ROAD STABILIZER PRODUCT PERFORMANCE
Buenos Aires National Wildlife Refuge

Publication No. FHWA-CFL/TD-05-011 **October 2005**

U.S. Department of Transportation
Federal Highway Administration

CTIP

Federal Lands Highway
Commitment to Excellence

Central Federal Lands Highway Division
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Lakewood, CO 80228

FOREWORD

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The FLH designs, administers and oversees an increasing amount of aggregate surfacing roadwork for clients in remote locations with limited budgets. Federal Land's clients, such as the National Park Service, US Forest Service, and Fish and Wildlife Service, often have limited budgets for construction and maintenance of their low volume roads. Dust generated by traffic on these unpaved roadways is a major problem that affects the experience of many visitors. Not only is excessive dust an irritation, but also causes reduced visibility, which is a driver safety hazard. Excessive dust from loose roadway material is also an indication of and contributes to roadway surface deterioration.

The primary objective of this project was to evaluate a number of road stabilizer products for potential use on FLH projects for dust control and surface stabilization. The performance of six different products was documented at the Buenos Aires National Wildlife Refuge in Arizona. Each section was evaluated for the products' application ease, performance over a 2-year period, and cost effectiveness.

F. David Zanetell, P.E., Director of Project Delivery
Federal Highway Administration
Central Federal Lands Highway Division

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-CFL/TD-05-011		

4. Title and Subtitle	5. Report Date
Road Stabilizer Product Performance: Buenos Aires National Wildlife Refuge	October 2005
	6. Performing Organization Code HFTS-16
7. Author(s) Roger W. Surdahl, P.E., J. Heather Woll, and Rick Marquez	8. Performing Organization Report No.
9. Performing Organization Name and Address Federal Highway Administration Central Federal Lands Highway Division 12300 W. Dakota Avenue, Lakewood, CO 80228	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Federal Highway Administration Central Federal Lands Highway Division 12300 W. Dakota Avenue, Suite 210 Lakewood, CO 80228	13. Type of Report and Period Covered Final Report August 2002 – August 2004 14. Sponsoring Agency Code HFTS-16.4

15. Supplementary Notes

COTR: J. Heather Woll, FHWA-CFLHD. Advisory Panel Members: Roger Surdahl, Rick Marquez, Randy Everett, Ron Andresen, and Brian Dobling, FHWA-CFLHD. This project was funded under the Federal Lands Highway Technology Deployment Initiatives and Partnership Program (TDIPP), and monitored under the Coordinated Technology Implementation Program (CTIP).

16. Abstract

Six different soil stabilizers were individually applied each on a 1.6 km (1mi) section to a depth of 150 mm (6 in) at the Buenos Aires National Wildlife Refuge in south central Arizona. These six products were monitored at 6-month intervals for a period of 2 years.

Visual evaluation included effectiveness in controlling dust, washboarding, and raveling. Materials tests and evaluation included Moisture/Density, Gradation, Liquid Limit, Plastic Limit, R-Value, CBR, and silt loading. Final analysis included an overall ranking of the six materials and their performance.

Roadway stabilization or dust abatement products are classified into the following seven basic categories:

1. Water
2. Water absorbing
3. Organic Petroleum
4. Organic Non-petroleum
5. Electrochemical
6. Synthetic Polymer
7. Clay Additives

For this specific semi-arid desert location and non-plastic roadway material, the best performing product was a formulation of an organic non-petroleum plus water absorbing material.

17. Key Words	18. Distribution Statement
DUST ABATEMENT, DUST PALLIATIVES, SOIL STABILIZER, DUST SUPPRESSANTS	No restriction. This document is available to the public from the sponsoring agency at the website http://www.cflhd.gov.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	78	

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	Millimeters	mm
ft	feet	0.305	Meters	m
yd	yards	0.914	Meters	m
mi	miles	1.61	Kilometers	km
		AREA		
in^2	square inches	645.2	Square millimeters	mm^2
ft^2	square feet	0.093	Square meters	m^2
yd^2	square yard	0.836	Square meters	m^2
ac	acres	0.405	Hectares	ha
mi^2	square miles	2.59	Square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	Milliliters	mL
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	Grams	g
lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	Lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	Newtons	N
lbf/in^2	poundforce per square inch	6.89	Kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	Inches	in
m	meters	3.28	Feet	ft
m	meters	1.09	Yards	yd
km	kilometers	0.621	Miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	Acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	Gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	Ounces	oz
kg	kilograms	2.202	Pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	Poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
C	Celsius
CFLHD	Central Federal Lands Highway Division
CBR	California Bearing Ratio
CTIP	Coordinated Technology Implementation Program
DCP	Dynamic Cone Penetrometer
DOT	Department of Transportation
F	Fahrenheit
F&WS	Fish and Wildlife Service
FHWA	Federal Highway Administration
FLH	Federal Lands Highway
FP	Federal Projects
HITEC	Highway Innovative Technology Evaluation Center
LTAP	Local Technical Assistance Program
MSDS	Material Safety Data Sheet
NWR	National Wildlife Refuge
SCR	Special Contract Requirement
TDIPP	Technology Deployment Initiatives and Partnership Program
US	United States
USFS	US Forest Service

EXECUTIVE SUMMARY

BACKGROUND

This study documents the results of a Federal Lands Highway Technology Program roadway dust stabilization project at the Buenos Aires National Wildlife Refuge. Six dust control products were installed and monitored for two years. The results show that for this specific semi-arid desert location and granular non-plastic roadway material, the best performing product was a formulation of an organic non-petroleum plus water absorbing material.

Controlling dust is an issue that concerns both private and public sector owners of unsurfaced roadways. There are approximately 6,359,568 km (3,950,042 mi[2]) of road in the United States. Of this total, about 2,327,332 km (1,445,548 mi), or 37% are unpaved. More specifically, of the 987,518 km (613,365 mi) of Federal Roads, 83.6% are unpaved. While the percentage of unpaved roads varies for each agency, each one shares the problem of dust generation from road user traffic. Stabilizing these unpaved roads and controlling dust is becoming a high priority as maintenance budgets continue to be woefully inadequate, as environmental concerns become more prevalent, and as quality road building materials are depleted and harder to procure. Owners of unsurfaced roadways face a big challenge. Identifying methods to effectively control dust on unsurfaced roads is a goal of the Federal Highway Administration (FHWA), Federal Lands Highway (FLH), and was the focus of this study conducted by the Central Federal Lands Highway Division (CFLHD).

Dust is defined as fine particulate material that can pass through a 75 µm (No. 200) sieve. It is material that has broken free from the unpaved roadway surface and floats in the air, carried by wind currents, until it finally settles to the ground. Dust can be particles of soil or rock. Road dust can be controlled, managed, reduced or even eliminated depending on the application, product, and strategy selected for the roadway.

A number of factors can contribute to the occurrence of dust. These include road material properties such as gradation, cohesion/bonding, and durability; construction controls such as level of compaction applied to the material and moisture (or lack there of) in the material; road use factors such as vehicle speed, number, weight, and wheels per vehicle; and environmental factors such as a dry climate.

There are several reasons to stabilize soil. The first is strength improvement to enhance load-bearing capacity. The second is dust control. The third is waterproofing to preserve the natural or constructed strength of a soil and to minimize the entry of surface water.

Soil stabilization materials can be applied by an admixture process or topically through surface penetration. In the admixture process, aggregate and soil materials are combined with the stabilizer product in one of three ways: 1) In-place mixing (blending the soil and stabilization materials with a reclamation machine), 2) Off-site mixing using stationary mixing plants, and 3) Windrow mixing using a grader. The second method of application is topical; that is, spraying a soil treatment material directly onto the existing roadway and allowing the palliative to penetrate.

A variety of stabilization and dust abatement products are on the market today. These products are classified by the United States Forest Service (USFS) into seven basic categories each with different attributes, applications, and limitations. The seven categories are 1) Water, 2) Water Absorbing, 3) Organic Petroleum, 4) Organic Non-Petroleum, 5) Electrochemical, 6) Synthetic Polymer, and 7) Clay Additives.

PROJECT DESCRIPTION

To broaden the base of knowledge about dust control products and application methods, the CFLHD applied six different road stabilizer or dust palliative products on a road reconstruction project at the Buenos Aires National Wildlife Refuge (NWR) in south-central Arizona. The purpose of the study was to evaluate the products for long-term performance and to recommend those products with acceptable performance for use on other CFLHD projects. This evaluation addressed each product's performance for dust control, rutting, washboarding, raveling, and soil stabilization over a 24-month period.

Using windrow mixing, the six roadway dust stabilizers were applied to 150 mm (6 in) depth in 1.6 km (1 mi) long sections throughout the construction project. The selected products, listed in Table 1, represent most of the major categories of stabilizers or dust suppressants and were those products most commonly used and available in the CFLHD 14-state oversight region. A seventh, 6.0 km (3.7 mi) long section, was also monitored and included in the report. On this section, Magnesium Chloride was surface-applied as a dust suppressant only. Since Magnesium Chloride is CFLHD's conventional dust abatement product, it was included in the evaluation as a performance reference point for comparison with the other six roadway dust stabilizers and palliative products.

It was anticipated that all of the products selected for this study would effectively stabilize the roadway material thereby controlling dust for at least 12 months. If, over this period, the stabilization significantly saved the owner agency manpower, machinery, and material costs equal to or more than the cost of the stabilization, then the study would be considered a success.

The cost and application rate of each product used in this study varied widely. No two manufactures recommended the exact same application rate. Because manufactures typically quote prices by the job depending upon the total quantity of product required, a simple price per gallon figure is difficult to pin point. In other words, price often will be reduced as the product quantity increases. A comparison using price per gallon is nearly impossible because price depends on varying market conditions as well as project location. Due to all of these factors, it is difficult to provide a detailed comparison of product costs. Finally, it should be noted that for this study, several manufactures either donated their products or sold them at a substantially reduced price to gain exposure from the work.

With this stated, a general comparison of product costs can be made by observing overall market prices and general cost data. The electrochemical enzyme products (Terrazyme and Permazyme in this study) are sold on the market at a cost significantly less than the other products used in this study. In a general comparison for a standard application, the enzyme products might cost approximately one-third of the chloride and sulfonated products (DC Caliber 2000, Mag/Lig, and the Lignosulfonate in this study) and one-fourth to one-fifth the cost of the Soil Sement product. Again, it should be noted that these comparisons are suggestions based on general cost data and are subject to many variations. Contractors or other agencies that use the results of this study should perform their own market analysis of product costs based on the proposed application, climate, specifications requirements, availability, and project location. The relative costs and application rates of the products used in this study are reported in Table 1.

Performance monitoring of each product occurred at 6-month intervals for a 24-month period beginning in March 2003, six months after the products were applied. Each monitoring event consisted of a visual inspection for dust control, washboarding, raveling, potholing, rutting, and leaching. The evaluation team also performed on-site physical testing consisting of Dynamic Cone Penetrometer (DCP) measurements, Silt Load evaluations, Nuclear Density Gauge readings, and GeoGage Soil Stiffness tests. The results of these observations are summarized in Table1. In general, the higher the number reported, the better the performance.

Table 1. Visual and physical value summary.

Test Section	Product	Visual Overall Average Score (x10)	Physical Overall Normalized Rank	Overall Average Score	Relative Cost	Relative Application Rate
I	**Mag/Lig**	65	90	77	Medium	High
II	**Caliber**	73	92	83	Medium	High
III	**Soil Sement**	55	76	65	High	Medium
IV	**Permazyme**	50	78	64	Low	Low
V	**Terrazyme**	55	78	66	Low	Low
VI	**Lignosulfonate**	56	84	70	Medium	High
VII	**Mag/Cl**	54	89	71	Medium	High

Each product's performance was fully acceptable throughout the 24-month study although, based on the levels of observed washboarding, some sections appeared to need a reapplication and blading to bring them back to full performance. Before stabilization, the owner agency had to grade, blade, or work the roadway at least every three months. During the entire 24-month study, they were requested not to maintain the roadway surface at all. Though some sections did need to be graded after 24 months, the owner agency had been saved from performing six to seven grading maintenance events.

In this report, the rating and performance of the electrochemical enzyme products, Permazyme and Terrazyme, deserve some special qualification. These electrochemical products are formulated to perform and react with materials containing clay particles. They are dependent on fine clay mineralogy to reach and achieve maximum performance for dust abatement and soil stabilization. Because the material used for borrow on this source was a "non-plastic" material containing no clay particles, these two products would probably not be optimal choices even though costs may be lower.

The tables, figures, and discussions in subsequent chapters show how each of the products performed in relation to the others. It is not the intent of this study to imply that any one product failed to adequately perform simply because its subjective visual rating values gave it a relative rank lower than another product. This project was considered a success for all products.

CONCLUSIONS

Assessment Methodology

The visual assessment was an acceptable method to compare performance of the products relative to each other at a single point in time; however it was limited for comparing product performance over time. The physical tests provided objective values over time but not all parameters of interest could be measured with physical objective tests. Thus, a combination of comparative visual and objective physical tests was used. As shown in Table 1, both methods appear valid as there is a clear correspondence between the average values of both the visual and physical observations. A summary of these average values may imply a higher level of precision than actually existed; so products have been simply grouped, and three groups are evident from the overall average scores. The Caliber product with the highest score is in the first group, the Mag/Lig is in the second, and all of the other products are in the third group. Similarly, from the overall average scores, there may be a desire to draw the conclusion that Caliber was a great product and Permazyme was not. This is not a correct conclusion. All products performed at an acceptable level under this study, and the Refuge benefited by not having to conduct six or seven maintenance activities over the 24-month period.

Performance Levels

Although varying levels of performance can be distinguished among the products at this particular project site, the order of observed performance may not be the same on another project where conditions such as specific soil type, climate, level of traffic, and rate of product application are different. The previously published literature on the effectiveness of these product categories also notes that product performance varies in relation to soil type, composition, climate, and traffic.

Supplier’s Role

Specifications for the use of some of these products are not yet developed for either surface or full-depth stabilization. Therefore, it was beneficial to have the product manufactures participating and providing recommendations for use and application. As was done under this study, a soil investigation and classification is needed to provide adequate information to the manufactures so that the site conditions can be matched with the best products. In addition, a physical sample of the proposed material for this roadwork should be given to each manufacturer.

Need for Special Contract Requirements (SCRs)

No single product is the only solution. Because all of the tested products performed well, these and additional products should be available for use on FLH projects. SCRs are needed in order to employ these newer products until such time that the FP-03, Standard Specifications for Federal Projects can be changed.

Stabilization Depth

With the observed drop in performance by the end of the study of the Mag/Cl surface application, it would appear that stabilization of a soil to a depth of 150 mm (6 in) is more effective and longer performing than surface applications. However, to prove this theory, the study should have employed a comparison of both surface and full-depth stabilization for each product. It could be further speculated that treating the roadway depth to half of what actually occurred would have also resulted in satisfactory results, but this is currently unsupported. This said, it appears there is a need in future studies to define a minimum effective depth of stabilization to provide for cost effective treatments, or to determine the cost effective balance between full depth stabilization and repeated applications of surface treatments.

Product Selection

Even though some product selection guidance already exists, education in the proper selection and specifying of roadway dust stabilizers is needed for Federal Lands Division designers and construction personnel as well as for Federal land management units that have road maintenance capabilities. Current selection processes start with the product, and show how they can be applied. For example, the USDA Forest Service publication entitled *Dust Palliative Application and Selection Guide* provides a table that indicates what kinds of soils and conditions best suit a particular class of products. A process that would work better would start first with identifying the composition and classification of the soil for a specific project, move to inputting climate, traffic, and environment requirements, then finally identify the best product or product class to use. While this study provided average scores for the products as well as relative costs and relative application rates, a different product selection process is needed to assist in deciding which product to use for a specific application.

Environmental Effects

No deleterious effects on the vegetation were observed for any of the products; however no physical environmental monitoring tests were done to conclusively verify this. Other non-visual effects may be measurable with other physical environmental monitoring tests. It must be acknowledged that at other locations with different conditions, some products may not be compatible with existing vegetation or may not be allowed by local agencies. There is a need to evaluate the various products' potential for environmental impacts.

RECOMMENDATIONS

- Develop SCRs to specify and allow the use of various dust and roadway stabilization products.

- Develop and employ a process for continued evaluation and validation of these and other products available in the FLH's jurisdictions. Include studies to define a minimum effective depth of stabilization to provide for cost effective treatments or to determine the cost effective balance between full depth stabilization and repeated applications of surface treatments. Consider partnering with the US Fish and Wildlife Service (F&WS) to evaluate environmental impact of the products.

