

Results
from a Study of
EarthGuard[®] Fiber Matrix
for Soil Stabilization:

Runoff Characteristics and Sediment Retention
Under Simulated Rainfall Conditions

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1.0 THE SAN DIEGO STATE UNIVERSITY SOIL EROSION RESEARCH LABORATORY (SDSU/SERL)

The San Diego State University Soil Erosion Laboratory (SDSU/SERL) integrates beneficial features from some of the primary soil erosion research facilities in the United States. Funding for the facility was provided by Caltrans, the California State Department of Transportation as part of a 1998-2000 erosion control pilot study, in which design, construction and operation of the SERL was supervised by URS Greiner Woodward Clyde and SDSU faculty. Actual modification of Industrial Technology Building Room #103 and construction of the soil test bed was carried out by the SDSU Physical Plant.

In designing the SDSU laboratory, members of the Caltrans pilot study team studied the physical layout, testing protocols, and past research activities of the following erosion laboratories:

Utah Water Research Laboratory (UWRL) at Utah State University, Logan, Utah;

USDA-Agricultural Research Service National Soil Erosion Research Laboratory (NSERL) at Purdue University, West Lafayette, Indiana; and

Texas DOT/Texas Transportation Institute (TTI) Hydraulics and Erosion Control Laboratory at Texas A & M, College Station, Texas.

Aspects of the SDSU Soil Erosion Laboratory design that resulted from examination of these facilities include the following:

Table 1.1: Design Features of Soil Erosion Laboratories

Design Feature	Erosion Facility
Norton Ladder Rainfall Simulator	NSERL
Hydraulically-lifted soil bed	UWRL
12-inch soil depth placed on porous, open-grid system for drainage	UWRL, NSERL
Suction chamber to speed up drying of soil between runs	UWRL
Procedures for collection of runoff and sediment samples	UWRL, NSERL, TTI
Confirmation of test plot size	UWRL, NSERL
Number of replicates for each test	UWRL, NSERL

These and other important design features of the SDSU Laboratory are described below.

1.1 Norton Ladder Rainfall Simulator

The rainfall simulation device selected for the SDSU Soil Erosion Laboratory is the Norton Ladder Rainfall Simulator, which was developed at the USDA-ARS National Soil Erosion Research Laboratory by Dr. Darrell Norton. This apparatus has been used worldwide, is reasonably inexpensive, and is easily transported and operated. The Norton simulator is reliable and is documented as giving reproducible results.

For testing in the indoor laboratory, multiple simulators (4) have been installed in parallel above the soil test bed to uniformly apply precipitation over the entire test plot area. The pre-fabricated rainfall devices were purchased from Advanced Design & Machine (Clarks Hill, Indiana), an experienced manufacturer specializing in production of the Norton simulator.

Physical Characteristics

The basic unit of the simulator is an aluminum frame 5.3 meters long, 0.32 meters wide, and 0.25 meters deep. Each frame is a self-contained unit, which includes nozzles, oscillating mechanism, drive motor, pump, float valve, piping, and sump.

The drop former used for the Norton simulator is the Spraying Systems Veejet 80100 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 rain storms when the nozzle is at least 2.4 meters above the soil surface. For this reason, the rainfall simulators used in the SDSU Soil Erosion Laboratory have been 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.

Design of Simulated Rainfall

Prior to testing, the Norton ladder-type simulators are placed into position above the soil test bed. Calibration is achieved by conducting rainfall tests and measuring rainfall volumes in collection devices placed at precise intervals within the 2 meter x 8 meter test plot. A full range of rainfall intensities can be achieved by adjusting either one, or both of the following parameters:

- The number of sweeps per minute (spm) of the spray nozzles, ranging from 25 to 125 spm.
- Adjusting the water pressure within the supply system. Each simulator has a system of valves that allow internal water pressure to be adjusted from a low of 2 psi to a high of 6 psi. Gauges atop each simulator allow for accurate, manual adjustment.

