ARID REGION NON-VEGETATIVE EROSION CONTROL STUDY

Final Report

For

Barstow, Dunaway Road, and Hinkley Sites

October 2008 – October 2010

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Acronyms and Abbreviations	Definition
ADV	Automated Data Validation
ASTM	American Society for Testing and Materials
ANOVA	Analysis of variance
BMPs	Best Management Practices
°C	Degrees Celsius
Caltrans	California Department of Transportation
CT	Control
EPA	(United States) Environmental Protection Agency
°F	Degrees Fahrenheit
GIS	Geographic Information System
HEAT	Highway Erosion Assessment Tool
I	Interstate
In.	inch
L	Liter
LR	Laboratory replicate
MDL	Method Detection Limit
MRA	Multiple Regression Analysis
MS	Matrix Spikes
mph	Mile per hour
OM&M	Operation, Maintenance, and Monitoring
PP	PolyPavement™
PSGM	Caltrans Pilot Study Guidance Manual
QA/QC	Quality Assurance/ Quality Control
RL	Reporting limit
RPD	Relative Percent Difference
RSP	Rock Slope Protection
RWQCB	Regional Water Quality Control Board
SC	Soil Cement
SR	State Route
SS	Soil Seal
ST	SoilTac®
Study	Arid Region Non-vegetative Erosion Control Study
Study Plan	Arid Region Non-Vegetation Erosion Control Study Plan and Experimental Design
TDS	Total Dissolved Solids
TSS	Total Suspended Solids

EXECUTIVE SUMMARY

In arid regions of California, it is often difficult to establish vegetative cover within California Department of Transportation (Caltrans) rights-of-way due to climate conditions, soil limitations, and lack of available water for supplemental irrigation. This Arid Region Non-vegetative Erosion Control Study (Study) was performed to address the need for non-vegetative erosion control technologies in roadside conditions that are typical of arid regions of California. The objective of the Study was to evaluate the effectiveness of non-vegetative erosion control products in reducing soil erosion caused by wind or water by monitoring sediment yield levels, soil movement, and volumetric runoff coefficients within test plots constructed at three study sites.

In 2002, Caltrans prepared a document entitled *Caltrans Arid Region Non-Vegetative Erosion Control Study Plan and Experimental Design* (CTSW-RT-02-038) (Study Plan) that identified experimental design, erosion control products, study sites and monitoring methods to be used to assess the effectiveness of hydraulically applied and surface cover non-vegetative erosion control products in reducing soil erosion and impacts to stormwater quality. The Study Plan was updated in 2006 with a Design Review Memorandum that re-evaluated the sites to ensure that site conditions would support the objectives of the Study.

An initial step in preparing the Study Plan was determining the types of non-vegetative erosion control products that would be appropriate for the Study. As indicated in the Study Plan, non-vegetative erosion control products come in a variety of forms designed to stabilize disturbed surfaces by providing protective cover or by binding top soil exposed to the elements. Ultimately, five non-vegetative erosion control products were selected for the Study. Three hydraulically applied products: PolyPavement™, Soil Seal and SoilTac®; and two surface cover products Soil Cement, and Rock Slope Protection were selected for the pilot study. In addition, untreated plots were also monitored to serve as controls for the experimental design.

Three study locations that represented typical roadside conditions within the arid regions of California were selected based on several factors, including consistency in slopes and soil types (within each site). Two study area locations were in Caltrans District 8 (Barstow and Hinkley), and the third was in District 11 (near El Centro). Each location consisted of two experimental units containing 12 test plots each. Within each experimental unit, two test plots were dedicated to each erosion control technology and the control plots.

Construction of the three project sites occurred in 2008. The layout of the test sites was consistent among the three locations. Each of the 24 rectangular test plots measured 26.25 feet in length and 6.5 feet in width. The five non-vegetative erosion control products were applied according to manufacturer-supplied application instructions to two randomly selected test plots within each experimental unit. The remaining four test plots were utilized as control plots. The control plots contained untreated soil in order to be representative of the native soils of that particular site. The plots were constructed to drain stormwater runoff and sediment through a rock screen into plot-specific collection barrels located near the toe of the slope.

The Study monitoring program consisted of multiple components designed to allow the performance of the various erosion control products and control plots to be measured over a two year period. The monitoring program included: weather tracking and monitoring, site preparation, collection and analysis of stormwater runoff samples, surface scan surveys, monthly visual observations and other operation and maintenance tasks. Administratively, the monitoring program included overall management of the project, review of downloaded weather data, preparation/submittal of Post-Storm Technical Memoranda, and preparation/submittal of sediment yield tables.

The Study was designed to measure both wind and precipitation at each of the three test site locations to assess product effectiveness against erosion. An interim study review of the wind and project data revealed that wind did not appear to significantly impact the erosion control products.

The amount and intensity of precipitation varied from site to site over the two year monitoring period. A total of 13, 9 and 11 precipitation events were monitoreed at the Barstow, Dunaway Road and Hinkley sites, respectively. After each of these storm events, the amount of captured runoff and sediment were measured and runoff samples were collected from the barrel collection systems at each test plot.

The sediment yield and volumetric runoff coefficient values were calculated after each storm event and on both an annual and cumulative basis over the two year study period for each test plot. In addition, monthly inspections, and routine and non-routine maintenance activities were conducted in order to evaluate the effectiveness of the five non-vegetative erosion control products.

The extensive monitoring performed at the three study sites over the two year period provided sufficient data to evaluate the effectiveness of the five non-vegetative erosion control products in reducing soil erosion. Generally, the surface cover erosion control products (Rock Slope Protection and Soil Cement) performed better (i.e. less sediment was lost from test plots with these products) than the hydraulically applied products (PolyPavement™, Soil Seal, and SoilTac®) and controls. The Study data indicated that the expected useful life for the hydraulically applied erosion control products was approximately one to two years. For the surface cover erosion control products, the estimated useful life for Soil Cement was 6 to 10 years and was at least 20 years for Rock Slope Protection.

The estimated present worth capital cost to apply the hydraulically applied erosion controls was $5,240, $5,500, and $5,650 per acre for Soil Seal, PolyPavement™, and SoilTac®, respectively. The estimated present worth capital cost to apply Rock Slope Protection and Soil Cement were $120,500 and $131,000 per acre, respectively. Based on these results the estimated costs, including the initial application and a range of present worth costs to apply the five erosion control products to a one-acre site over a 20 year implementation period were calculated.

Section 1 Introduction

The following sections identify the purpose of the Arid Region Non-Vegetative Erosion Control Study (Study), provide an overview of the objectives of the Study, describe the BMP technologies selected for the Study, and discuss the design and implementation of the Study Plan.

1.1 Purpose

In arid regions of California, it is difficult to establish vegetative cover as an erosion control technology within California Department of Transportation (Caltrans) rights-of-way due to climate conditions, soil limitations, and lack of available water for supplemental irrigation. This Study was performed to evaluate the effectiveness of a variety of non-vegetative erosion control products applicable in the arid regions of California as best management practices (BMP) for soil stabilization along roadsides. The products evaluated in this Study consisted either of soil binding agents (hydraulically applied or "spray-on" product) or surface cover products (i.e., Rock Slope Protection). This Study assessed the effectiveness of selected non-vegetative erosion control technologies in roadside conditions that are typical for California arid regions where vegetative systems may not be successful.

1.2 Project Overview and Objectives

The objective of the Study is to evaluate the effectiveness of non-vegetative erosion control products in reducing soil erosion caused by wind or precipitation. The Study was intended to:

- evaluate the effectiveness of each non-vegetative erosion control product in reducing soil loss from precipitation and evaluate the potential impacts on stormwater quality, and
- evaluate the effectiveness of each non-vegetative erosion control product in reducing soil loss from wind forces.

In addition, the cost-effectiveness and life expectancy of each erosion control product was determined based on multi-year monitoring.

During the Study, five different erosion control products were tested at three separate site locations. Two locations were in Caltrans District 8 (Barstow and Hinkley), and the third was in District 11 (near El Centro). The three site locations were determined to be ideal for this study because of consistency in slopes and soil types (within each site). This consistency reduced variability caused by differing slopes or soil types, and represented typical roadside conditions within the arid regions of California. Each site consisted of 2 experimental units of 12 test plots each (24 total). An experimental unit consists of 12 test plots. Plots were randomized to reduce bias due to location of test plots within the experimental unit. Randomization was assigned using random number techniques. Within each experimental unit, two test plots were dedicated to each erosion control technology and two plots served as untreated controls. Erosion control products and untreated controls were randomized across the 12 test plots in the experimental unit. Each plot was constructed to drain stormwater runoff and sediment through a large particle grate into a conveyance pipe and into collection barrels located downslope of each test plot. Field monitoring and maintenance activities were performed from October 2008 to September 2010.

1.3 BMP Description

The five non-vegetative erosion control products selected for this Study are described below.

- **Soil Seal**: Soil Seal (SS) is a hydraulically applied proprietary soil stabilizer that is composed primarily of high-grade latex acrylic which is typically diluted with water and applied by spray onto various types of soil. Soil Seal penetrates the soil surface and forms a cohesive bond among soil particles. According to the manufacturer's recommendations, the typical life span of Soil Seal is 12 months.

- SoilTac®: SoilTac® (ST) is a hydraulically applied proprietary ecologically safe, biodegradable, liquid copolymer used to stabilize and solidify soils to protect against wind and water erosion. The manufacturer specifications indicate that it is specifically engineered for use on projects ranging in size from large commercial projects down to smaller residential applications and is intended to be as simple to apply as watering the ground. The typical life span of SoilTac® is reported to be 12 to 24 months.

- **PolyPavement™**: PolyPavement™ (PP) is a hydraulically applied proprietary polymer that functions like an emulsion-based soil stabilizer. PolyPavement™ does not alter the color of the soil and is also suitable for a variety of soil conditions. This product is applied hydraulically and the manufacturer's specifications indicate that it requires little maintenance. With proper application, this product is reported to have a life expectancy of 5 to 10 years.

- **Rock Slope Protection**: Rock Slope Protection (RSP) is a surface cover erosion control application that has been used successfully at many erosion control projects under similar environmental conditions. Caltrans has standard specifications for RSP. The RSP applied in the Study consisted of 6-inch to 12-inch rock from local vendors. Although the initial cost for this erosion control method is high compared to spray-on type products, Rock Slope Protection requires little maintenance and has a reported life expectancy of 20 to 30 years.

- **Soil Cement**: Soil Cement (SC) is a surface cover erosion control product that is composed of cement, water, and native soil. The mixture of these items creates a mortar-type product that can be compacted to form a hardened surface over the soil slope. Soil cement is considered to be low maintenance, but is relatively expensive and requires significant installation time compared to spray-on erosion control products. The life expectancy is reported to be similar to that of concrete or mortar (20 to 30 years).

In addition to the five non-vegetative erosion control products described above, several plots were selected as "Control" (CT) plots; Control refers to the native soil on a slope without any erosion control product applied to it.

1.4 Study Plan Design and Implementation

In 2002, Caltrans prepared the *Caltrans Arid Region Non-Vegetation Erosion Control Study Plan and Experimental Design* (CTSW-RT-02-038) (Study Plan) for this Study. The Study Plan identified methods to measure and test various quantitative and qualitative variables related to the effect of non-vegetative erosion control products on soil stabilization and water quality.

In 2008, the Caltrans Arid Region Non-Vegetative Erosion Control Operations, Monitoring and Maintenance (OM&M) Plan was prepared for this study. The OM&M Plan was based on the Study Plan and Experimental Design for Non-Vegetative Erosion Control in Arid Regions" (CTSW-RT-02-038), and the 2006 "Caltrans Arid Region Non-Vegetative Erosion Control Study Plan and Experimental Design Review Memo". The OM&M Plan identified the project operation, maintenance and monitoring activities including the selected sites and site configuration, operation and maintenance activities, monitoring methodology, equipment configuration, monitored constituents, and schedule. In addition, the OM&M Plan identified the data quality objectives, data management and reporting procedures for the Study. The Study operation, maintenance and monitoring activities are described further in Section 2 and 3.

The Study was conducted to analyze the erosion control benefits of non-vegetative erosion control products, therefore, existing highway maintenance schedules and practices were performed without modification. Caltrans District Maintenance Staff were informed of the presence of the Study operation, maintenance and monitoring equipment to prevent damage that might have been caused by routine roadway maintenance operations.

The results of the Study were reviewed to develop future considerations for selection of the most effective types of non-vegetative erosion control products to be used in arid regions and to suggest refinement of the Study methodology for use in future pilot studies.

1.5 Report Organization

This report was prepared based on the most recent version of the Caltrans Pilot Study Guidance Manual (PSGM)(CTSW-RT-06-171.02.1 – Final, January 15, 2009). The organization of the report is presented below.

Section 1 – Introduction

This section presents the purpose, overview, and objectives for the monitoring Study. It provides descriptions of the erosion control products that were evaluated for their effectiveness in reducing soil erosion caused by wind or water, and it presents the general project information.

Section 2 – Study Plan Overview, Site Selection Criteria and Characteristics, and Key Design Features

This section presents the design objectives and conceptual design approach identified in the Study Plan, summarizes the site selection criteria, provides descriptions of subject sites, and provides details regarding implementation of the Study Plan.

Section 3 – Monitoring Methodology

This section provides a description of the criteria used during the monitoring events, and summarizes the monitoring procedures and analytical methods used in the Study.

Section 4 – Monitoring Results

This section summarizes how monitoring events were qualified, and how analytical data were collected regarding wind velocities, rainfall, flow, and operations, and hydrograph. It also discusses the Quality Assurance and Quality Control (QA/QC) program implemented for the Study.

Section 5 – BMP Performance

This section describes the analytical methods used to evaluate product performance.

Section 6 – Maintenance Requirements

This section addresses proposed changes to the maintenance practices based on issues associated with the maintenance activities conducted for this study.

Section 7 – Capital, Operations, and Maintenance Costs

This section presents the project cost information.

Section 8 – Conclusions

This section evaluates the Study objectives and presents conclusions regarding product effectiveness.

Section 9 – Future Considerations

This section presents a discussion of potential improvements that could be made to the erosion control products selected, the design specifications developed, and the maintenance procedures used.

Section 10 – References

This section consists of a bibliography of references, documentation, and past monitoring studies consulted for this Study.

Section 2 Study Plan Overview, Site Selection Criteria and Characteristics, and Key Design Features

The following sections provide an overview of the Study Plan prepared for this study, discuss the site selection process, summarize the site characteristics, and discuss key design features.

2.1 Study Plan Overview

The protocol and design for this Study are described in the 2002 Study Plan. As a precursor for site selection, the Study Plan established the criteria that were used to define the characteristics that constitute an "arid" region. Characteristics that define arid regions include an absence of available water, low annual percipitation, high daytime summer temperatures, and limited vegetation. Arid regions typically experience temperatures in excess of 131 degrees Farenheit (°F) in the summer and receive less than 10 inches of precipitation annually. The focus of the 2002 Study Plan was to develop a design to scientifically evaluate erosion control products that would provide objective and justifiable results.

Based on the characteristics that define an arid region, the Study Plan developed criteria to guide site selection in order to identify potential project sites that best represented conditions typically encountered during construction activities on roadsides in arid regions of California. The methods of site selection are provided in Section 2.2.

In order to evaluate erosion control products, measurements were taken from a test plot that had a known area, slope length, and soil type (Caltrans 2002). The Study Plan feasibility was first evaluated in a controlled setting using test plots of similar design. The design of the test plots and the expermental units are described in Section 2.3.

The Study Plan identified the need to collect monitoring data for the variables which could potentially impact the integrity of non-vegetative erosion control products over the course of several seasons. The purpose was to extrapolate from the data the drivers which impacted erosion control product integrity. Protocols for the monitoring of the test plots and data collection are described in the OM&M Plan. The monitoring methodology used for the study is described in Section 3.

An objective outlined in the Study Plan was to conduct comparisons of erosion control product performance as it related to soil type and slope. The Study Plan stated that sites would need to be selected to provide a sufficient comparison of soil type and slope. The Study Plan indicated that, to achieve this, two of the three sites should be similar and one different, to allow isolation of the effects of soils and slope for pairwise statistical comparisons. For pairwise comparison, two of the sites were to be similar in aspect, slope, climate, and other factors, but relatively dissimilar in soil texture. Therefore, site characteristic variables would be similar, with performance attributable to soils.

However, during the project implementation phase it was ultimately decided by the project team that since the study included only three sites, it was not possible to perform a formal statistical evaluation of site-to-site differences and the influence of site-specific factors (soil type, slope, etc.) on treatment performance. Accordingly, only qualitative evaluations of these differences were made.

2.2 Site Selection Criteria

The site selection criteria developed for the Study aided in the process of identifying potential sites that represented conditions and characteristics typical of roadsides in arid regions of California. Additionally, these criteria were selected to fulfill requirements of the Study Plan, facilitate construction activities, and ensure the safety of field teams.

Site selection criteria included:

- arid climate factors
- site location
- soil type
- slope aspect
- slope and topography
- site size and slope length
- surrounding environment
- accessibility/safety
- security issues
- permits required
- number of sites

The site selection process involved reviewing data provided by the Spatial Climate Analysis Service at Oregon State University. This service uses the Parameter Elevation Regression on Independent Slope Model to calculate mean annual rainfall in California. A GIS-generated map was used to display areas that receive low annual rainfall volumes.

Sites were evaluated using the parameters (e.g., aspect, area, slope, and soil) identified in the Caltrans document titled Highway Erosion Assessment Tool (HEAT) for Evaluation of Roadside Slopes (CTSW-RT-02-038). Sites initially selected in 2002 were revaluated in 2006 to ensure that site conditions would support Study objectives.

The sites ultimately selected for the Study provided the best representation of characteristics and climate factors that satisfied the requirements of the design statistical evaluations and monitoring conditions. The sites selected were located in two separate Caltrans districts (8 and 11. The three sites selected and their defining characteristics are presented in Table 2-1.

Table 2-1 Sites Selected for Arid Region Non-Vegetative Pilot Study

Site/ Caltrans District	Soil Texture	Slope (%)	Slope Aspect	Average Annual Rainfall (in.)	Average Temp (°F)	Number of 90-percent Probability Freeze-free Days	Potential for Operation and Maintenance Problems in Upslope Area[1]	Relative Safety Level[2]	Ease of Access[3]
Barstow/ District 8	Loamy Sand	35	South	4.4	64	212	Low	Moderate	Moderate
Hinkley/ District 8	Loamy Sand	41	South	4.4	64	212	Low	High	High
Dunaway/ District 11	Sandy Clay Loam	44	North	2.6	72.3	280	Low	Moderate	Moderate

Abbreviations/Notes:
F – Fahrenheit
Caltrans – California Department of Transportation
in. – inches
Temp – temperature
[1] Rating of "High" correspond to sites with large upslope areas contributing runon to sites; rating of “Low” corresponds to sites with top V-ditches to route runoff or small upslope areas.
[2] Corresponds to the width of the highway shoulder, proximity and nature of vehicular traffic, stability and slope of site, and other hazards.
[3] Corresponds to width of shoulder, presence of parking and laydown areas (e.g., turnarounds, emergency stop areas), presence of fences and other obstructions, right-of-way size.

The sites selected provided two soil types and were representative of most roadside conditions in arid regions of California.

2.3 Site Characteristics

Figure 2-1 displays the locations of the sites selected for this Study and average annual precipitation. Information regarding the points of collection, the County, Mile Post, and California Regional Water Quality Control Board jurisdiction in which each site is located is provided in Table 2-2.

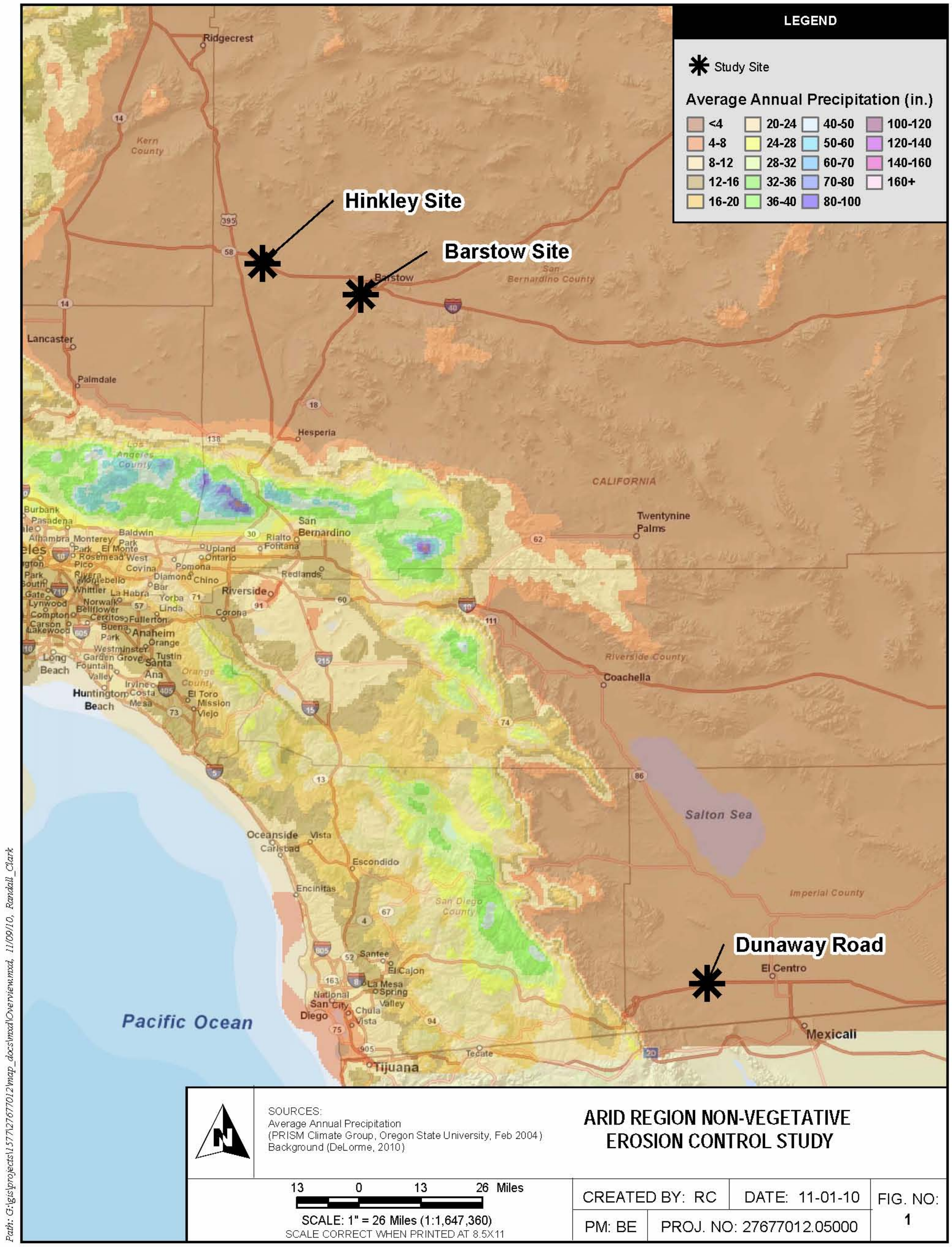

Figure 2-1 Sites Selected for Study

Table 2-2 Non-Vegetative Erosion Control Study Site Information

Site	Point of Collection	County	Mile Post	RWQCB District
Barstow	Runoff	San Bernardino	34.81	Lahontan
Hinkley	Runoff	San Bernardino	11.5	Lahontan
Dunaway Road	Runoff	Imperial	23.48	San Diego

Abbreviation:

RWQCB – California Regional Water Quality Control Board

2.3.1 Barstow Site

The Barstow site is located within the State Route (SR)-58 loop of the Interstate (I)-15 and SR-58 interchange in Caltrans District 8 (Figure 2-2). For the Barstow site, the south- and north-facing slopes were both listed in the study plan as potential experimental locations. The south-facing slope is the preferred slope, since erosion control is more of a challenge historically for the Caltrans Maintenance Department on this slope and due to site conditions. The south-facing slope has wide, flat shoulders between the edge of the pavement and the toe of slope that allows for the storage of equipment and plenty of horizontal slope length to site two replicate test plot systems. Also, the south-facing slope is on the inside of a curve and therefore more protected from accidents than the north-facing slope on the outside of the curve. The angle of the slope is approximately 35 percent.

