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Evaluation of Application Methods and Products for Mitigating Dust for Lines-of-Communication and Base Camp Operations

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and Jeb S. Tingle

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Geotechnical and Structures Laboratory

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ABSTRACT: The ERDC was tasked by the U.S. Marine Corps Systems Command to develop two dust control systems, one for expeditionary use on Forward Area Refueling Points (FARPs) and one for sustainment use on roads and other large area applications. The project consisted of evaluating various dust palliatives and application equipment under controlled laboratory conditions and during field tests. The products of this effort include equipment recommendations, palliative recommendations, and complete application guidance. This report addresses testing performed to evaluate commercial palliatives and application processes for constructing and maintaining lines-of-communication. Twenty-four test sections were constructed at Douglas, AZ, using both experimental and commercial palliatives for dust abatement. Several application procedures were evaluated in the process as well. Each test section was evaluated at 0, 30, 60, and 90 days after construction. The evaluation consisted of dust particle collection and soil property measurements. Pertinent conclusions from the testing conducted are noted, and recommendations for selecting dust abatement methods and materials are provided.

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Preface

The purpose of this report is to present results from the evaluation of methods for mitigating dust on unpaved roads subjected to lightweight truck traffic in sustainment applications. A sustainment application, as defined in this experiment, is a dust abatement material or method that is designed for long-term use during sustained military operations. The application of dust palliatives for sustainment missions assumes that construction equipment will be available in the theater of operations. The dust abatement materials and application methods must effectively control dust for at least 90 days. This report includes the evaluation of commercially available and experimental dust palliatives, as well as the evaluation of alternative methods for applying the products. This report provides data for the following:

a. Evaluating commercially available dust palliatives for mitigating dust on unsurfaced roads under lightweight truck traffic.

b. Evaluating construction procedures to determine the most efficient means of applying dust palliatives for long-term use.

c. Selecting palliative dilution ratios for treatment of unpaved roads in sustainment environments.

d. Selecting palliative application rates for treatment of unpaved roads in sustainment environments.

Users of this report include the U.S. Marine Corps' Systems Command, units charged with unpaved road construction, and agencies assigned operations planning responsibilities.

The project described in this report is part of the Dust Abatement Program currently sponsored by Headquarters, U.S. Marine Corps Systems Command, 2200 Lester Street, Quantico, VA 22134-6050.

This publication was prepared by personnel of the U.S. Army Engineer Research and Development Center (ERDC), Geotechnical and Structures Laboratory (GSL), Vicksburg, MS. The findings and recommendations presented in this report are based upon a series of field tests conducted at Douglas, AZ, during March through August 2004. The research team consisted of Messrs. John F. Rushing, J. Andrew Harrison, Jeb S. Tingle, Timothy McCaffrey, Quint Mason,

and Mike Crawford and Ms. Eileen Velez-Vega, Airfield and Pavements Branch (APB), GSL. Messrs. Harrison, Rushing, and Tingle prepared this publication under the supervision of Mr. Don R. Alexander, Chief, APB; Dr. Albert J. Bush III, Chief, Engineering Systems and Materials Division; and Dr. David W. Pittman, Director, GSL.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL James R. Rowan, EN, was Commander.

Recommended changes for improving this publication in content and/or format should be submitted on DA Form 2028 (Recommended Changes to Publications and Blank Forms) and forwarded to Headquarters, U.S. Army Corps of Engineers, ATTN: CECW-EWS, Kingman Bldg, Rm 321, 7701 Telegraph Road, Alexandria, VA 22315.

Executive Summary

The field testing of dust palliatives discussed in this report was conducted in Douglas, AZ, during the period March through August 2004 by personnel of the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. The testing included the evaluation of construction procedures for dust palliative placement to identify the most effective application method for durability and long-term effectiveness. This report summarizes the construction, trafficking, and monitoring of the 24 different test sections. An evaluation of 13 commercially available dust palliatives was also conducted to determine the most effective products available for mitigating dust in desert climates. Palliative effectiveness was evaluated using dust particle collection equipment as well as visual observations of product performance.

Analysis of the results of the tests and visual observations led to the following conclusions:

a. Performing only a topical application can provide satisfactory dust abatement on aggregate roads with a high load-bearing capacity. However, when applying dust palliatives to unimproved roads, topical applications may not allow for significant penetration of product. Thin surface crusts are prone to disintegration with increased traffic, allowing the underlying material to produce dust.

b. Using a rotary mixer or soil stabilizer to incorporate dust palliatives into the soil works very well. It is not necessary that the road be tilled prior to spraying the product. As long as runoff of the product does not occur, mixing can be performed after spraying onto the existing road surface in order to minimize construction efforts. It may be necessary to disturb the surface if the product does not soak into the road readily or if working on an inclined or crowned surface.

c. Compacting a tilled surface with a steel-wheeled roller provides an exceptionally smooth and durable surface.

d. A final topical application of at least part of the optimum product application rate is desired to effectively seal the surface.

e. The following products performed excellently during testing of the road sections with lightweight truck traffic 90 days after construction: Envirotac II®, Soiltac®, Envirokleen®, Dust Fyghter®, and Surtac®.

Based upon the information presented in this report, the following recommendations are given for using dust palliatives in desert environments:

a. A topical application procedure with compaction is recommended for light traffic, and a spray/till/compact/spray technique is recommended for heavy traffic.

b. A final surface application is desired after compaction to seal the surface of the road and to form a weather-resistant layer. Binding surface particles will also provide more resistance to raveling under traffic.

c. Some products may not prove as effective in climates where precipitation occurs frequently. Dust Fyghter®, Surtac®, and Dustex® are susceptible to leaching from the soil, and further evaluation of these products is recommended for more temperate climates characterized by significant rainfall levels.

d. The following products are recommended for use in sustainment operations in desert environments with a 90-day effectiveness rating: Envirotac II®, Soiltac®, Envirokleen®, Surtac®, and Dust Fyghter®.

e. Envirotac II®, Surtac®, and Soiltac® should be diluted with water to a 3:1 solution and applied at a total application rate of 0.8 gallon per square yard (gsy).

f. Envirokleen® and Dust Fyghter® should be applied "neat" at a rate of 0.8 gsy.

Chapter 2 in this report provides detailed information on the test location as well as the equipment and procedures used to identify the desired construction process for palliative placement. Descriptions of the dust palliatives evaluated in this test and analysis of their performance are given in Chapter 3. Chapter 4 provides recommendations and conclusions from the information gained in this test. Figures and photos follow the report text.

1 Introduction

The U.S. military was plagued by fugitive dust during Operations Enduring Freedom and Iraqi Freedom. Dust generation was a major concern during military maneuver operations in theater. Numerous unpaved roads were trafficked with long convoys of military vehicle traffic in both combat and sustainment roles. The surface of the low-volume roads and main supply routes deteriorated under the abrasive action of both wheeled and tracked vehicles. The generation of dust also permeated through the large network of base camps, impacting rear-area support activities and, ultimately, support and stability operations. The widespread accumulation of dust during ground vehicle operations and in base camps adversely impacted the ability of military personnel to effectively conduct combat operations.

The U.S. Army Engineer Research and Development Center (ERDC) was tasked by the U.S. Marine Corps' Systems Command (MCSC) to conduct a comprehensive dust abatement program for developing two dust control systems, one for expeditionary use on Forward Area Refueling Points (FARPs) and one for sustainment use on roads and other large area applications. The project consisted of the evaluation of various dust palliatives and application equipment under controlled laboratory conditions and during field tests. The products of this effort include equipment recommendations, palliative recommendations, and complete application guidance. This report represents the development of dust abatement materials and methods for sustainment use in arid and semi-arid environments.

Objective

The primary objectives of this phase of the evaluation were to develop recommendations for dust palliatives and application procedures for applying products in a sustainment environment, principally roads and base camps. This report provides data for the following:

a. Evaluating commercially available dust palliatives for mitigating dust on unsurfaced roads under lightweight truck traffic.

b. Evaluating construction procedures for the most efficient means of applying dust palliatives for long-term use.

c. Selecting palliative dilution ratios for treatment of unsurfaced roads in sustainment environments.

d. Selecting palliative application rates for treatment of unsurfaced roads in sustainment environments.

The testing initiated in this evaluation represents the second phase of the comprehensive dust abatement program. The results of the overall program will provide the USMC with the equipment, products, and criteria for mitigating dust in the theater of operations.

Scope

A dust control exercise was scheduled for 16-23 March 2004 in Douglas, AZ, to evaluate construction procedures for application of dust palliatives and palliative suitability for use in sustainment operations. The U.S. Border Patrol (USBP) provided a 3.2-mile section of unpaved road (Photo 1) for use during the test (POC: Mark Vaughan, USBP Douglas Station). The Douglas test included two phases. The first phase was to determine the most effective equipment and procedures for dust palliative placement. The second phase of the test consisted of comparing commercial-off-the-shelf (COTS) dust palliatives using a singular construction method identified in phase one for placement. Twelve COTS products touted as being effective at controlling airborne dust were acquired by the ERDC and evaluated during the test. One experimental product developed by the Naval Research Laboratory was also tested. Because the objective of the test was to identify methods for long-term dust control, additional testing was performed at intervals of 30, 60, and 90 days from palliative placement to evaluate effectiveness. This document briefly describes the application equipment/ procedures evaluated, the palliatives used, the results from periodic evaluation, and recommendations regarding materials and methods to be used to mitigate dust for sustainment operations.

2 Evaluation of Palliative Application Methods

A major component of ERDC's tasking by the Marine Corps Systems Command was to evaluate equipment requirements and application procedures for dust palliative placement. General criteria used to evaluate palliative distribution systems included:

a. Uniformity of product distribution.

b. Simplicity of the distribution process.

c. Effectiveness in applying a variety of palliative types.

d. Manpower requirements for product application.

Equipment used during the field test was chosen to simulate military construction capabilities from the available inventory. Items used were supplied by ERDC or rented from local vendors. A commercially available hydroseeder (Finn T-90) was leased and used for the application of the palliatives (Photo 5). This type of machinery was identified during the expeditionary dust palliation testing in Yuma, AZ, as being an effective means for product distribution (Tingle et al. 2004).

Test Site Description

The test site for the field experiment consisted of 3.2 miles of an unpaved road paralleling the border between the U.S. and Mexico. The site was located approximately four miles west of Douglas, AZ, and directly south of the U.S. Borer Patrol, Douglas Station on King's Hwy. Use of the road is predominantly by Border Patrol vehicles, and traffic generally consists of 30 to 60 vehicles per day. The existing road consisted of well-graded gravelly clayey sand (Figure 1) with a maximum aggregate size of 3/4 in. and a maximum dry density of 136.8 lb/ft^3 as determined by American Society for Testing and Materials (ASTM) D1557 (2002). Moisture-density relationships for the material are shown in Figure 2. The road was disturbed to a 6-in. depth and graded prior to test section construction (Photo 2). Moisture and density values were determined using a Troxler® 3430 nuclear gauge in the 6-in. direct transmission mode (Table 1). Twenty-four 20-ft by 500-ft sections were marked with traffic delineators for identification (Photos 3 and 4). The first ten sections were used for the evaluation of application methods. The final fourteen sections were used to compare the effectiveness of different dust palliatives using the same construction procedure. Untreated zones of a minimum 100-ft length were used to separate sections as transition areas. A layout depicting the procedures and products is shown in their respective locations in Figure 3.

Table 1
Pre-Treatment Moisture and Density Data

Section	Wet Density, pcf	Moisture Content, pcf	Dry Density, pcf	Moisture Content, %
1	124.9	3.5	121.5	2.9
2	132.1	6.7	125.4	5.4
3	133.5	4.8	128.7	3.7
4	125.9	7.0	118.9	5.9
5	130.9	5.0	125.9	4.0
6	127.4	5.2	122.1	4.3
7	121.1	6.2	114.9	5.4
8	131.0	4.6	126.3	3.7
9	125.3	5.7	119.5	4.8
10	134.2	8.2	126.0	6.5
Average:	128.6	5.7	122.9	4.7

Test Section Construction

Several types of application methods were used to apply dust palliatives to ten test sections (Sections 1 through 10) as shown in Figure 3, from 17 to 19 March 2004. Table 2 lists the sections constructed and identifies the method, equipment used, required manpower and overall application time. The application equipment included a heavy-duty T-90 Finn hydroseeder pulled by a High Mobility Multi-Wheeled Vehicle (HMMWV) (Photo 5), a John Deere 770 BH motor grader (Photo 6), a model MO76 Seaman Maxon Travel-Mixer tiller (Photo 7), and two compactors, a 6-ton BOMAG model BW 142 D-2 and a 12-ton Ingersoll-Rand model DD-110 (Photos 8 and 9). A 4,000-gal commercial water truck was leased to maintain accessibility to dilution water when required.

The T-90 Finn hydroseeder was used to apply the dust palliatives to each of the test sections. Hydroseeding equipment was identified from a previous dust palliative test in Yuma, AZ, during February 2004 as being an excellent choice for product distribution due to even dispersion and flexibility with various chemical types. Unless otherwise noted, the products were sprayed onto the road surface using a distribution bar mounted 18 in. above the ground at the rear of the hydroseeder (Photo 10). The distribution bar was capable of spraying up to 50 gal/min through 5 spray nozzles. The system required three persons to operate; one to drive the HMMWV, one to operate the pump on the hydroseeder, and one to monitor fluid levels within the tank. The tower gun on the hydroseeder was used when spraying narrow windrows in the center of the section. The following paragraphs describe the general construction of each section.

Table 2 Dust Palliative Application Procedure and Time				
Section	**Palliative**	**Method**	**Manpower**	**Time (min)**
1	Water	Spray/Compact	4	60
2	Envirotac II®	Prewet/Spray/Compact	4	180
3	Envirotac II®	Spray/Compact	4	105
4	Envirotac II®	Windrow/Spray/Grade	4	42
5	Envirotac II®	Windrow/Spray/Grade/Compact	5	48
6	Envirotac II®	Spray/Windrow/Grade/Compact	5	48
7	Envirotac II®	Spray/Till/Grade/Compact	6	78
8	Envirotac II®	Till/Spray/Grade/Till/Compact	6	136
9	Envirotac II®	Till/Spray/Till/Compact/Spray	5	125
10	Envirotac II®	Spray/Till/Compact/Spray	5	46
		Range of Values:	4 to 6	42 to 180
All sections were freshly graded prior to construction or product application.				

Section 1

The first section was used as an untreated section (Photo 11). It was sprayed with water to approach the estimated optimum moisture content of the granular surface material and compacted. The amount of water added to the soil was calculated from moisture and density values previously gathered from the Troxler® nuclear gauge. Seven and one-half passes were made with the hydroseeder to distribute 850 gal of water. The final pass only covered half of the section because the tank ran out of water. After the water application, the 6-ton BOMAG vibratory compactor was used to make two coverages over the section.

Section 2

The second section consisted of prewetting the road surface with water followed by a topical application of the dust palliative and compaction. Two passes of the hydroseeder applied 200 gal of water onto the road surface. The moisture was allowed to penetrate for 30 min prior to palliative placement to let the water evenly disperse. Five passes of the hydroseeder were used to spray 700 gal of a 3:1 dilution of water and Envirotac II®. Some puddling of product and runoff were observed (Photo 12). The section was allowed to soak for 30 min prior to compaction to prevent the product from sticking to the roller of the compactor. Two coverages were made with the 6-ton BOMAG vibratory roller for compaction. The road surface was very smooth and resisted break-up during initial traffic.

Section 3

The third section included a topical surface application with no prewetting of the section. First, 175 gal of Envirotac II® and 725 gal of water were mixed in the hydroseeder and applied in six passes over the section. Compaction was delayed 30 min to allow the liquid to penetrate the surface. Two coverages were made with the Ingersoll-Rand 12-ton vibratory compactor.

Section 4

The fourth section was intended to incorporate the dust palliative into the soil at a greater depth. The grader was used to scrape the road surface and create a windrow in the center of the section. The windrow was approximately 4 ft wide at the base and 2 ft high. The hydroseeder was then used to spray 175 gal of Envirotac II® diluted with 725 gal water onto the windrow using the tower gun (Photo 13). One pass on each side of the windrow was made to complete spraying. The section was then graded with 9 passes to mix and level the surface. No compaction was performed on the section.

Section 5

The fifth section used the same method as described for Section 4 with the exception that the section was compacted upon final grading with two coverages of the 12-ton Ingersoll-Rand vibratory compactor.

Section 6

The sixth section attempted to perform a more uniform distribution of product within the section. The hydroseeder was filled with 175 gal Envirotac II® and 725 gal of water and sprayed onto the road surface using the tower gun. The grader was then immediately used to create a windrow in the center of the section to mix the soil and achieve better penetration depth. Final grading of the section was followed by two coverages with the 12-ton Ingersoll-Rand vibratory compactor.

Section 7

The seventh section used only the rotary mixer for incorporation of product within the section. First, the hydroseeder was filled with 175 gal of Envirotac II® and 725 gal of water and sprayed onto the road surface using two passes with the tower gun. Three passes with the rotary mixer immediately following spraying mixed the soil to a depth of 3 in. (Photo 14). The grader was used to level the section prior to compacting with two coverages of the 12-ton Ingersoll-Rand vibratory roller.

Section 8

The eighth section was first scarified with three passes of the rotary mixer to a depth of 3 in. The hydroseeder was then used to spray 175 gal of Envirotac II® and 725 gal of water over two passes, one on each side of the section, using the tower gun. The product immediately soaked into the soil. The grader was then used to level the surface. The rotary mixer was used to make three more passes to attempt to distribute the product more uniformly. The section was allowed to dry for 30 min prior to compaction with two coverages of the Ingersoll-Rand 12-ton vibratory compactor.

Section 9

The ninth section was first scarified to a depth of 3 in. to allow better penetration of the dust palliative. The hydroseeder was filled with 175 gal Envirotac II® and 725 gal of water, but only half of the product was sprayed onto the tilled surface. Attempts to compact the section were postponed for 30 min due to a moist surface layer that stuck to the roller of the compactor. The section was mixed using three passes of the rotary mixer to distribute the product before compaction. After two coverages with the 12-ton vibratory compactor, the remaining product was sprayed onto the section to seal the voids and create a wearing surface. Absorption into the road section was relatively fast and no runoff was observed.

Section 10

The method used for the tenth section was similar to Section 9 with the elimination of the initial scarification step in order to simplify the procedure and save time. Half of the diluted Envirotac II® was sprayed onto the road surface and immediately mixed with the rotary mixer using three passes to distribute the product within the top 3 in. of the section. Two coverages with the 12-ton vibratory compactor immediately followed the mixing procedure. The remaining product was then sprayed onto the surface to seal the road.

Evaluation of Application Procedures

Each of the sections used to evaluate product application methods and equipment was treated with Envirotac II®. Use of the same product and dilution ratio allowed for controlled observation of the effectiveness of the application methods. This product provided good performance during field testing at Yuma, AZ (Tingle et al. 2004) and was available in the necessary quantities for this part of the experiment. The results of these initial sections are not necessarily indicative of the performance of the product used. Product effectiveness should be judged from the second phase of this evaluation, Sections 11 through 24, where a singular application method was used to apply all of the products included in the test. The following paragraphs provide an evaluation of the application methods based upon construction experience and visual observations made one day after construction by the research team.

Section 1

The application method, spray/compact, was simple and easily achievable. The Finn hydroseeder was pulled using the HMMWV vehicle at a speed slightly above idle in low range. The distribution bar was equipped with the maximum size nozzles (10 gpm) available at the site and required seven and one-half passes to distribute the 850 gal. Additional options were explored in the other sections to minimize the number of passes required. Compaction of the surface after spray application was achieved with the 6-ton BOMAG vibratory compactor. The required compaction could be achieved with increasing passes; however, it was determined from observation that a larger compactor would improve construction. Construction conclusions from this section included the recommendation to reduce the number of passes to distribute the product with the distribution bar and to increase the size of vibratory compactor.

Section 2

This section, pre-wet/spray/compact, was first sprayed with water to pre-wet the surface before topically applying the dust palliative. Efforts to reduce the number of passes to provide an even distribution of product were explored; however, seven passes were still required. The pre-wetting of the surface did not appear to be beneficial to the section since the water used to pre-wet was taken from the total amount of dilution water needed for the section. The final application of product did not soak readily into the surface and some runoff was observed. This application was a more concentrated mixture of product with a higher viscosity and, therefore, a higher resistance to penetration of the soil surface. The 6-ton Bomag vibratory compactor was also used on this section since the large compactor had not arrived at the construction site. Although the surface was allowed to soak in for approximately 30 min, some product did stick to the vibratory compactor during compaction, creating minor imperfections in the surface. Generally, the topical application gave a good wearing surface, but the thin layer is prone to rapid deterioration with applied traffic. Long-term dust abatement may be minimal if the underlying layer is exposed. Lessons learned from the construction of Section 2 include: (1) the quantity of product applied to the surface before final compaction should be applied such that product runoff is minimized and (2) surface application of product before final compaction requires time for the product to soak in the surface layer to prevent sticking to the compactor. In some areas the product may become too dry.

