Caltrans Erosion Control Pilot Study

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BIOGRAPHICAL SKETCHES

Michael V. Harding, CPESC

Michael V. Harding is one of the leading technical experts in the erosion control industry. A graduate from Purdue University, Michael has over 22 years experience in erosion and sediment control, resource management, mined land reclamation, wildlife habitat development, and nonpoint source pollution control both in the United States and overseas. Michael specializes in the evaluation, research, development, and application of cost-effective erosion control materials and techniques. He has contributed significantly to the body of knowledge related to the effectiveness of alternative approaches to erosion control through field and laboratory testing programs. Michael is three times past President of the International Erosion Control Association (IECA) and is Chairman of the CPESC Ethics Committee. Michael is the current Director of the San Diego State University Soil Erosion Research Laboratory in San Diego, CA.

Carol L. Forrest, P.E.

Carol L. Forrest is a Vice President with URS Corporation. She has over 24 years experience in watershed management, urban runoff, and storm water pollution. Ms. Forrest is a nationally known expert in erosion and sediment control. She is twice past President of the International Erosion Control Association (IECA), twice past President of the Western Chapter of the IECA, and Chair of the CPESC Council. Ms. Forrest is a registered civil engineer, registered geotechnical engineer, Certified Professional Erosion and Sediment Control Specialist, and a Storm Water Quality Specialist. She has been involved in projects related to watershed management, erosion control, water quality, and resource management throughout the United States and overseas.

Nancy Gardiner

Nancy Gardiner has more than 14 years of consulting experience performing and managing water quality and water resource projects in California. In recent years, her practice has focused specifically on storm water monitoring, NPDES permitting, management, and training. Nancy has been involved in research, pilot studies and training for Caltrans on erosion and storm water pollution associated with highway runoff. She is a Masters level geologist/hydrogeologist with both management and technical experience in storm water management.

Howard H. Chang, PhD

Dr. Howard H. Chang is on the Civil and Environmental Engineering faculty at SDSU. As a registered civil engineer, he is involved in research and professional consulting in the areas of hydraulics, hydrology and sedimentation. He has been active in floodplain mapping, hydrology and watershed modeling, hydrological simulation, designs of channels and floodwater detention basins, river channel erosion and sedimentation. He is the author of over 100 technical papers, several computer models for channel design and river hydraulics, and the book *Fluvial Processes in River Engineering* published in 1988. Dr. Chang has taught short courses on river and sedimentation engineering, hydrology for flood control, and the use of the HEC-2 and Fluvial programs. He has also served as a consultant for consulting firms, local, state and federal governmental agencies, and the United Nations.

CALTRANS EROSION CONTROL PILOT STUDY

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ABSTRACT

The objective of the Erosion Control Pilot Study was the evaluation of alternative soil stabilization methods designed to minimize the erosion and transport of sediment from Caltrans rights-of-way to drain inlets. Field and laboratory programs were developed to test the candidate erosion control measures. The field program included test plots for measuring erosion rates from existing Caltrans cut and fill slopes under natural rainfall conditions and test plots for monitoring the effectiveness of sixteen different types of temporary erosion control measures on the establishment of a native California plant community. The laboratory test program included the measurement of erosion rates from simulated Caltrans slopes, the measurement of erosion rates from existing slopes with various vegetation densities and water quality analyses on runoff from simulated Caltrans slopes that were treated with sixteen different non-vegetative erosion control measures. All elements of the laboratory test program were performed with typical southern California rainfall patterns as obtained from a rainfall simulator. The laboratory testing program was performed by San Diego State University on a rainfall simulation facility with a tilting test bed that was constructed for this study.

BACKGROUND

The California Department of Transportation (Caltrans) conducted a $3.2M Erosion Control Pilot Study (ECPS) from 1998 to 2000. The objective of the ECPS was to evaluate alternative soil stabilization methods designed to minimize the erosion of Caltrans highway slopes and transport of sediment to Caltrans storm drain inlets in District 7 (Los Angeles).

Caltrans selected URS Corporation to design and manage the study, with Great Circle International as a subconsultant. The design phase of the ECPS employed a systematic approach to defining current Caltrans erosion problems, and identifying candidate soil stabilization measures and practices that will mitigate such problems. Field and laboratory programs were developed to test candidate soil erosion control measures.

In order to perform comparative laboratory tests of erosion control effectiveness, a rainfall simulation facility, the Soil Erosion Research Laboratory (SERL), was designed and constructed at San Diego State University through the Civil and Environmental Engineering Department. The portable rainfall simulators were also used on field test plots in Los Angeles. Other portions of the ECPS relied on the results of natural rainfall on field test plots.

