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16. Abstract

Roadside slope failure, as well as drainage channel and structure siltation, is related to the health and character of the roadside vegetative community. Native grasses and prairie plant associations are well adapted to the harsh open environments of open prairies and plains, a characteristic shared by many highway roadsides.

This study hypothesized that the growth habit of native plants, which includes a tough, deep, fibrous root system, and a dense surface protecting cover, may make them better suited for slope protection and erosion control than most introduced grass species commonly used on the roadside. Furthermore, researchers hypothesized that these native vegetation associations would require less cultural maintenance than the introduced grasses and would be less subject to invasion of noxious weeds.

The researchers compared the erosion control and surface soil-reinforcing properties of four native grass, wildflower, and forb mixes to common Bermudagrass. The performance testing procedures were in accordance with the test procedures developed by the Texas Department of Transportation (TxDOT) and the Texas Transportation Institute (TTI) for the evaluation of rolled erosion control products. Tests were performed at the Texas Transportation Institute's Hydraulics and Erosion Control Field Laboratory, College Station, Texas.

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EROSION CONTROL AND ENGINEERING PROPERTIES OF NATIVE VEGETATION COMPARED TO BERMUDAGRASS

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Sponsored by the
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DISCLAIMER

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Texas Transportation Institute staff that deserve recognition for their hard work in the collection of data, and the installation and monitoring of test plots are: Jim Schutt, Jett McFalls, Rodney Jackson, Alex Ferrazas, and Douglas Artz. We also wish to thank Karen Eddleman for her work and professionalism in preparation of the project reports and deliverables.

Finally, we wish to express our appreciation to TxDOT and the Federal Highway Administration for their financial sponsorship of the project.

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NATIVE VEGETATION AND ROADSIDE EROSION CONTROL

Over the past two decades, increased interest has surfaced around using native plants in roadside revegetation efforts rather than the more standard practice of using introduced species and exotics. Interest in using natives has evolved from a number of different practical and environmental concerns. Researchers are facing issues such as the need to back-breed seed sources in order to recover pest and disease resistance, the collection and use of regionally native seed to achieve greater survivability, and concerns over the escape of introduced species like Sapium and Melaluca. Each of these concerns represents a legitimate area of inquiry in its own right, and some of the findings would, on the surface, appear to argue strongly for the use of native plants for reclamation and revegetation activities like those associated with roadside stabilization.

On the other hand, there has been little systematic research focused on the benefits of using native grasses, forbs, and wildflowers rather than commercially available, introduced, or selected grasses for roadside reclamation efforts. A modest body of research has been developed related to the reclamation of forest and park road slopes, landfills, and opencast mined lands. This research has been focused on the reestablishment of stable, early successional plant communities, or concerned with the establishment of productive forage and pastureland. However, few studies compare the productivity or value of either strategy. This lack of comparative research, whether related to the highway or other land uses, is most likely a result of the disparate objectives of a program to reestablish a self-supporting natural landscape, a managed landscape designed to produce food or fiber, or a safe, stable, and attractive roadside.

RESEARCH FOCUS

This project looked specifically at the performance of native plant materials with an introduced species commonly used in the erosion control mixes for the stabilization of roadsides. The research questions were:

- Do the native grasses, forbs, and wildflowers provide better or equal erosion protection to the roadside as measured by sediment reduction?
- Do the native species tend to maintain themselves and resist invasion of other species based on percent of surface cover?
- How do native species compare in terms of their soil nailing and reinforcing characteristics with respect to sliding based on surface shear strength?

TEST DESIGN

The researchers conducted this investigation at the Texas Department of Transportation's and Texas Transportation Institute's Hydraulics and Erosion Control Field Laboratory. This facility allowed researchers to conduct tests at a scale, and under conditions, which fairly represented the highway roadside environment. Researchers used the following procedures in the investigation.

Test Plot Method

Researchers conducted tests on clay and sandy soils. These soils represent typical soils weathered in arid to semi-arid conditions of the southwestern portion of the United States. The embankment plots measured 6.2 m x 15 m and were sloped at 2:1 for clay plots and 3:1 for sandy plots.

Installation

The project director (PD) selected four native seed mixes. Researchers tested these seed mixes against control plots seeded with common Bermudagrass (Cynodon dactylon). Seed and fertilizer were hydraulically applied to all seeded plots in accordance with standard TxDOT specifications for hydraulic mulching and seeding. The clay plots were protected with a mulch and tackifyer. Sand plots were covered with a rolled erosion control product. This installation process is consistent with recommended best management practices for soils and slopes 1:3 and greater. Researchers established the control plots, one each of sand and clay soils. Each plot was seeded and protected as noted for the other plots.

Initial Establishment

The study design allowed the plots one growing season to establish vegetative cover. The planting schedule for various vegetation types was set for optimum establishment:

- September 1 - November 1 for cool season grasses,
- February 1 - September 1 for warm season grasses and forbs,
- August 15 - November 30 for cool season legumes, and
- September 1 - July 31 for wildflowers and warm season legumes.

In accordance with laboratory practice, the researchers applied no supplemental irrigation to the seeded plots until 32 consecutive days passed without measurable moisture. These conditions were met after planting and supplemental irrigation was used to assist in establishment.

TESTING PROCEDURES

After initial establishment, researchers subjected each test plot to vegetation establishment and sediment control tests used to test erosion control blankets on slopes. Researchers used a rainfall simulator to emulate rainfall intensities at 1.2 in/hr, 5.75 in/hr, and 7.25 in/hr. Each rainfall event was applied to the plots in two separate repetitions. After the rainfall simulation events, researchers collected and weighed the sediment.

Vegetation density of the 1 m plots was documented with the use of random video/digital pictures. After processing the photographs with proprietary software, researchers used these photos to determine the vegetation surface cover. In addition, researchers used the software to analyze random quadrats for the coverage of desirable and planted species in relation to the total vegetative coverage.

Data Collection

Researchers collected and weighed all sediment generated by the rainfall events. Comparisons of sediment retention were based on kg/m^2 for each vegetation and soil association. The detailed erosion control performance data collection procedures are included in the procedures manual included in Appendix B.

Shear strength values were based on a comparison of samples taken from the control plots. Five random 10 cm x 3 cm cores were extracted from each plot. The cores were tested for shear strength using new methods. Root density was then determined for 1 cm sections of each core. In addition, standard field measures, vane, and penetrometer tests were used to estimate the relative reinforcing value of the vegetation types.

Documentation

Documentation utilized photographic records and standard text report formats. Complete daily meteorological records from an on-site weather station were available for most of the project period. These data allowed estimation of daily conditions, which were used to characterize vegetation stress conditions.

CHRONOLOGICAL PROJECT DESCRIPTION AND NOTES

VEGETATION GROWTH MONITORING AND EROSION TESTING

Planting and Establishment Period, 1997-1998

The project began in fiscal year 1997. Planting began in November 1997 and continued through April 1998. Figure 1 shows the plot locations on the test embankment. Table 1 documents the seeding rates and species planted.

The year 1998 proved to be one of the driest and hottest years on record for the Bryan and College Station area. Because it was so dry and hot, some supplemental irrigation was provided late in the season in an attempt to salvage the plots. In the heat there was very little evidence of emergent vegetation, and it was feared that the experiment had been lost. However, in the spring of 1999 the plots began to produce a reasonable vegetative cover given the conditions. Refer to Appendix A to view photographs taken in May 1999.

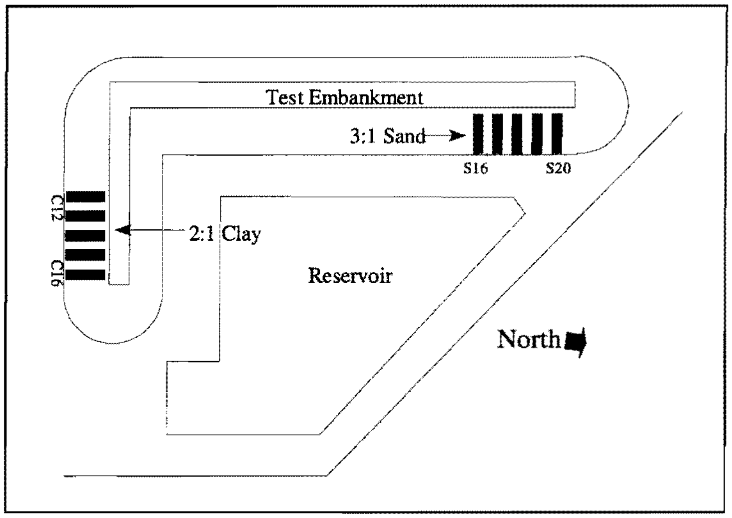


Figure 1. Location of Plots on Test Embankment.

Growth Cycle and Inspection Period, 1998-1999

Close inspection of the plots in the winter of 1998 and very early in the spring of 1999 suggested that there was sufficient loss of seed to warrant overseeding of the plots. Sufficient funds were available in the budget to allow for overseeding, and it was carried out between March and April of 1999. The decision was also made at this time to allow another year for establishment prior to doing any formal testing. The 1999 growing season proved to be moderate with adequate rainfall. The plots responded, but establishment was slow. This slow growth was particularly evident in the plots planted with native grasses, forbs, wildflowers, and Crownvetch. The Bermudagrass plots covered well.

There was an unusual invasion of wild sunflowers into all of the established plots. These were manually removed from the plots to reduce competition. Table 2 shows the species distribution found in the individual plots, following a review of the plots in late summer of 1999.

Table 1. Species and Seeding Rates for Test Plots.

Plot[1]	Seeding Rates (kg/ha)[2]	Species
Controls	18.57	Bermudagrass
Native Grasses	44.4	Canada Wild Rye Little Bluestem Sideoats gramma June Grass Indian Grass Switchgrass Prairie Drop Seed
Wildflower Mix	20.89	Texas Bluebonnet Scarlet Flax Indian Blanket Tickseed Lemon Mint Purple Coneflower Drummond Phlox Cornflower Rocket Larkspur Baby Blue-eyes Ox-eye Daisy California Poppy Yellow Cosmos Baby's Breath African Daisy Plains Coreopsis Clasping Coneflower Black-eyed Susan Mexican Hat Tuber Vervain Corn Poppy Toadflax Dwarf Red Coreopsis Showy Primrose Yarrow Texas Paintbrush

[1] Plots were in pairs. Each pair consisted of a sand plot, at a 3:1 slope, and a clay plot, at a 2:1 slope. Each plot was prepared and seeded in the same way.

[2] The seed rates were evenly distributed among the included species.

Table 1. Species and Seeding Rates for Test Plots (cont.)

Plot	Seeding Rates (kg/ha)	Species
Native Forbs and Grasses	20.89	Canada Wild Rye Little Bluestem Sideoats gramma Indian Grass Wine Cup Plains Coreopsis Black-eyed Susan Texas Lupine Mealy Blue Sage Gayfeather Rocky Mountain Penstemon Bergamot Yellow Evening Primrose Blanket Flower Maximilian Sunflower Prairie Aster Purple Prairie Clover Indian Paintbrush Milkweed Blanket Flower
Crownvetch	20.89	Crownvetch

Observations

1. The Bermudagrass was persistent and generally covered the plot where it was planted. Bermudagrass also invaded and was common, to fairly abundant, in all of the other plots.

2. Of the native grasses planted, Little Bluestem was the only one that was visible at this stage.

3. Of the 26 wildflower species planted, only 5 were observed in the plot, with Indian Blanket, Coreopsis, and Larkspur being the most prevalent. Researchers observed two other species, Drummond Phlox and Ox-eye Daisy, but not in the plots where they were planted.

4. Three of the 19 species planted in the forbs and grass mix plot were present. None of the native grasses were apparent at this time. Only Maximilian Sunflower, Coreopsis, and Purple Prairie Clover were in evidence.

5. No Crownvetch was apparent at this time.

6. The most prevalent plant species was common roadside weed species. Since the site is surrounded by rangeland typical of the land adjacent to rural highways in Texas, researchers expected this sort of invasion.

Table 2. Plot Inventory of Dominant Vegetation Species on Sand Plots, Summer 1999.[1]

		Plot Type				
Number	Plant Name	Bermudagrass S16	Native Grasses S17	Wildflower Mix S18	Native Forbs and Grass Mix S19	Crownvetch S20
1	3-Leaf Vine	1	2		1	1
2	Bermudagrass	5	2	3	4	4
3	Bundleflower	1	2	2	2	
4	Cockelbur	1	2	3	3	2
5	Coreopsis			2	1	
6	Croton sp.	2		2	2	2
7	Ox-eye Daisy					1
8	Dandelion	1	1	2	2	2
9	Drummond Phlox				1	
10	Evening Primrose			3		
11	Giant Ragweed					2
12	Maximilian Sunflower				3	2
13	Horsetail		1			2
14	Indian Blanket		1	2	3	2
15	Johnsongrass	1	4	2	2	2
16	Little Bluestem		2			
17	Rocket Larkspur			1		
18	Bur Clover	2	1	3	2	
19	Purple Prairie Clover	3	3	3	4	4
20	Bergamot Mint			3		
21	Partridge Pea					1
22	Ragweed		3	2	2	2
23	Black-eyed Susan			1		
24	Sow Thistle		1		1	2
25	Low Hop Clover	2				1
26	Wine Cup					

[1] The ranking represents the relative presence of the particular species on the following scale: 1 = rare, one or two individuals present; 2 = present, found in 25 percent of the plot; 3 = common, found in 50 percent or more of the plot; 4 = fairly abundant, found in 75 percent of the plot; 5 = abundant, numerous individuals over the entire plot.

Erosion Testing

Erosion control testing began in the summer of 1999. The tests documented sediment loss, vegetative cover, and soil shear strength. The results of the vegetation cover and sediment loss tests are summarized in Table 3.

Table 3. 1999 Vegetation Cover and Sediment Loss Test Results.

	Plots	Crop	Vegetation Cover (Percent)	Sediment Loss (kg/m^2)
Sand	S16	Bermudagrass	90.14	1.214
	S17	Native Grasses	71.79	1.252
	S18	Wildflower Mix	65.57	1.547
	S19	Native Forbs/Grasses	88.45	1.301
	S20	Crownvetch	76.16	1.255
Clay	CL12	Crownvetch	86.53	0.028
	CL13	Native Forbs/Grasses	79.64	0.035
	CL14	Wildflower Mix	69.36	0.040
	CL15	Native Grasses	82.47	0.033
	CL16	Bermudagrass	70.94	0.030

Observations

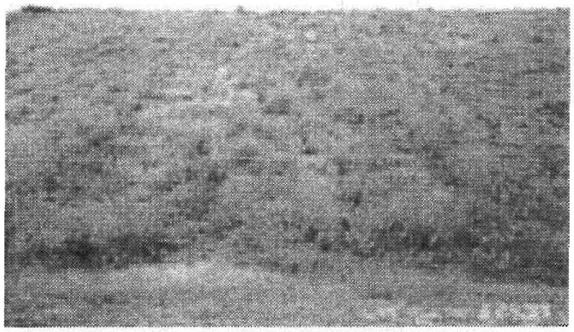
1. On the sand plots (see Figure 2), the best cover was obtained by the Bermudagrass at 90.14 percent, followed by the native grasses at 71.79 percent, and native forbs and grasses at 88.45 percent. The Crownvetch plot showed 76 percent cover, but the cover was all due to non-planted species. No Crownvetch was observed in the plot. The wildflower plot had the least cover, at 65.57 percent.

2. The sediment loss performance on sand was quite good for all of the plots ranging from a low of 1.2 kg/m^2 for the Bermudagrass to a high of 1.5 kg/m^2 for the wildflower mix. By comparison initial growing season sediment losses for sand plots, seeded and covered with erosion control blankets, ranges from 8 kg/m^2 up to 50 kg/m^2.