Section 3

Section 3, spray/compact, was treated with a topically applied palliative with no pre-wetting of the surface. The absorption of the product into the surface did not appear to be different from the previous section where pre-wetting was performed. Although time was allowed for the product to soak in, the surface was very damp and problems existed with the product sticking to the roller of the compactor (Photo 15). This section was compacted with a 12-ton Ingersoll-Rand compactor instead of the 6-ton compactor used on the previous two sections. The road surface contained rough areas due to product sticking to the roller and caused the surface crust to peel (Photo 16). Lessons learned from Section 3 included: (1) the larger 12-ton compactor required fewer passes and resulted in a better compacted surface than the smaller 6-ton compactor, (2) applying product before compaction can require additional time for penetration and/or sand blotting, and (3) 900 gal could be applied to the surface in six passes using the distribution bar; however, this required duplicate passes over previously sprayed areas.

Section 4

The application method used on this section, windrow/spray/grade, was difficult to achieve due to the roadbed consisting of a steep embankment with deep ditches on both sides. The dust palliative was applied to the windrow using the tower gun on the hydroseeder. This was accomplished in two passes due to the larger gpm rating of the tower nozzle. Grading followed the windrow spraying. It was noted immediately that only the surface of the windrow contained dust palliative and the core was dry. Mixing the product into the surface with the grader to create a uniform consistency was very difficult due to the stickiness of the product and inability of the grader to roll the material. The dispersion was uneven and the uncompacted surface was easily pulverized with light traffic (Photo 17). Dust abatement on this section was minimal. Lessons learned included: (1) the dust palliative does not soak into the windrow very deep, (2) mixing the dust palliative into the surface to provide a uniform distribution will be difficult and (3) not compacting after grading leaves a loose surface, easily disturbed under traffic.

Section 5

The application method used on this section was the same as in Section 4 but with compaction following the final grading, windrow/spray/grade/compact. Again, the ability of the grader to create a uniform distribution of product on the surface was very difficult. The distribution was non-uniform creating pockets of soil containing too much product and others with very little or no product. The product could not penetrate beyond the surface layer of the windrow, and the windrow retained a dry inner core (Photo 18). This hindered compaction, and the final road surface was not tightly bound. Dry areas were able to break apart with minimal traffic and dust abatement was not very effective. Lessons learned were the same as for Section 4. However, the compaction following the final grading did improve the wearing surface.

Section 6

The application method, spray/windrow/grade/compact, was not too difficult to achieve; however, it required a highly skilled grader operator. The distribution of product was more uniform than in Sections 4 and 5, and the overall condition of the road was improved. Compaction with the 12-ton vibratory compactor followed the final grading. Light traffic did disturb the surface crust and lead to light dust formation. Lessons learned included: (1) grading following the application of dust palliative is difficult due to product sticking to the grader blade and (2) compaction of the mixed product did improve the surface; however, there was an insufficient amount of product near the surface to prevent raveling from light traffic.

Section 7

This was the first section to use the rotary mixer to incorporate the material into the surface. The application method, spray/till/grade/compact, was performed. It was immediately noticed that the rotary mixer provided a uniform dispersion of product into the surface. The rotary mixer produced a level uncompacted surface; however, the grader was used to smooth out the surface before final compaction. The rotary mixer only mixed to a depth of approximately 3 in., and the grader had a tendency (due to stickiness of product) to move/shove the treated surface and expose some of the loose, untreated material. These exposed areas on the surface were not tightly bound and were easily broken by light traffic. Lessons learned included: (1) grading the material with dust palliative can be difficult if the product is wet enough to cause sticking to the grader blade and (2) there was an insufficient amount of product on the surface to produce a tightly bound surface.

Section 8

The application for Section 8 was the same as for Section 7 except the rotary mixer was used to try and produce a more uniformly mixed surface after grading and before compaction. The application method for Section 8 was coded as till/spray/till/grade/compact. The mixing did expose some dry areas beneath the treated layer and created uneven product distribution (Photo 19). Small patches with excess moisture did stick to the roller during compaction and the section was left with areas of loosely bound materials that raveled under light traffic, producing light dust. Lessons learned included: (1) compaction could be accomplished following the rotary mixing operation and (2) again there was an insufficient amount of product on the surface to produce a tightly bound surface.

Section 9

The application method, till/spray/till/compact/spray, was the first method used to try incorporating one half the product into the surface and end the construction process with the other half applied topically. It was determined during this application method that one-half of the product could be placed with two passes of the hydroseeder using the distribution bar. This required the HMMWV to move at idle speed (1 to 2 mph) with the hydroseeder pump motor operating at full throttle. This method produced a uniform distribution of product on the road surface in just four passes, two passes with product mixed in and two passes with final topical application of product. The road surface was in excellent condition and prevented dust generation with light traffic. Lessons learned included these: (1) 900 gal could be distributed uniformly over the section in four passes and (2) ending the treatment of the section with a topical application of product seemed to seal the surface.

Section 10

This application method, spray/till/compact/spray, was the same as for Section 9 except the initial tilling was eliminated. The initial application of spray (approximately 450 gal) soaked into the surface with little or no runoff. The rotary mixer produced a uniform mixture to a depth of approximately 3 in. (Photo 20). Compaction of the mixture was excellent with the surface being tightly bound. The final application of palliative (~450 gal) soaked into the compacted surface and produced a tight sealed surface (Photo 21). The end product was efficiently constructed and resistant to surface break-up under traffic. The main lesson learned during this application was that the initial tilling of the roadbed was not necessary to produce the desired results. This application method was selected for use during the product evaluation phase (Sections 11 through 24).

Baseline Data Collection

In-situ material property data were collected using a Dynamic Cone Penetrometer (DCP) and a Troxler® 3430 nuclear gauge one day after test section construction (Photo 22). DCP tests were conducted according to the procedure described by ASTM D6951 (2003). The DCP had a 60° conical cone with a base diameter of 0.79 in. The test procedure involved placing the DCP cone point on the surface and driving the cone into the ground surface until the base of the cone was flush with the surface. Next, a baseline measurement was recorded to the nearest 5 mm. The 17.6-lb hammer was then raised and dropped 22.6 in. onto an anvil, which drove the penetrometer rod and cone into the soil. Depth of the cone penetration measurements and number of hammer blows were recorded approximately every inch (25 mm) or whenever any noticeable increase in penetration rate occurred. A DCP strength index in terms of penetration per hammer blow was calculated for each measurement interval. The DCP index was then converted to CBR percentage using the correlation: $CBR = 292/DCP^{1.12}$ where DCP is in mm/blow. DCP data for this report was processed using a Microsoft Excel spreadsheet.

The Troxler® 3430 nuclear gauge was used to collect density and moisture data in the center of each test section. The gauge contains two radioactive sources: cesium-137 for density measurement and americium-241:beryllium for determining moisture content. Density measurements were taken in the 6-in. direct transmission mode after creating a hole in the section using a drill rod. Tests with both devices were performed along the centerline of the test section. Results are shown in Tables 3 and 4.

DCP data indicated most test sites were high in strength and did not display individual layers. However, performing DCP tests in the granular material often resulted in variations of the observed strength at different depths. Direct contact of the DCP cone perpendicular to flat regions on a large particle could result in isolated areas of strong resistance. These instances made it difficult to identify the average strength of the soil.

Table 3 Baseline DCP Results			
Section	Application Method	Depth (in.)	CBR (%)
1	Spray/Compact (Water)	2 - 10	30
2	Prewet/Spray/Compact	0 - 7	28
3	Spray/Compact	4 - 10	60
4	Windrow/Spray/Grade	1 - 8	8
5	Windrow/Spray/Grade/Compact	3 - 11	35
6	Spray/Windrow/Grade/Compact	4 - 11	20
7	Spray/Till/Grade/Compact	0 - 9	10
8	Till/Spray/Grade/Till/Compact	4 - 14	30
9	Till/Spray/Till/Compact/Spray	4 - 10	50
10	Spray/Till/Compact/Spray	3 - 8	70

Section 4 had the lowest CBR value which is reasonable to expect because this section was not compacted. Compacted sections had an average CBR of approximately 35. Variations in the strength of these sections are most likely due to variation in site conditions and testing locations in the heterogeneous soil.

The average dry densities and moisture contents of the sections one day after application were 123.7 pcf and 4.3 percent, respectively. The slight increase in the density of the section compared to pretreated sections is expected due to compaction of all but one of the sections. The moisture content, however, was reduced from its original values. The addition of water during treatment should have increased the moisture content. Some drying was expected to occur during the period between initial grading and section construction due to warm weather and consistent wind. These factors may have contributed to the absence of any significant difference in moisture as determined by the nuclear gauge.

Table 4 Baseline Moisture and Density Data					
Section	Application Method	Wet Density (pcf)	Moisture (pcf)	Dry Density (pcf)	Moisture (%)
1	Spray/Compact (Water)	127.3	5.4	121.9	4.4
2	Prewet/Spray/Compact	135.0	6.5	128.6	5.1
3	Spray/Compact	131.2	4.4	126.8	3.4
4	Windrow/Spray/Grade	124.1	5.3	118.8	4.5
5	Windrow/Spray/Grade/Compact	120.6	4.8	115.8	4.2
6	Spray/Windrow/Grade/Compact	133.1	5.3	127.8	4.2
7	Spray/Till/Grade/Compact	131.9	6.6	125.3	5.3
8	Till/Spray/Grade/Till/Compact	132.0	6.7	125.3	5.4
9	Till/Spray/Till/Compact/Spray	124.0	4.4	119.7	3.7
10	Spray/Till/Compact/Spray	131.1	3.9	127.2	3.1
	Average:	129.0	5.3	123.7	4.3

Initial dust collection was performed by ERDC using two stationary dust samplers on 23 March 2004. Two sport utility vehicles (SUVs) were used to apply traffic to the sections at a target speed of 30 mph (Photo 23). Ten total vehicle passes were used for the evaluation. Visual rankings were given to the sections based on a 10-point scale with 10 being the best. Two stationary dust collectors (Photo 24) were located near the center of the 500-ft section and approximately 4 ft from the centerline on the downwind side of the treated section. Two dust collectors were used on each section and spaced approximately 20 ft apart. The dust collectors consisted of a filter placed over a wire mesh screen through which a slight vacuum pressure was drawn using an electric vacuum pump (Photo 25). The dust collectors were manufactured by General Metal Works, Inc., a subsidiary of Andersen Samplers, Inc. The model number of the stationary samplers was BM2200H. The results are given in Table 5. The relative effectiveness of each of the sections is shown in Figures 4 and 5.

Table 5
Baseline Stationary Dust Collection Data

Section	Method	Dust Collected (g)	Visual Rating
1	Spray/Compact (Water)	0.221	8
2	Prewet/Spray/Compact	0.067	10
3	Spray/Compact	0.076	9
4	Windrow/Spray/Grade	0.449	7
5	Windrow/Spray/Grade/Compact	0.568	6
6	Spray/Windrow/Grade/Compact	0.25	8
7	Spray/Till/Grade/Compact	0.301	7
8	Till/Spray/Grade/Till/Compact	0.273	8
9	Till/Spray/Till/Compact/Spray	0.056	10
10	Spray/Till/Compact/Spray	0.067	10
	Range of Values:	0.056 to 0.568	10 to 6

Dust accumulation on the collectors coincided with the visual observations made during the testing sequence. The sections generating the most dust were those constructed with a windrow technique. The dust palliatives were not able to penetrate beyond the shell of the windrow, and uneven distribution resulted during grading. These sections produced more dust than the section treated only with water. The presence of a smooth, tightly bound wearing surface is imperative for prevention of surface break-up and dust abatement. The sections providing the greatest benefit were those with the final application of palliative being topical. Sealing the surface of the section appears to provide the greatest benefit of the dust abatement products.

Midwest Research Institute (MRI) was contracted by ERDC to perform additional dust collection using a tow-behind evaluation system (Photo 26). The system uses a modified version of the filter system used by ERDC mounted onto a 21-ft aluminum bar that was attached to the bed of a pickup. The intake nozzle is adjusted so that it is 8-ft behind the vehicle and 3-ft above the ground. This type of system allows for continual measurement directly behind the vehicle. Initial data collection was performed on 27 and 28 March, and additional testing resumed at intervals of 30, 60, and 90 days. Preliminary dust collection results are found in Table 6. Figure 8 shows the relative effectiveness of each section. Weather data was collected from Libby Army Airfield at Ft. Huachuca to monitor climatic conditions during the test. These data are found in Table 7.

Table 6
Baseline Mobile Dust Collection Data

Section	No. of Passes	Total Travel Distance (ft)	Dust Collected (mg/1000 ft)	Reduction from Control (%)
1	6	2700	11.2	61
2	12	5400	2.1	93
3	12	5400	4.1	86
4	12	5400	44.5	None
5	12	5400	47	None
6	6	2700	27.5	5
7	6	2700	39.6	None
8	6	2700	27.8	4
9	18	8100	4.5	84
10	12	5400	5.9	80
		Range of Values:	2.1 – 44.5	93 - 0

The number of passes made over the section was governed by the amount of dust emerging from behind the vehicle. The sections producing very little dust were trafficked more times than the others in order to get a significant amount of material on the filters. The data was then normalized to the amount collected per 1000 ft of testing. The percent dust reduction from the control Section 24 was also determined. Section 24 is an additional control section constructed during the product evaluation. A description of this section is given in Chapter 3. Variation of dust generation on Section 24 from the control Section 1 is most likely due to differences in construction methods used. Section 1 would be expected to generate less dust because the water was applied to the surface and not mixed to the 3-in depth of Section 24. Additional water near the surface would not only serve to suppress dust, but also to aid in compaction of the surface.

The data collected by MRI using the mobile collector is similar to that produced during ERDC's testing using the two stationary collectors. The sections with the most effective dust control are those with surface applications to help seal the road. Data indicate sections 2 and 3 as having the maximum dust reduction. These two sections were only constructed with topical applications. The evaluation team speculated that incorporating dust palliatives into the surface using the admix procedure would provide for longer durability although the initial performance of topical applications was exceptional. Techniques using the grader to create windrows were not effective in controlling dust because of inadequate mixing provided by the grader. Obtaining an even distribution of product is imperative for successful dust reduction. The poor performance of sections 4 through 8 was most likely caused by construction procedures disturbing the soil on the road surface and exposing unbound fines without contact with the dust abatement chemical.

Table 7
Libby Army Airfield Weather Data

March-04				April-04				May-04				June-04			
Date	Date	Max Temp (°F)	Min Temp (°F)	Precip (in.)	Max Temp (°F)	Min Temp (°F)	Precip (in.)	Date	Max Temp (°F)	Min Temp (°F)	Precip (in.)	Date	Max Temp (°F)	Min Temp (°F)	Precip (in.)
1	1	68	47	0.09	68	47	0.09	1	76	47	0	1	96	67	0
2	2	54	38	0.25	54	38	0.25	2	78	49	0	2	99	68	0
3	3	51	34	0.81	51	34	0.81	3	84	50	0	3	100	65	0
4	4	56	42	0	56	42	0	4	88	55	0	4	96	70	0
5	5	63	43	0.41	63	43	0.41	5	87	63	0	5	97	70	0
6	6	66	47	0	66	47	0	6	87	62	0	6	96	66	0
7	7	73	47	0	73	47	0	7	91	62	0	7	94	65	0
8	8	73	45	0	73	45	0	8	84	64	0	8	90	63	0
9	9	71	47	0	71	47	0	9	86	64	0	9	87	64	0
10	10	70	50	0	70	50	0	10	86	60	0	10	85	57	0
11	11	63	42	0	63	42	0	11	82	63	0	11	89	56	0
12	12	70	38	0.33	70	38	0.33	12	82	59	0	12	92	58	0
13	13	76	49	0	76	49	0	13	80	51	0	13	95	63	0
14	14	80	55	0	80	55	0	14	86	53	0	14	96	67	0
15	15	79	51	0	79	51	0	15	91	59	0	15	95	62	0
16	16	80	50	0	80	50	0	16	89	57	0	16	91	61	0
17	17	76	58	0	76	58	0	17	87	61	0	17	94	61	0
18	18	75	41	0	75	41	0	18	91	57	0	18	93	59	0
19	19	76	48	0	76	48	0	19	91	59	0	19	95	64	0
20	20	75	46	0	75	46	0	20	89	59	0	20	93	68	0
21	21	78	50	0	78	50	0	21	85	60	0	21	90	63	0
22	22	79	48	0	79	48	0	22	82	56	0	22	82	58	0.5
23	23	72	47	0	72	47	0	23	85	55	0	23	83	60	0.05
24	24	77	47	0	77	47	0	24	86	62	0	24	91	62	0
25	25	79	52	0	79	52	0	25	86	65	0	25	94	59	0
26	26	83	52	0	83	52	0	26	80	66	0	26	95	72	0
27	27	77	57	0	77	57	0	27	80	55	0	27	95	66	0
28	28	82	52	0	82	52	0	28	86	55	0	28	91	64	0
29	29	77	54	0	77	54	0	29	83	57	0	29	90	64	0.05
30	30	71	48	0	71	48	0	30	86	56	0	30	91	62	0
31								31	93	63	0				
		Avg. 72	Avg. 48	Total 1.89	Avg. 72	Avg. 48	Total 1.89		Avg. 85	Avg. 58	Total 0		Avg. 93	Avg. 63	Total 0.6

30-Day Data Collection

In-situ material property data were collected using a DCP and a Troxler® 3430 nuclear gauge approximately thirty days after test section construction. The DCP data represent the soil strength at different depths. The nuclear gauge was used to measure soil density and moisture content in the 6-in. direct transmission mode. Tests with both devices were performed along the centerline of the test section. Results are found in Tables 8 and 9.

DCP data indicate most test sites were higher in strength after the 30-day period and did not indicate individual layers. The addition of the polymer to the sections is expected to cause an increase in the strength properties of the soil, even at application rates used for dust control. Section 10 had increased in strength to the point that the DCP could not penetrate the road surface at all. Section 4 still had the lowest CBR value, but this section was not compacted, and the results could be expected. Variations in the strength of the sections are most likely due to variation in site conditions and testing locations.

Table 8
DCP Results After 30 Days

Section	Application Method	Depth (in.)	CBR (%)
1	Spray/Compact (Water)	6 - 12	70
2	Prewet/Spray/Compact	0 - 3	80
3	Spray/Compact	0 - 7	30
4	Windrow/Spray/Grade	0 - 12	20
5	Windrow/Spray/Grade/Compact	2 - 10	40
6	Spray/Windrow/Grade/Compact	4 - 12	20
7	Spray/Till/Grade/Compact	3 - 12	20
8	Till/Spray/Grade/Till/Compact	1 - 8	30
9	Till/Spray/Till/Compact/Spray	0 - 12	40
10	Spray/Till/Compact/Spray	0	100

Table 9
Moisture and Density Data After 30 Days

Section	Application Method	Wet Density (pcf)	Moisture (pcf)	Dry Density (pcf)	Moisture (%)
1	Spray/Compact (Water)	134.1	4.3	129.7	3.3
2	Prewet/Spray/Compact	131.3	4.7	126.6	3.7
3	Spray/Compact	126.5	4.0	122.5	3.2
4	Windrow/Spray/Grade	127.0	4.9	122.1	4.0
5	Windrow/Spray/Grade/Compact	128.1	3.0	125.1	2.4
6	Spray/Windrow/Grade/Compact	132.3	3.7	128.6	2.9
7	Spray/Till/Grade/Compact	132.9	4.6	128.3	3.5
8	Till/Spray/Grade/Till/Compact	131.4	4.7	126.7	3.7
9	Till/Spray/Till/Compact/Spray	127.4	4.1	123.3	3.3
10	Spray/Till/Compact/Spray	-	-	-	-
	Average:	130.1	4.2	125.9	3.3

The average dry densities and moisture contents of the sections thirty days after application were 125.9 pcf and 3.3 percent, respectively. There was a slight increase in the density of most of the sections compared to initial construction data. This result may be caused by further compaction of the soil from natural traffic on the road. The moisture content, however, was reduced from its original values. Some drying was expected to occur during the period between initial construction and this testing due to warm weather and little precipitation. The moisture content is most likely affected by weather patterns more than any other factor. Nuclear moisture and density data were not collected on Section 10 due to inability to penetrate the surface of the road.

