ROAD STABILIZER PRODUCT PERFORMANCE
Seedskadee National Wildlife Refuge

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U.S. Department
of Transportation
Federal Highway
Administration

CTIP

Federal Lands Highway
Commitment to Excellence

Central Federal Lands Highway Division
12300 West Dakota Avenue
Lakewood, CO 80228

FOREWORD

The Federal Lands Highway (FLH) of the Federal Highway Administration (FHWA) promotes development and deployment of applied research and technology applicable to solving transportation related issues on Federal Lands. The FLH provides technology delivery, innovative solutions, recommended best practices, and related information and knowledge sharing to Federal agencies, Tribal governments, and other offices within the FHWA.

The FLH designs, administers and oversees an increasing amount of aggregate surfacing roadwork for clients in remote locations. 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 unpaved roads. Thus, identifying methods to effectively control dust and prevent raveling, rutting, wash boarding, and potholing on these unpaved roads is an important goal of the FLH.

The primary objective of this project, like its predecessor project at Buenos Aires National Wildlife Refuge in Arizona, was to evaluate six different road stabilizer products for potential use on FLH projects for dust control and surface stabilization. This project at the Seedskadee National Wildlife Refuge in Wyoming evaluated the same six products, but the climate, road surfacing material, and depth of stabilization were different. A new objective monitoring system was added so that trends over time as well as comparative observations could be analyzed and evaluated.

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

Notice

Quality Assurance Statement

Technical Report Documentation Page

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16. Abstract

Roadway stabilization or dust abatement products are classified into seven categories: 1) Water, 2) Water Absorbing, 3) Organic Petroleum, 4) Organic Non-petroleum, 5) Electrochemical, 6) Synthetic Polymer, 7) Clay Additives.

Six different soil stabilizers from the above categories of 2, 4, 5, and 6 were individually applied each on a 0.8-km (0.5-mi) section to a depth of 125 mm (5 in) at the Seedskadee National Wildlife Refuge in south western Wyoming. These six products were monitored for a period of two years.

Both subjective and objective monitoring systems were used to evaluate the products' effectiveness in controlling dust, wash boarding, raveling, rutting, and potholing. 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 products and their performance, comparisons of silt load results and dust observations, and a correlation study of the subjective and objective monitoring systems.

For this specific semi-arid desert location and non-plastic crushed aggregate surfacing material, the evaluation of each product's performance in order from the highest rank was 1) an Organic Non-Petroleum (Lignosulfonate), 2) Water Absorbing/Organic Non-Petroleum mix (Mag/Lig), 3) Water Absorbing/Organic Non-Petroleum mix (Caliber), 4) Electrochemical Enzyme (Permazyme), 5) Electrochemical Enzyme (Terrazyme), and 6) Synthetic Polymer (Soil Sement.)

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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)

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LIST OF ABBREVIATIONS AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
BLM	Bureau of Land Management
CFLHD	Central Federal Lands Highway Division
CBR	California Bearing Ratio
CTIP	Coordinated Technology Implementation Program
DCP	Dynamic Cone Penetrometer
DOT	Department of Transportation
F&WS	Fish and Wildlife Service
FHWA	Federal Highway Administration
FLH	Federal Lands Highway
FP	Federal Projects
LL	Liquid Limit
NP	Non-plastic
NWR	National Wildlife Refuge
PI	Plasticity Index
PL	Plastic Limit
SCR	Special Contract Requirement
TDIPP	Technology Deployment Initiatives and Partnership Program
US	United States
USFS	US Forest Service

CHAPTER 1 – INTRODUCTION AND BACKGROUND

SURFACE STABILIZATION PROJECTS

The Federal Highway Administration (FHWA), Federal Lands Highway (FLH) designs, administers, and oversees an increasing amount of aggregate surfacing roadwork for clients in remote locations throughout the western United States. There are approximately 6,359,568 km (3,950,042 mi(1)) 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 1 shows, of the 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 the percentage of unpaved roads varies for each agency, each one shares in the problems of dust generation from road user traffic and maintaining unpaved roads for traffic access. 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. Maintenance of these unpaved roads for their intended use is also a big challenge because traffic on unpaved roads breaks down the surfacing materials, resulting in raveling of the larger rocks once the binding material is gone, and promotes rutting or deformation of the underlying roadway materials as well as washboarding and potholing that make for a very uncomfortable ride. Owners of unpaved roadways face a big challenge and identifying methods to effectively control dust and prevent raveling, rutting, washboarding and potholing on these roads is a goal of the FLH.

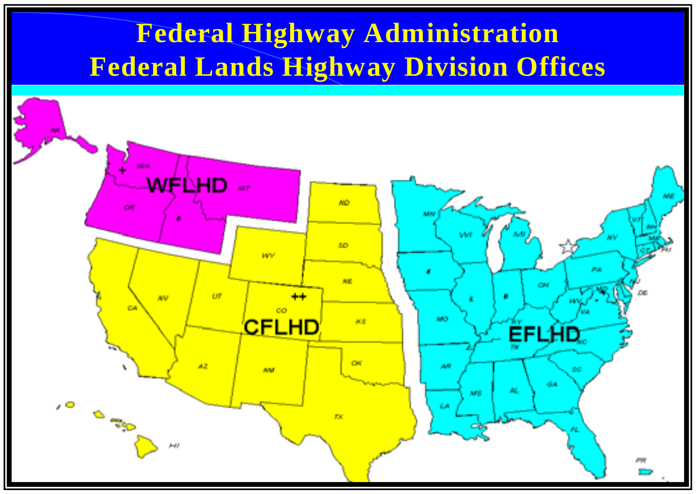


Figure 1. Map. FHWA FLH Divisions.

One of three Federal Lands Highway offices, the Central Federal Lands Highway Division (CFLHD) specifically oversees the construction of highways on Federal Lands in 14 western states as shown in Figure 1. This study conducted at the Seedskadee National Wildlife Refuge (NWR) in southwest Wyoming is the second project undertaken by the CFLHD to broaden the base of knowledge about dust control products and application methods. A report on the first study at Buenos Aires NWR, in south-central Arizona, is available.(2)

Currently in the FHWA FLH's FP-03 Standard Specifications for Highway Construction(3) 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 stabilizing surfacing materials, thus reducing maintenance costs.

Table 1. 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%

The First Study – Buenos Aires National Wildlife Refuge

In 2002, the CFLHD applied six different road stabilizer or dust palliative products on a road reconstruction project at the Buenos Aires NWR in south-central Arizona. The purpose of the study was to evaluate the six 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.

The study showed that 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 needed grading after 24 months, the owner agency had been saved from performing its typical six to seven grading maintenance events.

The Second and Current Study – Seedskadee National Wildlife Refuge

The primary objective of the Seedskeedee project, covered in this report, was to test the same six products that were used at Buenos Aires in a different road surfacing material at a different stabilization depth and in a different climate. The evaluation again addressed each product's performance for dust control, rutting, washboarding, raveling, and soil stabilization over a 24-month period. The products with acceptable performance would again be recommended for use on other CFLHD projects.

An additional objective for this project was to carry out some of the recommendations from the Buenos Aires study. Those recommendations are listed below along with a progress update:

1. **Develop SCRs to specify and allow the use of various dust and roadway stabilization products.** Developing a new Special Contract Requirement (SCR) to specify and allow use of new road stabilizer products is not an easy task because an SCR cannot specify any brand name product. However, the performance monitoring at Seedskadee has resulted in changes to the maximum size of aggregate and the minimum plasticity index allowed by CFLHD construction contracts calling for aggregate surfacing. Both the Buenos Aires and Seedskadee studies have stimulated discussion about how to write a performance specification for stabilizer products.

2. **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.** These recommended studies are aimed at long-term needs. The current road stabilizer investigation at Seedskadee NWR provides data that can be used to help meet these long term needs. Whereas the depth of stabilization was 150 mm (6 in) at Buenos Aires, a 125-mm (5-in) depth was used at Seedskadee.

3. **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.** The Seedskadee project provided a great deal more objective data to track performance of the products over time. This additional data was the result of a new objective assessment method developed for the Seedskadee project to strengthen objectivity and track performance over time.

4. **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.** As pointed out in the Buenos Aires report, a detailed economic comparison of stabilizer products is not possible. In general, 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. For a standard application, the enzyme products might cost approximately one-third the cost of the chloride and organic products (DC Caliber 2000, Mag/Lig, and Lignosulfonate) and one-fourth to one-fifth the cost of the Soil Sement. These comparisons are suggestions based on general cost data and are subject to many variations. Contractors or other agencies that use this study should perform their own market analysis of product costs based on the proposed application, climate, specifications requirements, availability, and project location.

5. **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.** A selection process for road designers to select a suitable stabilizer product category is proposed in the final appendix following this report.

6. **Develop and provide training for designers and field personnel on the application and use of these products.** The project engineers who were assigned to the Buenos Aires and Seedskadee projects have given presentations on the application method used on their project so as to pass on their experience and insights. The authors of these studies have also shared this information at conferences, workshops, and in published papers.

7. **In partnership with the F&WS, incorporate environmental effects testing into future product comparison and monitoring projects on Federal Lands.** Subsequent to the contract being signed for the Seedskadee product application, the Fish and Wildlife Service (F&WS) issued direction that any further F&WS projects using dust stabilizers must include a minimum three-year environmental monitoring plan to include monitoring during the year prior to application, the year of application, and a year following the application. Thus, the FHWA did not incorporate strict environmental monitoring into this study. Visual observations for product leaching were done, but no other physical monitoring for ground water quality, fresh water aquatic environment, or plant community was conducted to document any environmental effect of the products. To address this issue, the F&WS initiated an Environmental Protection Agency study, which is now being conducted by the US Geological Survey. It is the hope that future NWR projects that use road stabilizer

products will be able to incorporate a more rigorous product selection and environmental examination in partnership with the F&WS.

The performance of the products used for the Seedskadee project as a whole were considered, by the evaluation team, to be less effective than at the Buenos Aires project. After two years of monitoring, both dust production and washboarding were considered to be unacceptable in some of the product sections. There were, however, obstacles that affected performance, and they need to be recognized. First, the percentage passing the 75 µm (No. 200) sieve for the aggregate surfacing material was low at 0% to 4%, coupled with a PI of non-plastic (NP) to 4. So some of the products that react with clay fines could have no stabilizing effect. Second, a very harsh winter and rapid spring thaw damaged one of the sections and severely reduced its monitoring area. Nonetheless, Refuge personnel have been pleased with the project as a whole. The Refuge Headquarters parking area, which was stabilized with the Caliber product, has remained smooth and produced very little dust. Since washboarding of Refuge roads has traditionally been a big problem requiring maintenance blading three or four times per year, the full depth stabilization performed in this project using a pulverizing machine has substantially alleviated this problem. Therefore, this project was considered a success.

PROJECT BACKGROUND

Figure 2. Photo. Bluffs above the Green River at the boat launch.

The project site selected for this evaluation, shown in Figure 2, was located in the Seedskadee NWR in southwest Wyoming as. Seedskadee NWR was established in 1965 through the Colorado River Storage Project Act of 1956 that authorized construction of Colorado River storage facilities and also provided for wildlife habitat development areas to offset the loss of wildlife habitat resulting from reservoir construction.(4) The Seedskadee Reclamation Act of 1958 specifically authorized acquisition of lands for Seedskadee NWR. The northern boundary of the Refuge is 11 km (7 mi) downstream of Fontenelle Dam on the Green River and extends 60 km (37 mi) downstream and further south. Its width ranges from 1.5 to 3 km (1 to 2 mi) and its total relief is 90 m (300 ft) from an elevation of 1,980 m (6,490 ft) near the north end to 1,890 m (6,190 ft) at the south end.

The Seedskadee NWR manages for a variety of native plants and wildlife with emphasis on migratory birds and threatened and endangered species. The Refuge also provides interpretation of the natural and human history of the area and provides access for wildlife-dependent recreation that is compatible with Refuge purposes. These uses include floating and fishing on the Green River and viewing wildlife in the wetland areas, on the river, and along the Refuge

Tour Routes in the upland sagebrush habitat. The name Seedskadee is derived from the Shoshone Indian name for the river "Sisk-a-dee-agie" or "river of the prairie hen."

On average, the traffic counts on the roads maintained by the Seedskadee NWR are very low. No traffic counts were available, but the road maintenance foreman on the Refuge estimated that the average annual daily traffic is about four vehicles per day. However during high-use seasons, hunting in the fall and fishing in the spring and summer, traffic is estimated to be ten to fifteen vehicles per day. Since the town of Rock Springs has been booming with new oil exploration, campgrounds have been full and traffic is generally higher on the Refuge than in past decades. As long as the oil boom continues, traffic on this Refuge's roads is expected to remain above historic levels.

The Seedskadee reconstruction project, Wyoming RRP SEED 12(1),(5) was designed and constructed 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 (TDIPP) that promotes deployment of transportation-related research and technology, and the monitoring was funded by the FLH Coordinated Technology Implementation Program (CTIP). The construction contractor was Desert Sage Contractors, Inc., Idaho Falls, Idaho. Construction of the project, including the application of the roadway dust stabilizers, was completed in October 2004.

This project was carried out using mostly English measurements, and reference material typically also used English measurement units. Therefore, for the most part, the English measurements in parentheses are the true measurements, and the metric units are hard conversions (not exact) based on reasonableness. Distances in this report are shown to a precision of hundredths of a mile as a surveyor's wheel was used to locate the monitoring areas.

PROJECT LAYOUT AND PRODUCTS

The Seedskadee project site is shown in Figure 3. One area of the Refuge called Dodge Bottoms is situated in the northern end of the Refuge and contained five of the six monitoring sections. Near the southern end of the Refuge, 27 km (17 mi) away, was Six Mile Hill Road where the sixth section was located. The stabilizer products applied in each section are shown in Table 2. The surfacing aggregate was 125 mm (5 in) deep, and the stabilizer products were milled together with the aggregate to this full 125-mm (5-in) depth using a CMI 650 pulverizer.

The categories listed in the third column of the table refer to the seven basic categories presented in the United States Forest Service's (USFS) *Dust Palliative Application and Selection Guide*(6). The Seedskadee project evaluation team found this 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 showed the various types of suppressants within each category and offers a list of specific product names and manufactures. A product selection flowchart was also used from the USFS publication.

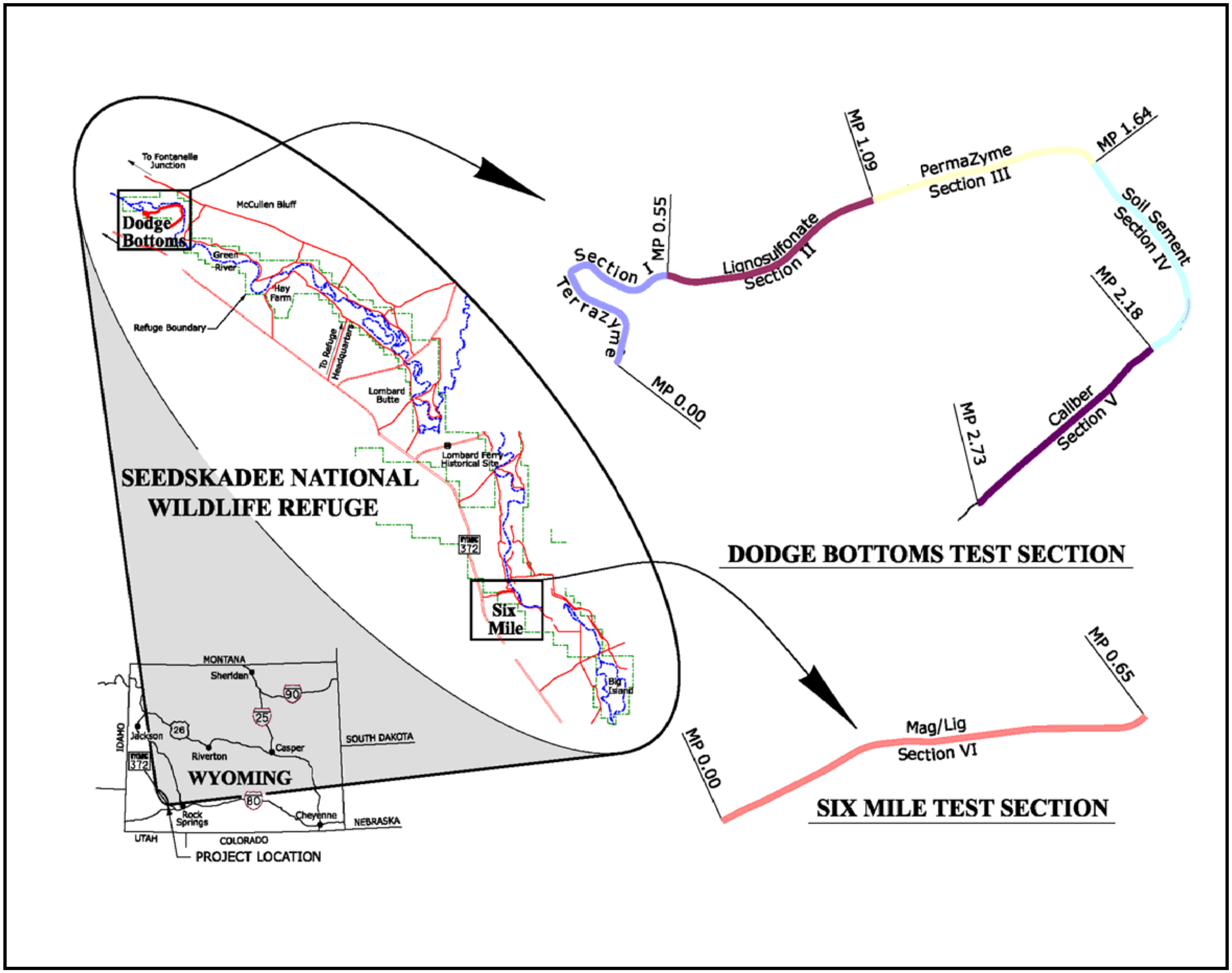


Figure 3. Map. Location and layout for Seedskadee National Wildlife Refuge road stabilization project.