This paper presents the results of three elements of the Erosion Control Pilot Study (ECPS):

(1) The measurement of erosion rates from simulated highway slopes that were roughened with different mechanical techniques;
(2) The measurement of erosion rates from existing highway slopes with various vegetation densities; and
(3) The evaluation of erosion rates and runoff from slopes that were treated with fifteen different non-vegetative, erosion control measures.

Erosion rates were determined by collecting all runoff and sediment and comparing values against a bare soil (control) or untreated condition.

SAN DIEGO STATE UNIVERSITY SOIL EROSION RESEARCH LABORATORY

The SDSU Physical Plant constructed the laboratory facilities with funding provided by Caltrans. The San Diego State University Soil Erosion Research Laboratory (SDSU/SERL) integrates beneficial features from three of the primary, soil erosion research facilities in the United States. The purpose of the SDSU/SERL is to study erosion problems associated with highway slopes. The ECPS evaluated soil losses during single storms as well as the mean annual soil loss. Typical rainfall intensity-duration-frequency curves for Los Angeles County, California were employed as the basis for single storm events, including the 5-year, 10-year, and 50-year storms.

Norton ladder rainfall simulator

The rainfall simulation device selected for the SDSU Soil Erosion Research Laboratory is the Norton Ladder Rainfall Simulator, which was developed at the USDA-ARS National Soil Erosion Research Laboratory by Dr. Darrell Norton. For testing at the indoor laboratory, multiple simulators have been installed in parallel above the soil test bed to uniformly apply precipitation over the entire test plot area. The simulators are also routinely taken down and transported to the outdoor, vegetative coverage test plots.

The drop former used for the Norton simulator is the Spraying Systems Veejet nozzle, and the nozzles are spaced 1.1 meters apart. For uniform intensity across the plot, the center of spray patterns from two laterally adjacent nozzles meet at the plot surface. This gives a 2.25-mm median drop size, a nozzle exit velocity of 6.8 m/s, and a spherical drop. The impact velocities of almost all drops from the Veejet nozzle are nearly equal to the impact velocities of those from natural rainstorms when the nozzle is at least 2.4 meters above the soil surface. For this reason, the rainfall simulators used in the SDSU/SERL are installed such that the nozzles are a minimum of 2.5 meters above the soil surface. Rainfall intensity can be changed instantaneously with the simulator in operation, and the maximum intensity produced is 135 mm/hr.

Soil test bed

The soil test bed is a 3-meter wide by 10-meter long (323 square feet) metal frame that is supported by two hydraulic cylinders near the upper end of the bed. These telescopic cylinders extend to tilt the test bed from its horizontal position to a 1V:2H slope gradient. The test bed is designed to support a 60-cm (2-feet) depth of soil, which is sufficient to allow placement and compaction of soil and the implementation of the various surface treatment practices to evaluate their effect on erosion rates.

The total usable surface area of the soil bed is 3 meters by 10 meters; however, only a portion of the treated bed, 2 meters wide by 8 meters long, is typically delineated for evaluation by the use of metal edging. Runoff and sediment are directed to a flume at the toe of the slope and conveyed to collection containers placed on the floor beneath the bed.

Water treatment and storage

In order to obtain accurate results from the rainfall simulation/erosion rate evaluations, the municipal water supply is treated by reverse osmosis and softened to remove minerals. The water treatment system consists of a reverse osmosis unit, preceded by one activated carbon vessel and two softening vessels arranged in series. Treated water is stored in a 3,785-liter (1,000-gallon) polyethylene storage tank for use in the laboratory simulations. When the simulators are transported for the outdoor, vegetative coverage tests, truck-mounted tanks are used to deliver treated water for rainfall simulations.

SOIL ROUGHNESS TESTING

Soil roughening is the creation of a soil surface roughness by mechanical means. Typically, the roughening is performed parallel to the slope contours and perpendicular to the direction of runoff. The benefits provided by soil roughening are slowing runoff, enhancing infiltration, moderating soil temperature, trapping moisture, and enhancing seed germination and root penetration.

To evaluate the effectiveness of different roughness techniques in reducing erosion rates for different storm events, roughness tests were conducted at the SDSU/SERL using simulated storm events corresponding to the 5-year, 10-year, and 50-year storms for the Los Angeles area. All tests were run on a 2 meter wide x 8 meter long plot, using a clayey sand soil, on a 1V:2H slope, with three (3) replications of each test condition.

Runoff water and sediment collected at the end of the test bed were separated mechanically. Water volumes and sediment weights were recorded separately for each test replicate and each storm type. Runoff water was reported as clear (supernatant) volume in liters, and sediment was reported as dry weight in kilograms.