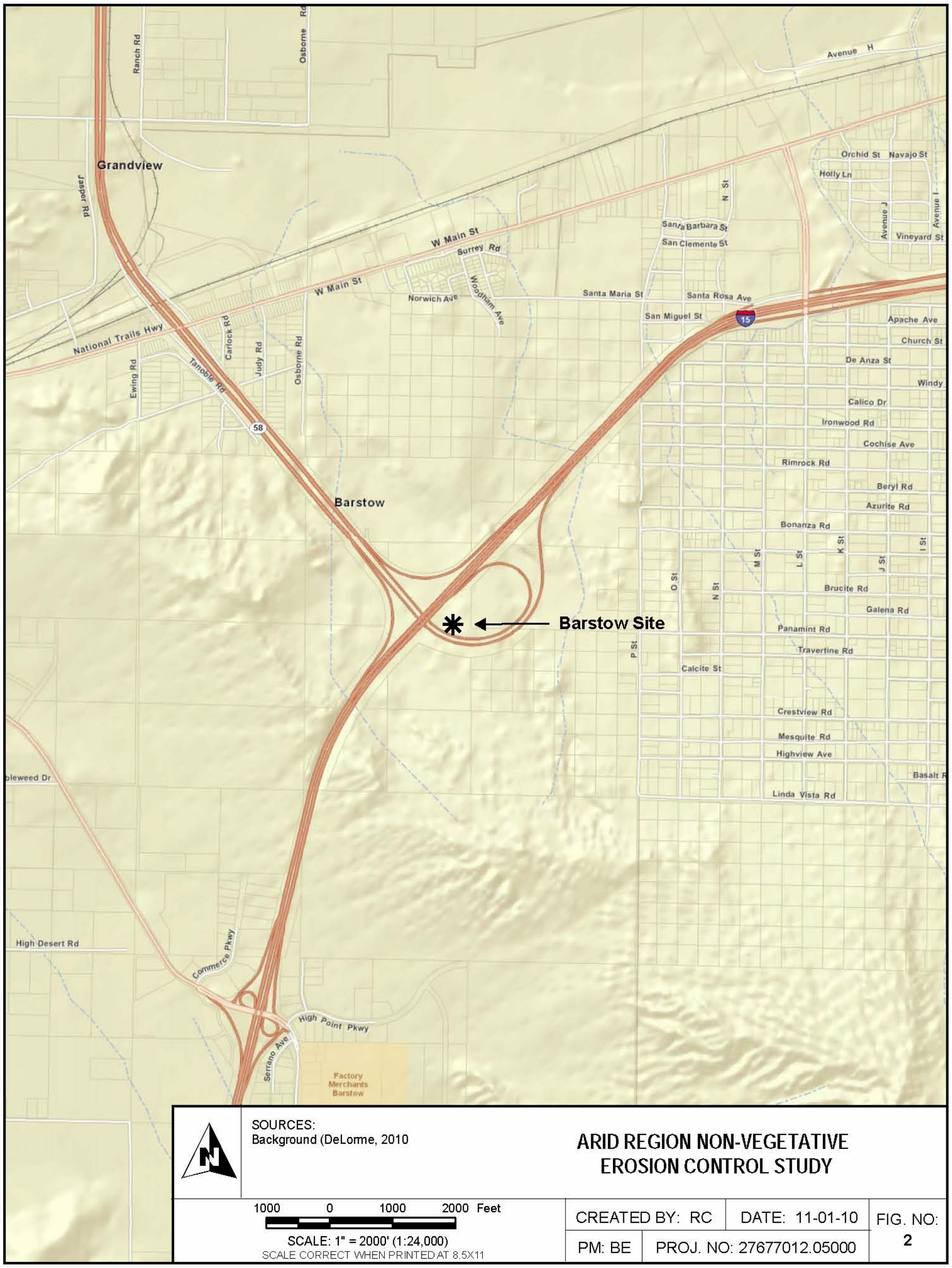

Figure 2-2 Barstow Site Location

2.3.2 Dunaway Road Site

The Dunaway Road site is located on the north slope of the Dunaway Road on-ramp to westbound I-8 in Caltrans District 11 (Figure 2-3). The interchange consists of large, wide fill slopes within the Caltrans right-of-way. Specifically, the on-ramp portion of this interchange between Dunaway Road and westbound I-8 offers the best opportunity, with a long north-facing slope that has sufficient horizontal space to co-locate two replicate test plot systems. Access is from Dunaway Road north of the freeway via a dirt access road below the fill slope. The distance between the toe-of-slope and the right-of-way fence line is approximately 50 feet, providing sufficient area to store sampling equipment. The slope is approximately 44 percent.

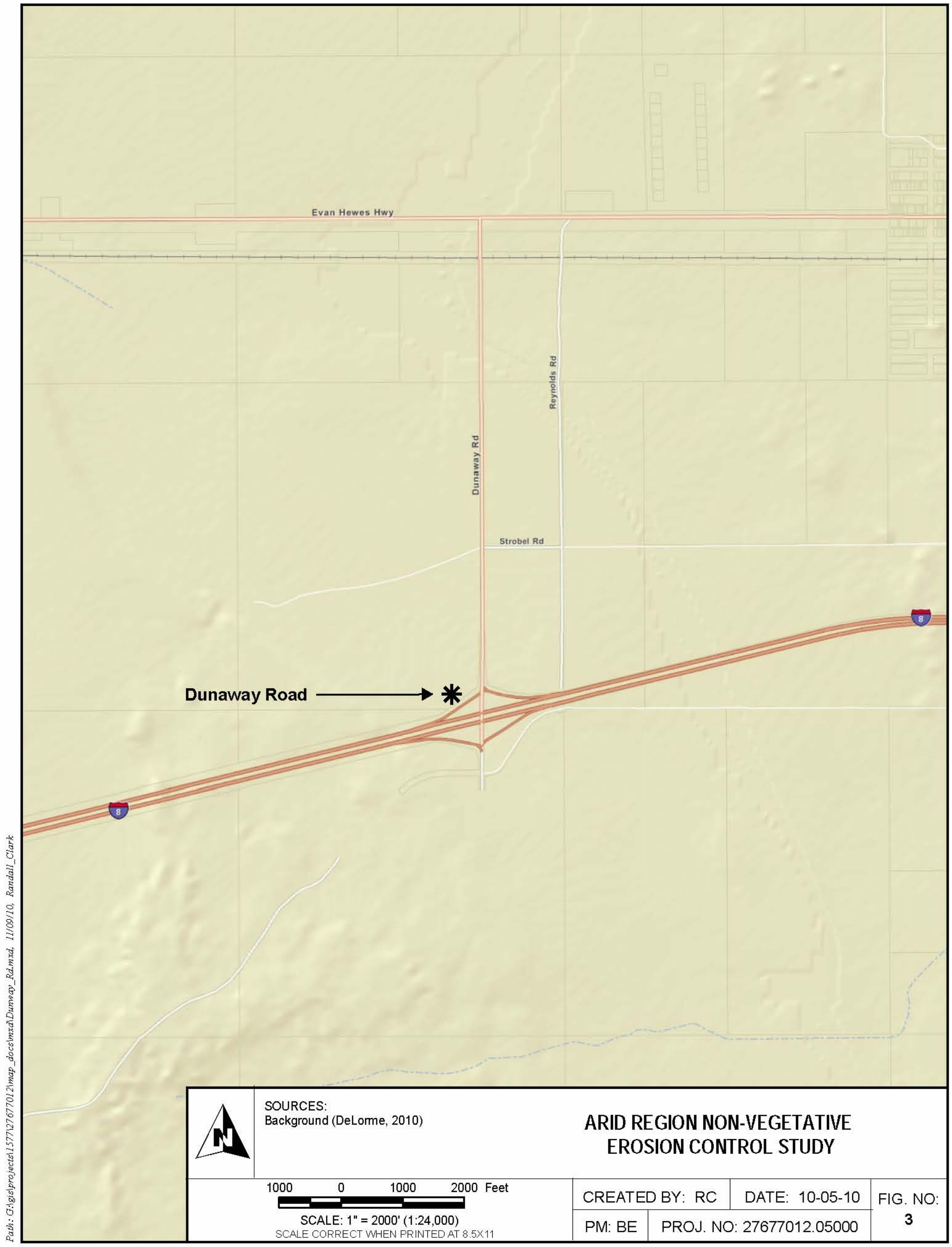

Figure 2-3 Dunaway Road Site Location

2.3.3 Hinkley Site

The Hinkley site is located on SR-58 approximately 25 miles west of the I-15 and SR-58 interchange in Caltrans District 8 (Figure 2-4). The Hinkley site has wide, flat shoulders on both sides of the freeway, and adequate horizontal slope length to accommodate two replicate test plot systems. As with the Barstow site, both the south- and north-facing slopes are listed in the Study Plan. The major difference between the slopes is that the south-facing slopes are shorter than the north-facing slopes, with a slope length of 36 feet compared to over 60 feet on the north-facing slopes. The angle of the slope is approximately 41 percent.

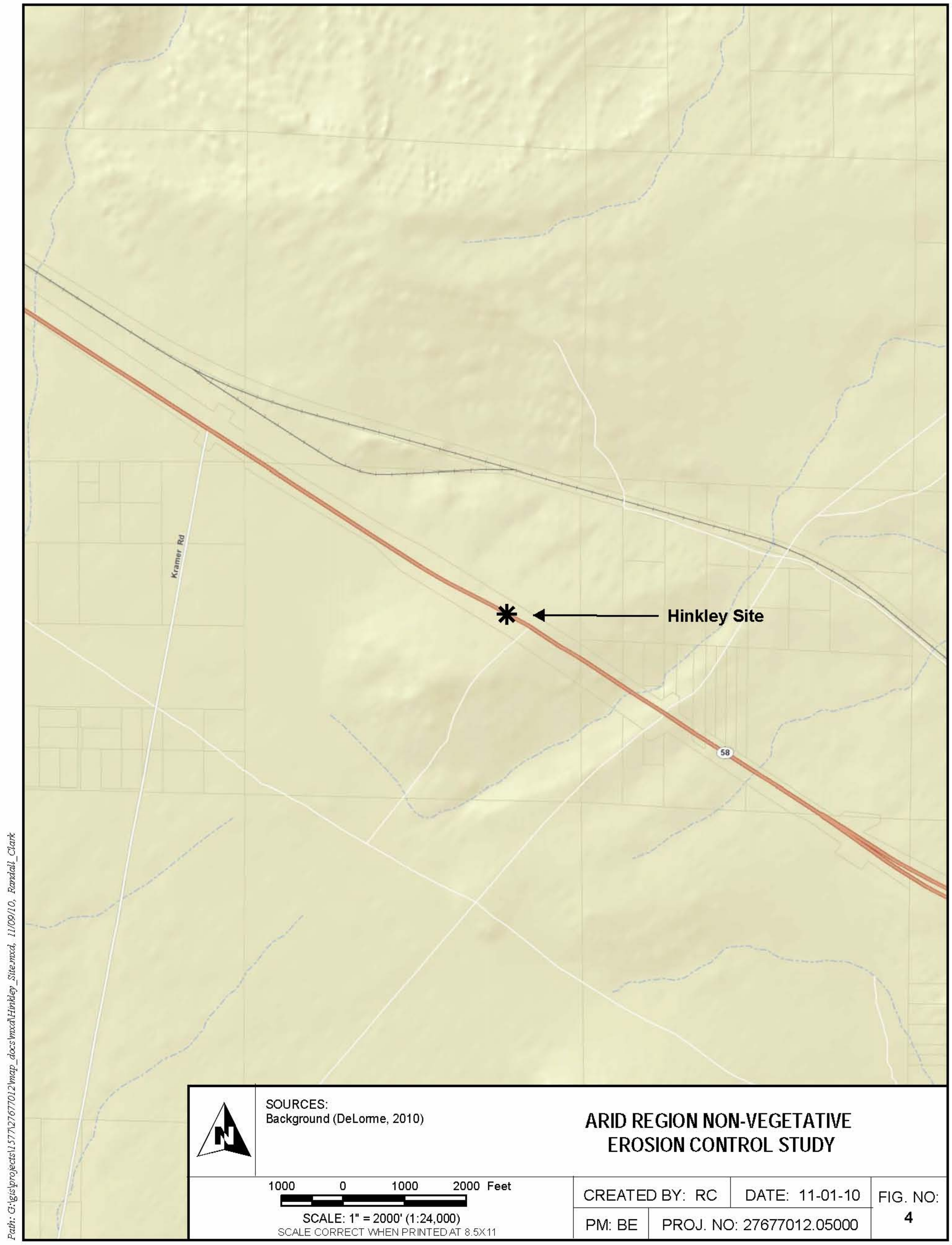

Figure 2-4 Hinkley Site Location

2.4 Project Permit, Design, and Construction

To initiate the Study, encroachment and environmental permits were obtained for construction of the project sites. Due to the nature of the Study, field design adjustments were necessitated and construction of the project sites provided valuable lessons. The permit, design specification and construction processes are described below.

2.4.1 Permits and Initial Site Activities

The initial steps to obtain permits necessary to perform construction in the rights-of-way began in 2007. Initial activities conducted in the project site area included: site selection, reconnaissance surveys, topographic surveys, construction, construction site inspections, operations, maintenance, and monitoring.

As a result of the field activities for this Study being conducted within Caltrans rights-of-way, it was necessary to obtain encroachment permits for the field activities. Project sites were located immediately adjacent either to a highway (Barstow and Hinkley) or an on-ramp (Dunaway Road). Encroachment permits were obtained from the local District in accordance with instructions provided in the PSGM. The encroachment permits provided field teams and contractors with the authority to enter the State highway rights-of-way to construct approved facilities and to conduct Study Plan activities (Caltrans 2002). In accordance with the encroachment permit clearance requirements, the District Encroachment Permit Office was notified of the pending Study in June 2007.

Due to the relatively small scale size of the project sites and the nature of the Study, the Study was deemed exempt from California Environmental Quality Act determination requirements.

2.4.2 Design

The following sections provide a summary of the design elements associated with the project sites. The intention of the design was to capture runoff and erosion data in the field from each erosion control product to use as a measure of comparison. Erosion control products were selected during the Study Plan in 2002.

2.4.2.1 Overall Design

The objective of the study was to evaluate the effectiveness of non-vegetative erosion control products in reducing soil erosion caused by wind or water. The purpose of the experimental design was to allow comparison among plots with different erosion control products and slope lengths within roadside sites in arid regions of California. The general comparison measures described below were conducted as part of the study.

- Measure erosion losses caused by wind and water.
- Compare erosion control effectiveness among five non-vegetative erosion control products.
- Evaluate effectiveness of erosion control products on similar slopes.

- Evaluate each erosion control product over several test plots within a project site.

As indicated in the above list, differences in erosion control products were compared within specific areas. Comparisons were based on replicating results within the same project site and factors such as slope, aspect, and soil type. Each level of comparison provided additional information about the effectiveness and applicability of specific erosion control products. Components integral to the plot design and subsequent evaluation included plot configuration, replication, and site comparisons.

2.4.2.2 Plot Configuration

Measurement of erosion requires separation of runoff plots of known area, slope, slope length, and soil type (Caltrans 2002), whereby the effects of a given treatment (i.e., erosion control product) are isolated. In this Study, treatments were assigned to plots separated by dividers.

Plot configurations were designed to be similar to past laboratory erosion control product studies performed for Caltrans (Caltrans 2000). Test plots were 26.2 feet long and 6.6 feet wide. Because the experimental design used in the Study Plan was similar to that employed during previous field work, the Study provided information and data that assessed the effectiveness of product type while being exposed to the variables of weather and wind.

Figure 2-5 through Figure 2-7 show the design of the three project sites. The toes of the slopes were adjacent to the highway at both the Barstow and Hinkley sites, whereas the top of the Dunaway Road site was adjacent to the highway on-ramp. An experimental unit consists of 12 test plots designed to evaluate five erosion control products against the untreated control ([5 + 1] x 2 = 12 treatments). Each project site contains two experimental units.

Figure 2-5 Barstow Site

Figure 2-6 Dunaway Road Site

Figure 2-7 Hinkley Site

2.4.2.3 Replication

Statistical evaluations require replication of data to provide a sufficient number of data to produce reliable distributions and present practically important relationships. The replicates in the Study were measured values that were compared across various treatments. For this Study, values included soil loss volumes recorded in the runoff collection barrels and water runoff volumes measured in the collection barrels. For the purposes of the following statistical discussions, the term "product performance" correlates to soil loss volumes measured in the field (caused by both wind and runoff).

Replication of data in this study was accomplished: (1) "spatially," where measurements for the same treatment combination are taken in different areas at the same time, and (2) "temporally," where measurements were taken monthly and after every storm event for the duration of the Study. Spatial replication was accomplished by using three separate sites, which accounted for larger-scale variability (*i.e.,* slope, soils, climate, and site design). Temporal replication, a necessity in any field study, accounted for seasonal changes in wind, rain, temperature, and other random environmental factors which provided sufficient numbers of data for valid statistical analysis.

The five erosion control products, SS, ST, PP, SC, and RSP, as well as CT areas, were replicated for evaluation. Table 2-3 through Table 2-5 summarize the technologies used and the replication strategy associated with the Barstow, Dunaway, and Hinkley sites. The Barstow and Hinkley sites utilized a side 'A' and 'B' designation while the Dunaway Road site utilized an 'East' and

'West' designation. This layout was set up prior to the issuance of Caltrans-approved Site identifications. On each side (A/B or E/W), each of the erosion control product was applied or installed in two plots.

Table 2-3 Barstow Site Plot Identification Information

Technology Used	Unit A*	Unit B*
PolyPavement™ (PP)	8-310	8-328
Control (CT)	8-311	8-324
SoilTac®(ST)	8-312	8-323
Control (CT)	8-313	8-329
Soil Seal (SS)	8-314	8-322
Rock Slope Protection (RSP)	8-315	8-325
Soil Cement (SC)	8-316	8-326
SoilTac®(ST)	8-317	8-330
Soil Seal (SS)	8-318	8-332
Rock Slope Protection (RSP)	8-319	8-327
PolyPavement™(PP)	8-320	8-331
Soil Cement (SC)	8-321	8-333

*The site consisted of two experimental units (A and B), each with 12 test plots. Within each experimental unit, two test plots were dedicated to each erosion control technology

Table 2-4 Dunaway Road Site Plot Identification Information

Technology Used	East Unit*	West Unit*
Rock Slope Protection (RSP)	11-302	11-318
Soil Seal (SS)	11-303	11-315
Soil Cement (SC)	11-304	11-320
SoilTac®(ST)	11-305	11-317
Soil Seal (SS)	11-306	11-314
Rock Slope Protection (RSP)	11-307	11-322
Soil Cement (SC)	11-308	11-325
SoilTac®(ST)	11-309	11-324
PolyPavement™(PP)	11-310	11-316
Control (CT)	11-311	11-321
PolyPavement™(PP)	11-312	11-319
Control (CT)	11-313	11-323

*The site consisted of two experimental units (East and West), each with 12 test plots. Within each experimental unit, two test plots were dedicated to each erosion control technology.

Table 2-5 Hinkley Plot Identification Information

Technology Used	Unit A*	Unit B*
Control (CT)	8-334	8-346
Soil Cement (SC)	8-335	8-347
Control (CT)	8-336	8-348
Soil Cement (SC)	8-337	8-349
PolyPavement™(PP)	8-338	8-350
Rock Slope Protection (RSP)	8-339	8-351
SoilTac®(ST)	8-340	8-352
Soil Seal (SS)	8-341	8-353
SoilTac®(ST)	8-342	8-354
Soil Seal (SS)	8-343	8-355
Rock Slope Protection (RSP)	8-344	8-356
PolyPavement™(PP)	8-345	8-357

*The site consisted of two experimental units (A and B), each with 12 test plots. Within each experimental unit, two test plots were dedicated to each erosion control technology.

2.4.2.4 Randomization of Experimental Unit Location

To reduce bias due to the location of test plots within an experimental unit, test plot locations were assigned using random numbering techniques. Details of the test plot randomization are presented in the project OM&M Plan.

2.4.3 Construction

The bidding process for the Study proved to be a challenge due, in part, to the vague nature of the erosion control product specifications. The relative small size of the study and the remote location also played a part in the contractor determination process. Some erosion control products that were chosen for this Study did not contain sufficient detail in the product specifications to make an informed determination as to the effort that would be required to construct the sites.

Construction of the sites was performed between April 2008 and October 2008. Field teams began construction of the Barstow and Hinkley project sites in April 2008 and completed construction in September 2008. Slopes were prepared to accommodate test plots and product application. Construction of the Dunaway Road project site began in August 2008 and was completed in October 2008 (Figure 2-8). During the construction phase, the initial Study design for the Dunaway Road project site was altered to accommodate the existing site configuration. Initiation of construction at the site was delayed due to difficulties with slope stabilization efforts required to construct the Study site. Although slope stabilization was not specified in the construction design plan, soil compaction was determined to be necessary for construction of the test plots and for product application. Access to appropriate machinery to complete adequate soil compaction proved difficult. The construction contractor found that procuring machinery that had a low center of gravity and wide tracks necessary for the site slope was difficult. It was determined that a thorough geotechnical analysis and topographic survey should have been performed at the onset of construction.

Erosion control products were applied in stages, beginning with the application of the erosion control products at the Barstow and Hinkley project sites. RSP and SC were applied separately due to the difference in the application processes. PP, SS, and ST were applied hydraulically. Table 2-6 summarizes information regarding the product application dates at the three sites.

Each hydraulically applied erosion control product (PP, SS, ST) utilized manufacturer-recommended specifications for application and dilution rates for different types of surface applications. For application at the project sites, the surface was considered to be average slope. The hydraulically applied erosion control products also require that the soil be pre-wet prior to the application of the product. In addition, the dilution ratio for each product varied depending on the product. For PP, the dilution ratio was 20 to 1 (parts water to parts product). For SS and ST, the ratios were 30 to 1 and 10 to 1, respectively. A hydroseeder was used to mix the product with water and each was applied with a 1" diameter hose and nozzle vertically and horizontally to the slopes. Special application provisions that apply to application of the surface cover erosion control products are included in Appendix A.

Table 2-6 Erosion Control Product Application Dates

Erosion Control Product	Barstow	Dunaway Road	Hinkley
Rock Slope Protection (RSP)	07/25/2008	10/08/2008	08/01/2008
Soil Cement (SC)	09/11/2008	10/09/2008	08/29/2008
Hydraulic Products (PP, SS, ST)	07/29/2008	10/20/2008	07/30/2008

March 2008

August 2008

September 2008

October 2008

Figure 2-8 Construction Stages at the Dunaway Road Project Site

Figure 2-9 depicts the SC application process. Due to the steep grade of the slopes as well as the relatively small area where the product was to be applied, manual application of the product was required. This process proved to be laborious.

Figure 2-9 Soil Cement Application Process

During the construction phase, modifications to the project site and erosion control products selected were implemented to meet Study objectives. Several issues were identified during site construction. Generally, the issues were related to the fact that the specifications for the erosion control products selected did not contain sufficient detail. In addition, procurement of the initially selected erosion control products proved difficult due to lack of availability. Therefore, modifications were considered and approved. The modifications and issues related to the application of the erosion control products are summarized below.

- Plans and specifications were developed using best professional judgment during the construction phase to resolve the lack of detail required to complete the application of erosion control products.

- It was discovered that Soil Master WR was no longer readily available in California. SS was selected as an acceptable replacement for Soil Master WR. SS had been previously tested by the Texas Transportation Institute and by Caltrans at San Diego State University.

- Special provisions for the application of SC lacked sufficient detail. It was determined that a plaster mixer was required to achieve the proper consistency for the application of SC (this was due to the more appropriate types of paddles used in plaster mixers as opposed to cement mixers). Methodology used to apply SC is included in Appendix A.

- RSP specifications presented availability issues. Additionally, special provisions for the RSP plots were not consistent with Caltrans Standard Specifications for RSP. A revised specification for RSP was developed that was consistent with Caltrans Standard Specifications. Specifications used for RSP are included in Appendix A.

- Erosion control gauges were removed because it was determined that topographic survey equipment would provide more precise data by utilizing surface scan techniques.

2.4.3.1 Lessons Learned

This section presents valuable lessons learned during the construction phase of the Study. The purpose of lessons learned is to provide a record of the experience gained and disseminate the experience to others who may benefit from it.

Lessons learned have been grouped into one of three categories for reporting:

A: a practice promoting or resulting in a positive outcome.

B: a fact, discovery, or lesson of benefit to others.

C: an action that resulted in adverse consequences.

Table 2-7 summarizes the lessons learned.