- Perform further investigations using these same products with different types of soils, climates, and conditions to refine product selection processes. Further refine assessment parameters to strengthen objectivity and performance tracking over time.

- Collect additional information to develop more precise economic product comparisons based on initial and installation costs; application rates; and product effectiveness in terms of stability, dust mitigation, and longevity.

- Develop a selection chart for the optimum match of a product category with the site-specific parameters of soil type, composition, classification, climate, traffic, and environment.

- Develop and provide training for designers and field personnel on the application and use of these products.

- In partnership with the F&WS, incorporate environmental effects testing into future product comparison and monitoring projects on Federal lands.

CHAPTER 1 – INTRODUCTION AND BACKGROUND

THE DUST ISSUE

Dust is most always unwanted. In manufacturing, dust can seriously affect the quality of production. Without proper air filters, automobile engines wear down from the abrasive friction of dust particles. In dusty regions, people find it difficult to breath, and their body's reaction to dust is to cough and sneeze. Dust can create major economic disasters like what happened during the dust bowl era of the 1940's where uncontrolled farming practices exposed wide areas of soil to blowing wind, and dust storms of epic proportions choked entire states like Oklahoma and Kansas.

Today on unsurfaced roads or on road construction projects or travel ways adjacent to fields with loose material, blowing dust, as shown in Figure 1, is an irritant and obstacle that slows travel times and decreases driver safety due to loss of visibility. Several western State Department of Transportations (DOTs) now post signs on their roadways warning travelers to beware of dust.

Dust is defined as fine particulate material that can pass through a 75 µm (No. 200) sieve. It is material that has broken free from an unpaved roadway surface and floats in the air, carried by wind currents, until it finally settles to the ground. Road dust can be controlled, managed, reduced or even eliminated depending on the application strategy selected for the roadway.

Figure 1. Photo[1]. Dust typical of untreated roadway.

A number of factors can contribute to the occurrence of dust. These include road material properties such as gradation, cohesion/bonding, and durability; construction controls such as the level of compaction applied to the material and moisture (or lack there of) in the material; road use factors such as vehicle speed, number, weight, and wheels per vehicle; and environmental factors such as dry climate.

Controlling dust is an issue that concerns both private and public sectors, and many improvements have become standard practice. Strip farming practices and tree rows now prevent the reoccurrence of the dust bowls. Large building demolition projects now have requirements to use sprinklers to moisten the area. The Occupational Safety and Health Administration requires safety masks for workers exposed to dust. Sweeping compounds that attract fine particulate matter are now used in factories. Keeping haul road dust controlled is a constant effort, and roadway construction contractors are required to keep exposed areas moistened or covered with some kind of tackifier.

The owners of unsurfaced roadways probably face one of the biggest challenges today. There are approximately 6,359,568 km (3,950,042 mi[2])of road in the United States. Of this total, about 2,327,332 km (1,445,548 mi), or 37% are unpaved. More specifically as Table 2 shows, 987,518 km (613,365 mi) of roads that serve Federal and Indian lands, 825,247 km (512,576 mi) or 83.6% are unpaved.

While this information is derived from a FHWA document [3] published in 2000 and current lengths may vary slightly, it still shows the relative percentage of unpaved roads for each agency and how each one shares in the problem of dust generation due to the road user traffic. Thus, a high priority for each Federal Land Management Agency is to find economical and long lasting ways to control road dust. The challenge is amplified as maintenance budgets continue to be woefully inadequate, environmental concerns become more prevalent, and as quality road building materials are depleted and harder to procure. For these reasons, identifying methods to effectively control dust on unsurfaced roads is a goal of the Federal Highway Administration (FHWA), Federal Lands Highway (FLH) and was the focus of this study conducted by the Central Federal Lands Highway Division (CFLHD).

DUST STABILIZATION

Roads constructed of native borrow materials typically do not have the ideal range and distribution of particle sizes to have a good load bearing capacity. Dust palliative products applied for in-depth stabilization can enhance the strength or load bearing capacity of the native road. Gravel road materials typically have been engineered for strength, yet all gravel roads suffer surface abrasion loss when dry. Application of a dust palliative can preserve adhesion between fine particles which reduces dusting. If adhesion is not preserved, the fine loose material in the road blows away in the wind or washes away under heavy rain. Over time, the amount of fine binding soil in the road is reduced, and gradually, more and larger particles break away. The loose surface material becomes prone to increased dusting, potholing, and corrugation making road travel uncomfortable and less safe.

There are several reasons to stabilize soil. The first is strength improvement to enhance load-bearing capacity. The second is dust control. The third is waterproofing to preserve the natural or constructed strength of a soil and to minimize the entry of surface water.

Soil stabilization materials can be applied by an admixture process or topically through surface penetration. In the admixture process, aggregate and soil materials are combined with the stabilizer product in one of three ways: 1) In-place mixing (blending the soil and stabilization materials with a reclamation machine), 2) Off-site mixing using stationary mixing plants, and 3) Windrow mixing using a grader. The second method of application is topical; that is, spraying a soil treatment material directly onto the existing roadway and allowing the palliative to penetrate.

Table 2. Summary of Federal Roads

Federal Lands Served	Road Category	Owner	Length Miles	Unpaved Miles	Percent Unpaved
Department of Agriculture					
National Forests	Forest Highways	State and Local	29,200	7,800	26.7%
	Forest Development Roads (60,000 miles Public Roads)	Forest Service	385,000	357,000	92.7%
Department of Interior					
National Parks	Park Roads and Parkways	National Park Service	8,127	2,988	36.8%
Indian Lands	Indian Reservation Roads	Bureau of Indian Affairs and Tribes	23,000	17,500	76.1%
	Indian Reservation Roads	State and Local	25,600	15,450	60.4%
Wildlife Refuges	Wildlife Refuge Roads	Fish and Wildlife Service	5,900	5,400	91.5%
	Administrative Roads	Fish and Wildlife Service	3,100	3,100	100%
Public Lands (BLM lands)	Land Management Highways	State and Local	7,200	3,600	50.0%
	Public Lands Development Roads (Administrative Roads)	Bureau of Land Management	83,000	81,300	98.0%
Reclamation Projects	Reclamation Roads (Intended for Public Use)	Bureau of Reclamation	1,980	980	49.5%
	Administrative Roads	Bureau of Reclamation	8,000	7,200	90.0%
Department of Defense					
Military Installations	Military Installation Roads	Department of Defense	23,000	0	0%
	Missile Access Defense (Malmstrom, Minot, and Warren)	State and Local	1,858	1,858	100%
U.S. Army Corps of Engineers					
Corps of Engineers Recreation Areas	Corps Recreation Roads	Corp of Engineers	4,800	4,800	100%
	Corps Leased Roads	State and Local	3,600	3,600	100%
		TOTAL	613,365	512,576	83.6%

STABILIZATION AND DUST ABATEMENT MATERIALS

There are numerous products on the market today for stabilization and dust abatement purposes. Currently these products are classified by the United States Forest Service (USFS)[(4)] into seven basic categories each with different attributes, applications, and limitations:

1. **Water** acts to bind material together by surface tension. As such, dust will not float into the air while attached to larger particles. Water is easy to apply but it tends to dry or evaporate quickly. When the material loses its surface tension, dusting and other surface deterioration will occur.
2. **Water Absorbing** products include various chlorides of salt. These materials have the ability to absorb moisture from the air and retain that moisture in the soil. Aggregates treated with these products can be re-wetted and re-worked. Their effectiveness is a function of the air temperature and relative humidity.
3. **Organic Petroleum** products include asphalt emulsions, cutback asphalts, and dust oils. These tend to bind particles together through adhesion, and can waterproof the road. They are relatively insensitive to moisture but under dry conditions may not retain their resilience. In thin layers, they may form a crust and fragment under traffic and could be difficult to maintain.
4. **Organic Non-Petroleum** products include lignin derivatives, tall-oil derivatives, sugar beet extracts, and vegetable oils. These products bind aggregates in much the same way that petroleum products do, but they may be less effective because they are more water-soluble and oxidize more rapidly. These products are more environmentally friendly than the Organic Petroleum products.
5. **Electrochemical** products include enzymes, ionic compounds and sulfonated oils. Their performance depends on the clay mineralogy, and they need time to react with the clay fraction. Some of the products are highly acidic in their undiluted form.
6. **Synthetic Polymer** emulsions include polyvinyl acetate, vinyl acrylic, and polymer combinations. These emulsions bind aggregates together through the polymer’s adhesive properties. These too, once applied and set in place as thinner layers, may crust and fragment under traffic and be difficult to maintain.
7. **Clay Additives** are natural clays such as bentonite and montmorillonite. These materials gather together the fine dust particles of the aggregate. They tend to increase the dry strength of the aggregate under dry conditions. However, if too much product is applied, the roadway surface may become slippery when wet.

The evaluation team found this USFS *Dust Palliative Application and Selection Guide* to be a very valuable resource in that it not only presents Dust Suppressant Category information - Attributes, Limitations, Applications, Origin, and Environmental Impact - but also shows the various types of suppressants within each category and offers a list of specific product names and manufactures. The guide also advises that these products be applied as recommended by the supplier for the soil type and conditions specific to the project with a review of the products’ Material Safety Data Sheets (MSDS) to identify and address any applicable environmental concerns. A product selection flowchart is also included in this publication.

OTHER DUST STUDIES

A literature search reveals that many studies have been conducted to investigate effective methods to control dust, or to categorize the numerous dust control products. The ones discussed below are in chronological order and have significantly contributed to the overall effort of documenting solutions to the dust problem.

Non-Standard Stabilizers

In 1992 prior to the USFS study discussed above, the FHWA prepared a similar work entitled *Non-Standard Stabilizers* [5] to summarize dust stabilization products. As its title suggests, this work listed new and emerging products, their applications, the manufacturers and suppliers, and relative costs. Now a decade or more later, this work is somewhat dated in that many of the non-standard products are either now standard or unavailable, and many of the suppliers and product names have changed. Nevertheless, it still is a good reference for overall product categories and for finding recommendations on matching the best product with the specific site condition.

Gravel Roads Maintenance and Design Manual

In 2000, the South Dakota Local Technical Assistance Program (LTAP) produced a *Gravel Roads: Maintenance and Design Manual* [6]. The majority of this publication deals with designing and maintaining gravel roads, however one chapter is devoted to controlling dust. It makes general recommendations for the applicability, selection, and use of various products. While this information is not as detailed as some of the other studies, it is unique in that it links recommendations for dust control with the routine roadway maintenance activities.

Dust Control on Low-Volume Roads

In 2001, the FHWA in cooperation with the LTAP produced *Dust Control on Low-Volume Roads, a Review of Techniques and Chemicals Used*[7]. This document was very similar to the USFS and FHWA publications noted earlier and presented updated information on products, prices, application rates, and performance.

The World Bank Study

In September 2002 a World Bank sponsored study was completed by the Brazil's National Department of Roads and Highways that reported results in a document, *A Comparative Study of the Performance of the Soil Stabilizers in Secondary Unsurfaced Roads in Paraguay*[8]. Under this study nine different products from three stabilizer categories were installed on seven experimental sites with seven to ten products per site. Two products could be categorized as Organic Non-Petroleum, six products as Electrochemical, and one as Synthetic Polymer Emulsion. The roadway material compositions varied from sandy to clayey soils with low to high Plasticity Indices. No sites were categorized as having Non Plastic material. During the installation at each site, the roadway surface was scarified to a depth of 20 mm (¾ in), and re-compacted after the each product application.

The study used three monitoring methods, the Dynamic Cone Penetrometer (DCP), the Clegg Impact Soil Tester, and the Unsurfaced Road Condition Assessment. While these three methods all produced different results, they still found that five of the seven stabilized sites performed better than the adjacent untreated sites. They also found that product performance varied with soil type. They noted that the electrochemical enzymes worked best on clayey, sandy clay, and silty sand type soils, and the electrochemical sulfonated oils worked best on clayey type soils.

The usefulness of this study is its contribution to understanding what kind of soils might be enhanced by a given product. However, the results are not conclusive on which classes of products work best for a particular kind of soil – for example, soils that are Non Plastic.

The HITEC Pool Fund Study

In 2002, the Highway Innovative Technology Evaluation Center (HITEC) initiated a long-term study entitled *Evaluation Plan for the Group Evaluation of Soil Stabilization and Dust Suppression Products* [(9)].

The primary objective of this study was to perform well-defined field and laboratory tests of dust suppressant and soils stabilizer products that would provide performance and baseline environmental data. Performance data would be related to soil type, level of traffic, and climate. This data would answer questions such as:

- Do the products perform as claimed or intended?
- How do they perform in relation to various climatic conditions?
- How long do the products remain effective?

Baseline environmental data would focus on how friendly the products are to people and the environment:

- Do the products have any characteristics of hazardous waste?
- Do the products impact water quality?
- Do the products impact air quality?
- Are the products easy and safe to use?

Finally, the cost effectiveness issue would be explored.

To date only four vendors have participated and no results are yet available. When conclusions are documented, they will be posted at the HITEC website.

STUDY JUSTIFICATION AND GOALS

The FLH designs, administers, and oversees an increasing amount of aggregate surfacing roadwork for clients in remote locations throughout the western United States. The CFLHD specifically, oversees the construction of highways on Federal Lands in 14 western states as shown in Figure 2.

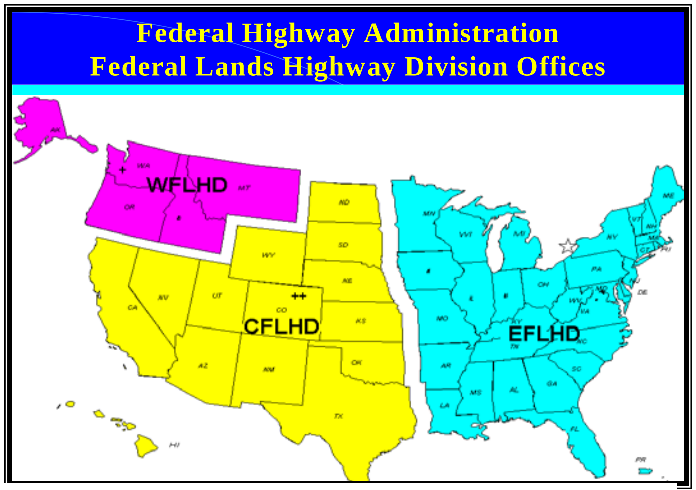

Figure 2. Map. FHWA FLHD regions.

FLH's clients, such as the National Park Service, USFS, Bureau of Indian Affairs, Department of Defense, and US Fish and Wildlife Service (F&WS) often have limited budgets for construction and maintenance on their low volume roads. To save money they often request their roads be surfaced with native materials. While many of these materials are adequate for their intended use, at times additional processing is required to add stabilizing and dust control components.

Currently in the FHWA FLH's FP-03 Standard Specifications for Highway Construction[10] the dust abatement options provided are water, magnesium chloride, Lignosulfonate, calcium chloride, and emulsified asphalt. The FLH recognizes that there are many other options available that may be viable solutions for controlling dust and reducing maintenance costs.

As discussed above, there are many completed and ongoing studies on the topic of stabilization and dust control. However, no studies specifically addressed the products readily available in CFLHD's 14-state oversight area or the specific soil conditions found at the project site. In addition, long-term performance data and cost comparison data was unavailable. Thus, a practical study covering commonly available products, their method of application, long-term performance, and relative costs was needed. Results of such a study would not only provide valuable information to the owner agency, but would also add to a growing knowledge base on product performance related to various soil types and climates.

The primary objective of this project was to incorporate six different road stabilizers and dust palliatives on one of the CFLHD's construction projects, to evaluate the products for long-term performance, and to recommend those products with acceptable performance for use on other CFLHD projects. The evaluation addressed each product's performance for dust control, rutting, washboarding, raveling and material stabilization over a 24-month period.

While visual observations for product leaching were done, no other physical monitoring such as ground water quality, fresh water aquatic environment, or plant community was conducted to document any environmental effect of the products. Still, it continues to be a point of concern as subsequent to the completion of this study, one of the FLMAs issued direction that any further projects using dust stabilizers on their lands must include a minimum 3-year environmental monitoring plan to include monitoring during the year prior to application, the year of application, and a year following the application.

It was anticipated that all of the products selected for this study would effectively stabilize the roadway material thereby controlling dust for at least twelve months. If over this period, the stabilization significantly saved the owner agency manpower, machinery, and material costs equal to or more than the cost of the stabilization, then the study would be considered a success.

