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Evaluation of Strategies to Control Erosion along U.S. Highway 50 Between Carson City and Lake Tahoe

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Keith Dennett[1], Pat Fritchel[2], Raj Siddharthan[3], and Amir Soltani[4]

PROJECT OVERVIEW

Severe erosion is occurring at several locations along U.S. Highway 50 in Nevada between Carson City and Lake Tahoe. Surface water runoff from seasonal snowmelt and infrequent high intensity rain events can cause erosion and transport substantial quantities of soil and sediment. Severe erosion can cause problems related to slope stability along the roadway, especially at the discharge of culverts. During significant runoff events, erosion negatively impacts water quality as evidenced by dramatic increases in turbidity and suspended solids entering surface streams. The erosion, transport, and deposition of soil and sediment also increases maintenance requirements for the Nevada Department of Transportation (NDOT). The deposition of suspended solids within drop inlets and culverts can substantially reduce the hydraulic capacity of these drainage structures. This may lead to overtopping of curbing along the roadway shoulders resulting in surface flow across unstable, easily erodible slopes.

Corrective action must be taken to limit the erosion of soil and transport of sediment during runoff events. NDOT has budgeted approximately $1 million per year over the next several years to implement erosion control strategies along this section of Highway 50. Numerous erosion control products are commercially available. However, the effectiveness and suitability of these products is often difficult to predict.

This ongoing research project is investigating a variety of erosion control strategies. A combination of laboratory tests and field studies are being conducted to assess the performance of potential erosion control products. This research project will help NDOT identify appropriate and cost effective strategies for mitigating erosion problems along this section of Highway 50.

BACKGROUND AND INTRODUCTION

Erosion can cause problems related to slope stability along roadways and generally increases maintenance requirements, especially those associated with drainage structures. During significant runoff events, erosion can also cause dramatic increases in turbidity and suspended solids entering surface streams. The subsequent deposition of suspended sediments in slower moving receiving waters can also negatively impact fish populations and may smother the

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benthic community (Dennison, 1996).

Erosion involves the processes of particle detachment, transport, and deposition. Any site where soils are exposed to water, wind, and ice is susceptible to erosion (Dennison, 1996). For erosion caused by water, the specific forces that initiate the detachment of particles include the impact of raindrops and the shear stresses exerted by surface runoff (Lal and Elliot, 1994; Dennett, 1995).

Three recognized types of soil erosion that may occur along hillsides and steep slopes include: (1) surface erosion; (2) gully erosion; and (3) mass soil movement (Ffolliott *et al.*, 1995). Surface erosion occurs as a result of the collective action of the impact of raindrops, thin film surface flows, and concentrated surface runoff flows. Surface erosion may also be further classified as either interrill erosion or rill erosion (Lal and Elliot, 1994; Elliot and Ward, 1995) because it promotes the formation of rills and small gullies on the land surface.

As overland flow becomes concentrated and moves downslope, the velocity of the flow generally increases which increases the kinetic energy of the flow (Ffolliott *et al.*, 1995). This subsequently increases the turbulence and ultimately the erosive potential of the flow, which varies with the square of the velocity (Goldman *et al.*, 1986). In general, surface flows with velocities as low as approximately 0.5 feet per second (160 mm/s) are capable of eroding soil particles that are 0.3 mm in diameter (Bell, 1999). In order to reduce the erosive potential of flowing water, the channel velocity can be reduced by lining the channel bottom with a roughened surface such as vegetation and rip rap or by increasing the width of the channel.

A gully is a relatively deep, recently formed eroding channel on hillslopes where no well-defined channels existed previously. Gullies usually result from uncontrolled, concentrated surface runoff down hillslopes that have very little vegetative cover and contain highly erodible soils (Ffolliott *et al.*, 1995). Gullies are likely to form whenever concentrated surface flow passes over a point where an abrupt change in elevation or gradient of the land surface occurs. After gully erosion is initiated, it is very difficult and costly to control (Ffolliott *et al.*, 1995).

The four principal factors that influence the erosion of soils are: (1) climate; (2) soil characteristics; (3) topography; and (4) groundcover (Goldman *et al.*, 1986; Roberts, 1995). Groundcover usually refers to vegetation but also includes other surface treatments such as mulches, wood chips, crushed rock, jute mesh or netting, and filter fabric (Goldman *et al.*, 1986). Most of these surface treatments are considered as temporary erosion control measures until natural vegetation is established. In regions with harsh climates, it is usually difficult to establish vegetative cover. Thus, more permanent surface treatments such as geotextile blankets and mats are commonly used in these regions in order to allow more time for vegetation to become established.