Simulated rainstorm events utilized for most of the current testing at the SDSU/SERL have an initial period (Part 1) of low intensity rainfall, followed by a period (Part 2) of relatively high intensity rainfall, and ending with a period (Part 3) of relatively low intensity rainfall.

1.2 Soil Test Bed

The soil test bed is a 3-meter wide by 10-meter long (323 square feet) metal frame which rests on a series of pivots located at the lower end of the bed, and 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 maximum 2H:1V slope gradient.

The test bed is designed to support a 30.5-cm (1-foot) depth of soil. The depth of 30.5 cm is sufficient to allow placement and compaction of soil and the application of various surface erosion control practices to evaluate their effect on erosion rates.

The sides and ends of the soil test bed are constructed of steel frame-supported 1.0-cm thick Plexiglas which allows ambient light onto the soil surface, and facilitates viewing of the effects of rainfall impact and runoff. The total usable surface area of the soil bed is 3 meters wide by 10 meters long, but during testing only a portion of the treated bed, 2 meters wide by 8 meters long, is generally delineated for evaluation by the use of plastic edging. Runoff and sediment are collected at the toe of the slope by a metal flume.

Drainage grates have been installed in the floor underneath and at the front of the soil bed, and all runoff not collected is directed to a sanitary sewer. As a safety precaution, stationary steel support posts are placed beneath the bed when it is raised for rainfall simulations.

1.3 Hydraulic System

The soil test bed has been designed to be lifted hydraulically to the desired slope inclination for testing. Two 5-stage, single-acting, telescopic cylinders are positioned approximately 3.0 meters (10 feet) from the top of test bed. The cylinders, which weigh 505 lbs each, have a 20.3-cm (8-inch) diameter as the largest moving stage.

The complete hydraulic system consists of the cylinders, a 60 gallon hydraulic fluid reservoir, a 30 gpm hydraulic pump, and a 50 hp electric motor with motor starter. Also included are a suction strainer, return oil filter, pressure relief valve, and a directional control valve.

1.4 Sediment Collection System

Water and soil runoff from the test bed is collected by plastic edging, flume, and collection containers. The components of the sediment collection system on the test bed are installed prior to each rainfall simulation. For most erosion control treatment evaluations, the plastic edging is installed prior to application of the erosion control treatment.

1.5 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. This treatment process produces “softer” water that is more similar in quality to natural rainfall. Using municipal water without treatment would cause a decrease in sediment load, because minerals in the water serve to decrease erosion.

Water Treatment System

The water treatment system consists of a reverse osmosis unit, preceded by one activated carbon vessel and two softening vessels arranged in series (i.e. carbon/softener/softener). The system, which is capable of producing 300-600 gallons per day (1,140-2,270 liters per day), also includes a pre-filter to remove particulates greater than 5 microns in size that may escape the service vessels. The system is serviced monthly by U.S. Filter.

Delivery of water to the rainfall simulators positioned above the soil test bed is by a pump attached to hard plumbing and flexible hoses. A key aspect of the Norton design is that unused water from within the simulators is returned to the holding tank and available for reuse. Flexible plumbing is installed to accommodate this return flow.

Treated Water Storage

Treated water is stored in a 1,000 gallon (3,785 liter) polyethylene storage tank for use in the laboratory simulations. For outdoor test plots, two 200 gallon (757 liter) tanks are truck or trailer-mounted to deliver treated water to the field for rainfall simulations.

2.0 EARTHGUARD® FIBER MATRIX STUDY

2.1 Introduction

There are numerous chemicals marketed to the erosion control industry that when added to water, form emulsions. These materials range from simple plant mucilages to complex synthetic formulations. When applied hydraulically to the soil surface, either with or without the benefit of fibrous mulch, these emulsions provide varying degrees of soil stabilization.