Roughness types that were tested included:

- Smooth-rolled soil: The characteristics of a smooth-rolled, compacted surface were simulated by placing soil in the test bed, tilling it to uniform consistency, compacting it with hand tools, and lightly raking the surface.
- Trackwalking: The characteristics of a trackwalked surface were simulated by first preparing the soil to a smooth-rolled condition, then placing a metal template on the surface to produce the required roughness. Three tracks from a Caterpillar D-9 bulldozer were welded together to form a template for the trackwalking procedure. A small gasoline-powered compactor was used to compress the tracks into the soil surface.
- Sheepsfoot-Rolling: The roughness characteristic of a sheepsfoot-rolled slope was accomplished by designing and utilizing hand tools to create the appropriate impression in the soil surface. As with other roughness techniques, the soil surface was first tilled and compacted by hand before application of the sheepsfoot tool.
- Ripping: To simulate the effect of ripping the surface with bulldozer tines, the soil was first tilled and compacted by hand. Following hand compaction, the soil surface was ripped to a depth of 10 cm (4 in.) using a hand pick. The ripping was done perpendicular to the flow of water down the slope, with each incision 30-35cm (12-14 in.) apart.
- Imprinting: The characteristic pattern of an imprinter/roller was replicated by utilizing a hand tool designed and constructed to the dimensions of an actual imprinting machine. The orientation, depth, and spacing were monitored and adjusted for consistency of surface preparation.

Roughness techniques are important for permanent stabilization in three ways:

1. Most techniques can be accomplished with existing on-site equipment so finished slopes have a margin of temporary protection until permanent vegetation is established.
2. Roughness techniques complement most erosion control methodologies (i.e., hydraulic soil stabilization) making them perform better.
3. Roughness techniques, through increased infiltration and decreased runoff of water, improve vegetation establishment.

Results

Dry sediment weight was subjected to an analysis of covariance with roughness treatment and storm type as treatment factors and total runoff volume as the covariate. Storm type and roughness treatments were highly significant, as was the interaction between the two. Thus, both storm type and roughness treatment influenced sediment weight, with the effects of different roughness treatments depending significantly on storm type. The covariate effect was not statistically significant, but was strongly related to storm type. This may reflect the fact that storm type is affected by factors other than just runoff (e.g., rainfall intensity) that were not specifically addressed in this study.

The weight of discharged sediment was normalized based on the unit surface area of the test bed and rainfall volume. Overall, sediment discharge increased more with increased storm intensity than increased storm volume (each Type (2) storm had a lower intensity and higher volume than the Type (1) storm for the same return period). Ripping produced slightly lower sediment yields than the smooth-rolled (baseline). Sheepsfoot-rolling and trackwalking produced even lower sediment yields, and were not significantly different from one another. Imprinting produced significantly lower sediment yields than any other treatment considered in this experiment. The superiority of the imprinting treatment was roughly consistent across all the tested storm types.

When making a decision as to which soil stabilization practice to implement on a site, it is important to compare the performance of a particular technique over a broad range of storms that might be encountered during the construction period (e.g., 5-yr, 10-yr, 50-yr). Therefore, a practical interpretation of the roughness data is expressed in the last column of Table 1. This column shows the average, relative increase or decrease in erosion or runoff for a particular roughness practice, as compared to smooth rolled, over a wide range of storm events.

The results of the soil roughness tests (normalized erosion rate and runoff) are summarized in Figure 1. From Figure 1, some general statements can be made:

- The imprinting technique appears to be the most effective practice in reducing erosion (76 percent decrease in soil loss);
- Sheepsfoot-rolling and trackwalking provide a good level of erosion control (55 percent and 52 percent decreases in soil loss, respectively);
- Ripping provides the least effective erosion control (12 percent decrease in soil loss), but is most effective in reducing runoff (19 percent decrease in runoff).

FIELD TESTING FOR VEGETATION DENSITY AND EROSION RATE

The purpose of the outdoor laboratory testing was to demonstrate and quantify the inverse relationship between vegetative cover and rate of erosion; that is, as vegetation coverage increases, soil erosion rate decreases. Two test locations were selected within the Los Angeles Basin. Both sites were within Caltrans' right-of-ways, with one being comprised of a fill slope and the other site a cut slope. At each site three replicate, 2-meter wide x 8-meter long plots were established utilizing metal edging and flumes to differentiate the side-by-side test areas.

Each 2-meter x 8-meter plot was planted with 33 containerized plants of *Myoporum sp.* *Myoporum* was chosen because its rapid growth characteristics were well suited for the testing time frame and because it is typically used for re-vegetation along Caltrans rights-of-way. The plants were irrigated and grown to 100 percent coverage. Over a period of 10 monoths, the plots were systematically pruned to cover percentages of 35, 50, 65, 80, and 95 percent. Immediately following each pruning, the rainfall simulators from the SDSU/SERL were used to rain on the plots. Runoff and sediment was collected from each test and transported to the SDSU/SERL for analysis.