Table 2. Test sections, locations, products, and suppliers.

Test Section	Approximate Milepost Locations	Product and Category	Manufacturer's Undiluted Application Rate	Supplier
I	0.00 – 0.55 Dodge Bottom N.	TerraZyme *(Electrochemical Enzyme)*	0.006 gal/yd^3	Nature Plus, Inc 555 Lordship Blvd. Stratford, CT 06615
II	0.55 – 1.09 Dodge Bottom N.	Lignosulfonate *(Organic non-Petroleum)*	5.6 gal/yd^3	DustPro, Inc. 725 S. 12th Place Phoenix, AZ 85034
III	1.09 – 1.64 Dodge Bottom N. and S.	PermaZyme 11x *(Electrochemical Enzyme)*	0.006 gal/yd^3	Idaho Enzymes, Inc. 1010 W. Main Jerome, ID 83338
IV	1.64 – 2.18 Dodge Bottom S.	Soil Sement *(Synthetic Polymer Emulsion Vinyl Acrylic)*	2.9 gal/yd^3	Earth Care Consultants 285 N. Meyer, Suite 1 Tucson, AZ 85701
V	2.18 – 2.73 Dodge Bottom S.	DCA - 2000 Caliber *(Organic non-Petroleum (vegetable corn oil) + water absorbing (Mag/Cl))*	7.2 gal/yd^3	Desert Mountain Corp. P.O. Box 1633 Kirkland, NM 87417
VI	0.00 – 0.65 Six Mile Hill Road	DMC 820 Magnesium/ Lignosulfonate *(Water adsorbing + Organic non-Petroleum)*	7.2 gal/yd^3	Desert Mountain Corp. P.O. Box 1633 Kirkland, NM 87417

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.

GENERAL PRICE ANALYSIS AND SAVINGS

As with the Buenos Aires study, the cost of the products varied widely, and it was difficult to develop a detailed comparison of product costs that would apply to any locale. Each product manufacturer recommended a specific application rate for the type of soil being stabilized. Since no two manufactures recommended the exact same application rate, a direct comparison was not possible. In addition to application rates, a simple price per gallon figure is difficult to pin point because manufacturers typically quoted prices by the job depending upon the amount of product required. In other words, there usually is a unit cost savings as the product quantity increases. The comparison by price per gallon was further complicated because of varying market conditions such as demand, economy, competition, project location, and many other factors.

Nevertheless, for the 125-mm (5-in) stabilization depth, the actual material unit costs from low to high for the six products procured under this project were: Permazyme - \$1.10/m^3 (\$0.84/yd^3); Terrazyme - \$1.95/m^3 (\$1.49/yd^3); Mag/Lig - \$8.00/m^3 (\$6.11/yd^3), Lignosulfonate \$9.55/m^3 (\$7.30/yd^3); Caliber \$11.00/m^3 (\$8.42/yd^3); and Soil Sement \$16.55/m^3 (\$12.66/yd^3).

A historical maintenance cost per mile to maintain roads at Seedskadee NWR also has not been developed because of many variables. The Seedskadee Refuge maintenance crew tries to keep down road maintenance costs by coordinating their efforts with the weather. They do not have a water truck and depend on rainfall to moisten the roads for blading. They usually use a loaded dump truck to compact the surface after blading, as they do not own a roller. They often rent a roller when Refuge funds are available. They like to blade their roads three times per year or four times if the moisture is right. Washboarding is the main problem. They have 48 to 56 km (30 to 35 mi) of road, and to blade them all takes about 40 hours and uses about 760 L (200 gal) of fuel. For a dust suppressant, they typically use Magnesium Chloride (Mag Water) and the cost is approximately $930 per km ($1,500 per mi). Its major drawback is that it is corrosive to vehicles. They use 8,220 to 14,100 L per km (3,500 to 6,000 gal per mi) of Magnesium Chloride depending on its concentration in water. They have also found that Lignosulfonate (Tree Sap) also works quite well.

In the report covering the similar Buenos Aires NWR project(2), a general analysis using average maintenance costs from a study(7) of Minnesota counties revealed a benefit to cost ratio of 1.0 or slightly better for that project. When the same methodology and assumptions was used in the Seedskadee NWR study, a much lower benefit to cost ratio resulted. Specifically, for the total of 5.43 km (3.37 mi) of gravel road in the Seedskadee study, and assuming a cost of $3,105 /km ($5,000/mi) for the Refuge due to its remoteness, the savings are estimated at $33,710 over the two years of the study. The cost that the contractor was paid to procure and incorporate the products was $62,538. Thus the benefit to cost ratio is only about 0.5.

The difference in the two benefit/cost ratios can be traced to two specific elements and some intangible elements. First, there were increased costs for some of the stabilizer products that had been nearly donated for the earlier Buenos Aires project. Second, the application methods were entirely different. Buenos Aires used a windrow method – requiring only a grader, water truck, and roller – that cost approximately $1730 per km ($2800 per mi). At Seedskadee, however, a tiller method was used – requiring a specialized reclamation machine in addition to a grader, distributor truck, and roller – and this process cost $5,000 per km ($8,000 per mi).

One of the intangible elements that should be considered is that resurfacing of gravel roads is generally expected to last more than two years. The facts that the surfacing was stabilized to full depth and that residual stabilizer product remains in the surfacing material below the exposed road surface would increase that expectation. The benefit to cost comparison above only considered the two years of monitoring that was carried out for both projects.

Washboarding has traditionally been the primary maintenance problem at Seedskadee necessitating maintenance grading three or four times per year. After two years, some of the full depth stabilized sections still showed only minimal washboarding. Whereas surface applications of Magnesium Chloride can control dust, they do not control washboarding. It appears that the full depth stabilization using the reclamation machine is a major breakthrough in controlling washboarding at Seedskadee NWR.

A final intangible benefit to both of the Refuges is the knowledge of which stabilizer products work well in the particular locale for controlling dust, reducing maintenance efforts, and side-stepping the corrosive effects of continuous use of Magnesium Chloride. These intangible elements are difficult to measure but should be taken into account as significant benefits outweighing the costs on both projects.

MONITORING PROGRAM

Once the road construction and product application was completed in September 2004, a 24-month monitoring period followed consisting of four monitoring events during which the sections were observed, measured, and field-tested for strength, silt loading, and the degree of dusting, washboarding, raveling, rutting, and potholing. The monitoring efforts are covered in four topic areas in the report, and a chapter is devoted to each topic. They are:

Chapter 3 – Laboratory Analysis of Materials
Chapter 4 – Subjective Observations
Chapter 5 – Objective Measurements
Chapter 6 – Onsite Physical Testing

Table 3 lists the standard specifications and tests used to characterize the material and also the monitoring activities that were performed. The table also shows when the tests and inspection activities were carried out. Due to seasonal concerns, it was decided to conduct the biannual monitoring in May and August each year. The Seedskadee NWR experiences extremes of climate. Some winters have a large snow pack and others very little snow. Winds can be light

Table 3. Standard specifications and monitoring activities.

Test Number	Description	Initial	8-month	11-month	20-month	23-month
AASHTO T 11	Material Finer Than 75-um (No. 200) Sieve in Mineral Aggregate by Washing	X	X	X	X	X
AASHTO T 27	Sieve Analysis of Fine and Coarse Aggregate	X	X	X	X	X
AASHTO T 88	Particle size Analysis of Soils	X	X	X	X	X
AASHTO T 89	Determining the Liquid Limit of Soils	X				
AASHTO T 90	Determining the Plastic Limit and Plasticity Index of Soils	X				
AASHTO T 180	Moisture-Density Relations of Soils Using 4.54 Kg (10 lb) Rammer and 457 mm (18 in) Drop	X				
AASHTO T 190	Resistance R-value and Expansion Pressure of Compacted Soils	X				
AASHTO T 193	The California Bearing Ratio	X				
AASHTO T 310	In-Place Density and Moisture Content of Soil and Soil-Aggregate by Nuclear Method	X				
AASHTO M 145	Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes	X				
ASTM D 2487	Standard Practice for Classification of Soils for Engineering Purposes (Unified System)	X				
ASTM D 2974	Moisture, Ash, and Organic Matter of Peat and Other Organic Soils	X				
Dust	Comparative visual rating & agreed objective rating based on visual observation		X	X	X	X
Washboarding	Comparative visual rating & objective rating based on field measurements		X	X	X	X
Raveling	Comparative visual rating & objective rating based on field measurements		X	X	X	X
Rutting	Comparative visual rating & objective rating based on field measurements		X	X	X	X
Potholing	Comparative visual rating & objective rating based on field measurements		X	X	X	X
ASTM D 6951	Standard Test Method for Use of Dynamic Cone Penetrometer	X	X	X	X	X
40 CFR	Silt Loading, 40 CFR 52.128(b)(16)(i)(B)		X	X	X	X

but often are strong and unrelenting. Refuge personnel advised that monitoring not take place any earlier than late May and no later than early September to assure decent weather. That is why the monitoring events were spaced unequally at 8, 11, 20, and 23 months after application of the products in late September of 2004.

All available weather data for the monitoring period is on file at CFLHD. However, for this report, only a simple review of the weather during the monitoring events or a few days before the events was deemed relevant. Generally, rainfall was very light or non-existent prior to all the monitoring events except for the first one on October 20, 2004, shortly after product installation.

Conditions were wet during this initial, 1-month, monitoring event. Prior to the 8-month event that occurred on May 18 and 19, 2005, minimal precipitation occurred about once per week. The previous morning, on May 17, 1.5 mm (0.06 in) of rain fell. Before the 11-month event that occurred on August 29 and 30, 2005, there was no precipitation for 11 days. Before the 20-month event that occurred on May 17 and 18, 2006, no rain had fallen for 12 days and the road surface was dry. However, humidity was building on the second day of monitoring and it rained 4 mm (0.16 in) in the early evening after all monitoring had been completed. In addition, just prior to this 20-month event, there was significantly more traffic using the Section VI Six Mile Hill Road stabilized with the Mag/Lig product. This was because the Refuge maintenance crew did some work on a road accessed through Section VI, and multiple loaded dump trucks went up and down this section. Measurable but again very little rain fell two and three days before the final 23-month monitoring event on August 28 and 29, 2006. On August 26, 2006, there was 2 mm (0.08 in) of rain and on August 25, 3 mm (0.12 in) of rain.

Winds were generally light in the mornings but increased in intensity in the afternoons making some of the sampling conditions less than optimal. Though the monitoring team assured that no sampling for dust or other monitoring for dust occurred early in the morning when dew might be on the ground, in the case of Seedskadee, the occurrence of dew was never a problem because there was very little moisture and the dew point was always significantly below early morning temperatures.

The severe winter snows of 2005 and the rapid spring melt caused damage to one of the newly-constructed sections at Seedskadee. This Section V, stabilized with the Caliber product, was damaged and required some drainage corrections to avoid future erosion problems. Two repair areas within the section, MP 0.20 to 0.34 and MP 0.46 to 0.52, required re-grading and application of additional aggregate base. But since during the July 2005 repair additional Caliber product was not available to add to these repair areas, these repaired sites were excluded from the monitoring program. The area between the two repair areas (MP 0.34 to 0.46) was not new material; this area was re-graded and was retained for monitoring performance of the Caliber product. No other maintenance or repairs were done to any of the remaining project sections throughout the two-year monitoring period.

CHAPTER 2 – PRODUCT INSTALLATION

The Seedskadee National Wildlife Refuge (NWR) and Desert Sage Contractors agreed to participate in the full-depth aggregate surface course stabilization study sponsored by CFLHD's Technology Deployment Program. The incorporation of six brand name dust palliative products took place over the course of three days on 5.43 km (3.37 mi) of two of the main routes into the Seedskadee NWR. These six products were the same ones that were applied in a similar stabilization experiment at the Buenos Aires NWR in south-central Arizona two years earlier. The method used to incorporate the various products into the newly placed aggregate surface course at Seedskadee was very different from that used at Buenos Aires. At Buenos Aires, each product was applied to the roadway materials in windrows; blade mixed, and then compacted with an 11 Mg (12 ton) 9-wheel pneumatic roller to a total stabilized depth of 150 mm (6 in). At Seedskadee, a tiller method, using a CMI 650 pulverizer, mixed the products with the aggregate surfacing material to the full 125 mm (5 in) depth. One other major difference between the two projects was that the Buenos Aires project used a native pit-run surfacing course whereas the Seedskadee roads used specified aggregate surfacing.

PRODUCT APPLICATION

The application of the products took place on September 22-24, 2004 at the Dodge Bottoms road and at the Six Mile Hill Road. The Headquarters Parking area and the Hayfarm and Lombard kiosk pullouts were also treated.

Desert Sage Contractors administered the application of the TerraZyme, Lignosulfonate, Perma-Zyme 11X, and Soil Sement. These products were shipped to the project and used by Desert Sage according to the manufacturers' recommendations without the presence of a product representative. An International 15,000-L (4,000-gal) water truck, a John Deere 772CH Motor Grader and Hamm 2420 steel drum roller were used to introduce and process the material. Valentine Surfacing, Inc. was subcontracted to perform the full-depth processing. They used a CMI 650 pulverizer to mill the aggregate to a 125-mm (5-in) depth and mix in the various products as shown in Figure 4. Desert Mountain Corporation delivered their products (DCA-2000 Caliber and DMC 820 Lignosulfonate/Magnesium Chloride) accompanied by a product representative to oversee the application of their products. They used a 17,000-L (4,500-gal) distributor truck to apply the products. The CMI pulverizer, grader, and roller were then used to process, grade, and compact the treated aggregate.

Figure 4. Photo. CMI 650 pulverizer following water truck.

Section I (TerraZyme)

The clear concentrate TerraZyme stabilizer was applied in two batches using 19 L (5 gal) of concentrate for each 15,000 L (4,000 gal) of water. Mixing was accomplished by running the mixture through the 100-mm (4-in) hose and back into the water truck through the topside portal. The water truck was then hooked up to the front of the pulverizer where the solution was introduced into the aggregate surface course through liquid dispersion nozzles as it was milled to a 125-mm (5-in) depth. The right lane was processed first, and then the left lane. The middle 0.6 m (2 ft) of the 5.5-m (18-ft) roadway received a double application due to the overlap of the 3-m (10-ft) wide milling machine. The mixture was then graded and rolled for the final appearance as shown in Figure 5.

Figure 5. Photo. The change from Section I (TerraZyme) to Section II (Lignosulfonate).

Section II (Lignosulfonate)

The aggregate surface course was scarified to a 125-mm (5-in) depth with the motor grader while the water truck, which was half full of water, added 8,780 L (2,320 gal) of the Lignosulfonate solution. The water truck then hooked up to the front of the CMI 650 pulverizer where the solution was introduced into the aggregate surface course through liquid dispersion nozzles as it was milled to a 125-mm (5-in) depth. The left lane was processed first, then, the right lane. The middle 0.6 m (2 ft) of the 5.5-m (18-ft) roadway received a double application due to the overlap of the 3-m (10-ft) wide milling machine. The mixture was then graded and rolled.

Section III (Perma-Zyme 11X)

The clear, concentrated Perma-Zyme stabilizer was applied in two batches using 19 L (5 gal) of concentrate for each 15,000 L (4,000 gal) of water. Mixing was accomplished by running the mixture through the 100-mm (4-in) hose and back into the water truck through the topside portal. The water truck was then hooked up to the front of the pulverizer where the solution was introduced into the aggregate surface course through liquid dispersion nozzles as it was milled to a 125-mm (5-in) depth. The right lane was processed first, and then the left. The middle 0.6 m (2 ft) of the 5.5-m (18-ft) roadway received a double application due to the overlap of the 3-m (10-ft) wide milling machine. The mixture was then graded and rolled.

Section IV (Soil Sement)

An empty water truck was filled with 9,370 L (2,475 gal) of the Soil Sement stabilizer. It took nearly three hours to empty the nine 1,040-L (275-gal) containers of the polymer emulsion into the water truck. The batch was topped off with 5,700 L (1500 gal) of water. The water truck was then hooked up to the front of the pulverizer where the solution was introduced into the aggregate surface course through liquid dispersion nozzles as it was milled to a 125-mm (5-in) depth along the middle 3 m (10 ft) of the 3.7-m (12-ft) roadway. The mixture was then graded and rolled.

Section V (DCA – 2000 Caliber)

The 3.7-m (12-ft) wide roadway was watered, the top 50 mm (2 in) of the road scarified, and then the Caliber stabilizer applied using the Desert Mountain distributor truck at a rate of 3 L/m^2 (0.75 gal/yd^2). After allowing the solution to marinate for approximately twenty minutes, the CMI pulverizer was used as shown in Figure 6 to thoroughly mix the product into the aggregate surface course to a 125-mm (5-in) depth. The 3.7-m (12-ft) wide roadway was then graded and rolled, at which time a topical application of the solution was sprayed at a rate of 1 L/m^2 (0.25 gal/yd^2).

Figure 6. Photo. 650 CMI pulverizer mixing Caliber product into Section V.

Section VI (DMC – 820 Lignosulfonate/Magnesium Chloride)

The 5.5-m (18-ft) wide roadway was watered as shown in Figure 7, the top 50 mm (2 in) of the road scarified with the motor grader, and after watering again, the Mag/Lig mixture was applied with the Desert Mountain distributor truck at a rate of 3 L/m^2 (0.75 gal/yd^2). After allowing the solution to marinate for approximately twenty minutes, the CMI pulverizer was used to thoroughly mix the product into the aggregate surface course to a 125-mm (5-in) depth. This section was processed one lane at a time, and then the entire 5.5-m (18-ft) roadway was graded and rolled. This was followed by a topical application of the solution sprayed at a rate of 1 L/m^2 (0.25 gal/yd^2).