EarthGuard as manufactured by Terra Novo, Inc. is chemically classified as a copolymer of acrylamide/sodium acrylate. Some of the beneficial uses claimed by the manufacturer include:

- | | | |
|---------------------------|----------------------------|----------------------------|
| * Erosion Control | * Slope Stabilization | * Dust Abatement |
| * Landscape Design | * Storm Water Runoff | * Fire Burn Rehabilitation |
| * Land Development | * Golf Course Construction | * Re-Vegetation Projects |
| * Silt Reduction Projects | * Water Quality Control | |

According to the manufacturer, Terra Novo, Inc., **EarthGuard** is effective immediately and can be applied in any kind of weather. The stabilizer can be applied by itself for temporary erosion control lasting up to a few months. **EarthGuard** can also be mixed with seed and mulch to create a *fiber matrix* (FM) increasing water penetration and retention time leading to improved seed germination, plant and sod establishment.

It was *the combination of EarthGuard soil stabilizing emulsion and hydraulic fiber* that was examined in this study to determine its effect on soil erosion and runoff. According the test material was classified as **EarthGuard Fiber Matrix (FM)**, as marketed by Terra Novo, Inc.

Typical equipment used for applying the **EarthGuard FM** includes:

- Hydro-seeders
- Aerial application by helicopters.

2.2 Study Objectives

There were three (3) main objectives for the **EarthGuard Fiber Matrix (EGFM)** study:

- 1) To provide scientific, reproducible and defensible data on the effectiveness **EarthGuard FM** to reduce runoff and control erosion.
- 2) To relate these tests to previous evaluations of other erosion control materials and methods under similar test conditions.
- 3) To present the results of the testing in a format useful to field engineers in the design and specification of **EarthGuard FM** for stabilization of steep slopes against erosion.

2.3 Test Procedures

The test procedures followed for the **EarthGuard FM** study were adapted from portions of the testing protocols developed for the *Slope Stabilization for Temporary Slopes Study (Caltrans, October 1999)* and the *Caltrans Erosion Control Pilot Study (June 2000)*.

Test Conditions

- The soil used was classified as a clayey sand (SC)
- The test area was 2 meters wide x 8 meter in length
- The storm event was a 10-year storm as predicted for the Los Angeles Basin (5 mm for 30 minutes/40 mm for 40 minutes/5 mm for 30 minutes)
- The slope was 1V:2H
- Three replications for the bare soil (control) and three replications for the treated condition were performed, yielding a total of six (6) tests.

Bed Preparation

- Prior to each test, soil in the bed was removed to a depth of 3-4" and replaced with new, untested soil.
- The new soil was moisturized, tilled and hand-compacted to uniform consistency.
- Edging and flumes were installed to differentiate a 2m x 8m plot.
- Prior to all testing, the surface of the compacted soil was loosely raked.

Application

Prior to each rainfall event, and under the manufacturer's supervision, the **EarthGuard** was mixed with water in a Finn 300 gallon hydroseeder at the rate 0.33 gallons of **EarthGuard** product per 200 gallons of water. Additionally, 50 pounds of recycled paper fiber and 50 pound of wood fiber were added and the mixture was allowed to blend for ten minutes. The matrix was then applied to the soil test bed at the rate of 10 gallons of **EarthGuard** and 3,000 pounds of fiber per acre using a standard fan nozzle.

Rainfall Event

- Rainfall consisted of a 10-year storm event as modeled from Los Angeles Basin hydrologic data, consistent with those values of the Caltrans SSTS Study (October 1999) and the Caltrans ECPS Study (June 2000).
- The intensity and duration of the storm were as follows:
 - Period 1: 5 millimeters/hour rain for 30 minutes
 - Period 2: 40 millimeters/hour rain for 40 minutes
 - Period 3: 5 millimeters/hour rain for 30 minutes
- Settings on the rainfall simulators to achieve these intensities were based on previous calibrations conducted at the laboratory.