The tables, figures, and discussions in subsequent chapters show how each of the products performed in relation to each other. It is not the intent of this study to imply that any one product failed to adequately perform simply because its subjective visual rating values gave it a relative rank lower than another product. Each product's performance was fully acceptable throughout the 24-month study, although based on the levels of observed washboarding; some sections required a reapplication of the product to reestablish an acceptable ride surface. Before the stabilization project, the owner agency had to grade, blade, or work the roadway at least every three months. During the entire 24-month study, they were requested not to maintain the roadway surface at all. By the end of this 24-month study, some sections did need to be graded; however the owner agency had been saved from performing six to seven grading maintenance events.
Therefore, this project was considered a success for all products and for the owner agency.

Figure 3. Map. Buenos Aires NWR site location.

PROJECT BACKGROUND

The project site selected for this evaluation is located in the Buenos Aires National Wildlife Refuge (NWR) in south central Arizona as shown in Figure 3. Buenos Aires NWR is a 46,575 ha (115,000 ac) refuge established to preserve the endangered masked bobwhite quail. It also is home to 300 other species of birds, including hawks, herons, gray hawks, vermilion flycatchers and golden eagles. Resident mammals include coyotes, deer, foxes, and pronghorn antelope.

The Refuge contains extensive semi-desert grasslands, various types of cacti, and groves of small trees. Due to the desert climate, the land is mostly dry; but during the monsoon season there are streams and a lake that fill with water. Several popular hiking trails are located on the eastern side of the Refuge near the town of Arivaca. However, the vehicular tour roads are the most popular access route to view all of the flora and fauna. Improving the visitors' experience on these travel ways was an important rationale for upgrading the roads.

The original Buenos Aires NWR Tour Roads were constructed using local materials from a nearby borrow source. The sections suffered from severe raveling, potholing, and dusting. The Refuge reported that the average daily traffic was low, ranging from 8 to 25 vehicles per day depending on the season of the year. The FLH also measured traffic volumes at various locations on the route, and confirmed these estimates. However, even these low traffic volumes generated dust, created visual and air quality concerns for Refuge visitors and wildlife, and also covered vegetation along the roadway.

The resulting reconstruction project, Arizona RRP BUAI 10(2) Auto Tour Roads [11], was designed and administered by the CFLHD. The CFLHD Construction Branch was responsible for contract negotiations and project layout, and also provided the construction inspection, reporting and initial materials sampling. The stabilization portion of the project was primarily financed under the FLH Technology Deployment Initiatives and Partnership Program that promotes deployment of transportation-related research and technology, and the monitoring was funded by the Coordinate Technology Implementation Program. The construction contractor was A&S Paving, Tucson, Arizona. Construction of the project, including the application of the roadway dust stabilizers, was completed in August 2002.

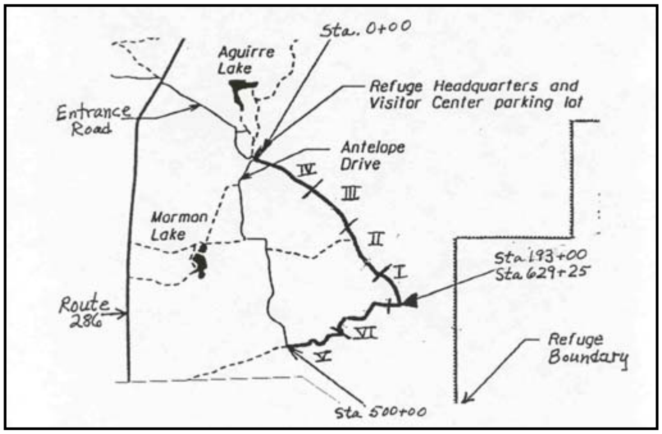

Figure 4. Map. Buenos Aires NWR site and test locations.

PROJECT LAYOUT AND PRODUCTS

Figure 4 shows the layout of the project. Six types of roadway dust stabilizers and palliatives were applied 15.2 cm (6 in) deep in 1.6 km (1 mi) long sections throughout the 9.6 km (6 mi) long reconstruction project. The selected products, as shown in Table 3, represent most of the major categories of stabilizers or dust suppressants. The products chosen were based on those products most commonly used and available in the CFLHD 14-state oversight region.

A seventh, 6.0 km (3.7 mi) long section, was also monitored and included in the study. This section was the north-south segment between Mileposts 6.2 and 0.0 on which Magnesium Chloride was surface-applied as a dust suppressant only. Since Magnesium Chloride is one of CFLHD's conventional dust abatement products, it was included in the evaluation for comparison with the other six-roadway dust stabilizers and palliative products that are not current options in the standard FP-03 specifications**.**

GENERAL PRICE ANALYSIS AND SAVINGS

The cost and application rate of each product used in this study varied widely. No two manufactures recommended the exact same application rate. Because manufactures typically quote prices by the job depending upon the total quantity of product required, a simple price per gallon figure is difficult to pin point. In other words, price often will be reduced as the product quantity increases. A comparison using price per gallon is nearly impossible because price depends on varying market conditions as well as project location. Due to all of these factors, it is difficult to provide a detailed comparison of product costs. Finally, it should be noted that for this study, several manufactures either donated their products or sold them at a substantially reduced price to gain exposure from the work.

With this stated, a general comparison of product costs can be made using overall market prices and general cost data. The electrochemical enzyme products (Terrazyme and Permazyme in this study) are sold on the market at a cost significantly less than all the other products used in this study. In a general comparison for a standard application, the enzyme products might cost approximately one-third the cost of the chloride and sulfonated products (DC Caliber 2000, Mag/Lig, and the Lignosulfonate) and one-fourth to one-fifth the cost of the Soil Sement. Again, it is noted that these comparisons are suggestions based on general cost data and are subject to many variations. Contractors or other agencies that use the results of this study should perform their own market analysis of products costs based on the proposed application, climate, specifications requirements, availability, and project location.

Table 3. Test sections, locations, products, and suppliers.

Test Section	Approximate Milepost Locations	Product and Category	Manufacturer's Undiluted Application Rate	Supplier
I	3.0 – 4.0	Magnesium/Lignosulfonate (Mag/Lig) *(Water absorbing + Organic non-Petroleum)*	6 gal/yd^3	Desert Mountain P.O. Box 163 Kirtland, NM
II	2.0 – 3.0	Caliber DC 2000 (Caliber) *(Organic non-Petroleum (vegetable corn oil) + water absorbing (Mag/Cl))*	6 gal/yd^3	Desert Mountain P.O. Box 163 Kirtland, NM
III	1.0 – 2.0	Soil Sement *(Synthetic Polymer Emulsion Vinyl Acrylic)*	1.1 gal/ yd^3	Earth Care Consultants P.O. Box 8431 Canton, OH
IV	0.0 – 1.0	Permazyme *(Electrochemical enzyme)*	0.006 gal/ yd^3 (0.77 oz/ yd^3)	International Enzymes, Inc 1706 Industrial Road Las Vegas, NV
V	5.2 – 6.2	Terrazyme *(Electrochemical enzyme)*	0.006 gal/ yd^3 (0.77 oz/ yd^3)	Nature Plus, Inc 555 Lordship Blvd. Stratford, CT
VI	4.0 – 5.2	Lignosulfonate *(Organic non-Petroleum)*	6 gal/yd^3	Desert Mountain P.O. Box 163 Kirtland, NM
VII	6.2 – 0.0	Magnesium/Chloride (Mag/Cl) *(Water absorbing)*	0.25 – 0.50 gal/yd^2	Desert Mountain P.O. Box 163 Kirtland, NM

Since the Refuge did not need to conduct routine maintenance on the roadway throughout this study, there was a definite benefit in maintenance cost savings. Unfortunately, the annual roadway maintenance costs were not recorded at the Refuge for previous years. Other cost estimates however can be found in a 2003 study[13] of gravel roads in four Minnesota counties where the average annual cost to maintain the gravel roads varied from $857 to $3,386 per km ($1,380 to $5,452 per mi). For the total 15.6 km (9.7 mi) of gravel road in this study, and assuming a higher cost of $3,105/km ($5,000/mi) for the Refuge due to its remoteness, the savings could be estimated at $97,000. As discussed earlier, since this was an evaluation study with some but not all of the costs borne by some of the suppliers, the overall true cost of the study was not determined. What can be noted is that the construction contractor was paid $83,168.28[(11)] to procure and install the products. As a result, the benefit to cost ratio for this study can be estimated as approaching 1 or just slightly higher.

CHAPTER 2 – PRODUCT INSTALLATION AND MONITORING

Figure 5. Photo. Typical product application.

Figure 6. Photo. Typical borrow material and product blending.

Figure 7. Photo. Typical rolling and compaction.

PRODUCT APPLICATION

All products shown in Table 3 were applied according to each supplier's recommendation. Each company provided an on-site representative to ensure their product was applied properly in two to three applications as they requested. Each product was applied to the roadway materials in windrows; blade mixed, and then compacted with a 9.4 Mg (12-ton) 9-wheel pneumatic roller to a total stabilized depth of 150 mm (6 in.) Figures 5, 6, and 7 show the typical process used to apply the products on the Buenos Aires NWR Tour Roads project.

A summary of the application processes for the products used in the individual sections is as follows:

Sections I, II, & VI (Mag/Lig, Caliber, Lignosulfonate)

- 75 mm (3 in) of Select Topping Material was bladed off and windowed to the side of the road.
- The product was applied to the bladed surface in two passes.
- 75 mm (3 in) of the windrowed material was placed on top of the applied surface.
- The product was applied to the top surface in three passes.
- The material was bladed back and forth to level it and work cobbles to the side.
- The material was rolled in with a 9-wheel pneumatic roller.

Section III (Soil Sement)

- The select borrow roadway was scarified 150 mm (6 in) deep and windrowed to one side of roadway.
- The product was applied to the bladed surface and allowed to soak in.
- The blade pulled material from the windrow and spread it in a 75 mm (3 in) lift.
- Additional product was applied to the top surface and allowed to soak in.
- The blade pulled more material from the windrow spreading it in a second 75 mm (3 in) lift.
- The product was applied a third time.
- The material was processed back and forth with a blade to level it and work cobbles to the side.
- The material was rolled in with a 9-wheel pneumatic roller.
- The following day the road was tight bladed, popping all loose and large cobbles from the surface, which were windrowed to the side.
- Plain water was applied to the road from the water truck.
- The product was applied again topically in three passes and allowed to soak in between each application.

Section IV (Permazyme)

- The select borrow roadway was scarified 150 mm (6 in) deep and windrowed to one side of roadway.
- The manufacturer's recommended dosage rate was 3.785 liters (1 gal) of product concentrate per 3785 liters (1000 gal) of water.
- The diluted product was sprayed over the section and blade mixing began. The diluted product was applied while mixing occurred until the required amount of solution was put down. For this first application, a total of two truckloads of diluted product were applied, or about 30 liters (8 gal) of concentrate.
- The material was processed and mixed using a blade with additional plain water from the water truck.
- The material was windrowed to one side of the road to promote total moisture adsorption and was left for finishing until the next day.
- On the second day, additional diluted product was applied to the windrow and roadway surface with the water truck.
- The blade pulled treated material from the windrow and spread it in a 50 to 75 mm (2 to 3 in) lift.
- The material was rolled in with a 9-wheel pneumatic roller.
- The water truck made another pass with the diluted product.
- The blade pulled more treated material from the windrow and laid it over the previous lift.
- The roller compacted the material.
- The water truck made another pass spraying the diluted product.
- The blade processed the material back and forth smoothing it out evenly.
- The water truck made a final pass with the diluted product.
- The blade continued to process the material with the water truck adding plain water as needed.

- The roller made 2 final passes over the test section.

Section V (Terrazyme)

- The select borrow roadway was scarified 150 mm (6 in) deep and windrowed to one side of roadway.
- Before the product was applied, 75 mm (3 in) of untreated select borrow roadway material was spread back over the roadway surface.
- A water diluted solution of the product was sprayed over the roadway with a water truck.
- The blade pulled more material from the windrow and spread over the roadway.
- The water truck made another pass with the diluted product.
- The remaining material from the windrow was spread over the roadway.
- The water truck made a final pass with the diluted product.
- The material was processed back and forth with a blade to level it and work cobbles to the side.
- The material was rolled in with a 9-wheel pneumatic roller.

MONITORING PROGRAM

Performance monitoring of each product occurred at 6-month intervals for a 24-month period beginning on March 2003, six months after the products were applied. Each monitoring event consisted of a visual inspection for dust generation, washboarding, raveling, potholing, rutting, and leaching. The evaluation team also performed on-site tests of DCP measurements, Silt Load evaluations, Nuclear Density Gauge readings, and GeoGage Soil Stiffness tests. Table 4 lists the sampling and testing performed during various evaluation periods.

Visual Inspection Parameters

The primary categories or parameters of visual inspection were: 1) effectiveness against visual dust, 2) degree of washboarding affecting the ride smoothness, and 3) amount of raveling. Dust was monitored using a two-vehicle caravan that traveled at 40 to 50 kph (25 to 30 mph) throughout each test section. The evaluators in the trailing vehicle noted the relative amounts of visible dust produced by the leading vehicle. Other secondary parameters such as the amount of potholing and rutting were also evaluated. Visible leaching of stabilizing material due to rain was included. Additional observations noted the overall structural appearance, that is, hardness or softness, binding or loss of material, crusting and fragmenting, and impacts on roadside vegetation.

Visual Assessment Methodology

The main goal of the monitoring project was to determine how each stabilizer product performed in relation to the others. Initially in monitoring the products, objective rating systems were tried, such as the Corps of Engineer's method [12], but these proved to be insensitive to subtle differences in performance. Therefore, an 11-point comparative rating system was selected that, though subjective, allowed for the desired sensitivity.

Table 4. Parameters evaluated during each monitoring period.

Monitoring Parameter	Monitoring Event				
	Initial (August 17, 2002)	**6-month** (March 4 & 5, 2003)	**12-month** (August 11, 2003)	**18-month** (March 17, 2004)	**24-month** (August 24, 2004)
Dust		X	X	X	X
Washboard		X	X	X	X
Raveling		X	X	X	X
Potholing		X	X	X	X
Rutting		X	X	X	X
Leaching		X			
Density	X	X			
Gradation	X	X			
R-value	X	X			
DCP			X	X	X
CBR	X(a)	X(a)	X(b)	X(b)	X(b)
Silt Loading			X	X	X
Stiffness			X		

(a) CBR values produced from laboratory testing
(b) CBR values measured from field tests with the DCP

The scale of this method was from 0 to 10 with neither 0 nor 10 referring to any absolute value, description, or picture. Rather, larger numbers indicated a better condition and smaller numbers a worse condition. The first section driven received an arbitrary rating of 5 for each parameter and served as the benchmark. Then as the 3 evaluators road in the inspection vehicle, each of them independently scored each stabilization section as comparatively better (larger numbers) or worse (smaller numbers) than the benchmark section. The individual scores were averaged, and these average values are shown in the rating tables and charts within this report.

With this comparative system, the relative standing of each product among its peers was observed. Depending on varying conditions, such as temperature and precipitation at each monitoring event, the relative standings between products was expected to vary somewhat. Therefore, an overall average standing from the four monitoring events was calculated and used in summary tables.

After completion of the study, the evaluators became aware of possible bias created by carrying out the comparative rating always starting with the same section – Section IV Permazyme. Doing the evaluations in the same order at each monitoring event perhaps created a strong pattern of expectation in the evaluators. In future studies the beginning, or baseline, section that receives a 5 rating will be rotated among the sections. The authors apologize for this procedural oversight but still believe product performance was rated fairly.

One interesting outcome from using this comparative rating system was the complete lack of any data showing expected decreasing performance over time. An objective (outside written criteria) system would provide this kind of data. However, the major study goal of determining the best performing products for soil type at the Refuge was definitely supported by the comparative rating system.

FIELD SAMPLING AND LABORATORY TESTING

Material from a wash of a local dry streambed was used as the borrow source for the select topping. This borrow material was generally of good quality and met the Special Contract Requirement Section 704.08[11]. The specific borrow characteristics prior to and after treatment are discussed in Chapter 4.

Sampling and testing were performed during the initial placement and over the 24-month evaluation period. Table 5 summarizes the specifications and other tests used to evaluate the roadway materials on this project.

Figure 8. Photo. Stockpile of granular material used for topping.

Table 5. Standard specifications, sampling and testing.