This portion of the ECPS evaluated the effect of percent cover on erosion rate and runoff volume under one test storm type (the 10-year (2) storm for the Los Angeles area). Runoff water and sediment collected at the end of each test plot were separated mechanically. Water volumes and sediment weights were recorded separately for each test plot, each site and for each vegetative cover percentage. Runoff water was reported as clear (supernatant) volume in liters, and sediment was reported as dry weight in kilograms.

Results

Means and standard deviations of normalized erosion rate in kg/m^2/mm and runoff for the outdoor *Myoporum* tests are presented in Figures 2 and 3. The total weight of sediment recovered from each test was measured in the SDSU/SERL. Sediment results were normalized by plot size and rainfall depth. For the cut slopes, the data indicates a trend of decreasing erosion rate with increased percent cover. The data for the fill slope show less of a trend, decreasing at first (between 35 and 50 percent cover), then exhibiting a slight increase in erosion rate with increasing cover. The reason for this difference is due to the effects of gopher activity on the fill slopes.

Runoff amounts and sediment weights were subjected to analyses of variance using slope type (site) and percent cover as treatment factors. From the data, it appears that percent cover significantly influenced runoff, but slope type (cut or fill) did not. Both percent cover and slope type significantly influenced sediment weight. The interaction between the two factors also significantly influenced sediment.

SOIL STABILIZATION MEASURES

This part of the ECPS addressed the erosion control effectiveness of alternative erosion control products. The soil stabilization measures provide a second step (after soil roughening) in the process of establishing permanent erosion control vegetation. The 15 soil stabilization measures that were evaluated are typically used in the early stages of slope stabilization. Since vegetation takes time to grow and may not provide effective erosion control for several months to years, the soil stabilization measures provide interim erosion control, and provide a nurturing environment for seeds and plants to become established. Data collected during this portion of the study were evaluated to establish a rank order of erosion control effectiveness under the conditions of the test.

Erosion rate tests

The erosion rate tests on 15 soil stabilization measures were performed at the SDSU/SERL indoor laboratory on a 1V:2H slope of clayey sand soil, using the 10-year (2) storm event for the Los Angeles area. The plot configuration consisted of three (3) replicate plots within the simulator test bed, each 0.66 meters wide x 8 meters long

These measures included the following:

- Bare soil (BARE)
- Bonded fiber matrix (BFM)
- Coconut blanket (CB)
- Coir blanket (COIR)
- Compost (COMP)
- Curled wood fiber blanket (CWFB)
- Gypsum treatment (GYP)
- Paper mulch with psyllium (PMG)
- Paper mulch with polymer (PMP)
- Wheat straw incorporated (RS)
- Straw blanket (SB)

- Straw-coconut blanket (SCB)
- Wood fiber blanket (WFB)
- Wood mulch with psyllium (WMG)
- Wood mulch with polymer (WMP)

During the test, all sediment and runoff were collected in containers at the end of the test bed and separated mechanically. Water volumes and sediment weights were recorded separately for each test replicate. Runoff water was reported as clear (supernatant) volume in liters, and sediment was reported as dry weight in kilograms.

Results

Results of the erosion rate study with respect to normalized erosion rate and percent change in runoff for the soil stabilization measures that were tested are shown in Figure 4. Overall, the table illustrates that all of the erosion control products tested greatly reduced the amount of soil loss.

The range of erosion control performance in this study was consistent with what has been observed in previous rainfall simulation testing at both the Utah Water Research Laboratory (UWRL) and the Texas Transportation Institute (TTI):

- Erosion control effectiveness of most rolled erosion control products (RECPs) is in the 90-100% range;

- Hydraulic applications of bonded fiber matrix (BFM) perform in the same range of effectiveness as RECPs; and

- Hydraulic applications of mulch (wood fiber or paper) are notably less effective in controlling erosion, although in this study their performance appears to be substantially enhanced by the addition of a binder (psyllium or polymer).

Based on the results of this laboratory study, each of the treatments was rated according to its effectiveness in reducing erosion rate (Figure 5). Figure 6 illustrates the increase or decrease in runoff from the plots tested as compared to runoff from the bare plots. Six of the products resulted in a decrease in runoff, with the largest decrease (approximately 90 percent) coming from the coconut blanket (CB) plot. Eight of the products resulted in increased runoff.

Evaluation of the change in the runoff of the treated plots compared to the bare soil (control) condition yielded the anticipated results; that is, the more physically stable materials (i.e., RECPs, BFM, incorporated straw) were more successful at decreasing runoff.