Figure 7. Photo. Distribute truck applying DMC-820 Ligno/Mag to Section VI.

CHAPTER 3 – LABORATORY ANALYSIS OF MATERIALS

TESTS FOR MATERIAL CHARACTERISTICS

The material attributes for the aggregate surfacing were determined using the test procedures shown in Table 3 at the end of Chapter 1. Results from untreated material samples taken from the stockpile shown in Figure 8 or from material delivered to one of the six project sections are shown in Table 4. Though most of the initial testing was done by the CFLHD Materials Laboratory, a commercial laboratory also performed tests on the untreated surfacing aggregate. Table 5 reports laboratory test results on the treated material after stabilizer products were applied. All the post-application testing was performed by a commercial laboratory. Observation and discussion of laboratory test results follows.

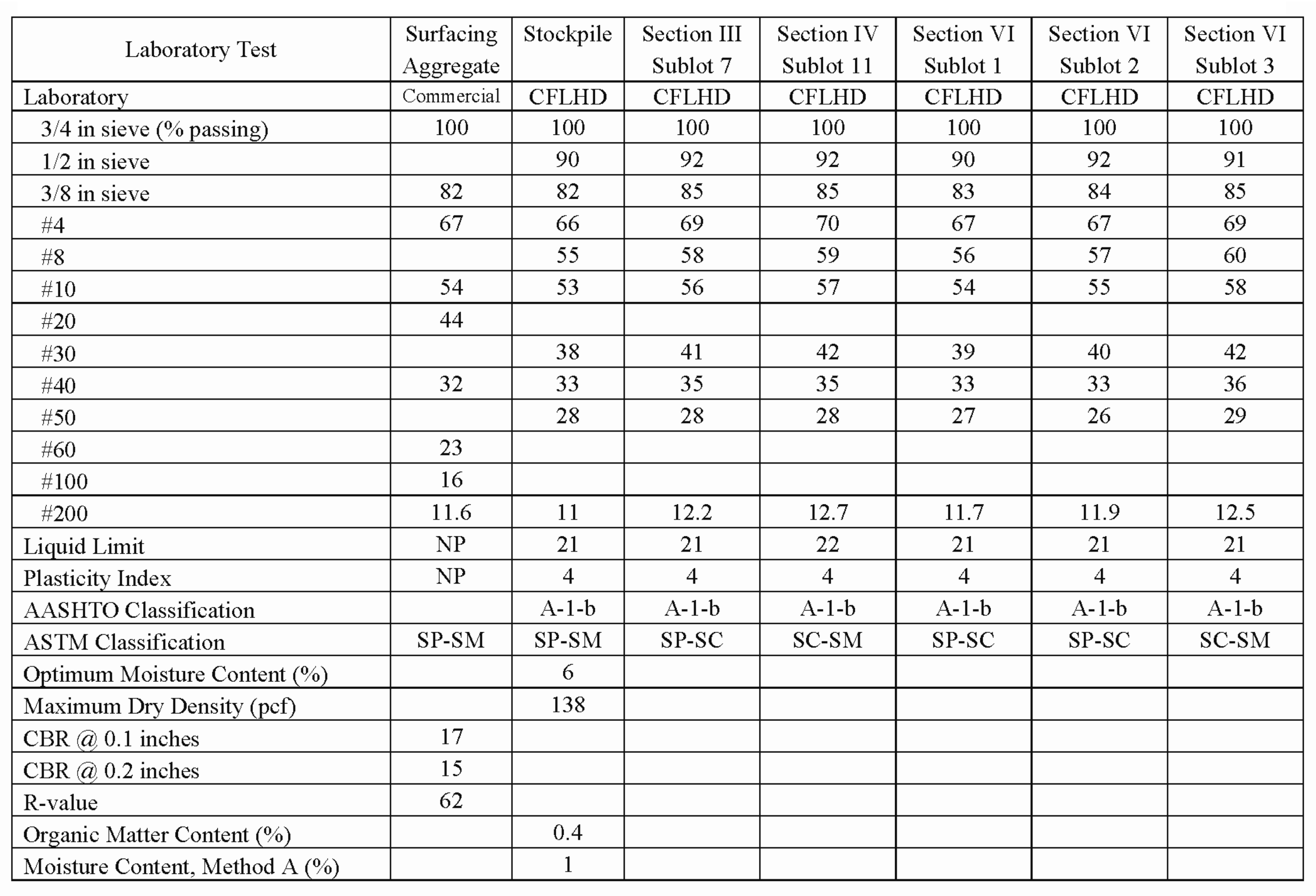
SOIL CLASSIFICATION

Figure 8. Photo. Materials stockpile at Seedskadee Pit.

The construction contract specified a surface course aggregate for the Seedskadee project. Test results of the sampled material show that the material was within the contract tolerances. Despite differences in plasticity that are discussed in the following subsection the soil classification results show only minor variations across the samples. As shown in Table 4, under the AASHTO M 145 classification system, the aggregate surfacing material was an A-1-b material defined as well-graded finer stone fragments, gravel, and sand with a plasticity index (PI) less than or equal to 6%. Under the ASTM D 2487 classification system, the aggregate surfacing material fell into three different classifications of course-grained soils: SP-SM (poorly graded sand with silt), SP-SC (poorly graded sand with clay), and SC-SM (silty clayey sand.) The monitoring team did not consider these ASTM classification differences to be significant.

In Table 5 that shows test results following application of the stabilizer products, the sieve analysis of Section II materials indicates 5% retained on the 19-mm (3/4-in) sieve. Though not shown in this table, the commercial lab actually reported nearly 4% retained on the 37.5-mm (1½-in) sieve. The presence of this larger sized material indicates that the contractor may have dug into the sub-grade when processing the materials during application in that section. However, this variation did not change that section’s soil classification.

Table 4. Initial test results on aggregate surfacing material.



Laboratory Test	Surfacing Aggregate	Stockpile	Section III Sublot 7	Section IV Sublot 11	Section VI Sublot 1	Section VI Sublot 2	Section VI Sublot 3
Laboratory	Commercial	CFLHD	CFLHD	CFLHD	CFLHD	CFLHD	CFLHD
3/4 in sieve (% passing)	100	100	100	100	100	100	100
1/2 in sieve		90	92	92	90	92	91
3/8 in sieve	82	82	85	85	83	84	85
#4	67	66	69	70	67	67	69
#8		55	58	59	56	57	60
#10	54	53	56	57	54	55	58
#20	44						
#30		38	41	42	39	40	42
#40	32	33	35	35	33	33	36
#50		28	28	28	27	26	29
#60	23						
#100	16						
#200	11.6	11	12.2	12.7	11.7	11.9	12.5
Liquid Limit	NP	21	21	22	21	21	21
Plasticity Index	NP	4	4	4	4	4	4
AASHTO Classification		A-1-b	A-1-b	A-1-b	A-1-b	A-1-b	A-1-b
ASTM Classification	SP-SM	SP-SM	SP-SC	SC-SM	SP-SC	SP-SC	SC-SM
Optimum Moisture Content (%)		6					
Maximum Dry Density (pcf)		138					
CBR @ 0.1 inches	17						
CBR @ 0.2 inches	15						
R-value	62						
Organic Matter Content (%)		0.4					
Moisture Content, Method A (%)		1					

Table 5. Test results following application of the stabilizer products.

Laboratory Test	Section I TerraZyme	Section II Lignosulfonate	Section III PermaZyme	Section IV Soil Sement	Section V Caliber	Section VI Mag/Lig
Laboratory	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial
3/4 in sieve (% passing)	100	95	100	100	100	100
3/8 in sieve	82	82	84	83	85	83
#4	67	66	67	68	70	69
#10	54	54	54	54	57	56
#20	43	43	43	42	46	45
#40	31	32	30	31	32	32
#60	22	24	21	21	22	22
#100	15	17	14	14	15	15
#200	10.3	12.5	9.3	9.6	10.2	10.6
Liquid Limit	NP	20	NP	NP	NP	NP
Plastic Limit	NP	14	NP	NP	NP	NP
Plasticity Index	NP	6	NP	NP	NP	NP
AASHTO Classification	A-1-b	A-1-b	A-1-b	A-1-b	A-1-b	A-1-b
ASTM Classification	SP-SM	SC-SM	SP-SM	SP-SM	SP-SM	SP-SM
Optimum Moisture Content (%)		5.3			5.2	
Maximum Dry Density (pcf)		141			140.7	
CBR @ 0.1 inches	15	16	20	18	16	15
CBR @ 0.2 inches	15	14	17	19	17	13
R-value	76	42	78	81	72	64

PLASTICITY

Figure 9. Photo. Collecting treated samples for laboratory testing.

The material was sampled before and after treatment as shown in Figure 9. The test results in Table 4 above for the untreated material show that a commercial laboratory determined the material was non-plastic (NP), whereas the CFLHD laboratory found it to have a plasticity index (PI) of 4%. Since the contract specified a PI target value of 8% plus or minus 4%, the CFLHD laboratory test results were used to initially determine that the material met the specifications.

The PI of a sample is the difference in test results for liquid limit (LL) and plastic limit (PL). The LL signifies the percent of moisture at which the sample changes, with a decrease in moisture, from a liquid state to a plastic state. The PL is the percentage of moisture at which the sample changes, with a further decrease in moisture, from a plastic to a semisolid state. The PI, in percent water content, is the range of plasticity of the material.

All test procedure results have an inherent variability introduced by material, equipment, and operators, and this precision is identified for the LL in AASHTO T 89 and the PL in AASHTO T 90. For materials having a liquid limit range from 21 to 67, the repeatability of results for a single operator on the same sample, in the same laboratory, using the same equipment, on different days, should not vary by more than 7% of the average. The reproducibility between different laboratories should not vary by more than 13% of the average. Similarly for materials having a plastic limit range from 15 to 32, the single operator repeatability should not exceed 10%, and the different laboratories reproducibility should not exceed 18%. AASHTO however, does not discuss how these precision statements contribute to the calculation of the PI. Conceivably, if one laboratory erred within the allowable precision on the high side of the LL and the low side of the PL, potentially the reported PI could have a variation as much as 17%. Similarly, different laboratory result comparisons could have a variation as much as 31%.

For this project, when the material was noted to be plastic, the LL and the PL varied from 20 to 22, and 14 to 17, respectively. As a result, the PI results for all the test results were low, ranging from NP to 6%. For instance, the Lignosulfonate-treated material in Section II tested by the commercial laboratory reported in Table 5, showed a PI of 6% whereas the other sections' samples tested NP. In hindsight, even though some of the LL and PL values fell outside AASHTO's ranges by just one point, it should have raised concerns that the material test results were indicating that the overall PI may not have been what was wanted. Also, applying an interpretation of the AASHTO precision statements to estimate a higher potential PI still does not resolve concerns over those test results shown as NP.

Therefore, this low or lack of plasticity of the surfacing material at Seedskadee may have been significant in how some classes of stabilizer products performed. Specifically, the enzyme products – that is the TerraZyme and PermaZyme used on Sections I and III – were formulated to react with materials containing clay particles and are dependent on fine clay mineralogy to achieve maximum performance for dust abatement and soil stabilization. For these products, there must be both sufficient fines with material passing the 75-µm (No. 200) sieve and sufficient plasticity; that is, clay rather than silt fines.

MAXIMUM DRY DENSITY

Tests to determine the optimum moisture at which the material could be compacted to its greatest density were performed on initial samples taken from the stockpile of aggregate surfacing material. From this testing, the target values of 6% moisture and 2,220 kg/m^3 (138 lb/ft^3) maximum dry density were determined. Subsequent laboratory test results shown in Table 5 following application of the stabilizer products showed that the maximum dry density that could be achieved was 2270 kg/m^3 (141 lb/ft^3) at 5.3% moisture. In other words, the addition of stabilizer products did not significantly change compaction characteristics.

In-place density readings, using a nuclear device, were taken 3 to 4 weeks after completion of the project and showed that all sections were compacted to at least 95% of the maximum dry density target. No additional nuclear density testing was performed during the two years of monitoring.

CALIFORNIA BEARING RATIO (CBR)

The construction contract did not require the CBR test; rather the test was performed to establish a base line for the monitoring activities. To determine a laboratory CBR, the sample with the maximum dry density, while still in its compacting mold, was soaked in water for four days. Then a cylindrical piston was forced into the confined specimen to 2.5-mm (0.1-in) and 5.0-mm (0.2-in) depths while load-deformation data was collected. By definition, the CBR is the ratio of the load carried by the test specimen to the load carried by an excellent crushed rock base course multiplied by 100. Unfortunately, CBRs depend on a lot of factors like quality of compaction, moisture content, and amount of fines so they can be quite variable.

For the Seedskadee surfacing aggregate, laboratory CBR results ranged from 15 to 20. A comparison of the initial CBR values on untreated material, as shown in Table 4, to those following application of stabilizer products, as shown in Table 5, showed little change. The stabilization products apparently did not have any effect on the CBRs as tested in the laboratory. The monitoring team decided that the laboratory CBR test would not be done again during monitoring because it was not an in-situ test. The Dynamic Cone Penetrometer test was performed instead throughout the two years of monitoring and the results were converted to in situ CBR values.

R-VALUE

The R-value, generally defined as the resistance of the material to deformation, gives a general indication of the quality of a material. There is generally less test variability with the R-values than with CBR values. R-values can range from 0, the resistance of a fluid, to 100 that would be the resistance of an infinitely rigid solid. All R-value tests on the Seedskadee material were done by the commercial laboratory. The R-value test was performed to establish a baseline for monitoring rather than for contract acceptance, and likewise the test was not repeated during the monitoring period because of the desire to use in situ tests.

A high laboratory CBR and high laboratory R-value would be ideal and indicative that rutting would not be a problem. For Seedskadee, the overall values were not ideal - laboratory CBR values were low and R-values were quite high – yet rutting was not noted as a problem. The stockpile material had an R-value of 62, while the samples from treated sections were generally a little higher. The Lignosulfonate section was an exception with a lower R-value of 42. The Soil Sement section appeared to gain the most immediate strength with an R-value of 81. Results of monitoring for rutting in Chapters 5 and 6 show that actual product performance used with the Seedskadee material was more accurately indicated by the R-value.

LOSS ON IGNITION TEST FOR ORGANIC CONTENT

In the past, some enzymes have been produced as organic and others as inorganic enzymes. To work effectively, they were formulated to either react with organic matter inherent in the clay particles, or they could externally supply organics to form a protective layer around the clay particle. The FHWA report, *Dust Control on Low Volume Roads*(8) notes that most of the common enzymes are based on a bacterial culture, and that the bacteria when exposed to air produce large organic molecules that are absorbed by the clay particle lattice.

In an attempt to explain the performance of the enzymes used in this study, the monitoring team performed the ASTM D 2974 Loss on Ignition test to estimate the level of organics in the material, even though it was not conducted on the previous Buenos Aires NWR study. Results of this test showed the material had an organic content of 0.4%, which was considered to be a value of virtually none, and substantially met the contract requirement that the material be free of organic content.

The evaluation team could find no manufacture statements for the two enzyme products to indicate that an initial organic level was necessary to optimize their performance. Therefore they concluded that the lower ranking of the enzymes' performance was due to a lack of PI in the material rather than a lack of available organics.

CHAPTER 4 – SUBJECTIVE OBSERVATIONS

COMPARATIVE SUBJECTIVE INSPECTION SYSTEM

After the products were installed in September 2004, the first follow-up monitoring occurred in May 2005. The subjective observations reported in this chapter were a result of using the same system as was used for the Buenos Aires project in south-central Arizona. Under this monitoring system the project sections were observed in a predetermined order while the four evaluators visually rated them as they rode in a vehicle for 1) effectiveness against dust in dry conditions, 2) amount of wash boarding, 3) amount of raveling, 4) amount of rutting, and 5) amount of potholing.

For each of the four monitoring events, the comparative visual rating started with a different section to minimize any bias occurring if the team always used the same section as the baseline. The Monitoring Order and Mileposts Plan, shown in Appendix A, and Table 6, below, show the order in which the sections were driven and monitored at each event.

Table 6. Sections serving as baselines sequence for monitoring events.

Monitoring Event	Baseline Section	Observation Sequence
8-month	I – TerraZyme	I, II, III, IV, V, VI
11-month	III – PermaZyme	III, II, I, IV, V, VI
20-month	VI – Mag/Lig	VI, V, IV, III, II, I
23-month	IV – Soil Sement	IV, III, II, I, VI, V

At each monitoring event, the first observed section received a rating of five and served as a baseline for the other sections. The other sections were compared to the first section and rated higher (better condition) up to ten points or lower (worse condition) down to zero points. The four evaluators independently rated the sections for each parameter. Their scores were then averaged for reporting.