Four soil characteristics that are important in determining the erodibility of soils and sediments include texture, organic content, structure, and permeability (Goldman *et al.*, 1986). These characteristics largely determine the infiltration capacity of soils. The steepness and length of slopes are important considerations related to topography. Long, continuous slopes tend to increase the momentum of flowing water, thereby increasing the erosive potential of the water.

Erosion can be accelerated by any activities that: (1) change natural drainage patterns; (2) alter undisturbed soil conditions; and (3) decrease the amount of permeable area for infiltration of water (Dennison, 1996). All of these activities tend to increase the quantity and the velocity of surface runoff. Areas that are most highly susceptible to erosion due to the increased quantity and rate of surface runoff include areas with steep slopes and areas with little or no vegetative cover (Dennison, 1996).

Ffolliott *et al.* (1995) summarized a number of actions that can be taken to limit the progression of surface erosion. These include: (1) protecting the soil surface against the impact of raindrops; (2) increasing the roughness of the soil surface in order to reduce the velocity of the surface flow; (3) reducing the inclination of slopes; (4) increasing the infiltration capacity of soils in order to reduce the quantity of surface runoff; and (5) preventing the concentration of overland flow. In most cases, significant surface erosion can be prevented or minimized using appropriate vegetative management practices (Ffolliott *et al.*, 1995). Thus, the implementation of erosion control strategies that improve the infiltration of water into a soil will generally improve the opportunity for plant growth that can eventually lead to the development of a protective vegetative cover.

The selection of appropriate strategies to prevent and/or control erosion of soils and the transport of sediments must consider site-specific conditions such as land use, existing structures, hydrology, climate, soil type, and topography (Dennison, 1996). In locations where significant surface erosion has already occurred, structural and/or mechanical erosion control strategies must typically be employed in order to control additional surface erosion until protective vegetative cover can be established (Ffolliott *et al.*, 1995).

Structural and mechanical controls are typically designed to reduce the erosive energy of flowing water. Examples of structural erosion control strategies include the construction of pipe slope drains, energy dissipators, check dams, and terraces as well as the installation of gabions and channel linings such as rip rap. Examples of mechanical controls include contour furrows, contour trenches, pitting, and basins. The main disadvantage of structural and mechanical erosion control strategies is their relatively high cost.

As mentioned previously, the most effective long-term methods for controlling surface erosion are based on establishing and maintaining a cover of protective vegetation (Ffolliott *et al.*, 1995). A variety of erosion control strategies involve the application of temporary or permanent surface materials or treatments that are designed to promote the establishment of a protective vegetative cover over time. Examples of these surface treatments include topsoiling, mulching, chemical stabilization, and erosion control blankets (ECBs) and mats.

Topsoiling may be used when the existing soil is not suitable for establishing vegetation because of acidity, low nutrient content, poor texture, or other conditions (Roberts, 1995). In general, topsoiling is not recommended on slopes steeper than 2 horizontal to 1 vertical (Roberts, 1995).

Mulching is typically a temporary erosion control method that protects soil from the impact of rainfall and overland flow. Mulching also promotes retention of moisture within the soil horizon which encourages the growth of vegetation. The materials commonly used for mulching may be organic or synthetic and include hay, straw, fiber mulch, and soil binders (Roberts, 1995).

Chemical stabilization techniques can also be used to stabilize and protect the soil surface (Roberts, 1995) or promote the aggregation of soil particles within the soil horizon (Haigh, 2000). Chemical stabilization involves the application of soil binders or tackifiers such as emulsified asphalt, nonasphaltic emulsions, polyvinyl acetate, and acrylic copolymers. These soil binders may be used alone or in conjunction with mulches. The application of soil binders is only a temporary method for controlling erosion since they typically decompose within 90 days (Roberts, 1995). In addition, commercially available soil binders are relatively expensive, are usually designed for agricultural use, and do not work reliably on all soils (Haigh, 2000).