Sample Collection and Analysis

- Water and sediment were collected at the downstream (toe) end of the flume in polyethylene lined, 35 gallon containers.
- At the end of each rainfall event, 500 grams of gypsum was added to each collection barrel to aid in settling out the fine sediments.
- The samples were allowed to settle overnight (24 hours)
- The supernatant, or clear water, was siphoned from each container, and its weight and volume recorded.
- The weight of the remaining wet sediment was recorded.
- A sample of the remaining wet sediment was taken and placed in an oven overnight to determine moisture content of the wet sediment.
- The moisture content of the wet sediment sample was used to determine the total dry sediment weight of the collected sediment.

3.0 RESULTS

Tables 3.1 and 3.2 show the results of the laboratory analysis of sediment weight and runoff volumes for each of two test conditions:

- Table 3.1 presents the sediment and runoff yield from the bare soil (control) plots.
- Table 3.2 presents the sediment and runoff yield on the **EarthGuard Fiber Matrix**

Table 3.1: Sediment and Runoff Yield for Bare Soil (control)

SEDIMENT LOSS					
Soil loss (kg)	Rep #1	Rep #2	Rep #3	Rep #4	Avg. Total (kg)
Period 1	0.10	0.45	2.33	0.16	0.76
Period 2	54.46	44.19	50.36	43.90	48.23
Period 3	2.20	2.59	4.75	4.45	3.50
Ave. total (1,2,3 periods)					52.49
RUNOFF					
Runoff (L)	Rep #1	Rep #2	Rep #3	Rep #4	Avg. Total (L)
Period 1	11.43	20.34	19.32	15.52	16.65
Period 2	375.25	336.82	354.87	312.40	344.84
Period 3	57.22	63.75	62.92	53.69	59.40
Ave. Total (1,2,3 periods)					420.88

Table 3.2: Sediment and Runoff Yield for EarthGuard Fiber Matrix

SEDIMENT LOSS					
Soil loss (kg)	Rep #1	Rep #2	Rep #3	Rep #4	Avg. Total (kg)
Period 1	0.00	0.00	0.00	0.00	0.00
Period 2	4.03	1.98	1.39	0.63	2.01
Period 3	0.39	0.61	0.14	0.76	0.48
Total (1,2,3 periods)					2.48
RUNOFF					
Runoff (L)	Rep #1	Rep #2	Rep #3	Rep #4	Avg. Total (L)
Period 1	7.19	7.57	13.25	3.79	7.95
Period 2	272.73	266.37	278.68	115.09	233.22
Period 3	78.94	50.18	74.51	45.07	62.18
Total (1,2,3 periods)					303.34

Figures 3.1 and Figure 3.2 provide relative comparisons of sediment weights and runoff volumes for each slope condition. The data illustrate that the use of **EarthGuard Fiber Matrix** reduced erosion and sediment delivery by approximately 95% when compared to the untreated soil condition (Figure 3.1). Runoff from the treated plot was significantly lower, approximately 28% less than that of the untreated bare soil control plot (Figure 3.2).