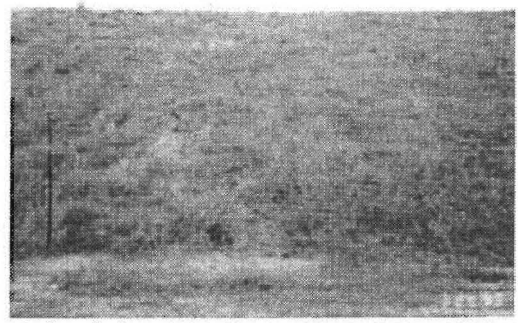
3. On the clay soils (see Figure 3), the Crownvetch plots achieved the best vegetative cover. Like the sand plots, volunteer and weed species made up the vegetative cover, with only traces of Crownvetch being visible. Researchers observed the next best vegetative cover performance on the native grasses, and native forbs and grasses plots. The Bermudagrass and wildflower plots showed significantly less cover.

4. The sediment reduction achieved by the various plots was not significantly different. The best performance, at 0.028 kg/m^2, was the Crownvetch plot covered with volunteer species. The worst performance was the wildflower mix at 0.40 kg/m^2. The grass mix plots were in the range of 0.30 to 0.35 kg/m^2.

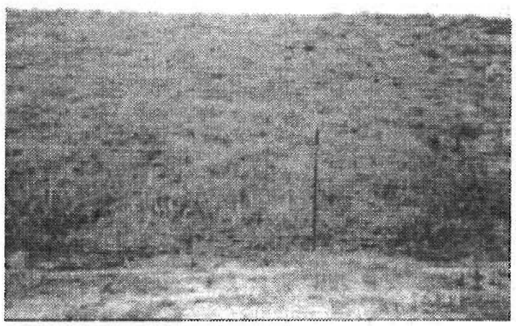
5. Researchers conducted the first shear strength testing with a unique apparatus that measures surface scour by extruding a soil plug into a shallow water stream. This apparatus controls flow velocity in order to allow the calculation of the surface scour rate. Researchers ran soil plugs for each soil type and vegetation cover. Results from this method proved inconclusive and showed no statistically significant difference in surface scour rates between vegetation types.



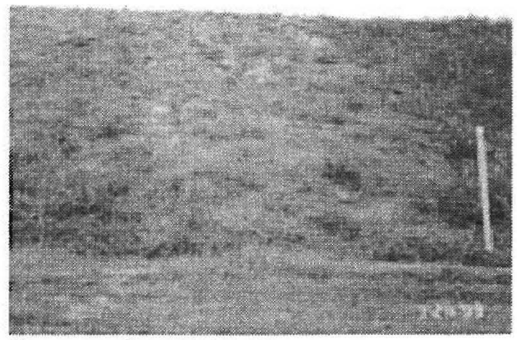
Native grass (middle), Bermudagrass (right)



Native forbs and grass



Wildflower mix

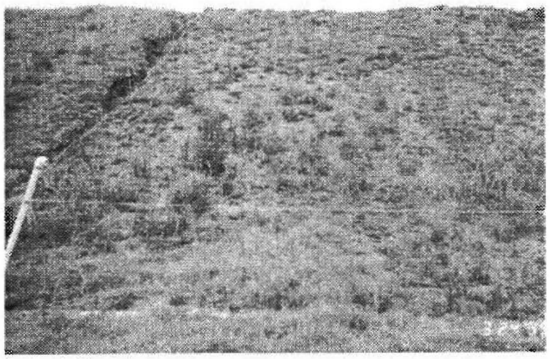


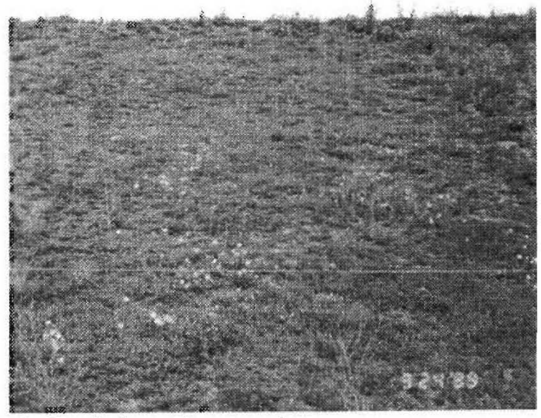
Crownvetch

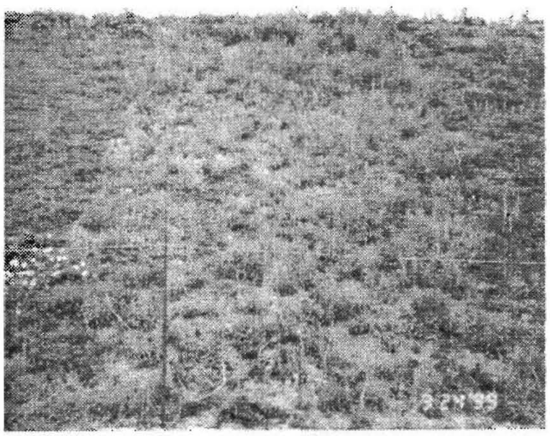
Figure 2. Sand Test Plots, 1999.

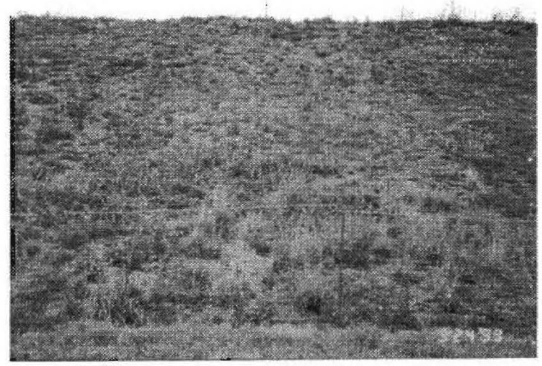
Growth Cycle and Inspection Period, 1999-2000

While the weather in fiscal 1998-1999 was mild, fiscal 1999-2000 proved to be another year of extreme climate. Only 2.57 inches of precipitation were recorded in June, July, and August. There was no measurable precipitation in July and only 0.22 inches in August of that year. Nonetheless, work continued and testing was completed. Table 4 summarizes the results of the vegetative cover and sediment loss for the growing season of the year 2000. Tables 5 and 6 give the vegetation cover distribution for the plots by soil type.


Bermudagrass


Native forbs and grass mix


Wildflower mix


Native grasses

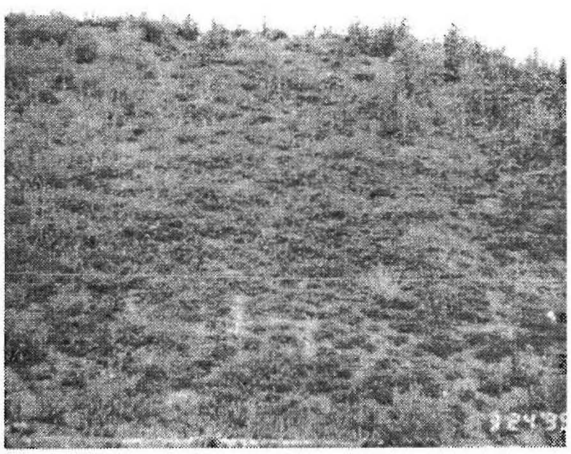

Crownvetch

Figure 3. Clay Test Plots, 1999.

Table 4. 1999-2000 Vegetation Cover and Sediment Loss Test Results.[1]

	Plots	Crop	Vegetation Cover 1999 (Percent)	Vegetation Cover 2000 (Percent)	Sediment Loss 1999 kg/m^2	Sediment Loss 2000 (kg/m^2)
Sand	S16	Bermuda only	90.14	91.59	1.214	1.214
	S17	Native Grasses	71.79	81.96	1.252	1.252
	S18	Wildflower Mix	65.57	63.27	1.547	1.547
	S19	Native Forbs/Grasses	88.45	87.11	1.301	1.301
	S20	Crownvetch	76.16	80.42	1.255	1.255
Clay	CL12	Crownvetch	86.53	70.22	0.028	0.028
	CL13	Native Forbs/Grasses	79.64	77.85	0.035	0.035
	CL14	Wildflower Mix	69.36	65.39	0.040	0.040
	CL15	Native Grasses	82.47	84.17	0.033	0.033
	CL16	Bermuda only	70.94	64.48	0.030	0.030

1. Note to be approved for use by TxDOT, vegetative cover should not lose more than 1.22 kg/m^2 on sand, and no more than 0.034 kg/m^2 on clay.

Observations

1. The hot, dry weather resulted in a decrease in overall vegetative cover on many of the plots. On the sand plots, researchers observed decreases on the wildflower plots and the native forbs and grasses. In both cases, the decreases were small. On the clay plots there were decreases in vegetative cover on the Crownvetch, native forbs and grasses, and the wildflower mix. The most significant decrease in cover was observed for the Crownvetch on clay soil, decreasing from 86.53 percent to 70.22 percent. The other decreases were less than 6 percent.

2. It is important to note that the vegetative cover measure is based on the surface cover for all vegetation species. It does not consider the percent of planted versus volunteer vegetation.

3. Native grasses increased significantly on the sand plot, which were the only increase in cover the researchers observed.

4. There were significant shifts in the vegetation composition of all plots. The most significant change was in the overall presence of Bermudagrass and the onset of grass invasion into other plots. The significant increases were in Switchgrass, Sideoats gramma, Little Bluestem, and K.R. Bluestem. It would seem that in the hot, dry weather of 2000, the native grasses were able to survive and even increase. In contrast, wildflowers do not appear to have fared well.

5. There were numerous rosettes found in the clay plots. These were recorded as forb rosettes, but may also be wildflowers and or native grasses.

6. For the most part, the sediment loss figures showed little change. As might be expected, there were some very minor increases in sediment loss in 2000, related to the decrease in vegetative cover.

7. Because the soil extrusion method used in 1999 did not produce a significant difference in shear strength, researchers used more traditional methods of vane and penetrometer tests. However, due to extreme dry and wet conditions these tests have afforded little insight at this time. The Analysis section offers more details concerning these conditions.

Table 5. Plant Inventory, Sand Plots 2000.

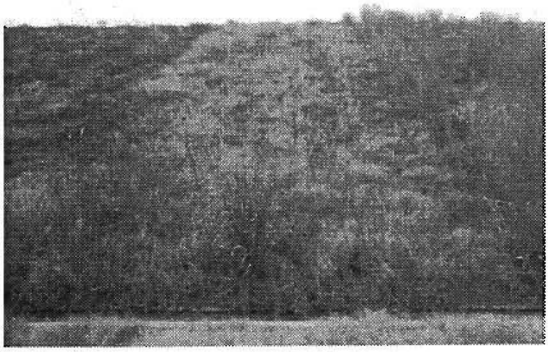
Plant Name	Plot S16 1999	Plot S16 2000	Plot S17 1999	Plot S17 2000	Plot S18 1999	Plot S18 2000	Plot S19 1999	Plot S19 2000	Plot S20 1999	Plot S20 2000
3-Leaf Vine	1		2				1		1	
Bare ground		2		3		4		3		2
Bermudagrass	5	5	2	1	3	4	4	5	4	5
Black-eyed Susan					1					
K.R. Bluestem		3				2		2		2
Bundleflower	1		2		2		2			
Bur Clover	2		1		3		2			
Bushy Broomsedge		1		1		1		1		1
Clover		5		2		5		4		3
Cockelbur	1		2		3		3		2	
Coreopsis					2		1			
Croton sp.	2	1			2	1	2	1		1
Crownvetch									2	2
Dandelion	1		1		2		2		2	
Drummond Phlox							1			
Evening Primrose					3					
Giant Ragweed									2	1
Horsetail									2	
Indian Blanket			1		2		3		2	
Indian Grass								2		1
Johnsongrass	1		4		2	1	2	1	2	2
Low Hop Clover	2									
Maximilian sunflower							3	1	2	1
Ox-eye Daisy									1	
Partridge Pea						2		4		2
Purple Prairie Clover	3		3		3		4		4	
Ragweed		2	3		2		2		2	
Rattlebox		2		1		1		1		1
Rocket Larkspur					1					
Sideoats Gramma				2				2		1
Sow Thistle			1				1		2	
Switchgrass				5		1		2		
Threeawn										1
Wine Cup									1	

Table 6. Clay Plots, Spring 2001.

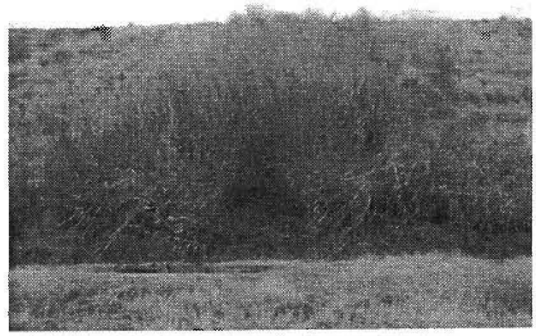
Plant Name	Plot C12 Crownvetch	Plot C13 Native forb and grass mix	Plot C14 Wildflower mix	Plot C15 Native grass mix	Plot C16 Bermudagrass
Bare ground	3	2	3	3	5
Bermudagrass	2				
Rattlebox		1	1		
Brushy Broomsedge		1			
Ragweed		1			
Clover					3
Switchgrass	2	2	1		
Sideoats Gramma	2	4	1	2	
Johnsongrass	2	1	1	1	1
Crownvetch	1		3	2	1
Giant Gagweed	1	1	1	1	1
Sunflower					1
Amaranthus					1
Paspalum					1
Witchgrass					1
Plantago	1		1		1
Dewberry	1		2	2	3
Salvia	1			2	
Tragia				1	
Silver Bluestem	2				
Forb Rosettes	4	2	2	2	1

Supplemental Moisture Application

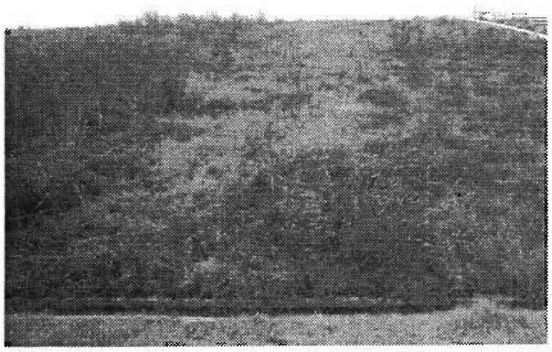
The photographs in Figures 4 and 5 show the distinct shift in vegetation cover between the 1999 and 2000 growing seasons. One important observation is that even though the actual rainfall was the lowest total ever recorded for the period, all plots did receive supplemental water in the form of rainfall simulation. This did provide some supplemental moisture over what would have been expected in a true roadside environment. The total supplement amounted to 3.61 inches and was applied during the months of July and August. Given the conditions, the amount of supplemental moisture applied to the plots was significant.