ECBs and mats may be used to control erosion while providing time for vegetation to become established. ECBs can provide important protection against periodic, highly erosive overland flows that are common in dry climates and drought prone regions where vegetation is typically slow to develop (Bhandari *et al.*, 1998). Erosion control blankets may be organic or synthetic. Organic blankets may be composed of wood fibers (excelsior), jute net, or coconut coir fiber (Roberts, 1995; Bhandari *et al.*, 1998). Coconut coir blankets are relatively resistant to decay and may last for as long as five to ten years in arid regions.

Synthetic ECBs or mats (e.g., gabions, mattresses, geogrids, geomats, geocells, and geowebs) are typically constructed of non-biodegradable materials and will last for many years (Bhandari *et al.*, 1998; Rickson, 1995). The two main categories of synthetic blankets include turf reinforcement mats and erosion control and revegetation mats (Roberts, 1995). These mats are typically permanently installed and allow vegetation to grow through surface of the mats.

The most severe erosion along Highway 50 typically occurs at the discharge of culverts. In some locations, the free discharge of culverts onto unstable hillslopes has resulted in the formation of gullies as shown in Figures 1 and 2. In a number of other locations, there is evidence of additional surface erosion due to overtopping of the curb and gutter along the outer edge of the roadway shoulder.

Erosion along Highway 50 is exacerbated by steep slopes, shallow soil profiles with low permeability, a lack of nutrients and organic matter in the soils, and limited vegetative cover. Also, the cold and dry climate in the higher elevations of the Sierra Nevada mountains is not very favorable for growth of natural vegetation. Thus, the soils in this region are highly susceptible to erosion.

In order to prevent or effectively control the formation of gullies, the gradient of hillslopes must be stabilized and abrupt changes in elevation must be eliminated. Check dams are often an effective structural erosion control strategy for controlling gully erosion (Ffolliott *et al.*, 1995). Another alternative that has been used at some culverts along Highway 50, as shown in Figure 3, is a pipe slope drain that conveys water from the top to the bottom of the slope. Pipe slope drains are commonly used in conjunction with diversion dikes or swales constructed at the top of a slope (Goldman *et al.*, 1986). The installation of channel linings such as rip rap has also been effective at some locations along Highway 50 as shown in Figure 4. Each of these strategies for mitigating gully erosion is relatively expensive and difficult to construct and/or install.

This research project is evaluating the effectiveness and suitability of alternative, economical, long-term erosion control strategies designed to establish and maintain a cover of protective vegetation. Specific erosion control strategies that will be examined include surface treatments like chemical stabilization and the installation of ECBs and mats.

PRODUCT EVALUATION

A variety of erosion control products, namely chemical stabilization and ECBs and mats, are being evaluated using a combination of laboratory and field-testing. Representative soil and sediment samples from the watershed along U.S. Highway 50 have been characterized. Bulk quantities of soil and sediment have been obtained by NDOT and transported to the University of Nevada, Reno (UNR).

The performance of the erosion control products is being evaluated initially by monitoring the erosion of soil and the resuspension of sediment during laboratory flume studies. The studies are being conducted in a manner that simulates the field conditions of soils and sediments as closely as possible. The results of the laboratory studies will help expedite the selection of products that are suitable for further study during field testing.

Based on the results of the laboratory studies, the most effective erosion control products will be evaluated further during field testing. Test plots at the project site will be constructed and monitored for a period of 24 months. Recommendations for the most suitable erosion control strategies will be developed by considering the results from both the laboratory studies and the field testing

Collection and Characterization of Soil Samples

The locations within the project area where substantial erosion is occurring have been identified. Whenever possible, the type of erosion will be classified as surface erosion, gully erosion, or soil mass movement (Ffolliott *et al.*, 1995).

Samples of the soil and sediment at these locations have been characterized with respect to grain size distribution using sieve analyses. Typical results of the sieve analyses are shown in Figure 5 and a sample of the typical soil is shown in Figure 6. The brown colored soil particles range in size from approximately .25 to 7.5 mm, with a mean particle size (D_{50}) of 1.6 mm. This cohesionless soil consists mainly of decomposed granite and appears to be the dominant soil type that is subject to erosion. The properties of each soil sample are being classified initially according to the Unified Soil Classification System (USCS). In locations where eroded sediments have been redeposited, changes in particle size distribution with sediment depth will also be examined. Column settling tests will be performed to determine the settling velocities of the various size fractions within each sample.