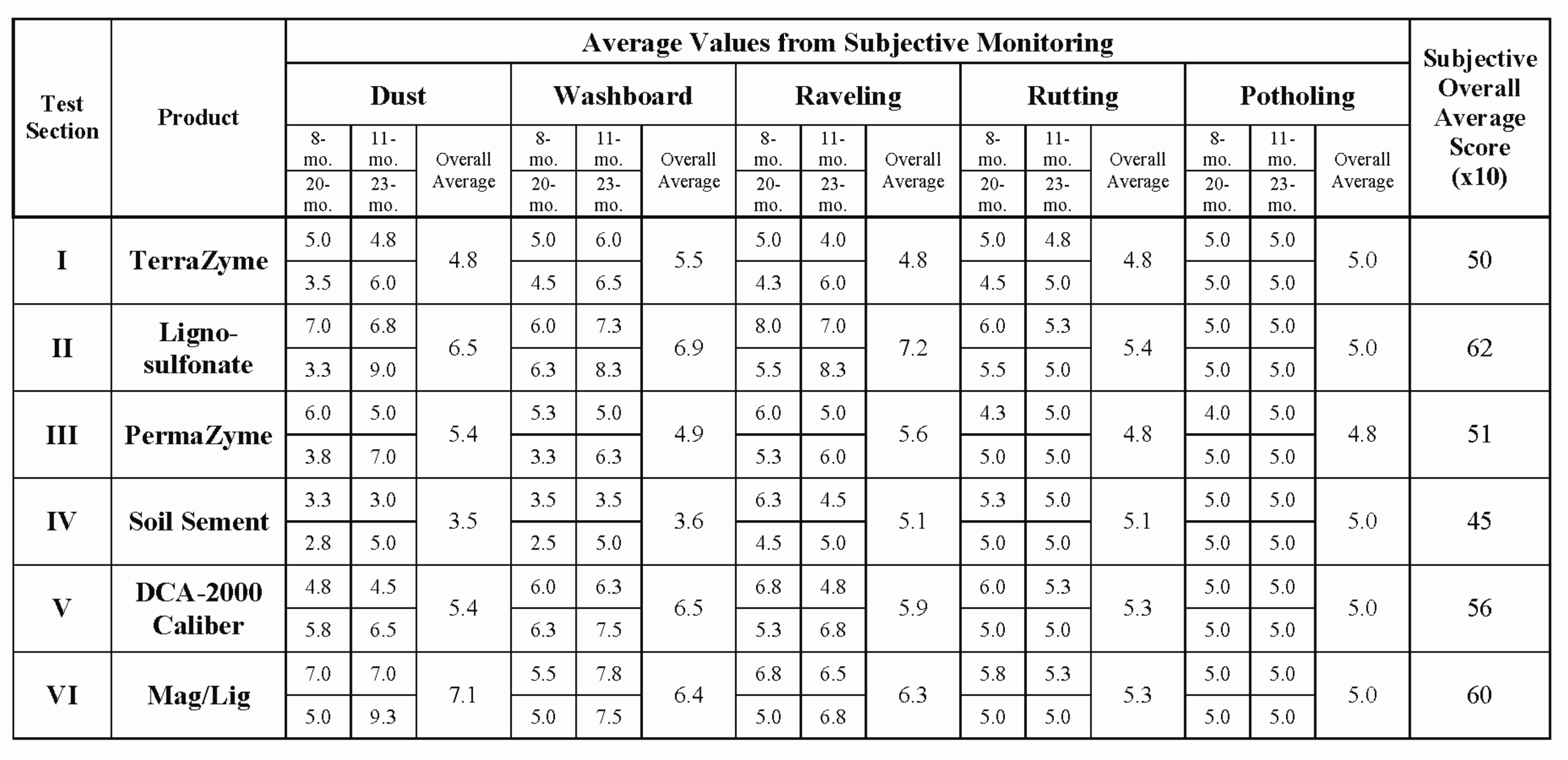
The benefits of this comparative visual inspection system, developed under the Buenos Aires project, were first its ability to capture subtle differences in performance of the products at one monitoring event and second that it was easy and quick to perform. Its limitation, however, was that it gave no information about the products’ performance over time. No visual indications were noted.

While driving the project multiple times to carry out the comparative visual inspection the monitoring team also reviewed each section for leaching of soluble stabilizing material due to rain, impacts on roadside vegetation, application uniformity, and overall structural appearance.

SUBJECTIVE RESULTS

The results presented in Table 7 show the averaged scores from the comparative judgments of four independent evaluators. Note, in Table 7, that for each product and for each parameter of dust, washboarding, raveling, rutting, and potholing, there is an average score for each

Table 7. Subjective monitoring results.



Test Section	Product	Average Values from Subjective Monitoring															Subjective Overall Average Score (x10)
		Dust			Washboard			Raveling			Rutting			Potholing			
		8-mo. 20-mo.	11-mo. 23-mo.	Overall Average	8-mo. 20-mo.	11-mo. 23-mo.	Overall Average	8-mo. 20-mo.	11-mo. 23-mo.	Overall Average	8-mo. 20-mo.	11-mo. 23-mo.	Overall Average	8-mo. 20-mo.	11-mo. 23-mo.	Overall Average	
I	TerraZyme	5.0	4.8	4.8	5.0	6.0	5.5	5.0	4.0	4.8	5.0	4.8	4.8	5.0	5.0	5.0	50
		3.5	6.0		4.5	6.5		4.3	6.0		4.5	5.0		5.0	5.0		
II	Ligno-sulfonate	7.0	6.8	6.5	6.0	7.3	6.9	8.0	7.0	7.2	6.0	5.3	5.4	5.0	5.0	5.0	62
		3.3	9.0		6.3	8.3		5.5	8.3		5.5	5.0		5.0	5.0		
III	PermaZyme	6.0	5.0	5.4	5.3	5.0	4.9	6.0	5.0	5.6	4.3	5.0	4.8	4.0	5.0	4.8	51
		3.8	7.0		3.3	6.3		5.3	6.0		5.0	5.0		5.0	5.0		
IV	Soil Sement	3.3	3.0	3.5	3.5	3.5	3.6	6.3	4.5	5.1	5.3	5.0	5.1	5.0	5.0	5.0	45
		2.8	5.0		2.5	5.0		4.5	5.0		5.0	5.0		5.0	5.0		
V	DCA-2000 Caliber	4.8	4.5	5.4	6.0	6.3	6.5	6.8	4.8	5.9	6.0	5.3	5.3	5.0	5.0	5.0	56
		5.8	6.5		6.3	7.5		5.3	6.8		5.0	5.0		5.0	5.0		
VI	Mag/Lig	7.0	7.0	7.1	5.5	7.8	6.4	6.8	6.5	6.3	5.8	5.3	5.3	5.0	5.0	5.0	60
		5.0	9.3		5.0	7.5		5.0	6.8		5.0	5.0		5.0	5.0		

monitoring event. Also there is an overall average score, covering the entire monitoring period, for each product and parameter. This overall average score best shows the relative standings of the products for a particular parameter. Finally, in the far right column of Table 8, there is an overall score that represents the ranking of the products based on subjective observations. Figure 10 plots the relative product standings for each parameter and the overall subjective score for each product taking all parameters into consideration.

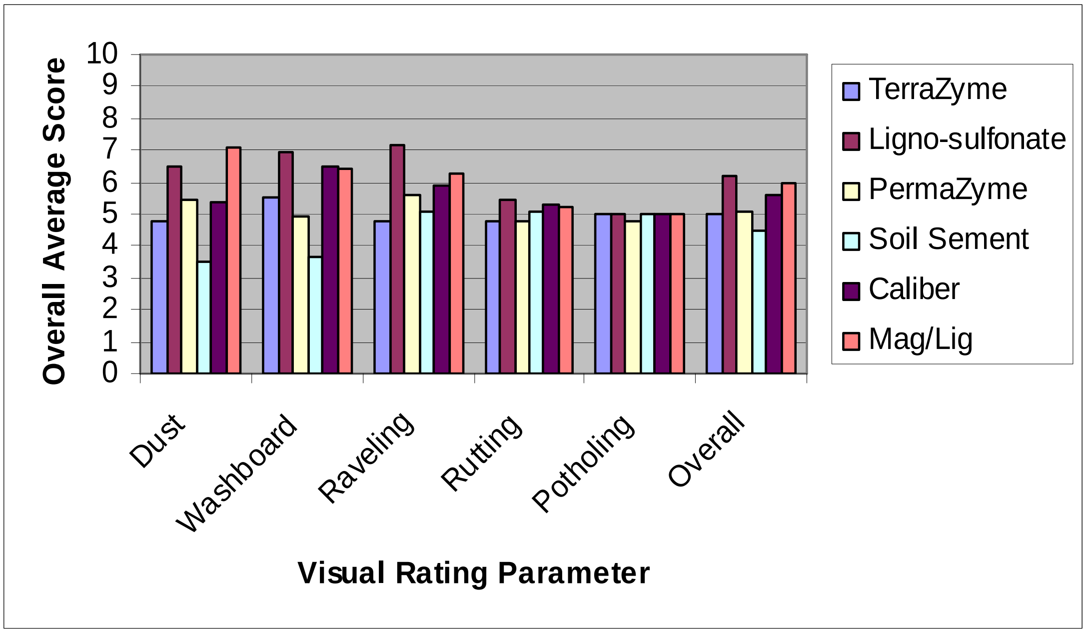


Figure 10. Plot. Relative product standings from subjective observations.

Dust Abatement

During all of the monitoring events – at 8, 11, 20, and 23 months following the September 2004 construction completion - the weather was dry. This was fortunate as it enabled the observers to distinguish the various levels of dust generation in each section.

Figure 11. Photo. Monitoring for dust.

Looking at the Figure 10 plot for dust, the products can be separated into three dust abatement groups. The columns represent for each product the overall average score it received for the entire monitoring period. In the first group, Mag/Lig and Lignosulfonate showed the least amount of airborne particles. In the second group consisting of PermaZyme, Caliber, and TerraZyme; more dust was generated relative to the first group. In the third group was Soil Sement that exhibited the most dust.

Washboarding

In looking at the washboarding overall average scores in Figure 10, the products can be separated into three groups. In the first group were Lignosulfonate, Caliber, and Mag/Lig. These products produced the least amount of washboarding. In the second group, showing more washboarding were the enzyme products - TerraZyme and PermaZyme. In the third group was Soil Sement that had the highest level of washboarding as shown in Figure 12. It should be noted again that the scores given in Table 10 for each monitoring event are not absolute scores in reference to some objective criteria, but rather ratings given in comparison to a baseline section.

Figure 12. Photo. Section IV Washboarding.

Raveling

For raveling, Table 7 and Figure 10 show overall scores ranging from 4.8 to 7.2. Lignosulfonate was the best performing product and generally showed less loose material on the road surface than any of the other sections. In fact, the Lignosulfonate surface course appeared hardened from the first monitoring event as the applied product was visible consistently throughout the section – not blotchy as in other sections. By the 20-month event, however, the product was appearing more grayed-out than it had in previous monitoring events.

Figure 13. Photo. Raveling.

The overall scores for the other products formed no clear groups but rather stepped down in the order of Mag/Lig, Caliber, PermaZyme, and Soil Sement to the lowest ranked performer for raveling – Terrazyme. By the end of the monitoring period, the middle ranked sections typically had loose aggregate spread fairly uniformly over the entire roadbed, and defined wheel paths were just beginning to show. PermaZyme and Caliber appeared tighter than Soil Sement, and this was consistent throughout their lengths. In the TerraZyme section, no product, blotchy or otherwise, was evident except at the kiosk parking area where there had been little or no traffic use. Elsewhere, clear wheel paths were evident as raveled material was pushed to either side. It should be noted that the TerraZyme section has many curves, and near these curves, not only was there more raveling but also more rutting and washboarding. In general, wherever there was product clearly showing in a test section, there was also significantly less loose material.

Rutting

The overall average scores for rutting only varied from 4.8 to 5.4, but still could be grouped logically into two groups. In the group with the higher scores, that is, less observed rutting, were Lignosulfonate, Caliber, Mag/Lig, and Soil Sement. In the group with the lower scores were the two enzyme products – TerraZyme and PermaZyme.

The team did not consider worn tracks in the roadway as ruts if the condition appeared to be linked to raveling. At the beginning of monitoring, the team thought there could be greater potential for more pronounced rutting on a 3.7-m (12-ft) wide road than on a 5.5-m (18-ft) one because the traffic would be concentrated into one path. The sections stabilized with the Soil Sement and Caliber products, were only 3.7 m (12 ft) wide. The team did observe that on the 3.7-m (12-ft) wide sections there were two wheel paths, whereas on the 5.5-m (18-ft) wide sections there were at least three. But overall, there was very little rutting in any of the sections. The Figure 10 plot reflects this because the rutting columns representing the overall average score for each product are all close to the same height. One exception was the Permazyme Section III where rutting was apparent on a steep hill as shown in Figure 14. This rutting appeared in May of 2005 after heavy winter snows and a quick spring thaw. Most likely, it was caused by one vehicle being in the area when conditions were extremely wet and having a hard time getting up the hill. The rutting on this hill appeared to repair itself over time; it was not noticeable at the 23-month monitoring event.

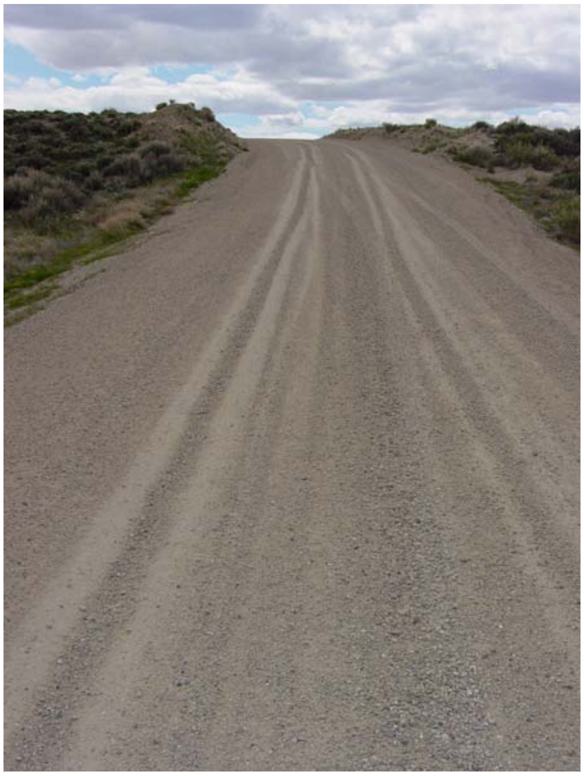


Figure 14. Photo. May 2005 ruts in PermaZyme Section III.

Potholing

Potholing was included in the evaluation based on CFLHD’s prior experience with surface applications of dust abatement products, such as magnesium chloride, that tend to produce a thin hardened surface layer that can break up, or pothole, in areas of lesser compaction. Conceptually therefore, since in this project the roadway was stabilized to a depth of 125 mm (5 in), the extent of potholes that normally develop under thin surface applications was not expected to occur. The evaluation team, however, was not certain whether this full-depth stabilized roadway would form potholes or not, so they monitored it for potholes.

As shown in the Figure 10 plot, potholing was not an issue except for in the PermaZyme section. This section was downgraded in the 8-month monitoring event because one pothole was discovered in the section. A total of only three potholes were evident on the entire project – the second appeared in the TerraZyme section at the 13-month event and the third also in the TerraZyme section at the 20-month event. Though the team rated the PermaZyme section lower at the 8-month event, it was later decided that a total of only one or two potholes in a half-mile of roadway had to be due to something other than poor performance of a stabilizer product such as uncompacted material left in a hole by a removed rock or a gopher hole.

SUBJECTIVE INSPECTION SUMMARY

The overall average scores for each product covering all the parameters are shown in the extreme right column of Table 7 and plotted in Figure 10 as the right-most set of bars. These numbers, for each product, are the average of the scores it received for dust, washboarding, raveling, rutting, and potholing. Thus from subjective observations, three groups of product performance are evident. In the first group performing best, second and third, were the Lignosulfonate, Mag/Lig, and Caliber sections. The two enzyme products, TerraZyme and PermaZyme, were in the second group, and the third group consisted of the Soil Sement product that had the lowest overall average.

OTHER OBSERVATIONS

Whereas the subjective observation method was used to evaluate the five parameters of dust, washboarding, raveling, rutting and potholing, other observations in the areas of environmental effects, application uniformity, and design geometrics and structural appearance were also made and are briefly summarized below.

Observed Environmental Effects

At the first monitoring event in May 2005, no leaching off the road into the ditch was observed in any of the sections nor were impact to roadside vegetation seen in any of the sections. Neither was there any leaching impacts observed during subsequent events. By August 2005, Halogeton, a noxious weed that takes root in disturbed areas, was growing vigorously along the roadway and in the ditch. The team observed in the final monitoring event in August 2006, that vegetation had also come up in areas where there was very little traffic such as the middle of the road, pullouts, and parking areas. Most places, even those sections without treatment, along the entire project had Halogeten growing along the edges of the roadway. Curiously, some areas had none or only a little with stunted growth, and this variability in growth was not correlated to any one product. Since the Refuge had not done any control spraying, the extremely long dry period preceding the last monitoring event may have stunted this noxious weed.

Application Uniformity

Since the roadway, which varied from 3.7 to 5.5 m (12 to 18 ft) wide, was reconditioned using a 3-m (10-ft) wide CMI 650 pulverizer, the team expected to see areas of concentrated treatment where the two passes overlapped. At the 8-month event, this effect was observed only in the Lignosulfonate section as shown in Figure 15. The overlapping was quite pronounced at this first monitoring event but diminished over time. The Mag/Lig section had a blotchy appearance in the wheel paths rather than in the center as was seen in the Lignosulfonate section.

By the 11-month event in August 2005, no product was visible in the TerraZyme, PermaZyme, or Soil Sement sections. The Lignosulfonate section was showing a lot of product in the wheel paths. The Caliber section showed product in a few areas, and the Mag/Lig section showed product at the beginning of its length.

Figure 15. Photo. Lignosulfonate Section II product still showing two years after application.

In the 20-month event of May 2006, pullout areas with kiosks were showing a lot more residual product than the roadways. These areas may have had a heavier application (shot then spread with a grader) than the main roads which had products applied using the pulverizer. Another theory was that in parking areas, there was little traffic whereas on the road, where traffic breaks down the aggregate, any product on the surface was also broken down. Below the surface of the road it was expected that residual product was still present. During sampling for the Silt Load Test, covered in Chapter 6, all loose material in a 0.3 by 0.9-m (1 by 3-ft) swath was swept up off the road, and underneath residual product could still be seen in all the sections.

As of the last 23-month monitoring event in August 2006, the Lignosulfonate Section II still had some product showing as blotches throughout its length. A small amount of the Caliber product in Section V could also be seen at its end near the cattle guard that marks the Refuge boundary.