There were, however, some notable exceptions:

- The coconut blanket (CB) performed at a higher rate than expected. This is possibly due to retention of sediment and water at the toe of the plot. This phenomenon, observed in many field applications, creates a “pillow” of water and sediment behind the closely-woven fibers of coconut at the downslope portion of the blanket where it is trenched in or heavily stapled.

- The paper mulch with polymer binder (PMP) reduced runoff at a much higher rate than similar hydraulic applications. From the material’s historic performance in similar tests (USWRL/TTI) one would have expected an increase in runoff similar to the paper mulch with psyllium (PMG), wood mulch with psyllium (WMG), and wood mulch with polymer (WMP) plots.

CONCLUSIONS

The objective of the ECPS was to evaluate alternative permanent soil stabilization methods designed to minimize the transport of sediment from cut and fill slopes within Caltrans District 7 rights-of-way to storm drain inlets. The basic assumption of the pilot study was that erosion of slopes can be reduced by increasing the percentage of vegetative cover on cut and fill slopes to provide soil protection from wind and water.

Evaluation of slope roughness

Soil roughening is complementary to most soil stabilization techniques, such as hydraulic mulches that can be applied over the surface roughness treatment. The surface roughness provides a permanent slope surface configuration that works in conjunction with the short-term soil stabilization and permanent vegetation to provide an effective erosion control system.

Five surface roughness techniques were evaluated as part of this study: smooth rolling, sheepsfoot-rolling, ripping, trackwalking, and imprinting. The five soil roughness techniques were evaluated against one criterion, erosion rate. The five techniques were rated with respect to how they performed during the erosion rate testing.

Vegetative Cover

Low percent cover (less than 50%) of *Myoporum* leads to large amounts of runoff. Higher values of percent cover (greater than 50%) lead to lower amounts of runoff; however, values of percent cover (65% or more) do not differ appreciably in their ability to reduce runoff. The pattern is different for sediment loss. High values of percent cover (90% or greater) lead to low sediment losses, intermediate values of percent cover (65% to 85%) lead to intermediate sediment losses, and low values of percent cover (50% or less) lead to high sediment losses.

Soil Stabilization Measures

The soil stabilization measures tested in this study can be ranked in accordance with the criteria that were evaluated as part of the ECPS testing program, such as erosion rate and runoff volume. However, testing of these materials does not indicate approval or disapproval of a particular method. At this time, Caltrans does not hold any method or material to a numerical standard of performance, since there are other evaluation criteria that should be considered when selecting an appropriate erosion control measure for a given set of site conditions. Examples of other selection criteria include:

- Long-term cost (maintenance)
- Environmental compatibility
- Regulatory acceptability
- Availability
- Durability
- Longevity
- Feasibility
- Public acceptability
- Risk/liability
- Suitability for the site

These site and project-specific criteria can be added to the numerical quantification of erosion control performance obtained from the ECPS. Field and design engineers thus have a wealth of new information on which to make sound decisions when selecting from a diverse group of erosion control materials and methods.

Figure 1
RESULTS OF RAINFALL SIMULATION TESTING FOR ROUGHNESS

Treatment	Measurement	Statistic	Storm						Average Increase (+) Decrease (-)
			5-yr (1)	5-yr (2)	10-yr (1)	10-yr (2)	50-yr (1)	50-yr (2)	
Smooth	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.06	0.07	0.16	0.09	0.12	0.09	
		St. Dev.	0.03	0.07	0.04	0.01	0.02	0.02	
		% of Smooth	100%	100%	100%	100%	100%	100%	0%
	Runoff (L)	Mean	255.7	364.4	419.2	470.3	422.3	611.0	
		St. Dev.	11.9	35.1	19.6	9.7	10.6	20.3	
		% of Smooth	100%	100%	100%	100%	100%	100%	0%
Imprinted	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.03	0.02	0.03	0.02	0.03	0.02	
		St. Dev.	0.03	0.19	0.11	0.12	0.04	0.05	
		% of Smooth	49%	26%	18%	25%	22%	19%	76% (-)
	Runoff (L)	Mean	222.3	415.6	380.8	446.6	464.4	501.8	
		St. Dev.	13.3	96.1	49.4	84.0	21.1	37.8	
		% of Smooth	87%	114%	91%	95%	110%	82%	4% (-)
Ripped	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.04	0.07	0.12	0.08	0.15	0.06	
		St. Dev.	0.18	0.03	0.07	0.04	0.01	0.09	
		% of Smooth	66%	99%	75%	88%	121%	71%	12% (-)
	Runoff (L)	Mean	154.2	276.3	387.3	416.3	373.5	443.4	
		St. Dev.	75.6	17.0	29.8	24.7	7.0	79.2	
		% of Smooth	60%	76%	92%	89%	88%	73%	19% (-)
Sheepsfoot	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.03	0.03	0.02	0.05	0.06	0.04	
		St. Dev.	0.03	0.14	0.06	0.03	0.04	0.03	
		% of Smooth	58%	46%	14%	56%	51%	46%	55% (-)
	Runoff (L)	Mean	361.3	374.8	525.1	511.8	503.3	584.4	
		St. Dev.	11.9	71.3	26.7	22.5	26.0	24.3	
		% of Smooth	141%	103%	125%	109%	119%	96%	12% (+)
Trackwalked	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.04	0.04	0.05	0.04	0.04	0.07	
		St. Dev.	0.11	0.05	0.08	0.06	0.09	0.04	
		% of Smooth	80%	60%	30%	40%	30%	80%	52% (-)
	Runoff (L)	Mean	218.7	448.3	460.7	468.5	410.6	579.9	
		St. Dev.	48.0	26.8	35.5	38.4	49.7	36.0	
		% of Smooth	86%	123%	110%	100%	97%	95%	2% (+)