Test Number	Description
AASHTO T 11	Material Finer Than 75-µm (No. 200) Sieve in Mineral Aggregate by Washing
AASHTO T 27	Sieve Analysis of Fine and Coarse Aggregate
AASHTO T 89	Determining the Liquid Limit of Soils
AASHTO T 90	Determining the Plastic Limit and Plasticity Index of Soils
AASHTO M 145	Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes
AASHTO T 180, Method D	Moisture-Density Relations of Soils Using a 4.54 Kg (10 lb) Rammer and 457 mm (18 in) Drop
AASHTO T 190	Resistance R-value and Expansion Pressure of Compacted Soils
AASHTO T 193	The California Bearing Ratio
AASHTO T 310	In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Method (shallow Depth)
ASTM D 6951	Dynamic Cone Penetrometer
40 CFR 52.128(b)(16)(i)(B)	Silt Loading
ASTM D 6758	GeoGage Soil Stiffness Modulus Testing

CHAPTER 3 – VISUAL MONITORING RESULTS AND EVALUATIONS

CLIMATE AND WEATHER AT THE MONITORING SITE

During each monitoring event, monthly weather charts from the Refuge's weather station were collected. These monthly weather charts for the study period are held on file at CFLHD. The desert climate at Buenos Aires NWR is predominantly dry but experiences periods of heavy monsoon-type storms especially in July and August. The temperatures and precipitation for the 24-month monitoring period were typical of a semi-arid desert grassland with temperature reaching highs of 40^o C (103^o F) in July and lows of -7^o C (20^o F) in December. The precipitation was heaviest during July with as much a 150 mm (6 in) of rain. The driest months with no significant rain were April through June, and an average of 5 mm (0.2 in) was reported during the months of August through March.

The evaluation team thought that a tabulation of the daily weather data for the entire 24-months would not contribute to the conclusions as most days showed no precipitation. In the rare event when rainfall was recorded, it was on the order of 3 mm (0.1 in) per day. However, at least one monsoon event was noted at 43 mm (1.7 in) for that day.

What was deemed important, however, was the weather during each actual monitoring event and the days immediately prior. Primarily, the weather influenced the visual observations of dust. A relatively dry monitoring event period would allow for greater amounts of dust, whereas a moist or wet event would limit it. This was not considered an issue because the measures during each monitoring period were relative to each other and not an absolute measure.

Rainfall data was also needed to evaluate the level of each product's potential leaching from the stabilized roadway. The evaluation team concluded that rainfall levels of 3 mm (0.1 in) could not produce enough moisture to saturate the roadway into a state where leaching was possible. On the other hand, monsoon events of 75 mm (3 in) in a single day would wash any visible leachable product material far away from the source.

At the 6-month monitoring event on March 4-5, 2003, the weather was cold and windy with intermittent light sprinkles. Weather in the 3-weeks prior to this was also rainy, windy, and cold. At the 12-month monitoring event on August 11, 2003, the weather was very warm reaching a high of 120^o. There was a trace of rain as is typical this time of year. At the 18-month monitoring event on March 17, 2004 the weather was warm and in the eighties for the day. At the 24-month monitoring event on August 24, 2004 the day started out with a few sprinkles. By midday however, the weather was warm in the upper eighties, and a light breeze of 10 to 15 miles per hour lasted most of the day.

DUST ABATEMENT

Table 6 indicates the dust rating values for each of the monitoring periods. As discussed earlier, these values are the average of the three evaluators' ratings. The final column on the right is, for each of the test sections, an overall average value representing performance over the entire 24-

months. Since these values are based on a scale of 0 to 10, they represent a normalized scale and can be directly compared with the average values of the other subjective observations. The values for each product at each monitoring event and the overall average are plotted in Figure 9.

Table 6. Dust rating values.

Test Section	Product	6-Month Average Value	12-Month Average Value	18-Month Average Value	24-Month Average Value	Overall Average Value
I	**Mag/Lig**	6.3	6.7	7.7	7.3	7.0
II	**Caliber**	8.3	8.0	8.7	7.7	8.2
III	**Soil Sement**	5.0	5.3	7.7	5.3	5.8
IV	**Permazyme**	5.0	5.0	5.0	5.0	5.0
V	**Terrazyme**	5.7	5.0	6.3	5.0	5.5
VI	**Lignosulfonate**	6.3	5.7	7.0	5.0	6.0
VII	**Mag/Cl**	7.3	5.3	6.0	4.3	5.8

Note: These averaged scores are based on a 0 to 10 scale with 10 indicating the best performer and 0 the worst performer. The baseline product (Section IV) was the first product to be rated and was given a score of 5. All other products were compared to that product.

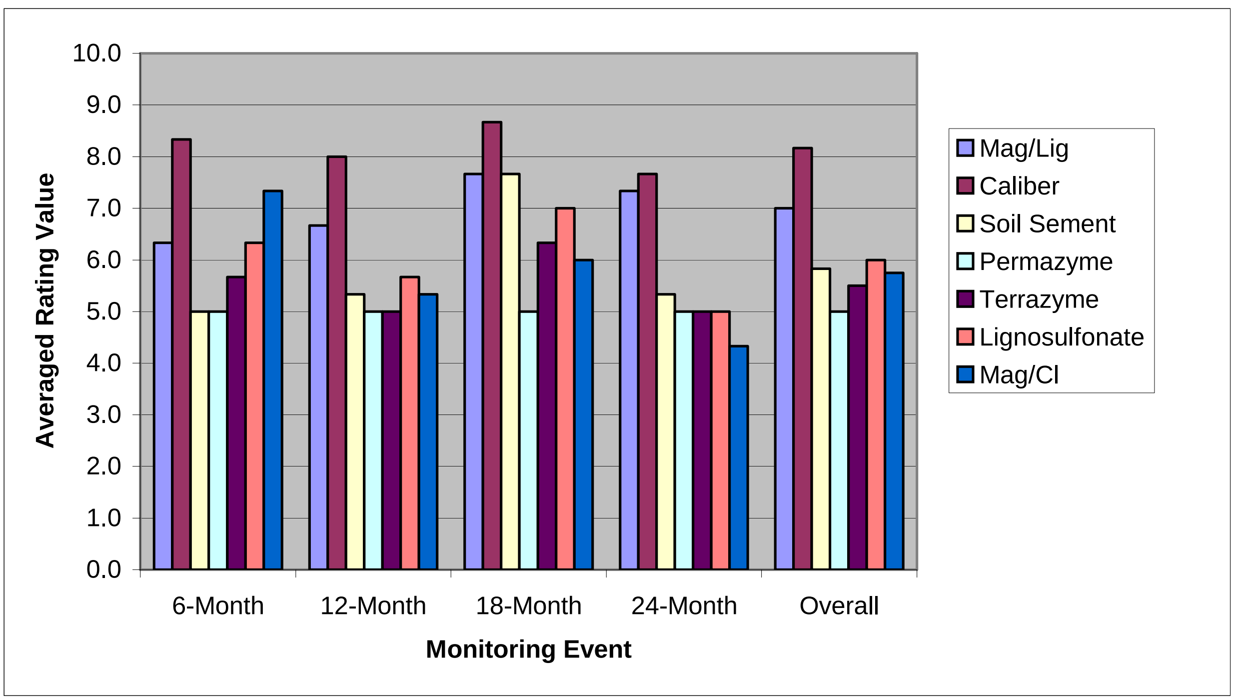

Figure 9. Plot. Dust values over time.

As indicated by the data in Table 6 and plotted in Figure 9, over time each product's relative standing in the group stayed pretty much the same. There were variations, for instance the improved relative values for Soil Sement at the 18-month event, but the relative standings remained substantially the same. The average over the four monitoring events best shows the overall relative performance of the products in dust abatement.

Looking at both the 24-month values and the overall average values, the products can be separated into two dust abatement groups. In the first group, the Caliber and the Mag/Lig sections allowed the least amount of airborne particles. In the second group, all of the other products also indicated acceptable performance, but with slightly more dust being generated relative to the first group. In the second group was the Mag/Cl in Section VII. This was a surface application only and not mixed to a depth of 150 mm (6 in) as were the other products, yet it initially performed similarly to the other sections. By the 24-month period, however, the values observed for this surface application of Mag/Cl were the lowest. This was not unexpected as a primary assumption of this project was that full depth stabilization would be more effective for a longer period than that of a surface application.

A similar observation is that these two groups may indicate some level of service life that could be expected from each of the products. It would appear from Figure 9 that even at the 18-month event all of the products were still relatively comparable. But by the 24-month event, a clear distinction is apparent between these two groups. One could also conclude that there may be a weather effect as the relative values for the 6 and 18-month events, both recorded in March, are similar. Just as the relative values for the 12 and 24-month events, both recorded in August, are similar.

Expanding on this thought, a key item to note is that for dust specifically, the best conditions to evaluate a product's performance would be when the climate is at its driest such as that recorded at the 12 and 24-month events. The relative average values for these two periods clearly support the observation that two groups exist with distinguishable differences in how they mitigated dust on this project.

Nevertheless, even though two groups were distinguished, all products performed acceptably throughout the 24-month period.

WASHBOARDING

Table 7 shows the washboarding rating values for each of the monitoring periods and the overall averages. These values for each product are plotted in Figure 10. As indicated by both the table and figure, over time each product's values generally corresponded in similar relative trends.

The products shown in Table 7 can be separated into three washboarding groups. In the first group, the Caliber and the Mag/Lig allowed the least amount of washboarding. In the second group were the Soil Sement, Terrazyme, and Lignosulfonate products. In the third group were the other products of Permazyme and Mag/Cl products whose sections had the highest levels of washboarding.

Section IV, treated with Permazyme, was noted to have the most washboarding. Figure 11 shows the washboarding typical on the Mag/Cl Section VII, which had value totals similar to Section IV. One explanation for this is that Section IV was the first section following a paved section of roadway and therefore experienced higher speed traffic than the other sections. However, it still exhibited a consistent level of washboarding throughout its length even where traffic would have slowed. The 6.0 km (3.7 mi) long Section VII actually does carry slightly more traffic than the other sections.

Table 7. Washboarding rating values.

Test Section	Product	6-Month Average Value	12-Month Average Value	18-Month Average Value	24-Month Average Value	Overall Average Value
I	**Mag/Lig**	7.3	6.7	7.7	7.3	7.3
II	**Caliber**	8.3	8.0	9.0	8.7	8.5
III	**Soil Sement**	5.3	6.0	5.3	6.3	5.8
IV	**Permazyme**	5.0	5.0	5.0	5.0	5.0
V	**Terrazyme**	5.0	6.0	6.7	6.3	6.0
VI	**Lignosulfonate**	5.0	5.3	6.3	6.7	5.8
VII	**Mag/Cl**	5.3	4.0	5.3	6.0	5.2

Note: These averaged scores are based on a 0 to 10 scale with 10 indicating the best performer and 0 the worst performer. The baseline product (Section IV) was the first product to be rated and was given a score of 5. All other products were compared to that product.

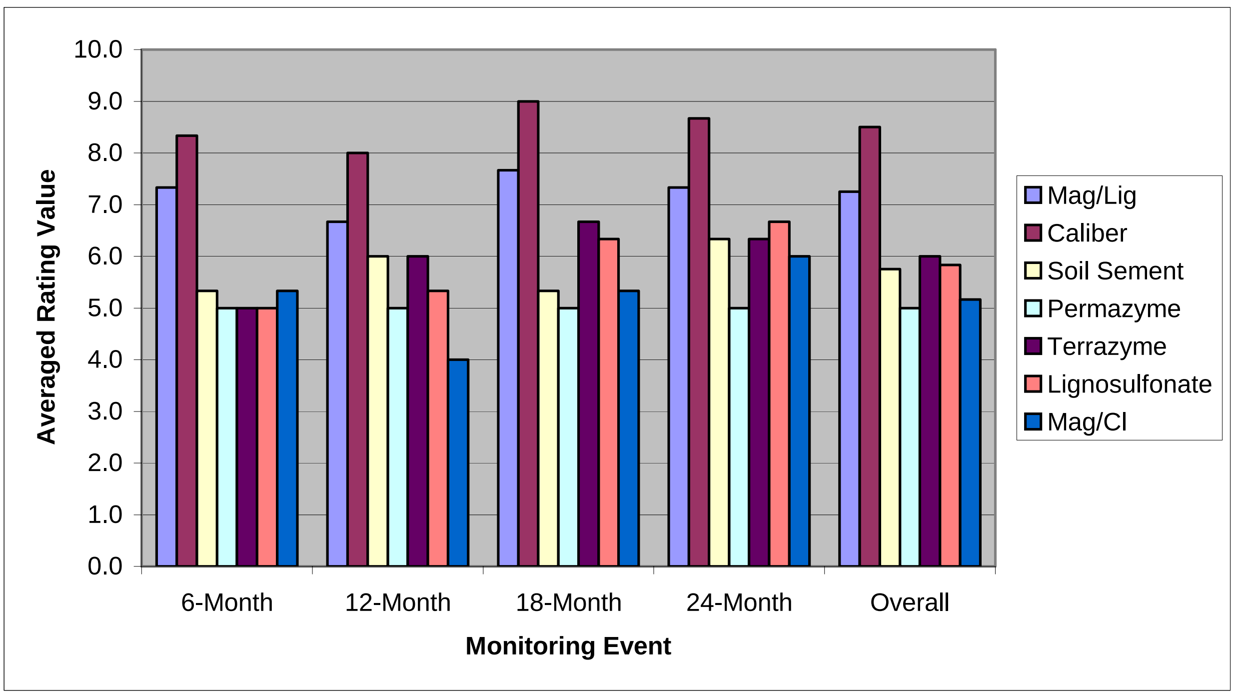

Figure 10. Plot. Washboarding values over time.

Figure 11. Photo. Washboarding, raveling, and dust.

An ideal study location would be one where all sections had identical geometry, grade, and composition. Unfortunately, the terrain varied throughout the project from relatively level or slightly rolling hills to some steeper sections as shown in Figure 12. The Mag/Lig, Terrazyme and Lignosulfonate roadway sections all had areas of rougher terrain, steeper grades, and curvilinear alignment. The evaluation team recognized that the effects of vehicles traveling on these steeper grades and curvilinear alignments would be greater than on the relatively flat and straight portions of each of these sections. Thus, difficult terrain areas were excluded from the rating process. Similarly, longitudinal water erosion “rivulets,” which were evident in the Lignosulfonate Section VI shown in Figure 12 were a result of adverse weather on the steeper grades and curved alignment. These types of distress areas did not reflect on the affected product’s evaluation of performance.

RAVELING

Table 8 shows the raveling rating values for each of the monitoring periods and the overall averages. These values for each product are plotted in Figure 13.

As indicated by the data in Table 8 and plotted in Figure 13, over time each product’s relative standing in the group did not significantly change.

Figure 12. Photo. Water erosion rivulets.

Table 8. Raveling rating values.

Test Section	Product	6-Month Average Value	12-Month Average Value	18-Month Average Value	24-Month Average Value	Overall Average Value
I	**Mag/Lig**	6.7	7.0	7.7	7.3	7.2
II	**Caliber**	8.0	8.0	8.7	8.3	8.3
III	**Soil Sement**	5.0	5.3	4.7	6.3	5.3
IV	**Permazyme**	5.0	5.0	5.0	5.0	5.0
V	**Terrazyme**	5.0	5.7	6.7	5.7	5.8
VI	**Lignosulfonate**	5.3	5.7	5.7	6.7	5.8
VII	**Mag/Cl**	6.0	4.7	5.0	5.7	5.3

Note: These averaged scores are based on a 0 to 10 scale with 10 indicating the best performer and 0 the worst performer. The baseline product (Section IV) was the first product to be rated and was given a score of 5. All other products were compared to that product.