Figure 3.1: Comparison of Relative Sediment Loss

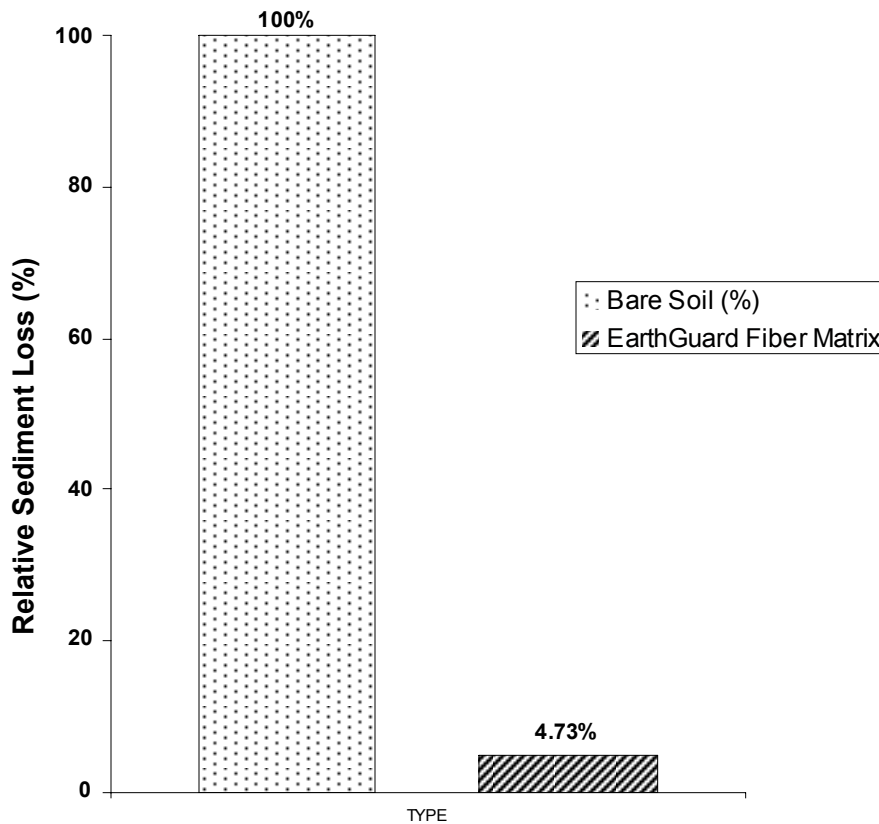
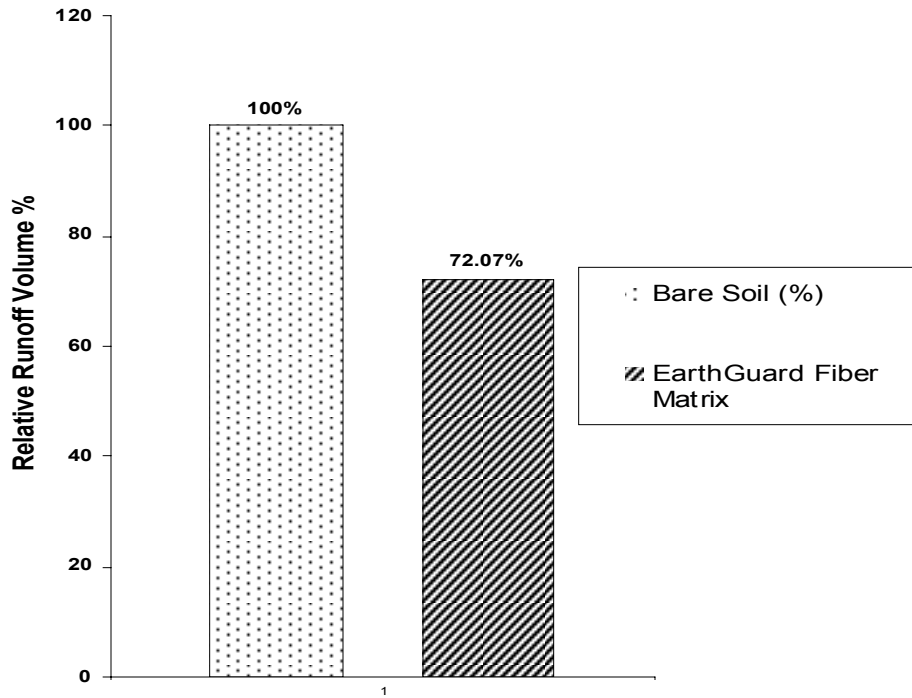


Figure 3.2: Comparison of Relative Runoff Volumes



Figures 3.3 and 3.4 illustrate the cumulative sediment delivery and runoff volume over the duration of the test (1 hour and 30 minutes).