Dust collection was performed by ERDC on 29 and 30 April 2004. An SUV was used to apply traffic to the sections at a target speed of 30 mph. Ten total vehicle passes were used for the evaluation. Visual rankings were given to the sections based on a 10-point scale with 10 being the best. The same dust collection procedure from the initial tests was used during this evaluation. The results are given in Table 10.

Table 10
30-Day Stationary Dust Collection Data

Section	Method	Dust Collected (g)	Visual Rating
1	Spray/Compact (Water)	0.181	7
2	Prewet/Spray/Compact	0.076	10
3	Spray/Compact	0.019	9
4	Windrow/Spray/Grade	0.132	8
5	Windrow/Spray/Grade/Compact	0.12	8
6	Spray/Windrow/Grade/Compact	0.11	7
7	Spray/Till/Grade/Compact	0.111	5
8	Till/Spray/Grade/Till/Compact	0.112	7
9	Till/Spray/Till/Compact/Spray	0.009	9
10	Spray/Till/Compact/Spray	0.09	9
	Range of Values:	0.009 to 0.181	10 to 5

Dust accumulation on the filters did not coincide well with the visual observations made during this testing sequence. This result was unexpected after collecting correlating data during the initial test. Variations in the data may be caused by inconsistent weights of filters used in the dust collectors. During the first test, it was noted that very little variation existed in the weight of the different filters, and an average weight was used to determine total dust measurement. However, a different box of filters was used during this test, and their weights were not as consistent. This was noticed only after all measurements were performed. The variation of the filter weights was enough to obscure significant differences between the test sections, and the visual ratings are probably more indicative of section performance. Another source of error for dust sampling is variation in wind speed and direction during testing. The volume of dust that passes over the dust collectors and the length of time that it is exposed to the vacuum are determined by wind conditions.

The sections most effective in controlling dust after 30 days were those with some topical application of palliative. Sections 2 and 3 were still very effective with little surface damage. Sections 9 and 10 also had almost no dust visible during traffic. Sections constructed using windrow techniques were not nearly as effective during testing.

MRI performed tow-behind dust collection on 27 and 28 April. Results are shown in Table 11. The number of passes made over each section was governed by the amount of dust emerging from behind the vehicle during initial testing. The sections producing very little dust were trafficked more times than the others in order to capture a significant amount of material on the filters. The number of passes during the first testing sequence was used during this evaluation. The data was normalized to the amount collected per 1000 ft of testing. The percent dust reduction from the control Section 24 was also determined. Section 1 was not tested since Section 24 was chosen as a more appropriate control for consistency with application procedures used on Sections 11 through 24.

Table 11 30-Day Mobile Dust Collection Data				
Section	No. of Passes	Total Travel Distance (ft)	Dust Collected (mg/1000 ft)	Reduction from Control (%)
1	-	-	-	-
2	12	5400	1.47	86
3	12	5400	3.73	65
4	12	5400	2.26	79
5	12	5400	1.35	87
6	6	2700	2.12	80
7	6	2700	3.64	66
8	6	2700	2.58	76
9	18	8100	0.74	93
10	12	5400	1.44	86
		Range of Values:	0.74 to 3.73	93 to 65

The data collected by MRI show relatively effective dust control for all sections. Most of the data agree with the visual observations made during testing. The most effective sections had some topical application of palliative, but there was not a significant difference among sections.

60-Day Data Collection

In-situ material property data were collected using a DCP and a Troxler® 3430 nuclear gauge approximately sixty days after test section construction. The DCP data represent the soil strength at different depths. The nuclear gauge was used to measure soil density and moisture content in the 6-in. direct transmission mode. Tests with both devices were performed along the centerline of the test section. Results are shown in Tables 12 and 13.

Table 12 DCP Results After 60 Days			
Section	Application Method	Depth (in.)	CBR (%)
1	Spray/Compact (Water)	0 - 3	100
2	Prewet/Spray/Compact	0 - 3	80
3	Spray/Compact	0 - 6	100
4	Windrow/Spray/Grade	0 - 12	20
5	Windrow/Spray/Grade/Compact	0 - 6	100
6	Spray/Windrow/Grade/Compact	4 - 12	30
7	Spray/Till/Grade/Compact	0 - 12	30
8	Till/Spray/Grade/Till/Compact	0 - 12	30
9	Till/Spray/Till/Compact/Spray	3 - 12	40
10	Spray/Till/Compact/Spray	0 - 4	100

DCP data indicate that little strength change occurred between the 30- and 60-day period. A few of the sections had slightly higher CBR values, but no significant differences were observed. It would be expected that the materials incorporated into the soil had already provided any additional strength during the first 30 days and that no further binding of soil particles would occur. Variations in

Table 13 Moisture and Density Data After 60 Days					
Section	Application Method	Wet Density (pcf)	Moisture (pcf)	Dry Density (pcf)	Moisture (%)
1	Spray/Compact (Water)	131.8	3.2	128.6	2.5
2	Prewet/Spray/Compact	133.4	3.2	130.2	2.5
3	Spray/Compact	130.4	2.4	128.0	1.9
4	Windrow/Spray/Grade	123.7	3.9	119.8	3.3
5	Windrow/Spray/Grade/Compact	121.5	2.4	119.1	2.0
6	Spray/Windrow/Grade/Compact	133.2	3.3	129.9	2.6
7	Spray/Till/Grade/Compact	128.0	3.0	125.0	2.4
8	Till/Spray/Grade/Till/Compact	130.8	2.9	126.8	3.1
9	Till/Spray/Till/Compact/Spray	126.8	2.6	124.2	2.1
10	Spray/Till/Compact/Spray	131.4	2.1	129.4	1.6
	Average:	129.1	2.9	126.1	2.4

the strength of the sections are most likely due to variation in site conditions and testing locations.

The average dry density and moisture content of the sections 60 days after application were 126.1 pcf and 2.4 percent, respectively. There was little difference in the density of most of the sections compared to data collected 30 days after construction. The moisture content, however, was somewhat lower than previous values. The weather during this time period was extremely dry, allowing further evaporation of water in the road sections to occur.

Dust collection was performed by ERDC on 23 and 24 May 2004. An SUV was used to apply traffic to the sections at a target speed of 30 mph. Ten total vehicle passes were used for the evaluation. Visual rankings were given to the sections based on a 10-point scale with 10 being the best. The same dust collection procedure from the initial tests was used during this evaluation. The results are given in Table 14.

Table 14 60-Day Stationary Dust Collection Data			
Section	Method	Dust Collected (g)	Visual Rating
1	Spray/Compact (Water)	0.222	5
2	Prewet/Spray/Compact	0.04	10
3	Spray/Compact	0.046	9
4	Windrow/Spray/Grade	0.114	7
5	Windrow/Spray/Grade/Compact	0.071	7
6	Spray/Windrow/Grade/Compact	0.068	8
7	Spray/Till/Grade/Compact	0.135	6
8	Till/Spray/Grade/Till/Compact	0.081	7
9	Till/Spray/Till/Compact/Spray	0.04	9
10	Spray/Till/Compact/Spray	0.051	8
	Range of Values:	0.04 to 0.222	10 to 5

Dust accumulation on the filters coincided very well with the visual observations made during this testing sequence. The four sections that were treated with a final topical application provided the best dust abatement and retained the

Table 15 60-Day Mobile Dust Collection Data				
Section	No. of Passes	Total Travel Distance (ft)	Dust Collected (mg/1000 ft)	Reduction from Control (%)
1	-	-	-	-
2	12	5400	0.81	96
3	12	5400	0.69	97
4	12	5400	2.81	88
5	12	5400	2.81	88
6	12	5400	4.02	82
7	6	2700	4.37	81
8	6	2700	3.94	82
9	12	5400	0.98	96
10	12	5400	2.98	87
		Range of Values:	0.69 to 4.37	97 to 81

smoothest wearing surface. The local traffic had compacted all of the sections to the point where little loose till was visible. The difference in the performance of the sections was less evident during this testing sequence, except for the control section, which produced heavy dust during traffic.

MRI collected data on the test sections on 25 May. The results of their procedure are shown in Table 15. The number of passes made over the section was governed by the amount of dust emerging from behind the vehicle during initial testing. The sections producing very little dust were trafficked more times than the others in order to capture a significant amount of material on the filters. The number of passes during the first testing sequence was used during this evaluation. The data was normalized to the amount collected per 1000 ft of testing. The percent dust reduction from the control Section 24 was also determined. Section 1 was not tested since Section 24 was chosen as a more appropriate control for consistency with application procedures used on Sections 11 through 24.

The data collected by MRI show relatively effective dust control for all sections. Most of the data agree with the visual observations made during testing. The most effective sections had some topical application of palliative, but there was no significant difference between section performance.

90-Day Data Collection

In-situ material property data were collected using a DCP and a Troxler® 3430 nuclear gauge approximately ninety days after test section construction. The DCP data represent the soil strength at different depths. The nuclear gauge was used to measure soil density and moisture content in the 6-in. direct transmission mode. Tests with both devices were performed along the centerline of the test section. Results are found in Tables 16 and 17.

DCP data indicate that little strength change occurred between the 60- and 90-day periods. Sections 1 and 3 did have significantly lower CBR values. These observations may be due to loss of water within the section and subsequent

Table 16
DCP Results After 90 Days

Section	Application Method	Depth (in.)	CBR (%)
1	Spray/Compact (Water)	0 - 3	20
2	Prewet/Spray/Compact	0 - 6	100
3	Spray/Compact	0 - 7	20
4	Windrow/Spray/Grade	1 - 10	30
5	Windrow/Spray/Grade/Compact	0 - 3	100
6	Spray/Windrow/Grade/Compact	0 - 10	20
7	Spray/Till/Grade/Compact	0 - 8	30
8	Till/Spray/Grade/Till/Compact	0 - 6	30
9	Till/Spray/Till/Compact/Spray	2 - 8	100
10	Spray/Till/Compact/Spray	4 - 12	60

Table 17
Moisture and Density Data After 90 Days

Section	Application Method	Wet Density (pcf)	Moisture (pcf)	Dry Density (pcf)	Moisture (%)
1	Spray/Compact (Water)	124.4	2.2	122.2	1.8
2	Prewet/Spray/Compact	130.0	3.3	126.7	2.6
3	Spray/Compact	127.0	2.9	124.1	2.4
4	Windrow/Spray/Grade	123.5	2.5	121.0	2.0
5	Windrow/Spray/Grade/Compact	121.6	1.9	119.7	1.6
6	Spray/Windrow/Grade/Compact	128.2	3.5	124.7	2.8
7	Spray/Till/Grade/Compact	122.7	3.3	119.5	2.7
8	Till/Spray/Grade/Till/Compact	125.7	3.5	122.2	2.9
9	Till/Spray/Till/Compact/Spray	124.6	2.6	122.0	2.1
10	Spray/Till/Compact/Spray	124.1	2.2	121.9	1.8
	Average:	125.2	2.8	122.4	2.3

stiffening of the soil. It would be expected that the materials incorporated into the soil had already provided any additional strength during the first 30 days and that no further binding of soil particles would occur. Variations in the strength of the sections are most likely due to variation in site conditions and testing locations.

The average dry densities and moisture contents of the sections 90 days after application were 122.4 pcf and 2.3 percent, respectively. The density of the sections was consistently lower compared to the data collected at 60 days. The moisture content was also slightly lower. The extremely dry weather during the period between tests would account for a decrease in moisture content, but the density of the test sections should not have significant variation.

Dust collection was performed by ERDC on 23 and 24 June 2004. An SUV was used to apply traffic to the sections at a target speed of 30 mph. Ten total vehicle passes were used for the evaluation. Visual rankings were given to the sections based on a 10-point scale with 10 being the best. Two stationary dust collectors were located near the center of the 500-ft section and approximately five feet from the centerline. The variable wind direction during this test sequence made it necessary to place one dust collector on each side of the road, unlike previous tests in which both collectors were placed in a downwind location. The results are given in Table 18.

Table 18
90-Day Stationary Dust Collection Data

Section	Method	Dust Collected (g)	Visual Rating
1	Spray/Compact (Water)	0.154	4
2	Prewet/Spray/Compact	0.05	10
3	Spray/Compact	0.03	10
4	Windrow/Spray/Grade	0.098	6
5	Windrow/Spray/Grade/Compact	0.077	7
6	Spray/Windrow/Grade/Compact	0.099	6
7	Spray/Till/Grade/Compact	0.074	6
8	Till/Spray/Grade/Till/Compact	0.053	7
9	Till/Spray/Till/Compact/Spray	0.033	9
10	Spray/Till/Compact/Spray	0.097	7
	Range of Values:	0.03 to 0.154	10 to 4

Dust accumulation on the filters coincided very well with the visual observations made during this testing sequence. The four sections that were treated to a final topical application provided the best dust abatement and retained the smoothest wearing surface. The local traffic had compacted all of the sections to the point where little loose till was visible. Only the performance of the control section had deteriorated significantly from the time of original construction.

MRI collected data on the test sections on 22 and 23 June 2004. The results of their procedure are shown in Table 19. The number of passes made over the section was set to 12 for all sections. The data was normalized to the amount collected per 1000 ft of testing. The percent dust reduction from the control Section 24 was also determined. Section 1 was not tested since Section 24 was chosen as a more appropriate control for consistency with application procedures used on Sections 11 through 24.

Table 19
90-Day Mobile Dust Collection Data

Section	No. of Passes	Total Travel Distance (ft)	Dust Collected (mg/1000 ft)	% Reduction from Control
1	-	-	-	-
2	12	5400	0.17	99
3	12	5400	1.5	94
4	12	5400	5.56	76
5	12	5400	1.56	93
6	12	5400	2.98	87
7	12	5400	4.28	82
8	12	5400	4.09	82
9	12	5400	2	91
10	12	5400	3.11	87
		Range of Values:	0.17 to 5.56	99 to 76

The data collected by MRI show relatively effective dust control for all sections. Most of the data agree with the visual observations made during testing. The most effective sections had some topical application of palliative, but there was not a significant difference among them all. A water stain was found on the filter for Section 2. The data for this particular section is suspect because this value was the lowest obtained throughout the testing process. It is also significantly lower than the value obtained during the 60-day test and only slightly above the detection limit of the collection system. The other data collected appears to be valid.

HMMWV Distribution System

During the dust control exercise at Douglas, AZ, in March 2004, Midwest Industrial Supply, Inc., provided a prototype spray system for evaluation. The E-Spray Model D system (Photo 27) was designed specifically for use in the military HMMWV vehicle. The spray system was designed to be a self-contained compact system (Photo 28), which could be transported on a heavy-duty skid pallet and easily loaded onto a HMMWV using a military forklift. Once the system is loaded and unpacked, it provides two methods of dust palliative application. The application methods include both a boom spray system with eight wide fan nozzles (Photo 29) and a 100-ft hand-held hose distribution system (Photo 30). The hand-held hose, fittings, and extra nozzles are stored in a compartment (Photo 31) located at the rear of the system. A Yanmar 6.7 HP Electric Start Diesel Engine powers the system. The pressure is controlled manually with a regulator and gauge located at the rear of the system. During boom spraying operations, the movement of the HMMWV provides coverage and the boom spray is controlled in the cab using a remote electronic switch box.

The evaluation of the system included loading the system onto the HMMWV, unpacking the system, and operating the system by applying three 275-gal totes of Envirokleen® to the transition areas located between each test item (Figure 3). Based on the evaluation of the system, the following recommendations were made to the manufacturer to modify or improve the operation of the system:

a. The overall length of the spray system was approximately 2 in. too long. If the system was 2 in. shorter, the tailgate on the HMMWV could be raised during transporting. Recommended shortening the system by 2 in.

b. The spray system did not have positive anchor points to connect to the HMMWV. It was geometrically semi-secure; however, it was recommended to have positive anchor points to better secure the system to the HMMWV.

c. The locking pins that secured the boom arm up (transport position) and down (spray position) were too long. There was insufficient space between the HMMWV fender and the system to remove the pins. Recommended shortening or changing the locking pins.

d. The boom extensions (outside two nozzles on each side) were secured to the boom using a two-latch coupler. The latches on the couplers were rotated in the vertical position. During operation, the vibration of the system caused the bottom latch to loosen. Recommended rotating these couplers with the latches in the horizontal position.

e. The throttle control lever was small and located on the side of the engine. It was slightly difficult to adjust during operation due to the small locking thumbscrew. Recommended a larger more accessible throttle control.

f. The standard muffler system on the engine was insufficient during operation. Recommended a different muffler system to reduce the noise level during operation and also to vent the exhaust away from the plastic tank.

g. The diesel fuel tank was located on the top of the engine and would hold less than 2 gal of fuel. This would allow approximately 2 hr of operation. It was recommended to increase the size of the fuel tank.

h. The system was designed to pump product from a tote into the sprayer tank. This operation took too long (approximately 1 hr for 275 gal). It was recommended to increase the capacity (gpm) of the pump to decrease the time required for this operation.

i. The spray boom came with three sets of nozzles: 5 gpm, 7.5 gpm and 10 gpm. At the distribution rate the product was being applied on the test items, the HMMWV had to travel at a speed of less than 1 mph. It was recommended to provide up to 30 gpm nozzles for the spray boom.

j. During boom spraying operations, the pressure could be adjusted by climbing onto the tailgate of the HMMWV to access the rear center of the system. It was recommended to improve the accessibility of the pressure adjustment during operation.

k. The spray system contained two fluid level sight gauges facing the rear of the system located on each side just in front of the HMMWV fender. It was recommended to have a fluid level sight gauge visible from the cab of the HMMWV.

l. The electronic boom spray control box contained two push switches, one for each side of the boom. It was recommended to have only one switch on the control box with manual controls on the boom in the rear.

m. The hand-held hose application system contained a fire hose type distribution nozzle (circular). A better application of product could be made using a wide fan nozzle. Several wide fan nozzles from 20 to 40 gpm with inline ball-valve on/off control were recommended.

n. The suction line was located on the side of the tank at the rear. Several gallons (25 to 50) of product could not be drained from the tank. It was recommended that the suction line pull from the bottom of the tank with a tapered sump to allow complete drainage of product during application.

o. During this evaluation of the spray system, only a "neat" product was used, requiring no dilution or agitation. Several of the products used in the dust control exercise required diluting and mixing. It was recommended to improve the capabilities of the spray system to agitate the product.

p. The empty weight of the system was approximately 1,500 lb. The maximum operating weight would be over 5,500 lb. Although the system was only loaded to approximately 4,400 lb for this evaluation, the HMMWV showed no signs of overloading. It was recommended to decrease the maximum operating weight to approximately 4,400 lb, the maximum rated payload for the HMMWV A2 model.

q. Finally, it was recommended that the operators manual contain charts relating nozzle size, pressure, speed and coverage rates for both boom and hose application methods.

Overall the HMMWV spray system was well designed for the product used in this evaluation. The unpacking and operation of the system was simple and very user friendly. With the recommended improvements to the system, it would provide a capable and expeditionary dust palliative application system.

3 Field Evaluation of Dust Palliatives

As shown in Figure 3, thirteen test sections were treated with dust palliatives including twelve COTS products and an experimental product developed by the Naval Research Laboratory (NRL). An additional section was treated with water to serve as a control section. Table 20 gives detailed test section information including product name, amount used, dilution water, and total application rate. Sections 11 through 24 were all constructed in the same manner using the spray/till/compact/spray technique used to construct Section 10.

Table 20
Palliative Application Quantities by Section

Sectio n	Palliative	Additive Amounts (gal)			Application Rate (gsy)	Crust Thickness (in.)
		Product	Water	Total		
11	Blue Goo®	12 lb	900	900	0.81	1.000
12	Hydrostik®	20 lb	900	900	0.81	0.875
13	Surtac®	225	675	900	0.81	0.875
14	Dust Fyghter®	510	390	900	0.81	0.688
15	Road Oyl®	225	675	900	0.81	1.000
16	Dustex®	225	675	900	0.81	0.563
17	Polytac®	225	675	900	0.81	0.875
18	Envirotac II®	225	675	900	0.81	0.500
19	Soiltac®	225	675	900	0.81	0.750
20	Soil-Sement®	225	675	900	0.81	0.750
21	EK-35®	900	0	900	0.81	1.875
22	EnviroKleen®	900	0	900	0.81	1.875
23	CSS-1	333	250	583	0.52	0.250
24	Water	-	800	800	0.72	-
			Range of Values:	583 to 900	0.52 to 0.81	0.25 to 1.875

Dust Palliatives

Several different classes of materials were used in this evaluation. Blue Goo® is a product sold by Easy Lawn, Inc. for use in their hydroseeders. It is a powdered polyacrylamide. These materials are water-soluble and suppress dust by moisture retention and soil binding. Hydrostik®, a product sold by Finn

Corporation, uses the same mechanism for dust abatement but has a different chemical makeup. It is a Guar gum, a natural product with similar properties to polyacrylamides. The Hydrostik® had some difficulty completely dissolving during the mixing process. As a result, balls of swollen product were distributed onto the section surface during spraying (Photo 32).