Laboratory Flume Studies

Laboratory flume studies are being conducted in a rectangular, recirculating, tilting flume at UNR in order to evaluate the performance of various erosion control products. The flume is 24 meters long and 0.9 meters wide. Plan and profile views of the flume are shown in Figure 7. The soil test section for the flume studies is 6 m long by 0.9 m wide by 15 cm deep. The test section has a 5 cm by 10 cm wooden perimeter for attaching and anchoring the erosion control products in place over the test section. The soil test section is shown in Figure 8.

Specific objectives of the laboratory studies are: (1) to determine the critical shear stresses required to initiate the erosion of soil and/or the resuspension of sediment; (2) to determine the erosion rates of soils and the rates of resuspension and/or deposition of sediments under varying flow conditions; and (3) to monitor the reduction in erosion due to various erosion control strategies.

The bed shear stress applied to the soil and sediment samples can be adjusted by varying the depth of the flow, the approach velocity of the flow, and the bed slope of the flume. The critical shear stress is the bed shear stress required to initiate the erosion and/or resuspension of particles. When the bed shear stress is below the critical shear stress, no erosion or resuspension will occur. When the critical shear stress is exceeded, particles will be eroded and transported (Dennett, 1995; Dennett *et al.*, 1998; and Ravisangar *et al.*, 2001).

The flume studies are being conducted in a manner that simulates the field conditions of the soils and sediments and the flow induced shear stresses as closely as possible. ASTM D 6460-99: Standard Test Method for Determination of Erosion Control Blanket (ECB) Performance in Protecting Earthen Channels from Stormwater-Induced Erosion provides some guidelines for conducting the flume studies. As recommended, the duration of each test is 30 minutes at the desired bed shear stress. The performance of each product is being evaluated by comparing the sediment yields with and without erosion protection over a range of bed shear stresses.

The performance of four ECBs and turf reinforcement mats (TRMs) manufactured by SI Geosolutions (Chattanooga, Tennessee, USA) has been evaluated during laboratory flume testing. These included Landloc 435, Landloc 450, Pyramat, and natural coir (coconut) fiber mat. Three of these products are shown in Figure 9. In order to compare the performance of products available from another manufacturer, three additional products manufactured by North American Green (Evansville, Indiana, USA) will be tested using identical test procedures. These ECBs and TRMs include SC250, C350, and P550. The properties of the various products being tested are summarized in Table 1. These products are anchored along the perimeter of the soil test section in the laboratory flume in accordance with the recommendations of the manufacturer.

The sediment yield for the unprotected, bare soil over a range of shear stresses is shown in Figure 10. For this cohesionless soil, the sediment yield varies linearly with bed shear stress. Figure 11 shows the substantial reduction in sediment yield that was observed when the soil test section was protected using the four different ECBs. For example, when the soil was protected with Pyramat, the mass of soil eroded was approximately 10.4 kg at a bed shear stress of 31.7 N/m^2. This was about one half of the mass of unprotected, bare soil that eroded at a bed shear stress of only 2.5 N/m^2. Thus, ECBs like Pyramat have the potential to significantly reduce the erosion of soils along Highway 50 within the project site.

Construction and Monitoring of Field Plots

Following the completion of laboratory flume studies, selected erosion control products will be evaluated further through the construction and monitoring of field plots along Highway 50. Field plots will be constructed and monitored using the methodologies developed by Mutchler *et al.* (1994). The performance of each field plot will be monitored for a period of 24 months.

It is anticipated that three to five field plots will be constructed. Various products will be evaluated for slope stabilization and channel protection. The exact location and size of the field plots will be determined in consultation with the Hydraulics Section and maintenance personnel at District II of NDOT.

CONCLUSIONS

This research will help design engineers in the Hydraulics Section at NDOT identify the most suitable and cost effective strategies for controlling erosion along U.S. Highway 50 between Carson City and Lake Tahoe. The combination of laboratory studies and field studies can expedite the selection of suitable commercially available erosion control products.

Preliminary results of the laboratory flume studies indicated that the use of erosion control blankets and mats will substantially reduce the erosion downstream from the outlets of culverts along Highway 50. Further evaluation during field-testing will help identify various products that are durable enough over time to withstand the rather harsh climate in the Sierra Nevada mountains. It is expected that the engineers in the Hydraulics Section will be able to incorporate some of the results of this research project into erosion control mitigation plans to be developed within the next 12 to 24 months.