Figure 3.3: Sediment Loss Over Time

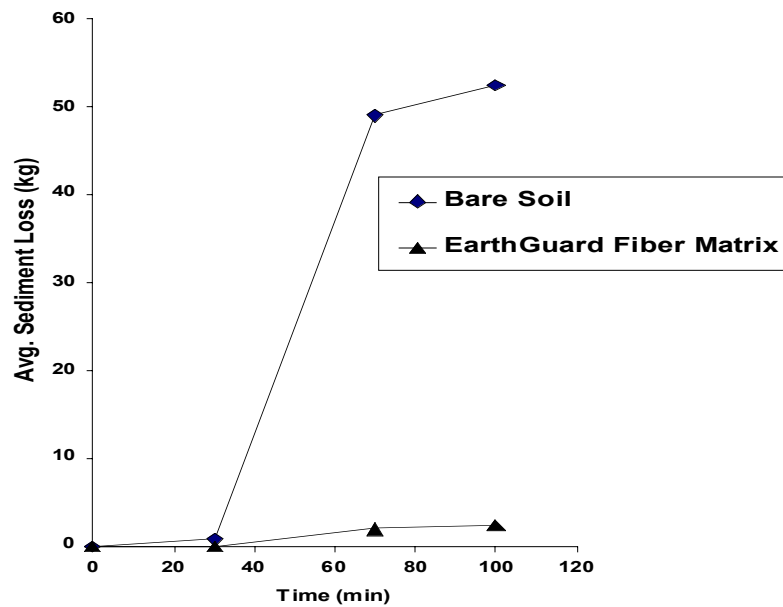
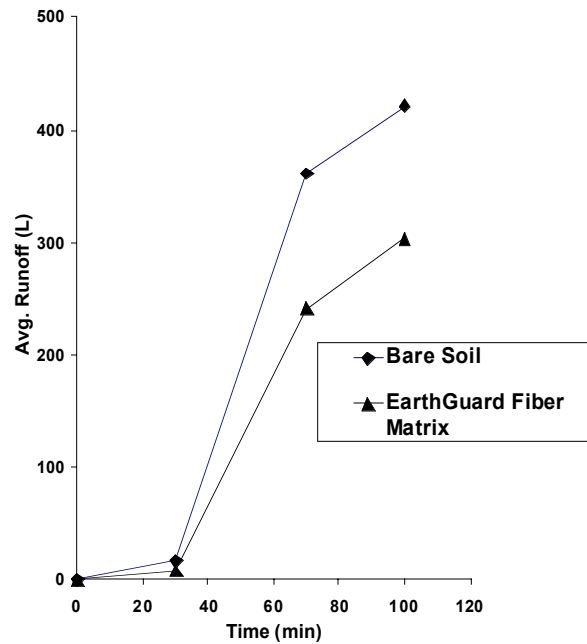


Figure 3.4: Runoff Volume Over Time



4.0 CONCLUSIONS

The data from this series of tests appear to support the use of **EarthGuard Fiber Matrix (EGFM)** to reduce soil erosion and off-site delivery of sediment from steep slopes. A 95+% reduction in sediment delivery/weight is a high level of performance comparable to the best performing best management practices such as some rolled erosion control products (RECPs) and bonded fiber matrices (BFMs). The **EarthGuard Fiber Matrix** manufacturer, Terra Novo, Inc. claims an installed cost of \$0.035-\$0.06 per square foot compared to \$0.085-\$0.15 for BFMs and RECPs. A reduction in runoff of around 28% is consistent with most surface-applied fibers, where retention of moisture in the soil is beneficial to plant establishment and growth.

Figures 3.3 and 3.4 seem to support a conclusion that once saturated, soils treated with **EarthGuard Fiber Matrix** appear to erode and release water at a steady rate. The same can be said for the bare soil control plots. These results are consistent with previous testing of hydraulically-applied products at the SDSU/SERL.