Table 2-7 Lessons Learned During Construction

Lesson Learned	Category
The plans and specifications lacked sufficient detail to seek lump sum bids from contractors. Additionally, many inconsistencies were found with the plans and specifications.	C
The plans and specifications lacked sufficient detail to describe how to apply the rock slope protection and the soil cement. These details should have been resolved during the planning and design phase.	C
Locally available products should be selected when designing the project. This did not occur in two instances: 1) Soil Master WR was no longer readily available in California; and 2) 6-inch to 14-inch rock was not available in the region. Subsequently, product substitutions were made, including 1) Soil Seal instead of Soil Master WR, and 2) 6-inch to 12-inch rock instead of 6-inch to 14-inch rock.	B
An engineer's estimate was not prepared during the planning and design phase. Consequently, the task order to construct the pilot study sites could not be fully developed. As a result, a task was included to prepare an engineer's estimate, which was used as the foundation for the task order to be amended to include construction of the pilot. This caused a significant delay in constructing the sites.	C
The project would have benefited from a value engineering analysis before the plans and specifications were bid. Many changes were proposed during construction, which ultimately resulted in cost savings.	B
A geotechnical investigation should have been performed during the planning and design phase. During construction, the slope was found to be unstable at the Dunaway Road project site and was not compacted sufficiently to allow the test plot frames to be properly anchored. Consequently, a contract change order was issued to track walk the slope to provide a suitable condition to anchor the test plot frames.	B
A topographic survey should have been performed during the planning and design phase instead of relying on record drawings. During the construction staking, it was discovered that the Dunaway Road project site lacked the sufficient area to construct the test plots as presented on the plans. Consequently, the test plots were located closer together to fit in the available area.	B
Stairs should have been incorporated into the plans during the design phase to provide safe access up and down the slope.	B

Table 2-7 Lessons Learned During Construction

Lesson Learned	Category
The hydromulcher nozzle should have been equipped with a manual shutoff valve. Visual communication between the spray equipment operator and nozzle man was required in order for the nozzle man to tell the operator when to cut the application of spray. Ensuring a proper nozzle accomplishes two things: 1) only one person would be required to complete the application, and 2) the nozzle man would have a better control of the spread and quantity of materials applied.	B
A plaster mixer worked better than a cement mixer for application of the Soil Cement because a smaller number of paddles are used in the plaster mixer drum.	B
Adequate consideration was not paid to the effects of wind blown material (dust, etc.) depositing in the flumes, pipes, and barrels. Subsequently, covers were installed, and flumes and barrels were draped with plastic to prevent wind-blown material from entering the collection devices.	A, B

Category Key:
A - A practice promoting or resulting in a positive outcome
B - A fact, discovery, or lesson of benefit to others
C - An action that resulted in adverse consequences

The modifications to the Study did not impact the operation and maintenance activities, or field activities at the project sites. Operation and maintenance activities are discussed in Section 6.

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Section 3 Monitoring Methodology

Accurate and timely monitoring was essential in providing the data necessary to achieve the Study objectives. Data collection was performed on a regular schedule and in a consistent manner to avoid unnecessary data variability. The data collected included precipitation, runoff and erosion measurements. Appropriate staff and equipment were provided to efficiently implement monitoring activities. Each of the three sites was monitored in accordance with the OM&M Plan. Specific monitoring activities for each site are described in the following sections.

3.1 Monitoring Program

In previous sections, descriptions of the overall configuration of experimental units, plots, and sites were provided, including the method by which treatment combinations were replicated within sites and further duplicated for site-pair comparisons. The following sections provide descriptions of the procedures by which physical measurements (erosion data) were collected. These data were statistically analyzed to determine differences resulting from factors such as the erosion control product used, slope length, soil type, slope aspect, and slope degree.

The following monitoring activities are described in this section:

- measurement of erosion from runoff,
- measurement of erosion from wind,
- weather station monitoring, and
- empirical observations and data collection.

Potential storm events were monitored to assess the post-storm monitoring activities that would be required. Table 3-1 provides a summary of the monitoring activies and methodologies used to conduct this Study.

Table 3-1 Summary of Monitoring Activities, Methodology and Frequency

Monitoring Component	Measurement Parameters	Measurement Frequency	Field Procedures	Calculation/ Analysis Methodology
Surface water and sediment	Runoff volume and sediment yield	Post-storm	Sample runoff (with suspended sediment) collected in collection system containers according to sampling protocol. Measure and record volume of runoff and sediment in both containers	Subtract the volume of sediment from runoff volume to determine runoff volume. Use relational volume equation to determine the volume of sediment and runoff.
Weather stations	Precipitation, wind speed and direction, and temperature	Monthly and post-storm	Download weather station data logger to laptop computer or download data from KJNK site.	Use wind gust equation to determine wind gusts from wind speeds.
Wind erosion	Soil elevation	Monthly/ Annually	Measure and record the soil surface elevation in test plots using automated survey gun and recorder.	Total soil loss from wind erosion is the difference between sediment yield captured and the calculated loss or gain in elevation of each test plot.
Empirical observation	Various types of erosion including incidental vegetation, splash erosion, and rills.	Monthly and post-storm	Check for any signs of erosion types. Record observation on field data sheet and photo document.	N/A
Empirical observation	Product Integrity	Monthly and post-storm	Inspect products in test plots for cracks, lifting from slopes, or any other evidence of product deterioration. Document observations on the field data sheet.	N/A
Empirical observation	General product performance	Monthly and post-storm	Photo document each test plot from standardized location.	N/A

Acronym:
N/A = not applicable

In general, monitoring activities were conducted on a monthly basis and at the completion of an individual storm event. However, with regard to high-intensity storm events (>1 inch of rainfall per day), the sites were visited during the storm events to ensure that the capacity of the sample collection devices had not been exceeded. Additionally, an inspection was performed at the Dunaway Road site during a storm event to verify that the collection systems were performing according to the design plan. During storm monitoring was conducted at Dunaway Road because there was a known extened storm event that facilitated during storm inspection. All post-storm mobilization activities were determined based on the storm selection criteria stated in the OM&M Plan.

3.2 Weather, Runoff and Erosion Measurements

The erosion control products were monitored and evaluated through collection of weather data and runoff and erosion measurements. Monitoring of these variables effect on test plots occurred on a monthly basis and after each storm event. Using these measurements, project teams were able to determine the total runoff and infiltration associated with each of the erosion control products. Constituents were monitored using the measurement protocol described in the OM&M Plan.

3.2.1 Weather Monitoring

In the Study Plan, the effects of wind speed, wind direction, temperature, precipitation intensity and amount of precipitation were identified as factors that may degrade erosion control product performance. These site conditions were monitored to use in the statistical analysis of product effectiveness and to determine the environmental drivers of product deterioration.

3.2.1.1 Precipitation Measurement

To record site conditions, a rain gauge was installed on-site to measure precipitation events. Potential storm events were monitored daily using the National Weather Service, and the on-site rain gauge was monitored remotely. Data were downloaded on a monthly basis. The on-site rain gauge measured rainfall intensity and duration of storm events. In addition, it allowed calculation of dry period(s) between storm events.

3.2.1.2 Wind and Temperature Measurement

In addition to rain gauges, weather stations were used to monitor and record site conditions. The Barstow and Hinkley project sites utilized on-site weather stations to collect weather data. The weather stations were connected to a digital logger and recorded precipitation, wind speed, direction, and temperature. Weather data were downloaded on-site during routine visits. For the Dunaway Road site, weather data were obtained from the National Weather Service weather station KNJK located at Naval Air Facility, El Centro, approximately 9 miles northeast of the Dunaway Road site. Data downloaded from the KNJK station included wind speed, direction, and temperature among other weather variables.

3.2.2 Runoff and Erosion Measurement

The runoff measurement system consisted of a two-barrel system to collect surface runoff flow and sediment (Figure 3-1). Runoff captured in the collection system consisted of precipitation that fell directly onto the test plots. Test plots were designed with runoff diverts at the top of the structure to avert potential runon from entering the test plots. Precipitation that fell directly on the test plot was captured as sheet flow runoff into the collection system. Runoff and sediment moved over the slope and passed through a rock screen into a triangular flume, and into a collection pipe sized for the flow intensity of a 24-hour, 100-year storm. Ultimately, runoff and sediment flowed into a splitter barrel, designed with six evenly distributed holes carefully machined at the same level on the barrel. One of these holes was connected to a splitter barrel that collected the total flow that overflowed out of the splitter barrel. This value was based upon the maximum amount of runoff that could be collected by a 189-liter (55-gallon barrel) in a 100-year storm for a full-length test plot. The remaining holes were designed to discharge runoff when capacity was reached. It should be noted that the collection barrel system was modified during the Study as described in Section 3.2.3.1.

Figure 3-1 Splitter Barrel Runoff and Sediment Collection System

Measurement activities are described in detail below.

- Prior to installation, barrels were cleaned with potable water and measured internally to derive a volumetric equation. The relationship between the depth and volume of the barrel was determined so that the volume of runoff and sediment captured in each barrel could be calculated.

- During post-storm monitoring activities, field teams measured runoff and sediment collected in the barrels with a calibrated measuring rod before a sample was collected. The measuring rod had 1/8-inch graduations. Runoff depths less than 1/8-inch were recorded as <1/8-inch. Field teams performed measurements in sequential steps in each collection barrel to quantify total runoff and sediment volume.

- Measurements of runoff and sediment in the splitter barrel and collection barrel were taken as described below.

    1. Measure and document the surface height of the total volume of runoff and sediment collected in each barrel (as needed) with a measuring rod.

2. Sample the water column in the splitter and collection barrels using a barrel sampling device (Drum Sampler) and submit the sample for TSS analysis (sample collection methodology is described in Section 4.3.1).

3. Decant remaining runoff from the barrel. Decanting was performed in a manner that minimized re-suspension of sediment that had settled in the bottom of the barrel. In the event that resuspension occurred, field teams would allow sediment to settle before resuming decanting.

4. Measure the depth of the sediment directly with a measuring rod and document the measurement.

5. Remove the sediment from the barrel after measuring height of settled sediment and record the height in the field data sheet..

6. Clean the barrel to remove residual traces of sediment.

Figure 3-2 shows sediment in a barrel being measured externally using a measuring tape.

Figure 3-2 Sediment Measurement Method

To quantify the total runoff collected, the recorded volume of sediment was subtracted from the total volume captured in the collection barrel. Field data were then processed using a devised algorithm which quantified the total volume of runoff and sediment collected. Sediment documented in the field was then quantified with TSS results from the laboratory analysis to provide total sediment volume captured. The formula used for calculation of the volume of soil lost in runoff from each test plot is identified below.

Where:

TS (cf) = Total Volume of Sediment in Collection Barrel
VM (cf)= Volume of Measured Sediment in Collection Barrel (Field Measured)
VS (cf)= Volume of Suspended Sediment in Collection Barrel (Empirically Calculated)

Equation 1:

$$MS = (TSS * VR) \qquad \text{(mg)}$$

Equation 2:

$$VS = \left(\frac{MS}{\rho}\right) * (35.34) \qquad \text{(cf)}$$

Equation 3:

$$TS = (VM) + (VS) \qquad \text{(cf)}$$

TSS (mg/L) = Total Suspended Solid Concentration (Laboratory Measured)
MS (mg) = Mass of Suspended Solids as determined by TSS results
VR (L) = Volume of Runoff in Collection Barrel (Field Measured)
ρ (Kg/m3) = Average Bulk of Sediment in Collection Barrel (Field and Laboratory Measured)

Note: If flows were captured in the secondary barrels, then the above equations are applicable and the TS value determined from the primary collection barrel is added to the TS value determined from the secondary barrel.

Soil movement caused by erosion can result in a change in the soil surface level, which also can be measured. Measurement of the soil surface can be used to estimate soil loss due to wind and runoff. As described in the OM&M Plan, a baseline topological digital surface model survey (survey) was conducted at the three sites at the beginning of the Study. The purpose of the survey was to establish the baseline surface conditions from which surface erosion due to wind and runoff could be determined over the course of the Study. Routine surveys were conducted by field teams on a monthly basis and during post-storm activities for the first year of the Study. Annual surveys were conducted at the end of each monitoring year and the data generated were compared with the previous year.

Each test plot (except the RSP plots) was surveyed using a standard 2-foot by 2-foot grid, unless otherwise instructed. RSP plots were not surveyed because those test plots did not have any exposed soil and would not be affected by wind erosion. The annual surveys included variations to the standard grid, where the size of the grid was adjusted on two occasions. Annual surveys occurred on two occasions—once in October 2009 (1-foot by 1-foot grid) and again in September 2010 (0.5-foot by 0.5-foot grid).

Comparison of the post-event digital surface model data to the previous post-event digital surface model data and to the baseline digital surface model data sets was intended to allow the calculation of the volume of sediment lost or gained in each plot for the event, annual, and study time increments, respectively.

The annual survey results were used to measure the ultimate loss or gain to the surface of the plots due to water and wind erosion over the course of the study. The survey results, in the form of soil movement from each Study site, are provided in Section 4.4.

3.2.3 Post-construction Monitoring Modifications

A number of post-construction modifications were required to meet Study monitoring methodology objectives. It was determined that natural factors, such as wind erosion, intense heat, arid air quality, unaccounted for runoff, and channeled runoff between the plot sites, required field modification to generate effective data and maintain site integrity. Post-construction modifications implemented to effectively address natural factors are described below.

3.2.3.1 Plastic Aprons

During the initial months of monitoring, it was observed by field staff that sediment was being deposited into the primary collection barrels in the absence of rainfall. Wind-blown sediment was entering the barrels through the five free-discharging orifices on each primary barrel. The decision was made to cover each primary barrel with a plastic apron that would prevent wind-blown sediment from entering the overflow orifices while still allowing runoff to freely discharge through each orifice during storm events.

The plastic aprons were installed at the three sites in early December 2008. However, subsequent storm data and field observations revealed that the aprons might be compromising the effectiveness of overflow discharge of runoff from the five overflow orifices during large storm events. Following a field test of the apron effect on overflow discharge, the decision was made to remove the plastic aprons from the primary barrels at both the Barstow and Hinkley sites.

The field staff at the Dunaway Road project site modified the apron design to incorporate large, hollow "spacers" underneath each discharge orifice that would prevent the plastic aprons from making contact with the barrel near the orifice opening and allow free discharge of runoff. Figure 3-3 displays the collection barrel with the plastic apron. The hollow "spacers" were secured by a bungee cord.

Figure 3-3 Plastic Apron with Spacer

3.2.3.2 Rubber O-ring Replacement

At the Barstow and Hinkley sites, the bottom of each collection barrel was equipped with a drain valve that was sealed on the inside and outside with a rubber o-ring. The o-rings were originally installed in June 2008, but became compromised from exposure over time. Rubber o-ring inspections were performed at approximately six-month intervals at the Barstow and Hinkley sites, and compromised o-rings were replaced each time.

3.2.3.3 Inter-plot Erosion Control

By February 2009, signs of erosion between the test plots were observed. It was determined that this erosion potentially could compromise the structural integrity of the study plots and equipment enclosures.

A decision was made to line the areas between the plots with non-woven filter fabric and stabilize it with approximately one-inch aggregate rock to prevent further erosion. This system was installed at the Barstow site in June 2009 and at the Dunaway Road and Hinkley sites in July 2009. Field observations confirmed that the installed rock remedied erosion issues in the median of the test plots.

Due to minor erosion exhibited on the upper slopes of the Barstow site, a decision was made to apply Soil Seal which was the most cost-effective solution for temporary erosion control in the areas above the test plots. Soil Seal was applied to the entire area within the Study limits at the Barstow and Hinkley sites; the material was applied as specified by the manufacturer. This was not necessary at the Dunaway Road site, because enough material remained from the filter fabric and one-inch aggregate application between the test plots to stabilize the upper portions of the slope area.

3.2.3.4 Graded Gravel Access Roadway

In July 2009, access roads along the frontage of the Barstow and Hinkley sites were graded and one-inch aggregate rock was applied to the surfaces. The purpose was to provide improved accessibility to each site during the rainy season. Field teams found that the muddy conditions during the post-storm monitoring activities presented difficulties with ingress and egress. The field conditions at the Dunaway Road site did not necessitate the addition of gravel to the roadway at that location.

3.2.3.5 Rock Screen and Flume Gap Sealing

In July 2009, field staff observed minor rill development under several of the collection flumes at the base of the plots at the Dunaway Road site. Further inspection revealed that gaps between the flume and the study plot had developed in a subset of the collection flumes. The affected test plots were sites 11-308 through 11-312. It was determined that storm runoff may have been diverted through these gaps causing minor erosion underneath the collection flumes. Aside from allowing runoff to circumvent the collection system and potentially bias the monitoring results, the partially eroded areas were determined to have the potential to undermine the stability of the collection flume supports. The identified gaps subsequently were filled and sealed with silicone caulking.

At the Hinkley site, the conditions were similar to the Dunaway Road site, where gaps between the collection flume and the study plot had developed. It was also determined that storm runoff may have been diverted through these gaps causing minor erosion underneath the collection flumes. Test plots were inspected for integrity and, where a gap was observed, the flumes were sealed with silicone caulking and are currently inspected during each site visit.

The Barstow site was noted as having very slight gaps, but did not show signs of erosion under any of the flumes as the Dunaway Road and Hinkley sites did. Each study plot was inspected and silicone caulking was applied as necessary to the plots noted as having gaps.

3.2.3.6 Barrel Swap Modification

Examination of the runoff capture data from the first monitored storm at the Dunaway Road site suggested that the two-barrel collection system may not have been functioning as originally designed. The two-barrel runoff measurement system was originally designed to collect a proportion of the surface runoff flow and sediment from the test plots to allow capture of up to a 24-hour, 100-year storm. The original design was to allow runoff and sediment to be collected from the test plots and flow into a splitter barrel, designed with six evenly distributed holes carefully machined at the same level on the barrel.

A subsequent flow test was conducted at the Barstow site to verify that the primary barrels were splitting flows at the correct ratio. This test revealed that the five free-discharging orifices were discharging at relatively equal rates, but flow into the outlet orifice, connected via pipe to the collection barrel, was not. At lower flows, it was observed that runoff would leave the barrel through the five splitter orifices with very little runoff cresting the conveyance outlet orifice and discharging into the secondary collection barrel. Larger flows would allow more flow into the secondary collection barrel, but the rate of flow into the collection barrel was not consistent with the other free-discharging orifices. As a result of the conveyance outlet hole requiring more head to discharge flow, runoff preferentially discharged through the five free-discharging orifices.

Results of the splitter flow test performed at the Barstow site indicated that the existing conveyance arrangement was not functioning per the original study design. Beginning in July 2009, several solutions were proposed, discussed, and beta tested, but none could remedy the flaws observed in the splitter system. It was decided that reliance on precise splitting of flow in the field should be abandoned in favor of capturing 100 percent of the runoff into the barrels. This arrangement was achieved by reversing the order of the primary barrel with the secondary collection barrel at each site, allowing for the secondary collection barrel to fill and then discharge 100 percent of overflow into the primary barrel. If the primary barrel were to fill up, runoff would simply discharge through the existing overflow orifices. This exercise was the most cost-effective solution as it did not require any fabrication, additional materials or equipment, and was completed by field staff in one day.

3.2.4 Modifications to Project Methodology

Based on the data recorded and field observations made, certain components of the original Study design were found to be inadequate in providing the desired field results. The modifications required as a result of the design flaws are discussed below.

3.2.4.1 Measurements of Erosion from Runoff

As described in the Arid Region Non-Vegetative Erosion Control Study End of Year Report (CTSW-RT-09-210.12.01), runoff data were examined to verify whether the collection systems performed as designed. As a result of the examination of runoff data and field observations collected during the first storm events captured in late 2008 and early 2009, it was determined that the two-barrel system designed to collect a proportion of the surface runoff flow and sediment (described in the project OM&M Plan) may result in inaccurate quantification of runoff volumes. The potential source of the inaccuracy was determined to be the configuration and function of the splitter barrel.

The splitter barrel was designed with six evenly distributed holes machined at the same level on the barrel. Field observations indicated that slight variances in the orifice placement on the barrels, minor slopes in the concrete pads used to anchor the splitter barrels, and/or stress deformity of the plastic collection barrels caused by the weight of captured water may have resulted in differential discharge among the six splitter holes. Accordingly, the collection barrel may have received a larger or smaller volume than one-sixth of the flow discharging from the splitter barrel, depending on barrel orientation and degree of differential discharge to the transfer pipe. Given the importance of accurate flow measurement to Study objectives and the overall determination of product performance, it was determined that the existing runoff and sediment collection system required modifications to improve runoff measurement accuracy.

Ultimately, the project team decided that reconfiguring the existing barrels so that the collection barrel received runoff directly from the flume and was connected in series to the splitter barrel was the best and most cost-effective method to correct the deficiencies. This configuration allowed a total of roughly 98 gallons of runoff and sediment to be collected in the revised two-barrel system prior to overflow occurring.

3.2.4.2 Adjustments to Monitoring Measurements

The Study Plan identified certain markers that could be used to measure erosion and impairment to water quality. However, due to the nature and location of the study sites, the measurement of pH and rills (two of the markers identified in the Study Plan) were not performed. During the first storm event, it was determined that the collection of pH was not applicable to the Study due to the remote locations of the sites and the variability of storm patterns. To comply with the EPA-approved methodology for pH field testing, runoff must be sampled within 15 minutes of discharge.

The project OM&M Plan identified that rill measurements would be performed on a monthly basis. However, rills were not measured due to inability of the field teams to access the center of the plots without impairing the integrity of the products. Although measurement of rills was not conducted, field teams provided photo documentation of the erosion control products on a monthly basis.

3.3 Sampling Methods

The following sections provide an overview of the general sampling methodology used for this Study and discuss the sampling methods used for barrel sample collection, conveyance pipe sample collection, and soil density testing. Sampling occurred during the post-storm activities conducted to assess erosion and water quality. Runoff and sediment samples were collected according to sampling procedures described in the OM&M Plan.

3.3.1 Barrel Sample Collection

Runoff samples were collected by field teams for analysis of TSS. Samples were collected in accordance with the methodology established in the OM&M Plan. Samples were collected using a drum sampler, which consists of an open-ended long cylindrical tube. Samples were taken of the entire runoff column to collect representative samples of the entire column strata. This technique ensured that the different layers of suspended fine particles would be captured in the runoff sample.

The drum sampler was inserted into center of the runoff column through the top of the collection barrel, as shown in Figure 3-4. Aliquots collected by the drum sampler were deposited in a 1 L plastic sample bottle. Samples were then labeled and submitted to the laboratory for analysis.

Figure 3-4 Drum Sampling Method

3.3.2 Conveyance Pipe Sample Collection

After the first storm at the Dunaway Road site, field staff discovered substantial quantities of sediment had settled in some of the conveyance pipes that connect the flumes to the collection barrels. It was determined that the sediment that had collected in the conveyance pipe should be measured and included in the total sediment yield for the storm event. Based on this decision, conveyance pipe cleaning and sediment measurement protocol was employed during the monitoring visits and continued to be utilized throughout the remainder of the Study.

Measurable amounts of sediment from the conveyance pipes were not found at the Barstow and Hinkley sites until the end of the last storm of the 2008-2009 monitoring season. A protocol similar to the Dunaway Road site protocol was implemented to quantify sediment captured in the conveyance pipes during this storm event.

3.3.3 Soil Density Testing

Soil density and moisture measurements provided data on the effects of density and moisture on erosion control performance. Data were examined in order to assess the soil density and moisture variability at the measured depths, and the spatial variability across each of the test plots. This section describes the methods used to measure soil density. Soil density testing was performed on the soils surrounding the test plots and on the sediment collected in the runoff from the test plots, as is described in the OM&M Plan. The results of soil density testing were used to convert the measured amount of sediment from volume to mass.

3.3.3.1 In-situ Slope Testing

In spring 2009, in-situ slope density testing was performed. Soil density at the test plot locations was determined using ASTM D 2922 - *Standard Test Methods for Density of Soil and Soil Aggregate in Place by Nuclear Methods (Shallow Depth)*. This test method determines the total or wet density of soil and soil-rock mixtures by measuring the attenuation of gamma radiation where the cylindrical probe containing the source and detector is lowered to the desired test depths. The dry density is calculated by dividing the wet density of the soil by its moisture content.

Soil moisture was determined using ASTM D 3017 - *Standard Test Method for Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth)*. This method determines the water content of soil by the thermalization or slowing of fast neutrons where the neutron source and thermal neutron detector are lowered to the desired test depths.

The soil density and moisture measurements used to calculate soil bulk density were obtained using a nuclear test gauge at two depths (two and six inches) at each of three locations (top, middle and toe of slope) adjacent to every other test plot (i.e., every two test plots) within each site.

3.3.3.2 Sediment Density Testing

In early 2010, soil density measurements were obtained from the collected sediment in the runoff collection barrels at the three Study sites. The objective was to obtain an estimate of the average bulk density of gravity-settled sediment of each erosion control product including control. The results were used to evaluate the difference between the weight/mass of sediment on the slopes and the sediment captured in the collection barrels and to ultimately calculate tons per acre loss of eroded soil for each erosion control product.