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Figure 1. Culvert with free discharge at top of slope

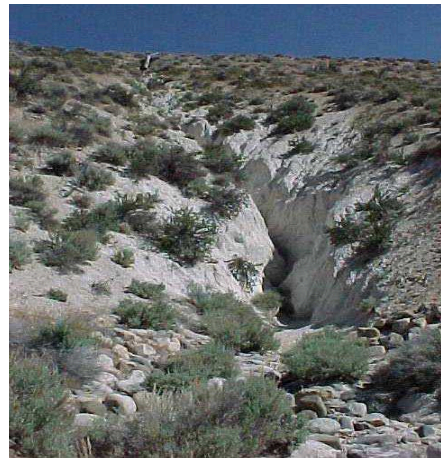


Figure 2. Gully erosion resulting from culvert with free discharge

Figure 3. Culvert with a pipe slope drain

Figure 4. Channel lined with rip rap

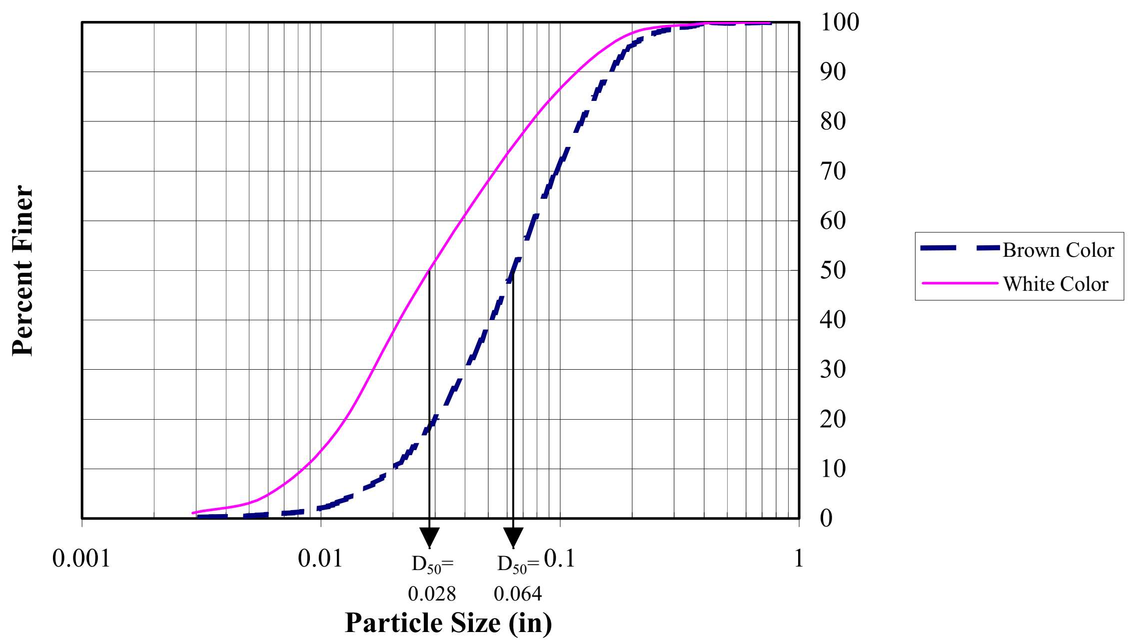