Previous testing at the SDSU Soil Erosion Research Laboratory has demonstrated the variable effectiveness of different surface treatments, such as other hydraulically-applied soil binders, bonded fiber matrices and rolled erosion control products to control soil erosion. Recent tests have also shown that changes in the surface roughness of a soil – such as trackwalking, sheepsfoot rolling or imprinting - can also have a dramatic impact in reducing soil erosion. It is therefore reasonable to conclude that the application of **EarthGuard Fiber Matrix** in combination with a surface roughening treatment such as trackwalking or imprinting can provide a highly-effective means of soil erosion control.

APPENDIX A: Compaction of Soil within the Test Bed

Compaction Procedures:

The placement and preparation of soil in the test bed can be divided into two distinct activities: 1) the initial “filling” of the test bed with a base layer of compacted soil 30-40 cm (12-16 inches) in depth, and 2) the creation of a second 10 cm (4 inches) “testing” layer of soil on top of the fill layer.

1) The “fill layer” of soil is placed in the bed in 10 cm (4 inches) lifts. Each lift is moistened to optimum moisture content as determined by an initial series of Modified Proctor tests (ASTM D1557) for the soil being evaluated. A mechanical wacker is used to compact each lift. Following compaction, eight randomly positioned sand cone tests are performed (ASTM D1556) to verify 95% relative compaction of the fill layer.

2) After placement of the fill layer and compaction as described, the top 10 cm (4 inches) of compacted soil is loosened using a rotor-tiller. After tilling, the soil is then re-compacted by hand using an 20 cm x 20 cm (8 inch x 8 inch) hand tamp weighing 5 kg (11 pounds). Following hand-tamping, the soil is lightly raked perpendicular to the length of the test plot and is considered ready for testing.

Following each rainfall simulation test, the eroded soil is removed to a depth of 5-10 cm (2-4 inches) depending on saturation and replaced with new untested soil from storage bins located inside the laboratory. The rotor-tilling and hand compaction steps are then repeated in preparation for the next test.

Sand Cone Testing Procedures (ASTM D1556):

1. Prepare a level surface in the fill and dig a cylindrical hole about 5in. (125 mm) in diameter and about 5in. (125 mm) deep. Save all of the soil that comes out of the hole and determine its weight.
2. Fill the sand cone apparatus with a special free-flowing SP sand, of a known density, similar to that found in an hourglass. Then determine the weight of the cone and the sand.
3. Place the sand cone over the hole. Then open the valve and allow the sand to fill the hole and the cone.
4. Close the valve, remove the sand cone from the hole, and determine its new weight.
5. Through comparing the weight of the sand used in the test with the weight of the soil removed from the hole the density of the soil can be determined.

Nuclear Density Testing is performed in accordance with **ASTM D2922**.

APPENDIX B: Mixture/Application Rate Formulas and Calculations

Quantities

In Laboratory Hydroseeder:

Water	200 gallons
Fiber	50 pounds wood fiber 50 pounds paper fiber
EarthGuard emulsion	42.5 oz = 0.3320 gallons

Per Acre Rate:

Water	6,000 gallons
Fiber	3,000 pounds
EarthGuard emulsion	10 gallons

Application

Based on the mixture application rate (10 gallons of Earth Guard stabilizing emulsion and 3,000 pounds of fiber per acre), water-to-material ratio, and average fill time (for 4 gallon bucket), the application time for a 2 meter by 8 meter test plot, t [sec], was calculated as follows:

$$t = \frac{W_{hydro} MAT_{subplot} t_4}{(15.14 \text{ liters}) MAT_{hydro}}$$

where:

W_{hydro} = volume of water added to the hydroseeder (liters)

$MAT_{subplot}$ = weight of treatment material to be applied on each subplot [kg], as calculated from the application rate and subplot area

t_4 = time required to fill a standard bucket to a 15-L (4-gal.) mark (sec)

MAT_{hydro} = weight of treatment material added to the hydroseeder (kg).

The **EarthGuard FM** treatment was applied under the supervision of a representative from Terra Novo who verified that the treatment was applied at the calculated rate.