Surtac® is an experimental dust palliative developed by NRL and composed of a polysaccharide solution with an added surfactant for dispersion and penetration. It is water soluble and therefore susceptible to leaching from the soil surface after exposure to precipitation. The product is designed for short duration dust control due to its ability to biodegrade.

Dust Fyghter® is a 38 percent by weight solution of inorganic salts designed for moisture retention. It contains mostly calcium chloride, with some magnesium and sodium chlorides. These types of materials have been studied for a number of years for dust suppression and prove marginally effective in suitable environments. They are susceptible to leaching from the soil with exposure to precipitation and are very corrosive to metals.

Dustex® and Road Oyl® are classified as lignosulfonates. They are naturally derived from tree rosins and serve as binding agents in soils. Road Oyl® and Dustex® are shipped in an emulsified state containing approximately 50 percent solids by weight.

Four of the products, Polytac®, Envirotac II®, Soiltac®, and Soil-Sement® are acrylic polymer emulsions. These types of materials have been in use for a number of years and have been proven effective in many environments for their ability to bind soil particles and create a weather resistant surface. These materials are in the form of an emulsion and typically contain 40 to 60 percent solids by weight. Their method of dust suppression is particle encapsulation and formation of a binding network that adheres soil grains together. One problem encountered with Polytac® was excess foaming while filling the hydroseeder (Photo 33). Mixing in the emulsion after adding all water to the tank can minimize this phenomenon.

EK-35® and EnviroKleen® are products containing synthetic fluids and rosins that create a reworkable binder in the soil. They are insoluble in water and designed for "neat" application. "Neat" application means the product is not diluted and is designed to be distributed in full strength. These palliatives do not dry or cure with time.

The CSS-1 is a cationic slow-setting asphalt emulsion. Previous research indicated that these materials are very effective at dust palliation, but they require specialized equipment for application. The material used in this test was delivered in a heated tanker equipped with a distribution bar capable of very rapid application. The emulsion was diluted with water to approximately 25 percent solids by weight.

Application Procedure

Each section was graded prior to any construction. The procedure used to apply dust palliatives to Sections 11 to 24 was chosen from the previous phase of the evaluation. The water-miscible palliatives were diluted 3:1, and approximately 400 to 500 gal of product were applied to the surface using the hydroseeder and the distribution bar in two passes. Two of the products were too viscous to disperse evenly through the distribution bar and had to be applied using the tower gun. These were EK-35® and Blue Goo® (Photo 34). All products soaked into the soil within several seconds after application. Mixing immediately followed the initial application. Three passes were made with the Maxon rotary mixer to ensure even dispersion of product to a depth of 3 in. Compaction immediately followed the tilling to prevent premature "breaking" of the emulsified products. Two coverages were made with the Ingersoll-Rand 12-ton vibratory compactor. The remaining 400 to 500 gal of product were sprayed onto the compacted surface to seal the section. Product viscosities were low enough to allow rapid penetration and to prevent puddling on the road surface. The section containing the CSS-1 asphalt emulsion was not constructed in the same manner because the procedure had not been selected at the time of application. It was purchased from Western Emulsions in Tucson, AZ, and delivered in a heated tanker on 18 March. The emulsion was sprayed onto the graded surface and allowed to cure (Photo 35). No compaction was performed on the section. All other sections were constructed during the period from 20 to 22 March using the application methodology from the first test phase as described previously. Table 21 lists the application procedures and time required for placement.

Table 21
Dust Palliative Application Data

Section	Product	Method	Manpower	Time (min)
11	Blue Goo®	Spray/Till/Compact/Spray	5	50
12	Hydrostik®	Spray/Till/Compact/Spray	5	50
13	Surtac®	Spray/Till/Compact/Spray	5	47
14	Dust Fyghter®	Spray/Till/Compact/Spray	5	61
15	Road Oyl®	Spray/Till/Compact/Spray	5	45
16	Dustex®	Spray/Till/Compact/Spray	5	52
17	Polytac®	Spray/Till/Compact/Spray	5	44
18	Envirotac II®	Spray/Till/Compact/Spray	5	46
19	Soiltac®	Spray/Till/Compact/Spray	5	43
20	Soil-Sement®	Spray/Till/Compact/Spray	5	40
21	EK-35®	Spray/Till/Compact/Spray	5	37
22	EnviroKleen®	Spray/Till/Compact/Spray	5	58
23	CSS-1	Prewet/Spray	4	23
24	Water	Spray/Till/Compact/Spray	5	48
		Range of Values:	4 to 5	23 to 61

All sections were freshly graded prior to construction or product application.

Baseline Data Collection

In-situ material property data were collected using a DCP and a Troxler® 3430 nuclear gauge one day after test section construction. The DCP data represent the soil strength at different depths. The nuclear gauge was used to measure soil density and moisture content in the 6-in. direct transmission mode. Tests with both devices were performed along the centerline of the test section. Results are found in Tables 22 and 23.

Table 22
Palliative Comparison Test, Baseline DCP Results

Section	Depth (in.)	CBR %
11	2 - 14	20
12	5 - 14	27
13	2 - 7	40
14	3 - 9	25
15	0 - 8	22
16	2 - 13	15
17	7 - 14	38
18	4 - 12	40
19	2 - 8	100
20	4 - 8	75
21	2 - 8	22
22	2 - 13	18
23	3 - 12	10
24	3 - 13	15

Table 23
Palliative Comparison Test, Moisture and Density Data

Section	Wet Density (pcf)	Moisture Content (pcf)	Dry Density (pcf)	Moisture Content (%)
11	132.8	6.3	126.4	5.0
12	133.0	7.2	125.8	5.7
13	141.6	6.0	135.6	4.4
14	130.3	5.2	125.1	4.1
15	133.4	5.9	127.5	4.7
16	130.0	5.7	124.3	4.6
17	125.9	5.1	120.8	4.2
18	122.7	6.0	116.7	5.2
19	138.6	5.0	133.6	3.7
20	135.0	5.2	129.7	4.0
21	128.8	10.5	118.3	8.9
22	134.4	7.5	126.9	5.9
23	133.4	5.7	127.7	4.4
24	130.6	5.2	125.3	4.2
Average:	132.2	6.2	126.0	4.9

DCP data indicate that each of the sections has relatively high CBR values that are mostly attributed to soil type. The variation among the sections is most likely due to differences in site conditions and testing location. Products were limited to distribution within the top 3 in. of the surface, and the DCP was unable to determine any significant differences among the products or detect formation of layers of increased strength.

The average dry density and moisture content of the treated sections were 126.0 pcf and 4.9 percent, respectively. Section 21 (EK-35®) had a significantly higher moisture content than the other sections. Some differences exist in the dry densities and moisture contents of the various sections, but this variability is attributed to site conditions.

Initial dust collection was performed by ERDC on 23 March. Two SUV vehicles were used to apply traffic to the sections at a target speed of 30 mph. Ten total vehicle passes were used for the evaluation. Visual rankings were given to the sections based on a 10-point scale with 10 being the best. Two stationary dust collectors were located near the center of the 500-ft section and approximately 4 ft from the centerline on the downwind side of the treated section. Two dust collectors (Photo 24) were used on each section and spaced approximately 20 ft apart. The dust collectors consisted of a filter placed over a wire mesh screen through which a slight vacuum pressure was drawn using an electric vacuum pump (Photo 25). The dust collectors were manufactured by General Metal Works, Inc., a subsidiary of Andersen Samplers, Inc. The model number of the stationary samplers was BM2200H. The baseline results after product application are given in Table 24. Several of the sections were not tested due to the absence of any visible dust coming from behind the wheels of the vehicles traveling at 30 mph. Figures 6 and 7 show the relative effectiveness of the sections.

Table 24
ERDC Palliative Comparison, Baseline Data Collection

Section	Palliative	Dust Collected (g)	Visual Rating
11	Blue Goo®	0.175	8
12	Hydrostik®	0.182	8
13	Surtac®	-	10
14	Dust Fyghter®	-	10
15	Road Oyl®	-	10
16	Dustex®	0.101	9
17	Polytac®	-	10
18	Envirotac II®	-	10
19	Soiltac®	-	10
20	Soil-Sement®	-	10
21	EK-35®	-	10
22	EnviroKleen®	-	10
23	CSS-1	0.086	9
24	Water	0.25	7
	Range of Values:	0 to 0.25	10 to 7

Very little dust was generated from any of the treated sections during the baseline data collection. The section containing only water produced the most dust, but visibility was not significantly hindered. The CSS-1 asphalt emulsion exhibited some surface wear mainly due to the textured nature of the uncompacted surface. The two products performing the poorest during the test were Blue Goo® and Hydrostik®. They both reduced dust formation but were not as effective as the other products.

MRI was contracted by ERDC to perform additional dust collection using a tow-behind evaluation system that they developed (Photo 26). The system uses a modified version of the filter system used by ERDC mounted onto a 21-ft aluminum bar that was attached to the bed of a pickup. The intake nozzle is adjusted so that it is 8-ft behind the vehicle and 3-ft above the ground. This type of system allows for continual measurement directly behind the vehicle. Initial data collection was performed on 27 and 28 March, and additional testing resumed at intervals of 30, 60, and 90 days. Preliminary results are found in Table 25. Figure 9 shows the relative effectiveness for each section.

Table 25
Baseline MRI Dust Collection Data for Palliative Comparison

Section	Product	No. of Passes	Total Travel Distance (ft)	Dust Collected (mg/1000 ft)	Reduction from Control (%)
11	Blue Goo®	12	5400	17.6	39
12	Hydrostik®	12	5400	10.9	62
13	Surtac®	18	8100	4.9	83
14	Dust Fyghter®	12	5400	11.9	59
15	Road Oyl®	18	8100	3	89
16	Dustex®	12	5400	10.3	64
17	Polytac®	18	8100	4.3	85
18	Envirotac II®	18	8100	2.3	92
19	Soiltac®	12	5400	6	79
20	Soil-Sement®	18	8100	4.5	84
21	EK-35®	18	8100	3.7	87
22	EnviroKleen®	18	8100	2	93
23	CSS-1	12	5400	9.9	66
24	Water	6	2700	29.5	-
			Range of Values:	2 to 29.5	93 to 39

The number of passes made over the section was governed by the amount of dust emerging from behind the vehicle. The sections producing very little dust were trafficked more times than the others to get a significant amount of material on the filters. The data was then normalized to the amount collected per 1000 ft of testing. The percent dust reduction from the control Section 24 was also determined.

Many of the products were very effective in suppressing dust during the initial collection. Sections containing EnviroKleen®, Envirotac II®, Road Oyl®, EK-35®, Polytac®, Soil-Sement®, Surtac®, and Soiltac® all reduced dust generation by approximately 80 percent. These products were rated excellent during initial testing. Sections containing the CSS-1, Dustex®, Hydrostik®, and Dust Fyghter® all reduced dust generation from about 60 to 65 percent. These products were rated good during initial testing. Only one product, Blue Goo®, was rated as poor. Dust generation was only reduced by approximately 40 percent during the initial tests for that section.

30-Day Data Collection

In-situ material property data were collected using a DCP and a Troxler® 3430 nuclear gauge thirty days after test section construction. The DCP data represent the soil strength at different depths. The nuclear gauge was used to measure soil density and moisture content in the 6-in. direct transmission mode. Tests with both devices were performed along the centerline of the test section. Results are found in Tables 26 and 27.

Table 26
Palliative Comparison, DCP Results After 30 Days

Section	Depth (in.)	CBR (%)
11	1 - 11	20
12	5 -13	20
13	0 - 3	100
14	1 - 2	100
15	0 - 5	25
16	5 - 11	20
17	0 - 3	40
18	4 - 8	100
19	1 - 3	100
20	1 - 8	60
21	0 - 12	40
22	4 - 13	15
23	1 - 5	40
24	0 - 4	40

Table 27
Palliative Comparison, Moisture and Density Data After 30 Days

Section	Wet Density (pcf)	Moisture Content (pcf)	Dry Density (pcf)	Moisture Content (%)
11	128.4	4.3	124.1	3.5
12	131.0	5.1	125.8	4.1
13	128.1	4.8	123.3	3.9
14	131.7	4.3	127.4	3.4
15	130.6	4.9	125.7	3.9
16	131.8	5.8	126.0	4.6
17	134.6	5.6	128.9	4.3
18	127.8	4.8	123.0	3.9
19	135.6	3.5	132.1	2.6
20	135.5	4.9	130.6	3.8
21	125.2	9.2	115.9	8.0
22	135.8	7.4	128.4	5.7
23	129.8	4.8	125.0	3.8
24	129.6	4.6	125.0	3.6
Average:	131.1	5.3	125.8	4.2

DCP data indicate that several of the test sites were higher in strength after the 30-day period. There was no evidence of individual layers, except for some surface crust on the soil-binding palliatives. The sections with the greatest strength increase were the most effective in dust mitigation. Sections containing Surtac®, Dust Fyghter®, Envirotac II®, and Soiltac® all had CBR values of

100 at or near the surface of their section. Each of these products had excellent surface conditions with very little damage from traffic. None of the sections had significant reductions in strength during the 30-day period.

The average dry density and moisture content of the sections thirty days after application were 125.8 pcf and 4.2 percent, respectively. There was very little change from the baseline testing. However, the moisture content was reduced from its original values. Some drying was expected to occur during the period between initial construction and this testing due to warm weather and little precipitation. This data also agrees with that collected for the first ten sections. The moisture content is most likely affected by weather patterns more than any other factor.

Dust collection was performed by ERDC on 29 and 30 April. An SUV was used to apply traffic to the sections at a target speed of 30 mph. Ten total vehicle passes were used for the evaluation. Visual rankings were given to the sections based on a 10-point scale with 10 being the best. The visual rankings of the sections were based upon the perceived visibility loss behind a vehicle traveling the section. The ratings were a subjective collaboration by the research evaluation team. Sections rated 10 during the test would have no visibility loss while a ranking of 5 would correspond to 50 percent reduction in visibility. The dust collection procedure from the initial tests was used during this evaluation. The results are given in Table 28.

Table 28
ERDC Palliative Comparison, 30-Day Data Collection

Section	Palliative	Dust Collected (g)	Visual Rating
11	Blue Goo®	0.172	6
12	Hydrostik®	0.134	7
13	Surtac®	0.093	8
14	Dust Fyghter®	0.125	10
15	Road Oyl®	0.251	4
16	Dustex®	0.073	7
17	Polytac®	0.104	8
18	Envirotac II®	0.003	10
19	Soiltac®	0.055	9
20	Soil Sement®	0.019	9
21	EK-35®	0.111	6
22	EnviroKleen®	0.072	10
23	CSS-1	0.068	7
24	Control	0.132	3
	Range of Values:	0.003 to 0.251	10 to 3

Dust accumulation on the filters was more consistent with the visual observations made during this part of the test than the data collected for the first ten sections. However, the relative values were expected to correlate more closely after achieving excellent results during baseline testing. Variations in the data may be caused by inconsistent weights of filters used in the dust collectors. During the first test, it was noted that very little variation existed in the weight of the different filters, and an average weight was used to determine total dust measurement. However, a different box of filters was used during this test, and their weights were not as consistent. This was noticed only after all measurements were performed. Due to the relatively small quantity of dust generated, the variation of the filter weights was enough to obscure significant differences between the test sections, and the visual ratings are probably more indicative of palliative effectiveness. It is also necessary to consider variations in wind velocity as a possible source of error during this test.

Several of the products were still excellent in controlling dust on the roads, and nearly all products appeared to have some dust suppression capability. The only product that could be considered ineffective was Road Oyl®. The dust collectors measured more dust on this section than the control section, and the visual appearance was very similar.

The first two sections, Blue Goo® and Hydrostik®, were the least effective of the remaining products. Over 80 percent of the road surface had exhibited surface raveling due to traffic on these sections during the 30-day period. Visibility was only reduced 30 to 35 percent for these sections, but their long-term performance appears to be limited.

The NRL experimental product, Surtac®, performed very well during the test. The road surface was approximately 85 percent intact, and very little visibility loss occurred during the testing. The material that was beginning to dislodge from the surface was mostly smaller than 1/4 in. in diameter. The dry climate has probably benefited this product because it is projected to be susceptible to leaching from the soil with heavy precipitation.

The section with the calcium chloride salt, Dust Fyghter®, was very effective after the 30-day period. The road surface was mostly undisturbed with less than ten percent raveled. The loose material on the surface was all less than 1/4 in. in diameter. Visibility loss during testing was less than 5 percent. The climate in the region where the test was conducted is optimum for this type of material. Several brief rain showers came during the 30-day period between testing. Light precipitation will reactivate the product and help it maintain its performance. The product is susceptible to leaching from the soil if heavy rains occur.

Section 16, Dustex®, performed moderately well during the evaluation. It did not have very effective binding properties, and the road surface was about 80 percent raveled from traffic. Visibility loss during testing was approximately 30 percent.

The next four sections, 17 through 20, all contained polymer emulsions. This type of product appears to perform well as dust palliatives. The section producing the best results was Section 18, Envirotac II®. The road surface was less than 5 percent raveled and no visible dust was generated from traffic (Photo 36). Section 19, Soiltac®, was also very effective. Most of the road surface was undisturbed, but small patches of raveling were becoming visible. Approximately 10 percent visibility loss occurred on the section during testing. Section 20, Soil-Sement®, had comparable visibility loss to Soiltac®, but the surface of the section was in worse condition. Nearly the entire section had gravel beginning to dislodge from the crust. Raveling was not severe but it was not isolated. The surface of Section 17, Polytac®, was in much worse condition. The east end of the section was about 85 percent disturbed while the west end of the section was only about 50 percent raveled. The uneven surface wear may be caused by an uneven distribution of product during construction. Visibility loss during traffic on this section was approximately 25 percent.

Section 21, EK-35, had very little surface raveling, but the dust generated during testing resulted in about 60 percent visibility loss. The east end of the section was in excellent condition and generated no dust, but the west end was very dry (Photo 37). During construction, this product had to be sprayed with the hand wand due to its high viscosity and inability to be sprayed with even coverage through the distribution bar. This method applied a heavier dosage of product to the area directly behind the hydroseeder and did not overlap well in the center of the road section. The greater volumetric application rate also contributed to product runoff on the east end of the section. The dust generation directly behind the test vehicle in the center of this section may give misleading data during the testing. The major concern with the product is its viscosity and ability to be applied using a range of equipment.

The section treated with Envirokleen®, Section 22, was one of the most effective sections at reducing dust. The surface of the road retained a wet appearance and had less than 5 percent raveling. A lighter colored strip on the centerline may have been caused from an insufficient overlap of material during construction. Very light dust was visible during traffic on the section, but no visibility loss occurred.

Section 23, the asphalt emulsion, was in fair condition. This section was not compacted during construction and the surface was mostly disturbed (Photo 38). Some compaction had resulted from traffic on the road. Dust suppression was evident on this section and only about 20 percent visibility loss occurred during traffic.

The control section, Section 24, was completely disturbed with loose material on the entire section. Heavy dust emerged during traffic and 80 percent of visibility was lost. This section had conditions that would make troop maneuvers difficult during operations.

MRI collected data on the test sections on 27 and 28 April. The results of their procedure are shown in Table 29. The number of passes made over the section was governed by the amount of dust emerging from behind the vehicle during initial testing. The sections producing very little dust were trafficked more times than the others in order to get a significant amount of material on the filters. The number of passes during the first testing sequence was used during this evaluation. The data was normalized to the amount collected per 1,000 ft of testing. The percent dust reduction from the control Section 24 was also determined.