Design Geometrics and Structural Appearance

The design geometrics of the sections appeared to an have influence on performance of some of the products. The TerraZyme Section I had more curves which may have affected the amount of raveling and possibly washboarding that occurred over the two-year study period. During the first monitoring event, ruts approximately 18 m (60 ft) long were observed on a fairly steep hill in the PermaZyme Section III. It is possible that a heavy vehicle went up the hill in saturated conditions and may have spun its wheels to get to the top. No ruts were apparent in the remainder of this section or in the Caliber Section V that has a gradual hill climbing up away from the river. This same section, however, suffered erosion damage from rapid melting of winter snows as discussed earlier in this report.

CHAPTER 5 - OBJECTIVE MEASUREMENTS

FIELD MEASUREMENTS AND OBJECTIVE RATING SYSTEM

The evaluation team used two methods to rate the roadway sections for dust, washboarding, raveling, rutting, and potholing. The first, discussed in Chapter 4, was a subjective and comparative method. The second method, discussed here, was an objective method with specific criteria, as presented in Appendix B, to use for the rating. Using the objective criteria, the product ratings could be compared over time, and deterioration of the roadbed over time would naturally be captured in the ratings.

This objective rating system focused on measuring rather than observing. Each monitoring location was an area 7.6 m (25 ft) long and the width of the roadbed. The depth of washboarding, raveling, rutting, and potholing occurring within the 7.6-m (25-ft) long area could all be measured. Using the appropriate Appendix B descriptive conversion table, the measurements data for each parameter were converted into a rating.

Monitoring locations were determined in advance and listed in the Monitoring Order and Mileposts Plan shown in Appendix A so that they would be uniquely located in each section and not result in a repeat monitoring of any particular location. Due to the repairs of the damage caused by rapid snow melt in the spring of 2005, the available area for monitoring in Section V was reduced and many of the planned monitoring locations in that section had to be moved. The monitoring locations in Section VI were also different from sections I through IV because Section VI was longer than the other five sections. The final monitoring locations for each event are shown in Appendix C along with all the measurement data that was collected.

During each monitoring event, four 7.6-m (25-ft) long locations were monitored in each of the six sections. To assist in finding the prescribed monitoring locations, the beginning of each treated section was semi-permanently marked with a steel fence post. The 7.6-m (25-ft) long monitoring locations were located by driving to the beginning of each section, setting the vehicle’s trip counter to zero, driving to the tenth-of-the-mile point, and using a surveyor’s wheel as shown in Figure 16 to find the hundredth-of-a-mile location specified in the Monitoring Order and Mileposts Plan. A 7.6-m (25-ft) long area was then measured off behind the point location to set the boundaries for the data collection.

Figure 16. Photo. Locating specified monitoring area.

To illustrate how the objective measurements system worked, Table 8, shows the measurements that were taken for raveling during the 20-month monitoring event in August 2005. According to the assessment methodology described for raveling in Appendix B, three raveling depths – right, center, and left - were recorded at each location. These depths were averaged. Once the average depths of raveling at each of four locations in a section were obtained, they were then averaged to give a section average. Referring to the descriptive table for raveling in Appendix B, the section average was converted to a rating for that section. Therefore, by way of example, at the 20-month event, the average depth of raveling for the TerraZyme section was 16 mm (0.6 in). This converts to a rating of 6, defined as loose material between 15 mm (0.6 in) and 20 mm (0.8 in) thick, for raveling in the TerraZyme section during the 20-month event.

The benefits of the objective measurement system was its success in both capturing subtle differences in performance of the sections and providing a way to compare performance over time. It was discovered through use that it also had one glaring limitation – the predetermined monitoring areas did not align with what were, in the opinion of the monitoring team, some of the poorer performing parts of a section as observed visually. Therefore the subjective judgments of the monitoring team were not necessarily reflected in the objective ratings. This difference could be minimized by taking more on-site samples.

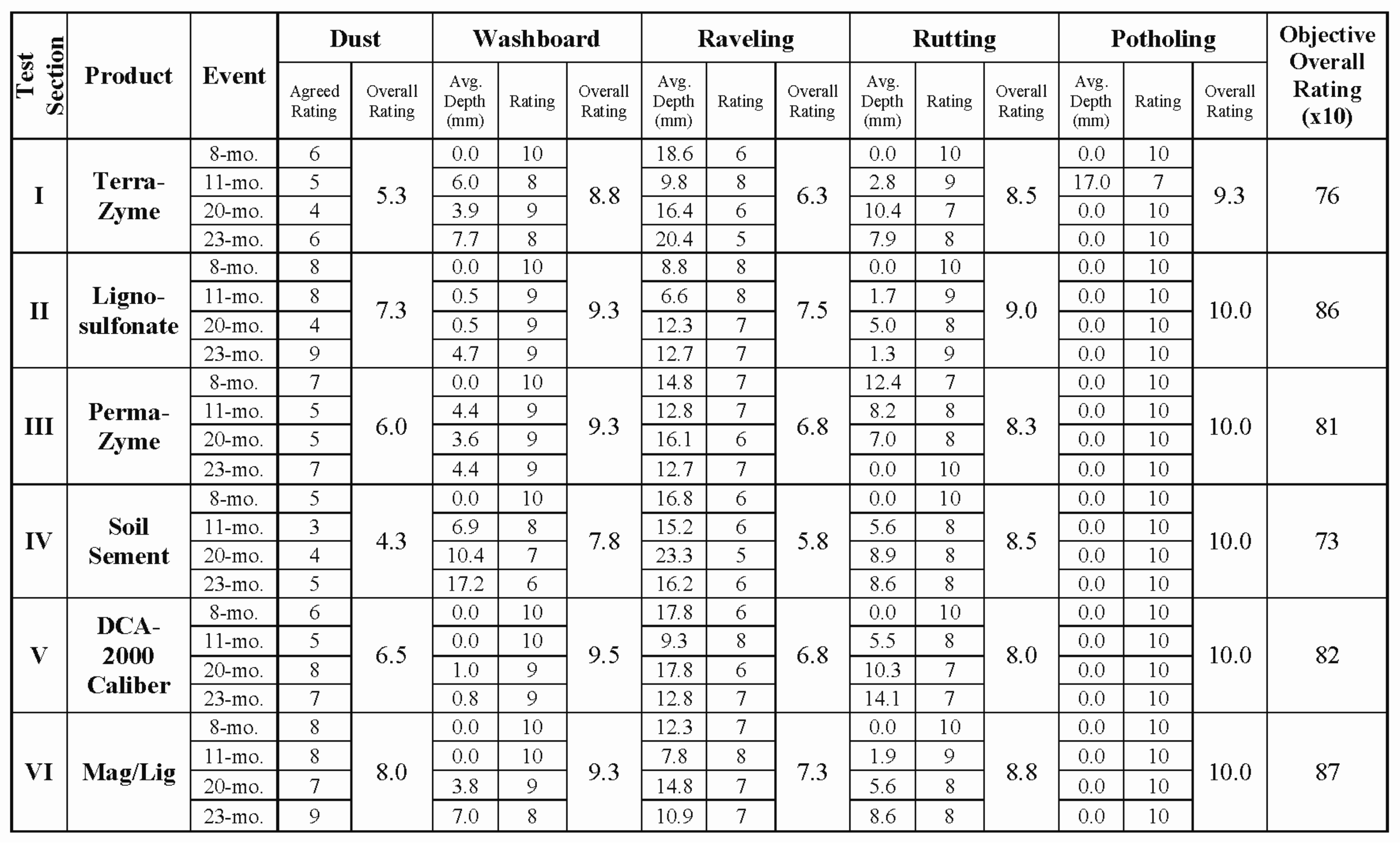
Table 8. Raveling measurements from the 20-month event converted to objective rating.

Section	MP	Rt.	CL	Lt.	Avg. Depth (mm)	Section Avg. (mm)	Objective Rating
I - Terra-Zyme	0.05	11	13	22	15	16	6
	0.18	18	12	11	14		
	0.33	20	16	28	21		
	0.52	13	10	23	15		
II - Ligno-sulfonate	0.05	16	8	12	12	12	7
	0.18	12	8	16	12		
	0.33	13	7	17	12		
	0.52	13	12	13	13		
III - Perma-Zyme	0.05	22	7	13	14	16	6
	0.18	22	11	26	20		
	0.33	30	15	12	19		
	0.52	8	14	13	12		
IV - Soil Sement	0.05	38	22	21	27	23	5
	0.18	18	14	27	20		
	0.33	30	21	18	23		
	0.52	25	26	19	23		
V - DCA 2000 Caliber	0.05	19	30	23	24	18	6
	0.18	17	20	17	18		
	0.35	20	15	20	18		
	0.54	10	10	12	11		
VI - DMC 820 (Mag/Lig)	0.05	4	16	16	12	15	7
	0.25	10	11	19	13		
	0.45	10	17	16	14		
	0.55	11	28	20	20		

FIELD MEASUREMENTS TABLE AND OBSERVATIONS

Whereas Table 8 shows the objective raveling rating for each product at one monitoring event, Table 9 combines the ratings from four events into an overall rating for each parameter as well as an overall objective rating for each product considering all five parameters. Approximately 1300

Table 9. Objective ratings from field measurements.



Test Section	Product	Event	Dust		Washboard			Raveling			Rutting			Potholing			Objective Overall Rating (x10)
			Agreed Rating	Overall Rating	Avg. Depth (mm)	Rating	Overall Rating	Avg. Depth (mm)	Rating	Overall Rating	Avg. Depth (mm)	Rating	Overall Rating	Avg. Depth (mm)	Rating	Overall Rating	
I	Terra-Zyme	8-mo.	6	5.3	0.0	10	8.8	18.6	6	6.3	0.0	10	8.5	0.0	10	9.3	76
		11-mo.	5		6.0	8		9.8	8		2.8	9		17.0	7		
		20-mo.	4		3.9	9		16.4	6		10.4	7		0.0	10		
		23-mo.	6		7.7	8		20.4	5		7.9	8		0.0	10		
II	Ligno-sulfonate	8-mo.	8	7.3	0.0	10	9.3	8.8	8	7.5	0.0	10	9.0	0.0	10	10.0	86
		11-mo.	8		0.5	9		6.6	8		1.7	9		0.0	10		
		20-mo.	4		0.5	9		12.3	7		5.0	8		0.0	10		
		23-mo.	9		4.7	9		12.7	7		1.3	9		0.0	10		
III	Perma-Zyme	8-mo.	7	6.0	0.0	10	9.3	14.8	7	6.8	12.4	7	8.3	0.0	10	10.0	81
		11-mo.	5		4.4	9		12.8	7		8.2	8		0.0	10		
		20-mo.	5		3.6	9		16.1	6		7.0	8		0.0	10		
		23-mo.	7		4.4	9		12.7	7		0.0	10		0.0	10		
IV	Soil Sement	8-mo.	5	4.3	0.0	10	7.8	16.8	6	5.8	0.0	10	8.5	0.0	10	10.0	73
		11-mo.	3		6.9	8		15.2	6		5.6	8		0.0	10		
		20-mo.	4		10.4	7		23.3	5		8.9	8		0.0	10		
		23-mo.	5		17.2	6		16.2	6		8.6	8		0.0	10		
V	DCA-2000 Caliber	8-mo.	6	6.5	0.0	10	9.5	17.8	6	6.8	0.0	10	8.0	0.0	10	10.0	82
		11-mo.	5		0.0	10		9.3	8		5.5	8		0.0	10		
		20-mo.	8		1.0	9		17.8	6		10.3	7		0.0	10		
		23-mo.	7		0.8	9		12.8	7		14.1	7		0.0	10		
VI	Mag/Lig	8-mo.	8	8.0	0.0	10	9.3	12.3	7	7.3	0.0	10	8.8	0.0	10	10.0	87
		11-mo.	8		0.0	10		7.8	8		1.9	9		0.0	10		
		20-mo.	7		3.8	9		14.8	7		5.6	8		0.0	10		
		23-mo.	9		7.0	8		10.9	7		8.6	8		0.0	10		

measurements support Table 9. For all parameters except dust, which was a rating agreed upon by the evaluators, field measurements were taken and averaged. While the averaged numbers shown in the table are a higher precision than the original measurements, the precision was maintained to capture subtle variations between the products.

For dust, no objective dust measurements were actually made. Rather, the team directly used the rating descriptions for dust in Appendix B and together agreed on the appropriate rating for each section. The evaluation team was aware that some dust measuring devices exist, but decided that transporting such a device the distance to this remote project location (which also describes most projects within CFLHD's 14-state coverage area) was not feasible.

One of the greatest strengths of the objective rating system was that performance trends over time could be plotted and reviewed. The following five subsections discuss these trends for each of the five evaluations parameters.

Dust Abatement Trends

For all of the monitoring events – at 8, 11, 20, and 23 months following the September 2004 construction completion - the weather was dry. This was fortunate as it enabled dust observations to be more comparable over time. The silt load test, discussed in the next chapter, included moisture measurements that confirmed consistent and low moisture contents.

The plot in Figure 17 shows how the products rated over time for dust abatement. The products remained in approximately the same order of effectiveness over time except for the 20-month

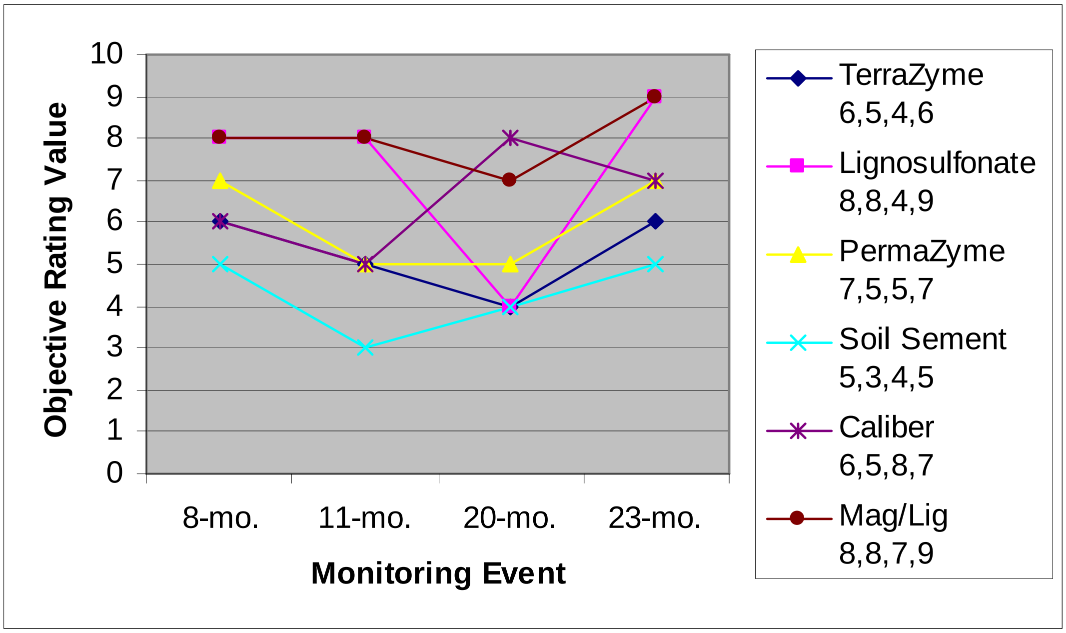


Figure 17. Plot. Dust trends.

event where the Caliber product rose three points due to less observed dust while the Lignosulfonate product dropped four points due more dust production. One explanation for this may be tied to the weather, relative humidity, and product compositions. Though it did not rain during the actual time of monitoring, 4 mm (0.16 in) of rain was recorded for the day. Lignosulfonate appeared particularly sensitive to the dry conditions at Seedskadee and received an agreed dust rating of only 4 that is described, in Appendix B, as significant loss of visibility and some uneasiness driving at 25 mph. Since Lignosulfonate does not pull moisture from the air but rather needs a moist environment, it did not perform at its best. Caliber and Mag/Lig, on the other hand, received the best scores probably because they contained magnesium chloride which absorbs moisture from the air.

It is interesting that all the products at 23 months rated equal to or higher than at 8 months. It would seem that over time, the products should have decreased in effectiveness against dusting, not become more effective. As discussed in the next chapter, silt load testing results also show that dust generation decreased over time. Also, while criteria for a threshold of acceptability under this test may be valuable, the evaluation team did not address it.

Washboarding Trends

The plot in Figure 18 shows how the six products compared over time for washboarding. As would be expected due to the low traffic volumes over the winter months, there was no measurable washboarding at 8 months. By the 20-month event, a year later, all of the sections showed some washboarding. Five products - TerraZyme, Lignosulfonate, PermaZyme, Caliber, and Mag/Lig - had an average rating of 9 and washboarding was barely visible. The four measurement locations within each of these five sections had washboard troughs that were slight

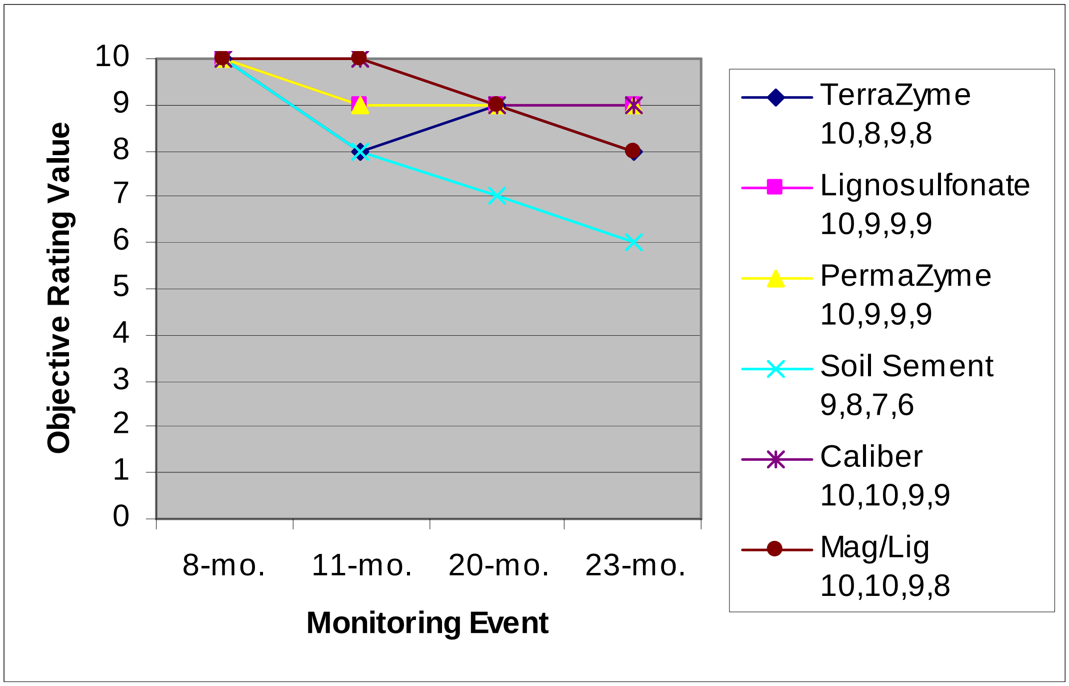


Figure 18. Plot. Washboarding trends.