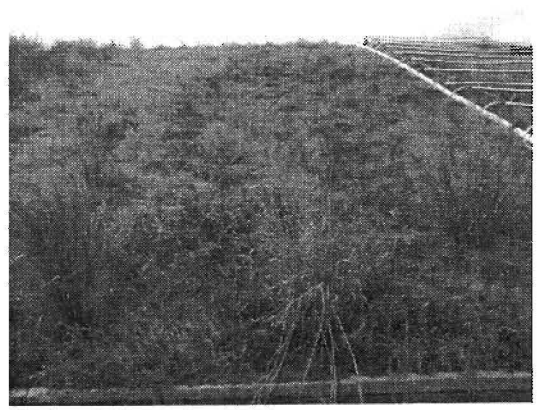
Bermudagrass



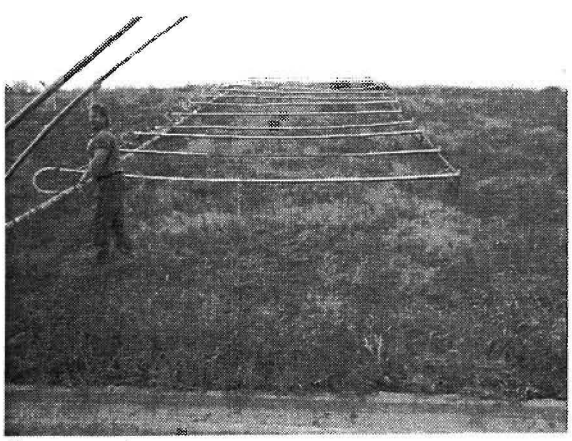
Native grasses



Wildflower mix

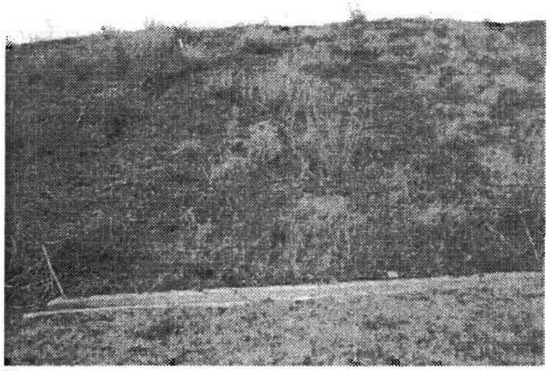


Native forbs and grasses

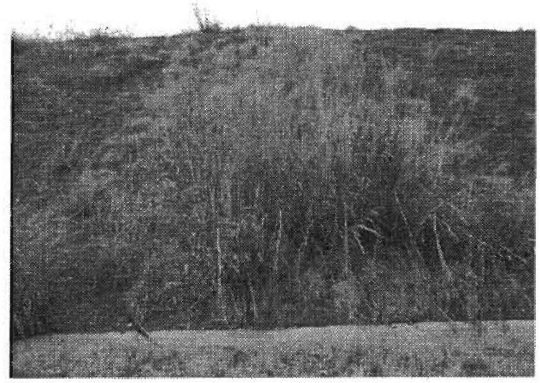


Crownvetch

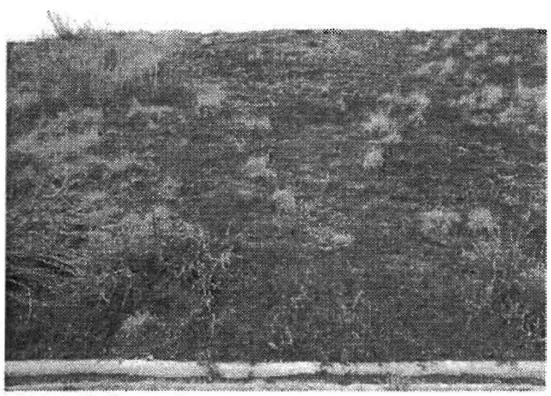
Figure 4. Sand Test Plots, 2000.



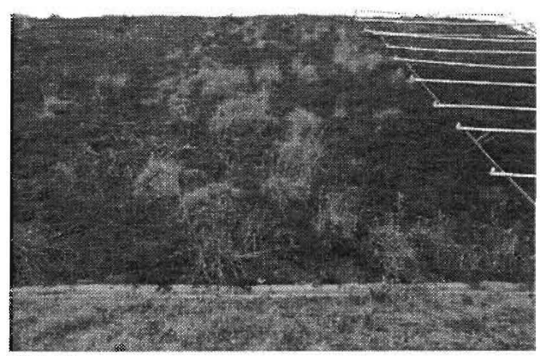
Bermudagrass



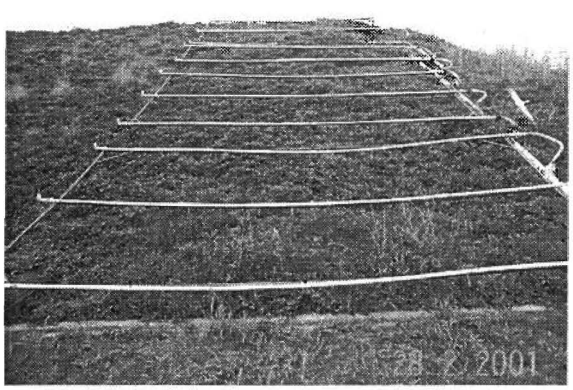
Native grasses



Native forbs and grasses



Wildflowers



Crownvetch

Figure 5. Clay Test Plots, 2000.

ANALYSIS AND FINDINGS

The climatic conditions over the term of the project were some of the most severe recorded in this region of Texas. Nonetheless, most the plots performed better than might be expected for the conditions. Perhaps the plots performing better than expected could be due to the rainfall simulation as part of the erosion control testing procedure. As a result of the tests, an additional 3.6 inches of supplemental water was added to each plot. This supplemental moisture would clearly have helped the plots as compared to plants in a genuine roadside condition.

This section discusses several basic characteristics of the test plots, including:

- vegetation cover,
- vegetation species and distribution,
- sediment loss, and
- soil-reinforcing properties of the vegetation association.

Each section discusses and compares data from the 1999 and 2000 testing periods. It is also noted that some of the early photo data and plant inventory data from 1997, 1998, and some of 1999 were lost due to the "I Love You" computer virus and the loss of a computer hard drive. Fortunately, much of the data were backed up, so the overall loss was minimal.

VEGETATION COVER

Researchers allowed the vegetation to establish in two growing seasons because of the drought conditions experienced in the summer of 1997 when the initial planting was conducted. When researchers reviewed the plots in November 1997, and again in the spring of 1998, they found the established cover so poor that testing was infeasible.

Because the erosion control mats were still in reasonable condition, the surface was not excessively eroded. A considerable number of rosettes were visible under the blankets; therefore researchers decided to lightly overseed the plots, and to allow a second growing season for the vegetation to establish. Therefore, researchers only made detailed observations of the vegetation cover in the 1999 and 2000 growing seasons.

The technique for determining vegetative cover utilizes random digital or video frames taken at a set distance from the ground so that the frame represents 1 m^2. The individual frames are processed using an image processing software to determine the percent of ground visible in the frame. The area of ground subtracted from the 1 m^2 area represents the percent of vegetative cover. While this measure does not represent the vegetation mix providing the surface cover, the cover percent has a very strong correlation to sediment loss.

Vegetative Cover Performance

TxDOT requires that a plot covered by an approved erosion control mat or blanket achieve, in one growing season, vegetation coverage of at least 80 percent of the surface for clay soils and 70 percent of the surface for sandy soils. Researchers planted all the plots according to TxDOT requirements, and none of the plots achieved 70 percent cover in the first year. However, in the second year only the wildflower mix failed to achieve what TxDOT considers a minimum cover on both plots, while the native forb and grass mix was just short of reaching the required 80 percent on the clay plots.

In the extreme heat and drought of the 2000 growing season, most of the plots experienced a decline in vegetation cover. The only vegetation types that experienced some increase in cover were the Bermudagrass, Crownvetch, and native grasses on the sand plots. Only the native grasses increased on the clay plots. Tables 7 and 8 show both the sand (S) and clay (CL) vegetation cover results for 1999 and 2000.

The decrease in vegetation cover over the 2000 growing season meant that neither wildflower plot would have met the TxDOT requirement for cover, and only the native grasses would have met the requirement for clay soils.

These observations must be tempered somewhat by considering how much of the observed cover was the result of seeded species against volunteer species.

Table 7. 1999 and 2000 Vegetation Cover Results.

Plot	Plot Type	Vegetation Cover 1999 (Percent)	Vegetation Cover 2000 (Percent)
S16	Bermuda only	90.14	91.59
S17	Native grasses	71.79	81.96
S18	Wildflower mix	65.57	63.27
S19	Native forbs/grasses	88.45	87.11
S20	Crownvetch	76.16	80.42
CL12	Crownvetch	86.53	70.22
CL13	Native forbs/grasses	79.64	77.85
CL14	Wildflower mix	69.36	65.39
CL15	Native grasses	82.47	84.17
CL16	Bermuda only	70.94	64.48

VEGETATION SPECIES AND DISTRIBUTION

In 1999, and again in 2000, researchers conducted a vegetation inventory in order to identify the species present in the test plots. The species were inventoried along a transect in each plot, and then researchers used a visual inspection to rank the relative presence of that species in the plot. The scale is composed of the following:

1 = Rare, one or two individuals present in the plot;

2 = Fairly Common, present in about 25 percent of the plot;

3 = Common, found in 50 percent of or more of the plot;

4 = Fairly abundant, found in 75 percent of the plot;

5 = Abundant, numerous individuals over the entire plot.

Since there was no data available for the clay plots in 1999, researchers compared only the sand plots' vegetation distribution. These data appear in Tables 2 and 8.

Table 8. Vegetation Distribution in Sand Plots, December 2000.

	Plot Type				
Plant Name	**Bermudagrass S16**	**Native Grasses S17**	**Wildflower Mix S18**	**Native Forbs and Grass Mix S19**	**Crownvetch S20**
Bare ground	2	3	4	3	2
Bermudagrass	5	1	4	5	5
Rattlebox	2	1	2	2	2
Brushy broomsedge	1	1	1	1	1
K.R. bluestem	3		2	2	2
Croton sp.	1		1	1	1
Ragweed	2				1
Purple Prairie Clover	5	2	5	4	3
Switchgrass		5	1	2	
Sideoats gramma		2		2	1
Johnsongrass			1	1	2
Partridge pea			1	4	2
Little Bluestem				2	
Indian Grass				2	1
Maximilian Sunflower				1	1
Crownvetch					2
Threeawn					1
Giant ragweed					1

Of the combined 45 species of wildflowers and forbs planted, researchers identified only 11 species in 1999. Researchers did observe a few more wildflowers, such as Indian Paintbrush, but these were no longer in evidence when the inventory was done. Only two grass species were in evidence: Bermudagrass, which had invaded all of the sand plots, and Little Bluestem, which was fairly common in the native grass plot. The Bermudagrass had a significant presence in all but the native grass plot where it was fairly common.

A computer hard drive crash caused a records loss for the clay plots in 1999. However, researchers backed up the photographs, which appear in Figure 3. From this record, some general observations can be made. The wildflower, native grasses, and Crownvetch plots had almost no evidence of originally planted species, and the cover was very sparse. The native grass plots and the native grass and forb mix both show evidence of a developing association related to the originally planted species. In the native grass and forb mix plot, the most dominant species was Switchgrass, and in the native grass plot the dominant species was Little Bluestem.

Also consistent with the current condition of the plots is that most of the planted species occur in the bottom one third of the plot, which is probably due to some seed migration and the droughty condition of the upper two-thirds of the slope.

By the end of 2000, the dominant species composition had changed in most of the plots. The most striking change was that 16 of the forb and wildflower species found in 1999 were not in evidence. At the same time, the native grass species showed a marked increase. Even more significant was the fact that the increases occurred on the sand plots, which usually have the poorest vegetation response in the first year. In contrast, the clay plots lagged far behind in terms of number and abundance of species planted.

SEDIMENT LOSS

One of the primary reasons for establishing a vegetative cover is to protect the surface from erosion. Sediment from the channel and bank erosion is a primary water pollutant and increases the maintenance burden on drainage ways and structures. The sediment loss numbers for 1999 and 2000, shown in Table 9, reveal that most all the seed mixtures, with the exception of the wildflower mix and the Bermudagrass on clay, produced 70 percent to 80 percent vegetation cover on the respective soils.

However, the sediment loss numbers on sand are above the TxDOT minimum 1.22 kg/m^2 requirement for a single growing season. On the sand plots, the native grasses improved to meet the minimum standard of 1.22 kg/m^2. On clay, the wildflowers and Bermudagrass did not meet the minimum standard of 0.034 kg/m^2 for 2:1 slope. The Bermudagrass plot had acceptable performance in 1999 but failed to meet the standard in 2000.

Table 9. 1999 and 2000 Sediment Loss Test Results.

Plot	Plot Type	Sediment Loss kg/m^2 1999	Sediment Loss kg/m^2 2000
S16	Bermuda only	1.214	1.158
S17	Native grasses	1.252	1.200
S18	Wildflower mix	1.547	1.660
S19	Native forbs/grasses	1.301	1.395
S20	Crownvetch	1.255	1.391
CL12	Crownvetch	0.028	0.024
CL13	Native forbs/grasses	0.035	0.031
CL14	Wildflower mix	0.040	0.038
CL15	Native grasses	0.033	0.032
CL16	Bermuda only	0.030	0.035

SOIL STRENGTH

Whether the type of vegetation established on a slope can or does contribute to the strength and stability of the slope remains a long-standing question. This is particularly significant with respect to the high incidence of shallow slope failures in highly plastic clay common in much of the southwestern part of the United States. Plants offer two mechanisms that have the potential to improve slope stability, they are:

- massive fibrous root systems, which serve to tie the upper soil layer together and spread shear loads over the upper soil layer; and

- dense root systems and full heads of foliage, which will serve to dissipate the soil moisture quickly after precipitation events, and should help prevent failure.

In this study, the objective was to determine whether or not there was a soil-reinforcing benefit of one species mix over another as they developed. Researchers used two methods to investigate significant differences. The first method, SRICOS (Scour Rate In COhesive Soils), is an apparatus developed by Texas A&M University and Texas Transportation Institute researchers to quantify the surface scour rate of cohesive soils. The method utilizes 24 inch x 3 inch deep plugs of soil that are extruded into low depth, low velocity water flows. The rate of scour is directly related to the shear strength of the soil cross section. The second method was to use vane and hand penetrometer tests as a means of establishing the soil shear strength near surface up to a depth of 6 inches.

Researchers determined both sets of tests conducted on sand and clay inconclusive. In each case, control tests were done on clay and sand samples. Researchers found that the vegetated tests showed no significant difference between the vegetated samples and the navigated samples.

PROJECT SUMMARY

As outlined in the introduction there were three research questions this study wished to address:

- Is the erosion control performance of native plant mixes, as measured by sediment loss, equal to or better than standard TxDOT seeding mixes?
- Do the species mixes establish themselves and resist invasion of exotic and introduced species?
- Do native vegetation mixes provide soil-reinforcing properties that could lead to more stable embankments?

Erosion Control

Initially, the erosion control properties of the native mixes do not compare favorably with the standard seed mixes developed and used for highway planting in the central part of Texas. This finding is true, particularly on sandy soils where only the native grass mix achieved a sediment reduction rate that would meet the current TxDOT standard for sediment loss. On clay soils it is difficult to judge the performance because only two plots, the native grass mix and the native grass and forbs plots, established a cover that could be related to the original seeding. These seemed to perform well, but so did the Crownvetch plot that was primarily volunteer species. Interestingly, the Bermudagrass plot had satisfactory performance in 1999, but did not fair well in the drought and heat of 2000. A similar decline in cover was also noted in the Bermudagrass plot on sand.

The data from this part of the testing support the long-held maxim that native species require an extended period of time to develop. However, as they develop it appears that erosion control properties are at least equal to the introduced species mixes in current use.

Establishment and Persistence

The most significant finding at this point is that the native grasses and native grass and forb mixed plantings start slowly but continue to develop as time goes on.

On the clay and sand plots seen in Figure 6, the 1999 picture shows good cover but a considerable population of non-planted species. Then, in 2000, the native species proliferated and became much more dominant.