Figure 5. Gradation Curves for Test Soils

Figure 6. Typical Soil Sample

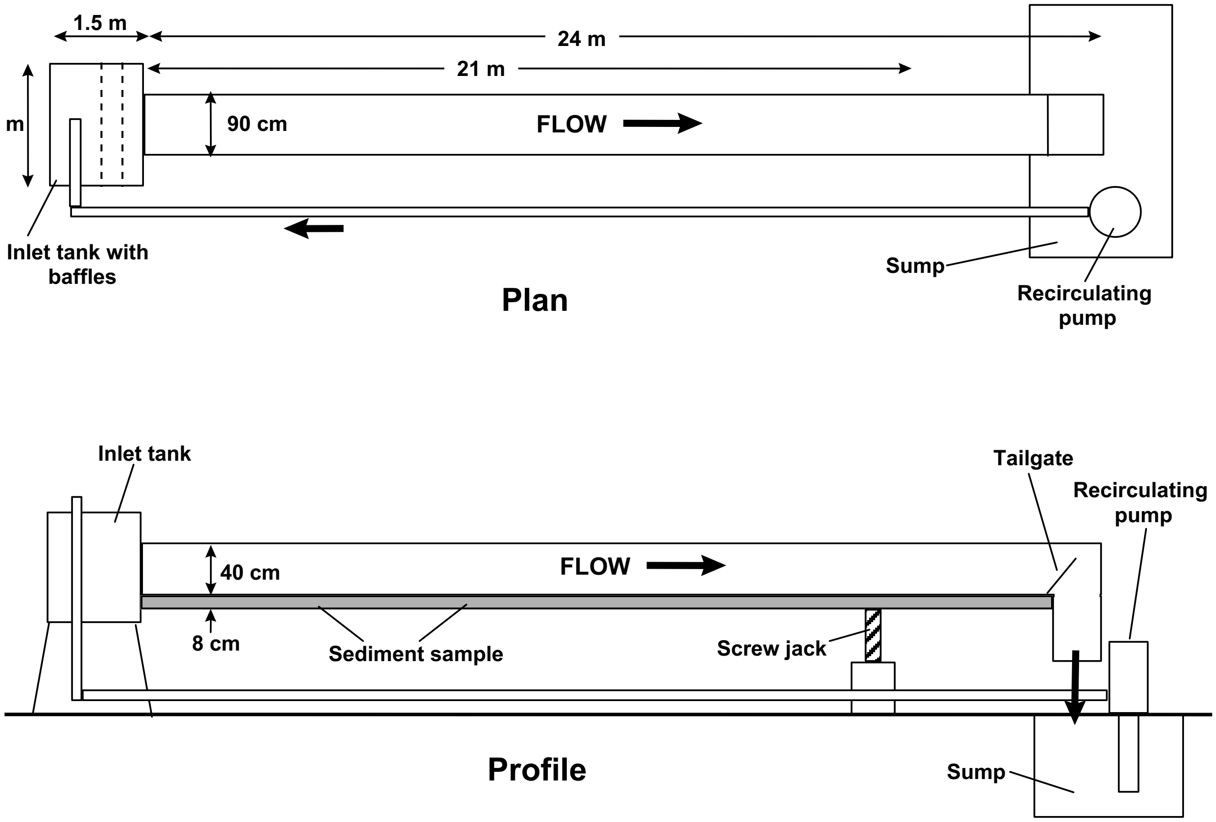
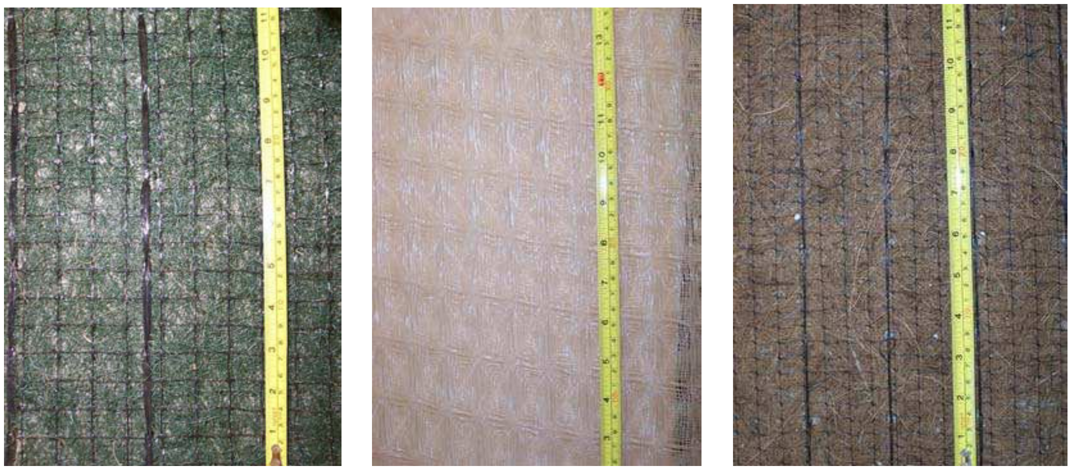


Figure 7. Plan and profile views of the laboratory flume

Figure 8. Soil Test Section within Flume



(a) (b) (c)

Figure 9. Photos of Erosion Control Blankets: (a) Landloc 435; (b) Pyramat; and (c) Coconut fiber