A unique procedure was devised to duplicate the gravity-settled sediment test by core method due to the constraint posed by collection barrels for core extraction. The devised procedure mimics collection barrel conditions in a laboratory using a container of known dimensions to achieve bulk density. The bulk density is calculated by dividing the dry composite sample weight/mass by the composite gravity-settled soil sample volume.

Dry composite sample weight/mass was determined by baking the soil in a thermostatically controlled heating chamber to determine the oven-dry weight. Composite soil sample volume was determined empirically using a tin with a known volumetric equation.

Grab samples collected by field teams were combined by product type to prepare a composite sample representative of each erosion control product being evaluated. The premise for composite analysis of each erosion control product type was that bulk densities should be relatively constant regardless of test plot location.

Bulk density testing was performed once during the Study based on the assumption that bulk density of product type should remain constant throughout the course of the Study, regardless of storm event. The procedure and method used to determine bulk density of product types are provided in Appendix B.

3.4 Analytical Methods

Runoff samples were collected and submitted to a laboratory for analysis of TSS. The analysis method described in Table 3-2 was used, as directed by the OM&M. TSS results were added to measurements of soil captured in the collection barrels to determine total sediment yield.

Table 3-2 Analytical Constituent, Method Specification and Recommended Reporting Limits

Analyte	Purpose	Analytical Method	Holding Time	Container Type	Sample Volume	Preservation	Reporting Limit
Total Suspended Solids	Indicates sediment load	EPA 160.2	7 days	glass or PE	1,000 ml	4ºC	1 mg/L

Acronyms:
ºC - Celsius
EPA – united states environmental protection agency
L - liter
mg - milligram
ml – milliliter
PE – polyethylene

3.5 Operational Monitoring Methods

The following sections discuss the data collection methods and additional testing that was performed during the monthly site inspections. Throughout the Study, empirical data were collected to assess product integrity. Field forms were utilized to record empirical observations and photographs were taken to document observations. Additional empirical observations and tests were performed to verify that the collection systems and project site design functioned as intended.

3.5.1 Operation Monitoring Data Collection

Empirical observations were used to record and evaluate study conditions that were not quantified using other defined measurements. Field data sheets were designed for collection of these data. Visual observations provided information on different types of erosion that occurred throughout the Study. Empirical data were collected by field teams on a monthly basis and after every storm event. The empirical data collected provided information regarding product integrity as it related to the different types of erosion that occurred. The different erosion types and other observations of note were recorded on the field data sheets and photo logged. Empirical data results are discussed in Section 4. The empirical data described below were collected at each study site.

Incidental vegetation - During monthly site inspections, personnel checked for any signs of incidental vegetation. If any was observed, personnel made a note of the observations in the appropriate section of the empirical data sheet.

Evidence of raindrop splash erosion - During monthly site inspections, personnel checked the plot edging for attached soil particles. Personnel recorded observations (e.g., location, distribution, and particle size) in the appropriate section of the empirical data sheet.

Product integrity - During monthly site inspections, personnel inspected products in each plot for cracks, lifting from slope surface, piping underneath product, and any other evidence of product deterioration. Personnel documented observations on the field data sheet.

3.5.2 Additional Testing

The monitoring activities identified in the Study Plan were performed as discussed above. However, based on the initial field measurements collected, additional monitoring activities were conducted at the three study sites. These additional activities are detailed in the following subsections.

3.5.2.1 Splitter Flow Test

Examination of the runoff capture data from the first storm events suggested that the two-barrel collection system may not have been functioning as originally designed. The two-barrel system runoff measurement system was originally designed to collect a proportion of the surface runoff flow and sediment from the test plots to allow capture of up to a 24-hour, 100-year storm. The original design intended for runoff and sediment to be collected from the test plots and flow into a splitter barrel, designed with six evenly distributed holes carefully machined at the same level on the barrel. One of these holes was then connected to a collection barrel that was intended to collect one-sixth of the total flow that overflows out of the splitter barrel, therefore allowing capture of a representative sample for larger storm events.

Runoff data collected during the first monitored storm event at the Dunaway Road site indicated that the splitter barrel may have been disproportionately distributing runoff from the six splitter orifices, resulting in collection of inaccurate runoff measurements. Field staff examined this issue using a non-stormwater source and found that a majority of the splitter barrels discharged water unevenly. Reasons for the uneven discharge included: slight barrel material deformation, small inaccuracies in orifice placement on the barrel and minor configuration inconsistencies in the splitter barrel/collection barrel connection conveyance. A subsequent flow test was conducted at the Barstow site to verify that the primary barrels were splitting flows at the correct ratio. This test revealed that the five free-discharging orifices were discharging at relatively equal rates, but flow into the outlet orifice, connected via pipe to the collection barrel, was not. At lower flows, it was observed that runoff would leave the barrel through the five splitter orifices with very little runoff cresting the conveyance outlet orifice and discharging into the secondary collection barrel. Larger flows would allow more flow into the secondary collection barrel, but the rate of flow into the collection barrel was not consistent with the other free-discharging orifices. As a result of the conveyance outlet hole requiring more head to discharge flow, runoff preferentially discharged through the five free-discharging orifices.

3.5.2.2 Monitoring during Extended Storm Event

During an extended storm event that occurred on January 21, 2010, field teams visited the Dunaway Road site to assess the effectiveness of the erosion control products during extended periods of higher-than-average precipitation. Field teams observed collection system function, site conditions, and erosion control performance. The empirical data collected consisted of photo and video documentation of the event. The project site was observed to have experienced accelerated product deterioration and test plot destabilization due to the high intensity of precipitation and extended duration of the storm event. In addition, it was observed that large amounts of precipitation resulted in the run-on diverter contributing to test plot runoff. However, the contributing area of the run-on diverter was considered minimal and did not significantly impact the test plot. Visual observations of the Barstow and Hinkley sites after the extended storm event in January 2010 indicated that these sites performed similar to the Dunaway Road site as described above.

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Section 4 Monitoring Results

The number of storm events monitored at each site ranged from 9 to 13 for the duration of the study. Monitored storm events were sequentially numbered in each monitoring season. On field forms, the sequential storm number was preceded by the year in which the wet season began. A detailed Post-Storm Technical Memorandum was prepared for each monitored event (Appendix C). The following sections discuss the Quality Assurance/Quality Control (QA/QC) program developed for this Study, the events that were monitored at the three sites, the rainfall and runoff results, survey results, operation monitoring results, analytical results and sediment yield results.

4.1 Quality Assurance/Quality Control

The following sections address the QA/QC procedures associated with sample collection and laboratory analyses for water quality samples collected during the study period. Field QC samples were used to evaluate potential contamination and sampling error that might have been introduced prior to submittal of the samples to the analytical laboratory. Laboratory QC procedures provided information needed to assess potential laboratory contamination and analytical precision and accuracy.

4.1.1 Quality Assurance Objectives

Quality assurance objectives are broad goals for data collection and review. The quality assurance objectives for this Study are described below.

- **Precision** is defined as the degree of reproducibility of the measurements under a given set of conditions. Precision is documented on the basis of Relative Percent Difference (RPD) among replicate/duplicate analyses: usually laboratory duplicate, laboratory control sample duplicates or matrix spike duplicates. RPD is calculated as follows:

$$\%\ RPD = \frac{\text{Concentration}^A - \text{Concentration}^B}{(\text{Concentration}^A + \text{Concentration}^B)/2} \times 100 \qquad \textit{Equation 4}$$

Where:

Concentration^A = Observed concentration of first replicate analysis

Concentration^B = Observed concentration of second replicate analysis

The RPD serves as a measure of the reproducibility, or precision, of the analytical method.

- **Accuracy** is defined as the bias in a measurement system. Accuracy is documented on the basis of recovery of surrogates, laboratory control samples, and matrix spikes (MSs). MSs are generally not applied to water quality samples analyzed for TSS.

- **Representativeness** is the degree to which data accurately and precisely portrays the environmental conditions being studied. The representativeness of the analytical data is a function of the procedures and the level of care in collecting and processing the samples. The representativeness can be documented by the relative percent difference between separately acquired, but otherwise identical sample aliquots.

- **Completeness** is the estimate of the number of valid measurements made as compared to the total number of measurements performed. The completeness objective for an analysis is to provide sufficient data of acceptable quality such that the goals of the analytical project can be achieved. The overall project completeness is expressed as the percentage of planned data that is usable for its intended purpose.

- **Comparability** is an analysis of the data for which the accuracy, precision, representativeness, completeness, and detection limit are similar to the same quality indicators generated by other laboratories for similar samples. The comparability objectives are documented by inter-laboratory studies, carried out by regulatory agencies, or carried out for specific projects or contracts, and by comparison of periodically generated statements of accuracy, precision, and detection limits with those of other laboratories.

These data quality objectives were evaluated during the limited data validation process. The data validation process also included a technical review to ensure that the data had been properly entered into the database for report generation. Data were reviewed against the project-specific limits for method detection and reporting limits as described in the OM&M Plan (Caltrans 2009).

4.1.2 QA/QC Procedures

This section addresses the QA/QC procedures conducted for this Study associated both with sample collection and laboratory analyses. Field duplicate samples were collected at each sample location for field quality control during at least one monitored storm event. For laboratory quality control purposes, laboratory replicate (LR) samples were analyzed for the monitoring events measured at each location.

- **Field Duplicates** – Field duplicates are two samples collected at the same time from the same location that are submitted to the laboratory as separate samples (i.e., "blind" duplicates). Field duplicate samples can be used to assess the variability of compounds within the sample matrix and the consistency of the overall sampling effort, including collection, shipping, and analysis procedures. The purpose of submitting the samples "blind" is to assess the consistency or precision of the laboratory's analytical equipment. Field duplicate samples were analyzed for the same parameters as the corresponding primary sample.

- **Laboratory Replicates** – Laboratory replicates are replicates of the original field samples split by the laboratory and analyzed for the same compounds. These results are compared to the results of the original samples by assessing the RPD between the sample replicates.

4.1.3 Limited Data Validation and Verification

Chemical water quality data were validated using the Caltrans Automated Data Validation (ADV) software for the QA/QC elements of precision, accuracy, reporting limits, and contamination in accordance with the Caltrans Comprehensive Protocols Guidance Manual (Caltrans 2003a). Chemical water quality data were validated by Laboratory Data Consultants of Carlsbad, California. Laboratory results that met data quality objectives were accepted without qualification. Results associated with QC parameters that did not meet objectives were qualified as estimated values (J flagged). Data qualified as estimated is considered usable for its intended purpose. Data verification is based on the same QA/QC parameters as data validation, except that raw data record reviews and recalculation of results from the raw data were not performed during verification.

Analytical sample results were entered into a Microsoft Access database, and verification checks for each sample result against the associated method detection limit (MDL), reporting limit (RL), and numerical and/or overall qualifier, if applicable, were performed. Individual analytical results were qualified during the limited data validation procedures.

During the evaluation of the data, no qualifiers were assigned. Values detected were found to be above the MDL and the RL.

Data qualified as a result of qualification by the Caltrans ADV software are indicated as such in the analytical result tables.

No data estimations were performed and no contamination problems occurred.

4.2 Monitored Events

This section presents the results for the monitored storm events at the three sites. The measured rainfall amount, intensity and storm duration for each monitored event at the three sites are presented below. Additionally, cumulative rainfall during the study period is presented.

Monitoring events that occurred at the Barstow Site are provided in Table 4-1. A total of 13 storm events were monitored at the Barstow Site.

Table 4-1 Barstow Site Monitoring Events

Event ID	Date	Event Rainfall Quantity (in)	Event Peak Rainfall Intensity (in/hr)	Rainfall Duration[1] (hr)	Cumulative Rainfall (in)
2008-01	11/24/2008	0.72	0.32	197.5	0.72
2008-02	12/9/2008	2.80	0.24	405.5	3.52
2008-03	2/5/2009	0.96	0.16	117.5	4.48
2008-04	2/12/2009	0.56	0.32	104.5	5.04
2009-01	11/27/2009	0.06	0.02	21.5	5.10
2009-02	12/5/2009	0.64	0.06	132	5.74
2009-03	1/13/2010	1.05	0.14	115.5	6.79
2009-04[2]	2/6/2010	0.50	0.16	31.5	6.79
2009-05	2/19/2010	0.75	0.08	216	7.54
2009-06	3/6/2010	0.29	0.08	70.5	7.83
2009-07	4/4/2010	0.31	0.08	28.5	8.14
2009-08	4/12/2010	0.10	0.04	21.5	8.24
2009-09	4/20/2010	0.28	0.04	34	8.52

[1]Rainfall Duration is calculated by the Caltrans Hydrologic Utility.

[2]Rainfall for Event 2009-04 (0.50") is not included with the cumulative rainfall quantity. Rainfall data was excluded from the statistical evaluation of erosion control products due to an issue with the weather station.

A total of nine storm events were monitored at the Dunaway Road site. The results storm monitoring events are presented in Table 4-2. One minor storm event occurred in the period between erosion control product application and the installation of the barrel collection monitoring equipment. This storm event has been included in the cumulative rainfall total to quantify total rainfall that impacted erosion control products.

Table 4-2 Dunaway Road Monitoring Events

Event ID	Date	Event Rainfall Quantity (in)	Event Peak Rainfall Intensity (in/hr)	Rainfall Duration[1] (hr)	Cumulative Rainfall (in)
2008-01	12/17/2008	1.28	0.60	11.70	1.45[2]
2008-02	02/05/2009	0.17	0.24	1.67	1.62
2008-03	05/19/2009	0.29	0.72	0.75	1.91
2008-04	09/05/2009	0.42	0.84	1.42	2.33
2009-01	12/07/2009	0.36	0.84	9.00	2.69
2009-02	01/18/2010	0.47	0.36	22.00	3.16
2009-03	01/20/2010	1.86	1.20	27.83	5.02
2009-04	03/07/2010	0.82	0.36	13.08	6.35
2009-05	08/02/2010	0.20	1.56	0.17	6.74

[1]Rainfall Duration is calculated by the Caltrans Hydrologic Utility

[2]Includes minor storm event that occurred prior to installation of barrel collection monitoring equipment

A total of 12 storm events were monitored at the Hinkley Site. The results of the monitored storm events are presented in Table 4-3.

Table 4-3 Hinkley Site Monitoring Events

Event ID	Date	Event Rainfall Quantity (in)	Event Peak Rainfall Intensity (in/hr)	Rainfall Duration[1] (hr)	Cumulative Rainfall (in)
2008-01	11/26/2008	0.75	0.32	20.5	0.75
2008-02	12/13/2008	1.48	0.48	312	2.23
2008-03	2/4/2009	0.68	0.16	116.5	2.91
2008-04	2/13/2009	0.36	0.16	73	3.27
2008-05	7/12/2009	0.24	0.22	195.5	3.51
2009-01	12/5/2009	0.37	0.08	128.5	3.88
2009-02	1/13/2010	0.87	0.14	111.5	4.75
2009-03[2]	2/6/2010	0.48	0.16	31	4.75
2009-04	2/19/2010	0.29	0.06	189.5	5.04
2009-05	3/6/2010	0.08	0.04	50	5.12
2009-06	4/12/2010	0.10	0.04	19	5.22
2009-07	8/17/2010	0.10	0.06	213	5.32

[1]Rainfall Duration is calculated by the Caltrans Hydrologic Utility.

[2]Rainfall for Event 2009-03 (0.48") is not included with the cumulative rainfall quantity. Rainfall data was excluded from the statistical evaluation of erosion control products due to an issue with the weather station.

4.3 Rainfall and Runoff Results

This section presents the captured runoff versus rainfall using the volumetric runoff coefficient (R_v) results for the monitored storm events at the three study sites. R_v is the measured relationship between the amount of runoff collected in the runoff capturing system from test plot area for a rainfall event of a known size. The potential maximum volume collected is determined by calculating the known test plot and flume area as projected on a horizontal plane against the quantity of rainfall from a given storm event. This volume equates to the maximum amount of potential runoff for a given storm event. R_v was determined by using runoff captured in collection barrels and dividing the volume by the maximum volume of potential runoff. R_v values were calculated for each test plot for monitored storm events. Over the course of the Study, the cumulative R_v values determined for each erosion control product are presented in Table 4-4 (Barstow Site), Table 4-5 (Dunaway Road Site), and Table 4-6 (Hinkley Site). Cumulative R_v values represent total runoff volume captured divided by total rainfall recorded throughout the Study.

Calculated R_v values at study sites indicate that hydraulically applied erosion control products (PP, SS, and ST) did not show a significant reduction runoff volume when compared against CT plots. However, R_v values for both RSP and SC showed significant reduction in runoff volume in comparison to CT plots.

R_v values for hydraulically applied erosion control products in study sites ranged in value from: 0.18 to 0.43 for PP; 0.05 to 0.40 for SS; and 0.01-0.40 for ST. The R_v values for the CT plots in the three study sites ranged from 0.12 to 0.42. Surface cover erosion control products, RSP and SC, R_v values ranged from 0.00-0.29 and 0.00 to 0.23, respectively.

The R_v values for the Barstow Site are presented in Table 4-4.

Table 4-4 Barstow Site R_v Values

Event ID	Date	Treatment Type (Site ID)																							
		PolyPavement™				Soil Seal				SoilTac®				Rock Slope Protection				Soil Cement				Control			
		8-310	8-320	8-328	8-331	8-314	8-318	8-322	8-332	8-312	8-317	8-323	8-330	8-315	8-319	8-325	8-327	8-316	8-321	8-326	8-333	8-311	8-313	8-324	8-329
2008-01	11/24/08	0.21	0.29	-0.01	-0.01	0.12	0.03	0.02	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.00	-0.01	-0.05	0.16	0.15	-0.01	-0.05
2008-02	12/09/08	0.11	0.08	0.12	0.11	0.11	0.01	0.10	0.11	0.09	0.05	0.00	0.11	0.04	0.01	0.00	0.08	0.00	0.00	-0.01	0.00	0.27	0.10	0.05	0.11
2008-03	02/05/09	0.15	0.10	0.01	-0.02	0.08	0.06	-0.01	-0.01	-0.02	-0.01	-0.01	-0.02	0.00	-0.01	-0.02	-0.01	-0.02	-0.01	-0.01	-0.01	0.09	0.08	-0.02	0.05
2008-04	02/12/09	0.29	0.24	0.12	0.03	0.27	0.31	0.04	0.01	0.01	0.02	0.01	0.01	0.22	0.05	0.03	0.05	0.02	-0.02	0.01	0.01	0.22	0.24	0.02	0.09
2009-01	11/27/09	0.03	0.09	0.03	0.06	0.00	-0.02	-0.02	0.03	0.03	0.09	0.03	0.06	0.09	0.03	0.03	0.09	0.09	0.09	0.09	0.06	0.00	0.03	0.00	0.03
2009-02	12/05/09	0.05	0.10	-0.01	-0.02	0.02	0.06	0.02	-0.02	-0.02	-0.01	-0.02	-0.02	-0.01	-0.01	-0.04	-0.02	-0.02	-0.02	-0.02	-0.02	0.05	0.02	-0.02	0.02
2009-03	01/13/10	0.87	0.89	0.88	0.90	0.90	0.88	0.85	0.92*	0.87	0.82	0.15	0.89	0.92	0.41	0.24	0.89	0.42	0.17	0.20	0.26	0.87	0.86	0.77	0.84
2009-04[1]	02/06/10	1.84	1.68	1.68	1.86	1.87	1.82	1.33	1.74	1.30	1.21	0.58	0.70	1.82	0.69	0.40	1.27	0.57	0.23	0.34	0.59	1.88	1.82	1.32	1.91
2009-05	02/19/10	0.24	0.17	0.15	0.24	0.22	0.22	0.19	0.17	0.00	-0.01	-0.03	0.02	0.14	0.01	-0.01	0.07	-0.03	-0.03	-0.03	-0.02	0.19	0.15	0.06	0.21
2009-06	03/06/10	0.36	0.35	0.24	0.26	0.34	0.37	0.35	0.17	0.02	0.02	0.02	0.02	0.21	0.08	0.05	0.12	0.02	0.02	0.02	0.00	0.35	0.36	0.20	0.29
2009-07	04/04/10	0.06	0.06	-0.02	0.03	0.01	0.00	0.03	-0.03	-0.05	-0.05	-0.06	-0.04	-0.07	-0.06	-0.06	-0.06	-0.06	-0.05	-0.05	-0.04	0.00	-0.07	-0.06	-0.06
2009-08	04/12/10	0.16	0.18	0.08	0.08	0.07	0.08	0.11	0.11	0.03	0.08	0.01	0.05	0.08	0.11	0.08	0.07	0.05	0.16	0.08	0.08	0.08	-0.05	0.03	0.03
2009-09	04/20/10	0.11	0.08	0.05	0.19	0.08	0.06	0.07	0.14	-0.02	-0.02	-0.01	-0.01	-0.02	0.02	0.01	0.00	-0.02	0.00	-0.02	-0.02	0.04	-0.02	-0.02	0.11
Study Totals		**0.24**	**0.23**	**0.18**	**0.18**	**0.22**	**0.18**	**0.18**	**0.05**	**0.13**	**0.12**	**0.01**	**0.14**	**0.16**	**0.06**	**0.03**	**0.15**	**0.05**	**0.02**	**0.02**	**0.02**	**0.27**	**0.20**	**0.12**	**0.18**

[1]Note: R_V values for storm event 2009-04 are shown, however, the values were excluded from the statistical analysis of the erosion control product due to an issue with the weather station

The R_v values for the Dunaway Road site are presented in Table 4-5. During the first storm event (2008-01) the collection barrel valve was inadvertently left open. Therefore, no data is available.

Table 4-5 Dunaway Road R_v Values

Event ID	Date	Treatment Type (Site ID)																							
		PolyPavement™				Soil Seal				SoilTac®				Rock Slope Protection				Soil Cement				Control			
		11-310	11-312	11-316	11-319	11-303	11-306	11-314	11-315	11-305	11-309	11-317	11-324	11-302	11-307	11-318	11-322	11-304	11-308	11-320	11-325	11-311	11-313	11-321	11-323
2008-01	12/17/08	0.78	0.80	-	0.65	0.84	0.87	0.77	0.80	0.12	0.73	-	0.08	0.05	0.01	0.02	0.00	0.00	0.03	0.01	0.02	-	0.77	0.53	-
2008-02	02/05/09	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
2008-03	05/19/09	0.01	0.01	0.14	0.06	0.05	0.01	0.06	0.07	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.03	0.03	0.03	0.09
2008-04	09/05/09	0.04	0.09	0.23	0.18	0.15	0.06	0.17	0.14	0.01	0.06	0.09	0.01	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.02	0.10	0.06	0.10
2009-01	12/07/09	0.21	0.28	0.24	0.18	0.16	0.05	0.21	0.13	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.12	0.02	0.22
2009-02	01/18/10	0.27	0.29	0.24	0.21	0.21	0.04	0.24	0.13	0.01	0.14	0.05	0.00	0.03	0.05	0.00	0.00	0.00	0.05	0.00	0.00	0.23	0.21	0.09	0.23
2009-03	01/20/10	0.57	0.62	0.59	0.53	0.52	0.31	0.57	0.49	0.15	0.41	0.42	0.14	0.06	0.05	0.13	0.08	0.01	0.18	0.08	0.01	0.49	0.47	0.42	0.53
2009-04	03/07/10	0.19	0.13	0.12	0.16	0.11	0.02	0.01	0.01	0.03	0.02	0.06	0.01	0.00	0.01	0.02	0.01	0.00	0.05	0.00	0.00	0.03	0.01	0.00	0.04
2009-05	08/02/10	0.26	0.16	0.23	0.33	0.28	0.06	0.10	0.07	0.07	0.07	0.09	0.00	0.03	0.03	0.04	0.01	0.00	0.10	0.01	0.00	0.12	0.13	0.07	0.08
Study Totals		**0.41**	**0.43**	**0.35**	**0.38**	**0.40**	**0.29**	**0.39**	**0.36**	**0.08**	**0.30**	**0.16**	**0.06**	**0.03**	**0.02**	**0.05**	**0.00**	**0.00**	**0.08**	**0.00**	**0.01**	**0.19**	**0.35**	**0.26**	**0.22**

Note: "-" Collection barrel valve inadvertently left open. No data available.

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The R_v values for the Hinkley Site are presented in Table 4-6.