(less than 13 mm (0.5 in)) or non-existent. This produced an average measured depth of less than 5 mm (0.2 in). The rating descriptions in Appendix B for washboarding convert washboarding troughs less than 5 mm (0.2 in) deep into a rating of 9.

In the final monitoring event at 23 months, washboarding was more prevalent and pronounced than previously measured. The Soil Sement section received the lowest scores over time for washboarding which was observed to be consistent and significant throughout the entire section. The average measured depth of washboarding troughs, which is illustrated in Figure 19, from the four monitoring locations in this section was 17 mm (0.7 in) that converts to a rating of 6. It is notable that both the Soil Sement section and also Caliber section are only 3.7 m (12 ft) wide and therefore typically experience traffic concentrated to only two tracks, yet the Caliber section's average measured depth of washboarding troughs was less than 1 mm (0.04 in) which gave it a rating of 9.

Figure 19. Photo. Measuring washboarding depths.

All the sections had some washboarding by the final monitoring event, but not necessarily throughout their entire lengths. The evaluation team naturally felt some frustration that the predetermined monitoring locations often fell outside of what appeared to be significant washboard areas, but adhered to the predetermined plan so as not to interject bias into the study. The specific monitoring locations were planned without reference to known field conditions and with the objectives of spreading the locations out fairly evenly across the available monitoring area and not repeating any locations.

Raveling Trends

The plot in Figure 20 shows how the products rated over time for raveling. In general, the scores for raveling were lower than for washboarding, though most motorists would probably complain about washboarding long before they complained about raveling. As shown in Figure 20, the amount of raveled material generally increased over time resulting in lower scores over time. Raveling of roadway material appeared to be significant as the average depth of raveled material in a section, as shown in Table 9, ranged from 7 to 23 mm (0.3 to 0.9 in). Again the scores that each section received were dependent on the specific locations of the four 7.6-m (25-ft) long measurement areas within each section. It also should be noted that both curves and travel speeds are important factors in kicking loose material to one side or the other, and there was

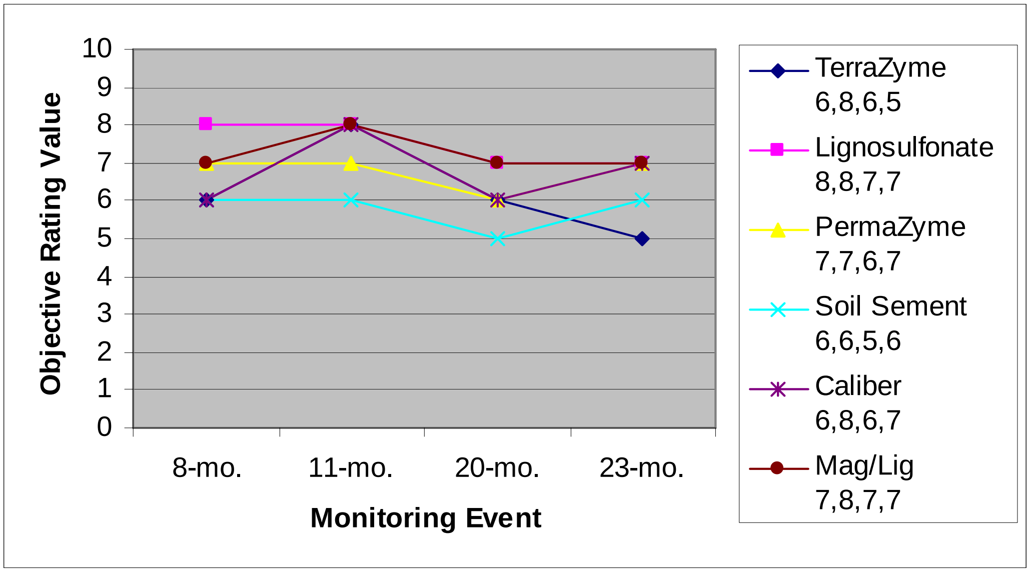


Figure 20. Plot. Raveling trends.

consistently more raveling on the outside of curves throughout all the sections. All measurement data is provided in Appendix C, and comments on road geometry are provided as well.

Rutting Trends

The plot in Figure 21 shows how the products rated over time for rutting. Generally, some rutting developed over time in all the sections. Rutting was measured multiple times in each wheel path within a 7.6-m (25-ft) long location, and an average depth reported for each wheel path. Final rutting depths for any of the products were not over 15 mm (0.6 in), and since traffic volumes were so low at the Seedskadee Refuge, it may not have been sufficient to cause extensive rutting. The only really significant rutting seemed to be on the Bureau of Land

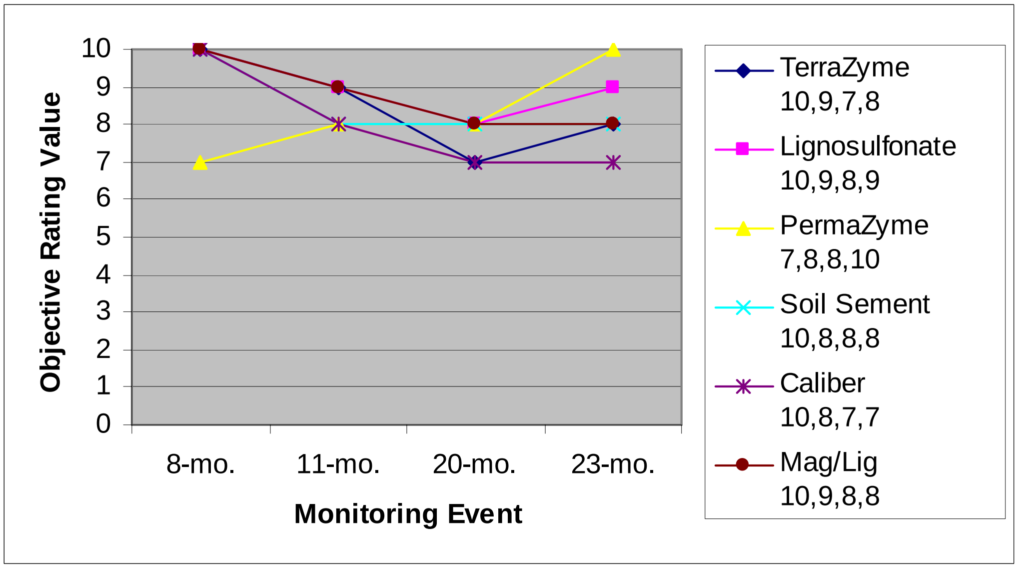


Figure 21. Plot. Rutting trends.

Management (BLM) access roads between the highway and the Refuge boundaries. But since these roads were not reconstructed as part of the Seedskadee project, these BLM access road ruts were not physically measured.

Though the objective measurements in the PermaZyme section show decreased rutting (higher scores) over time, this result is likely due to the variability of the distress within the section's four monitoring areas at any given event. For example, at the 8-month event, rutting was measured at three locations in PermaZyme section, and no other rutting was measured in any other section on the entire project. Thus PermaZyme received the lowest score at the 8-month event. But in the final 23-month monitoring event, no rutting was measured in any of the four monitoring locations in PermaZyme section, and all of the other sections' measurements showed some rutting.

Potholing Trends

The plot in Figure 22 shows how the products rated over time for potholing. It was not known at the beginning of the study whether there would be potholing or not. Potholes on this project were few and far between, and a score of 10 indicated that potholes were not evident at any of the four monitoring locations within a section. At the 11-month event, the TerraZyme section received a score of 7 because a pothole, measured to be 48 mm (1.9 in) deep, was found within one of the 7.6-m (25-ft) long measurement areas. There was no rating criterion that actually fit this occurrence of one pothole, but the fact that it occurred within a monitoring area was recognized with a score of 7.

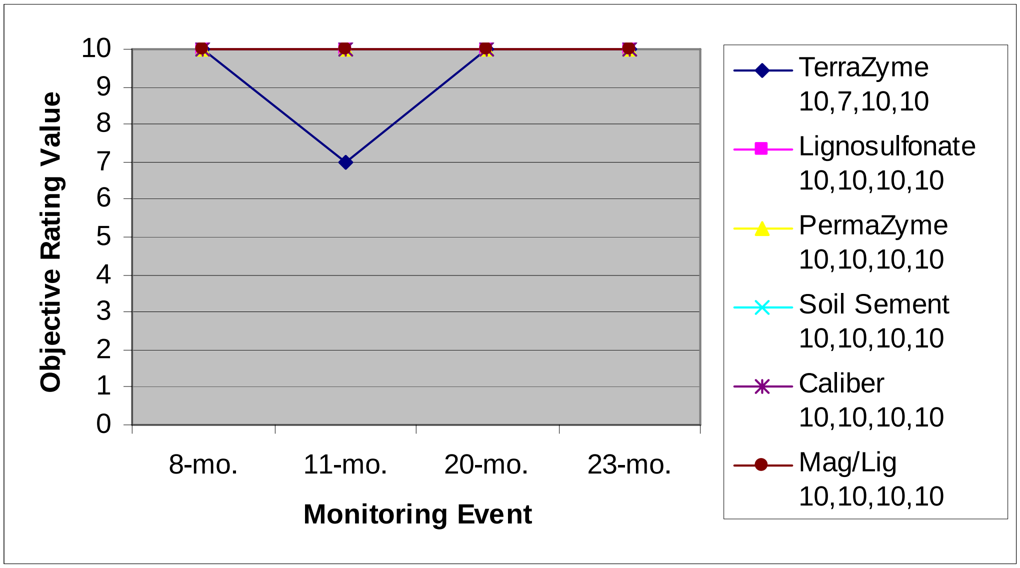


Figure 22. Plot. Potholing trends.

The objective rating criteria had been set up to rate areas of potholing where numerous potholes were developing. Thus, if one pothole occurred within a 7.6-m (25-ft) monitoring area, that area was likely to receive a low score. In another monitoring event, when that area was missed and no potholes were found, the section would receive a higher score. For this project, the monitoring team decided to track the few occurring potholes individually by measuring their diameter and depth at each subsequent event after they were discovered as shown in Figure 23. The pothole rating criteria may need to be revised later on for other monitoring projects.

Figure 23. Photo. Measuring Pothole Depth.

A total of three potholes were found on the entire project and their measurements through time are shown on Table 10. Their depths were measured both to the loose surface material and to the hard surface beneath. After measuring to the hard surface, the team then filled the pothole in to the original loose material depth. This practice continued throughout the two-year monitoring period, but it should be noted that a vehicle tire drops only to the loose surface, not to the hard surface beneath, and this surface can change over time. In fact, observing the depth to the loose surface of each pothole over time suggested that the potholes were repairing themselves.

In PermaZyme Section III, a pothole measuring 50 mm (2 in) deep was found during the first monitoring event. By the 11-month event this pothole had filled in some, and by the final event it appeared to be correcting itself measuring only 30 mm (1.2 in) deep. The first pothole in TerraZyme Section I at milepost 0.48 was discovered at the 11-month event in August 2005. It too became a little more shallow and wider over time. A second pothole in Section I had appeared at the May 2006 20-month event. This pothole only minimally changed in the three months leading up to the final 23-month monitoring event.

Table 10. Individual pothole measurements.

Location	Measurements	8-mo.	11-mo.	20-mo.	23-mo.
Section I TerraZyme, MP 0.47	Diameter (mm)			275	280
	Depth to Loose Surface (mm)			35	30
	Depth to Hard Surface (mm)			45	50
Section I TerraZyme, MP 0.48	Diameter (mm)		270	435	310
	Depth to Loose Surface (mm)		48	40	20
	Depth to Hard Surface (mm)		68	127	25
Section III PermaZyme, MP 0.43	Diameter (mm)	445	420	420	550
	Depth to Loose Surface (mm)	50	27	39	30
	Depth to Hard Surface (mm)	70	47	55	44

OBJECTIVE MEASUREMENTS SUMMARY AND EVALUATION

In Table 9, there is an overall rating covering the entire monitoring period for each product and parameter. These parameter ratings are plotted in Figure 24 along with an objective overall rating showing an averaged value of all of the parameters. From objective measurements, four groups of product performance are evident. In the first group were Lignosulfonate and Mag/Lig

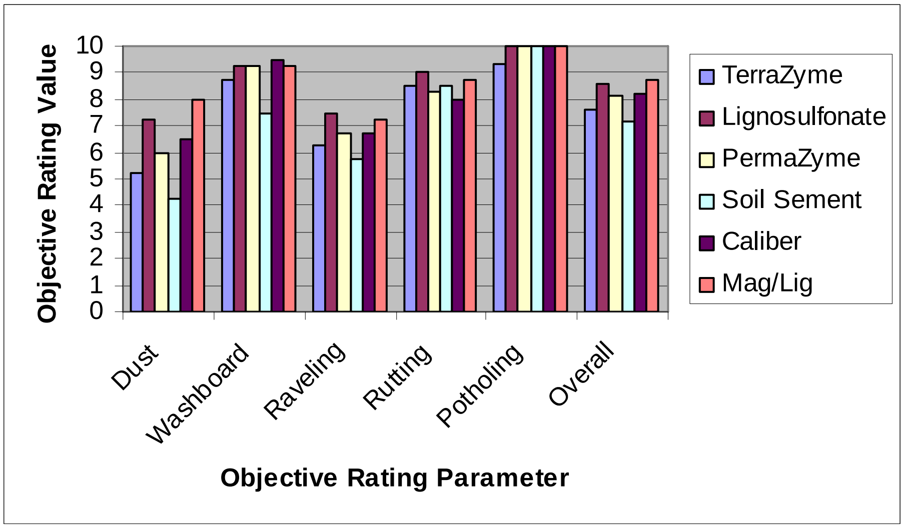


Figure 24. Plot. Relative product standings from objective rating system.

performing the best. In the second were Caliber and PermaZyme. TerraZyme was in the third group, and Soil Sement fell into a fourth group with the lowest overall average score.

The strength of the objective rating system lies in its descriptive criteria. If the descriptive criteria are meaningful, then the analysis provides 1) relative standings of the products just as the subjective method provided relative standings, 2) trends over time discussed in this chapter, and 3) a view of which parameters have the lowest ratings and therefore may be of greatest concern. The relative standings of the products for each parameter evaluated are clearly shown in Figure 24 and can be compared to the relative standings from the subjective comparative method covered in Chapter 4.

The third benefit of revealing which parameters have the lowest ratings and may be of greatest concern is a little more complicated than it first appears. From the point of view of road users or maintenance personnel, assuming that the parameters with the lowest values are the parameters needing the most attention and correction could be a mistake. According to Figure 24, dust generation and raveling were the parameters of greatest concern because they received the lowest values, while washboarding and rutting were of less concern, and potholing of very little concern. This observation is entirely dependent on the meaningfulness, defined as rooted in the experience of those who use the road, of the Appendix B descriptive criteria. These criteria were developed with a view of probable best case to worst case conditions expected to be encountered on a native material or gravel surface roadway. But someone driving the road may not agree that dust and raveling were the biggest problems even though Figure 24 indicates they were. Normally drivers are more concerned about washboarding, rutting, and potholing because of the damage that can be done to their vehicle. Dust and raveling are typically just irritants, though dust also may affect plant life in the area. Despite this possible confusion, the evaluation team felt that the objective rating system was one they would use again and recommend for use by others.

CHAPTER 6 – ON-SITE PHYSICAL TESTING

ON-SITE TESTING RESULTS AND OBSERVATIONS

The on-site testing and sampling with laboratory analysis consisted of the Silt Load Test and the Dynamic Penetrometer Test (DCP). The Silt Load Test provided, in ounces per square foot, the amount of surface material currently available for producing dust. In conducting the test, the evaluators also obtained gradation and moisture information. The DCP Test was significant because the test results could be converted to a CBR value to evaluate and compare the load carrying capacity of each section's aggregate surfacing. Results from these onsite tests are shown in Table 11.

At the 8-month monitoring event, only two silt load sampling locations per section were used, but starting with the 11-month event, sampling for the Silt Load Test was done at four locations within each section. This change provided more data and mirrored the four-location monitoring system set up under the Objective Measurements rating scheme.

DCP tests were performed at each of the monitoring events and also on October 20, 2004, just one month after the products were first applied. During the first two events, the 0-month and 8-month events, only two DCP tests were performed in each section. For the remaining three events, the evaluation team decided to do four rather than two DCP tests in each section. This change was made because the DCP test was fairly easy to perform in the aggregate surfacing material, and the increased data would hopefully lead to a better evaluation.

