)	---
12-24-94	13 °C (56 °F)	3 °C (38 °F)	---
12-25-94	16 °C (62 °F)	0 °C (32 °F)	---
12-26-94	18 °C (65 °F)	1 °C (34 °F)	---
12-27-94	17 °C (63 °F)	3 °C (39 °F)	---
12-28-94	11 °C (53 °F)	8 °C (48 °F)	26 mm (1.04 in.)
12-29-94	12 °C (55 °F)	8 °C (47 °F)	T
12-30-94	13 °C (57 °F)	10 °C (50 °F)	---
12-31-94	16 °C (62 °F)	9 °C (49 °F)	3 mm (0.12 in.)