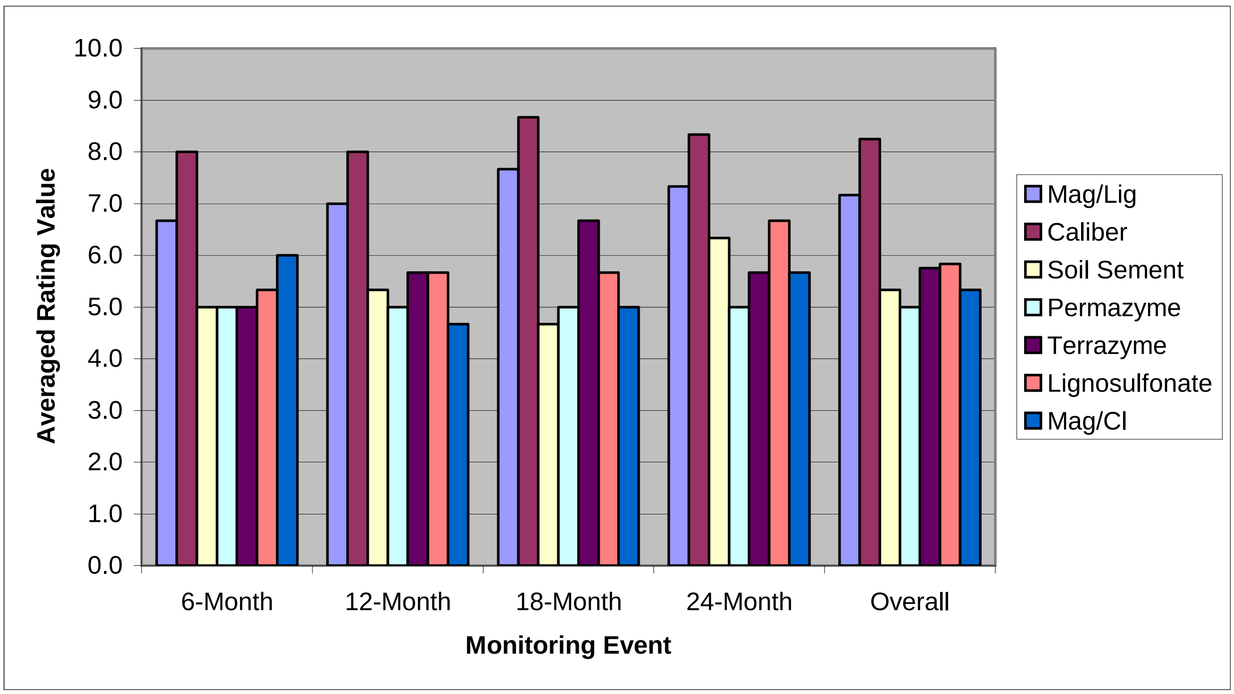

Figure 13. Plot. Raveling values over time.

The products shown in Table 8 can be separated into three raveling groups. In the first group was the Caliber section that appeared to have less loose particles at the roadway surface than other sections**.** It had a “tighter” surface appearance and little or no raveling. There was progressively more raveling in the Mag/Lig section in the second group. In the third group were all of the other products whose sections had higher but similar levels of raveling. Figure 11 shows the raveling on the Mag/Cl Section, typical of the sections in this third group.

Based on the request by the CFLHD at the start of this study, the Refuge did not perform any maintenance on this route from the initial placement of the borrow material with the stabilization and dust control products to the conclusion of the study. By the end of this 24-month study, all sections exhibited some roadway surface weathering. More raveled material was visible on the roadway surfaces of all sections during this monitoring event than on previous visits, and the roadway was clearly in need of maintenance grading.

RUTTING

Table 9 shows the rutting rating values for each of the monitoring periods and the overall averages. These values for each product are plotted in Figure 14.

Table 9. Rutting rating values.

Test Section	Product	6-Month Average Value	12-Month Average Value	18-Month Average Value	24-Month Average Value	Overall Average Value
I	**Mag/Lig**	6.7	5.0	6.0	6.7	6.1
II	**Caliber**	6.7	5.0	6.7	7.7	6.5
III	**Soil Sement**	7.0	4.7	5.0	5.3	5.5
IV	**Permazyme**	5.0	5.0	5.0	5.0	5.0
V	**Terrazyme**	6.0	4.7	5.7	5.0	5.3
VI	**Lignosulfonate**	5.7	4.7	5.3	6.0	5.4
VII	**Mag/Cl**	7.3	5.0	5.3	5.3	5.8

***Note:** These averaged scores are based on a 0 to 10 scale with 10 indicating the best performer and 0 the worst performer. The baseline product (Section IV) was the first product to be rated and was given a score of 5. All other products were compared to that product.*

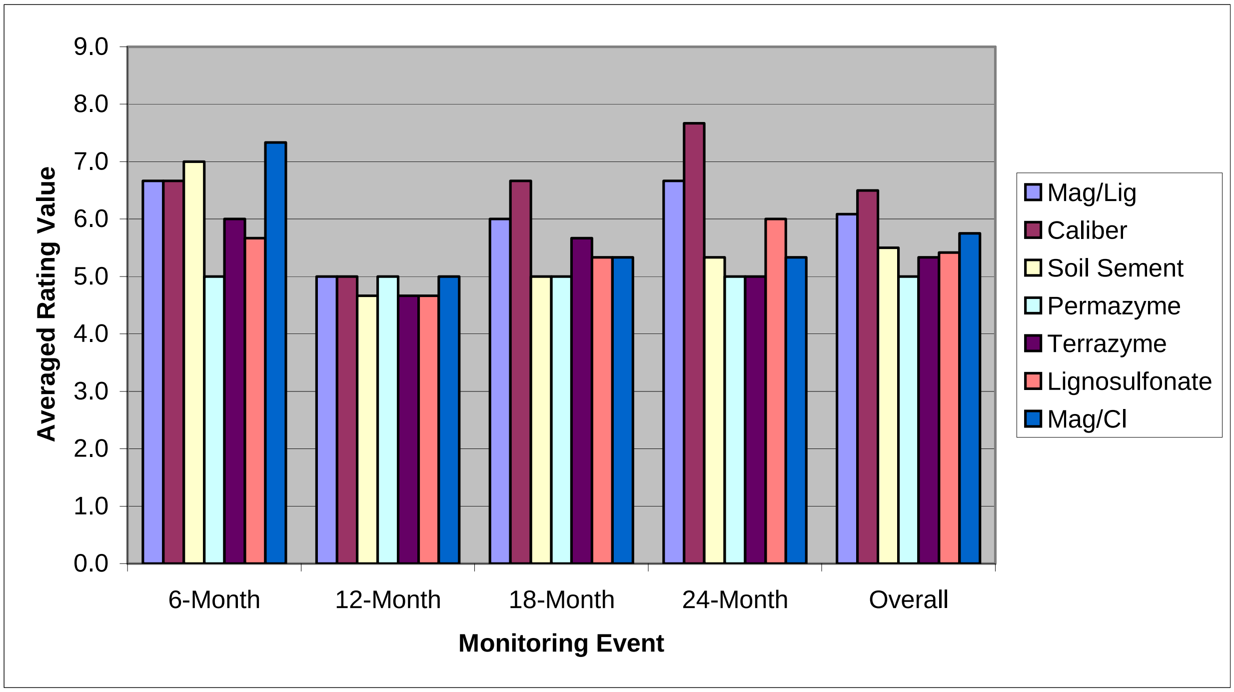

Figure 14. Plot. Rutting values over time.

As indicated by the data in Table 9 and plotted in Figure 14, over time each product's relative standing in the group remained pretty much the same. Although there were specific variations, for instance the improved rutting values for Lignosulfonate at the 24-month event, the relative standings remained quite consistent. The value totals at the end of the 24-month monitoring period best show the overall relative performance of the products with regard to rutting.

At the 6-month monitoring event, the Caliber product in Section II appeared to retain fines on the surface such that wheel tracks were clearly visible on the surface from traffic during a previous rain. The other sections did not have this appearance. Staff from the Refuge reported that this Section was “sloppy” and “slick” on February 10, 2003, when 25 mm (1 in) of rainfall occurred. These visible wheel tracks however did not constitute rutting to a depth to cause material deformation, nor was the “slippery and slick” surface condition observed on subsequent monitoring events.

While overall average values for each product in Table 9 show slight numerical differences for rutting, the evaluation team agreed that none of the sections exhibited any measurable rutting. Therefore, as all of the products performed on a relatively equal basis, they concluded that no single product could be separated out as having performed better or worse than the others.

POTHOLING

Potholing was included in the evaluation based on CFLHD’s prior experience with surface applications of products, such as magnesium chloride, that tended to produce a thin hardened surface layer that would break up, or pothole, in areas of lesser compaction. Conceptually therefore, since in this project the roadway was stabilized to a depth of 150 mm (6 in), the extent of potholes that normally develop under these thin surface type of applications should not occur. The evaluation team, however, was unsure whether this full-depth stabilized roadway would form potholes out or not, so they monitored it.

Table 10 shows the rating values for each of the monitoring periods and the overall averages for potholing. These values for each product are plotted in Figure 15.

Table 10. Potholing rating values.

Test Section	Product	6-Month Average Value	12-Month Average Value	18-Month Average Value	24-Month Average Value	Overall Average Value
I	**Mag/Lig**	5.0	5.0	5.0	5.0	5.0
II	**Caliber**	5.0	5.0	5.0	5.0	5.0
III	**Soil Sement**	5.0	5.0	5.0	5.0	5.0
IV	**Permazyme**	5.0	5.0	5.0	5.0	5.0
V	**Terrazyme**	5.0	5.0	5.0	5.0	5.0
VI	**Lignosulfonate**	5.0	5.0	5.0	5.0	5.0
VII	**Mag/Cl**	5.0	5.0	5.0	5.0	5.0

Note: These averaged scores are based on a 0 to 10 scale with 10 indicating the best performer and 0 the worst performer. The baseline product (Section IV) was the first product to be rated and was given a score of 5. All other products were compared to that product.

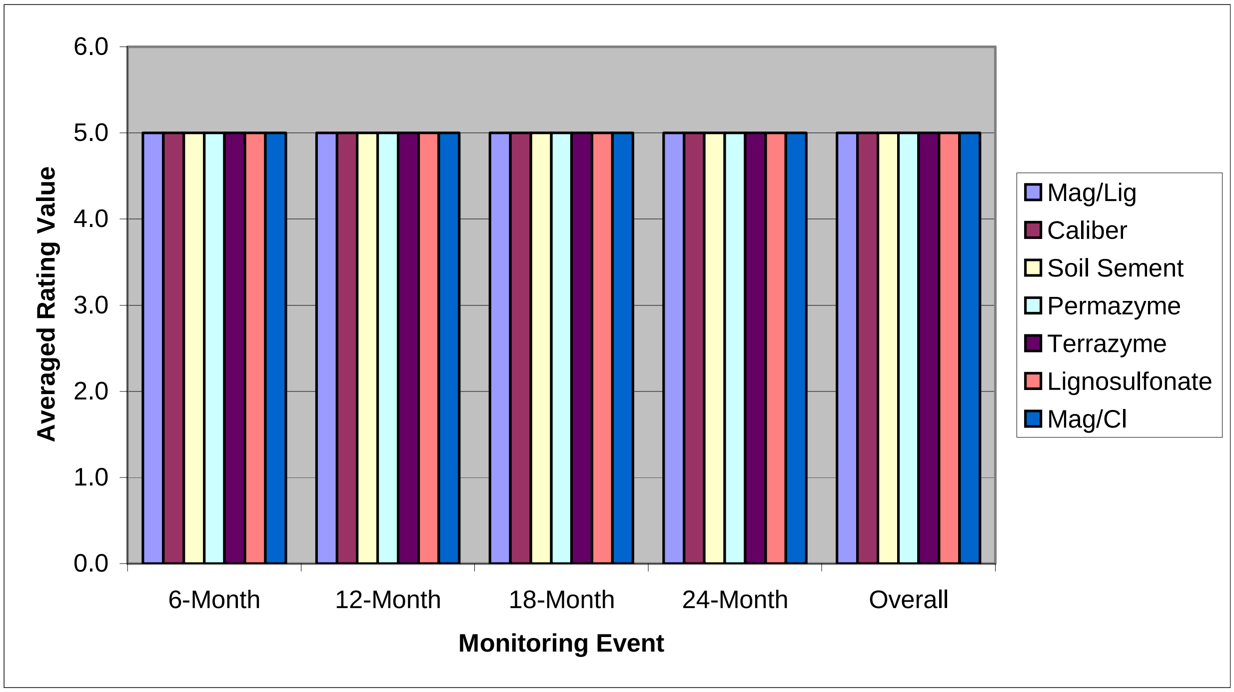

Figure 15. Plot. Potholing values over time.

As indicated by the data in Table 10 and plotted in Figure 15, no true potholing was observed. Therefore all products had similar relative performance over the entire 24-month monitoring period.

In the earlier monitoring events, the evaluation team observed what it thought were potholes in some sections, but it was unclear if these were truly potholes. For instance, there were three potholes noted in the Soil Sement Section III, two potholes in the Mag/Lig Section I, but none in any of the other sections. There was also no evidence that these few potholes were a result of the products' performance. It could even be speculated that the holes were due to large rocks pulled during the grading operation and the hole filled with poorly compacted material. By the end of the study, even though the Refuge had not performed any roadway maintenance, no evidence of potholes was apparent. As a result, no single product can be separated out as having performed better or worse than the others. In addition, the absence of potholing is significant because potholing is common on the Buenos Aires native material roadways.

LEACHING

Leaching of roadway stabilizing material was monitored, but it was not rated under the comparative evaluation method used for the dust, washboarding, raveling, rutting, and potholing parameters.

In the 6-month monitoring event, minor leaching of soluble stabilizing material was evident in the Caliber Section II as shown in Figure 16. Most of what appeared to be leaching occurred as crusting in some low-lying areas. Rather than leaching, this appeared to be the result of the product over-application during installation. In subsequent monitoring events, there was no

Figure 16. Photo. Minor surface crusting as a result of leaching.

visual evidence of leaching of soluble stabilizing material into the surrounding soils, nor did the earlier noted product appear to damage roadside vegetation.

VISUAL INSPECTION SUMMARY

A summary of the overall average values for each of the parameters and products is shown in Table 11. As an overall subjective measure of relative performance of each product, all of the overall parameter averages were averaged again to show a single average score for each product. These overall parameter average values as well as the average score for each product are plotted in Figure 17.

Table 11. Rating values summary.

Test Section	Product	Dust Overall Average Value	Washboard Overall Average Value	Raveling Overall Average Value	Rutting Overall Average Value	Potholing Overall Average Value	Visual Overall Average Score
I	**Mag/Lig**	7.0	7.3	7.2	6.1	5.0	6.5
II	**Caliber**	8.2	8.5	8.3	6.5	5.0	7.3
III	**Soil Sement**	5.8	5.8	5.3	5.5	5.0	5.5
IV	**Permazyme**	5.0	5.0	5.0	5.0	5.0	5.0
V	**Terrazyme**	5.5	6.0	5.8	5.3	5.0	5.5
VI	**Lignosulfonate**	6.0	5.8	5.8	5.4	5.0	5.6
VII	**Mag/Cl**	5.8	5.2	5.3	5.8	5.0	5.4

Note: These averaged scores are based on a 0 to 10 scale with 10 indicating the best performer and 0 the worst performer. The baseline product (Section IV) was the first product to be rated and was given a score of 5. All other products were compared to that product.

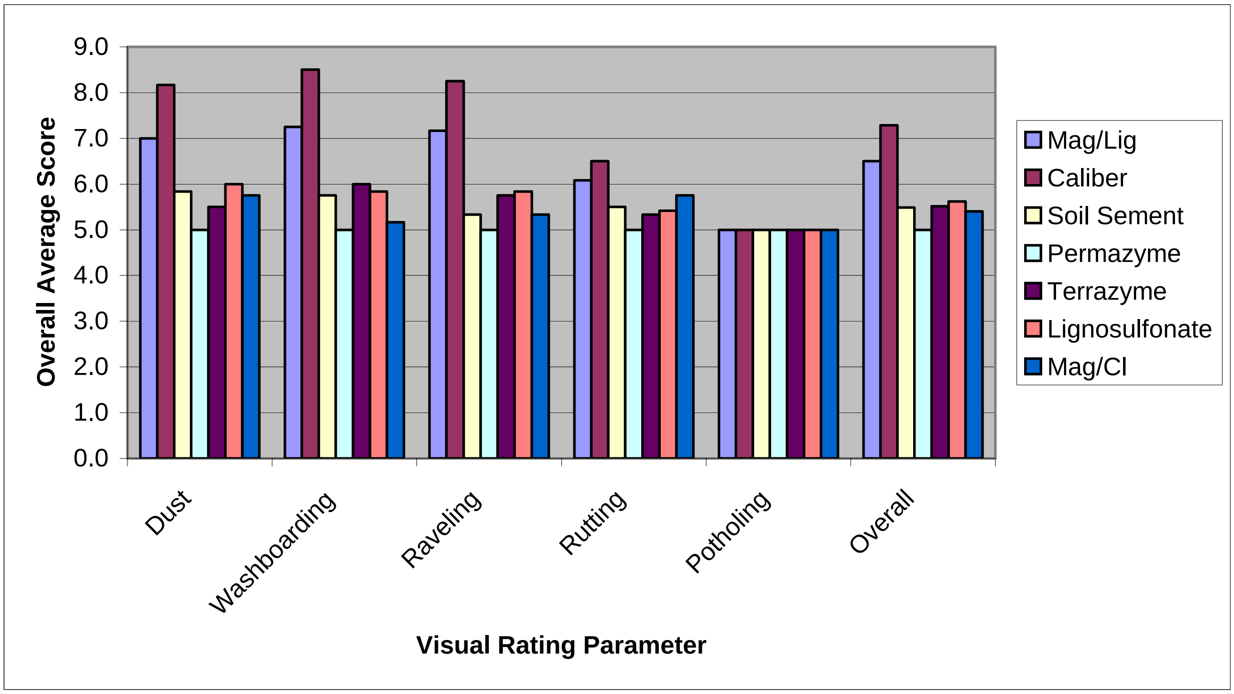

Figure 17. Plot. Overall average scores for each parameter.