Table 1. Properties of Erosion Control Test Products

Product Name	Product Description	Thickness (inches)	Mass Per Unit Area (oz/yd^2)	Tensile Strength (lb/ft^2)	Velocity Rating (ft/s)	Shear Stress Rating (lb/ft^2)	Similar Product Example Company Name (Product Name)	Total Cost ($\$/yd^2$)
SI Geosolutions, Inc., Chattanooga, Tennessee, USA								
C2	Erosion Control Blanket. For use as a channel liner with high velocity intermittent flows. Also used as an erosion control blanket on extreme slopes and very harsh sites. 100% natural coir (coconut) fiber, long lasting UV stabilized photodegradable netting on both sides.	0.30	10.5	150 x 150	6	2	North American Green (C125 & C350); PPS Packaging (XCEL Coconut CC4) American Excelsior (CURLEX III HV) Maccafer RI Gabions (BIOMAC C) Erosion Control Systems (High Impact Excelsior) Greenfix (CFO72 RR)	3.61
CS2	Erosion Control Blanket. Suitable for slopes with heavy runoff conditions where protection is needed for 2 to 4 years. Made from 70% wheat straw and 30% coir fiber. CS2 has a lightweight photodegradable netting on both sides, and long lasting UV stabilized, photodegradable netting on the topside.	0.40	8.7	100 x 100	6	2	North American Green (SC 150) PPS Packaging (XCEL Coconut/Straw C53) American Excelsior (CURLEX III) Maccafer RI Gabions (BIOMAC S/C) Greenfix (CFO72 R)	4.00
Landlok TRM 435	Turf Reinforcement Mat. For use on slopes and channels. Composed of a three dimensional web of green polyolefin fibers bonded between two nets. Considered non-biodegradable.	0.35	8	145 x 110	16	5	North American Green (C 350) PPS Packaging (PERMAMAT 200F) Mirafi (MIRAMAT TM8) AKZO Colbond (ENKAMAT 7020) TENAX (MULTIMAT 100) Greenfix (CFO72 RP)	6.70
Landmark TRM 450	Turf Reinforcement Mat. Thicker design than the LL 435. For use on slopes and channels. Composed of a three dimensional web of green polyolefin fibers bonded between two nets. Considered non-biodegradable.	0.50	10	170 x 130	18	7	North American Green 300) Mirafi (MIRAMAT 1800) AKZO Colbond (ENKAMAT 7220) Tensar (TB 1000) Contech (C-45)	7.60
PYRAMAT	For use on steep slopes, water containment structures and high flow channels. Composed of polypropylene monofilament yarns woven in a configuration of pyramid-like projections. Considered non-biodegradable.	0.50	14	3200 x 2200	20	8	AKZO Colbond (ENKAMAT S-20) Maccafer RI Gabions (MACMAT R-8)	13.50
North American Green, Inc., Evansville, Indiana, USA								
SC250	Composite turf reinforcement mat. Machine produced mat consisting of 70% straw and 30% coconut fiber matrix. Incorporated into a permanent three-dimensional netting structure. Designed for medium to high flow channels with slopes of 1:1 and greater.	0.73	16.21	700 x 500	9.5	3		5.65
P550	Composite turf reinforcement mat. Machine produced mat consisting of 100% UV stabilized polypropylene fiber matrix. Incorporated into a permanent three-dimensional netting structure. Designed for extremely high flow channels with a slope of 1:1 and greater.	0.76	20.28	1500 x 1300	12.5	3.5		8.65