Between 1999 and 2000, researchers noted that the persistence of Bermudagrass in both the clay and sand plots with native grasses markedly decreased. Likewise, the Bermudagrass plots were both being invaded by native forbs and grasses. This noted invasion does seem to support the notion that the native species will tend to be increasers, and that the introduced species will begin to decrease. The photograph in Figure 7 shows a distant view of the test plots in which native grasses appear to be well established after five years.

However, it is important to note that over the four years of the project, these plots have not been mowed or maintained other than to manually remove an early infestation of wild sunflowers.

The absence of mowing, particularly at common roadside heights of 4 to 6 inches, has probably contributed to the continued development and increase in the native grass species. Clearly, the native prairie grasses are taller, and they will tend to shade out the lower growing introduced

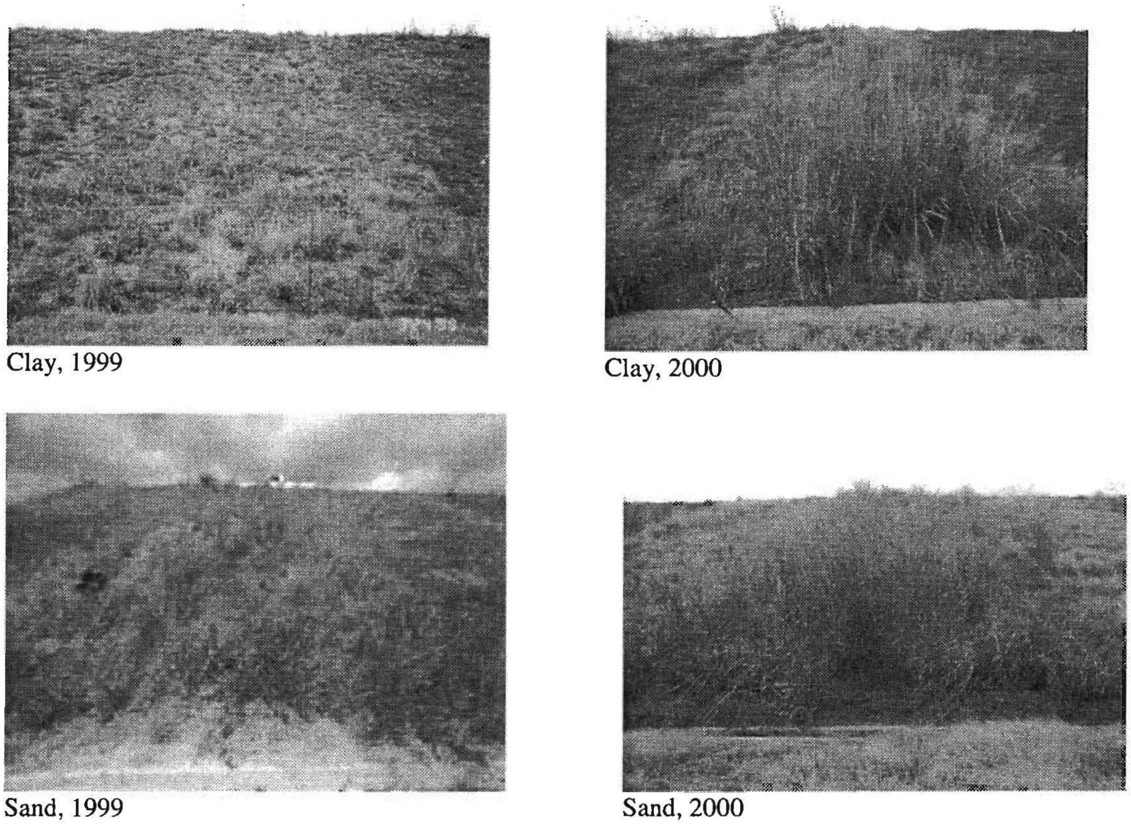


Figure 6. Native Grass Plots, 1999-2000.

species such as Bermudagrass.

Soil Reinforcing Value

Based on the data collected by two methods, it is simply not possible to make any conclusion about the relative soil-reinforcing value. It is believed that if the native plants are allowed to continue to develop, and if they are able to form a typical prairie grass turf, there will be a measurable reinforcing value. At this time there simply is not sufficient root structure and cover to measure a significant difference.

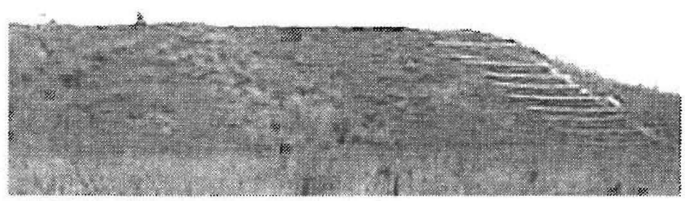


Figure 7. Distance View of Test Plots.

CONCLUSIONS

The period of the research and the climatic extremes experienced make any strong conclusions difficult. However, several observations can be made that should be of some benefit and provide a basis for continued investigation into the engineering properties of vegetation used in highway and public works construction.

First of all, it is important to note that the research was conducted on very steep slopes typical of highway and bridge embankments. This is in sharp contrast to most other research of this type. The steep slope exposes the vegetation to greater heating, and the upper parts of the slope will tend to be very drought prone.

Overall, the researchers conclude the following:

1. Wildflower mixes did not prove successful. They did show some germination in the first year of planting but were essentially gone by the second year of the project. Researchers were somewhat surprised by this finding, since the soils and sloped conditions do support reoccurring stands of Primrose, Texas Bluebonnet, and Indian Paintbrush. The fact that there was no better response could be related to the climate and because most good stands of wildflowers are mixed with other perennial plants.
2. Bermudagrass will be very aggressive in the first few years of planting. However, where native forbs and grasses have been planted, they will begin to gradually displace the Bermudagrass. This is probably due to the shading of the low-growing invaders.
3. Native grasses will continue to increase if mowing is not permitted. However, at some point in the development of the climax association, the native species will begin to decline due to the buildup of thatch and litter. Healthy stands of natives will still require some cultural management.
4. The erosion control properties of native grasses are not as effective as the grass mixes currently used by TxDOT. Native species tend to exhibit a clump-forming nature and are slow to develop, which would support the use of nurse grasses with the native prairie species.

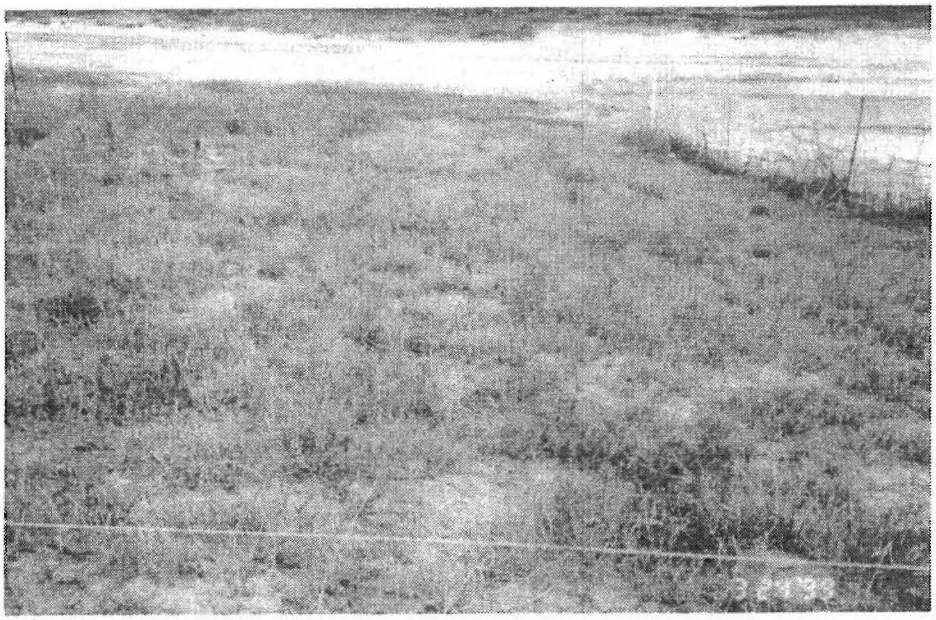
On the whole, the assessment that native vegetation species are a potential tool in the vegetation management scheme of a transportation system is based on several considerations:

- roadside mowing practices and use of herbicides,
- public sense of aesthetics,
- safety considerations,
- potential invasion of woody species in the east, and
- areas where the use of natives has application and requires greater consideration.

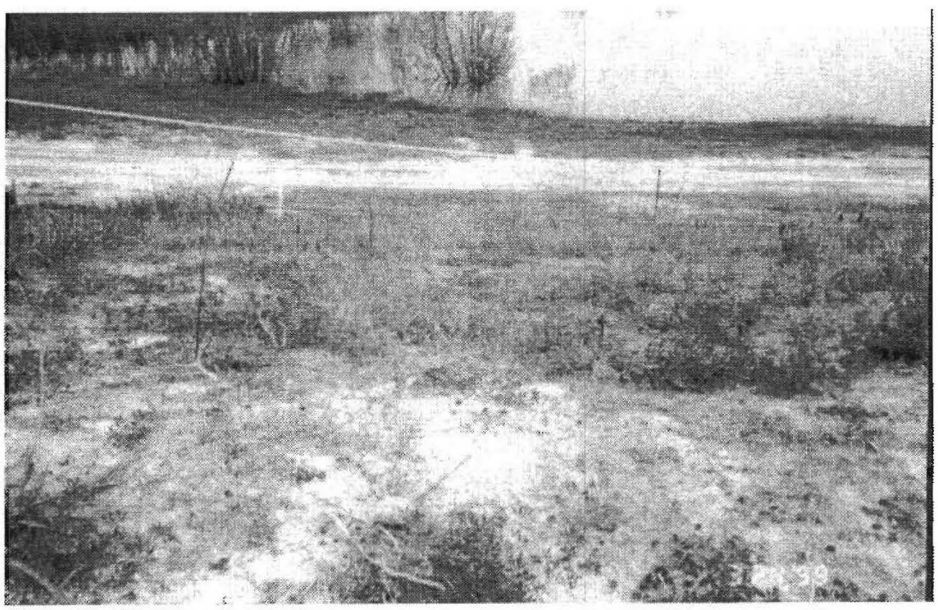
However, when all properties are considered, they are in no way superior to the vegetation mixes currently in use by TxDOT and other transportation agencies of the southwestern region of the United States.

Appendix A

1999 Test Plot Photographs

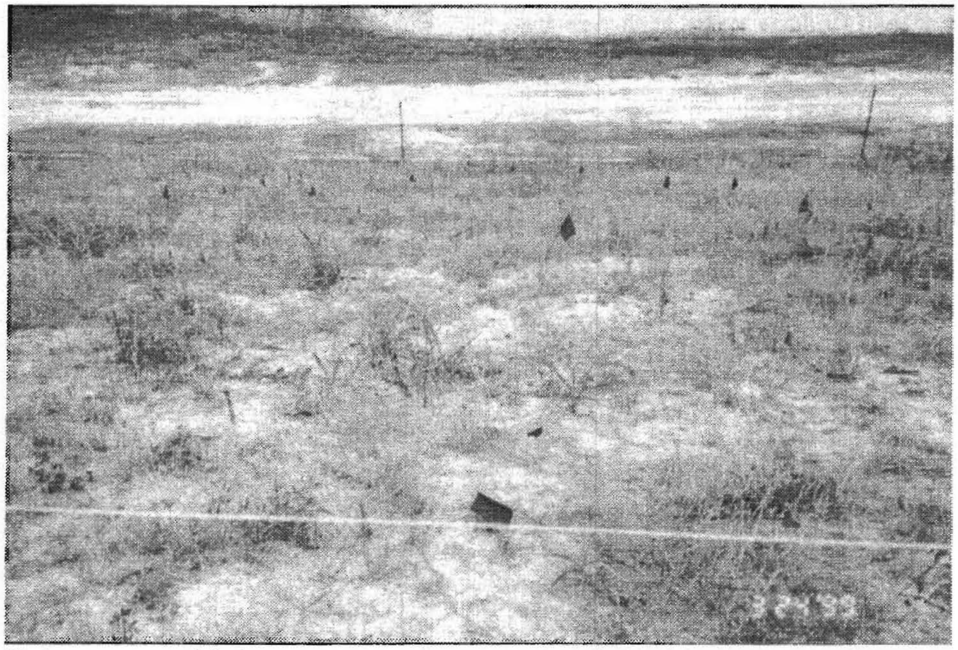


Bermudagrass



Crownvetch

Figure A-1. Sand Plots.



Native grasses and forbs

Native grass

Figure A-1. Sand Plots (continued).

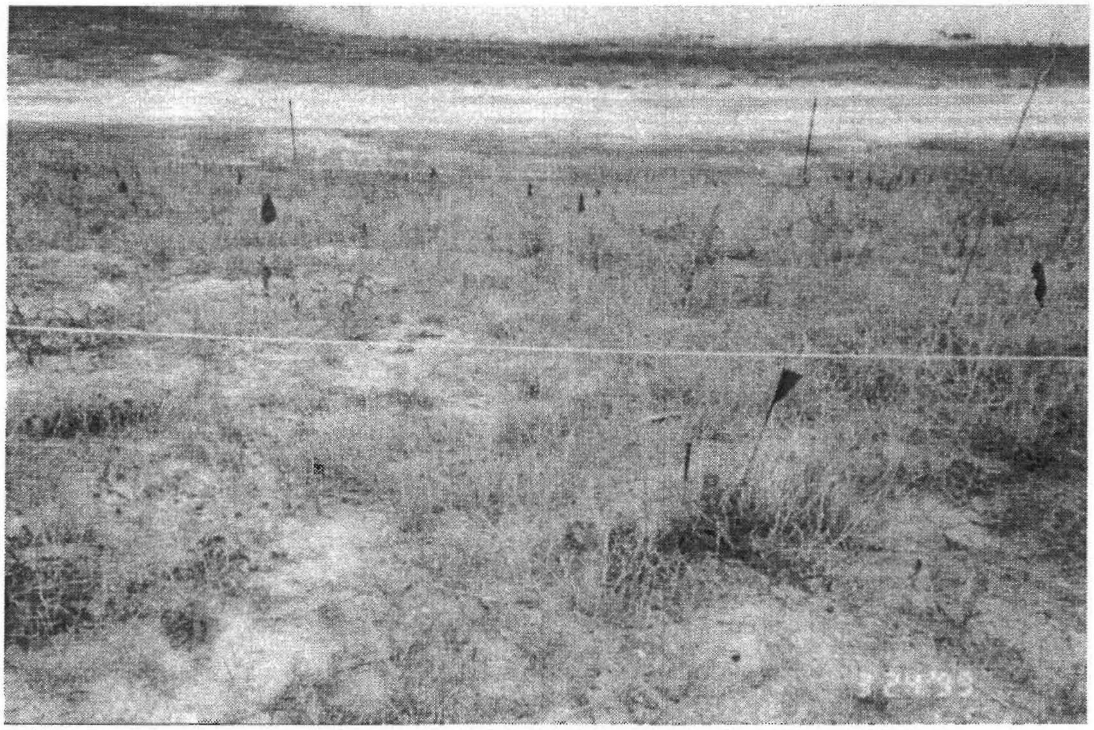
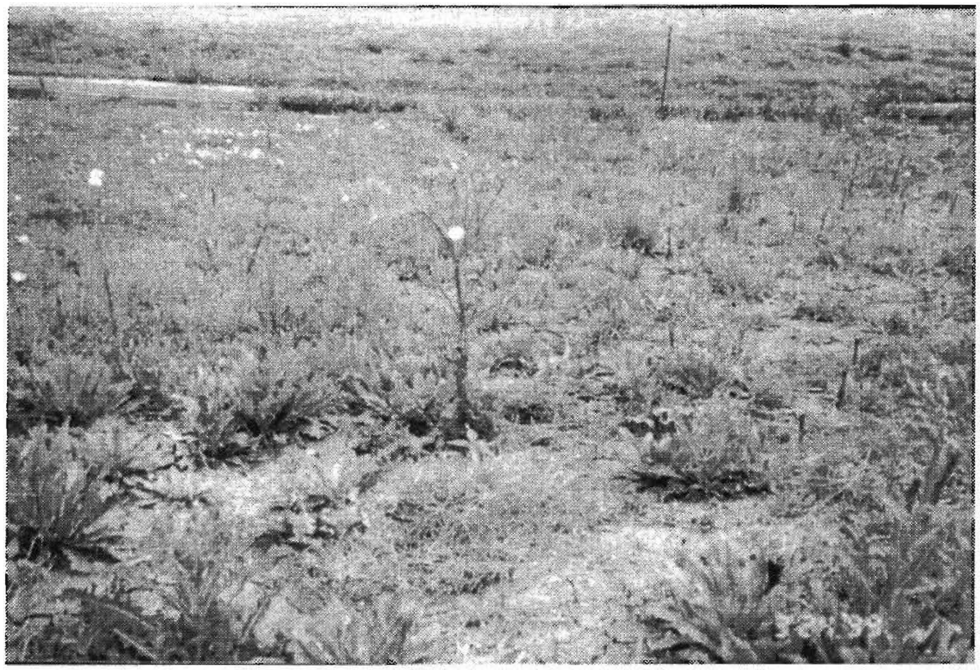

Wildflowers

Figure A-1. Sand Plots (continued).