Table 4-6 Hinkley Site R_v Values

Event ID	Date	Treatment Type (Site ID)																							
		PolyPavement™				Soil Seal				SoilTac®				Rock Slope Protection				Soil Cement				Control			
		8-338	8-345	8-348	8-349	8-341	8-343	8-351	8-353	8-340	8-342	8-354	8-356	8-339	8-344	8-347	8-355	8-335	8-337	8-350	8-357	8-334	8-336	8-346	8-352
2008-01	11/26/08	0.11	0.00	-0.02	-0.02	-0.01	-0.01	-0.01	-0.05	-0.02	0.03	-0.01	-0.01	-0.02	0.28	-0.01	-0.01	0.15	0.15	-0.01	-0.05	0.20	-0.01	0.02	-0.02
2008-02	12/13/08	0.25	0.24	0.14	0.28	0.27	0.13	0.28	0.27	0.28	0.19	0.43	0.65	0.28	0.25	0.30	0.27	0.14	0.11	0.06	0.06	0.19	0.60	0.20	0.36
2008-03	02/04/09	0.05	0.04	0.01	0.04	0.05	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.01	-0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0.10
2008-04	02/13/09	0.11	0.11	0.08	-0.07	0.13	0.04	0.05	0.07	0.04	0.04	0.01	0.05	0.06	0.00	0.08	0.08	0.02	0.02	0.04	0.03	0.03	0.13	0.06	0.04
2008-05	07/12/09	0.47	0.39	0.28	0.50	0.85	0.27	0.91	0.85	0.45	0.35	0.37	0.37	0.23	0.23	0.13	0.27	0.17	0.17	0.17	0.23	0.74	0.97	0.60	0.93
2009-01	12/05/09	0.27	0.36	0.35	0.34	0.53	0.48	0.57	0.54	0.34	0.26	0.31	0.35	0.18	0.10	0.12	0.18	0.12	0.12	0.12	0.12	0.54	0.47	0.39	0.60
2009-02	01/13/10	0.97	0.94	0.95	0.94	0.94	0.93	0.95	0.93	0.93	0.95	0.95	0.96	0.95	0.97	0.97	0.96	0.33	0.92	0.46	0.37	0.93	0.94	0.97	0.98
2009-03[1]	02/06/10	1.53	1.41	1.45	1.50	1.55	1.54	1.54	1.52	1.55	1.46	1.49	1.51	1.15	1.44	1.29	1.44	0.63	1.02	0.82	0.78	1.48	1.54	1.36	1.41
2009-04	02/19/10	0.12	0.06	0.13	0.10	0.15	0.16	0.22	0.16	0.12	0.09	0.08	0.13	0.07	0.04	0.02	0.05	0.02	0.08	0.08	0.05	0.23	0.08	-0.02	0.16
2009-05	03/06/10	0.19	0.16	0.19	0.22	0.19	0.19	0.19	0.22	0.16	0.13	0.19	0.13	0.19	0.19	0.19	0.22	0.16	0.22	0.22	0.16	0.13	0.08	0.19	0.19
2009-06	04/12/10	0.11	0.09	0.14	0.19	0.19	0.19	0.21	0.16	0.19	0.14	0.14	0.11	0.09	0.08	0.09	0.09	0.03	0.05	0.08	0.05	0.14	0.11	0.19	0.26
2009-07	08/17/10	0.01	0.01	0.05	0.09	0.03	0.01	0.01	0.03	0.01	-0.01	0.03	-0.01	0.01	0.03	0.03	0.01	0.01	0.01	0.05	0.01	-0.01	-0.01	0.09	0.03
Study Totals		**0.31**	**0.28**	**0.25**	**0.29**	**0.33**	**0.25**	**0.33**	**0.32**	**0.29**	**0.26**	**0.33**	**0.40**	**0.27**	**0.29**	**0.27**	**0.27**	**0.14**	**0.23**	**0.12**	**0.10**	**0.33**	**0.42**	**0.28**	**0.38**

[1]Note: R_v values for storm event 2009-03 are shown, however, the values were excluded from the statistical analysis of the erosion control products due to an issue with the weather station.

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4.4 Survey Results

This section presents the soil movement data measured from the plot surveys and digital surface model data. Due to the potential unreliability of the calculated amount of sediment loss/gain recorded by the monthly high resolution surface scan surveys, a decision was made on December 22, 2009 to discontinue the monthly and post-storm surface scan surveys. Two high resolution surface scan surveys were performed in October 2009 and September 2010 to measure the ultimate loss/gain to the surface of the plots due to water and wind erosion over the course of the study. This data was compiled into separate graphs and sorted by BMP product type. Each graph shows the volume of soil gain/loss within each plot with respect to time based on the baseline plot survey conducted at the beginning of the study period, the annual survey conducted in October 2009, and the end of study survey conducted in September 2010. The soil movement data which was acquired via surface scan survey is presented in Appendix D.

Review of the surface scan survey data indicates that the usefulness of the survey data and associated soil movement plots may be limited. An unexpected pattern evident in the soil movement plots is the frequency of net gain of soil in the test plots over the two year study period. This pattern is particularly evident at the Hinkley site, where a majority of the plots indicated a net loss of soil over the first year of the study, then showed a net gain over the second year. In many of the plots, the soil movement data indicated that overall, the plots had a net gain of soil over the study period. This data is inconsistent with the measured amount of sediment captured in the collection barrels (Section 4.7) and the visual observations (Section 4.5). As an example, at the Barstow site a PP test plot (8-320) showed a gain of 3 cubic feet of soil in the surface scan survey data, while the sediment yield data indicated a total of 0.36 cubic feet of sediment was captured in the sediment collection barrels over the 13 monitored storms. Conversely, at the Dunaway Road site, a ST test plot (11-309) showed a net gain of approximately 3 cubic feet of soil in the surface scan survey data, while the sediment yield data indicated a total of 4.0 cubic feet of sediment was captured in the sediment collection barrels over the nine monitored storms. Furthermore, the mortar-like surface SC plots which did not show significant signs of degradation or aggregation of soil over the course of the Study at the three monitoring sites, had significant net soil gains (up to 5 cubic feet) and losses (up to 2 cubic feet) as determined by surface scan survey data. Given these issues, the soil movement data derived from the surface scan survey data is presented in Appendix D and was not used in the statistical analyses of erosion control product performance presented in Section 5.

4.5 Operation Monitoring Results

This section describes the operation monitoring results for the Study sites. Operation monitoring consisted of empirical data collection during routine site inspection activities. Site inspection activities included a monthly general inspection of experimental plots and monitoring equipment, and completion of an empirical observation form for each plot.

Routine site inspection activities at each site began at the Study sites in late 2008 when site construction was completed. Monthly plot inspection data indicated that, in general, the experimental plots, runoff collection flumes, conveyance pipes and barrels, and other on-site monitoring equipment did not require excessive maintenance or repair. A number of minor maintenance and monitoring equipment performance issues were noted by field teams during individual monthly inspections. However, in general, it was possible to alleviate and/or repair these performance-related issues during the routine site visits. Routine and non-routine maintenance activities are detailed in Section 6.

The following sections provide a general summary of the empirical observation data collected from the plots associated with the five erosion control products included in this Study as well as the control plots.

4.5.1 PolyPavement™ (PP)

Empirical observation monitoring indicated that in general, field teams did not consistently observe signs of erosion in the PP plots during the first year of the study. Beginning in January 2010; however, field teams for each site noted the formation of minor rills and some cracking/chips of the erosion control product material in the PP plots. In addition, incidental vegetation was consistently observed in the PP plots beginning in January and February 2010.

Table 4-7 Example of Chronological Degradation of PolyPavement™ Test Plot

a) October 2008	b) January 2010
	
c) September 2010	d) September 2010- Detail
	

Dunaway Rd 11-312 Plot DEA11-PP

4.5.2 Soil Seal (SS)

Empirical observation monitoring of the SS plots indicated that field teams at each site did not consistently observe signs of erosion during the first year of the study. Beginning in January 2010; however, field teams began to note the formation of minor rills and some cracking/chips of the erosion control product material in the SS plots. In addition, incidental vegetation was consistently observed in the SS plots beginning in January and February 2010.

Table 4-8 Example of Chronological Degradation of Soil Seal Test Plot.

a) October 2008	b) January 2010
	
c) September 2010	d) January 2010- Detail
	

Dunaway Rd 11-314 Plot DWA01-SS

4.5.3 SoilTac® (ST)

Empirical observation monitoring indicated that, in general, field teams did not consistently observe signs of erosion in the ST plots during the first few months of the study. Field teams at each site began to note the formation of minor rills and some cracking/chips of the erosion control product material in the ST plots beginning in October 2009. In addition, empirical observations consistently noted incidental vegetation and bare areas within the ST plots beginning in January and February 2010.

Table 4-9 Example of Chronological Degradation of SoilTac® Test Plot.

a) October 2008	b) January 2010
	
c) September 2010	d) January 2010- Detail
	

Dunaway Rd 11-305 Plot DEA04-ST

4.5.4 Soil Cement (SC)

Empirical observation monitoring of the SC plots indicated that field teams did not observe signs of the formation of rills for the duration of the study. Field teams observed surface erosion of the SC erosion control product beginning in February 2010. Cracks and chips in the SC surface area were commonly observed in the SC plots, but did not appear to compromise the integrity of the erosion control product material surface. Additionally, field teams noted the presence of minor incidental vegetation during the latter part of the study period, generally after March 2010.

Table 4-10 Example of Chronological Degradation of Soil Cement Test Plot.

a) October 2008	b) January 2010
	
c) September 2010	d) January 2010- Detail
	

Dunaway Rd 11-325 Plot DWA12-SC

4.5.5 Rock Slope Protection (RSP)

Empirical observation monitoring of the RSP plots indicated that field teams did not observe signs of erosion for the duration of the study. The presence of bare areas and rills was not observed in the RSP plots. At each site, field teams noted the presence of incidental vegetation during the latter part of the study period, generally after March 2010.

Table 4-11 Example of Chronological Degradation of Rock Slope Protection Test Plot.

a) October 2008	b) January 2010
	
c) September 2010	d) September 2010- Detail
	

Dunaway Rd 11-318 Plot DWA05-RS

4.5.6 Control (CT)

Empirical observation monitoring indicated that, in general, field teams at each site did not consistently observe signs of erosion in the CT plots during the first few months of the study. Field teams began to note the formation of minor rills and some cracking/chips of the erosion control product material in the CT plots beginning in October 2009. In addition, incidental vegetation was consistently observed in the CT plots beginning in January and February 2010.

Table 4-12 Example of Chronological Degradation of Control Test Plot.

<table>
<tr><td>a) October 2008</td><td>b) January 2010</td></tr>
<tr><td></td><td></td></tr>
<tr><td>c) September 2010</td><td>d) January 2010- Detail</td></tr>
<tr><td></td><td></td></tr>
</table>

Dunaway Rd 11-313 Plot DEA12-CT

4.6 Analytical Results

This section presents the water quality results for the monitored storm events at the three sites. Total Suspended Solids (TSS) is the concentration of sediment on a mass per volume basis suspended in the runoff at the time of collection and is determined by laboratory analysis. TSS was the only water quality constituent monitored as part of this Study. The TSS laboratory results were converted into mass for the purpose of determining the sediment yield for each plot (Section 4.7) by using the per-event volume of runoff collected and the average bulk density of the soil. The TSS analytical data for all of the sites are presented in Appendix E.

At the three sites, the range of TSS values for the hydraulically applied erosion control products was highly variable. For smaller events (rainfall less than 0.25 inches), the TSS values were typically found to be low (less than 100 mg/L). Larger storm events (rainfall greater than 0.25 inches) generally resulted in higher TSS values for the plots with the hydraulically applied erosion control products. At the Barstow site, TSS values for PP ranged from 2 – 3,600 mg/L. The TSS values ranged from 6-3,300 mg/L for SS plots and from 3-2,100 mg/L for ST plots. The TSS values for the CT plots had a range of 3-9,600 mg/L. At the Hinkley site, PP TSS values ranged from 6-5,000 mg/L, SS ranged from 7-7,700 mg/L, and ST ranged from 8-4,500 mg/L. The CT plots at the Hinkley site ranged from 6-7,100 mg/L. At the Dunaway Road site, the TSS values for the hydraulically applied products were found to be larger than the Barstow and Hinkley sites. The TSS values for PP ranged from 22-40,040 mg/L, SS ranged from 19-41,940 mg/L, and ST ranged from 97-11,370 mg/L. The TSS values for the CT plots at the Dunaway Road site ranged from 18-54,190 mg/L. Although the results for the hydraulically applied products varied at each site, in general PP and ST performed better (yielded lower TSS values) than SS when compared to the CT plots.

The TSS values for RSP and SC were generally lower than the results for hydraulically applied products. At the Barstow site, the TSS values ranged from 2-190 mg/L for RSP and 1-300 mg/L for SC. At the Hinkley site, the TSS values for RSP ranged from 3-2,300 mg/L and from 1-390 mg/L for SC. At the Dunaway Road site, the TSS values ranged from 8-344 mg/L for RSP and 39-4491 mg/L for SC.

These results indicate that the five evaluated erosion control products reduce the quantity of suspended sediment in runoff.

4.7 Sediment Yield

This section presents the sediment yield results for the monitored storm events at the three project sites. Sediment yield (represented in cubic feet) is equal to the sum of the total amount of settled sediment, and the calculated volume of suspended sediment captured in the collection barrel(s). The volume of suspended sediment is calculated from the measured concentration of sediment suspended in the collected runoff (TSS) concentration as determined by laboratory analysis (Appendix E). The TSS laboratory results were used to determine total suspended sediment volume captured in the collection barrels. Suspended sediment mass was calculated by captured runoff volume of the collection barrels, TSS results and determined bulk densities of the sediment. Sediment bulk densities used to calculate sediment yield were determined as discussed in Section 3.3.3.2.

For collection barrels where runoff is measured but only trace amounts of sediment are present (sediment depth is less than the 1/8-inch measurement threshold), sediment volume is recorded as zero. In addition, Study cumulative sediment yield is also presented in the following tables.

The sediment yield data for the Barstow Site is presented in Table 4-13.

Table 4-13 Barstow Site Sediment Yield Results

Event ID	Date	Units	Treatment Type (Site ID)																							
			PolyPavement™				SoilSeal				SoilTac®				Rock Slope Protection				Soil Cement				Control			
			8-310	8-320	8-328	8-331	8-314	8-318	8-322	8-332	8-312	8-317	8-323	8-330	8-315	8-319	8-325	8-327	8-316	8-321	8-326	8-333	8-311	8-313	8-324	8-329
2008-01	11/24/08		0.000	0.000	0.000	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.011	0.000	0.011
2008-02	12/09/08		0.118	0.000	0.010	0.010	0.150	0.000	0.000	0.019	0.034	0.000	0.000	0.034	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.512	0.223	0.071	0.196
2008-03	02/05/09		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008-04	02/12/09		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009-01	11/27/09		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009-02	12/05/09		0.034	0.019	0.000	0.000	0.000	0.034	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.019	0.000	0.034
2009-03	01/13/10	cf	0.637	0.249	0.451	0.589	0.413	0.527	0.375	0.346	1.034	0.972	0.000	0.299	0.191	0.188	0.000	0.250	0.000	0.000	0.000	0.010	0.497	1.485	0.502	1.463
2009-04[1]	02/06/10		0.554	0.035	1.302	0.552	0.634	0.280	0.323	0.911	0.551	0.394	0.000	0.072	0.071	0.010	0.000	0.093	0.010	0.010	0.000	0.000	0.969	0.400	0.234	0.524
2009-05	02/19/10		0.118	0.051	0.118	0.181	0.145	0.145	0.034	0.093	0.019	0.051	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.248	0.145	0.019	0.093
2009-06	03/06/10		0.118	0.034	0.051	0.071	0.071	0.071	0.034	0.071	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.071	0.071	0.051	0.071
2009-07	04/04/10		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019
2009-08	04/12/10		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009-09	04/20/10		0.000	0.000	0.000	0.093	0.000	0.000	0.000	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.034
Study Totals			1.030	0.363	0.639	0.954	0.783	0.778	0.481	0.573	1.100	1.050	0.000	0.362	0.210	0.188	0.000	0.259	0.000	0.010	0.010	0.020	2.370	1.970	0.662	1.940

[1]Sediment Yield for Event 2009-04 was excluded from the statistical evaluation of erosion control products due to issues with the weather station.

The sediment yield data for the Dunaway Road site is presented in Table 4-14.

Table 4-14 Dunaway Road Site Sediment Yield Value

Event ID	Date	Units	Treatment Type (Site ID)																							
			PolyPavement™				SoilSeal				SoilTac®				Rock Slope Protection				Soil Cement				Control			
			11-310	11-312	11-316	11-319	11-303	11-306	11-314	11-315	11-305	11-309	11-317	11-324	11-302	11-307	11-318	11-322	11-304	11-308	11-320	11-325	11-311	11-313	11-321	11-323
2008-01	12/17/08		0.070	0.110	-	0.260	0.220	0.280	1.180	0.930	0.040	0.630	-	0.060	0.000	0.000	0.000	0.050	0.000	0.020	0.000	0.000	-	0.600	0.920	-
2008-02	02/05/09		0.014	0.062	0.052	0.014	0.014	0.014	0.000	0.038	0.000	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.000	0.101	0.014	0.000	0.067
2008-03	05/19/09		0.086	0.043	0.191	0.076	0.086	0.007	0.481	0.177	0.000	0.047	0.038	0.000	0.000	0.000	0.000	0.000	0.000	0.055	0.000	0.000	0.029	0.162	0.090	0.058
2008-04	09/05/09		0.024	0.076	0.120	0.074	0.129	0.038	0.338	0.278	0.012	0.088	0.052	0.012	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.146	0.350	0.253	0.402
2009-01	12/07/08	cf	0.024	0.063	0.320	0.112	0.067	0.000	0.244	0.208	0.000	0.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.062	0.093	0.038	0.185
2009-02	01/18/10		0.007	0.043	0.186	0.105	0.048	0.024	0.157	0.090	0.000	0.043	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.093	0.058	0.120	0.088
2009-03	01/20/10		0.635	1.067	1.102	0.899	0.784	0.338	3.080	2.253	0.086	1.575	0.298	0.103	0.000	0.000	0.000	0.047	0.029	0.148	0.167	0.000	1.328	1.314	2.318	1.480
2009-04	03/07/10		0.214	0.443	0.375	0.446	0.456	0.338	0.014	0.022	0.050	0.773	0.104	0.074	0.029	0.000	0.000	0.047	0.000	0.117	0.000	0.000	0.386	0.000	0.029	0.666
2009-05	08/02/10		0.393	0.563	0.607	0.666	0.468	0.350	2.204	1.512	0.062	0.828	0.116	0.074	0.000	0.000	0.000	0.047	0.000	0.186	0.000	0.000	0.503	0.674	1.440	0.551
Study Totals			1.467	2.470	2.953	2.652	2.272	1.389	7.698	5.508	0.250	4.008	0.636	0.323	0.029	0.000	0.000	0.191	0.029	0.552	0.167	0.000	2.648	3.265	5.208	3.497

Note:"-"Collection barrel valve inadvertently left open. No data available.

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The sediment yield data for the Hinkley Site is presented in Table 4-15.

Table 4-15 Hinkley Site Sediment Yield Values

Event ID	Date	Units	Treatment Type (Site ID)																							
			PolyPavement™				SoilSeal				SoilTac®				Rock Slope Protection				Soil Cement				Control			
			8-338	8-345	8-348	8-349	8-341	8-343	8-351	8-353	8-340	8-342	8-354	8-356	8-339	8-344	8-347	8-355	8-335	8-337	8-350	8-357	8-334	8-336	8-346	8-352
2008-01	11/26/08	cf	0.010	0.000	0.000	0.012	0.019	0.000	0.309	0.118	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.608	0.118	0.000
2008-02	12/13/08		0.146	0.669	0.000	0.176	0.248	0.051	0.208	0.362	0.071	0.034	0.338	0.722	0.118	0.000	0.000	0.248	0.000	0.000	0.000	0.000	0.034	0.737	0.338	0.398
2008-03	02/04/09		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008-04	02/13/09		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008-05	07/12/09		0.188	0.308	0.428	0.309	0.790	0.119	1.029	0.972	0.308	0.118	1.028	0.668	0.019	0.019	0.002	0.002	0.053	0.019	0.002	0.002	0.912	1.099	0.368	0.789
2009-01	12/05/09		0.118	0.034	0.034	0.034	0.118	0.071	0.121	0.094	0.119	0.034	0.034	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.177	0.118	0.034	0.119
2009-02	01/13/10		0.387	1.466	1.902	2.013	1.251	1.391	1.597	3.563	1.324	0.578	3.441	1.768	0.178	0.178	0.068	0.095	0.188	0.397	0.309	0.010	1.863	1.040	0.441	3.109
2009-03[1]	02/06/10		0.742	1.616	1.605	2.038	1.209	1.264	1.680	1.856	2.456	1.855	1.678	1.201	0.072	0.069	0.071	0.278	0.071	0.128	0.071	0.000	2.515	1.675	1.019	1.258
2009-04	02/19/10		0.019	0.071	0.093	0.071	0.175	0.145	0.248	0.145	0.071	0.071	0.145	0.071	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.071	0.121	0.034	0.248
2009-05	03/06/10		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.010	0.000	0.000
2009-06	04/12/10		0.000	0.000	0.000	0.000	0.000	0.000	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009-07	08/17/10		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Study Totals			0.879	2.920	2.480	2.620	3.150	1.810	3.710	5.440	1.920	0.855	5.010	3.300	0.316	0.199	0.075	0.345	0.250	0.426	0.311	0.011	3.780	4.100	1.760	4.880

[1]Sediment Yield for Event 2009-03 was excluded from the statistical evaluation of erosion control products due to due to issues with the weather station.

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Section 5 BMP Performance

The objective of the statistical analysis was to address study questions of interest involving the performance of the erosion control products relative to the control plots. Five erosion control products were evaluated in this study; namely, RSP, SS, SC, ST, and PP. The performance of each erosion control product was evaluated in terms of the average control-to-product reduction in sediment yield over the storm events. Sediment yield only included the amount of sediment collected in the barrels; potential soil erosion from the slope observed in the survey data was not considered. For the purposes of the statistical analysis, the sediment yield values presented in Section 4 (volume) were converted to mass using the sediment bulk density measurements presented in Appendix F. Specific study questions of interest were defined and appropriate methods of statistical analysis were selected. The results of statistical analysis were used to evaluate the statistical significance of observed differences in the performance of various erosion control products relative to the control at different study sites.

5.1 Study Questions of Interest

Based on discussions with the project team, the following study questions were defined:

1. Does the performance of any of the erosion control products degrade over time? Is there a break point in performance? Specifically, is there a point in time where a product's performance changes, and if so, when was that time?
2. Do any of the erosion control products perform differently from the control at individual study sites?
3. Is the performance of erosion control products significantly different from each other at individual sites?
4. Does the performance of individual erosion control products vary significantly over different sites?
5. If there is a break point in product performance, what is the subsequent rate of degradation for each erosion control product?
6. Is the performance of erosion control products affected by such environmental variables as amount and intensity of rainfall, infiltration, slope gradient, slope construction (cut or fill), soil type, wind speed, and temperature?
7. Do any of the individual erosion control products or categories of erosion control products collectively perform better than the controls at study sites? Evaluations were to include:
    a. SS at sites versus control.
    b. ST at sites versus control.
    c. PP at sites versus control.
    d. SC at sites versus control.

e. RSP at sites versus control.

f. Hydraulically applied products (SS, ST, and PP collectively) at sites versus control.

5.2 Methods for Data Analysis

The two major parts of the statistical analysis were exploratory data analysis and formal statistical tests. The specific methods used in each part are described below.

5.2.1 Exploratory Data Analysis

The objective of the exploratory data analysis was to understand data patterns, anomalies, and limitations; and to help select appropriate formal statistical tests to address the study questions of interest. Both graphical methods and numerical summaries were used to gain insights into the variability in the performance of various treatments over time at the different study sites.

The graphical methods included:

- Time series plots of treatment performance at each site; and
- Box plots of replicate treatment variability between plots within a block and between blocks.

Numerical summaries were prepared to tabulate key statistics of the data in the box plots. The key statistics included minimum, maximum, mean, median, standard deviation, and different percentiles. A correlation matrix was also prepared to assess the correlation between control-to-product reduction in sediment yield for each erosion control product and relevant environmental variables.

5.2.2 Formal Statistical Tests

The general framework of hypothesis testing was used to accept or reject various hypotheses related to the study questions of interest. Analysis of variance (ANOVA) was used to test the hypothesis that the average control-to-product reduction in sediment yield was 0.

Methods of multiple regression analysis (MRA) were used to evaluate the relationship between average control-to-product reduction in sediment yield for each product and relevant environmental variables. *F* test and Student's *t* test were applied to assess whether the overall relationship was statistically significant, and whether the influence of each environmental variable on product performance was statistically significant.

Because of time constraints, ANOVA and MRA were performed only for the Dunaway Road site. For Barstow and Hinkley sites, only exploratory data analysis was performed and the results were used to qualitatively evaluate erosion control product performance relative to control.