Figure 2
RESULTS OF RAINFALL SIMULATION TESTING ON MYOPORUM TEST PLOTS

Percent Cover	Measurement	Statistic	Cut Slope	Fill Slope
35	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.015	0.0078
		Std. Dev.	*0.0019*	*0.0079*
	Runoff (L)	Mean	303.7	96.9
		Std. Dev.	*80.7*	*6.0*
		As % of Rainfall Volume	44%	14%
50	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.0049	0.0026
		Std. Dev.	*0.0019*	*0.0019*
	Runoff (L)	Mean	195.8	144.1
		Std. Dev.	*11.6*	*15.5*
		As % of Rainfall Volume	28%	21%
65	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.0019	0.0007
		Std. Dev.	*0.0008*	*0.0003*
	Runoff (L)	Mean	144.3	105.7
		Std. Dev.	*40.2*	*19.8*
		As % of Rainfall Volume	21%	15%
80	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.0029	0.0012
		Std. Dev.	*0.0024*	*0.0006*
	Runoff (L)	Mean	122.7	149.6
		Std. Dev.	*19.9*	*15.0*
		As % of Rainfall Volume	18%	21%
90	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.0003	0.0024
		Std. Dev.	*0.0002*	*0.0015*
	Runoff (L)	Mean	40.4	104.4
		Std. Dev.	*14.8*	*8.8*
		As % of Rainfall Volume	6%	21%