Data collected by MRI generally agrees with the visual observations made by the ERDC team. Section 15, Road Oyl®, shows no improvement over the untreated section. Sections 11 and 12, Blue Goo® and Hydrostik®, also are relatively ineffective as dust palliatives from the gathered data. The best performing products were Envirotac II®, Soiltac®, Dust Fyghter®, and Envirokleen®. Each of these products worked excellently and allowed very little dust formation. Sections containing Soil-Sement®, the asphalt emulsion, Surtac®, Polytac®, EK-35®, and Dustex® were each effective during the test and suppressed approximately two-thirds of the dust on the test sections.

Table 29
MRI 30-Day Dust Collection Data for Palliative Comparison

Section	Product	No. of Passes	Total Travel Distance (ft)	Dust Collected (mg/1000 ft)	Reduction from Control (%)
11	Blue Goo®	12	5400	10.33	3
12	Hydrostik®	12	5400	9.1	14
13	Surtac®	18	8100	3.35	68
14	Dust Fyghter®	12	5400	0.72	93
15	Road Oyl®	18	8100	14.5	0
16	Dustex®	12	5400	4.13	61
17	Polytac®	18	8100	3.47	67
18	Envirotac II®	18	8100	0.45	96
19	Soiltac®	12	5400	0.76	93
20	Soil-Sement®	18	8100	2.94	72
21	EK-35®	18	8100	4.29	60
22	EnviroKleen®	18	8100	1.18	89
23	CSS-1	12	5400	3.17	70
24	Water	6	2700	10.47	-
			Range of Values:	0.45 to 14.5	96 to 0

60-Day Data Collection

In-situ material property data were collected using a DCP and a Troxler® 3430 nuclear gauge sixty days after test section construction. The DCP data represent the soil strength at different depths. The nuclear gauge was used to measure soil density and moisture content in the 6-in. direct transmission mode. Tests with both devices were performed along the centerline of the test section. Results are found in Tables 30 and 31.

Table 30
Palliative Comparison, DCP Results After 60 Days

Section	Depth (in.)	CBR (%)
11	0 - 12	30
12	0 - 3	100
13	0 - 3	100
14	0 - 3	100
15	0 - 3	60
16	2 - 5	100
17	2 - 5	100
18	3 - 5	100
19	0 - 3	100
20	0 - 3	100
21	2 - 12	20
22	0 - 16	20
23	0 - 16	15
24	0 - 16	20

Table 31
Palliative Comparison, Moisture and Density Data After 60 Days

Section	Wet Density (pcf)	Moisture Content (pcf)	Dry Density (pcf)	Moisture Content (%)
11	126.4	4.3	122.1	3.5
12	133.8	4.2	129.6	3.2
13	134.9	3.7	131.2	2.8
14	131.9	4.3	127.6	3.4
15	132.0	4.4	127.6	3.4
16	126.9	4.2	122.7	3.4
17	133.7	3.2	130.4	2.5
18	125.1	3.6	121.5	2.3
19	130.8	3.2	127.5	2.5
20	127.5	3.6	124.0	2.9
21	133.9	6.3	127.6	4.9
22	129.2	5.2	124.0	4.2
23	128.8	3.5	125.3	2.8
24	129.1	3.5	125.7	2.8
Average:	130.3	4.1	126.2	3.2

DCP data indicate that some strength change occurred between the 30- and 60-day period. Some sections had a high increase in surface strength that may be caused by drying of the soil and subsequent stiffening. Variations in the strength of the sections are most likely due to variation in site conditions and testing locations.

The average dry densities and moisture contents of the sections 60 days after application were 126.2 pcf and 3.2 percent, respectively. There was little difference in the density of most of the sections compared to data collected 30 days after construction. The moisture contents for the sections had decreased from the previous data. Warm weather and almost no precipitation would be expected to facilitate drying of the road during this period. The higher moisture values for Sections 21 and 22 are most likely caused by the gauge detecting the presence of the synthetic fluid-based products within the soil. It is possible that the polymer products would also be detected by the nuclear gauge, but the concentration of actual polymer in the section would be less because it is in an emulsified form.

Dust collection was performed by ERDC on 23 and 24 May 2004. An SUV was used to apply traffic to the sections at a target speed of 30 mph. Ten total vehicle passes were used for the evaluation. Visual rankings were given to the sections based on a 10-point scale with 10 being the best. The dust collection procedure from the initial tests was used during this evaluation. The results are given in Table 32.

Dust accumulation on the filters was more consistent with the visual observations made during this part of the test than the data collected after 30 days. Several of the products continued excellent performance in controlling dust on the roads, and nearly all products appeared to have some dust suppression capability. A few of the products could be deemed ineffective at this point in the testing sequence, and these products had dust values similar to the control section.

The first two sections, Blue Goo® and Hydrostik®, were both ineffective for road dust control at 60 days. Both visual observations and field tests suggest that these products do not significantly reduce dust at the application rates for this time period. The road surface had completely raveled due to traffic on these sections, and visibility would be hindered for any secondary vehicles traveling the road. These water-soluble products could not be applied at great enough concentrations to be effective and should not be used for dust control.

Table 32
ERDC Palliative Comparison, 60-Day Data Collection

Section	Palliative	Dust Collected (g)	Visual Rating
11	Blue Goo®	0.292	4
12	Hydrostik®	0.249	5
13	Surtac®	0.052	7
14	Dust Fyghter®	0.097	9
15	Road Oyl®	0.273	3
16	Dustex®	0.133	8
17	Polytac®	0.176	6
18	Envirotac II®	0.024	10
19	Soiltac®	0.054	8
20	Soil Sement®	0.102	8
21	EK-35®	0.378	5
22	EnviroKleen®	0.111	9
23	CSS-1	0.122	6
24	Control	0.391	4
	Range of Values:	0.024 to 0.391	10 to 3

The NRL experimental product, Surtac®, performed very well during the test. The road surface was approximately 50 percent intact, and only about 30 percent visibility loss occurred during the testing. The dry climate has probably benefited this product since it is expected to be susceptible to leaching from the soil with heavy precipitation.

The section with the calcium chloride salt, Dust Fyghter®, was very effective after the 60-day period. The road surface was in good condition with approximately 20 percent raveling. Visibility loss during testing was around 15 percent. The climate in the region where the test was conducted is optimum for this type of material. The product is susceptible to leaching from the soil if heavy rains should occur, but only trace precipitation occurred during the period between tests.

The section treated with Road Oyl® had the worst performance of all the treated sections. The surface was 100 percent raveled, indicating little binding properties of the product, and heavy dust was generated behind the vehicle. Approximately 80 percent visibility loss occurred on the area trafficked during testing. This occurrence would be detrimental for multiple vehicles traveling down a road in succession. This product would not be beneficial for treating dust in the environment in which it was tested.

Section 16, Dustex®, performed well during this evaluation. It did not have very effective binding properties, and the road surface was about 90 percent raveled from traffic. However, visibility loss during testing was only around 25 percent.

The next four sections, 17 through 20, all contained polymer emulsions. These types of products appear to perform well as dust palliatives. The section producing the best results was Section 18, Envirotac II®. The road surface was less than 5 percent raveled and no visible dust was generated from traffic. Section 19, Soiltac®, was also very effective. Approximately 70 percent of the road surface was undisturbed, but small patches of raveling were beginning to emerge. Approximately 20 percent visibility loss occurred on the section during testing. Section 20, Soil-Sement®, had comparable visibility loss to Soiltac®, but the surface of the section was in worse condition. Nearly the entire section had gravel beginning to dislodge from the crust. Only about 30 percent of the surface was still intact. The surface of Section 17, Polytac®, was in slightly better condition than Soiltac®. However, visibility loss during traffic on this section was approximately 50 percent. Polytac® was the worst performer for dust abatement of the polymer emulsions tested.

Section 21, EK-35®, had significant surface raveling since the previous test. The section was nearly 80 percent disturbed after 60 days. The dust generated during testing resulted in about 70 percent visibility loss. The surface of the section appeared dry, but excavating the section to a depth of 6-in. confirmed that the product was still in the soil. Some of the dry surface material could have been from settling airborne dust.

The section treated with Envirokleen®, Section 22, was one of the most effective sections at reducing dust. The surface of the road retained a wet appearance and had less than 25 percent raveling. A lighter colored strip on the centerline may have been caused from an insufficient overlap of material during construction. Very light dust was visible during traffic on the section, but only 5 percent visibility loss occurred.

Section 23, the asphalt emulsion, was in fair condition. This section was not compacted during construction and the surface was 80 percent disturbed. Some compaction had resulted from traffic on the road. Dust suppression was evident on this section, but approximately 50 percent visibility loss occurred during traffic.

The control section, Section 24, was completely disturbed with loose material on the entire section. Heavy dust emerged during traffic and 70 percent of visibility was lost. This section had conditions that would impact military maneuver operations.

MRI collected data on the test sections on 25 May. The results of their procedure are shown in Table 33. The number of passes made over the section was governed by the amount of dust emerging from behind the vehicle during initial testing. The sections producing very little dust were trafficked more times than the others in order to get a significant amount of material on the filters. The number of passes during the first testing sequence was used during this evaluation. The data was normalized to the amount collected per 1,000 ft of testing. The percent dust reduction from the control Section 24 was also determined.

Data collected by MRI generally agrees with the visual observations made by the ERDC team. Section 15, Road Oyl®, shows little improvement over the untreated section. Sections 11 and 12, Blue Goo® and Hydrostik®, however, appear to be effective based on these results. All other data indicate that these sections do not perform as reported in this particular data set. The best performing products were Dust Fyghter®, Surtac®, Envirotac II®, and Envirokleen®. Each of these products worked excellently and allowed very little dust formation. Other products were close to these in effectiveness for controlling road dust.

Table 33
MRI 60-Day Dust Collection Data for Palliative Comparison

Section	Product	No. of Passes	Total Travel Distance (ft)	Dust Collected (mg/1000 ft)	Reduction from Control (%)
11	Blue Goo®	12	5400	3.34	85
12	Hydrostik®	12	5400	2.93	87
13	Surtac®	18	8100	0.86	96
14	Dust Fyghter®	12	5400	0.50	98
15	Road Oyl®	12	5400	16.71	26
16	Dustex®	12	5400	11.2	50
17	Polytac®	12	5400	7.99	64
18	Envirotac II®	18	8100	1.54	93
19	Soiltac®	12	5400	4.43	80
20	Soil-Sement®	12	5400	9.30	59
21	EK-35®	12	5400	7.22	68
22	EnviroKleen®	18	8100	2.45	89
23	CSS-1	12	5400	6.77	70
24	Water	6	2700	22.5	-
			Range of Values:	0.5 to 22.5	98 to 26

90-Day Data Collection

In-situ material property data were again collected using a DCP and a Troxler® 3430 nuclear gauge ninety days after test section construction. The DCP data represent the soil strength at different depths. The nuclear gauge was used to measure soil density and moisture content in the 6-in. direct transmission mode. Tests with both devices were performed along the centerline of the test section. Results are found in Tables 34 and 35.

Table 34
Palliative Comparison, DCP Results After 90 Days

Section	Depth (in.)	CBR (%)
11	0 - 12	30
12	0 - 2	100
13	0 - 2	100
14	2 - 7	100
15	1 - 4	100
16	1 - 4	100
17	2 - 4	100
18	4 - 6	100
19	0 - 4	100
20	2 - 3	100
21	3 - 10	20
22	0 - 13	20
23	0 - 10	20
24	0 - 12	30

Table 35
Palliative Comparison, Moisture and Density Data After 90 Days

Section	Wet Density (pcf)	Moisture Content (pcf)	Dry Density (pcf)	Moisture Content (%)
11	129.6	4.1	125.5	3.3
12	129.3	3.8	125.3	3.0
13	134.9	3.5	131.4	2.7
14	125.5	3.1	122.5	2.5
15	130.1	3.9	126.2	3.1
16	127.1	5.2	121.9	4.2
17	130.7	3.4	127.3	2.7
18	121.0	2.6	118.4	2.2
19	126.7	2.9	123.7	2.4
20	134.4	5.1	129.4	3.9
21	125.6	7.0	118.6	5.9
22	131.4	6.6	124.7	5.3
23	132.0	4.1	127.8	3.2
24	126.5	2.7	123.8	2.2
Average:	128.9	4.1	124.8	3.3

DCP data indicate that little strength change occurred between the 60- and 90-day period. Variations in the strength of the sections are most likely due to variation in site conditions and testing locations.

The average dry density and moisture content of the sections 60 days after application were 124.8 pcf and 3.3 percent, respectively. There was little difference in the density of most of the sections compared to data collected 30 days after construction. The moisture content for each of the sections was also very similar to the previous data. The higher moisture values for Sections 21 and 22 are most likely caused by the gauge detecting the presence of the synthetic fluid-based products within the soil.

Dust collection was performed by ERDC on 23 and 24 June 2004. An SUV was used to apply traffic to the sections at a target speed of 30 mph. Ten total vehicle passes were used for the evaluation. Visual rankings were given to the sections based on a 10-point scale with 10 being the best. Two stationary dust collectors were located near the center of the 500-ft section and approximately 5 ft from the centerline. The variable wind direction during this test sequence made it necessary to place one dust collector on each side of the road, unlike previous tests in which both collectors were placed in a downwind location. The results are given in Table 36.

Table 36
ERDC Palliative Comparison, 90-Day Data Collection

Section	Palliative	Dust Collected (g)	Visual Rating
11	Blue Goo®	0.478	3
12	Hydrostik®	0.517	4
13	Surtac®	0.037	7
14	Dust Fyghter®	0.075	8
15	Road Oyl®	0.127	2
16	Dustex®	0.215	6
17	Polytac®	0.219	5
18	Envirotac II	0.015	10
19	Soiltac®	0.036	4
20	Soil Sement®	0.164	8
21	EK-35®	0.184	4
22	EnviroKleen®	0.1	8
23	CSS-1	0.173	5
24	Control	0.302	2
	Range of Values:	0.015 to 0.517	10 to 2

Dust accumulation on the filters was moderately consistent with the visual observations made during this part of the test. Variable wind direction and velocity created difficulty in controlling the exposure of the collection system to the dust generated from the test vehicle. Several of the products continued to demonstrate excellent performance in controlling dust on the roads, and a greater distinction among the performance of the products arose during the 90-day test. Some of the products were ineffective, having dust values similar to the control section.

The first two sections, Blue Goo® and Hydrostik®, were both ineffective for road dust control at 90 days (Photos 39 and 40). Both visual observations and field tests suggest that these products do not significantly reduce dust at the application rates for this time period. The road surface had completely raveled due to traffic on these sections, and visibility would be hindered for any secondary vehicles traveling the road. These water-soluble products could not be applied at great enough concentrations to be effective and should not be used for dust control.

Surtac®, the NRL experimental product, performed very well during the test. The road surface was approximately 40 percent intact, and only about 30 percent visibility loss occurred during the testing (Photo 41). The dry climate has probably benefited this product since it is projected to be susceptible to leaching from the soil with heavy precipitation.

The section with the calcium chloride salt, Dust Fyghter®, was not as effective as it was for the 60-day period. The road surface was in fair condition with approximately 50 percent raveling. Visibility loss during testing was around 25 percent (Photo 42). The climate in the region where the test was conducted is optimum for this type of material. The product is susceptible to leaching from the soil if heavy rains should occur, but only trace precipitation occurred during the period between tests.

The section treated with Road Oyl® had the worst performance of all the treated sections. The surface was 100 percent raveled, indicating little binding properties of the product, and blinding dust was generated behind the vehicle (Photo 43). Nearly 100 percent visibility loss occurred on the area trafficked during testing. This occurrence would be detrimental for multiple vehicles traveling down a road in succession. This product would not be beneficial for treating dust in the environment in which it was tested.

Section 16, Dustex®, performed well during this evaluation. It did not have very effective binding properties, and the road surface was 100 percent raveled from traffic. However, visibility loss during testing was only around 45 percent (Photo 44).

The next four sections, 17 through 20, all contained polymer emulsions. These types of products appear to perform well as dust palliatives. The section producing the best results was Section 18, Envirotac II®. The road surface was less than 15 percent raveled and only light visible dust was generated from traffic (Photo 45). Section 19, Soiltac®, performed as well as it did during the 60-day test. Fifty percent of the road surface was undisturbed, but the surface was becoming progressively worse with time. Approximately 15 percent visibility loss occurred on the section during testing (Photo 46). Section 20, Soil-Sement®, had about 60 percent visibility loss, and the surface of the section was in poor condition (Photo 47). Nearly the entire section had raveled. Only about 10 percent of the surface was still intact. The surface of Section 17, Polytac®, was in slightly better condition than Soil-Sement®. Despite less surface raveling, visibility loss during traffic on this section was approximately 55 percent (Photo 48). Polytac® was the worst performer for dust abatement of the polymer emulsions tested considering all the evaluation periods.

Section 21, EK-35®, had a surface condition similar to the previous test. The section was nearly 80 percent disturbed after 90 days. The dust generated during testing resulted in about 65 percent visibility loss (Photo 49). The surface of the section appeared dry, but excavating the section to a depth of 6 in. confirmed that the product was still in the soil. Some of the dry surface material could have been from settling airborne dust.

The section treated with Envirokleen®, Section 22, was one of the most effective of the sections at reducing dust (Photo 50). The surface of the road had lost its wet appearance and was around 80 percent raveled. A lighter colored surface may have been caused from airborne dust settling on the section and sticking to the product near the surface. Despite significant surface raveling, only light dust was visible during traffic but resulted in only about 20 percent loss in visibility.

Section 23, the asphalt emulsion, was in fair condition. This section was not compacted during construction and the surface was 85 percent disturbed. Some compaction had resulted from traffic on the road. Dust suppression was evident on this section, but approximately 60 percent visibility loss occurred during traffic (Photo 51).

The control section, Section 24, was completely disturbed with loose material on the entire section. Heavy dust emerged during traffic causing a 90 percent reduction in visibility (Photo 52). This section had conditions that would make troop maneuvers difficult.

MRI collected data on the test sections on 22 and 23 June 2004. The results of their procedure are shown in Table 37. The number of passes made over the section was set to 12 for all sections. The data was normalized to the amount collected per 1,000 ft of testing. The percent dust reduction from the control Section 24 was also determined. Section 1 was not tested since Section 24 was chosen as a more appropriate control for consistency with application procedures used on Sections 11 through 24.

Table 37
MRI 90-Day Dust Collection Data for Palliative Comparison

Section	Product	No. of Passes	Total Travel Distance (ft)	Dust Collected (mg/1000 ft)	% Reduction from Control
11	Blue Goo®	12	5400	22.37	3
12	Hydrostik®	12	5400	13.91	40
13	Surtac®	12	5400	1.92	92
14	Dust Fyghter®	12	5400	2.75	88
15	Road Oyl®	12	5400	27.35	None
16	Dustex®	12	5400	7.56	67
17	Polytac®	12	5400	13.5	42
18	Envirotac II®	12	5400	1.11	95
19	Soiltac®	12	5400	2.74	88
20	Soil-Sement®	12	5400	11.46	50
21	EK-35®	12	5400	14.11	39
22	EnviroKleen®	12	5400	1.83	92
23	CSS-1	12	5400	9.20	60
24	Water	12	5400	23.88	-
			Range of Values:	1.11 to 27.35	95 to 0

Data collected by MRI generally agrees with the visual observations made by the ERDC team. Section 15, Road Oyl®, shows no improvement over the untreated section. Sections 11 and 12, Blue Goo® and Hydrostik®, also demonstrated minimal effectiveness in reducing dust. The best performing products were Envirotac II®, Envirokleen®, Surtac, Dust Fyghter®, and Soiltac®. Each of these products worked excellently and allowed very little dust to become airborne. Other products including Dustex®, Soil-Sement®, and CSS-1 also exhibited effective dust abatement compared to the control section.

Weighted Palliative Rating

Each test section was rated using a weighted point system based upon four factors. The ability of the dust palliative to bind the soil and prevent surface deterioration was rated from 0 to 10 and represents 20 percent of the total score. The visual observations made by the ERDC research team on the ability of the product to reduce dust represent 30 percent of the total rating. The number corresponds to the percentage of dust reduced by the palliative divided by ten. Half of the total product rating is based upon these two visual data determined by ERDC researchers. The other 50 percent of the score is taken from the two dust collecting systems used in this study. Both the ERDC stationary dust collection system and the MRI mobile dust sampler are given 25 percent of the final score. The numbers assigned reflect the percentage reduction of dust collected from the control section. Final ratings are shown in Table 38.