Silt Load Test

Special care was taken in sampling the roadway surface material for the Silt Load Test as shown in Figure 25 to assure the laboratory test results for gradation and moisture were representative. Samples were carefully sealed because moisture content was measured as a part of the silt test. Since the amount of moisture present in the surface materials was expected to affect the availability of dust-sized material, it was decided that neither silt test sampling nor dust ratings would be done in the morning if dew was present. Silt sampling times are noted in Appendix C.

Appendix D contains the full silt analysis test procedure that is briefly summarized as follows. A gradation test was done on all the silt samples to obtain the mass passing the 75 µm (No. 200) sieve. This number was used to calculate the silt loading: Silt load (oz/ft^2) = mass passing No. 200 (g) / area (in^2) x 0.035 oz/g x 144 in^2/ft^2. Detailed calculations for the Seedskadee project are shown in Appendix E. Silt Load Test results, shown in Table 11, were averaged for each product section.

It may be noticed in Appendix E that the area used for calculating the silt loading was reduced after the first monitoring event. At the 8-month event, the evaluation team swept up a 1.2-m by 0.2-m (4-ft by 1-ft) swath across each wheel path giving a total sampling area of 0.75 m^2 (1150 in^2). Samples were taken from two milepost locations within each section. At subsequent monitoring events, the swaths were 0.9 m by 0.3 m (3 ft by 1 ft) giving a total area of 0.55 m^2 (864 in^2) at each of four monitoring locations in each section. Since silt load results are on a per

Table 11. Onsite testing results.

Test Section	Product	Event	Silt Loading					CBR from DCP Testing			Onsite Tests Overall Normalized Rank
			Average Moisture (%)	Average % Passing #200 Sieve	Average Loading (oz/sf)	Overall Average (oz/sf)	Silt Loading Normalized Rank[1.]	Average CBR	Overall Average	CBR Normalized Rank[2.]	
I	Terra-Zyme	1-month				0.72	83	28	39	39	61
		8-month	0.4	1.4	0.21			30			
		11-month	0.2	3.8	0.73			50			
		20-month	0.1	6.1	1.71			58			
		23-month	0.1	1.8	0.21			29			
II	Ligno-sulfonate	1-month				0.35	90	43	57	57	74
		8-month	0.2	0.4	0.02			38			
		11-month	0.2	2.8	0.43			85			
		20-month	0.1	4.9	0.84			68			
		23-month	0.1	0.9	0.11			53			
III	Perma-Zyme	1-month				0.58	85	28	38	38	62
		8-month	0.2	0.7	0.05			30			
		11-month	0.2	3.6	0.73			53			
		20-month	0.1	4.8	1.25			53			
		23-month	0.1	1.4	0.30			28			
IV	Soil Sement	1-month				1.51	63	21	38	38	51
		8-month	0.3	3.6	0.68			33			
		11-month	0.3	6.4	2.02			53			
		20-month	0.1	6.2	2.06			49			
		23-month	0.1	4.2	1.28			34			
V	DCA-2000 Caliber	1-month				0.53	88	17	42	42	65
		8-month	0.4	2.7	0.43			30			
		11-month	0.2	2.7	0.45			63			
		20-month	0.0	4.5	0.97			63			
		23-month	0.1	1.9	0.27			35			
VI	DMC 820 (Mag/Lig)	1-month				0.44	90	18	35	35	63
		8-month	0.3	1.1	0.09			33			
		11-month	0.1	2.9	0.24			53			
		20-month	0.1	4.7	1.28			48			
		23-month	0.0	0.8	0.14			25			

1. Silt Loading Normalized Rank = 100 - [Overall Average Loading / ∑ of the Overall Average Loadings) x 100]
2. CBR Normalized Rank is the same as the CBR Overall Average Value since its scale is already from 0 to 100.

Figure 25. Photo. Sampling for Silt Load Test.

square foot basis, these changes didn't affect the data other than providing more volume of material for the data.

Testing of silt samples provided moisture content information for each monitoring event. This data confirmed consistency within one event so products could be compared. Additionally, if the moisture content was consistent between the various events, it would allow additional reasonable comparisons to be made. As can be seen in Table 11, all moisture test results over the entire 24 months of monitoring showed that the average moisture content was less than one-half of one percent. It seems reasonable, therefore, that the amount of dust observed at any given time would correlate with the amount of silt available. Based on this, Chapter 7 presents a comparison of Silt Test results and the agreed objective dust ratings for each product.

Maricopa County, Arizona has established criteria for the Silt Load Test such that any silt load test result that exceeds 0.1 kg/m^2 (0.33 oz/ft^2) is an indication that the product has failed to control dust. Using this criterion, test results show that two sections were failing eight months after installation and five of the six were failing three months later at the 11-month monitoring event. Every section failed this criterion sometime during the monitoring period. During the third monitoring event at 20 months, most of the products showed more than double their previous silt load. It is possible that, in addition to the normal breakdown of material by traffic, the doubling and quadrupling of the average silt load in each section during this 20-month monitoring event is due in part to the 2006 winter being so much drier than the previous winter and the binder material having little or no moisture available for its stabilizing mechanism to work.

Dynamic Cone Penetrometer (DCP) Test

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 125 mm (5 in), the total blows to penetrate to this depth were recorded as shown in Figure 26. The overall average blows per inch were used to calculate the average CBR for the treated depth.

In Figure 27, the average CBR for each product is plotted through time. All the tests were performed in the wheel paths, and all the aggregate for the project met the same specifications. The higher the resulting CBR, the higher the road's load carrying capability. All DCP data and conversions to a CBR value are detailed in Appendix F.

Figure 26. Photo. DCP testing.

During the October 2004 DCP testing, the ground was wet, and, though the averaged data presented in this report does not illustrate it, the individual test results showed that the deeper the penetration the stiffer became the material. It is interesting that, in the initial October 2004 testing, the upper parts of each section were wet, and the resulting field CBR results were similar to the laboratory CBRs which are obtained using saturated material. Several inches down in the in-situ material where it was drier, the field CBR values were higher than the laboratory CBRs. By May 2005, when it was dry, all DCP-derived CBRs had exceeded the laboratory-determined CBRs. Considering the above, the monitoring team decided that laboratory CBRs and field CBRs should not be compared and that only the CBRs from the field DCPs would be compared over time.

As shown in Figure 27, by the 11-month event of August 2005 the load carrying capacity based on the CBRs of most of the sections had reached its highest point, and from there it generally decreased. Perhaps all the products had set up better over the dry summer months causing the higher CBR values. In addition, the road had some traffic over the summer which contributed to the compaction and density of the material. The fact that all the CBR values decreased may indicate that the effectiveness of the applied products were diminishing, or that there was insufficient clay material present in the aggregate to

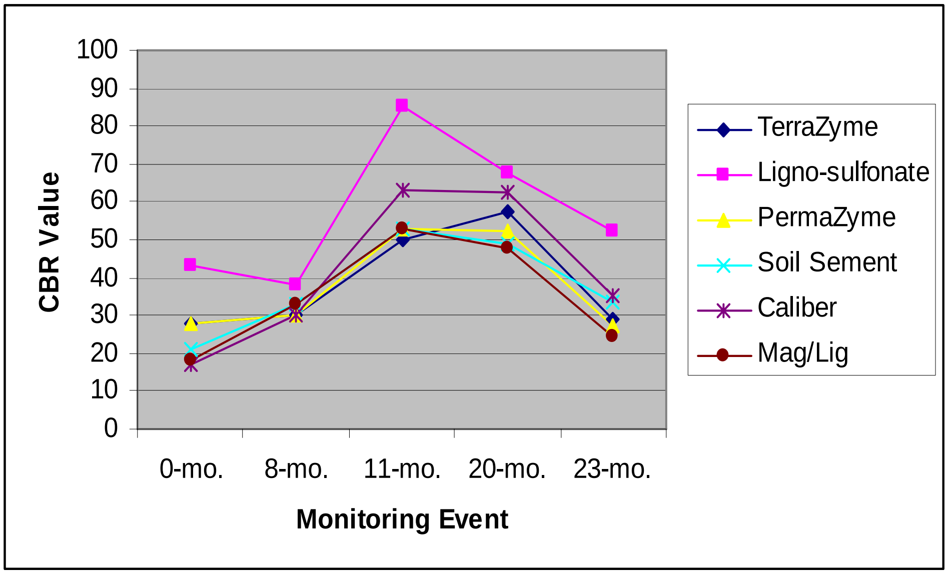


Figure 27. Plot. CBR values derived from DCP testing.

work with the stabilizer products. Section II Lignosulfonate consistently had the highest CBRs throughout the entire monitoring period. One explanation for this was that the test results, shown in Table 5 of Chapter 3 following application of the stabilizer products, indicated that lignosulfonate's PI was measured at 6 whereas all the other sections were NP.

ONSITE TESTING RESULTS SUMMARY

The ranking of the products from the two on-site tests is plotted in Figure 28. The overall rank from on-site tests is also shown. Looking at the normalized rankings in Figure 28, one might conclude that the road performed better for dust than it did for stability. This is not necessarily true because the normalized silt load results in Table 11 only rate a product's performance against the other five products. On the other hand, the calculated CBR values are based on directly measured values. The overall rank averages the values resulting from the two test procedures and is valuable to the extent of comparing the products' performances at Seedskadee NWR.

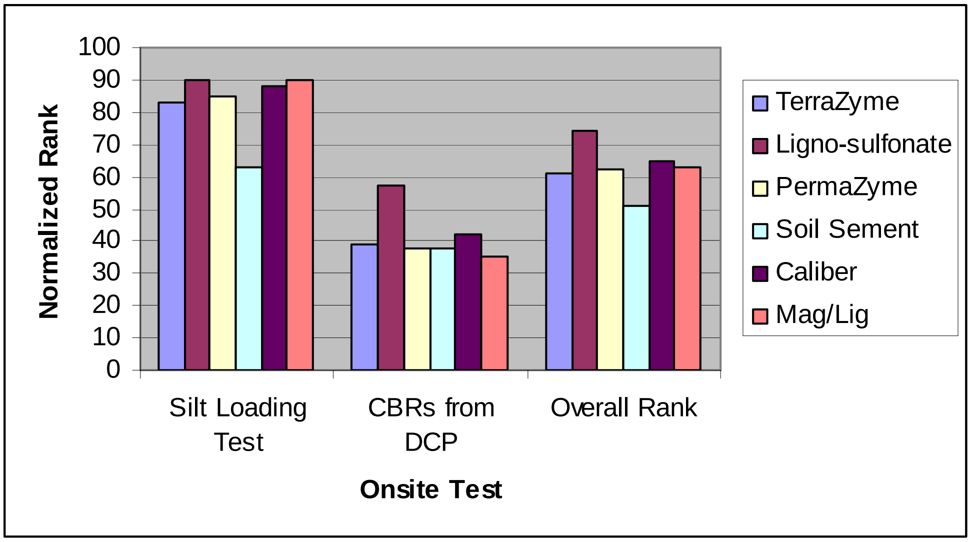


Figure 28. Plot. Product ranking from onsite tests.

CHAPTER 7 – EVALUATION AND DISCUSSION OF ALL MONITORING RESULTS

In Chapters 3 through 6, project data and test results were presented and observations were made. The purpose of this chapter is to highlight some of the data and observations and discuss their relevance.

OVERALL PERFORMANCE LEVELS

Table 12 summarizes product scores achieved from the three types of monitoring – Subjective Observations in Chapter 4, Objective Measurements in Chapter 5, and Onsite Physical Testing in Chapter 6. The sixth column of Table 12 is an average of the three scores earned and serves to rank product performance at the Seedskadee NWR. Since these numbers may imply a higher level of precision than actually existed, the products have been simply grouped, and four groups are apparent. The Lignosulfonate product with the highest score is in the first group, and the Mag/Lig and Caliber products are in the second group. The two enzyme products, TerraZyme and PermaZyme formed the third group, and Soil Sement ranking lowest was in the fourth group. Table 12 also shows relative initial cost, relative application rate, and relative in-place cost.

Table 12. Seedskadee monitoring summary.

Test Section	Product	Subjective Overall Average Score (x10)	Objective Measures Overall Rating (x10)	Physical Onsite Overall Normalized Rank	Product Ranking from All Monitoring	Relative Initial Cost ($/gal)	Relative Application Rate (gal/ 1000 CY for 5 inch depth)	Relative In-Place Cost ($/CY)
I	Terra-Zyme	50	76	61	62	High ($145)	Low (0.01)	Low ($1.49)
II	Ligno-sulfonate	62	86	74	74	Low ($1.30)	High (5.62)	Medium ($7.30)
III	Perma-Zyme	51	81	62	64	High ($98)	Low (0.01)	Low ($0.84)
IV	Soil Sement	45	72	51	56	Low ($3.09)	High (4.10)	High ($12.66)
V	Caliber	56	82	65	68	Low ($1.17)	High (7.20)	Medium ($8.42)
VI	Mag/Lig	60	87	63	70	Low ($0.85)	High (7.20)	Medium ($6.11)

The earlier project at Buenos Aires NWR had a somewhat different ranking. There, the Caliber product performed the best, Mag/Lig was in the second group, and all the other products fell into the third group. The surfacing materials used at Buenos Aires and Seedskadee were different but both were non-plastic materials. Table 13 provides other key parameters for comparing the two projects. Likely, no one product works best everywhere, and owners of unpaved roads should select dust abatement and stabilizer products based locale and on the characteristics of their proposed surfacing material rather than on claims made by any one manufacturer. There is a need for selection criteria to help designers chose what would be the most effective class of

Table 13. Comparison of general characteristics between two NWR stabilization studies.

General Characteristic	Buenos Aires NWR Project	Seedskadee NWR Project
Climate	Desert Climate with Monsoon Seasons	High Desert with Climactic Extremes
Traffic Level	Low: 8 to 25 Vehicles per Day	Low: 4 to 15 Vehicles per Day
Surfacing Type	Borrow Material	Surfacing Aggregate
Material Description	Coarse-grained Gravel and Poorly Graded Silty Sand	Coarse-grained Gravel and Poorly Graded Silty Sand
Maximum Size Gravel	1 ½ inch	¾ inch
Percent Fines Range	4% to 19 %	9% to 13%
Plasticity Index	NP	NP
Organic Matter Content	No Test Results	Very Low (0.4%)
Stabilization Depth	150 mm (6 in)	125 mm (5 in)
Product Application Method	Windrow Mixing	Tiller Method
Best Performing Product	Caliber	Lignosulfonate
Second Best	Mag/Lig	Mag/Lig
Third	Lignosulfonate	Caliber
Fourth	TerraZyme	PermaZyme
Fifth	Soil Sement	TerraZyme
Sixth	PermaZyme	Soil Sement

stabilizer products to use in a specific setting. A preliminary process for accomplishing this objective is proposed in Appendix G. Finally, it is important for owners to also find out how to use the selected product to achieve the best possible result.

PLASTICITY

The materials at both the Buenos Aires and Seedskadee projects were NP or very close to NP. Differences between laboratories in the results reported for Seedskadee were well within expected variability for AASHTO T89 and T90. There are two problems with a low PI. First is that fines create dust when there is nothing gluing them together. Plasticity is the glue, so a surfacing material that is NP but has lots of fines will be dusty. The second problem is that many of the stabilization products used are ineffective without adequate PI. In fact, the typical role that some of them play is to lower a high PI, and they tend to work best with a material that has a PI between 10% and 20%. The exception to this statement is the Lignosulfonate product with a PI of 6% that appeared to add plasticity. This product and the combination Mag/Lig product were the top two performers in the NP aggregate material at Seedskadee. At Buenos Aires, Mag/Lig ranked second and Lignosulfonate was third.

These two performance evaluation projects at Buenos Aires and Seedskadee have brought attention to the need for higher PI. One result of this finding is that CFLHD has increased the PI specification on some future projects.

SILT LOADING AND DUST

This section presents a comparison between objective dust observations and Silt Load Test results. The silt load was the amount of silt available, in ounces per square foot, in the loose surface material that would blow away as dust. In Figures 29 through 34, the agreed dust ratings for each product were compared over the two-year monitoring period to the average silt loading results for the same time period. Generally, the figures show that when there was a lot of silt available, more dust was observed. Since the trends generally moved together, the results of the two tests generally validated each other. Figure 33 that graphs the Caliber product appears to deviate from the general trend at the 20-month event. It must be remembered that the silt test result was an average of only four discreet samples where as the agreed dust rating considered the entire section.

It is interesting that, in all the graphs, the 23-month silt loading result was better than the earlier 11-month and 20-month results. The amount of loose dust size particles was less at the end of the project than earlier, and there was also less dusting observed. Since the weather was dry for all of the events, this phenomenon was curious. One possible explanation was that as the surfacing material broke down from traffic and weathering, the finest particles blew away leaving larger raveled material over the road surface. Under the raveled material was the remaining stabilized surfacing material. Over a longer monitoring period it was possible that silt load results could cycle. The silt test results from the Buenos Aires project did not show a similar consistent up-swing at the final monitoring event, nor were there any objective dust ratings available to compare dust and silt load. Any comparison was further hampered by the fact that only two samples were taken for the silt test from each section at Buenos Aires, so the resulting average of only two silt load values was necessarily less precise than Seedskadee’s four values.

Gradation analysis was performed as part of the Silt Load Test and the summary results are included at the end of Appendix E. The material gathered was only the loose material at the surface, but a comparison to the gradation of the full depth material as initially constructed in October 2004 shown in Tables 5 and 6 in Chapter 3 was interesting. A general observation was made that for the loose surface material, more material passed through the larger sieves (19-mm (3/4-in) down to 2-mm (No. 10) sieves) and less material passed through the 0.425-mm (No. 40) sieve down to the 75 µm (No. 200) sieves. This indicated first that the larger aggregate was likely

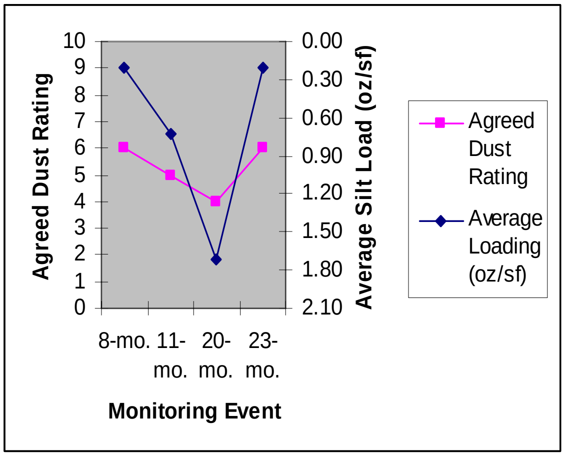


Figure 29. Graph. TerraZyme dust and silt load comparison.