Bermudagrass


Crownvetch

Figure A-2. Clay Plots.


Native grass and forbs

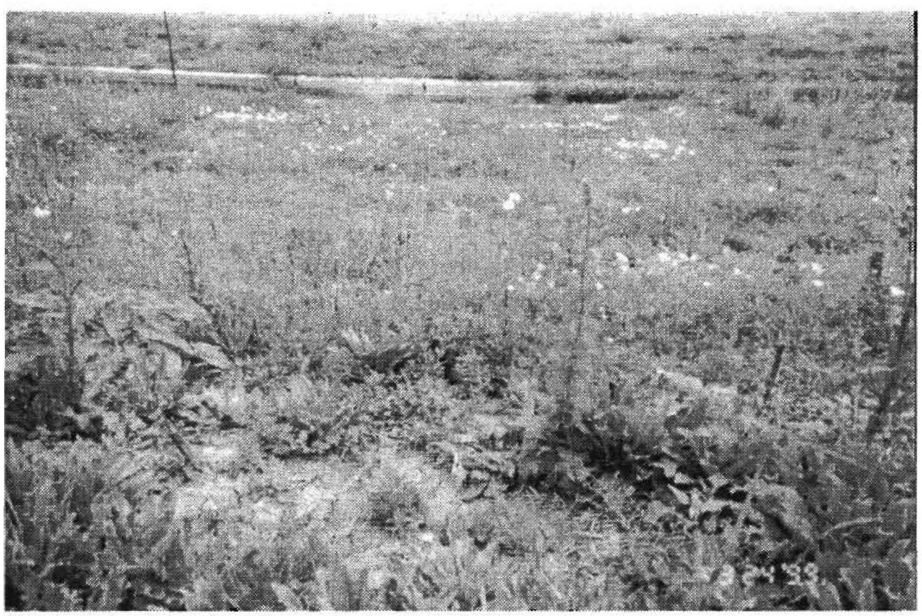

Native grass

Figure A-2. Clay Plots (continued).


Wildflowers

Figure A-2. Clay Plots (continued).

Appendix B

Procedures and Evaluation Criteria for Erosion-Control Blankets, Flexible Channel Lining Materials, and Hydraulically-Applied Mulch Products

PROCEDURES AND EVALUATION CRITERIA FOR EROSION-CONTROL BLANKETS, FLEXIBLE CHANNEL LINING MATERIALS, AND HYDRAULICALLY-APPLIED MULCH PRODUCTS

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Erosion Control Material Evaluation

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The Texas A&M University System
College Station, Texas 77843-3135

IMPLEMENTATION STATEMENT

This document provides the basic parameters of the research program conducted by the Texas Transportation Institute to meet the research objectives and goals set forth by the Texas Department of Transportation. Periodic updates will be written to keep current with the research program.

The findings from this work will have immediate application in the planning, design, construction, and maintenance of sites requiring erosion control and vegetation establishment. Methods used to evaluate the field performance of erosion-control blankets (soil retention blankets) in two different classes (Slope Protection and Flexible Channel Liners) two different slopes and two different soil types should provide engineers and landscape architects with current performance characteristics related to the highway environment. Field performance data on the performance of hydraulically-applied mulches, two different soil types, and a single slope condition will provide current information on vegetation establishment techniques.

Results from the study are used by TxDOT to produce an Approved Material List required by the standard specifications for the construction of highways. An important benefit is an annually updated listing of the erosion control materials and mulches which meet and exceed the minimum performance standards. This should encourage competitive marketing within the State of Texas. Research performed at this facility will continue to keep TxDOT as a pro-active leader in highway-related environmental concerns.

DISCLAIMER

AUTHOR'S DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes.

PATENT DISCLAIMER

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States of America or any foreign country.

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SUMMARY

Storm water management for large-scale construction and maintenance operations relies upon several factors including: proper design and application of erosion principles; planning and coordination of land disturbing activities; and the application of erosion and sediment control products, when necessary. Responsible transportation agencies, such as the Texas Department of Transportation (TxDOT), who try to meet stringent federal and state regulations need data which support recommendations for products which will help meet these requirements.

Within the erosion industry, limited resources were available for current performance data related to the highway environment. Independent laboratories supplied manufacturers with product characteristics such as strength, UV resistance, and fiber qualities; but they did not focus on important factors such as soil-fabric interaction and installation techniques. Most other erosion and sediment control related research came from the agriculture discipline and associated agencies such as the Soil Conservation Service. Physical and functional characteristics of agricultural systems do not provide an adequate resource or comparison for engineered systems like the highway system. TxDOT desired to create a formal testing facility through which products could be evaluated to help the Department meet its goals.

In concert with TxDOT, the Texas Transportation Institute (TTI) researchers developed methodologies and procedures to document the performance for evaluating the most pressing needs of erosion-control blankets, flexible channel liners, and hydraulically-applied mulches. At the TTI proving grounds, a research facility known as the Hydraulics and Erosion Control Laboratory was designed and constructed to meet the long-term needs of the Department. Since 1991, TTI has coordinated the erosion control research program and conducted the studies at this facility. While basic methodologies remain unchanged, the procedures have been altered to better meet TxDOT's needs.

Results produced from this work are provided to TxDOT who produces the Approved Materials List for standard specification Item 169 - Soil Retention Blanket. Approximately twenty erosion-control blankets, ten mulches, and nine channel liners have been approved for use by the Department. The researchers continue to conduct their research for the Department with each evaluation cycle synchronized around the growing season (March - November).

This document is a written research program guide developed to communicate the research objectives, study development, participation procedures, and evaluation procedures used by the researchers and TxDOT. Future modifications to this document may be necessary.

INTRODUCTION

The erosion control industry and the Federal Highway Administration (FHWA) recognize a variety of generic materials used as erosion control protection. Erosion-control blankets that met the Texas Department of Transportation's (TxDOT) standard specifications for the past twenty years consisted of two products. The specification and bidding process did not provide for material selection other than these two products because of the material-based requirements. In response to this practice, TxDOT has shifted from a material-type specification for hydraulically-applied mulches (termed "cellulose fiber mulches" within Standard Specification Item 164 *Seeding For Erosion Control*), and for roll-type erosion control mats (termed "soil retention blankets" within Standard Specification Item 169 *Soil Retention Blanket*,) into an "approved product"-type specification. The approved product list (APL) is based upon the demonstrated field performance of products tested through TxDOT's formal evaluation program.

TxDOT's current specifications for cellulose fiber mulches (See Appendix A), and for soil retention blankets (See Appendix B), do not include any of the typical ASTM-type material requirements, such as weight, tensile strength, elongation, water-holding capacity, pH, etc.

TxDOT has defined critical performance measures and has established minimum performance standards for selected erosion control and revegetation products which are promoted by industry for use within TxDOT's construction and/or maintenance activities. In cooperation with the Texas Transportation Institute (TTI) Environmental Management Program, TxDOT has funded the construction and annual operation of an extensive, outdoor, field-testing facility designed to collect performance data which may be used by TxDOT to produce and maintain a defensible APL. Laboratory tests and field observations indicate there is great variation in strength, durability, soil-blanket interaction and vegetation response between generic material classifications and between manufactured brands of similar materials. Soil-fabric interaction, vegetation establishment, and installation methods are critical factors to consider in figuring out field performance characteristics.

With respect to soil retention blankets, TxDOT felt that the critical performance factors were:

- how well does the product protect the seedbed or the geometry of a channel from the loss of sediment; and
- how well does the product promote the establishment of a warm-season, perennial vegetative cover over a single March - November growing season.

Further, TxDOT recognized that retention blankets should be divided into two distinct types:

- products designed for normal overland flows associated with typical embankment protection; and
- products designed for concentrated water flows associated with drainage channels.

With respect to cellulose fiber mulches, TxDOT felt that sediment loss was not a critical performance factor, in that TxDOT recommends limiting the use of these products to slopes of 1:3 or flatter. The single performance factor adopted is the amount of warm-season, perennial vegetation produced within a single March - November growing season. In the case of soil retention blankets, products must meet the minimum performance standards for both of the critical performance measures, vegetation establishment and sediment loss. Failure within either of the measures will automatically reject the product from being placed upon the APL.

Through formal, field performance testing at the TxDOT/TTI Hydraulics and Erosion Control Laboratory (HECL), TxDOT has adopted minimum performance standards for each application. In order for a product to be placed upon TxDOT's APL, it must meet (or exceed) the currently adopted performance standards associated with that application.

TxDOT and TTI developed evaluation methodologies to document the performance of erosion-control blankets in varying slope applications, flexible channel liners subjected to varying shear stresses, and hydraulically-applied mulches for vegetation establishment. The methods and procedures, are acceptable test methods to determine field performance within the highway rights-of-way. Subsequent work included the design and construction of a research proving facility. The HECL, a state-of-the-art facility, was constructed during two consecutive years and is a unique laboratory dedicated to transportation research. Today, the facility covers 8.5 ha with an earthen fill embankment that is approximately 300 linear meters by 6.7 meters, vertically, ten at-grade channels, two water reservoirs, pumping stations, rainfall simulators, weather station, and various instrumentation.

Since 1991, the researchers conduct annual evaluations on erosion control products at the HECL. Private industry, TxDOT, and TTI cooperatively work together to further this important area of environmental research and development. The purpose of this document is to provide general background on the adopted methodology, describe the Hydraulics and Erosion Control Laboratory facility, and to set forth the research program for performance evaluation of erosion-control blankets, hydraulically-applied mulches, and flexible channel liners.

INDUSTRY ADVISORY COUNCIL

The primary objective of this research program is to develop a defensible Approved Material list for use in TxDOT's construction and maintenance activities and to provide manufacturers of erosion control and vegetation establishment products with a fair program through which their individual products may be evaluated for use by the Texas Department of Transportation. To accomplish this objective, industry participation is necessary. To provide a vehicle for the desired industry coordination, an Industry Advisory Council (IAC) has been formed.

The following criteria have been established through the work of past advisory members:

- Membership of the council consists of one representative from each participating manufacturer, one representative from TxDOT, one representative from TTI, and one representative from the International Erosion Control Association (IECA). TTI solicits representatives before each evaluation cycle.

- A Technical Subcommittee formed for the channel lining research consists of three manufacturing representatives selected by the IAC.

- Representatives of the IAC call meetings to discuss procedures, results, or other items of business.

- All statistical analysis reports will be performed and distributed by TxDOT except for evaluation procedures and final reports. Deliverables such as the final report, video footage, slides, or photographs may be purchased for the cost of reproduction through the Texas Transportation Institute.

- Changes to procedures will be handled through an open meeting, fax, E-mail, or other appropriate communication method by discussion and majority opinion. TTI and TxDOT will make every effort to accommodate the recommendations made by the advisory group. Final decision with respect to the activities and operation of the research program and laboratory will remain with TxDOT.

STUDY OBJECTIVES

OBJECTIVES

The objectives for the research program at the TxDOT/TTI Hydraulics and Erosion Control Laboratory are as follows:

- To collect data which will enable TxDOT to produce a defensible Approved Material List, for flexible channel linings, soil retention blankets, and hydraulically-applied mulches.

- To establish a timely and fair evaluation program, through which new erosion control products developed by industry may be evaluated for possible use in TxDOT's construction and maintenance activities.

METHODOLOGY

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

EROSION-CONTROL BLANKET STUDY

For the erosion control products on a sloped condition, there are treatment plots and control of two replicates, one for each soil type (sandy, 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 measure in place. Treatment plot data, relative to each product's sediment retention performance and apparent vegetative density coverage with respect to slope's soil type and slope condition, is collected and provided to TxDOT for statistical analysis.

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) for the duration of the test cycle.

- In cohesive soils (clay) and a sloped condition, sediment loss should be no greater than 0.34 kg/10 m^2 for the duration of the test cycle.

- In non-cohesive soils (sandy) and slopes steeper than 1:3, sediment loss should be no greater than 26.84 kg/10 m^2 for the duration of the test cycle.

- In non-cohesive soils (sandy) and slopes flatter than 1:3, sediment loss should be no greater than 12.20 kg/10 m^2 for the duration of the test cycle.

Vegetation establishment criteria will be as follows:

- Acceptable erosion-control blankets should promote significantly greater vegetative cover on the protected treatment area as compared to 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, vegetative density should reach a minimum coverage of 80% for the duration of the test cycle.

- In non-cohesive soils (sandy) and sloped conditions, vegetative density should reach a minimum coverage of 70% for the duration of the test cycle.

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 for the duration of the test cycle 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 for the duration of the test cycle.

Study Development

Before the implementation of the research program, TxDOT's standard specification for soil retention blankets was a material type specification. This specification technically excluded products that did not meet this strict material specification. In response to this practice, TxDOT elected to establish a timely, fair, but formal testing program to select erosion control products based upon their performance.

Limited quantitative data existed for erosion from highway rights-of-way during the soil stabilization process, which occurs during construction (temporary or permanent vegetation establishment), or problems that developed from routine maintenance operations. The vast majority of existing research on effective erosion control methods came from agricultural, range, and forest management studies. Applying methods generated from these sources into an engineered system with much different physical and operational constraints does not always work well.

Governing bodies continue to set stringent requirements for controlling erosion and sediment during highway construction or other large-scale, land disturbing activities. A lack of industry standards and testing methods further complicates the issue of product reliability and performance characteristics. This places an increasing burden for state transportation agencies to implement more effective controls that are cost-effective to the taxpaying citizens. These factors combined, led to the development of the research program and the Hydraulics and Erosion Control Laboratory construction.

As stated earlier, the erosion industry and the Federal Highway Administration recognize a variety of generic materials used for erosion and sediment protection (5). Existing laboratory tests used to describe standard physical properties, do not adequately describe or test field performance. Soil-fabric interaction, vegetation establishment, and installation methods are critical factors to consider in determining product performance characteristics (10). A facility or laboratory that could simulate the highway environment would be beneficial in providing this information to TxDOT.