From these average scores covering all parameters, three groups of product performance are evident. In the first group, one product, Caliber, performed the best overall. Second to this was the Mag/Lig product. The other products showed a fairly comparable relative performance and comprised the third group.

As stated earlier, all products performed acceptably throughout this study. Therefore the conclusion to be drawn here is not that some products performed well and the others poorly, but that some products exhibited better performance than some of the others. The objective physical evaluations in the next chapter provide additional information that corresponds to and confirms these subjective visual evaluations.

CHAPTER 4 – PHYSICAL ANALYSIS

LABORATORY ANALYSIS

Source material from a nearby local stream wash was used as the select borrow for the roadway topping. Samples from three different locations at this borrow source were taken to determine its soil properties. The three samples were physically combined and tested as one sample. Based on laboratory analysis of particle size distribution, liquid limit and plasticity index, the soil type can be described a granular non-plastic material.

Classification Tests

The following test methods were performed to determine the characteristics of the borrow material:

- AASHTO T 11, Materials Finer Than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing
- AASHTO T 27, Sieve Analysis of Fine and Coarse Aggregates
- AASHTO T 89, Determining the Liquid Limit of Soils
- AASHTO T 90, Determining the Plastic Limit and Plasticity Index of Soils
- AASHTO T 180, Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and 457-mm (18-in) Drop, Method D
- AASHTO T 190, Resistance R-Value and Expansion Pressure of Compacted Soils
- ASTM D 1883 Test Method for CBR (California Bearing Ratio) of Laboratory Compacted Soils

Classification systems

Two systems are routinely used to classify soil. Under the American Association of State Highway and Transportation Officials (AASHTO)(14) system, this borrow material classifies as an A-1-b group soil. Under the American Society for Testing and Materials (ASTM)(15) system, this borrow material classifies as a poorly graded sand, or SP. While there is some overlap in the classification definitions of these systems for the range of coarse to fine, and level plasticity, there is not a direct one-to-one correspondence. These classifications are discussed below in a general overview of the two classification systems.

AASHTO

AASHTO M 145, Classification of Soil-Aggregate Mixtures for Highway Construction Purposes, divides soils into the two major groups of granular materials and silt-clay materials. The granular materials are those soils with 35% or less passing the 75 µm (No. 200) sieve consisting of:

A-1-a – Well-graded coarser stone fragments, gravel, and sand; plasticity index maximum of 6,

A-1-b – Well-graded finer stone fragments, gravel, and sand; plasticity index maximum of 6,

A-2-4 – Silty or clayey gravel or sand with higher portions of silt, lower liquid limit, plasticity index maximum of 10,
A-2-5 – Silty or clayey gravel or sand with higher portions of silt, higher liquid limit, plasticity index maximum of 10,
A-2-6 – Silty or clayey gravel or sand with higher portions of clay, lower liquid limit, plasticity index maximum of 10,
A-2-7 – Silty or clayey gravel or sand with higher portions of clay, higher liquid limit, plasticity index maximum of 10, and
A-3 – Clean, poorly graded sands; non-plastic,

The silty-clayey materials are those soils with more than 35% passing the 75 µm (No. 200) sieve consisting of:

A-4 – Silty soils, lower liquid limit, plasticity index maximum of 10,
A-5 – Silty soils, higher liquid limit, plasticity index maximum of 10,
A-6 – Clayey soils, lower liquid limit, plasticity index maximum of 10, and
A-7 – Clayey soils, higher liquid limit, plasticity index maximum of 10.

ASTM

ASTM D 2487, Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), divides soils into three major groups of coarse-grained soils (sands and gravels, fine-grained soils (silts and clays), and highly organic soils (peat and other highly organic soils). The coarse-grained soils are those with 50% or less material passing the 75 µm (No. 200) sieve consisting of:

GW – Well-graded gravel,
GP – Poorly-graded gravel,
GM – Silty gravel,
GC – Clayey gravel,
SW – Well-graded sand,
SP – Poorly-graded sand,
SM – Silty sand, and
SC – Clayey sand.

The fine-grained soils are those with more than 50% passing the 75 µm (No. 200) sieve consisting of:

ML – Low liquid limit silt,
CL – Low liquid limit clay,
OL – Low liquid limit organic,
MP – Poorly graded silt,
CH – High liquid limit clay, and
OH – High liquid limit organic.

The highly organic soils are classed as

Pt – Peat.

Borderline instances can occur in these classifications when the material properties fall between the limits such that some soils can be classified for instance as:

GM-ML – Low liquid limit silty gravel,
SC-SM – Silty clayey sand, or
SP-SM – Poorly graded sand with silt.

Table 12 is a summary of the soil characteristics for the select borrow prior to placement and treatment.

Table 12. Untreated borrow soil samples.

Attribute		Value
AASHTO Soil Classification		A-1-b (0)
ASTM Soil Classification		SP
Optimum Moisture, %		6
Maximum Dry Density, pcf		129
Liquid Limit		NV
Plastic Limit		NP
R-Value		66
CBR @ 0.1 in penetration		32.6 (sample 1) 30.2 (sample 2)
Sieve Size, % Passing	**$2\text{-}{}^{1}/_{2}$ in**	100
	$1\text{-}{}^{1}/_{2}$ in	93
	1 in	87
	${}^{3}/_{4}$ in	83
	${}^{1}/_{2}$ in	77
	${}^{3}/_{8}$ in	74
	No. 4	64
	No. 10	52
	No. 16	41
	No. 40	21
	No 100	8
	No. 200	4.4

In addition to sampling the borrow source, borrow material samples were also taken from each test section during the initial product application and from each test section at the 6-month evaluation. This was done to determine if any borrow material properties changed after it was processed and placed on the roadway. As discussed below, the evaluation team saw no significant variations.

Comparison of Data

Tables 13 and 14 summarize the soil characteristics at initial treatment and after 6-months, respectively. Some observations can be made concerning several of the parameters.

Soil Classification

No significant differences exist in the soil classification and grouping among the borrow stockpile results in Table 12, after initial treatment in Table 13, and after 6 months in Table 14. Under both systems the soils are placed into the same divisions described as coarse grained and granular materials, with AASHTO classified as A-1-b and ASTM classified as SW-SM and SP-SM.

Table 13. Borrow soil values after initial treatment.

Product	Test Section					
	I	II	III	IV	V	VI
	Mag/Lig	Caliber	Soil Sement	Permazyme	Terrazyme	Lignosulfonate
Field Sample Number	1b	2c	3b	4a	5c	6b
Milepost (within each section)	0.60	0.60	0.42	0.08	0.91	0.43
AASHTO Soil Classification	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)
ASTM Soil Classification	SW-SM	SP-SM	SP-SM	SW-SM	SP-SM	SP-SM
Dry Density, pcf	AASHTO T 180 Method D = 131 pcf					
Moisture, %	10.5	11.0	10.4	11.0	7.0	10.0
Liquid Limit	NV	NV	NV	NV	NV	NV
Plastic Limit	NP	NP	NP	NP	NP	NP
R-Value	55	74	73	71	76	67
CBR, computed	5	14	10	11	7	10
Sieve Size	Gradation, % Passing					
3 in	100	100	100	100	100	100
2-$^1/_2$ in	100	100	98	100	100	100
1-$^1/_2$ in	97	96	92	98	93	93
1 in	93	92	87	94	87	89
$^3/_4$ in	90	87	82	89	84	85
$^1/_2$ in	86	81	77	84	79	79
$^3/_8$ in	82	76	73	79	75	76
No. 4	70	64	64	71	66	65
No. 10	57	52	50	56	53	53
No. 16	48	42	41	47	43	43
No. 40	30	23	24	29	25	24
No 100	17	11	12	16	13	12
No. 200	12	7.6	7.7	10	9	8.8

Table 14. Treated borrow soil values at 6-month evaluation.

Product	Test Section						
	I	II	III	IV	V	VI	VII
	Mag/Lig	Caliber	Soil Sement	Permazyme	Terrazyme	Lignosulfonate	Mag/Cl
Field Sample Number	1	2	3	4	5	6	7
Milepost (within each section)	0.60	0.60	0.42	0.08	0.91	0.43	1.00
AASHTO Soil Classification	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)	A-1-b (0)
ASTM Soil Classification	SW-SM	SW-SM	SW-SM	SM	SP-SM	SW-SM	SP-SM
Dry Density, pcf	138	--	137	--	138	--	--
Moisture, %	6	--	6	--	6	--	--
Liquid Limit	NV	NV	NV	NV	NV	NV	NV
Plastic Limit	NP	NP	NP	NP	NP	NP	NP
R-Value	81	81	84	81	78	90	90
CBR @ 0.1-in Penetration	30.2	6.1	22.9	2.3	17.8	3.9	2.9
Sieve Size	**Gradation, % Passing**						
3 in	100	100	100	100	100	100	100
2-$^1/_2$ in	--	--	--	--	--	--	--
1-$^1/_2$ in	87	100	94	87	81	97	98
1 in	--	--	--	--	--	--	--
$^3/_4$ in	80	91	82	81	71	88	94
$^1/_2$ in	--	--	--	--	--	--	--
$^3/_8$ in	71	81	72	74	64	79	84
No. 4	62	70	63	66	56	69	75
No. 10	51	57	50	57	45	56	62
No. 16	--	--	--	--	--	--	--
No. 40	25	28	21	39	24	24	33
No 100	13	16	11	26	14	12	18
No. 200	9.4	10.9	7.6	19.3	9.6	7.8	11.2

Dry Density

The objective of the moisture-density test is to determine the maximum dry density and optimum moisture content for the soil. Granular soil is compacted with a standard amount of energy over a range of moisture contents to identify the optimum moisture content at which maximum dry density will be achieved.

In practice, highway and building fills must be compacted to attain appropriate strength and minimize settlement. The most common method of specifying compaction is to require a certain percent of the maximum that can be attained in proctor compaction tests, such as "90% of standard proctor" or “95% of modified proctor.”

The original moisture-density test was developed by R.R. Proctor and is commonly referred to as the Standard Proctor Test, Proctor Test, or Standard Moisture-Density Test. The Modified Proctor or Modified Moisture-Density Test is performed the same way but in a larger mold with higher compactive energy. Each of the 8 different variations of standard and modified proctor can produce different results. The project contract documents must specify which procedure is to be used.

A comparison of maximum dry densities of 2066 kg/m^3 (129 pcf) at the borrow source and 2098 kg/m^3 (131 pcf) after initial treatment could be considered minor and more attributed to gradation variations than to any effect of a stabilization product. Tests run at 6 months using samples from three of the test sections show an average maximum dry density of 2211 kg/m^3 (138 pcf). On the one hand, this may be due to a stabilizing effect of the products, but on the other it may just be a reflection of the randomness of the material.

Plasticity

All tests for plasticity on untreated and treated materials showed they were Non Plastic. This undoubtedly affected the rating and performance of the electrochemical enzymes products, that is, the Permazyme and Terrazyme used on Sections IV and V. These electrochemical products are formulated to perform and react with materials containing clay particles and are dependent on fine clay mineralogy to reach and achieve maximum performance for dust abatement and soil stabilization.

R-Value

The test for R-Value measures the resistance of the soil. This is one measure of soil strength where R = 0 would be a fluid and R = 100 an infinitely rigid solid. The untreated borrow material had an R-Value of 66. After initial treatment, R-Values for the 6 treated sections ranged from 55 to 76. After 6 months the range was 78 to 90. These values indicate a strong material that should structurally hold up well. Although not verified during subsequent events, the higher values obtained from samples taken after 6 months in the field suggest a stabilizing effect of the products. In hindsight, R-Values should probably have been measured on every monitoring event, but due to the labor intensive sampling and costs, it was decided not to further collect this information.

Laboratory CBRs

The California Bearing Ratio rates the strength of a material in terms of that of an excellent base course, which has a CBR of 100. Laboratory tests for CBRs were the most erratic of any of the tests on the Buenos Aires select topping material with results ranging from 2.3 to 32.6. These figures would indicate a very poor to a very good subgrade material. Probably the most important thing to note about this test is that it is not a field fest. Field samples are collected and taken back to the lab, broken up, compacted into molds, soaked, then penetrated to 0.1-inch be a piston. Any effects of the stabilization products on the material could likely be lost with the soaking process.

Starting with the second monitoring event at 12-months, an in situ strength test using a DCP was adopted. As will be shown, CBR values computed from this test show little resemblance to the laboratory CBRs.

Gradations

A comparison of the gradations between Tables 12, 13 and 14 indicate some differences, however these gradation differences are deemed minor and are probably more attributed to slight variations in the material's uniformity, sampling location, processing and sample time rather than any affect attributed to the stabilization product.

ON-SITE TESTING AND EVALUATION

In addition to the subjective visual inspection, nuclear density testing, dynamic cone penetrometer testing, soil stiffness and modulus testing, and silt load testing were performed during the monitoring events.

Nuclear Density Testing

Nuclear Density readings were taken only during the 6-month monitoring event to determine relative in-place material densities. Since the roadway did not display any visible evidence of soft or questionable subgrade, densities were not taken during subsequent visits. For each test section, a measurement for percent compaction was taken at a randomly selected location in both the 100 mm (4 in) depth and backscatter modes. These values are shown in Table 15.

AASHTO T 310 allows the in-place density and moisture content of soil to be performed using two methods. The backscatter or backscatter/air-gap method measure is more sensitive to the material at the surface because the source rod is never embedded into the material. The direct transmission method, however, requires the source rod to be lowered into a pre-driven hole in the materials to be tested. Density measurements with direct transmission are the preferred method.

The values for the backscatter mode for each measurement taken at the surface of the roadway were lower than the direct transmission. This was not unexpected as the thin layer of loose material on the surface in each section should naturally be less dense than the material underneath. This phenomenon is routinely observed on soil and aggregate surfaces, so the evaluation team felt no concern that the data from direct transmission mode was higher than from the backscatter mode.

Table 15. In-place density by nuclear method at 6-month evaluation.

Test Section	Product	Milepost (within test section)	Nuclear In-place Density/Compaction (%)	
			@ 4" depth	Back Scatter
I	**Mag/Lig**	0.60	104	96
II	**Caliber**	0.60	101	93
III	**Soil Sement**	0.42	99	89
IV	**Permazyme**	0.08	94	69
V	**Terrazyme**	0.91	95	87
VI	**Lignosulfonate**	0.43	94	69
VII	**Mag/Cl**	1.00	96	74

Note that on Sections I and II values for in-place densities greater than 100% were achieved. A value for in-place density of a material should not be greater than 100% of its maximum dry density. An explanation for these high compaction values is that nuclear test results can be affected by natural variation in material uniformity, such as the presence of large rock, or the chemical composition of the soil.

Using a calculated maximum dry density of 2098 kg/m3 (131 pcf) from the original borrow source material, the sections varied in nuclear density from 94% to 104% in the direct transmission mode. This was consistent with the original construction quality control that ensured the material was compacted to at least 90% of the maximum dry density.

There may be merit in the argument that nuclear density tests should have been taken for all remaining monitoring events to measure the stabilizing effect of each product over time. The evaluation team felt however, that if there were any loss of stability evident as a decrease in density, it would also be exhibited in the attributes of raveling, washboarding, potholing, and dust. Other than confirming that each section was properly constructed, no other conclusions are drawn from these test results.

Dynamic Cone Penetrometer (DCP) Testing

A Dynamic Cone Penetrometer (DCP) as shown in Figure 18 was used to evaluate the in situ strength of the treated soils. The evaluation team added this test procedure after the 6-month monitoring event. The DCP strength values were then used to estimate the California Bearing Ratio (CBR) or shear strength of the treated roadway material throughout its depth.

Calculations of CBR measurements at two or three locations in each of the sections are shown in the Appendix A, Tables 21, 22, and 23. Each table represents a different monitoring event. The

Figure 18. Photo. Dynamic cone penetrometer testing.

values from each event are summarized as one averaged CBR number in Table 16, and are plotted in Figure 19. No DCP measurements were taken in the Mag/Cl Section VII.