Table 38
Weighted Palliative Rating

Section	Product	Surface Raveling (20%)	Visual Dust Rating (30%)	ERDC Dust Reduction (25%)	MRI Dust Reduction (25%)	Total
18	Envirotac II®	9	10	10	10	98
19	Soiltac®	5	8	9	9	79
14	Dust Fyghter®	5	8	8	9	77
13	Surtac®	4	7	9	9	74
22	Envirokleen®	2	8	7	9	68
16	Dustex®	0	6	3	7	43
23	CSS-1	1	5	4	6	42
20	Soil Sement®	1	4	5	5	39
21	EK-35®	2	4	4	4	36
17	Polytac®	1	5	3	4	35
12	Blue Goo®	0	4	0	4	22
15	Road Oyl®	0	2	6	0	21
11	Hydrostik®	0	3	0	0	9
24	Control	0	2	0	0	6

4 Conclusions and Recommendations

The ERDC was tasked by the MCSC to develop two dust control systems, one for expeditionary use on FARPs and one for use on roads and other large area applications. This report addresses testing performed to evaluate commercial palliatives for use on roads and cantonment areas in sustainment situations. Twenty-four test sections were constructed on a U.S. Border Patrol access road in Douglas, AZ. The application of palliatives involved the use of several types of machinery associated with lightweight construction. Testing of the sections was performed using lightweight truck and SUV traffic. Other traffic included daily use of the road by Border Patrol personnel. The road sections were evaluated based upon the ability of the product to suppress dust and to prevent deterioration of the road surface. Conclusions from the tests conducted and recommendations for the application of dust palliatives on unsurfaced roads in arid and semi-arid environments are provided in the following text.

Conclusions

The following conclusions were derived from the application and testing of selected dust palliatives from March to June 2004:

a. Performing only a topical application can provide satisfactory dust abatement on aggregate roads with a high load-bearing capacity. However, when applying dust palliatives to unimproved roads, topical applications may not allow for significant penetration of product. Thin surface crusts are prone to disintegration with increased traffic, allowing the underlying material to produce dust.

b. When compacting after a topical application, saturation of the surface hindered compaction of the road section due to surface peeling resulting from material sticking to the roller of the compactor.

c. Spraying dust palliatives onto a windrow does not allow for effective distribution of liquid products. The material on the outer surface of the windrow will be saturated with product, and effective mixing cannot be completed with grading. Creating a windrow after the surface of the road has been sprayed with a dust palliative will lead to a better distribution of product, but untreated areas are still likely to exist.

d. Using a rotary mixer or soil stabilizer to incorporate dust palliatives into the soil works very well. It is not necessary that the road be tilled prior to spraying the product. As long as runoff of the product does not occur, mixing can be performed after spraying onto the existing road surface in order to minimize construction efforts. It may be necessary to disturb the surface if the product does not soak into the road readily or if working on an inclined or crowned surface.

e. Grading of the existing road prior to any treatment increases the effectiveness of the construction efforts by disturbing hard soil and removing potholes or ruts from the road surface. However, if mixing is used to incorporate dust palliatives into the soil, grading may not be required.

f. Compacting a tilled surface with a steel-wheeled roller provides an exceptionally smooth and durable surface.

g. A final topical application of at least part of the optimum product application rate is desired to effectively seal the surface.

h. The preferred application methods include the spray/till/grade/compact/spray followed by the prewet/spray/compact followed by the spray/windrow/grade/compact.

i. The HMMWV E-Spray distribution equipment provided an effective expeditionary means of distributing a variety of dust palliatives, but the prototype unit requires some modifications prior to fielding.

j. All products were effective at controlling dust from lightweight truck traffic one day after completion of construction.

k. The following products performed excellently during testing of the road sections with lightweight truck traffic 30 days after construction: Envirotac II®, Envirokleen®, Dust Fyghter®, and Soiltac®.

l. The following products performed well during testing of the road sections with lightweight truck traffic 30 days after construction: Soil-Sement®, Surtac®, Polytac®, CSS-1, Dustex®, and EK-35®.

m. The following products performed poorly during testing of the road sections with lightweight truck traffic 30 days after construction: Hydrostik®, Blue Goo®, and Road Oyl®.

n. The following products performed excellently during testing of the road sections with lightweight truck traffic 60 days after construction: Envirotac II®, Dust Fyghter®, Envirokleen®, Surtac®, and Soiltac®.

o. The following products performed well during testing of the road sections with lightweight truck traffic 60 days after construction: Soil-Sement®, CSS-1, Dustex®, Polytac®, and EK-35®.

p. The following products performed poorly during testing of the road sections with lightweight truck traffic 60 days after construction: Hydro-stik®, Blue Goo®, and Road Oyl®.

q. The following products performed excellently during testing of the road sections with lightweight truck traffic 90 days after construction: Envirotac II®, Soiltac®, Envirokleen®, Dust Fyghter®, and Surtac®.

r. The following products performed well during testing of the road sections with lightweight truck traffic 90 days after construction: Soil-Sement®, Dustex®, Polytac®, CSS-1, and EK-35®.

s. The following products performed poorly during testing of the road sections with lightweight truck traffic 90 days after construction: Hydro-stik®, Blue Goo®, and Road Oyl®.

Recommendations

Based upon the tests performed in Douglas, AZ, the following recommendations are provided:

a. Compaction can be performed immediately after tilling dust palliatives into the soil under conditions where the soil does not exceed its optimum moisture content. If the surface does begin to stick to the roller of the compactor, waiting approximately 30 min will allow the palliative to soak into the soil and begin to cure. A less tacky surface should exist and compaction can be resumed.

b. A final surface application is desired after compaction to seal the surface of the road and form a weather resistant layer. Binding surface particles will also provide more resistance to raveling under traffic.

c. Some products may not prove as effective in climates where precipitation occurs frequently. Dust Fyghter®, Surtac®, and Dustex® are susceptible to leaching from the soil, and further evaluation of these products is recommended for more temperate climates characterized by significant rainfall levels.

d. A topical application procedure with compaction is recommended for light traffic and a spray/till/compact/spray technique is recommended for heavy traffic.

e. The following products are recommended for use in sustainment operations in desert environments with a 90-day effectiveness rating: Envirotac II®, Soiltac®, Envirokleen®, Surtac®, and Dust Fyghter®.

f. Envirotac II®, Surtac®, and Soiltac® should be diluted with water to a 3:1 solution and applied at a total application rate of 0.8 gsy.

g. Envirokleen® and Dust Fyghter® should be applied "neat" at a rate of 0.8 gsy.

h. The HMMWV E-Spray system is recommended for use when larger capacity distribution systems are not available. However, this system should be modified to meet the desired changes and reevaluated before procurement.

i. Product application should follow the recommended quantities listed in Table 39.

Table 39
Dust Palliative Recommendations for Unpaved Roads[1]

Palliative	Application[2] Rate	Dilution Ratio	Quantity per Mile of Road		Cost[3] Per Gallon	Cost[3] per Mile of Road	GSA Number
			Product	Water			
Envirotac II®	0.8 gsy	3:1	2816 gal	8448 gal	$2.50	$7,040.00	none
Soiltac®	0.8 gsy	3:1	2816 gal	8448 gal	$2.18	$6,138.88	GS-07F-5364P
Envirokleen®	0.8 gsy	"neat"	11264 gal	0	$5.08	$57,221.12	GS-07F-0235M
Dust Fyghter®	0.8 gsy	"neat"	11264 gal	0	$2.50	$28,160.00	GS-07F-0235M
Surtac®	0.8 gsy	3:1	2816 gal	8448 gal	$5.75	$16,192.00	GS-07F-5364P

[1] These recommendations are based upon road dust mitigation tests in Douglas, AZ from March to June 2004.
[2] Application rates are based upon the recommended construction technique described in this document.
[3] Quantities and cost per mile of construction are based upon 24 ft. road width. Product pricing represents quotes received in September 2004.

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Figure 1. Soil gradation curve

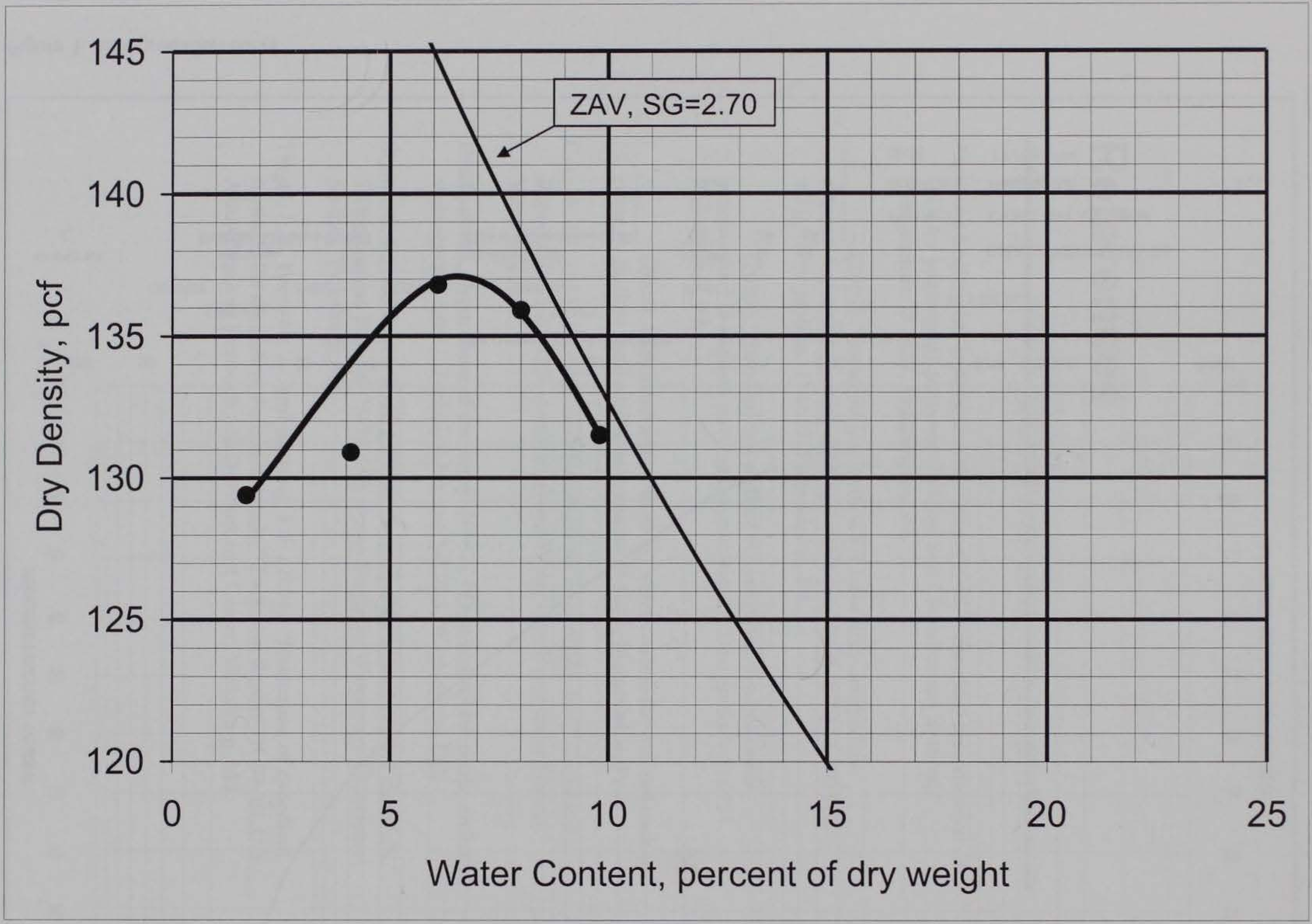

Figure 2. Modified Proctor compaction curve

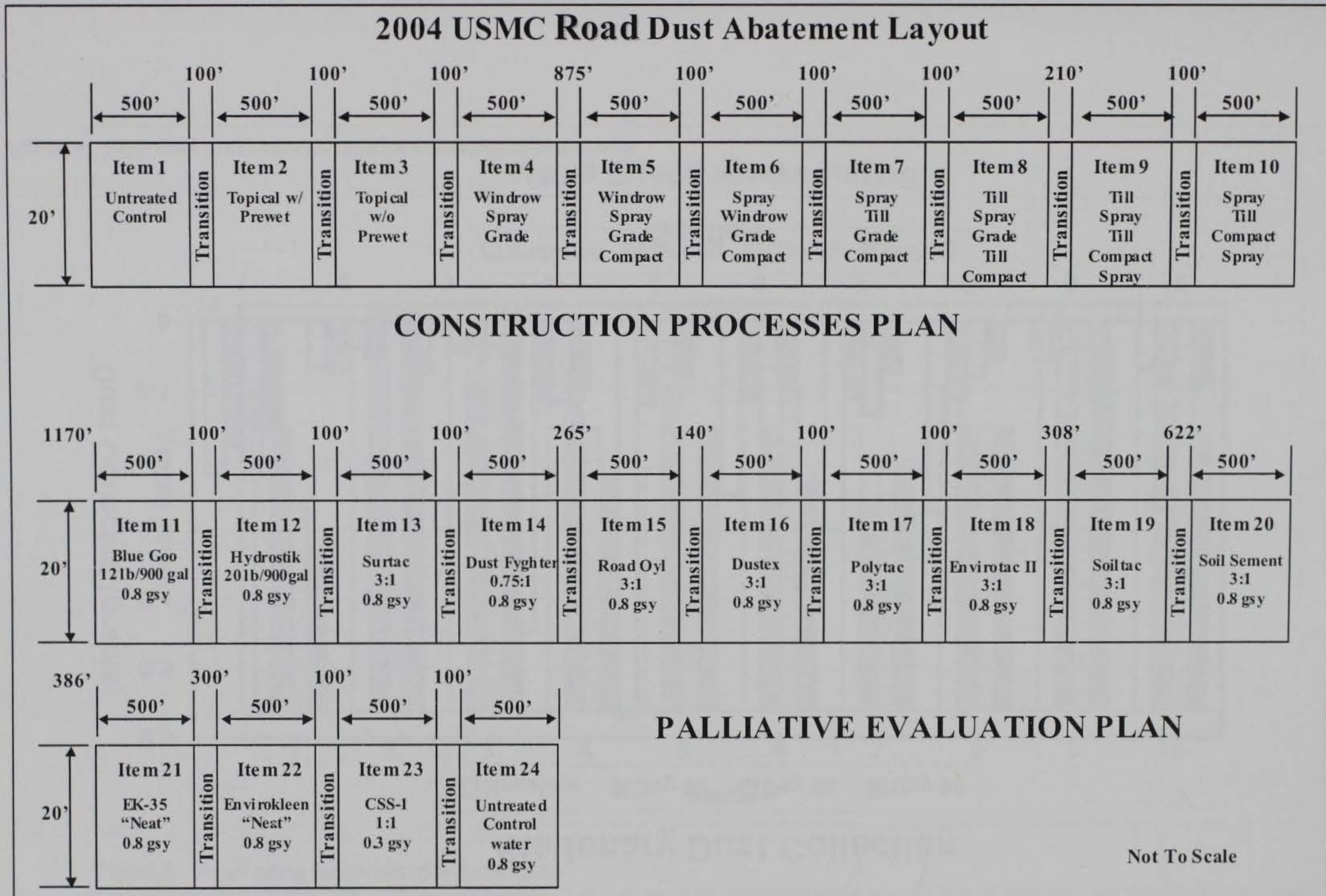

Figure 3. Test section layout (dilution ratio listed below product name, i.e. 3:1 refers to three parts water to one part product)