Previous studies sponsored by TxDOT used portions of the highway rights-of-way for collecting this data. Many subsequent problems occurred that would invalidate or compromise the resulting data. Problems cited included, but are not limited to, the following: roadside fire, herbicide spraying, mowing and equipment damage, plowing, unequal water distribution, and vehicle-induced damage. TxDOT elected to establish a full scale facility to conduct controlled tests in an environment which closely simulated a highway environment.

Rainfall Simulation

To maintain uniformity throughout a multi-year testing program, all results are based on artificially generated rainfall. 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 any unusual or mitigating events are noted and considered in the analysis.

Starting within two weeks after installation, each product is subjected to a series of six (6) simulated rainfall events. Each product receives two each, ten-minute duration repetitions of the following design storms:

1-Year = 30.2 mm/hr;
2-Year = 145.5 mm/hr; and
5-Year = 183.6 mm/hr.

Sediment is collected, dried and weighed after each individual rainfall event. The average sediment loss, expressed in kilograms per 10 square meters, collected in the six individual rainfall events is compared to the adopted maximum sediment loss standard to determine acceptance or rejection.

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 reaches 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:

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

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 blankets study by computing the values of *I* for the thirty-six county areas based upon a short storm duration. The researchers assumed that more damage occurs by the impacts of rain splash in a steep slope situation (1:3 or greater) subjected to a short duration, high probability design storms than from a moderate slope situation (1:4 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. 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 of pure live seed per hectare:

- Green Sprangletop 0.7 kg/ha
- Bermudagrass 0.9 kg/ha
- Little Bluestem 1.2 kg/ha
- Indiangrass (Lometa) 1.7 kg/ha
- K-R Bluestem 0.8 kg/ha
- Switchgrass (Alamo) 1.3 kg/ha

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

- Green Sprangletop 1.2 kg/ha
- Bermudagrass 1.7 kg/ha
- Bahiagrass (Pensacola) 7.5 kg/ha

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. Each product is sampled for vegetation density production over the March - November growing season. The initial sample is normally taken on or about the fourth week following product installation. The final sample is normally taken during November. The vegetative density production which has been achieved by the final sampling round only, is compared to the adopted minimum vegetative density standard to determine acceptance or rejection The researcher records the percentage of vegetation for each analyzed image.

The sediment retention and vegetative density data is furnished to TxDOT for analysis using the Statistical Analysis System, SAS; 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.

HYDRAULICALLY-APPLIED MULCH STUDY

The Texas Department of Transportation hydraulically-applied 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). TxDOT elected to test this premise by recording vegetative density achieved within both application methods. Sufficient data has been collected regarding the significance of vegetative density production between these two application techniques and TxDOT now recommends the one-step hydraulically-applied mulch application.

Vegetation establishment criteria is as follows:

- Acceptable hydraulically-applied mulch products should promote significantly greater vegetative cover on the protected treatment area as compared to the bare ground (Control).
- Acceptable hydraulically-applied mulches should promote a vegetative cover for the duration of the test cycle by protecting the seed bed from the impacts of rain splash.

- In cohesive soils (clay) and sloped conditions, final vegetative density must reach a minimum coverage of 50% during the test cycle.

- In non-cohesive soils (sandy) and sloped conditions, final vegetative density must reach a minimum coverage of 50% during the test cycle.

Currently, this method of application is repeated for each product: (1) A one-step process where seed, fertilizer and mulch are applied to the plot in a single application.

Cellulose fiber mulch products are not subjected to simulated rainfall events, as TxDOT feels they should not be used to protect a slope to the degree capable by a soil retention blanket. Each treatment, however, is sprinkle irrigated to provide sufficient moisture for vegetative growth. For the first three months, water is applied evenly to each plot to provide a minimum of 25 mm of water per month per plot. After the initial three month period, no supplemental water is provided except in the event of a drought in excess of 30 days. Vegetation density data is recorded throughout the duration of the March - November growing season. The vegetation density achieved by the final measurement round is compared to the adopted minimum vegetation density standard to determine acceptance or rejection. The vegetative density data are furnished to TxDOT for analysis using statistically analyzed by the Statistical Analysis System, SAS; 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 of one replicate on a cohesive (clay) soil in either a 7% or 3% centerline 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. Material performance will be documented but no statistical data will be included in the analysis.

Study Development

The first year for flexible channel liner trials was in 1994. The original adopted procedures with a few minor alterations governed the study methods. Adjustments were expected since this type of proving (large-scale, open channels) has not been replicated in many laboratories around the country. A brief discussion of the procedure development is included for reference.

Clearly, from the literature (Chow, Chen, and Cotton, FHWA Hydraulic Engineering Circular Numbers 3,11,14,15) the maximum permissible tractive force theory is the favored method for making design decisions and selecting flexible channel lining materials (2,3). The researchers developed field performance evaluation procedures based upon these findings and designed laboratory facilities to accomplish the research objectives.

In the laboratory open-channel design, the researchers selected a trapezoidal cross-section. Common practice among most transportation agencies is to construct a trapezoidal cross-section channel for unlined earth channels. The side slopes of this profile provide better stability versus other artificial channels. In addition, the hydraulic properties of an artificial channel may be designed to meet specific requirements or controlled to an extent needed for testing purposes (3). Therefore, the application of hydraulic theories to artificial channels will produce results fairly close to actual conditions. Reasonable accuracy may be achieved for practical design purposes.

In the facility design, the researchers assumed that peak discharge rate, Q_n, estimated with an accepted method for estimating runoff is acceptable. Based upon this theory, the channel could be sized to achieve a desired depth of flow. Uniform flow characteristics described by Manning's equation would depend on the hydraulic radius of the channel (R), the channel slope (*S*), velocity (*V*), flow rate (*Q*), flow cross-sectional area normal to the direction of flow (*A*), and the value of Manning's *n* as shown in the formula below.

$$Q_n=(\frac{1.486}{n})R^{2/3}S^{1/2}A$$

where (continuity equation): $Q = Va$

and:

$$V=(\frac{1.486}{n})R^{2/3}S^{1/2}$$

The hydraulic radius and slope controlled by having a fixed channel geometry is favorable. However, it is unlikely that all brands of flexible channel liners within a given generic material class will have the same roughness coefficient or "*n*" values. The depth of flow and resultant tractive force, τ_d, cannot be determined or held constant for all materials in the same generic classification. The ability to determine the value of Manning's *n* for each of the research materials is critical to making fair and valid comparisons between brands and their resultant performance.

Therefore, the researchers determine Manning's *n* value before the evaluation cycle in a flume located on the Texas A&M University campus. The development of the procedures was based on a theory by Chow (3) and the *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains,* FHWA-TS-84-204 (1). The Industry Advisory Council, Technical Subcommittee approved these procedures in 1994. A range of Manning's *n* values is recorded from the flume trials that include minimum, normal, and maximum roughness coefficients. The researchers use these values in the field trials to estimate the roughness coefficient prior to a simulated flow.

With the Manning's *n* values available, the researchers compute flow requirements for each material based upon their normal roughness coefficient value adjusted for the effects of compacted clay soil and irregularities. The researchers are then able to simulate flow conditions that produce the desired shear stress for each individual flexible channel liner. Comparisons of performance related to maximum permissible tractive force are possible with these procedures and methodology.

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 the Federal Highway Administration's *Hydraulic Engineering Circular No. 15* or *HEC 15* (2), the maximum recommended shear stress values for flexible channel liners were 96 Pascal (2 lb/sf). The research work accomplished at TTI continues the work cited in *HEC 15*. Maximum working shear stresses are approximately 192 Pascal (4 lb/sf) in the 3% sloped channels and 383 Pascal (8 lb/sf) 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.

Following installation, each product experiences a 90-day *rest* period to promote the initial growth of vegetation prior to initiating a series of increasing, shear-stress flows. After the 90-day *rest* period, a series of simulated flows begin.

Flow simulations conducted to emulate field conditions after a short duration, micro-watershed area, drainage ditch flow is the primary data generator. Prior to each flow, channels are pre-wetted to moisten the channel surface. Based upon the determined Manning's *n*, and the known geometry of the channel, the depth of water is controlled to initiate a series of increasing flows, starting at 96 Pascal, and continuing on a 48 Pascal increment. Each flow is repeated twice and continues for twenty (20) minutes after a stable flow has been achieved.

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. The water level rises until the desired depth is achieved. Velocity and depth measurements are taken at different locations along the channel during the flow. During the test flows, measurements are taken approximately every four minutes to determine the amount of soil displaced by the flow. Further, data is collected regarding product movement (loss of intimate soil contact.) The average soil displacement exhibited within the channel is compared to the adopted maximum soil displacement standard to determine acceptance or rejection.

All channels are also sampled to determine the growth of vegetation over a single, March-November growing season. Similar to the embankment, channels are initially sampled at the end of the 90-day resting period for vegetation production. The final density sample is normally taken during November. The vegetation density achieved within the channel by the final sampling is compared to the adopted minimum vegetation density standard to determine acceptance or rejection.

Vegetative 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. 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 of pure live seed per hectare:

- Green Sprangletop 0.7 kg/ha
- Bermudagrass 0.9 kg/ha
- Little Bluestem 1.2 kg/ha
- Indiangrass (Lometa) 1.7 kg/ha
- K-R Bluestem 0.8 kg/ha
- Switchgrass (Alamo) 1.3 kg/ha

The sediment retention and vegetative density data are furnished to TxDOT for analysis using the Statistical Analysis System, SAS; 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.

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 west of Bryan, Texas. The laboratory site 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 located 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 in 1990. The researchers built an earthen fill embankment constructed with density control as the compaction method. Construction was governed by the 1982 *Texas State Department of Highways and Public Transportation Standard Specifications for Construction of Highways, Streets and Bridges* (9). Density control method in accordance with 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 vertical height, 267 m in length, 1:2 sloped condition on the west side, and 1:3 sloped condition on the east side. Treatment plots are 6.2 m across and 15 m or 21 m lengthwise, depending upon the slope condition. The embankment design provides a total of seventy treatment plots. 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 hydraulically-applied 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.

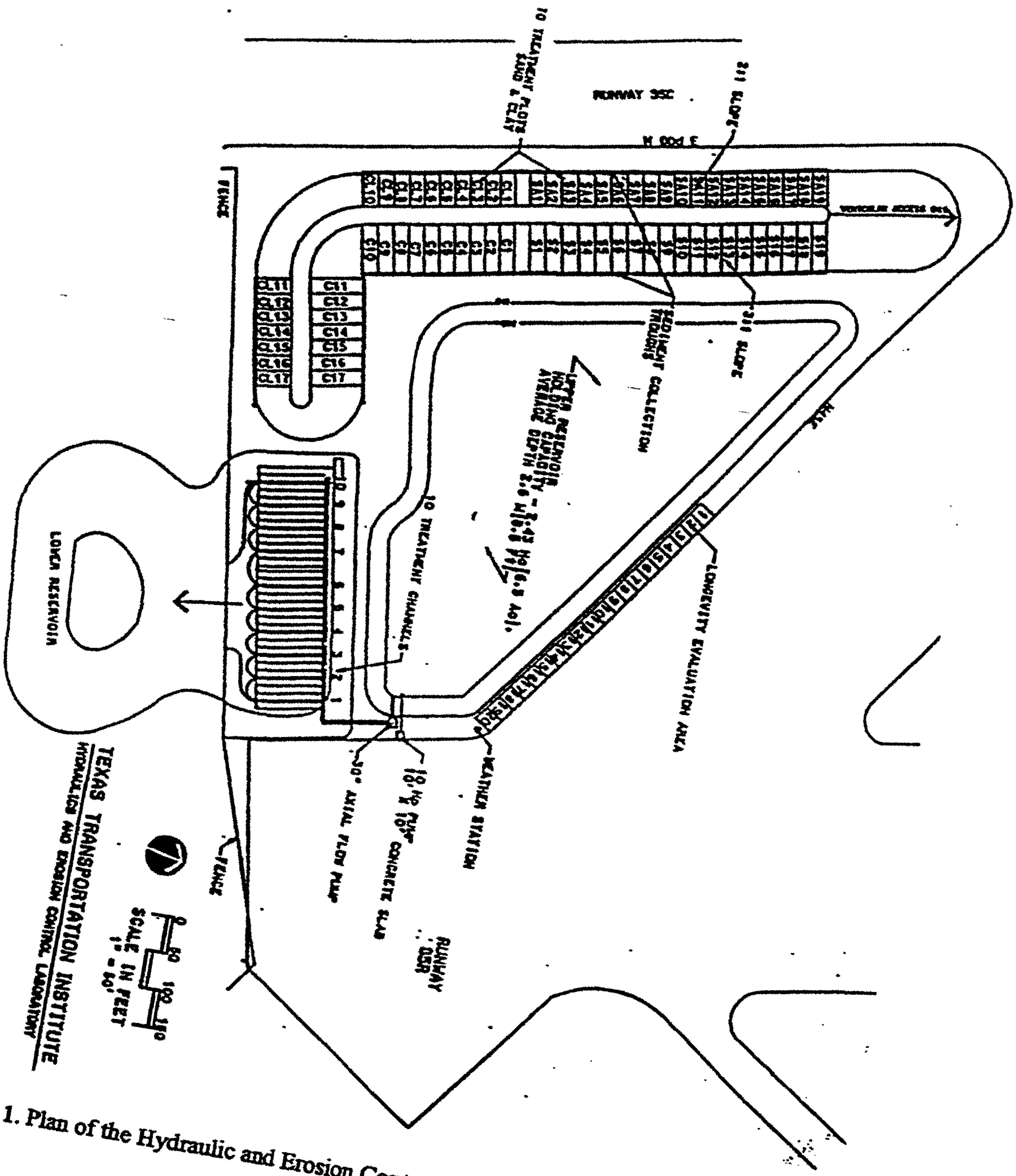

Figure 1. Plan of the Hydraulic and Erosion Control Laboratory

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 by 46 cm wide by 15 cm depth. The flow line is "V" shaped giving the box a holding capacity of approximately 418 liters. Removable plywood dividers separate the boxes (see Figure 2).

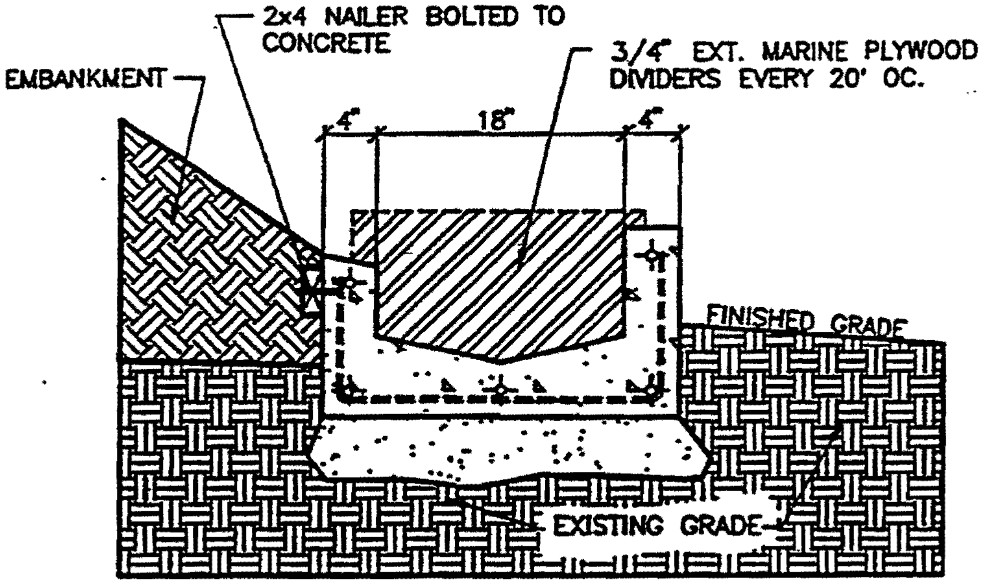

Figure 2. Section through Sediment Collection Trough

Two reservoirs created as the result of the embankment and channel construction have a vertical elevation difference of approximately 1-1/2 m. The upper reservoir surface area is 2.43 ha. 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 apart mounted on a steel frame and set approximately 0.60 meters 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 to provide greater drop velocity. Each unit may provide 25 - 300 mm 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. Each open channel has a trapezoidal cross section that includes a 0.30 m bottom, 1:1 side slopes, and a typical 0.91 m depth beginning 4.5 m downstream of the channel release. Total length of the test channel section equals 26 m 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.