Figure 3
NORMALIZED EROSION RATE FROM MYOPORUM PLOTS BY PERCENT PLANT COVER

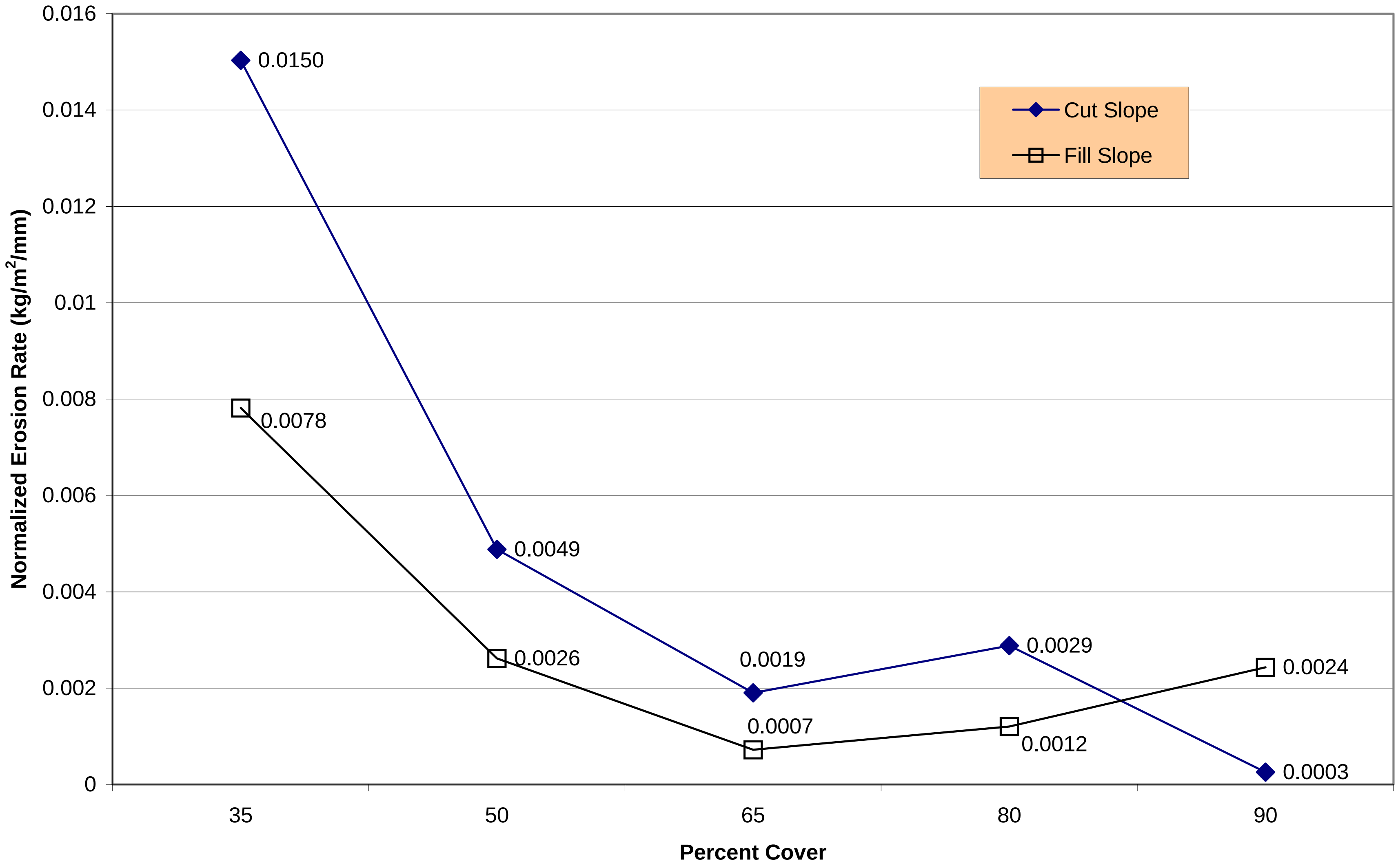

Figure 4

RESULTS OF EROSION RATE TESTS FOR SOIL STABILIZATION MEASURES (NORMALIZED SEDIMENT DATA)

Treatment	Measurement	Statistic	Value
Bare	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.116
		Std. Dev.	*0.038*
	Runoff (L)	Mean	153.9
		Std. Dev.	*0.3*
		% of Rainfall Volume	30%
Bonded Fiber Matrix (BFM)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.000
		Std. Dev.	*0.000*
	Runoff (L)	Mean	130.8
		Std. Dev.	*34.8*
		% of Rainfall Volume	26%
Coconut Blanket (CB)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.000
		Std. Dev.	*0.000*
	Runoff (L)	Mean	17.5
		Std. Dev.	*4.9*
		% of Rainfall Volume	3%
Coir (COIR)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.007
		Std. Dev.	*0.002*
	Runoff (L)	Mean	153.5
		Std. Dev.	*20.2*
		% of Rainfall Volume	30%
Compost (COMP)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.071
		Std. Dev.	*0.024*
	Runoff (L)	Mean	173.9
		Std. Dev.	*23.6*
		% of Rainfall Volume	34%
Curled Wood Fiber Blanket (CWFB)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.011
		Std. Dev.	*0.003*
	Runoff (L)	Mean	157.6
		Std. Dev.	*26.1*
		% of Rainfall Volume	31%
Gypsum (GYP)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.027
		Std. Dev.	*0.005*
	Runoff (L)	Mean	165.7
		Std. Dev.	*14.5*
		% of Rainfall Volume	24%
Paper Mulch with Polymer (PMP)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.029
		Std. Dev.	*0.003*
	Runoff (L)	Mean	94.6
		Std. Dev.	*8.2*
		% of Rainfall Volume	19%

Treatment	Measurement	Statistic	Value
Paper Mulch with Psyllium (PMG)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.045
		Std. Dev.	*0.016*
	Runoff (L)	Mean	195.7
		Std. Dev.	*10.8*
		% of Rainfall Volume	39%
Straw Blanket (SB)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.002
		Std. Dev.	*0.000*
	Runoff (L)	Mean	126.0
		Std. Dev.	*24.7*
		% of Rainfall Volume	25%
Straw-Coconut Blanket (SCB)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.004
		Std. Dev.	*0.002*
	Runoff (L)	Mean	157.1
		Std. Dev.	*6.8*
		% of Rainfall Volume	31%
Wood Fiber Blanket (WFB)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.002
		Std. Dev.	*0.000*
	Runoff (L)	Mean	182.7
		Std. Dev.	*14.3*
		% of Rainfall Volume	36%
Wood Mulch with Polymer (WMP)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.058
		Std. Dev.	*0.008*
	Runoff (L)	Mean	226.6
		Std. Dev.	*8.1*
		% of Rainfall Volume	45%
Wood Mulch with Psyllium (WMG)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.015
		Std. Dev.	*0.003*
	Runoff (L)	Mean	182.4
		Std. Dev.	*8.5*
		% of Rainfall Volume	36%
Wheat Straw Incorporated (RS)	Normalized Erosion Rate (kg/m^2/mm)	Mean	0.005
		Std. Dev.	*0.004*
	Runoff (L)	Mean	112.7
		Std. Dev.	*12.6*
		% of Rainfall Volume	22%

Note: Gypsum (GYP) erosion rate was tested as part of the Soil Stabilization for Temporary Slopes study that was performed between September and December 1999. Specific results for that study were presented in a *Field Guide* and supporting *Guidance Document*, dated November 30, 1999.