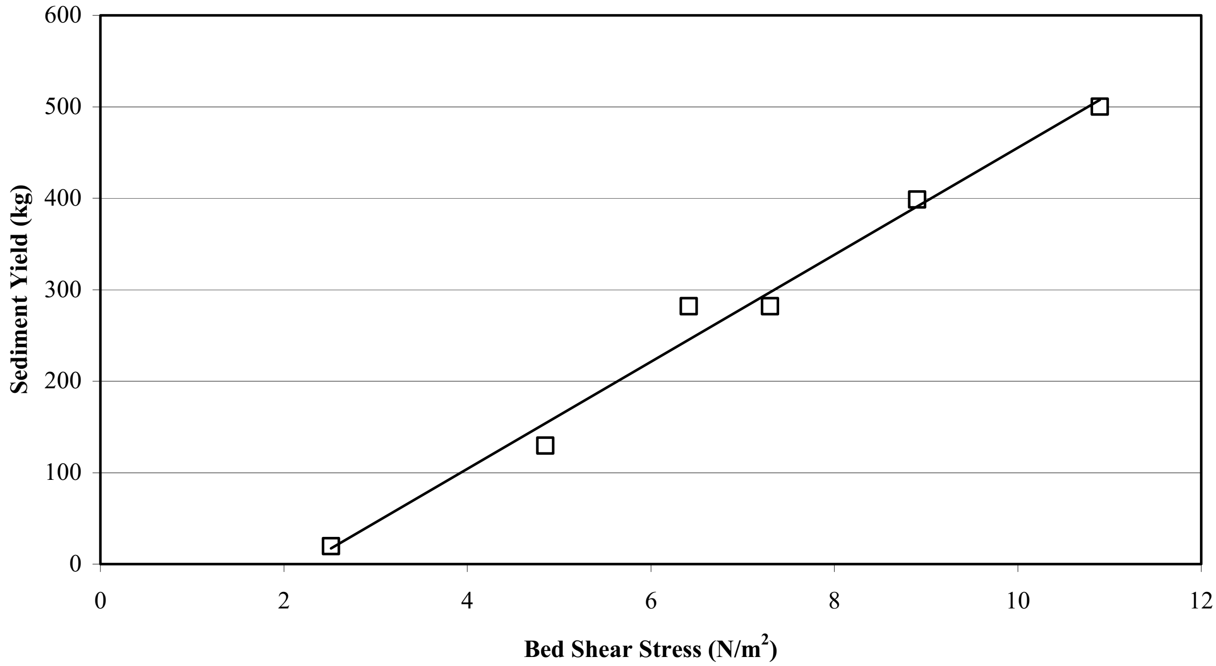


Figure 10. Variation in Mass of Bare Soil Eroded with Bed Shear Stress

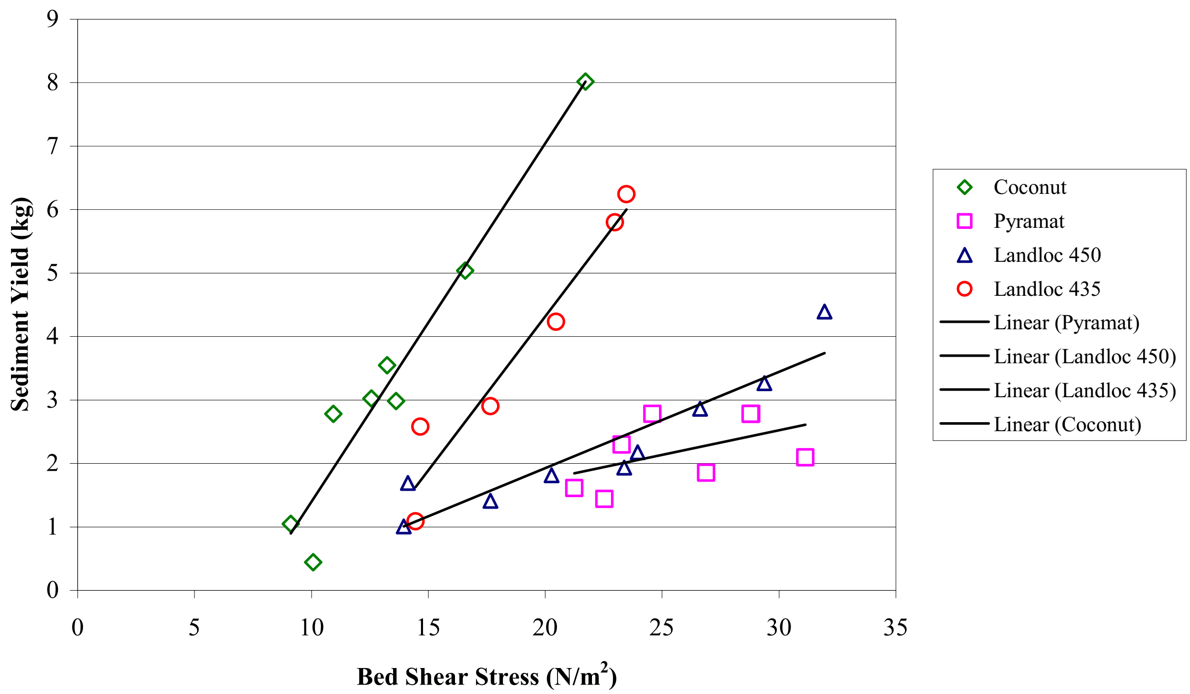


Figure 11. Variation of Mass of Soil Eroded with Bed Shear Stress for Four Erosion Control Blankets