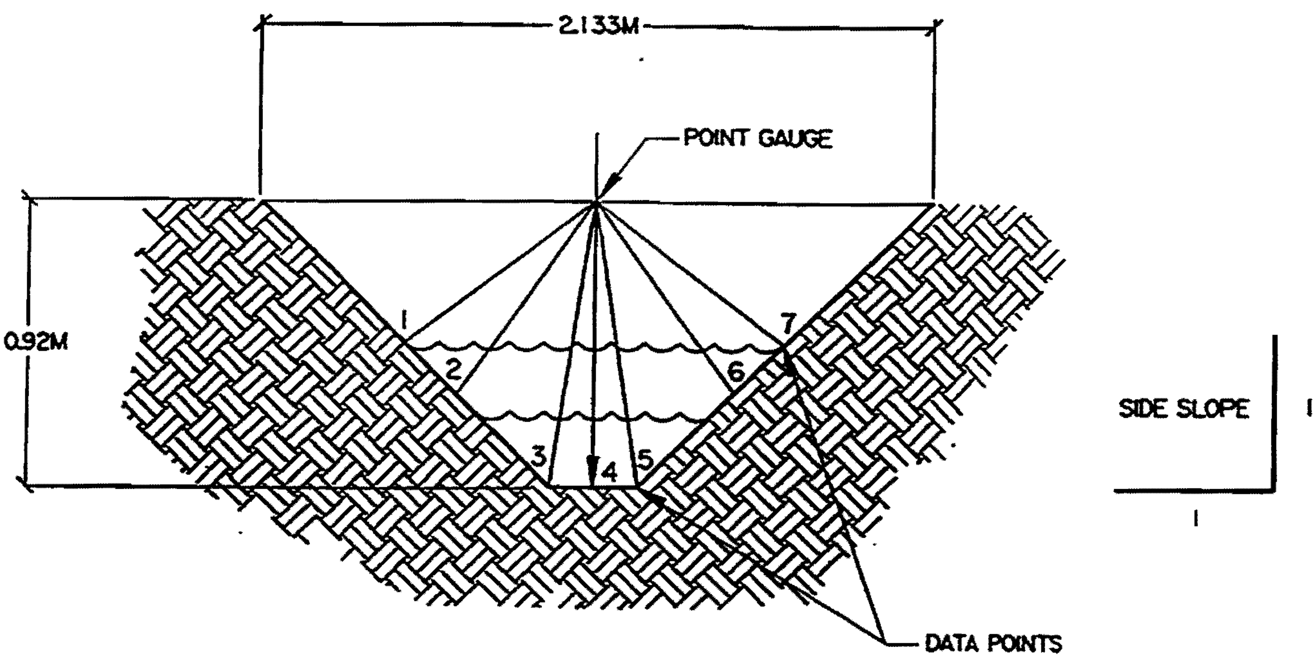

Figure 3. Treatment Channel and Station Locations.

EROSION CONTROL PRODUCT SELECTION

SELECTION OF PRODUCTS FOR EROSION CONTROL EVALUATION

Manufacturers interested in participating in the TxDOT/TTI erosion-control product evaluations for erosion-control blankets (soil retention blankets), hydraulically-applied mulches, or flexible channel liners may contact TTI at any time during the year. If a waiting list is necessary for any of the product evaluations due to full laboratory capacity, the list shall work in the following manner to facilitate fair and timely product evaluations for each manufacturer:

- **On going process.** The principal investigator, TTI representative, is responsible for mailing a package of information to the manufacturer once TTI is made aware of the manufacturer's interest in the research program. TTI refers to this package as the "Request for Performance Evaluation". Basic information and complete literature on the product, physical samples, manufacturer and distributor addresses, private label certification, contact person(s) name, and IAC representative is necessary for TTI to enter the manufacturer as a participant. The manufacturer is responsible for returning the package to TTI. The date *postmarked* on the **COMPLETED PACKAGE** or on the faxed entry forms is the entry date for the waiting list (if necessary). Personal memoranda or letters to the TTI facility manager will **NOT** be utilized to determine a product's position on the waiting list.

- **January through March 1 Participation Events.** TxDOT will notify participants regarding their performance within the previous evaluation cycle. In the event that the product has failed to meet TxDOT's performance standards, the participant may elect to retest the identical product within the next evaluation cycle. The participant shall confirm this decision by notifying the Hydraulic and Erosion Control Lab facilities manager by the date established by TTI. In the event the participant elects not to retest the identical product, and requests evaluation of either a different product, the participant will be placed upon the waiting list and slotted into the first available evaluation cycle. A test slot will be reserved for a product that has failed TxDOT's performance standards only once.

- **March 1 through installation.** TTI will begin product installations upon the final treatment plot preparation. Installation scheduling will be coordinated with TTI and the manufacturer's designated contact person. Manufacturers have three options for their product installation and shall notify TTI as to which option they have chosen.

TxDOT or TTI do not charge a testing or evaluation fee. Participants are given the following three installation options:

Option 1. The manufacturer donates the product(s) for evaluation and also the labor required to install the product. *

Option 2. The manufacturer donates the product(s) for evaluation and contracts the labor and equipment required to install the product with TTI, Environmental Management Program. *

Option 3. Manufacturer contracts the products purchased and installation with TTI, Environmental Management Program. *

*The Hydraulics and Erosion Control Laboratory manager will supervise and/or approve the installation process for all three options to provide continuity with compliance to the manufacturer's published literature and guidelines.

Rate of payment for labor is figured on an hourly basis depending upon the individual employee's rate. Cost for products and installation materials will be a direct cost reimbursable to TTI. TTI will provide a schedule of hourly rates as requested by the manufacturer. TTI will not prepare cost estimates for product installation.

Costs associated with the installation process include the following items. Table A shows a cost breakdown and assignment of responsible parties depending upon the installation options detailed above.

Table A. Installation Costs.

Item	Responsible Party	Alternative
Treatment plot preparation: Remove products after evaluation Earthwork (rough grade) Soil sterilization	 TxDOT funds TxDOT funds TxDOT funds	
Fine grading	Option 1 - Manufacturer**	Option 2,3 - TTI
Hydro seeding application Seed/fertilizer mixture	TxDOT funds	
Purchase products, staples, wood stakes, etc.	Option 1,2 - Manufacturer**	Option 3 - TTI
Install product (labor)	Option 1 - Manufacturer**	Option 2,3 - TTI
Clean up	Option 1 - Manufacturer**	Option 2,3 - TTI

**The manufacturer will be required to complete the listed items below before performing any work at the HECL as a requirement of the Texas A&M University System and the Texas Transportation Institute.

Requirements for non-Texas A&M University System (TAMUS) entities:

1) Show a **Certificate of Worker's Compensation** to the TTI representative who is the HECL facility manager. The certificate shall show who is covered and that the company is covered.

2) Show proof of **General Liability** coverage policy to the TTI representative (HECL manager). The minimum limits required are the following:

Bodily injury -	$300,000 each occurrence
	$500,000 aggregate
Property damage -	$100,000 each occurrence
	$300,000 aggregate

3) Show **Employer's Liability** that will cover items not covered by the Worker's Compensation.

4) An authorized signature(s) on the **TTI Release Agreement Form** releasing the Texas Transportation Institute for responsibility in case of accident or damages.

5) No bonding required.

Based upon space availability, TTI will offer an evaluation slot to new participants in the order of the postmarked date shown on the **completed** "Request for Performance Evaluation" packet. In the event that a participant fails to commit to testing by the deadline established by TTI, the next product on the waiting list will be offered the evaluation slot.

TTI and TxDOT reserve the right to restrict the number of products any single company, manufacturer or distributor may evaluate during any given evaluation cycle.

INSTALLATION OF SELECTED PRODUCTS FOR EVALUATION

For the erosion control research program, each erosion-control blanket or flexible channel liner product shall be installed in the following manner:

- Installation of the selected erosion control materials will be done in strict accordance with the manufacturer's published technical materials and recommendations.

- All work is accomplished under the supervision of the TTI representative (HECL facility manager).

- Manufacturer's Technical Representatives will be invited to inspect the installation to satisfy themselves that all published recommendations and installation requirements have been met prior to initiating formal evaluation procedures. It will be the responsibility of the manufacturers to confirm their installation schedule.

- If any problems occur during the installation, the Manufacturer's Representative must notify the TTI representative, HECL facility manager, in writing, within twenty-four hours of the site visit. The HECL facility manager will be the final authority as to whether the adjustments requested by the manufacturer are indeed oversights and that the changes requested are consistent with the manufacturer's published technical materials.

For the erosion control research program, each hydraulically-applied mulch product shall be installed in the following manner:

- Installation of the selected hydraulically-applied mulch materials will be done in strict accordance with the Texas Department of Transportation's Item 164.3, *Seeding for Erosion Control, Construction Methods*. The rate of application shall remain consistent with TxDOT's specifications in the current version of the TxDOT Standard Specifications for Construction of Highways, Streets, and Bridges.

- All work will be accomplished under the supervision of the TTI representative (HECL facility manager).

- Manufacturer's Technical Representatives will be invited to inspect the installation to satisfy themselves that all installation requirements have been met before initiating formal evaluation procedures. It will be the responsibility of the manufacturers to confirm their installation schedule.

- If any problems are noted in the installation, the Manufacturer's Representative must notify the TTI representative, HECL facility manager, in writing, within twenty-four hours of the site visit. The HECL facility manage will be the final authority about whether the adjustments requested by the manufacturer are oversights and that the changes requested are consistent with the standard specifications of TxDOT.

APPROVAL BY EXTENSION

For Class 1 "Slope Protection Products", if a product is evaluated on the severe-slope conditions only (Types C and D), and successfully meets the current minimum performance standards established by TxDOT for the particular application, the product will also be included as an approved product (by extension) on the associated, less-severe conditions as well. For example, if a product is evaluated on both Types C and D slopes (Slopes Steeper than 1:3 - Clay and Sand soils, respectively), and successfully meets the performance standards for Type C (Slopes Steeper than 1:3 - Clay Soils), the product will be added by extension to the approved product list for Type A (Slopes 1:3 or Flatter - Clay Soils).

Conversely, if a product is evaluated on the less-severe slope conditions only (Types A and B), the product will not be added to the severe-slope conditions as an approved equal regardless of the performance of the material.

If a product elects to test on each of the four available Class 1 applications, the product's performance, as documented within each individual application shall determine placement on the approved product list, and approval by extension shall not apply.

RELEASE OF PERFORMANCE DATA

With the exception of the final research report as published by TTI, all performance data will be released by TxDOT only. Data will only be released at the end of a complete evaluation cycle. As the annual operation of the HECL is funded with state funds, all performance data will be released regardless of the performance of any individual product.

Performance data for all products evaluated to date are available from TxDOT without charge to any interested party. Final research reports, as published by TTI are available for a fee through the Texas Transportation Institute Information and Technology Exchange Center.

RETEST PROCEDURES

Class 1 "Slope Protection" and Cellulose Fiber Mulch Products

If, after the initial test at the HECL, a product fails to meet the established minimum performance standards for any application, as established by TxDOT, TTI will reserve an evaluation slot within the next available evaluation cycle for that product. The participant must commit to retesting the identical product by the deadline established by TTI. In the event the participant fails to confirm retesting by the deadline established by TTI, the evaluation slot will be offered to the next product on the waiting list.

In the event a product is retested at the HECL and again fails to meet the established minimum performance standards for any application as established by TxDOT, an evaluation plot will not be guaranteed the product during the next available evaluation cycle. The product representative must complete a new "Request for Performance Evaluation" packet and the product will be scheduled for retesting according to the postmark date on the completed "Request for Performance Evaluation" and the procedures established within the normal waiting list process.

Class 2 "Flexible Channel Liner" Products

Due to the limited number of evaluation channels available at the HECL and the number of individual products currently requesting Class 2 applications evaluation, a product cannot be guaranteed an evaluation slot within the next available evaluation cycle in the event that product fails to meet any of the established minimum performance standards established by TxDOT.

The product representative must complete and forward to TTI, a new "Request for Performance Evaluation" packet if they desire to retest the identical product. The product will be scheduled for retesting according to the postmark date on the completed "Request for Performance Evaluation" packet, and the procedures established within the normal waiting list process.

REVISION OF MINIMUM PERFORMANCE STANDARDS
TxDOT reserves the right to revise the minimum performance standards for the APL as produced through the HECL.

In the event that a product's performance no longer meets the revised minimum performance standards, the product will be notified by TxDOT and provided the opportunity to retest the product within the next available evaluation cycle as determined by TxDOT.

The product will remain on the APL pending results of the next available evaluation cycle. In the event that the product fails to meet the revised standards at the end of the evaluation cycle retest, the product will be removed from the APL during the next scheduled revision. In the event that the product's performance meets the newly adopted minimum performance standards, the product will remain on the Approved Material List.

In the event that the participant fails to commit to retesting the product within the next available evaluation cycle by the deadline established by TTI, the product will be removed from the APL during the next scheduled revision.

CONTRACTOR'S OPTION
The APL will be maintained by TxDOT according to the Class and Type as may be appropriate for any given product. It is the Contractor's option to use any of the products provided that the product is listed by brand name on the current APL for the Class and Type specified, and provided the Contractor installs the product in strict accordance with TxDOT specifications and the manufacturer's installation literature.

PRIVATE LABELING
If the original manufacturer of a product tested and approved at the HECL will, to TxDOT's satisfaction, certify that the brand name tested is also distributed under other trade names (private labels), TxDOT will include those private label names on the APL for the appropriate Class and Type. Addition and/or revision of the APL due to private labels will only be made by TxDOT during the normally scheduled revision of the APL.

APPROVED PRODUCT LIST

Based upon the data collected through the HECL, TxDOT will establish and maintain a current approved product list. New products which are placed on the approved product list will become eligible for use by Contractors after statewide distribution of the official approved product list, normally issued in the form of a special provision to Item 169 *Soil Retention Blanket*. This event typically occurs during the May or June following the close of the previous March - November evaluation cycle.

Copies of the current approved material list for soil retention blankets, may be requested through the Director, Construction and Maintenance Division , Attn.: Mr. Paul Northcutt, 125 East 11th Street, Austin, TX 78701-2483.

EROSION-CONTROL BLANKET PROCEDURES

SOIL PREPARATION

All sloped treatment plots are cleared of vegetation, repaired with stockpiled or dug soil, and brought back to a reasonably uniform grade before installation. The soil is left in a loose condition and graded with a chain link drag. Each treatment plot is fumigated with a soil sterilant as recommended by the chemical manufacturer for soil sterilization. Immediately before the product installation, the plot is fine graded by hand raking the surface.