Figure 5
PERCENT EROSION REDUCTION FROM BARE SOIL

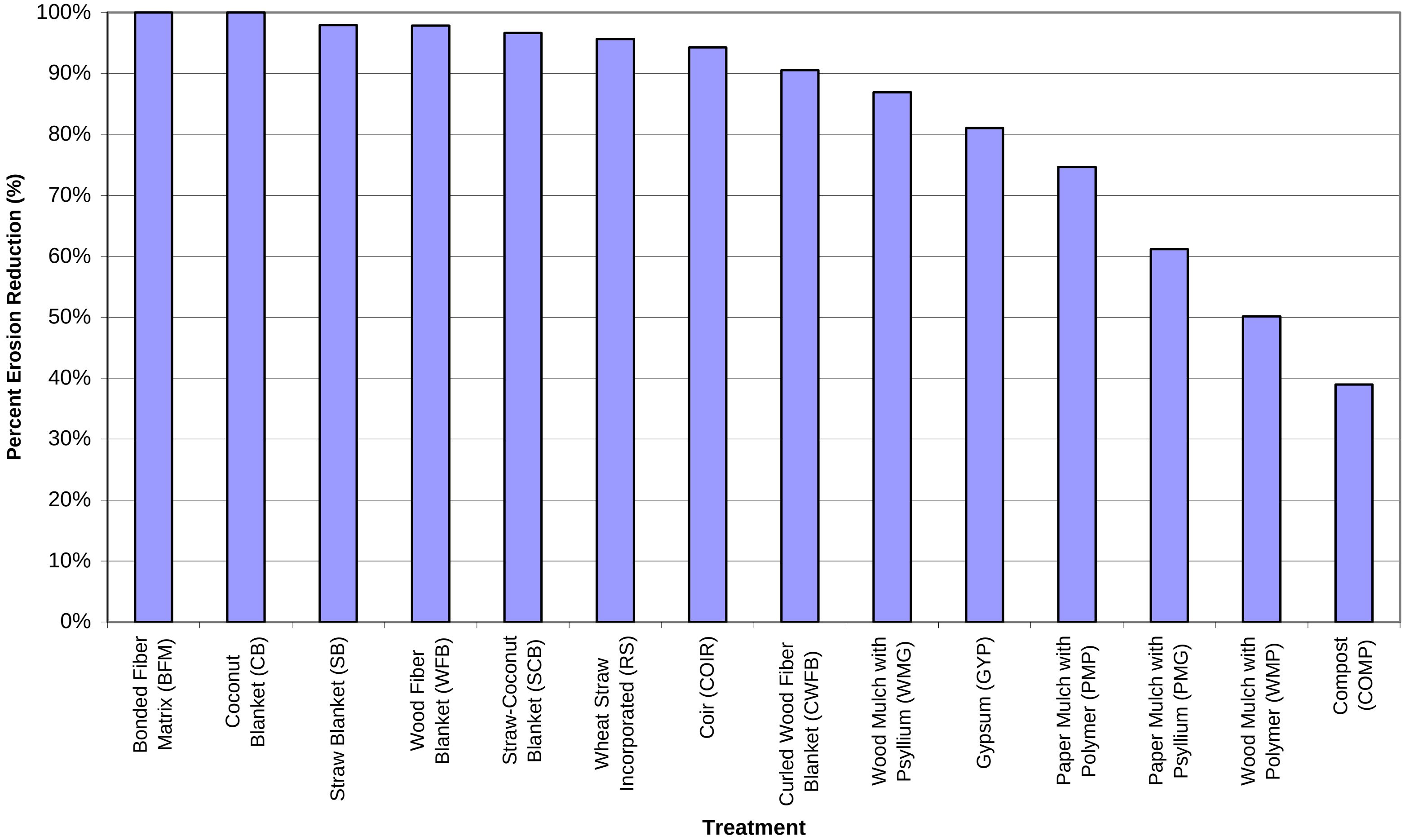

Figure 6
PERCENT CHANGE IN RUNOFF FROM BARE SOIL