Since the study included only three sites, it was not possible to perform a formal statistical evaluation of site-to-site differences and the influence of site-specific factors (soil type, slope, etc.) on treatment performance. Only a qualitative evaluation of these differences was made.

5.3 Results and Discussion

This section provides the results of the three study sites and the statistical evaluation of the effectiveness of the erosion control products.

5.3.1 Results at Dunaway Road Site

This subsection discusses the results found at the Dunaway Road site.

5.3.1.1 Results of Exploratory Data Analysis

The cumulative sediment yield for each erosion control product and control is plotted against cumulative rainfall total in Figure 5-1 and against the number of elapsed days since product application in Figure 5-2. RSP and SC show substantially lower sediment yield than the control. Figure 5-2 shows a sharp increase in sediment yield for PP and SS after about 450 elapsed days. This corresponds to approximately mid January 2010. However, control also shows a sharp increase in sediment yield at about the same point in time. Because the common environmental variables could affect both control and erosion control product in a similar manner, it is appropriate to evaluate the effectiveness of a product in terms of the control-to-product reduction in sediment yield. For example, even when a particular erosion control product shows a large increase in sediment yield at some point in time, the percent reduction in sediment yield from the control at that time could be similar to the previous reductions. In such a case, the erosion control product still might be considered to be effective in reducing sediment yield. For this reason, plots of control-to-product percent reduction were also prepared against cumulative rainfall total (Figure 5-3) and against number of elapsed days since product application (Figure 5-4). Percent reduction, rather than actual reduction, in sediment yield was graphed in Figure 5-3 and Figure 5-4. This is because actual reduction was generally higher for higher control sediment yields, while the percent reduction was fairly independent of control sediment yield and hence would more clearly show any systematic changes in erosion control product performance.

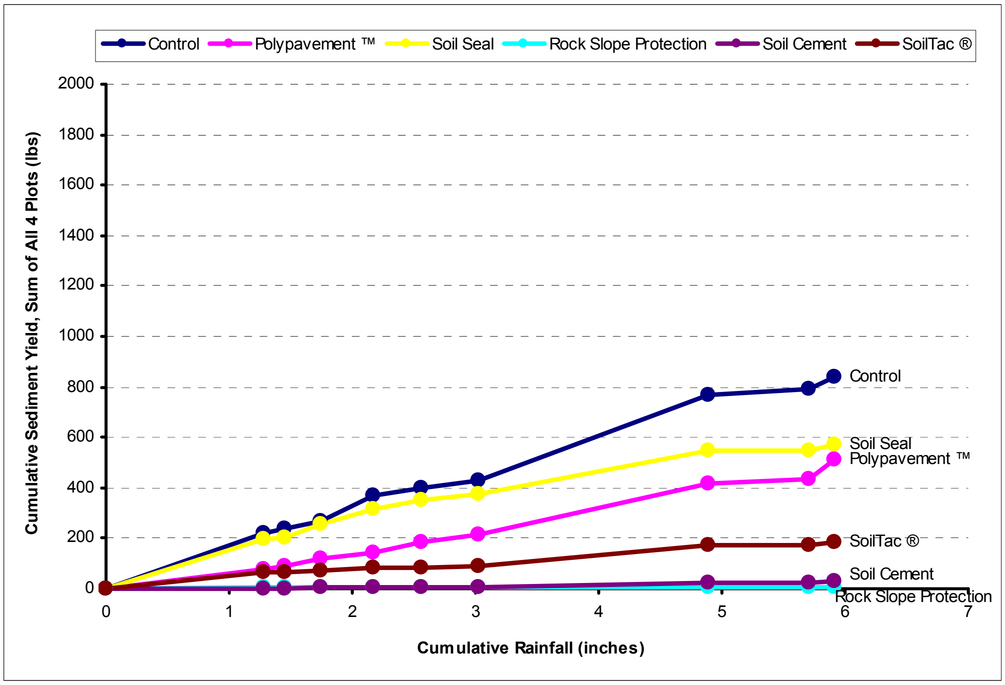


Figure 5-1 Dunaway Road Data Analysis of Cumulative Sediment Yield with Cumulative Rain

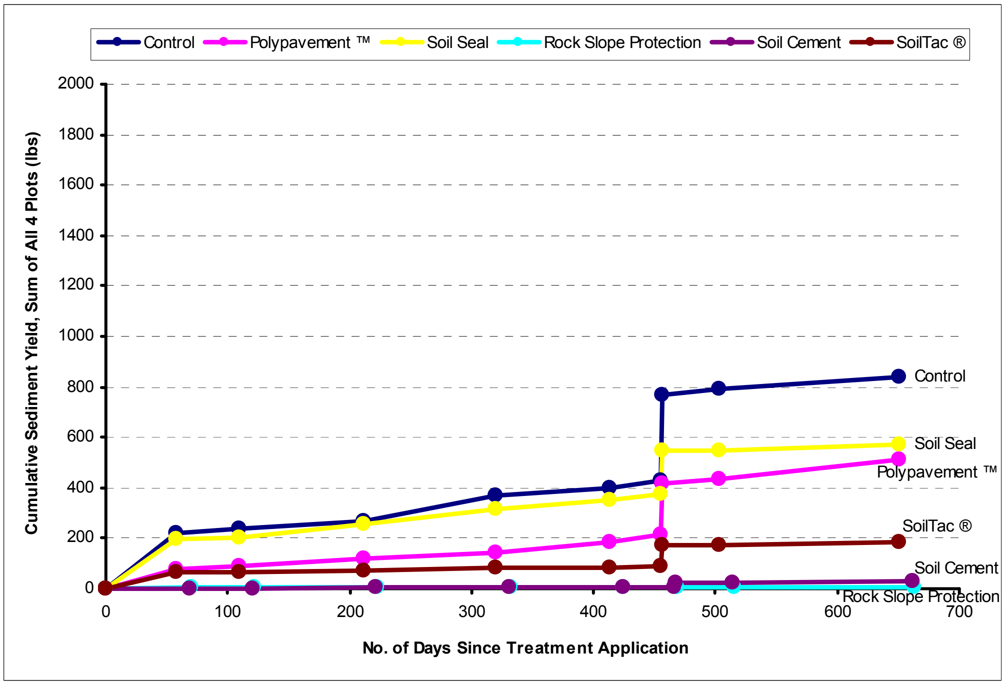


Figure 5-2 Dunaway Road Data Analysis of Cumulative Sediment Yield and Days Elapsed

Figure 5-3 does not show evidence of performance degradation as cumulative rainfall total increases. However, it does show a downward sloping line for PP at the last storm event, suggesting possible degradation in the performance of PP. A comparison of the performance of the five erosion control products in Figure 5-3 indicates that RSP, SC, and ST have substantially better and consistent performance (i.e., greater percent reduction in sediment yield) than SS and PP.

Figure 5-4 shows a graph of control-to-product percent reduction in sediment yield versus the number of elapsed days since product application. It shows the effect of product age on erosion control product performance. Figure 5-4 again shows no evidence of systematic degradation or break in the performance of any of the five products except for PP. The time series plot for PP shows a downward sloping line for the last three events, suggesting possible performance degradation after about 12 months.

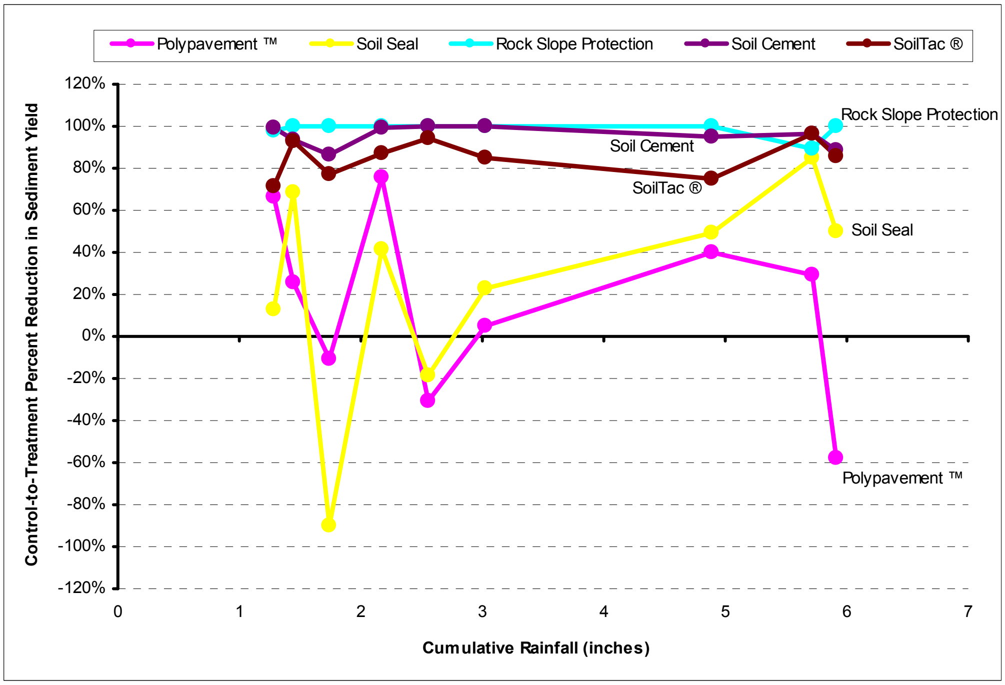


Figure 5-3 Dunaway Road Data Analysis of Cumulative Rainfall and BMP Sediment Yield Reduction

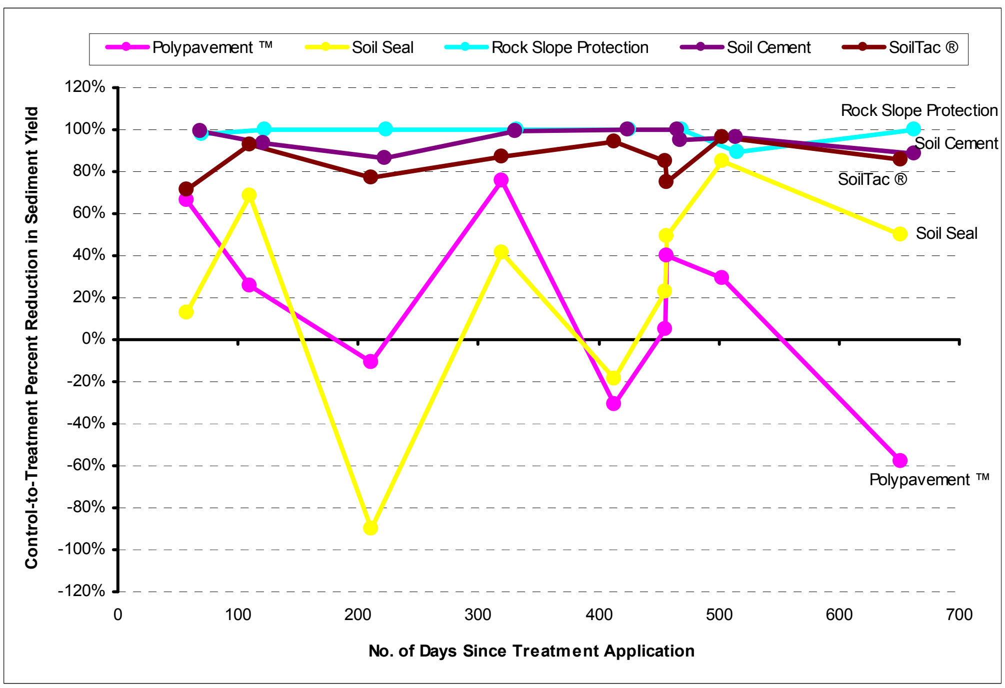
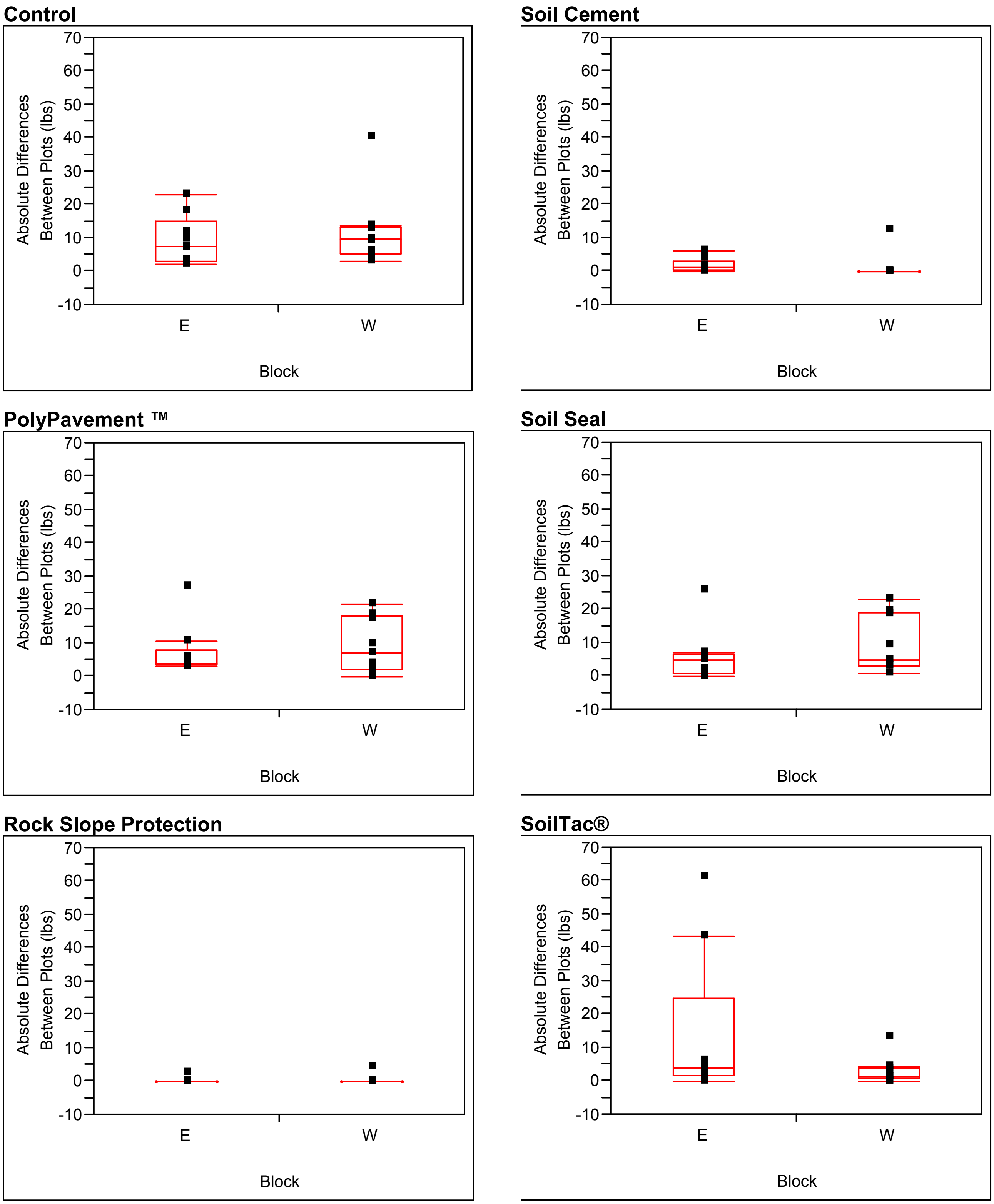


Figure 5-4 Dunaway Road Data Analysis of Days Elasped and BMP Sediment Yield Reduction

Figure 5-5 shows box plots of plot-to-plot replicate variability in sediment yield within each of the two blocks for each product. Key statistics of the box plot data are included in Appendix G. This replicate variability represents the effect of small-scale soil and topography changes between plots. Because each block had its own control and erosion control products in a block were compared to the matched control in the block, it was appropriate to assess the small-scale variability separately for the two blocks.

Figure 5-5 shows that plot-to-plot replicate variability is small for RSP and SC, and large for CT, PP, SS, and ST. The results of subsequent ANOVA identified plot-to-plot variability as being significant in affecting reduction in sediment yield for PP. Large plot-to-plot replicate variability could mask a significant reduction in sediment yield for the affected products. The plot-to-plot variability was taken into account in subsequently testing hypotheses of performance among erosion control products.

Figure 5-5 Box Plots of Replicate Variability in Sediment Yield between Plots in Each Block at Dunaway Road Site



5.3.1.2 Results of Formal Statistical Tests

ANOVA was performed to assess whether within-plot and within-block replicate variability was significant in affecting control-to-treatment reduction in sediment yield. The results showed that plot and block were not significant in affecting control-to-product reduction in sediment yield for RSP, SC, and ST. However, plot and block were significant for PP, and block was significant for SS.

Based on these results, we used the average control-to-product reduction in sediment yield over the four plots as the response variable in the MRA for RSP, SC, and ST; average control-to-product reduction in sediment yield over the two plots in each block as the response variable for SS; and individual control-to-product reduction in sediment yield in each plot as the response variable for PP.

MRA was performed next to evaluate the correlation between control-to-product reduction in sediment yield and relevant environmental variables. The key assumptions necessary for using for multiple (linear) regression analysis were: (1) the dependent ("*y*") variable varied linearly with each independent variable; (2) the residuals (i.e., the differences between observed and predicted values of dependent variable) had a constant variance over the range of predicted values; (3) the residuals were normally distributed; and (4) the residuals were not auto-correlated. Plots of residuals were examined to verify that these assumptions were valid for the present analysis.

The potential independent variables ("*x*" variables) for the MRA were:

- Storm rainfall total (inches).
- Cumulative storm rainfall total (inches).
- Storm rainfall intensity (inches/hr).
- Storm duration (hours).
- Average daily high temperature during the period since the preceding storm event (degrees F).
- Average daily low temperature during the period since the preceding storm event (degrees F).
- Average daily temperature during the period since the preceding storm event (degrees F).
- Number of days with high temperature above 90 degrees F during the period since the preceding storm event.
- Number of 90-percent probability freeze-free days during the period since the preceding storm event.
- Average dew point during the period since the preceding storm event (degrees F).
- Average wind direction during the period since the preceding storm event (degrees).
- Average wind speed during the period since the preceding storm event (knots).

- Average peak wind speed during the period since the preceding storm event (knots).
- Average wind gusts during the period since the preceding storm event (knots).
- Number of days since treatment application.

Because the list of potential independent variables was large and the number of data points was small (n =9), the independent variables were first screened based on their simple correlation coefficient, r, with the response variable. Specifically, only those independent variables with absolute r greater than 0.5 were retained for MRA. Correlations between the retained independent variables were also examined to make sure that none of the retained independent variables was highly correlated with another retained independent variable. Such high correlation among independent variables can introduce large uncertainty in the estimated regression coefficients. Table 5-1 shows the correlation coefficient for each independent variable and identifies the variables that were retained for MRA. None of these retained variables was highly correlated with any other retained variable. The retained variables were further screened using stepwise regression analysis as discussed below.

Table 5-1 Correlation Coefficients (r) between Control-to-Treatment Reduction in Sediment Yield and Environmental Variables at Dunaway Road Site

Independent Variable	RSP	SC	ST	SS (East Block)	SS (West Block)	PP (East Block, Plot 1)	PP (East Block, Plot 2)	PP (West Block, Plot 1)	PP (West Block, Plot 2)
Storm Rainfall Total (inches)	0.916	0.919	0.911	0.891	0.313	0.869	0.591	0.786	0.892
Cumulative Storm Rainfall Total (inches)	0.088	0.067	0.104	0.226	0.569	-0.154	-0.499	-0.002	-0.125
Storm Rainfall Intensity (inches/hr)	0.380	0.357	0.395	0.474	0.142	0.151	-0.007	0.020	0.088
Storm Duration (hours)	0.627	0.625	0.620	0.624	0.423	0.563	0.269	0.447	0.582
Average Daily High Temperature during the Period since the Preceding Storm Event	-0.026	-0.014	-0.003	-0.092	-0.348	0.063	0.291	0.022	-0.001
Average Daily Low Temperature during the Period Since the Preceding Storm Event	0.124	0.130	0.141	0.068	-0.333	0.184	0.401	0.040	0.095
Average Daily Temperature during the Period since the Preceding Storm Event (Degrees F)	-0.002	0.009	0.022	-0.062	-0.301	0.079	0.290	0.060	0.024
Number of Days with High Temperature above 90 degrees F during the Period since the Preceding Storm Event	-0.005	0.003	0.018	-0.041	-0.244	0.051	0.236	0.033	-0.037
Number of 90-percent probability freeze-free days during the Period since the Preceding Storm Event	-0.325	-0.327	-0.339	-0.300	0.132	-0.264	-0.228	-0.178	-0.256
Average Dew Point during the Period since the Preceding Storm Event (Degrees F)	0.536	0.532	0.574	0.552	0.503	0.452	0.238	0.658	0.540

Table 5-1 Correlation Coefficients (r) between Control-to-Treatment Reduction in Sediment Yield and Environmental Variables at Dunaway Road Site

Independent Variable	RSP	SC	ST	SS (East Block)	SS (West Block)	PP (East Block, Plot 1)	PP (East Block, Plot 2)	PP (West Block, Plot 1)	PP (West Block, Plot 2)
Average Wind Direction during the Period since the Preceding Storm Event (Degrees)	-0.680	-0.661	-0.710	-0.733	-0.547	-0.500	-0.236	-0.584	-0.579
Average Wind Speed during the Period since the Preceding Storm Event (Knots)	0.130	0.112	0.141	0.193	-0.163	-0.043	-0.041	-0.037	-0.033
Average Peak Wind Speed during the Period since the Preceding Storm Event (Knots)	-0.507	-0.499	-0.530	-0.531	-0.316	-0.363	-0.139	-0.454	-0.438
Average Wind Gusts during the Period since the Preceding Storm Event (Knots)	-0.307	-0.295	-0.341	-0.376	-0.688	-0.179	0.121	-0.558	-0.351
# of Days Since Application	-0.103	-0.125	-0.079	0.029	0.507	-0.339	-0.605	-0.261	-0.327

Grey Shaded Areas: Variables retained for stepwise multiple regression analysis.

A stepwise MRA was performed to identify the set of statistically significant independent variables. Table 5-2 lists the independent variables for each treatment that were selected in the stepwise regression analysis. The actual p for each significant variable is also shown. The smaller the p-value, the greater is the confidence that the variable has a significant effect on the response variable. Table 5-2 identifies variables that were significant at a 10% significance level.

As shown in Table 5-1, storm rainfall total is highly significant for most of the erosion control products, and average wind direction is also highly significant for some of the erosion control products. Cumulative rainfall total is not a significant variable for any of the erosion control products. The number of days since product application is significant only for one plot for PP. These results suggest that, among the environmental variables, storm rainfall total has a consistently significant effect on control-to-product reduction in sediment yield in a storm event. The results also confirm the finding from time series plots; namely, there is no evidence of performance degradation for any of the products except PP. This is reflected in the fact that cumulative rainfall total is not a significant variable for any product, and number of days since product application is also not significant for any product except for one plot with PP. Because of the small sample size ($n = 9$) for the MRA, the finding of no significance should be interpreted with caution. The sample size was considered to be adequate for detecting relatively large influences of cumulative rainfall or product age; specifically, when the variability in the sediment-yield reduction explained by a variable was greater than 50%. However, smaller influences of a variable may not be detected with the available sample size.

Table 5-2 Significant Environmental Variables Affecting Product Performance at Dunaway Road Site

Erosion Control Product	Plot/Block if Significant	Variable Affecting Reduction in Sediment Yield	Significance Level, p	Significant at 10% Significance Level?
Rock Slope Protection	All	Storm Rainfall Total (inches)	<0.001	Yes
		Average Wind Direction during the Period since the Preceding Storm Event (Degrees)	0.021	Yes
		Average Peak Wind Speed during the Period since the Preceding Storm Event (Knots)	0.098	Yes
Soil Cement	All	Storm Rainfall Total (inches)	0.002	Yes
		Average Wind Direction during the Period since the Preceding Storm Event (Degrees)	0.106	No
SoilTac®	All	Storm Rainfall Total (inches)	0.001	Yes
		Average Wind Direction during the Period since the Preceding Storm Event (Degrees)	0.012	Yes
		Average Peak Wind Speed during the Period since the Preceding Storm Event (Knots)	0.091	Yes
PolyPavement™	E1	Storm Rainfall Total (inches)	0.008	Yes
		Storm Duration (hours)	0.242	No
	E2	Storm Rainfall Total (inches)	0.044	Yes
		# of Days since Product Application	0.041	Yes
	W1	Storm Rainfall Total (inches)	0.037	Yes
		Average Dew Point during the Period since the Preceding Storm Event (Degrees F)	0.141	No
	W2	Storm Rainfall Total (inches)	0.004	Yes
		Storm Duration (hours)	0.193	No
Soil Seal	E	Storm Rainfall Total	0.001	Yes
		Average Wind Direction during the Period since the Preceding Storm Event (Degrees)	0.011	Yes
		Average Peak Wind Speed during the Period since the Preceding Storm Event (Knots)	0.099	Yes
	W	Average Wind Gusts during the Period since the Preceding Storm Event (Knots)	0.066	Yes
		Average Wind Gusts during the Period since the Preceding Storm Event (Knots)	0.226	No

To assess whether an erosion control product was effective, ANOVA was performed to formally test the (null) hypothesis that the average control-to-product reduction in sediment yield was 0. The null hypothesis would be rejected and the product would be considered to be effective only if the data showed strong evidence of positive reduction in sediment yield.