SEEDING

As mentioned earlier, seeding is done according to the TxDOT Standard Specification, Item 164, *Seeding for Erosion Control.* Fertilizer is applied, integrally with the seed mixture, at the recommended rate of 252 kg/ha. The slurry is hydraulically applied with a hydro seeder immediately before product installation.

RAINFALL SIMULATION CYCLES

During the evaluation period, a series of three simulated rainfall events at the one-year, two-year, and five-year return frequencies are completed. The first set of simulated rainfall events is a one-year return frequency, 30.226 mm/hr, simulated within one month after material installation. The second set of simulated rainfall events is a 2-year return frequency, 145.542 mm/hr, simulated one-three months following material installation. The third set of simulated rainfall events is a five-year return frequency 183.642mm/hr, simulated three-five months following material installation. All of the rainfall simulations are accomplished within six months of material installation. All simulations have a ten minute duration.

To conduct a rainfall simulation, the following conditions must be met:

- Rainfall simulations will not occur within twenty-four hours of a natural rainfall or during any precipitation.
- The simulations will not be performed when, in the opinion of the HECL facility manager, the wind conditions are such that most of the water is blown onto the adjacent plots.
- If the wind is calm and it is not raining, the researchers cover the adjacent treatment plots with a plastic film immediately before the rainfall simulation. Once the simulation is completed, the plastic film is removed and the sediment and water is collected in the trough(s).

In case a drought period of more than thirty (30) consecutive days, each plot will receive a simulated rainfall of twenty-five mm at an intensity equivalent to the two-year return frequency. All natural precipitation events will be recorded on a daily basis.

SEDIMENT DATA COLLECTION

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

Each soil sample goes through a drying process to arrive at the wet/dry ratio. First, the soil sample will be weighed, recorded, and emptied onto a microwave cooking dish. Any material left in the sample bottle is rinsed with water and added to the cooking dish. The soil will be cooked for several minutes and weighed. This process occurs until three consecutive weighs are equal. The dry sample weight is recorded and averaged with the other samples to determine an average wet/dry ratio. This ratio is divided into the total weight of sediment to obtain the dry weight of the collected sediment. Finally, the dry sediment weight total is divided by the number of 9.3 m^2 for each plot to figure total sediment loss.

VEGETATIVE DENSITY DATA

Vegetation establishment observations begin after completion of the two 1-year rainfall simulations and subsequently after the two 2-year and two 5-year rainfall events. The researchers use a random numbers table for the random sampling pattern. From an 8mm video camera positioned perpendicular to the surface, the researchers record thirty random observations (on the 1:3 slope). Twenty random observations are recorded in the same manner on the 1:2 sloped plots. The video images captured in digital form are equal to an area of one-half meters squared. Each image is processed to determine the percent of the apparent area covered by vegetation. Total cover will be based on the average of the observations.

MATERIAL PERFORMANCE DATA

Intermittently throughout the growing season, the treatment plot is visually inspected for any damage or undermining of the material. Any significant rips, tears, pulling away at the seams, etc. are recorded on a plot diagram and photographed.

PERFORMANCE DATA RESULTS

All of the performance data is submitted to TxDOT for analysis and production of approved list. The Texas Transportation Institute does not develop standards for the Department. Release of statistical analysis reports is through the Texas Department of Transportation, Construction and Maintenance Division. Other research deliverables are available for purchase through the TTI, Information & Technology Exchange Center, The Texas A&M University System, College Station, TX 77843-3135.

HYDRAULICALLY-APPLIED MULCH PROCEDURES

SOIL PREPARATION
All sloped treatment plots cleared of vegetation, repaired with stockpiled or dug soil, and brought back to a reasonably uniform grade before installation. The soil is left in a loose condition and graded with a chain link drag. Each treatment plot is fumigated with a soil sterilant as recommended by the chemical manufacturer for soil sterilization. Immediately before the product installation, the plot is fine graded by hand raking the surface. Unless otherwise specified by TxDOT, hydraulically-applied mulch plots will be limited to 1:3 plots only.

SEEDING
As mentioned earlier, seeding is done according to the TxDOT Standard Specification, Item 164, *Seeding for Erosion Control*. Fertilizer is applied, integrally with the seed mixture, at the recommended rate of 252 kg/ha.

MULCH APPLICATION
A one-step process is used on the treatment plot consisting of the seed, fertilizer, and mulch mixed and applied together. This is applied to both the clay soil and sand soil test plots.

RAINFALL
The hydraulically-applied mulch products will not be subjected to simulated rainfall events. Each treatment plot is sprinkle irrigated to provide sufficient moisture for vegetation growth. For the first three months, natural rainfall and/or supplemental water will be applied evenly to each plot to provide a minimum of 25 mm of water per month per plot. After the initial three months, the natural rainfall will be the source of moisture unless there is a prolonged period of drought. In case a drought period of more than thirty (30) consecutive days, each plot will be subjected to sprinkle irrigation. All natural precipitation events will be recorded on a daily basis.

VEGETATIVE DENSITY DATA
Vegetative density observations begin on or about the fourth week after treatment installation and continue at approximately six-week intervals for the duration of the growing season (March - November). Ten random observations are taken for each treatment area using an 8mm video camera positioned perpendicular to the soil surface. The researchers process each video image to determine the percent of the apparent area covered by vegetation. Total apparent vegetative density is based on the average of the ten observations.

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All sloped treatment plots cleared of vegetation, repaired with stockpiled or dug soil, and brought back to a reasonably uniform grade before installation. The soil is left in a loose condition and graded with a chain link drag. Each treatment plot is fumigated with a soil sterilant as recommended by the chemical manufacturer for soil sterilization. Immediately before the product installation, the plot is fine graded by hand raking the surface. Unless otherwise specified by TxDOT, hydraulically-applied mulch plots will be limited to 1:3 plots only.

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FLEXIBLE CHANNEL LINER PROCEDURES

FLOW SIMULATIONS IN THE FLUME

To determine Manning's *n* for each flexible channel liner, the researchers use 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 in width, 1.22 m in height, and 21 m in length. The energy gradient is 2% along the flume bottom. The researchers view the flows through the plexiglass sides of the flume. The flume bottom is plywood.

The researchers attach each material to the plywood flume bottom with carriage bolts and washers placed 0.46 m on center. Once installed, a simulated flow at a predetermined rate of flow (Q) begins. A series of three, twenty minute flows are run in the flume replicated at two different depths to collect data. Using a digital flow meter, the velocity of the water measured at 60.96 mm and 243.84 mm depths[5] is recorded. A point-gauge instrument calculates the flow depth. Both the velocity and flow depth measurements are collected in a uniform flow location. These measurements are recorded every four minutes during the twenty minute flows.

Therefore, Manning's *n* may be determined since the rate of flow (Q), the channel geometry and slope, the measured resultant mean water velocity and depth of flow, and effects of the plywood bottom are factored into the calculations. From these procedures, the researchers figure a minimum, normal, and maximum roughness coefficient.

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[5]Based on Chow's, *Open-Channel Hydraulics*, 1959 (3).

Table B. 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

SOIL PREPARATION

All sloped treatment plots are cleared of vegetation, repaired with stockpiled or dug soil, and brought back to a reasonably uniform grade before installation. The soil is left in a loose condition and graded with a specialized trapezoidal-shaped tool. Each treatment plot is fumigated with a soil sterilant as recommended by the chemical manufacturer for soil sterilization.

SEEDING

As mentioned earlier, seeding is done in accordance with the TxDOT Standard Specification, Item 164, Seeding for Erosion Control. Fertilizer is applied, integrally with the seed mixture, at the recommended rate of 252 kg/ha.

The researchers install each channel liner at this time according to the manufacturer's published literature. To help ensure vegetative growth during the evaluation period, there will be a ninety (90) day vegetation establishment or *rest* period after the material installation beginning with the 1995 cycle.

FLOW SIMULATIONS IN THE FIELD

After the ninety (90) day *rest* period, a series of simulated flows will begin. Before each flow the channels are pre-wetted to moisten the channel surface. After this process, the researchers turn on the pumping station to deliver the flow water at a steady rate. 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. Within three to four minutes, the water flows at the desired depth and continues for twenty minutes. During the twenty minutes, velocity and depth measurements are taken every four minutes. After the measurements are taken, the researchers close the pumping station and the water subsides within one to two minutes.

Since the channels are of a fixed shape, the depth of flow is the critical element to determine the performance range of tractive forces. The researchers recommend that the simulated flows begin at 96 Pascal in a vegetated state (2) and that each flow event be replicated twice. An incremental increase of 48 Pascal shear stress to the channel bottom will occur to each series of flow events until the material *fails*.

"Failure" in this context refers to the material physically pulling away from the surface and moving downstream leaving bare ground in its place. From the first cycle of channel evaluations, the researchers witnessed rapid channel degradation once the channel was denuded of the channel liner. The researchers will collect data for each "successful" flow event and cease to record data beyond an obvious material "failure." Currently, the channel liner facility is capable of producing shear stress ranges from 96 Pascal to 383 Pascal with a maximum depth of 0.70 m for uniform flow.

The researchers will not add supplemental water to the channels after the initial *rest* period unless a protracted period of drought occurs. In case of a drought period of more than thirty

(30) consecutive days, each treatment channel will receive supplemental irrigation. All natural rainfall events are reported as part of the weather records for the HECL.

CHANNEL DEGRADATION

Before and after each simulated flow, the researchers survey the channel profile to record deformation. To collect this data, the researchers use a point gauge to take section profiles at four stations located lengthwise along the treatment channel. These stations are at 10.675 m, 15.25 m, 19.825 m, and 24.4 m from the upper end of the channel (see Figure 3). Each individual profile sample consists of seven readings taken at each station as shown in Figure 4. This procedure enables the researchers to quantify sediment loss and sediment bed load migration, and all data is furnished to TxDOT for final analysis.

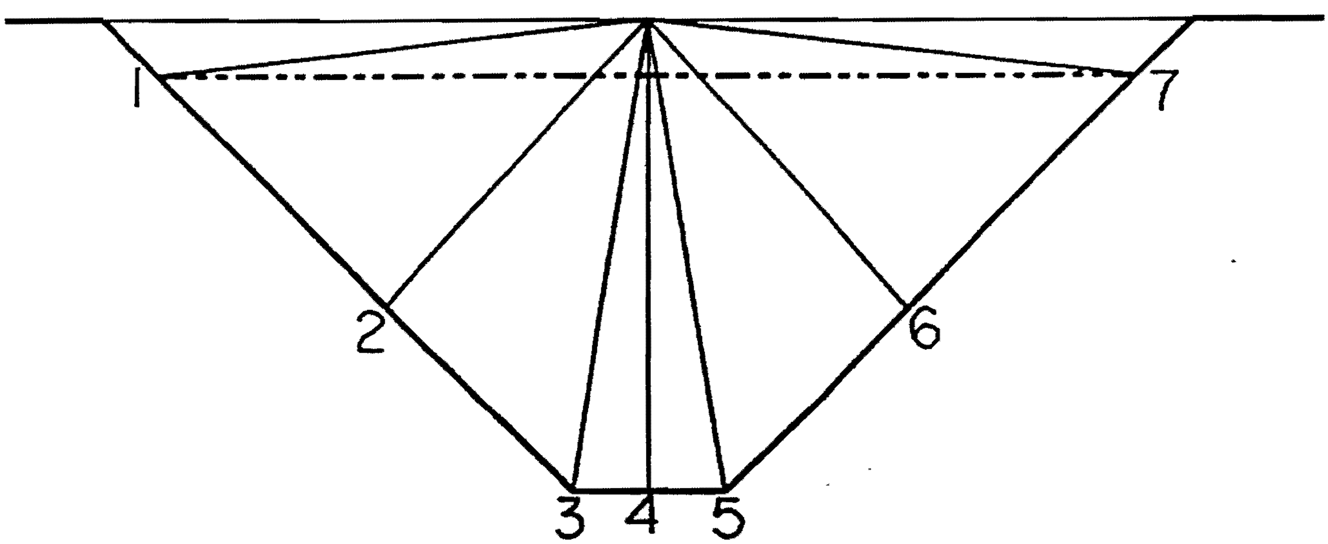

Figure 4. Section through Treatment Channel.

VEGETATIVE DENSITY
The vegetative density sampling begins on about the end of the ninety (90) day *rest* period. The first sample is taken before the channel test flows begin and subsequently after each test flow. The researchers use random patterns, established by a random number's table, for the bottom and sides of the channel to collect thirty-six (36) samples for each round of data collection. The researchers record their observations with an 8mm camera positioned perpendicular to the channel surface. From the video, single images are captured using a Targa 16 and TIPS software with the center of the image equal to 0.50 m^2. The researchers process each image (sample) with the VeCAP program to determine the percentage of apparent vegetation coverage. The average of the observations equals the total cover value. All data is furnished to TxDOT for analysis.

MATERIAL PERFORMANCE
Periodically during the evaluation cycle, each treatment channel is visually inspected for any damage or undermining of the material. Significant rips, tears, pulling away at the seams or loss of material, etc., are recorded on a channel diagram and photographed by the researchers. No material performance data is statistically analyzed.

PERFORMANCE DATA
The researchers submit all of the performance data to TxDOT for analysis. The Texas Transportation Institute does not develop standards for the Department. Release of statistical analysis reports is through the TxDOT, Construction and Maintenance Division. Other research deliverables are available for purchase through the TTI, Communications Division.

REFERENCES

1. Arcement Jr., G.J. and V.R. Schneider. 1984. *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains.* Office of Implementation, Federal Highway Administration. Report FHWA-TS-84-204. pp. 1-12.

2. Chen, Y.H. and G.K. Cotton. 1988. *Design of Roadside Channels with Flexible Linings, Final Report.* Office of Implementation, Federal Highway Administration. Report FHWA-IP-87-7, HEC #15.

3. Chow, V.T. 1959. *Open-channel Hydraulics.* McGraw-Hill Book Co. Inc., New York. Maple Press Co. pp. 19-22.

4. Chow, V.T. 1959. *Open-channel Hydraulics.* McGraw-Hill Book Co. Inc., New York. Maple Press Co. pp. 99-115.

5. Dimaggio, J. 1984. *Geotextile Engineering Course Manual.* Federal Highway Administration. Contract no. DTFH61-83-C-00150.

6. Northcutt, P.E. 1988. *Field Performance, Testing, and Comparison of Mulching Materials.* Texas State Department of Highways and Public Transportation, Maintenance and Operations Division. pp. 1-34.

7. State Department of Highways and Public Transportation. 1985. *SDHPT, Bridge Division, Hydraulic Manual, Third Edition.* SDHPT Publication. pp. 16-23.

8. Texas Department of Transportation. 1993. *Texas Department of Transportation Standard Specifications for Construction of Highways, Streets and Bridges.* TxDOT. pp 104-128.

9. Texas State Department of Highways and Public Transportation. 1982. *Texas Department of Transportation Standard Specifications for Construction of Highways, Streets and Bridges.* TSDHPT.

10. Federal Highway Administration. 1984. *Geotextile Engineering Manual.* March, Ch. 2.

APPENDIX A
GLOSSARY

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	Common Name (Acceptable Varieties)	Season Warm/Cool	Native Introduced
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 appropriate varieties)	W	N
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	Buffalograss	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 hydraulically-applied 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 four (4) 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 four (4) 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 (Pensacola)	6.7
	Indiangrass (Lometa) K-R Bluestem 0.7	1.5		
	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 1:3 slope or less	min. 2000 lbs./acre
Sandy soils with greater than 1:3 slope	min. 2300 lbs./acre
Clay soils with 1:3 slope or less	min. 2500 lbs./acre
Clay soils with greater than 1:3 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.