While the ASTM D 6951 procedure for the DCP recommends recording the depths of penetration every 10 hammer blows, the evaluation team used a modified method. Since the roadway was consistently treated to a depth of 150 mm (6 in), the total blows to penetrate to this depth were recorded. The overall average blows per inch were used to calculate the average CBR for the treated depth.

The CBR values showed some variation over time for each product. Some product's values consistently increased, some consistently decreased, and some went both up and down. These variations can be partly explained as a result of different sampling locations with slightly varying material compositions and compactions.

Interestingly enough, the two products with the highest CBR values also had the highest nuclear density readings. But while the Soil Sement had lower CBR values, it too had a higher nuclear density. So while it is tempting to correlate the two measures, in reality with an $R^2 = 0.31$, it is really quite weak.

Table 16. Dynamic cone penetrometer derived CBR values summary

Test Section	Product	12-Month CBR Mean	18-Month CBR Mean	24-Month CBR Mean	Mean of CBR Means	Normalized Rank[1]
I	**Mag/Lig**	79	93	87	86	86
II	**Caliber**	95	78	89	87	87
III	**Soil Sement**	49	50	61	53	53
IV	**Permazyme**	77	69	60	69	69
V	**Terrazyme**	59	53	58	57	57
VI	**Lignosulfonate**	62	70	84	72	72

1-Normalized Rank is the same as CBR value since its scale is already from 0 to 100.

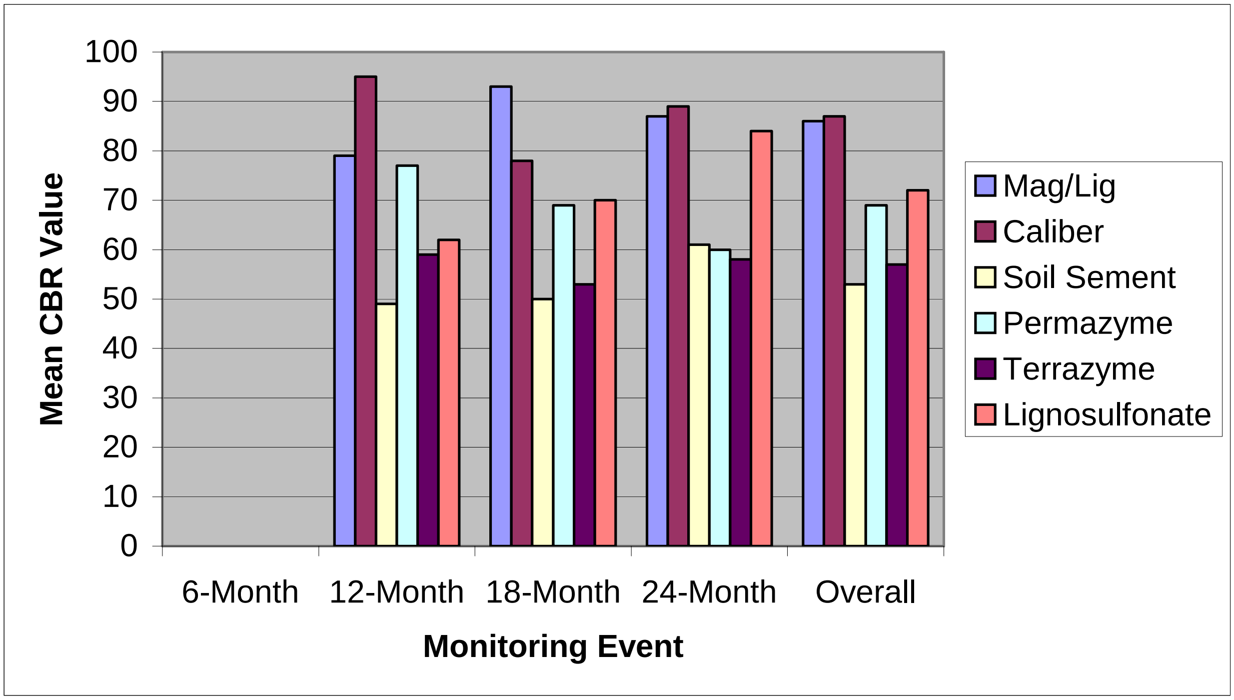

Figure 19. Plot. Dynamic cone penetrometer testing.

The evaluation team had hoped to see clear trends in the DCP data that showed how each product either maintained its stability over time, or more likely indicated a lessening of effectiveness. Unfortunately, the lack of a consistent trend in the overall data makes it difficult to draw conclusions about each specific product's performance over time. However, one observation that can be made is that the Caliber and Mag/Lig products consistently produced higher CBR values, while the Soil Sement and Terrazyme had the lowest. Even so, all CBR values were within a good to excellent range.

Soil Stiffness and Soil Modulus Testing

Soil stiffness and soil modulus testing were performed during the 12-month monitoring event using a Humboldt H-4140 GeoGage. This method was not originally part of the overall monitoring plan, but was included because one of the product suppliers offered their Samitron (GeoGage) Acoustic Soil Modulus Tester for a one-time evaluation. This test procedure is formalized under ASTM D 6758.

The GeoGage as shown in Figure 20 is a non-nuclear non-destructive acoustic device that measures stiffness and modulus throughout the depth of a section rather than at discrete depths. The gauge generates a series of varying frequency impedance, or mechanical vibrations, which produce small changes in force that induce small deflections of the surface. The response measurements are then recorded as stiffness and modulus. Both stiffness and modulus values are produced for each single test and are related to each other mathematically. The GeoGage's stiffness and soil modulus can be related to soil density, thus providing a quality control method for construction. Because the GeoGage data can be related to density, it is tempting to compare

Figure 20. Photo. Soil modulus testing device.

the relative standings of the products using GeoGage and Nuclear Gage results. Though little correlation exists, it must be acknowledged that far too little data from this project is available to study any correlation of these instruments.

The soil stiffness is a material's resistance to deflection. More specifically, stiffness is a structural property defined as the ratio of a change of force to a corresponding change in translational deflection of an elastic element, that is, a layer's resistance to deflection. The modulus (Young/Resilient modulus) is a material's resistance to change in shape in the direction of stress. It is the ratio of the increase in stress on a test specimen to the resulting increase in strain under constant traverse stress limited to materials having a linear stress-strain relationship over a range of loading. It is also called the elastic modulus.

Two GeoGage Soil Stiffness measurements were taken in each of the test sections and averaged as shown in Table 17. Only the soil modulus numbers results are included in this report. The higher the value the stiffer is the material.

Table 17. Modulus of soils by GeoGage method at 12-month evaluation.

Test Section	Product	GeoGage Reading – Soil Modulus			Normalized Rank[1]
		0.20 mi.	0.80 mi.	Mean	
I	Mag/Lig	10.41	15.85	13.13	92.4
II	Caliber	24.89	17.17	21.03	95.2
III	Soil Sement	11.80	10.96	11.38	91.2
IV	Permazyme	17.88	11.60	14.74	93.2
V	Terrazyme	10.53	10.92	10.73	90.7
VI	Lignosulfonate	18.19	16.06	17.13	94.2
VII	Mag/Cl	11.57	11.58	11.58	91.4

1-Normalized Rank = 100 - [(1 / Modulus Mean) x 100]

The products with the highest values and therefore the stiffest material were the Caliber, followed by the Lignosulfonate. The Permazyme and the Mag/Lig were next with similar but lesser stiffness values. The remaining three products with the lowest values were in the third group. While the Caliber had the highest values under this test method, just as it did for the nuclear density, DCP, and silt loading, the order of the remaining products' was different. The Lignosulfonate, for instance, showed the second highest GeoGage values, whereas it was in the middle to lower ranges for the other parameters. Please note that since under this one-time use of the GeoGage, no ASTM D 698 *Laboratory Compaction Characteristics of Soil Using*

Standard Effort correlations were established, the values are reported as measured relative to each other, and not referenced to an absolute value.

Figure 21. Photo. Silt load sampling.

Silt Load Testing

The evaluation team had initially identified only a visual monitoring system. However once monitoring began, several additional physical tests were proposed to be part of the monitoring process. The Silt Load Test was added to the system at the 12-month monitoring event. This test method from Title 40 of the Code of Federal Regulations [16] can be found in Appendix B. Under this method, silt is defined as material that passes the 75 µm (No. 200) sieve. The Silt Load test method is used to determine the amount of minus 75 µm (No. 200) on the surface of the road, which then can be correlated to the generation of airborne dust particles. Loose roadway materials are swept from the surface as shown in Figure 21 creating a 0.3 m (1ft) wide swath across each wheel path. The percentage of minus 75 µm (No. 200) is then computed from the total material volume collected from this area.

Under this method, for an aggregate surfaced road to be considered stabilized, the silt loading, that is the weight of silt per unit area, must be less than 0.1 kg/m^2 (0.33 oz/ft^2), or where the silt loading is greater than or equal to this limit, the silt content should not exceed six percent for unpaved road surfaces or eight percent for unpaved parking lot surfaces. Calculations of the Silt Load measurements at two locations in each of the sections are shown in the Appendix C, Tables 24, 25, and 26. These values are summarized as one average Silt Load value in Table 18, and are plotted in Figure 22.

Table 18. Silt load value summary.

		Ounces of -No. 200 / ft^2				Normalized Rank[1]
Test Section	**Product**	**12-Month Mean**	**18-Month Mean**	**24-Month Mean**	**Mean of Means**	
I	**Mag/Lig**	1.19	0.30	0.32	0.60	91.3
II	**Caliber**	0.44	0.14	0.44	0.34	95.1
III	**Soil Sement**	0.76	0.94	1.81	1.17	83.1
IV	**Permazyme**	1.77	1.14	2.81	1.91	72.4
V	**Terrazyme**	0.59	0.99	1.40	0.99	85.7
VI	**Lignosulfonate**	0.98	0.68	1.32	0.99	85.7
VII	**Mag/Cl**	1.00	0.86	Not Sampled	0.93	86.6

1-Normalized Rank = 100 - [(Mean of Monthly Means / Σ of Mean Values) x 100]

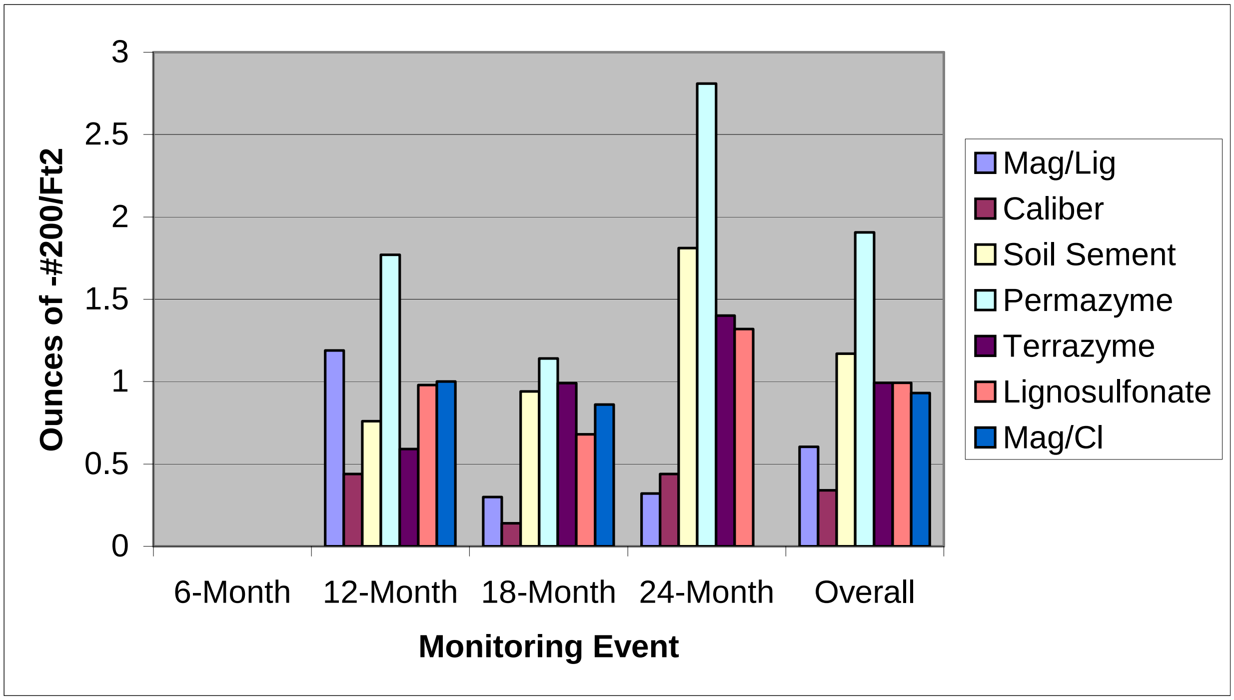

Figure 22. Plot. Silt Loading tests.

Once again three groups are evident based on the mean of the means. In the first group the products with the lowest silt loading value and therefore the least amount of material available for dust generation were the Caliber and the Mag/Lig. In the second group with somewhat higher silt loading values were the Soil Sement, Terrazyme, Lignosulfonate, and Mag/Cl. Only one product, Permazyme, was in the third group with the highest silt loading value. Unfortunately as indicated in Table 18, all of the products' mean of the means silt load values exceeded the maximum limit of 0.1 kg/m^2 (0.33 oz/ft^2) set for stabilized material according to the 40 CFR method.

It is interesting to note that the silt loading evaluations correspond to the subjective dust abatement observations noted in the previous chapter in Table 6 and Figure 9. There, the Caliber and the Mag/Lig were noted as producing the least dust, just as was measured with the silt loading test. And while all of the other products were included in the second subjective dust abatement group, a look at the actual overall average values shows that the Permazyme was the lowest of all, similar to the actual silt loading observations.

PHYSICAL ANALYSIS SUMMARY

The normalized rankings for DCP/CBR, Soil Stiffness, and Silt Loading are shown in Table 19 for each product. To arrive at an overall ranking of the products based on physical in situ tests, the three normalized rankings were averaged to show a single value.

From this average normalized rank for all physical parameters, three groups of product performance are evident. The first group's sole product, the Caliber, performed the best overall. Second to this were the Mag/Lig and Lignosulfonate products. The other products showed a fairly comparable relative performance in the third group. The order and rank of these objective physical evaluations correspond to the subjective visual evaluations noted in the previous chapter.

Table 19. Physical analysis normalized rank summary.

Test Section	Product	DCP/CBR	GeoGage Soil Stiffnes	Silt Loading	Physical Overall Normalized Rank
I	**Mag/Lig**	86	92.4	91.3	90
II	**Caliber**	87	95.2	95.1	92
III	**Soil Sement**	53	91.2	83.1	76
IV	**Permazyme**	69	93.2	72.4	78
V	**Terrazyme**	57	90.7	85.7	78
VI	**Lignosulfonate**	72	94.2	85.7	84
VII	**Mag/Cl**	N/A	91.4	86.6	89

As stated earlier, all products performed acceptably throughout this study. Therefore the conclusion to be drawn here is not that some products performed well and the others poorly, but that some products exhibited better performance than others.

CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Assessment Methodology

The visual assessment was an acceptable method of comparing performance of the products relative to each other at a single point in time; however, it was limited for comparing product performance over time. The physical tests provided objective values over time but not all parameters of interest could be measured with physical objective tests. Thus, a combination of comparative visual and objective physical tests was used. As shown in Table 20, both methods appear valid as there is a clear correspondence between the average values of both the visual and physical observations. A summary of these average values may imply a higher level of precision than actually existed; so products have been simply grouped, and three groups are evident from the overall average scores. The Caliber product with the highest score is in the first group, the Mag/Lig is in the second, and all of the other products are in the third group. Similarly, from the overall average scores, there may be a desire to draw the conclusion that Caliber was a great product and Permazyme was not. This is not a correct conclusion. All products performed at an acceptable level under this study, and the Refuge benefited by not having to conduct six or seven maintenance activities over the 24-month period. The relative costs and relative application rates are also shown in Table 20 for each product.

Table 20. Visual and physical value summary.

Test Section	Product	Visual Overall Average Score (x10)	Physical Overall Normalized Rank	Overall Average Score	Relative Cost	Relative Application Rate
I	**Mag/Lig**	65	90	77	Medium	High
II	**Caliber**	73	92	83	Medium	High
III	**Soil Sement**	55	76	65	High	Medium
IV	**Permazyme**	50	78	64	Low	Low
V	**Terrazyme**	55	78	66	Low	Low
VI	**Lignosulfonate**	56	84	70	Medium	High
VII	**Mag/Cl**	54	89	71	Medium	High

Performance Levels

Although varying levels of performance can be distinguished among the products at this particular project site, the order of observed performance may not be the same on another project where conditions such as specific soil type, climate, level of traffic, and rate of product application are different. The previously published literature on the effectiveness of these product categories also notes that product performance varies in relation to soil type, composition, climate, and traffic.