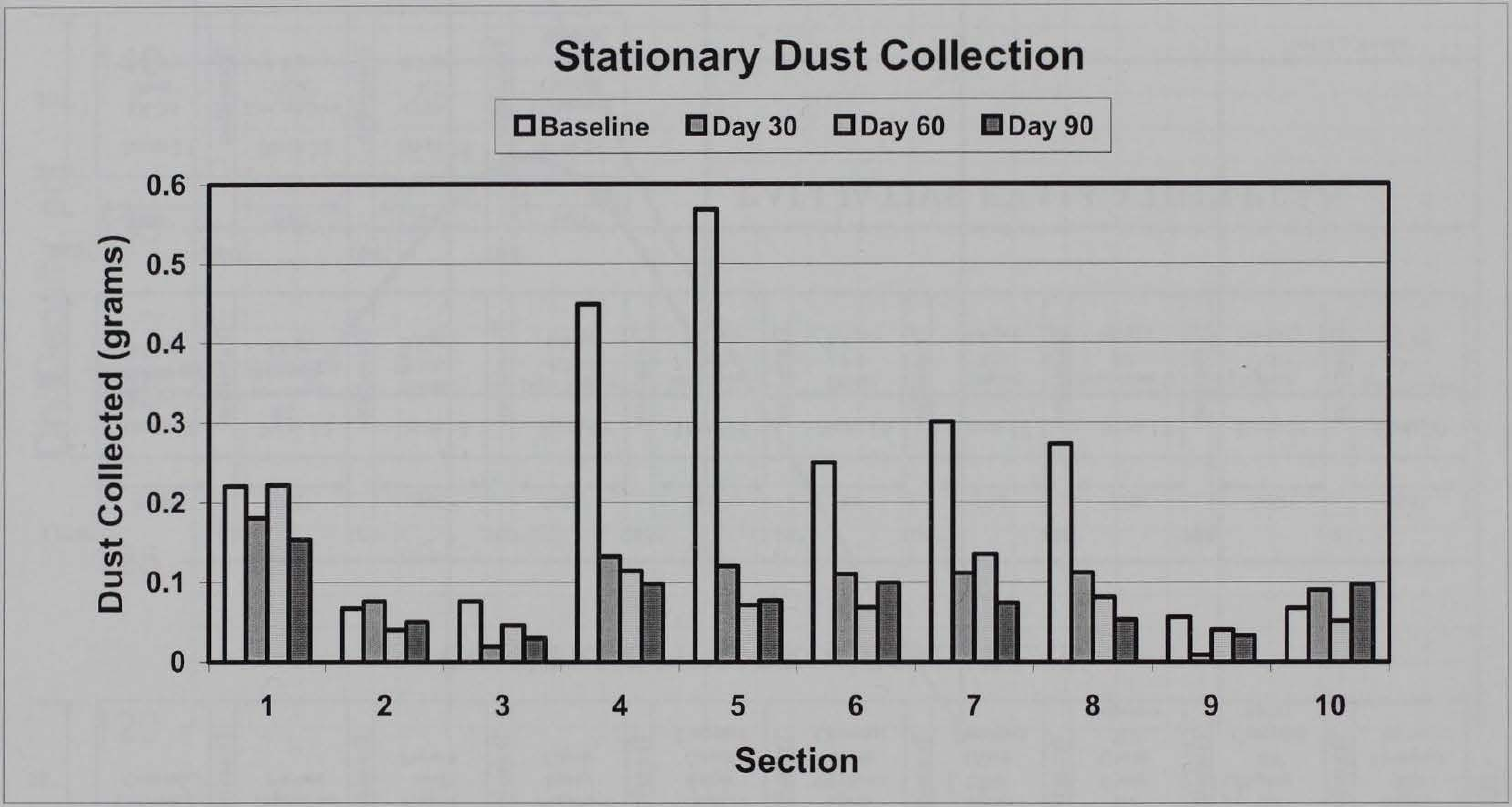

Figure 4. Stationary dust collector data for construction techniques

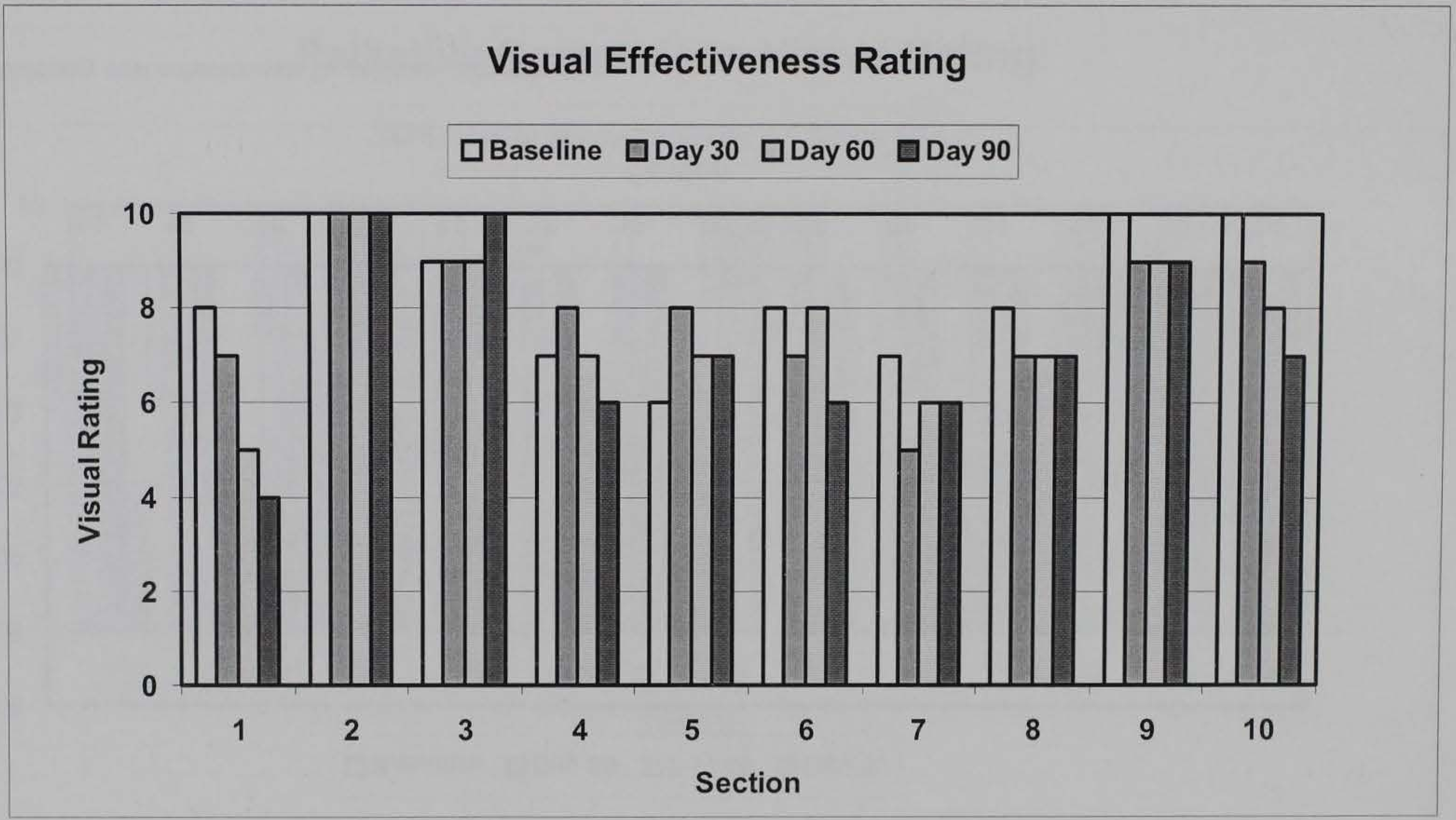

Figure 5. Visual rating for construction techniques

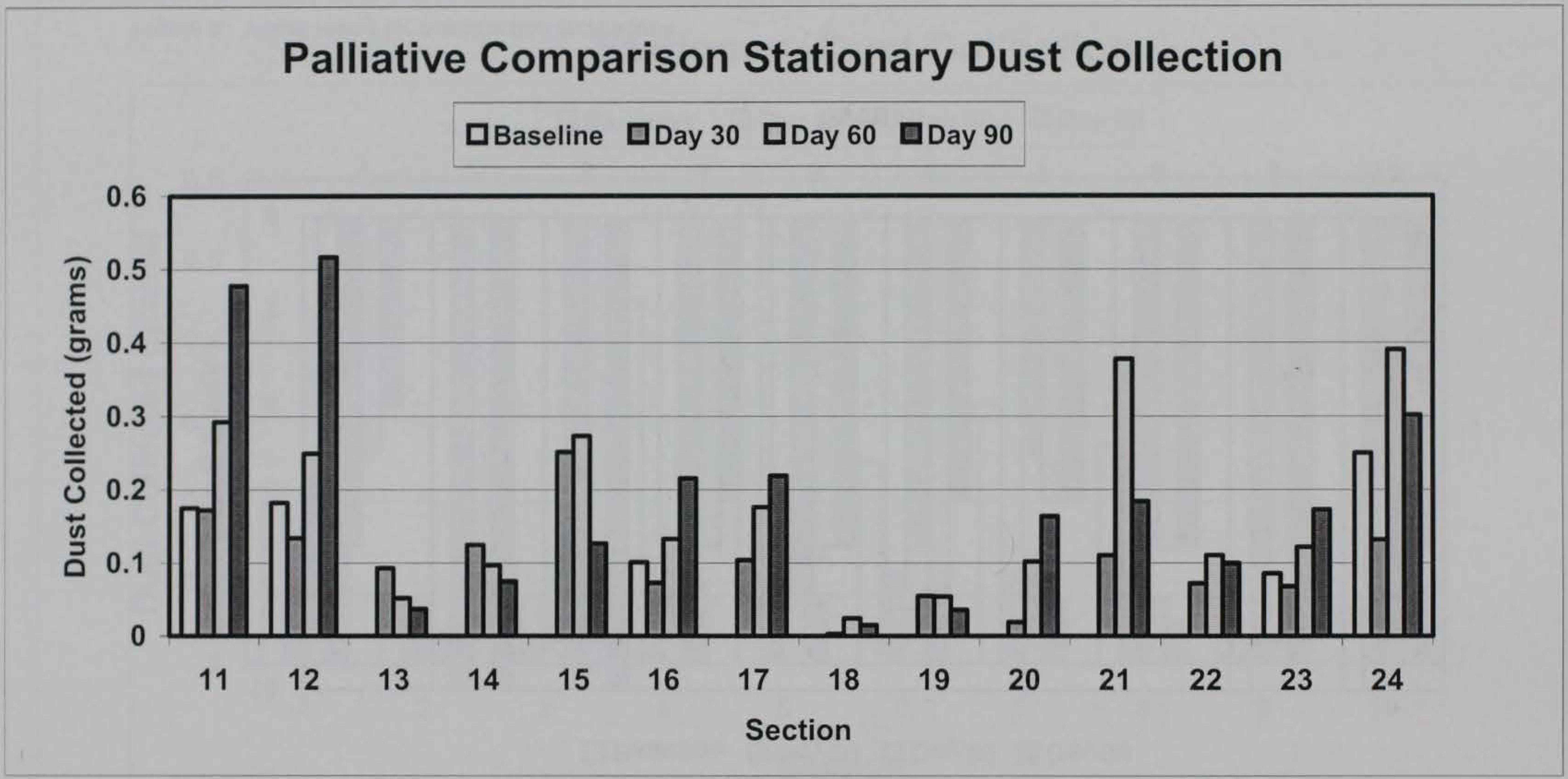

Figure 6. Stationary dust collector data for palliative comparison

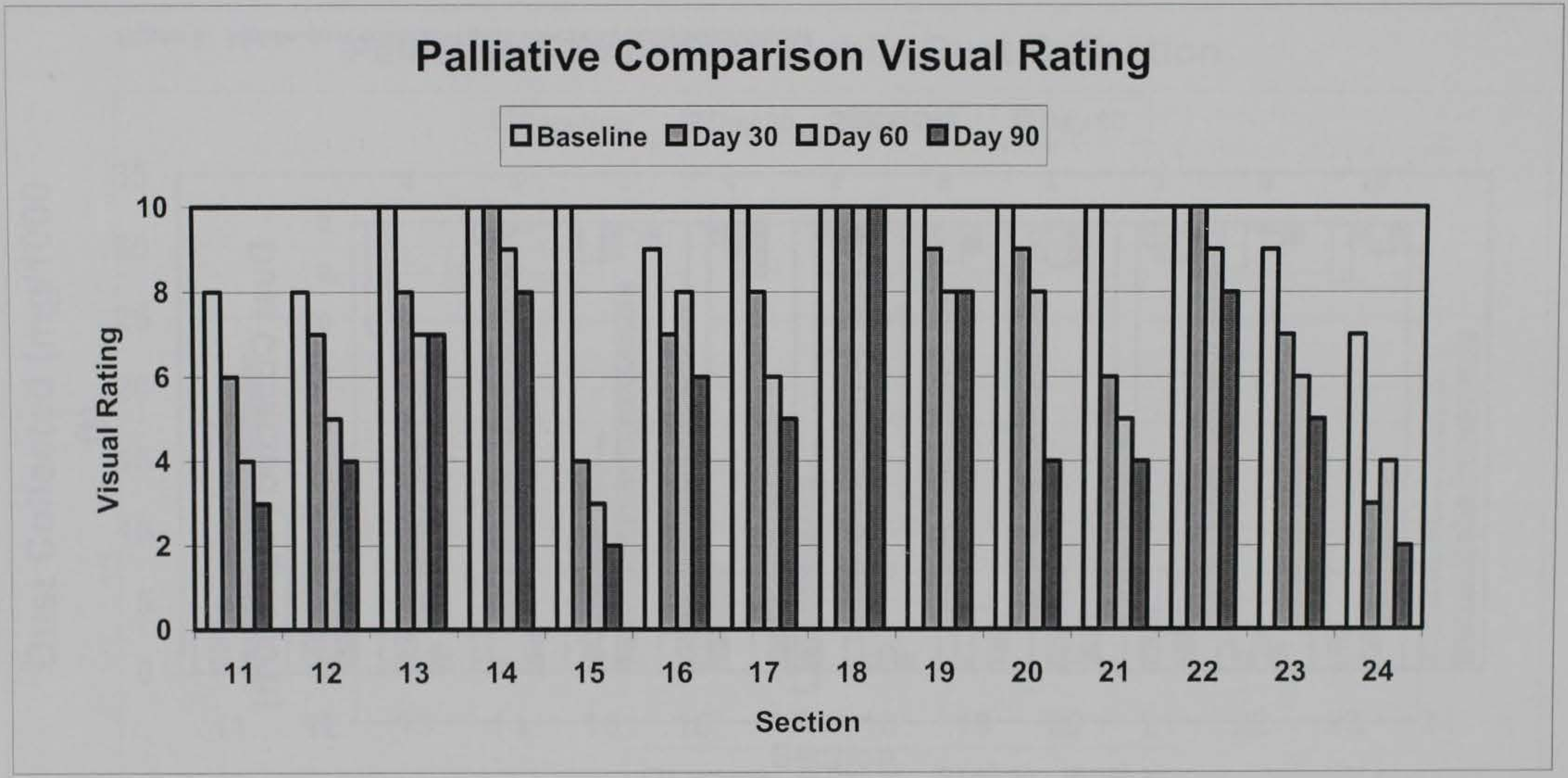

Figure 7. Visual rating for palliative comparison

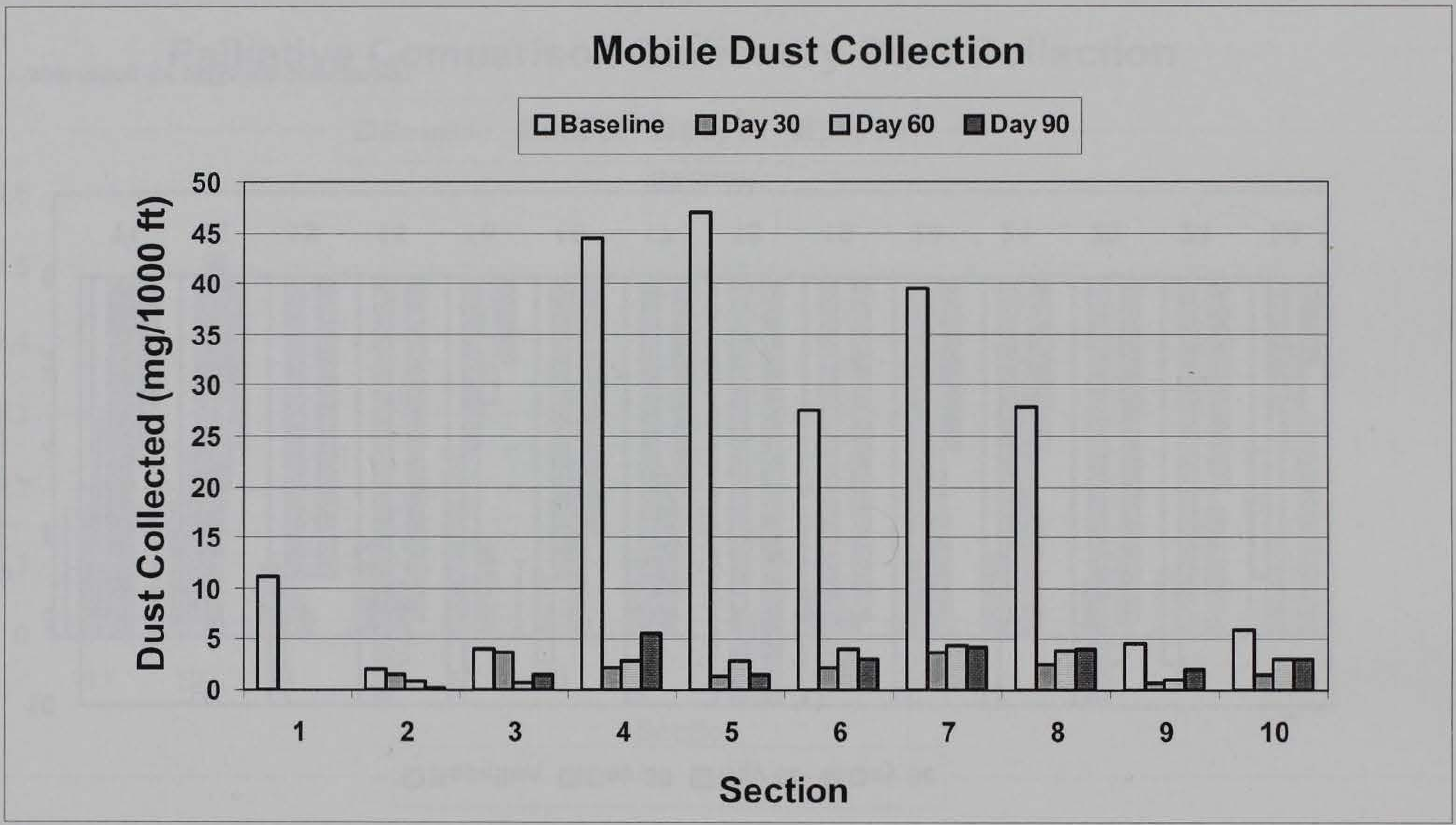

Figure 8. Mobile dust collection data for construction techniques

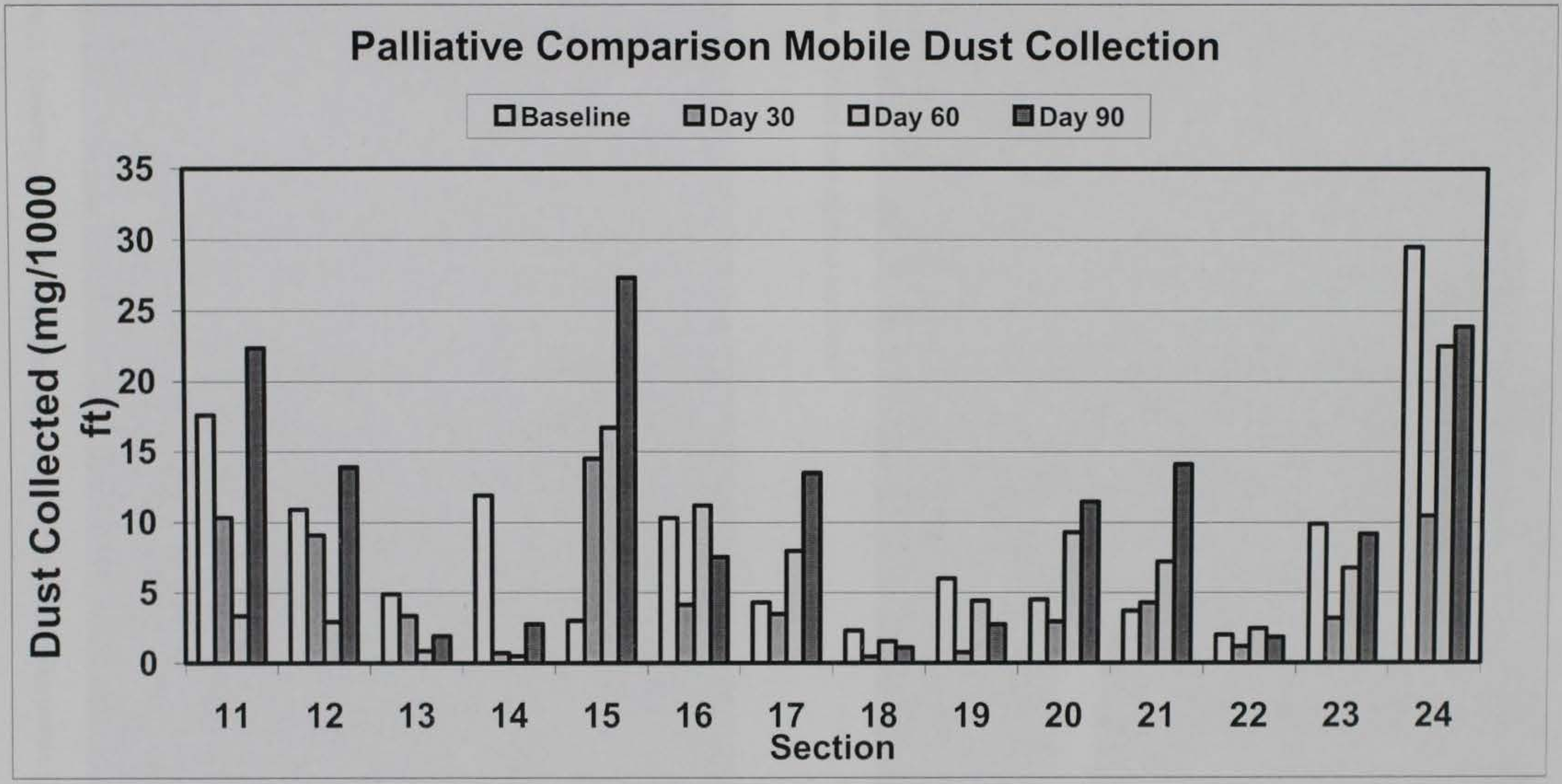

Figure 9. Mobile dust collection data for palliative comparison

Photo 1. Initial road surface condition

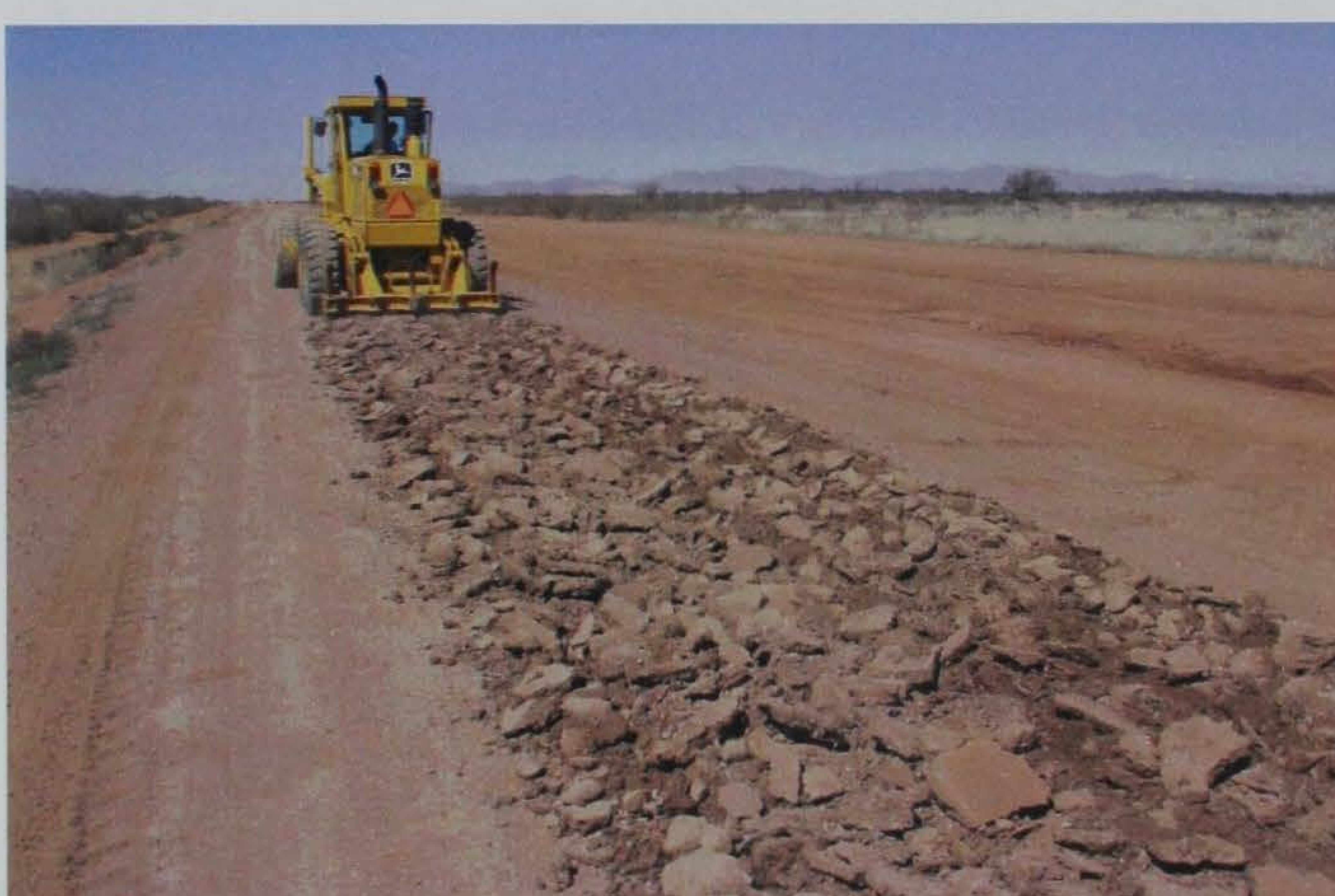

Photo 2. Breaking of surface and grading prior to test section construction

Photo 3. Site layout

Photo 4. Placement of traffic delineators

Photo 5. Finn T-90 hydroseeder pulled by HMMWV

Photo 6. John Deere 770 BH motor grader

Photo 7. Seaman Maxon rotary mixer

Photo 8. BOMAG 6-ton steel wheeled vibratory compactor

Photo 9. Ingersoll-Rand 12-ton vibratory compactor

Photo 10. Spraying from distribution bar on hydroseeder

Photo 11. Section 1 after compaction

Photo 12. Delayed penetration and product runoff on section 2

Photo 13. Spraying product on windrows using hand wand

Photo 14. Tilling surface after spraying product to incorporate palliative into soil