Table 5-3 summarizes the ANOVA results. Based on the previous results, “plot” was not a significant variable for RSP, SC, and ST. Hence, ANOVA was performed using data averaged from the four plots. The variance used in the hypothesis test was the sum of the event-to-event variance in the site average, and the variance of the site average in each event due to plot-to-plot variability. For SS, “block” was a significant variable, but plot (within a block) was not a significant variable. Hence, ANOVA was performed using data averaged over two plots within each block, and the variance for the hypothesis test was the sum of event-to-event variance of the block average and the variance of the block average in each event due to plot-to-plot variability. For PP, “plot” was a significant variable. Hence, ANOVA was performed using data from each plot separately, and the variance in this case was simply the event-to-event variance of plot values.

Table 5-3 shows the significance level, p, that the average reduction in sediment yield per storm event is greater than 0. Based on recommendation in the BMP Guidance Manual, values of p less than 10% are considered to be significant. The results confirm previous findings; namely RSP, SC, and ST are consistently effective in reducing sediment yield. However, the performance of PP and SS is highly variable and these two erosion control products are effective only for some of the plots.

Table 5-3 Results of Hypothesis Testing Regarding Average Control-to-Product Reduction in Sediment Yield at Dunaway Road Site

Erosion Control Product	Block/Plot (if it is a significant factor)	Average Control-to-Product Reduction in Sediment Yield per Storm Event (lbs)	% Reduction in Control-to-Product in Sediment Yield	Significance Level that Average Reduction in Sediment Yield is Greater than 0 (*p*)	Does Product Perform Better than Control at 10% Significance Level?
Rock Slope Protection	All	23.2	99%	0.019	Yes
Soil Cement	All	22.5	96%	0.018	Yes
SoilTac®	All	18.3	78%	0.017	Yes
PolyPavement™	E1	14.13	63%	0.024	Yes
	E2	7.785	35%	0.083	Yes
	W1	2.84	12%	0.302	No
	W2	11.679	48%	0.060	Yes
Soil Seal	E	16.86	76%	0.024	Yes
	W	-2.05	-8%	0.677	No

5.3.2 Results at Barstow Site

The cumulative sediment yields for each erosion control product and control are plotted against cumulative rainfall total in Figure 5-6 and against the number of elapsed days since product application in Figure 5-7. Figure 5-7 shows a sharp increase in sediment yield for PP, SS, and ST after about 500 elapsed days. This corresponds to approximately December 2009. However, control also shows a sharp increase in sediment yield at about the same point in time. To evaluate erosion control product performance relative to control, control-to-product percent reductions in sediment yield were examined. Figure 5-8 and Figure 5-9 show plots of control-to-product percent reduction in sediment yield versus cumulative rainfall total and the number of elapsed days since product application, respectively. These plots do not show any evidence of degradation or break in performance of RSP, SC, and ST. For PP and SS, the plots suggest possible performance degradation after about 500 days as indicated by generally downward sloping lines and a sharp decline in the percent reduction during the last storm event, particularly for PP.

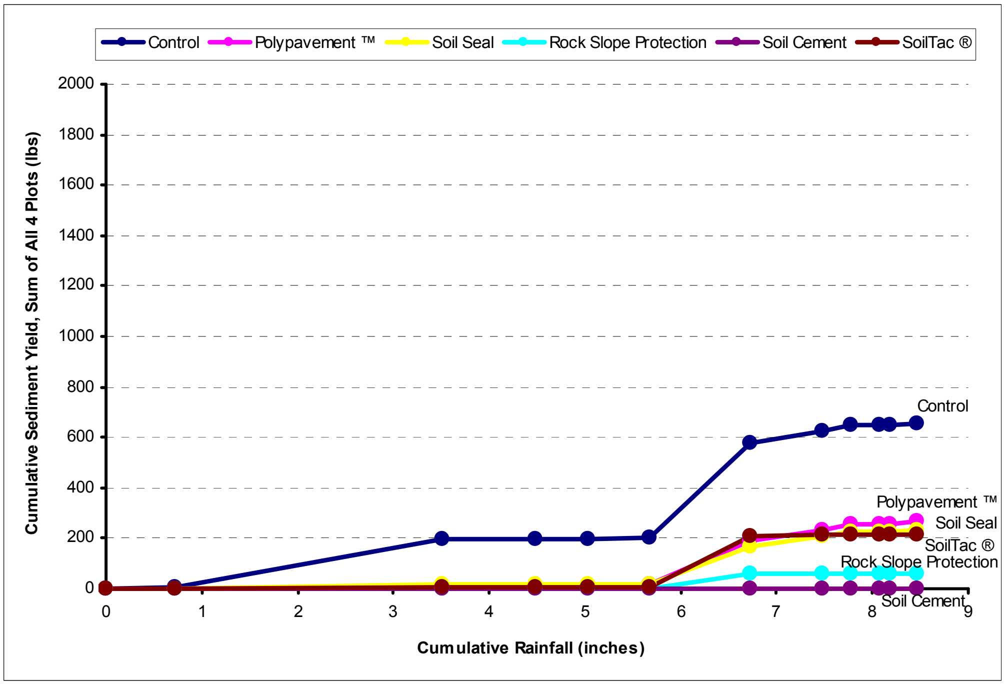


Figure 5-6 Barstow Site Data Analysis of Cumulative Rainfall and BMP Sediment Yield Reduction

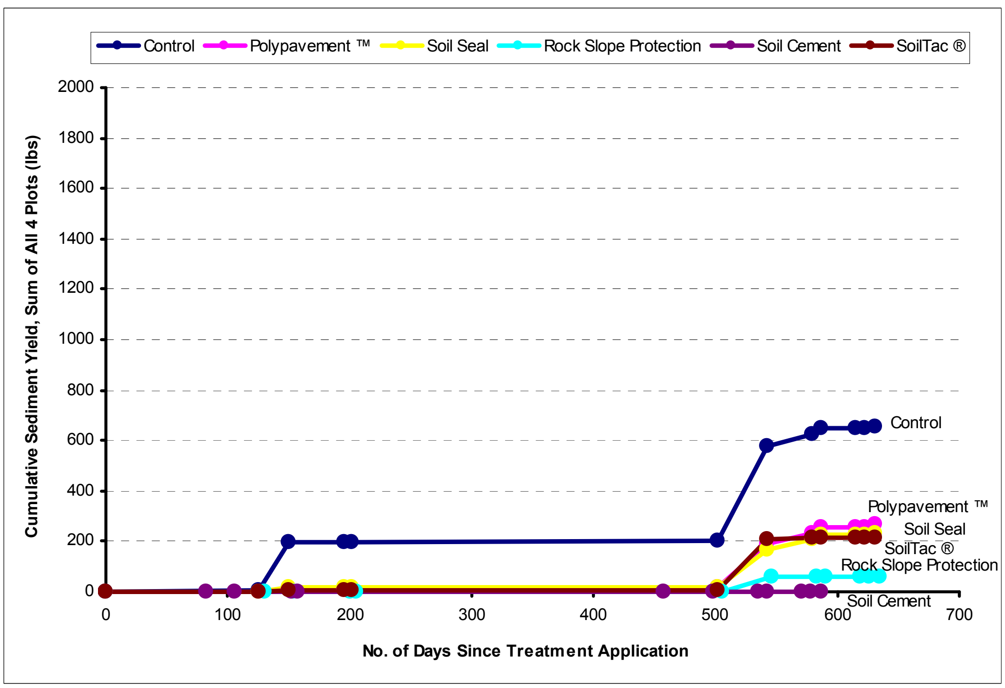


Figure 5-7 Barstow Site Data Analysis of Cumulative Sediment Yield and Days Elapsed

A comparison of the performance of the five erosion control products in Figure 5-8 and Figure 5-9 indicates that RSP, SC, and ST have substantially better and consistent performance (i.e., greater percent reduction in sediment yield) than SS and PP.

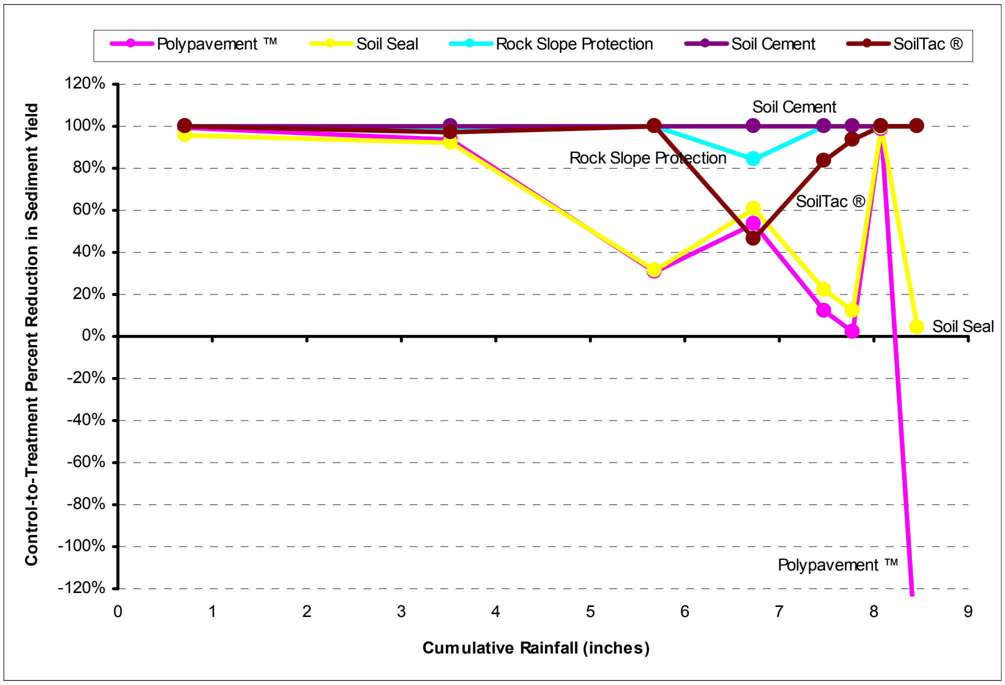


Figure 5-8 Barstow Site Data Analysis of Cumulative rainfall and BMP Sediment Yield

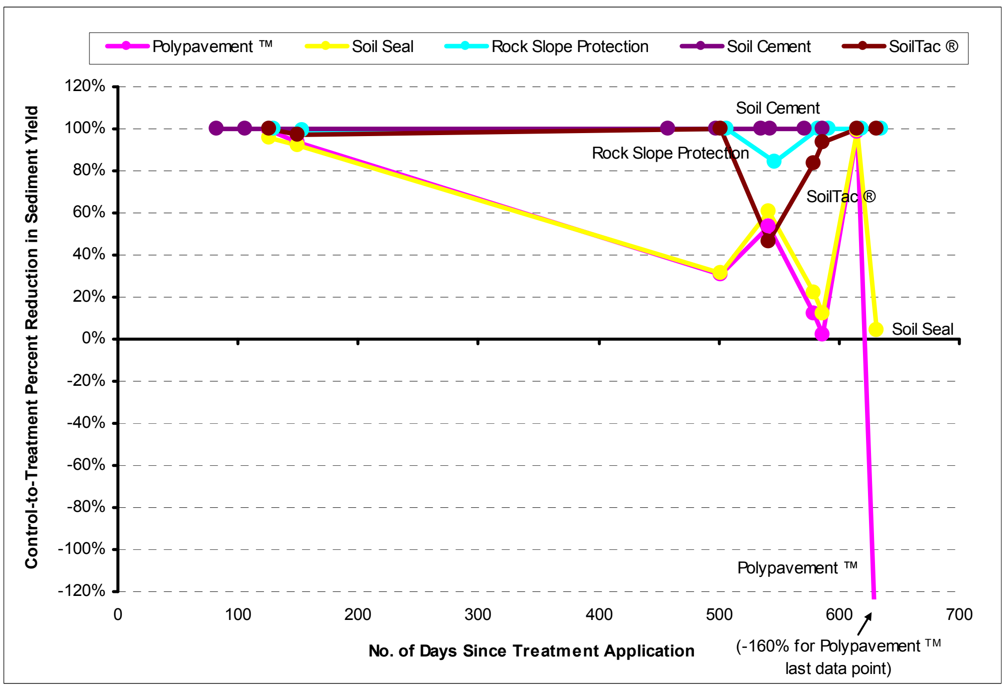


Figure 5-9 Bartstow Site Data Analysis of Days Elapsed and BMP Sediment Yield Reduction

5.3.3 Results at Hinkley Site

The cumulative sediment yields for each erosion control product and control are plotted against cumulative rainfall total in Figure 5-10 and against the number of elapsed days since product application in Figure 5-11. Figure 5-11 shows a sharp increase in sediment yield for PP, SS, and ST after about 500 elapsed days. This corresponds to approximately December 2009. However, control also shows a sharp increase in sediment yield at about the same point in time. To evaluate erosion control product performance relative to control, control-to-product percent reductions in sediment yield were examined. Figure 5-12 and Figure 5-13 show plots of control-to-product percent reduction in sediment yield versus cumulative rainfall total and the number of elapsed days since product application, respectively. These plots do not show any evidence of degradation or break in performance of RSP and SC. For ST, SS, and PP, the plots generally show downward sloping lines, suggesting possible degradation in performance after about 12 months for PP and ST, and after about 6 months for SS. However, for the last plotted event, the percent reduction is close to 100% for the five erosion control products, showing a contrary effect for ST, SS, and PP.

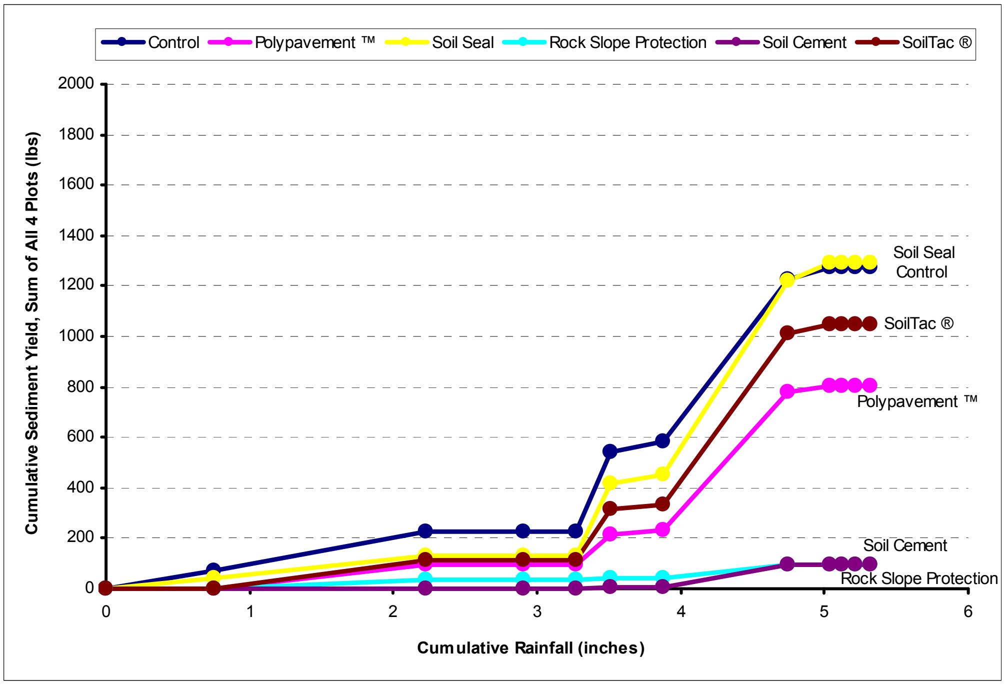


Figure 5-10 Hinkley Site Data Analysis of Cumulative Sediment Yield with Cumulative Rain

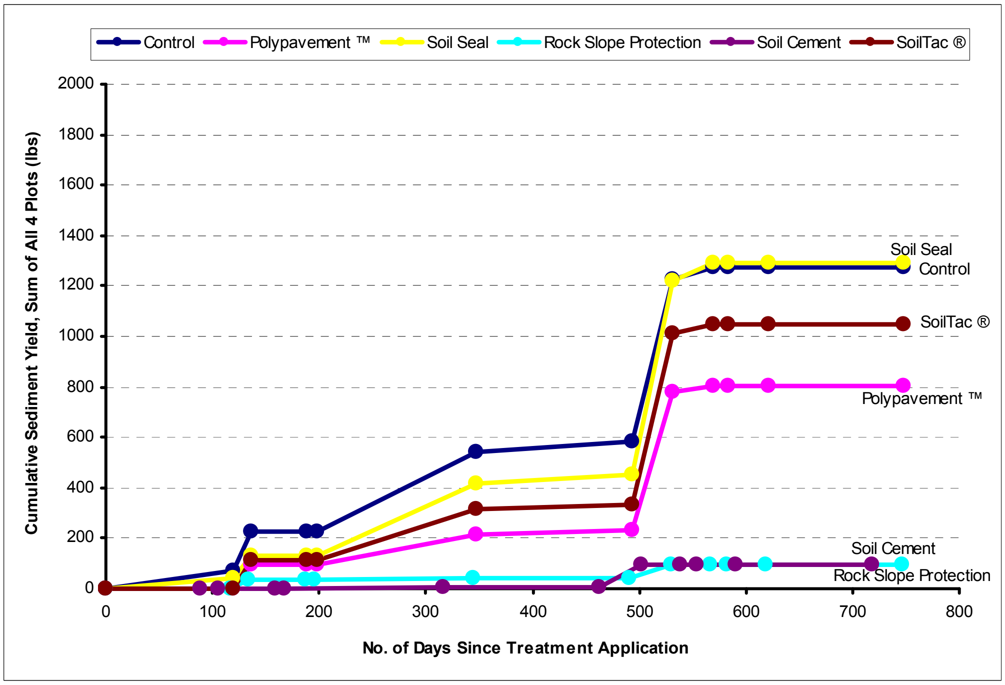


Figure 5-11 Hinkley Site Data Analysis of Cumulative Sediment Yield and Day Elapsed

A comparison of the performance of the five erosion control products in Figure 5-12 and Figure 5-13 indicates that SC and RSP have substantially better and consistent performance (i.e., greater percent reduction in sediment yield) than the other three erosion control products.

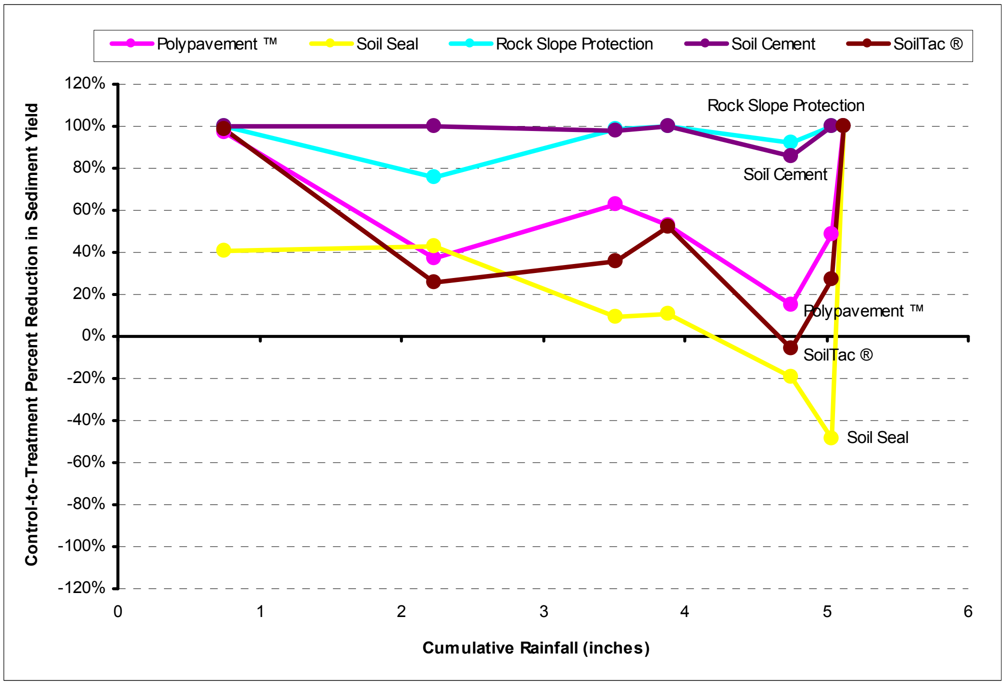


Figure 5-12 Hinkley SiteData Analysis of Cumulative Rainfall and BMP Sediment Yield Reduction

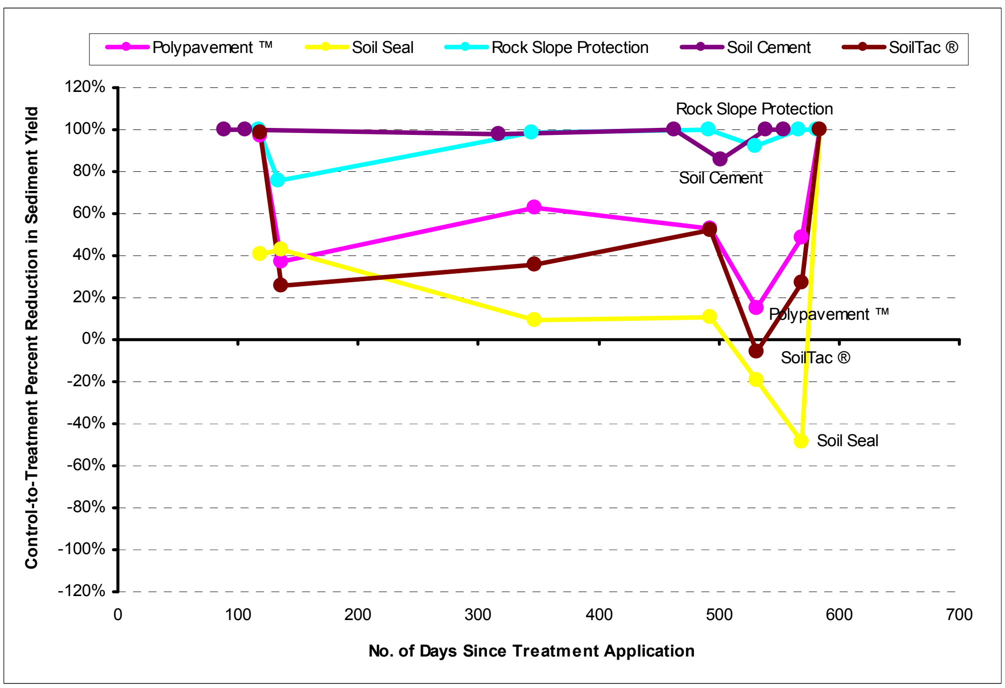


Figure 5-13 Hinkley Site Data Analysis of Days Elapsed and BMP Sediment Yield Reduction

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Section 6 Maintenance Requirements

This section describes the maintenance requirements which were associated with the Study as detailed in the OM&M Plan. The overall required maintenance at each site was minimal. Each site had routine maintenance activities as well as non-routine activities. There were no maintenance activities required at the sites for any of the erosion control products or control plots as the purpose of the Study was to determine each products' effectiveness in reducing erosion over the full term (approximately 2 years) of the Study. The products were initially applied in 2008 and regulary observed. At each site, there were various activities which were conducted regularly in order for the site to function properly. Also, there were non-routine maintenance activities required and both are presented below.

6.1 Routine Maintenance Activities

At the three Study sites, the most common operational maintenance activity was rectification of erosion and undercutting issues between the experimental plot boundaries that resulted from concentrated stormwater runoff origination from the top of slope shields above each experimental plot. This issue was resolved on an as-needed basis by backfilling the eroded area with sediment to prevent damage to the plots. As described in Section 2.4.4.3, non-woven filter fabric and one-inch aggregate rock were applied at each site between the experimental plots in July 2009 to reduce the need for backfilling maintenance activities.