Supplier's Role

Specifications for the use of some of these products are not yet developed for either surface or full-depth stabilization. Therefore, it was beneficial to have the product manufactures participating and providing recommendations for use and application. As was done under this study, a soil investigation and classification is needed to provide adequate information to the manufactures so that the site conditions can be matched with the best products. In addition, a physical sample of the proposed material for this roadwork should be given to each manufacturer.

Need for Special Contract Requirements (SCRs)

No single product is the only solution. Because all of the tested products performed well, these and additional products should be available for use on FLH projects. SCRs are needed in order to employ these newer products until such time that the FP-03, Standard Specifications for Federal Projects can be changed.

Stabilization Depth

With the observed drop in performance by the end of the study of the Mag/Cl surface application, it would appear that stabilization of a soil to a depth of 150 mm (6 in) is more effective and longer performing than surface applications. However, to prove this theory, the study should have employed a comparison of both surface and full-depth stabilization for each product. It could be further speculated that treating the roadway depth to half of what actually occurred would have also resulted in satisfactory results, but this is currently unsupported. This said, it appears there is a need in future studies to define a minimum effective depth of stabilization to provide for cost effective treatments, or to determine the cost effective balance between full depth stabilization and repeated applications of surface treatments.

Product Selection

Even though some product selection guidance already exists, education in the proper selection and specifying of roadway dust stabilizers is needed for Federal Lands Division designers and construction personnel as well as for Federal land management units that have road maintenance capabilities. Current selection processes start with the product, and show how they can be applied. For example, the USDA Forest Service publication entitled *Dust Palliative Application and Selection Guide* provides a table that indicates what kinds of soils and conditions best suit a particular class of products. A process that would work better would start first with identifying the composition and classification of the soil for a specific project, move to inputting climate, traffic, and environment requirements, then finally identify the best product or product class to use. While this study provided average scores for the products as well as relative costs and relative application rates, a different product selection process is needed to assist in deciding which product to use for a specific application.

Environmental Effects

No deleterious effects on the vegetation were observed for any of the products; however no physical environmental monitoring tests were done to conclusively verify this. Other non-visual effects may be measurable with other physical environmental monitoring tests. It must be acknowledged that at other locations with different conditions, some products may not be compatible with existing vegetation or may not be allowed by local agencies. There is a need to evaluate the various products’ potential for environmental impacts.

RECOMMENDATIONS

- Develop SCRs to specify and allow the use of various dust and roadway stabilization products.

- Develop and employ a process for continued evaluation and validation of these and other products available in the FLH’s jurisdictions. Include studies to define a minimum effective depth of stabilization to provide for cost effective treatments or to determine the cost effective balance between full depth stabilization and repeated applications of surface treatments. Consider partnering with the F&WS to evaluate environmental impact of the products.

- Perform further investigations using these same products with different types of soils, climates, and conditions to refine product selection processes. Further refine assessment parameters to strengthen objectivity and performance tracking over time.

- Collect additional information to develop more precise economic product comparisons based on initial and installation costs; application rates; and product effectiveness in terms of stability, dust mitigation, and longevity.

- Develop a selection chart for the optimum match of a product category with the site-specific parameters of soil types, composition, classification, climate, traffic, and environment.

- Develop and provide training for designers and field personnel on the application and use of these products.

- In partnership with the F&WS, incorporate environmental effects testing into future product comparison and monitoring projects on Federal lands.

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Table 21. Dynamic cone penetrometer values at 12-month evaluation.

		@ 0.20 Miles				@ 0.50 Miles				@ 0.8 Miles				
Test Section	**Product**	# Of Blows	Depth (mm)	Penn Per Blow	**CBR**	# Of Blows	Depth (mm)	Penn Per Blow	**CBR**	# Of Blows	Depth (mm)	Penn Per Blow	**CBR**	**CBR Mean**
I	**Mag/Lig**	40	190	5	**55**	100	160	1	**100**	70	170	2	**81**	**79**
II	**Caliber**	80	90	0	**98**	80	120	1	**100**	50	170	3	**88**	**95**
III	**Soil Sement**	30	160	5	**47**	30	150	5	**45**	40	160	4	**55**	**49**
IV	**Permazyme**	70	160	2	**100**	50	160	3	**64**	50	170	3	**68**	77
V	**Terrazyme**	30	160	5	**45**	30	140	5	**47**	70	160	2	**84**	**59**
VI	**Lignosulfonate**	50	160	3	**66**	30	150	5	**47**	50	160	3	**72**	**62**
VII	**Mag/Cl**	---	---	---	---	---	---	---	---	---	---	---	---	---

Table 22. Dynamic cone penetrometer values at 18-month evaluation.

		@ 0.20 Miles				@ 0.50 Miles				@ 0.8 Miles				
Test Section	**Product**	# Of Blows	Depth (mm)	Penn Per Blow	**CBR**	# Of Blows	Depth (mm)	Penn Per Blow	**CBR**	# Of Blows	Depth (mm)	Penn Per Blow	**CBR**	**CBR Mean**
I	**Mag/Lig**	100	160	2	**92**	---	---	---	---	90	160	2	**93**	**93**
II	**Caliber**	50	140	3	**76**	---	---	---	---	60	160	3	**80**	**78**
III	**Soil Sement**	30	150	5	**47**	---	---	---	---	40	160	4	**53**	**50**
IV	**Permazyme**	60	150	2	**80**	---	---	---	---	40	150	4	**58**	**69**
V	**Terrazyme**	40	150	4	**55**	---	---	---	---	30	170	6	**50**	**53**
VI	**Lignosulfonate**	50	160	3	**72**	---	---	---	---	50	150	3	**68**	**70**
VII	**Mag/Cl**	---	---	---	---	---	---	---	---	---	---	---	---	---

Table 23. Dynamic cone penetrometer values at 24-month evaluation.

		@ 0.20 Miles				@ 0.50 Miles				@ 0.8 Miles				
Test Section	Product	# Of Blows	Depth (mm)	Penn Per Blow	CBR	# Of Blows	Depth (mm)	Penn Per Blow	CBR	# Of Blows	Depth (mm)	Penn Per Blow	CBR	CBR Mean
I	Mag/Lig	40	140	3	75	---	---	---	---	140	100	0	99	87
II	Caliber	120	150	1	98	---	---	---	---	50	150	3	80	89
III	Soil Sement	30	160	5	48	---	---	---	---	40	150	2	73	61
IV	Permazyme	30	150	4	50	---	---	---	---	40	150	2	70	60
V	Terrazyme	30	150	5	50	---	---	---	---	40	160	3	65	58
VI	Lignosulfonate	40	140	1	78	---	---	---	---	60	150	2	90	84
VII	Mag/Cl	---	---	---	---	---	---	---	---	---	---	---	---	---

APPENDIX B – SILT ANALYSIS TEST PROCEDURE

40 CFR 52.128 Rule for unpaved parking lots, unpaved roads and vacant lots.

40 CFR 52.128(b)(16)(i)(B)

Silt loading (weight of silt per unit area) is less than 0.33 ounces per square foot as determined by the test method in section I.B of Appendix A of this section OR where silt loading is greater than or equal to 0.33 ounces per square foot and silt content does not exceed six (6) percent for unpaved road surfaces or eight (8) percent for unpaved parking lot surfaces as determined by the test method in section I.B of Appendix A of this section.

40 CFR 52.128 Appendix A I.B, Silt Content.

Conduct the following test method to determine the silt loading and silt content of unpaved road and unpaved parking lot surfaces.

(i) Collect a sample of loose surface material from an area 30 cm by 30 cm (1 foot by 1 foot) in size to a depth of approximately 1 cm or until a hard subsurface is reached, whichever occurs first. Use a brush and dustpan or other similar device. Collect the sample from a routinely traveled portion of the surface that receives a preponderance of vehicle traffic, i.e. as commonly evidenced by tire tracks. Conduct sweeping slowly so that fine surface material is not released into the air. Only collect samples from surfaces that are not wet or damp due to precipitation or dew.

(ii) Obtain a shallow, lightweight container and a scale with readings in half-ounce increments or less. Place the scale on a level surface and zero it with the weight of the empty container. Transfer the entire sample collected to the container, minimizing escape of particles into the air. Weigh the sample and record its weight.

(iii) Obtain and stack a set of sieves with the following openings: 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm. Place the sieves in order according to size openings beginning with the largest size opening at the top. Place a collector pan underneath the bottom (0.25 mm) sieve. Pour the entire sample into the top sieve, minimizing escape of particles into the air by positioning the sieve/collector pan unit in an enclosed or wind barricaded area. Cover the sieve/collector pan unit with a lid. Shake the covered sieve/collector pan unit vigorously for a period of at least one (1) minute in both the horizontal and vertical planes. Remove the lid from the sieve/collector pan unit and disassemble each sieve separately beginning with the largest sieve. As each sieve is removed, examine it for a complete separation of material in order to ensure that all material has been sifted to the finest sieve through which it can pass. If not, reassemble and cover the sieve/collector pan unit and shake it for period of at least one (1) minute. After disassembling the sieve/collector pan unit, transfer the material that is captured in the collector pan into the lightweight container originally used to collect and weigh the sample. Minimize escape of particles into the air when transferring the material into the container. Weigh the container with the material from the collector pan and record its weight. Multiply the resulting weight by 0.38

if the source is an unpaved road or by 0.55 if the source is an unpaved parking lot to estimate silt loading. Divide by the total sample weight and multiply by 100 to arrive at the percent silt content.

(iv) As an alternative to conducting the procedure described above in section I.B.(ii) and section I.B.(iii) of this appendix, the sample (collected according to section I.B.(i) of this appendix) may be taken to an independent testing laboratory or engineering facility for silt loading (e.g. net weight < 200 mesh) and silt content analysis according to the following test method from Procedures For Laboratory Analysis Of Surface/Bulk Dust Loading Samples", (Fifth Edition, Volume I, Appendix C.2.3 ``Silt Analysis", 1995), AP-42, Office of Air Quality Planning & Standards, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

1. Objective - Several open dust emission factors have been found to be correlated with the silt content (< 200 mesh) of the material being disturbed. The basic procedure for silt content determination is mechanical, dry sieving. For sources other than paved roads, the same sample that was oven-dried to determine moisture content is then mechanically sieved.

2.1 Procedure - Select the appropriate 20-cm (8-in.) diameter, 5-cm (2-in.) deep sieve sizes. Recommended U. S. Standard Series sizes are 3/8 in., No. 4, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be used. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available, or if buildup on one particulate sieve during sieving indicates that an intermediate sieve should be inserted.

2.2 Obtain a mechanical sieving device, such as a vibratory shaker or a Roto-Tap without the tapping function.

2.3 Clean the sieves with compressed air and/or a soft brush. Any material lodged in the sieve openings or adhering to the sides of the sieve should be removed, without handling the screen roughly, if possible.

2.4 Obtain a scale (capacity of at least 1600 grams [g] or 3.5 lb) and record the make, capacity, smallest division, date of last calibration, and accuracy. (See Figure A. Example silt analysis form, below)

2.5 Weigh the sieves and pan to determine tare weights. Check the zero before every weighing. Record the weights.

2.6 After nesting the sieves in decreasing order of size, and with pan at the bottom, dump dried laboratory sample (preferably immediately after moisture analysis) into the top sieve. The sample should weigh between 400 and 1600 g (0.9 and 3.5 lb). This amount will vary for finely textured materials, and 100 to 300 g may be sufficient when 90% of the sample passes a No. 8 (2.36 mm) sieve. Brush any fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.

2.7 Place nested sieves into the mechanical sieving device and sieve for 10 minutes (min). Remove pan containing minus No. 200 and weigh. Repeat the sieving at 10-min intervals until the difference between two successive pan sample weighings (with the pan tare weight subtracted) is less than 3.0%. Do not sieve longer than 40 min.

2.8 Weigh each sieve and its contents and record the weight. Check the zero before every weighing.

2.9 Collect the laboratory sample. Place the sample in a separate container if further analysis is expected.

2.10 Calculate the percent of mass less than the 200 mesh screen (75 micrometers [μm]). This is the silt content.

Figure A. Example silt analysis form

Dated: ___________
By: ___________________________
Sample No: _________ Sample Weight (after drying)
Material: __________
Pan + Sample: _____________
Pan: _____________
Split Sample Balance: _____________
Dry Sample: _______________
Make _____________ Capacity: _____________
Smallest Division _________
Final Weight _____________
% Silt = [Net Weight <200 Mesh] / [Total Net Weight x 100] =____%

Sieving

	Time: Start:	Weight (Pan Only)
Initial (Tare):		
10 min:		
20 min:		
30 min:		
40 min:		

Screen	Tare weight (screen)	Final weight (screen + sample)	Net weight (sample)	%
3/8 in...............................				
4 mesh.............................				
10 mesh...........................				
20 mesh...........................				
40 mesh...........................				
100 mesh.........................				
140 mesh.........................				
200 mesh.........................				
Pan..................................				

(v) The silt loading and percent silt content for any given unpaved road surface or unpaved parking lot surface shall be based on the average of at least three (3) samples that are representative of routinely-traveled portions of the road or parking lot surface. In order to simplify the sieve test procedures in section I.B.(ii) and section I.B.(iii) of this appendix, the three samples may be combined as long as all material is sifted to the finest sieve through which it can pass, each sample weighs within 1 ounce of the other two samples, and the combined weight of the samples and unit area from which they were collected is calculated and recorded accurately.

APPENDIX C – SILT LOADING DATA

Table 24. Silt Loading at 12-month evaluation.

Test Section	Product	Ounces of -No. 200 / ft^2			
		0.20 Miles	0.80 Miles	Mean	Rank
I	Mag/Lig	0.36	2.03	1.19	6
II	Caliber	0.51	0.36	0.44	1
III	Soil Sement	0.89	0.63	0.76	3
IV	Permazyme	1.80	1.74	1.77	7
V	Terrazyme	0.34	0.84	0.59	2
VI	Lignosulfonate	0.95	1.00	0.98	4
VII	Mag/Cl	1.34	0.65	1.00	5

Table 25. Silt Loading at 18-month evaluation.

Test Section	Product	Ounces of -No. 200 / ft^2			
		0.20 Miles	0.80 Miles	Mean	Rank
I	Mag/Lig	0.21	0.39	0.30	2
II	Caliber	0.03	0.26	0.14	1
III	Soil Sement	1.28	0.61	0.94	5
IV	Permazyme	0.88	1.41	1.14	7
V	Terrazyme	1.40	0.59	0.99	6
VI	Lignosulfonate	0.70	0.66	0.68	3
VII	Mag/Cl	0.86	--	0.86	4

Table 26. Silt Loading at 24-month evaluation.

Test Section	Product	Ounces of -No. 200 / ft^2			
		0.20 Miles	0.80 Miles	Mean	Rank
I	Mag/Lig	0.31	0.33	0.32	1
II	Caliber	0.21	0.68	0.44	2
III	Soil Sement	2.17	1.46	1.81	5
IV	Permazyme	2.80	2.82	2.81	6
V	Terrazyme	1.43	1.36	1.40	4
VI	Lignosulfonate	1.46	1.17	1.32	3
VII	Mag/Cl	Not Sampled @ 24-Months			

APPENDIX D – ACKNOWLEDGEMENTS

The authors, Roger Surdahl, J. Heather Woll, and Rick Marquez, would like to express their appreciation to the following individuals without whom this project could never have been a success:

- Specific FHWA CFLHD Engineers for providing information and technical comments used to develop this document and for reviewing the document:
  Brian Dobling, Project Engineer
  Randy Everett, Construction Operations Engineer
  Michael Peabody, Materials Engineer
  Ron Andersen, Materials
  Randall Caley, Materials

- The construction contractor for his effort in scheduling and coordination during the application and processing of the products:
  Mario Zappa, Project Manager, A & S Paving, Construction Contractor, Tucson, Arizona

- The manufacturers and suppliers of the stabilization and dust palliatives used on the project:
  Todd Hawkins, Midwest Industrial – Soil Sement
  John Sedwick, Nature Plus, Inc. – Terrazyme
  Eugene Nutsch, Idaho Enzymes, Inc. – Permazyme
  Klif Rader, Desert Mountain Corp. – Caliber, Lignosulfonate, Mag/Lig, and Mag/Cl

- The Buenos Aires NWR staff for providing information and on site assistance during the 24-month evaluation, and especially:
  Wayne Shifflett, Refuge Manager
  Sally Gall, Refuge Operations Specialist