Photo 15. Removal of surface crust from product sticking to roller on compactor

Photo 16. Rough surface on Section 3 caused by removal of tacky surface during compaction

Photo 17. Uncompacted surface on Section 4 with poor product distribution

Photo 18. Dry center of test section and uneven product distribution after spreading of windrow on Section 5

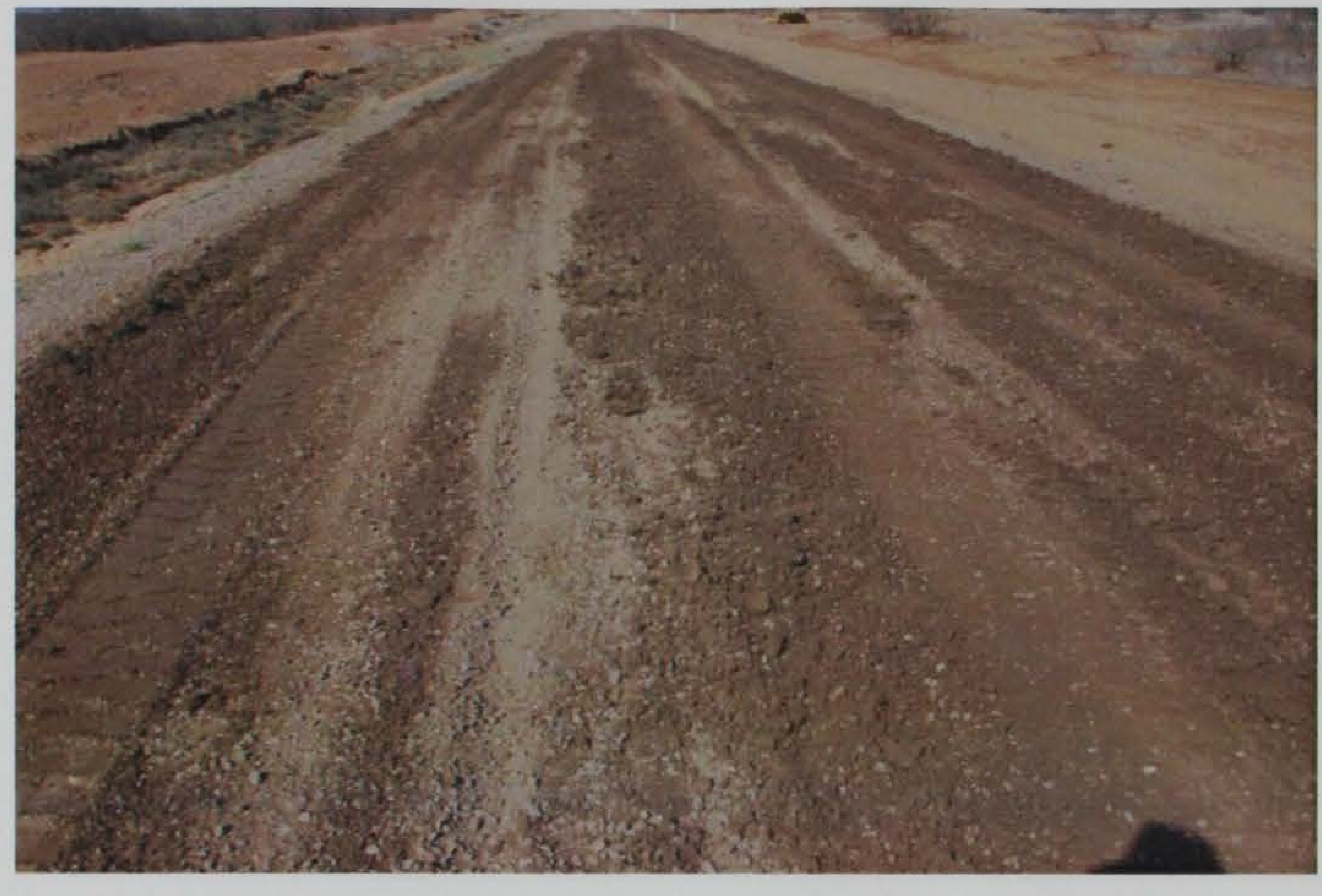

Photo 19. Exposure of untreated areas after grading of surface

Photo 20. Immediate tilling of product after spraying onto surface

Photo 21. Final road surface after topical application

Photo 22. Data collection with DCP and nuclear gauge 1 day after construction

Photo 23. Use of SUV to apply traffic during dust collection

Photo 24. Stationary dust collectors used to monitor palliative effectiveness

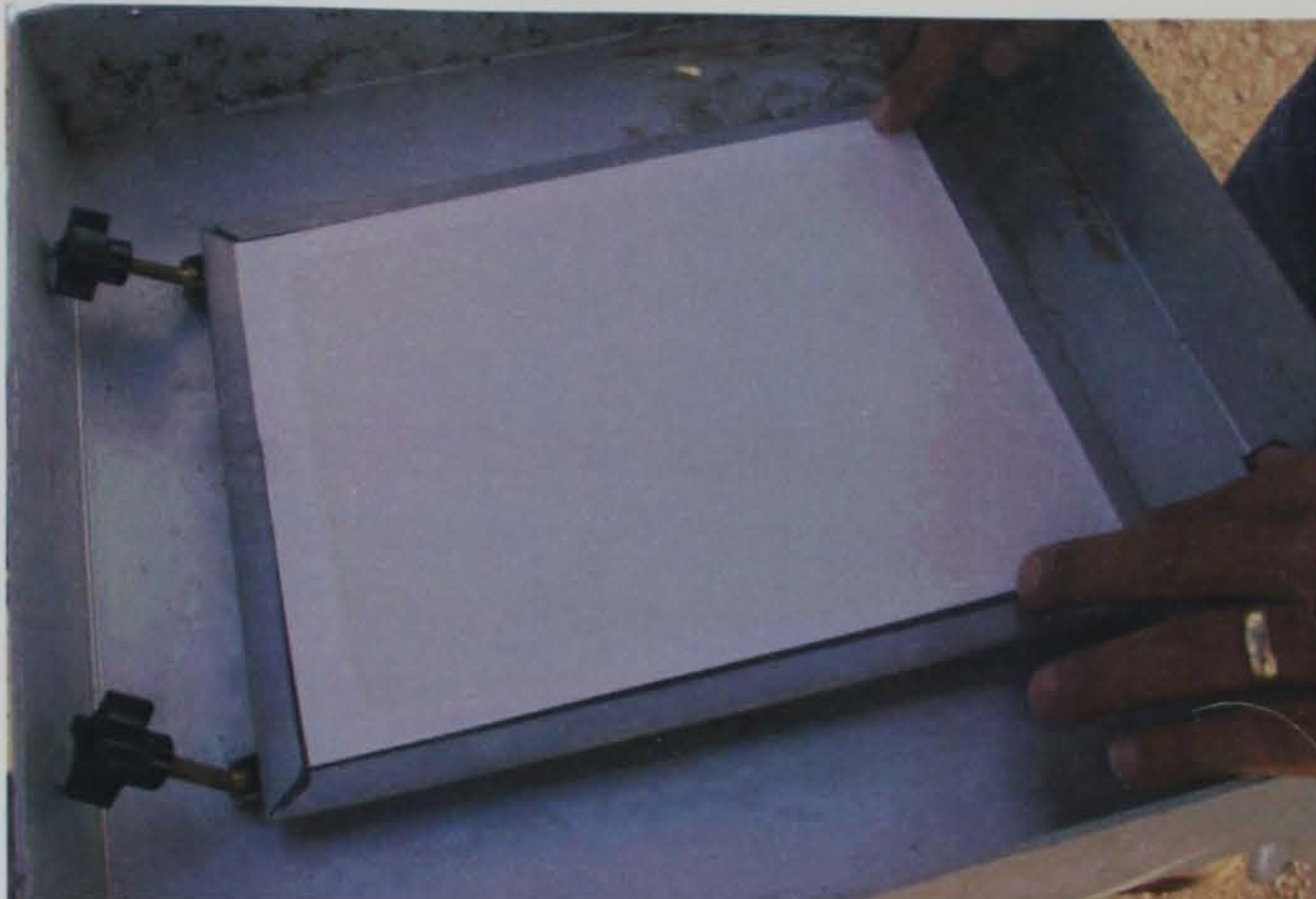

Photo 25. Accumulation of dust on filter paper after removal of wire screen

Photo 26. Tow-behind dust collection system used by MRI

Photo 27. E-Spray Model D system developed by Midwest Industrial Supply, Inc.

Photo 28. Unpacking the application system

Photo 29. Applying Envirokleen® to transition areas with spray boom

Photo 30. Applying EK-35® with hand wand on E-Spray system

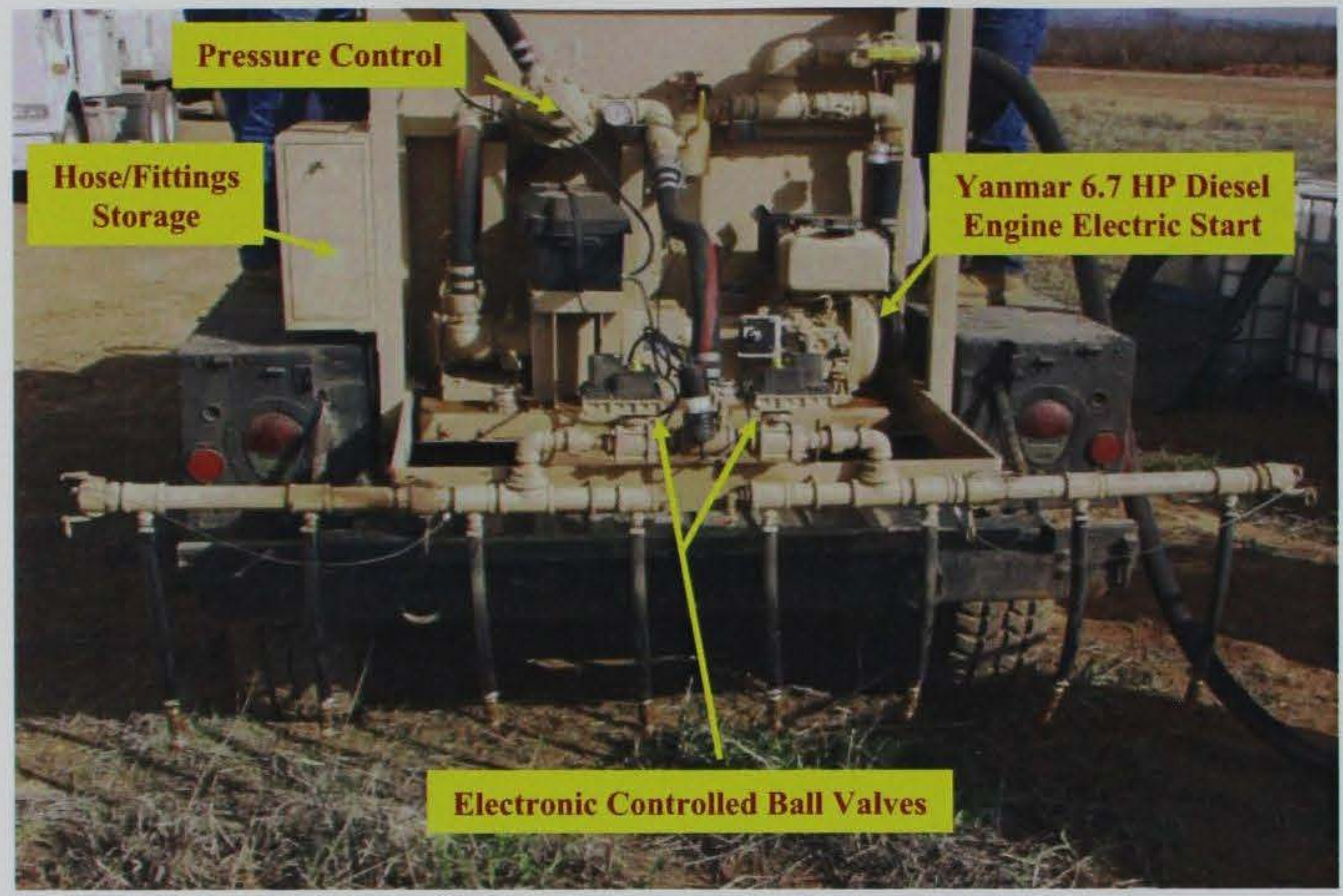

Photo 31. Basic components of spray unit

Photo 32. Balls of undissolved Hydrostik® sprayed from hydroseeder

Photo 33. Foam overflowing hydroseeder while filling with Polytac®

Photo 34. Spraying of high viscosity Blue Goo® solution with hand wand

Photo 35. Application of asphalt emulsion by heated tanker with distribution bar

Photo 36. Undisturbed surface of Section 18 after 30 days

Photo 37. Uneven product distribution on Section 21 after 30 days

Photo 38. Disturbed surface of asphalt emulsion on Section 23 after 30 days

Photo 39. Heavy dust emerging from vehicle on Hydrostik® section

Photo 40. Dust collection on Section 12, Blue Goo®

Photo 41. Test section treated with Surtac®

Photo 42. Light dust produced by vehicle traveling Section 14, Dust Fyghter®

Photo 43. Blinding dust and corrugation on Section 15, Road Oyl®

Photo 44. Data collection on test section treated with Dustex®

Photo 45. Excellent performance of Envirotac II® on Section 18

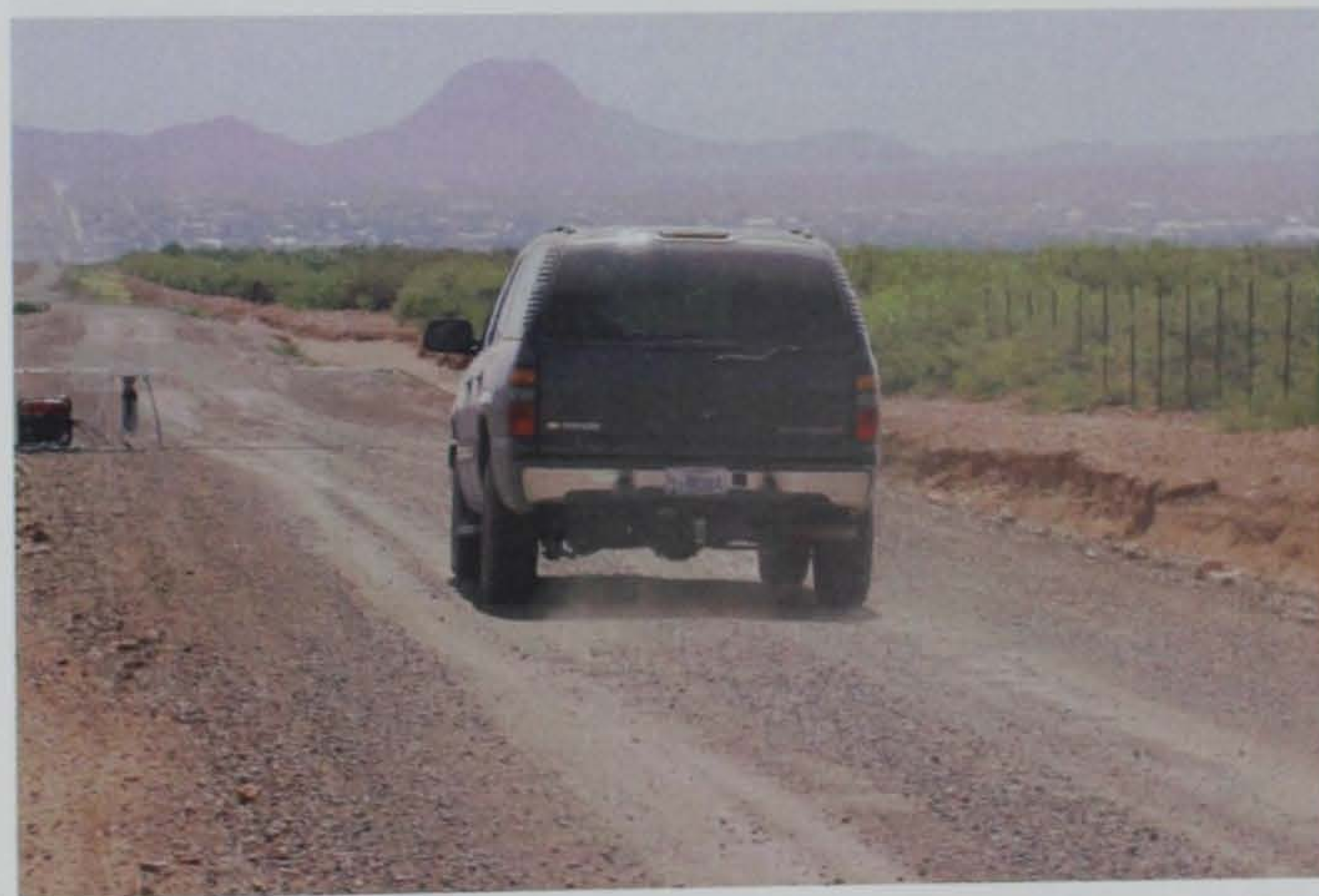

Photo 46. Good dust abatement on Section 19, Soiltac®

Photo 47. Moderate dust produced during testing on Secion 20, Soil-Sement®

Photo 48. Data collection on Section 17, Polytac®

Photo 49. Heavy dust during traffic on Section 21, EK-35®

Photo 50. Light dust behind vehicle traffic on Section 22, Envirokleen®

Photo 51. Reduced visibility behind vehicle on Section 23, CSS-1

Photo 52. Very heavy dust on untreated control section during testing

REPORT DOCUMENTATION PAGE

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The ERDC was tasked by the U.S. Marine Corps Systems Command to develop two dust control systems, one for expeditionary use on Forward Area Refueling Points (FARPs) and one for sustainment use on roads and other large area applications. The project consisted of evaluating various dust palliatives and application equipment under controlled laboratory conditions and during field tests. The products of this effort include equipment recommendations, palliative recommendations, and complete application guidance. This report addresses testing performed to evaluate commercial palliatives and application processes for constructing and maintaining lines-of-communication. Twenty-four test sections were constructed at Douglas, AZ, using both experimental and commercial palliatives for dust abatement. Several application procedures were evaluated in the process as well. Each test section was evaluated at 0, 30, 60, and 90 days after construction. The evaluation consisted of dust particle collection and soil property measurements. Pertinent conclusions from the testing conducted are noted, and recommendations for selecting dust abatement methods and materials are provided.

15. SUBJECT TERMS

Base camp maintenance	Dust control
Dust	Dust mitigation
Dust abatement	Lines of communication

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