At the Dunaway Road site, the frequent clogging of flume conveyance pipes during storm events was another routine maintenance activity regularly conducted. Due to the slope length and resulting site configuration at the Dunaway Road site, sediment from the plots had tendency to accumulate in the low gradient of the conveyance pipes between the runoff collection flumes and collection barrels. During post-storm visits, field teams at the Dunaway Road site removed the conveyance pipes, removed and quantified the accumulated sediment, then replaced the cleaned pipes. The Barstow and Hinkley sites did not experience the same issue because the gradient of each conveyance pipe was sloped enough so that sediment build-up seldomly occurred

At the Barstow and Hinkley sites, the collection barrels required a rubber o-ring to be replaced approximately every 6 months due to the environmental conditions at the sites. This is further described in Section 2.4.4.2. The Dunaway Road site utilized a different barrel outlet configuration and did not require the usage of rubber o-rings, therefore, did not have this maintenance activity.

6.2 Non-routine Maintenance Activities

There were very few infrequent operational issues which were encountered during the study period at the Study sites. Minor operational issues that required maintenance included one-time battery replacement at the Dunaway Road site for the on-site telemetry unit (August 2010). In Addition, at the three Study sites minor caulk replacement of several runoff collection system connections, as well as the removal of several trapped rodents and birds from the collection barrels was conducted.

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Section 7 Capital, Operations, and Maintenance Costs

This section describes the capital costs associated with each of the erosion control products studied as part of the Study.

7.1 Non-Vegetative Erosion Control Product Life Cost Analysis

Table 7-1 presents the estimated capital costs to implement the three hydraulically applied erosion control alternatives (SS, ST, and PP). These erosion control alternatives are not widely in use by Caltrans, and when used, may be included within the bid for other items of work. As a result, the estimated capital costs could not be developed using the Caltrans Basic Engineering Estimating System (BEES). Therefore, the estimated capital costs for the hydraulically applied erosion control alternatives were built up considering the combined costs of material, equipment, and labor. The estimated capital cost to apply the hydraulically applied erosion controls were \$5,240, \$5,500, and \$5,650 per acre for SS, PP, and ST, respectively.

Table 7-2 presents the estimated capital costs to implement the surface cover erosion control alternatives (RSP and SC). These estimated capital costs were derived through examination of cost data compiled in BEES, with emphasis on cost data from projects in Districts in Southern California which include arid areas. The estimated capital cost to apply RSP and SC were \$120,500 and \$131,000 per acre, respectively.

The capital cost estimates for the hydraulically applied and the Surface cover erosion control alternatives are not directly comparable on a per application basis because the products have different useful lives, different levels of effectiveness, and require different levels of operation, maintenance, and administration. To address the differences in useful lives, a present worth cost evaluation was conducted assuming a 20 year study period. The assumed 20 year study period was the assumed useful life of RSP which is expected to have the longest useful life of the erosion control products studied. The different levels of effectiveness and the different levels of operation, maintenance, and administration have not been addressed as part of this Study, but may be significant factors in the selection of erosion controls.

For the hydraulically applied erosion control products, an expected useful life based on this study was determined to be one to two years. This means that the hydraulically applied erosion controls would need to be reapplied every one or two years throughout the 20 year study period for a total of 10-20 total applications. For the surface cover erosion control products, SC was assigned a useful life of 6 to 10 years and RSP was assumed to have a life of at least 20 years. This means that SC would be reapplied every 6 to 10 years throughout the 20 year study period for a total of two to three applications.

Table 7-1 and Table 7-2 display the present worth of the capital costs required to maintain erosion control consistent with the capabilities of each alternative over a 20 year period. The present worth of capital costs for the hydraulically applied erosion control ranged from \$52,500 to \$56,500 when reapplied every other year and from \$105,000 to \$113,000 when reapplied every year. The present worth of capital costs for SC was \$261,500 when applied every 10 years and $523,000 when applied every 6 years throughout the 20 year study period. The present worth of the capital costs for RSP was $120,500, which is the cost of a single initial application.

The present worth capital cost comparison assumed that the costs of materials, equipment, and labor increased at 3% compounded annually and that the time value of money was also 3%. Therefore, money invested at time zero could earn 3% compounded annually, and that this amount of earnings was sufficient to offset construction cost increases that were also compounded annually at 3%. The present worth capital cost comparison does not take into account the administrative and operational costs that Caltrans would incur to periodically to reapply the hydraulically applied erosion control products or the SC by contracting out or through utilization of Caltrans forces.

Table 7-1 Estimated Capital Costs of Hydraulically Applied Erosion Control Products

Erosion Control Product	Product Coverage (per Manufacturer)		Price per Unit Manufacturer's	Unit Size(gal)		Units Required (1 acre Application)	Product Cost (1 acre[1] Application)	Shipping Costs[2]	Application time (hours)[3]	Estimated Labor Costs[4]	Estimated Equipment Cost[5]	$ / acre / Application	Present Worth $/acre/20yr[6]	
													2 years	1 year
Soil Seal	135	sq.ft./gal	$ 580	55	gal	6	$ 3,390	$ 150	5.33	$ 1,285	$415	$ 5,240	$52,500	$105,000
SoilTac®	100	sq.ft./gal	$ 480	55	gal	8	$ 3,790	$ 160	5.33	$ 1,285	$415	$ 5,650	$56,500	$113,000
PolyPavement™	300	sq.ft./gal	$ 1,400	55	gal	3	$ 3,700	$ 100	5.33	$ 1,285	$415	$ 5,500	$55,000	$110,000

Note 1: Product information does not include dilution costs.

Note 2: Total shipping estimate based on 4 drums per pallet and California delivery.

Note 3: Per the manufacturer, the time necessary for 1 acre of product application is 4 hours. Hours reflected in labor costs for 1 acre application are based on assumed 75% personnel productivity (i.e. drive time, setup, and shutdown).

Note 4: Labor costs are based on the prevailing wages pursuant to the Department of Industrial Relations http://www.dir.ca.gov/dlsr/PWD/index.htm (Assumptions: 2 laborers, 2 operators, 1 supervisor):

Personnel	Hourly	Determination	Dated
Laborer Group 1	$42.67	SC-23-102-2-2010-2	22-Aug-10
Laborer Group 5 - Supervisor	$45.67	SC-23-102-2-2010-2	22-Aug-10
Operating Engineer Group 2	$55.00	SC-23-63-2-2009-1	22-Aug-09

Note 5: Assumptions for hydraulically applied applications: 1 hydroseeder truck, 1 water truck, and 1 flat bed truck. Equipment costs are based on the following pursuant to Caltrans Labor Surcharge and Equipment Rental Rates (effective 4/01/10 through 3/31/11):

*Assume weight of truck 12,000 lbs and weight of water 16,000 lbs (2,000 gal) = Gross vehicle weight. Assume hydro-seed trailer loaded weight of 7,800lbs and hauling truck of 6,500lbs.

Trucks by weight (TT&T)	Code	Weight (lbs)	$/hour
Water truck*	(20-28)	28,000	$26.69
Hydro-seeder (truck & trailer)	(12-20)	14,300	$24.47
Flat bed truck	(20-28)	26,000	$26.69

Note 6: Present worth cost of each hydraulically applied product with useful life of 1 or 2 years (20 to 10 applications) over 1 acre for a 20 year period.. Calculation based on assumed 3% annual inflation and 3% time value of money.

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Table 7-2 Estimated Capital Costs for RSP and SC Products

Erosion Control Product	Caltrans Item Description[1]	Caltrans Item Code[1]	Average price per unit[1,2,3]		Caltrans estimated \$/acre[4,5]/application	Present Worth \$/acre/20yr[6,7]	
Rock Slope Protection	Rock Slope Protection (Backing No. 2 and Backing No. 3 Method B)	721011, 721012	\$ 149.79	cu. yd	\$ 120,500	**20 year**	\$120,500
						10 year	**6 year**
Soil Cement	Concrete (Slope Protection)	721400	\$ 486.00	cu. yd	\$ 131,000	\$261,500	\$523,000

Note 1: Pursuant to the Caltrans 2009 Contract Cost Data. Prices shown are the mechanically weighted averages of the awarded bidders.

Note 2: Assume bid information includes product installed/applied.

Note 3: Price for RSP averaged from District 8 and 11 data. Price for SC from District 11 data.

Note 4: For RSP assume applied at 6" thickness, 1,300 ton/acre, and density of 120 lbs/ft^3.

Note 5: For cement assume applied at 2" thickness. Does not include cost offset by native soil applied to mix.

Note 6: Present Worth cost to maintain RSP on 1 acre over a 20 year period (1 time application).

Note 7: Present Worth cost to maintain SC on 1 acre over a 20 year period (based on 6 to 10 year useful life, 2 to 4 applications respectively). Calculated based on assumed 3% annual inflation and 3% time value of money

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Section 8 Conclusions

The following section provides general conclusions derived from the Study monitoring results. The Study was performed to evaluate the performance of a variety of non-vegetative erosion control products applicable to the arid regions of California. The products evaluated in this Study consisted either of hydraulically applied soil binding agents or surface cover products. The conclusions presented below are related to the erosion control product performance and cost.

8.1 Product Performance

This study evaluated the two year performance of five types of erosion control products at three locations in arid regions of California. One of the fundamental conclusions from the Study results is that the amount of sediment lost from plots treated with the Rock Slope Protection (RSP) and Soil Cement (SC) was significantly less than the control plots or any of the hydraulically applied products (Table 8-1).

Table 8-1 Final Sediment Yield Results

Site	Sediment Yield in Pounds (All Plots Combined)					
	Rock Slope Protection (RSP)	Soil Cement (SC)	SoilTac® (ST)	Soil Seal (SS)	PolyPavement™ (PP)	Control (CT)
Barstow	61	1	217	232	266	655
Hinkley	92	97	1,049	1,293	804	1,276
Dunaway Road	7	32	182	574	513	841
Average	53	43	483	700	528	924

In order to allow comparison to other erosion control product evaluation studies, the average sediment yield results for the two year study presented in Table 8-1 were converted to tons per acre in Table 8-2 below.

Table 8-2 Final Sediment Yield Results Converted to Tons/Acre.

Erosion Control Product	Average Sediment Yield in Tons/Acre (All Plots Combined)
Rock Slope Protection (RSP)	6.8
Soil Cement (SC)	5.5
SoilTac® (ST)	61.7
Soil Seal (SS)	89.4
PolyPavement™ (PP)	67.4

Statistical analysis of the Study results for all three sites indicate that the two surface cover products, RSP and SC, show evidence of consistently better performance (i.e., greater percent reduction in sediment yield) relative to the control plots over the two year study period (Table

8-3). In general, the hydraulically applied products did not show consistently better performance relative to the control plots. The SoilTac® (ST) erosion control product had variable results among the three sites, showing evidence of better performance at the Barstow and Dunaway Road sites, but not at the Hinkley site. However, the Soil Seal (SS) and PolyPavement™ (PP) erosion control products did not show a statistically significant reduction in sediment yield relative to the control plots over the two year study period.

Table 8-3 Summary of Sediment Yield Reduction Results

Site	Evidence of Increased Performance Relative to Control?				
	Rock Slope Protection (RSP)	Soil Cement (SC)	SoilTac® (ST)	Soil Seal (SS)	PolyPavement™ (PP)
Barstow	YES	YES	YES	NO	NO
Hinkley	YES	YES	NO	NO	NO
Dunaway Road	YES	YES	YES	NO	NO

A second important conclusion related to product performance is the identification of indicators that suggest a degradation of erosion control product performance during the two year study period. This findings somewhat contradicts the manufacturer-supplied life expectancy information for the hydraulically applied erosion control products and generally accepted performance information for the surface cover erosion control products (Table 8-4).

Table 8-4 Erosion Control Product Life Expectancy

Erosion Control Product	Life Expectancy[1] (years)
Rock Slope Protection (RSP)	20-30
Soil Cement (SC)	20-30
SoilTac® (ST)	1-2
Soil Seal (SS)	1
PolyPavement™ (PP)	5-10

[1] Life expectancy based on manufacturer-supplied information.

The primary factors examined as potential drivers of product degradation included cumulative rainfall and days since application (age). In general, the RSP and SC products did not show evidence of performance degradation related to either cumulative rainfall or age during the study period (Table 8-5). The ST product showed evidence of degradation at the Hinkley site approximately 12 months after application. The evidence of performance degradation for the SS product was highly variable, ranging from 6 months at the Hinkley site to approximately 16 months at the Barstow site. The SS product at the Dunaway Road site did not show statistically significant evidence of performance degradation. Given that analysis of variance and multiple regression data analysis were performed only at the Dunaway Road site, observed site-specific variability in SS product is not able to be attributed to specific influence of site-specific factors (soil type, slope, etc.) or site-to-site differences on treatment performance. The PP product showed more consistent evidence of degradation during the study period, where the length of time after application when degradation began to become apparent varied from twelve to sixteen months at the three sites.

Table 8-5 Summary of Time Estimate for Possible Degradation of Product Performance

Site	Estimated Time to Evidence of Product Degradation				
	Rock Slope Protection (RSP)	Soil Cement (SC)	SoilTac® (ST)	Soil Seal (SS)	PolyPavement™ (PP)
Barstow	--	--	--	~16 months	~16 months
Hinkley	--	--	~12 months	~6 months	~12 months
Dunaway Road	--	--	--	--	~12 months

"-- " indicates no evidence of degredation

An important side benefit of the SC product is that it reduced runoff from the treatment area. As described in Section 4.3, the R_v value is a measure of the relationship between the runoff captured from the defined test plot area for a rainfall event of a given size. The SC product had the lowest R_v value at each of the three monitoring locations which indicates that it had the greatest infiltration rates. The SC product R_v value was, on average, nearly half of the next lowest erosion control product (RSP) runoff coefficient (Table 8-6).

Table 8-6 Summary of Volumetric Runoff Coefficients (R_v) Values

Site	Mean R_v Value (All Events)					
	Rock Slope Protection (RSP)	Soil Cement (SC)	SoilTac® (ST)	Soil Seal (SS)	PolyPavement™ (PP)	Control (CT)
Barstow	0.10	0.03	0.10	0.21	0.16	0.19
Hinkley	0.28	0.15	0.32	0.28	0.31	0.35
Dunaway Road	0.03	0.02	0.15	0.39	0.36	0.26
Average	0.13	0.07	0.19	0.29	0.28	0.27

8.2 Life Cycle Costs

An important consideration in overall evaluation of erosion control product effectiveness is life cycle cost. A summary of the estimated costs, including the initial application and a range of present worth costs to apply the five erosion control products to a one-acre site for a 20 year implementation period is presented in Table 8-7.

Table 8-7 Summary of Estimated Life Cycle Costs

Erosion Control Product	Estimated Single Application Cost (per acre)	Estimated Number of Applications Required (per 20 years)	Estimated Total 20 Year Life Cycle Cost Range[1] (per acre)	
			Low	High
Rock Slope Protection (RSP)	$120,500	1	$120,500	
Soil Cement (SC)	$131,000	2-3	$261,500	$523,000
SoilTac® (ST)	$5,650	10-20	$56,500	$113,000
Soil Seal (SS)	$5,240	10-20	$52,500	$105,000
PolyPavement™ (PP)	$5,500	10-20	$55,000	$110,000

[1] Costs rounded to the nearest $500.

As described in Section 7, the RSP and SC products require significant initial application cost when compared to the hydraulically applied erosion control products. However, the Study data indicates that the long-term performance of these two products may significantly exceed that of the hydraulically applied erosion control products. There are a number of environmental factors that may impact the year-to-year variability in performance for each of the hydraulically applied products, and to a lesser extent the SC product, such as amount and intensity of rainfall, temperature, and wind. Accordingly, a key component to managing life cycle cost for the hydraulically applied products is the number of applications required to maintain consistent performance. The Study data identified that for the hydraulically applied products, there was generally at least some evidence of product degradation 6 to 12 months after product application. Based on this evidence, it is anticipated that the hydraulically applied products may require re-application every one to two years to maintain product effectiveness. When applied annually, the present worth of the capital cost of the hydraulically applied products over 20 years is comprable to the cost of RSP installation. Accordingly, the hydraulically applied products should likely be considered temporary erosion control BMPs within the context of the Caltrans stormwater program.

The Study data presented in this report provides valuable performance and cost data for five erosion control products. Based on the study duration and other factors, it is acknowledged that the data does not allow specific conclusions to be made based on soil type and slope as it relates to product performance. In addition, it is recognized that the long-term performance of the five evaluated erosion control products may be highly dependent on site-specific and general environmental variables and other factors such as application method, project size, and site configuration. In this Study, results for the hydraulically applied products were based on application rates for slopes recommended by each manufacturer. Modifications to erosion control product application rate or method may impact performance results. Finally, there are other ancillary considerations that factor into specific erosion control product selection for a given project application. These considerations may include, but are not limited to: administrative costs associated with the execution of contracts for the reapplication of SC or any of the three hydraulically applied products, availability of erosion control product materials at a given site location; transportation impacts and potential environmental impacts or other costs associated with product implementation at a given site; and health and safety considerations for erosion control product application within Caltrans rights-of-way and arid region locations.

Accordingly, results of this Study, along with a variety of other project-specific factors should be considered when deciding on long-term erosion control methods and practices at a given project site location.

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Section 9 Future Considerations

The purpose of this Study was to evaluate the effectiveness of non-vegetative erosion control products in reducing soil erosion caused by wind and water on slopes in arid regions of California. This section summarizes future considerations based on lessons learned from various phases of the Study.

9.1 Suggested Improvements to Study Design and Technology

The Study was performed using an applied scientific process utilizing Caltrans procedures and guidance manuals. The study results provided useful information related to both product performance (Section 4) and overall study design and monitoring methods. Some of the findings obtained as part of this Study were a result of lessons learned during the pilot project planning, design, construction and monitoring efforts. Based on these findings, several potential improvements to performance of pilot studies and larger scale implementation plans for the application of erosion control products in arid regions were identified. Suggested improvements are identified below.

- ***Consider potential impacts of environmental factors in pilot study implementation.***

In this Study and in arid region climates in general, a large set of environmental conditions may potentially have impacts on erosion control products and the ability to collect meaningful monitoring data for pilot technologies. A consideration to improve future pilot project implementation is to consider potential impacts of a large suite of environmental variables and, to the extent feasible, make use of available monitoring methods and data to cost-efficiently apply information related to these variables to the focal pilot study. A summary of environmental factors with potential impacts to this and other pilot studies related to stormwater runoff management in arid regions is presented in Table 9-1.

Table 9-1 Environmental Variables with Potential Impacts to Caltrans Pilot Studies

Environmental Factor	Potential Impact(s) to Pilot Studies	Future Considerations
Geotechnical conditions	Existing or assumed geotechnical conditions may prevent efficient project implementation or statistical comparison of otherwise similar sites.	Perform site-specific geotechnical investigations to confirm existing conditions and site suitability for pilot study implementation.
Windblown material	Wind or other natural processes may negatively impact monitoring equipment or procedures.	Perform preliminary and/or pilot investigation of monitoring equipment and/or techniques prior to full-scale pilot project implementation.
Highly variable local rainfall patterns	Significant localized rainfall variation in arid regions can lead to unexpected or incongruous data.	Implement on-site rainfall monitoring equipment.

- ***Periodically revisit pilot study goals and objectives during projects with long planning and implementation timelines.***

This Study was performed over an approximately eight year period beginning with the publishing of the Study Plan in 2002 and ending with two years of monitoring from 2008 through 2010. This time frame led to a relatively long period between the development of study objectives, study design and implementation of the pilot project in the field. A consideration to improve future pilot project implementation may be to manage potential expansion and contraction of study objectives through the lifecycle pilot project development and implementation. During this Study, the project team conducted monthly meetings during the project implementation and monitoring period to discuss project challenges and interim project results. This effort provided valuable assistance to the project team and improved monitoring data collection efforts.

- ***Consider long-term availability of required products or materials for potential pilot study implementation.***

A key component identified in the Study Plan was the selection of the pilot erosion control products to be evaluated. The relatively long lag time between study design and implementation resulted in one of the erosion control products identified in the Study Plan to be unavailable in California at the time of site construction. This issue led to additional labor and cost to identify an appropriate product substitute during the construction phase.

- ***Confirm assumed site size, configuration and other conditions prior to pilot study construction and implementation.***

A key assumption identified in the Study Plan was related to the configuration of selected pilot study sites. The Study Plan did not include site-specific topographic surveys and relied on existing roadway plans to develop the pilot study site plans. The existing roadway plans ultimately did not provide sufficiently accurate roadside topographic information for the level of detail required for the pilot study site plans. As a result, several significant changes were required during site construction. A consideration to improve future pilot project implementation is to confirm site conditions using topographic, geotechnical and/or other applicable survey methods prior to pilot study construction and implementation.

- ***Perform an engineering analysis of pilot project plans and specifications.***

As part of the Study Plan, a set of plans and specifications containing site construction details were developed. Given the innovative nature of this study, the project may have benefited from an engineering analysis of the plans and specifications to explore areas for cost savings prior to the contractor bidding process. A consideration to improve future pilot project implementation is to perform an engineering analysis of pilot project plans and specifications in order to verify that the plans and specifications contain sufficient detail to seek responsive bids from contractors which would reduce the likelihood of inconsistencies with construction contractor bids based on interpretation of the plans. In addition, it may be beneficial to bench test or pilot test innovative monitoring techniques prior to full scale implementation to provide an opportunity to optimize their design prior to full-scale implementation.

- ***Consider use of paired treatment and control study design for plot-based studies to reduce variability.***

In this Study, test plot locations within each site were assigned using random numbering techniques. As a result of the potential large plot-to-plot replicate variability observed at some sites, it may be desirable to modify future study/sampling plans for similar plot-based studies by matching each treatment plot with an adjacent control plot. The proximity of treatment plot and matched control plot may help to reduce the replicate variability.

- ***Examine modifications to erosion control product application rates and/or methods to improve cost-effectiveness and/or product performance.***

Construction of the test plots and application of the erosion control products as part of this Study led the project team to identify several important issues. These issues included: the application method utilized for SC in the relatively small test plots was labor intensive and may not be feasible in larger implementation areas; the rate of application for some of the hydraulically applied products may be able to be varied depending on slope grade and soil texture; and the standard aggregate rock size utilized for RSP applications may be able to be varied depending on local site conditions or other factors. A consideration to improve future pilot project or large-scale erosion control product implementation is to examine how erosion control product application rate and/or methods may be modified or improved to increase cost-effectiveness and/or product performance. Specific modifications and/or improvements related to the issues identified include: mechanical incorporation of SC into the native soil structure in some applications; investigation of dilution ratio alternatives for hydraulically applied products to improve cost-efficiency and product effectiveness and/or longevity; and investigate the potential for use of smaller (less than 12 inch diameter rock) rock sizes for RSP.

- ***Perform long-term monitoring to understand useful life of Soil Cement.***

In this Study, the SC plots exhibited noticeable wear and degradation during the course of the two year monitoring period. Based on project team experience, the observed level of degradation during the initial two year deployment period was unexpected. Other studies have shown soil cement to have variable long-term performance depending on installation method, maintenance procedures and environmental factors (Clute et al 2008). A consideration to improve understanding of the product longevity for SC is to conduct long-term passive monitoring of the SC test plots at the three monitoring locations. A suggested long-term monitoring technique is to photo document the SC plots on a quarterly basis to allow identification of the time when substantial product degradation occurs.

- ***Include erosion control both within and around the test plots throughout the lifecycle of the pilot project.***

In this Study, the configuration of the study plots contributed to minor ancillary erosion adjacent to the test sites. A consideration to improve future pilot project implementation with a similar test plot design is to consider erosion control both within and around the test plots throughout the lifecycle of the pilot project.

- ***Implement more test plots or evaluate few erosion control products at a time.***

The short life spans of the hydraulically applied products and the infrequent rainfall in arid regions presented challenges in obtaining a representative data set sufficient to produce results to the required level of confidence. This could be addressed by implementing more test plots or utilizing the same number of test plots, but evaluating fewer erosion control products in future studies.

- ***Clearly expresses the need for a cost/benefit relationship between products in the Study Plan.***

The Study Plan did not include the means or methods to compare costs and environmental benefits of the erosion control products considering the full life cycle costs and the effectiveness of the products. For example, the present worth analysis shows that over 20 years, RSP (one application) and ST (annual applications) have generally similar costs ($120,500 vs. $113,000), but this does not factor in the value of benefits due to reduced sediment loss with RSP which was approximately one-tenth the sediment yield of the ST treated plots.

Section 10 References

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APPENDIX A SPECIAL APPLICATION PROVISIONS

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APPENDIX B BULK DENSITY PROCEDURE

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APPENDIX C POST STORM TECHNICAL MEMORANDA – BARSTOW, DUNAWAY ROAD AND HINKLEY

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APPENDIX D SOIL MOVEMENT– BARSTOW, DUNAWAY ROAD AND HINKLEY

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APPENDIX G BOX PLOT STATISTICS FOR DUNAWAY ROAD

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