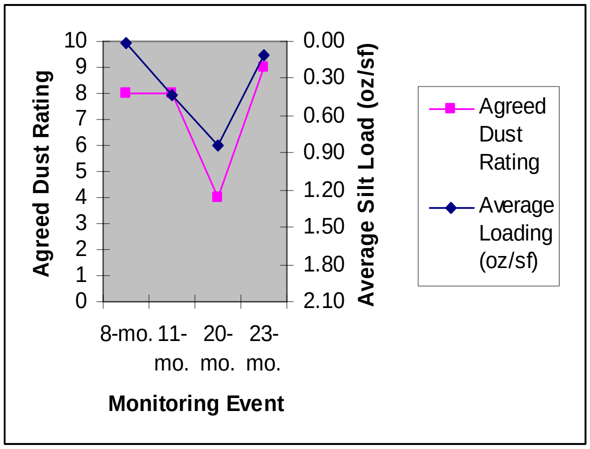


Figure 30. Graph. Lignosulfonate dust and silt load comparison.

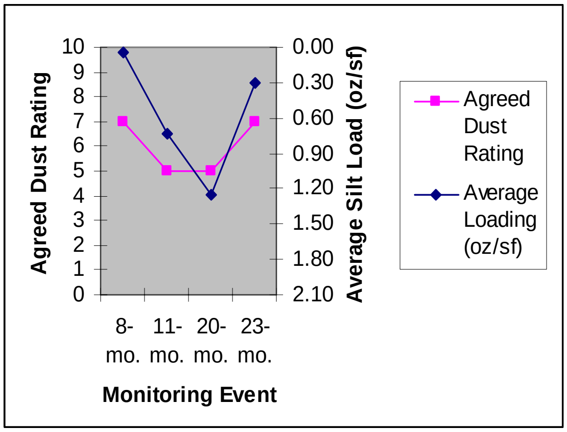


Figure 31. Graph. PermaZyme dust and silt load comparison.

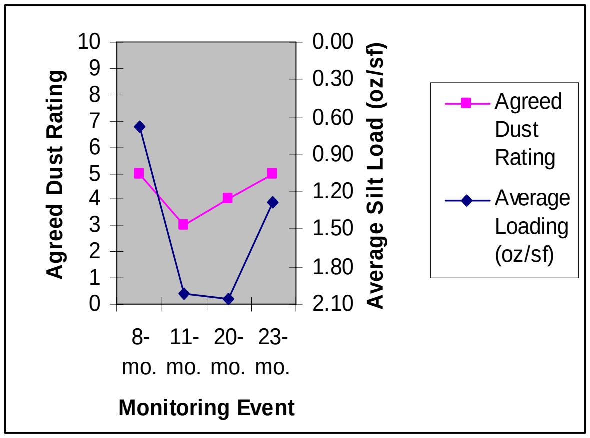


Figure 32. Graph. Soil Sement dust and silt load comparison.

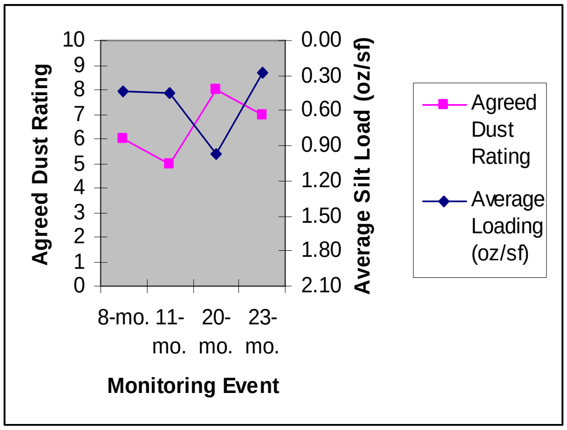


Figure 33. Graph. Caliber dust and silt load comparison.

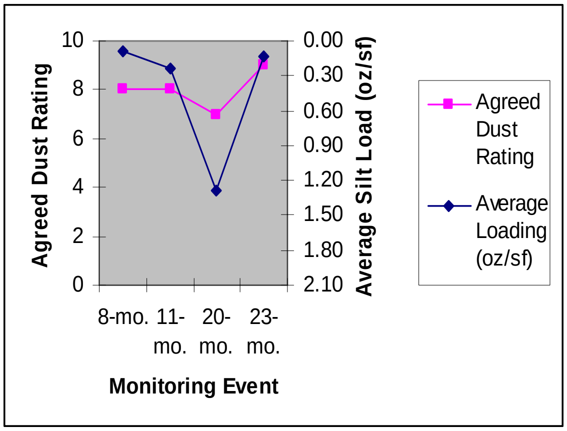


Figure 34. Graph. Mag/Lig dust and silt load comparison.

breaking down over the two years of monitoring. It also indicated that something happened to the smaller particles. In fact, material passing the 75 µm (No. 200) sieve ranged from 9.3% to 12.7% during installation in September 2004, and dropped throughout the monitoring period to a range of 0.8% to 4.2% in the surface layer after two years. This shows that binder material may have been lost to erosive forces such as traffic and climatic conditions. The loss of binder material over time may be one explanation for why the average silt loading for all the products actually decreased (improved) the last month of monitoring.

PRODUCT DISSIPATION

At one point during monitoring of Seedskadee, there was a concern that the stabilization products may have leached out in the first few months. The exception may have been the Lignosulfonate product that is very viscous and was ranked as the best performer at Seedskadee. One way of testing this hypothesis would have been to have a control section with the same traffic but without any stabilization product applied. This was not possible to accomplish on the Seedskadee NWR. Another solution might have been to run before and after tests to determine the amount of stabilization product in material samples.

Since these tests were not done, no conclusive statement can be made about product leaching. However, it should be noted that product leaching was never observed. Additionally, when sweeping up samples for the silt test, in all cases the hard underlying surface appeared to still contain product throughout the two-year monitoring period. A reasonable question for future studies was how can an agency quantify the amount of product present at the beginning of the study and then again quantify it at the end. Currently, the FHWA has only a method specification for application of stabilizer products.

COMPARISON OF CBR VALUES BETWEEN TWO PROJECTS

The average DCP-derived CBR values at Buenos Aires ranged from 57 to 87 for the six products. DCP tests at Buenos Aires were only performed during the last three monitoring events. At Seedskadee, the average in-situ CBRs for its last three events ranged from only 42 to 69. It appears from these numbers that the Buenos Aires material in general was more stabilized and would likely prevent wash boarding, rutting, and potholing for a longer period of time than at Seedskadee.

Since the degree of stabilization was somewhat greater at Buenos Aires, one question asked was whether or not it was an effective use of funds to try to stabilize the crushed aggregate surfacing at Seedskadee. A conclusive answer cannot be stated because there was no control section free of stabilizer product available for comparison at either project. It must be noted however that at Seedskadee, product was visible in all the sections underneath the loose raveled surface material. The significance of that observation is that the stabilizer products did not appear to leach out over the two-year monitoring period.

Each section at Seedskadee behaved somewhat differently in regards to loose aggregate. In one section, loose aggregate was spread evenly over the width of the road. In another, there were wheel paths that were clear of loose aggregate. It was suggested that defined wheel paths might indicate that the rocks were thrown aside from traffic but that no new rocks were breaking loose and moving to the surface. Since the traffic was approximately the same through all the sections, it seems plausible that areas where loose rocks were spread uniformly across the roadway were probably in less stable condition than areas where wheel paths had formed. Where rocks were spread uniformly across the road, it was thought that more rocks were continually coming to the surface as binder broke down. Thus, a hypothesis to be tested was that in sections with loose aggregate spread across the road, the CBR values derived from DCP tests would be lower than in sections where wheel paths have formed. And since each DCP test site was very near to the sampling locations for the Silt Test, and since the Silt Test provides a total mass in grams for the sample collected, it was thought that the total mass of the sample might correlate with the CBR derived from the DCP test performed in the wheel path. Even though there was a large amount of data, there was very little correlation between Silt Test sample size and in situ CBRs.

FULL DEPTH STABILIZATION AND WASH BOARDING

Surfacing materials for both of the projects were stabilized to their full depth. This was 150 mm (6 in) at Buenos Aires and 125 mm (5 in) at Seedskadee. This procedure may have been key at both projects for minimizing wash boarding. However, because there was no true control section that could be constructed at either project, there is no proof that full depth stabilization actually prevents wash boarding. At Seedskadee where recurring wash boarding has typically been the most difficult road maintenance problem, full depth stabilization of the aggregate surfacing worked very well. It is possible too, that the 19-mm (3/4-in) minus specified aggregate surfacing alone may have alleviated washboarding whether or not stabilizers were applied. It should be noted, however, that under the loose raveled surface, stabilizer product was still visible even after two years of monitoring at Seedskadee. Full depth incorporation of the stabilizer products was also successful in largely preventing potholing and rutting at both projects.

Since full depth stabilization was considered, by the evaluation teams on both projects, to be very important in preventing potholing, a discussion follows of the three main methods of incorporating stabilization products into the full depth of surfacing material. Each of the three methods was considered for both Buenos Aires and Seedkadee projects. They are 1) the Windrow Method, 2) the Tiller Method, and 3) the Pug Mill Method. On the Buenos Aires project, forms of the Windrow Method were used, and on the Seedskadee project the Tiller Method was used. The Pug Mill Method was not selected as the preferred method for either of the projects.

Windrow Method

This method involves windrowing the surfacing material to one side, spreading a layer of material, spraying it with the diluted product and water to achieve optimum moisture, blade mixing, and then repeating this process until the specified depth is achieved. The finish bladed roadway is then compacted with a pneumatic roller. This method is easy to do and requires equipment that is generally readily available – a grader, water truck and/or distributor truck, and roller. The layering process assures full depth penetration. Mixing with a grader, however, does not assure uniform distribution across the roadway. The roadway actually needs to be greater than 3.7 m (12 ft) wide to allow room to blade the material back and forth. It is difficult to achieve the correct application rate, and the quality of the job depends on the quality the grader operator can produce.

Tiller Method

Other names for this method include pulverization method and in-place full-depth reclamation. The roadway surfacing material is placed and compacted to the specified depth. Water is applied with a water truck to bring the surfacing material to its optimum moisture content. The stabilizer product is applied through the reclamation machine or, if too viscous, through a distributor truck immediately preceding the reclamation machine. The reclamation machine picks up the surfacing material to the specified depth (125 mm (5 in) on the Seedskadee project) mixes it with the stabilizer product, and lays it back down. The roadway surface is then finish bladed and compacted with a roller. This method uniformly mixes the product with the surfacing material and allows this mixing to occur at the project site unlike the pug mill method. One drawback is that when the product is sprayed on the compacted roadway just in front of the reclamation machine, there is a potential for the product to runoff onto the vegetation at the side of the road before it is picked up and mixed. Additionally, reclamation machines typically cannot make tight turns and therefore cannot be used in tight areas.

Pug Mill Method

This method was not used on either the Buenos Aires project or the Seedskadee project though it was strongly considered. In this method, the stabilization product is introduced into a pug mill at the material production site, and then the treated material is hauled to the project site. This is a controlled process that produces a uniform mixture of product and surfacing material. The equipment needed includes a pug mill, grader, and roller. A water truck is not needed. A spreader box could be used. One limitation of this method is that some products, even after being mixed with water, are too viscous to introduce into the pug mill. Lignosulfonate is one such product. The production rate is slower than with other methods because discrete batches are produced that then need to be hauled to the project site and spread before they set up. A risk of this method is that hauling delays have the potential to cause the material to set up, or react with the stabilization products before reaching the job site.

METHODOLOGY COMPARISON - SUBJECTIVE OBSERVATIONS AND OBJECTIVE MEASUREMENTS

As discussed at the end of Chapters 4 and 5, the subjective comparative system and the objective measurement system each have their strengths.

One recommendation from the Buenos Aires study on dust abatement and stabilizer products was to further refine assessment methods to track performance through time and to strengthen the objectivity and therefore defensibility of the method. The major strength of the subjective comparative inspection system developed for the Buenos Aires project was its ability to recognize subtle differences in performance between the products. What it could not do was track performance trends over time. Thus the evaluation team developed an objective measurement methodology, also based on a zero to ten scale, that attempted to define worst case to best case scenarios for each parameter of dust, washboarding, raveling, rutting, and potholing.

The question was raised early in the monitoring at Seedskadee whether the subjective rating system should be continued considering the 11-point objective measurement system had been developed. It was decided to continue the subjective system through the Seedkadee project, and to discuss both systems in the final report. The remainder of this section evaluates and compares the two monitoring systems.

The relative standings of the products using subjective observations are shown in Figure 35, and the standings using Objective Measurements are shown in Figure 36. At first glance it appears that the objective rating system using field measurements gave much higher scores than the visual comparative system. It must be remembered that the goals and methodologies of the two systems were very different.

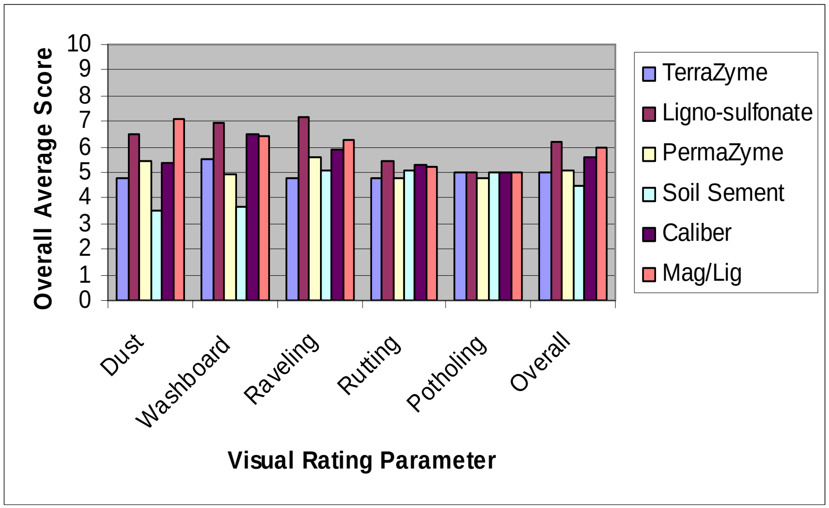


Figure 35. Plot. Relative product standings from subjective observations.

In the subjective comparative system, a different section's product served as the baseline for each monitoring event, and the remaining products were compared to it. Thus, most of the scores hovered around a score of 5 - the score of the baseline product.

In the objective system, however, averaged field measurements were converted to ratings using descriptive tables from the Appendix B Objective Rating System. Thus the ratings were dependent both on how the descriptive tables were set up and on the specific 7.6-m (25-ft) long areas chosen for measuring. These locations were set up in the Appendix A - Monitoring Order and Mileposts Plan prior to any monitoring to avoid bias in choosing measurement areas.

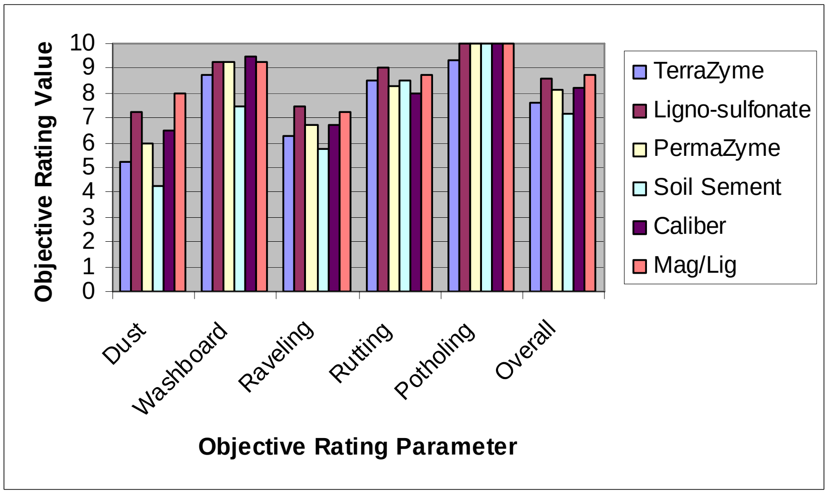


Figure 36. Plot. Relative product standings from objective rating system.

To compare the results from the two methodologies, a sample set of data consisting of the overall average scores of the products for each parameter using the subjective method and the overall ratings of the products for each parameter using the objective measurement method was selected. If the correlation between the results from the two systems were very good, then in the future either the visual comparative system could be ignored as being much more subjective, or the objective system could be ignored because it required more time and effort. In Figures 37 through 41, objective ratings on the y-axis for each parameter are plotted relative to subjective comparative scores on the x-axis. The six data points on each plot represent the six different stabilization products. A simple regression analysis yielded a best fit line through the data points, and a correlation value, R^2, is also shown. The correlations vary from excellent to poor depending on the parameters, and are discussed below.

Dust Correlation

The Figure 37 correlation for dust results shows excellent correlation, at $R^2 = 0.9696$, between results from the objective measurement monitoring method and the subjective comparative method. This is not surprising because in both methods the evaluation team used visual criteria to estimate the level of dust even though the objective method offered more definitive criteria. Instead, they together agreed on the appropriate objective rating using the Appendix B criteria. This step was done in conjunction with the subjective comparative scoring of dust generation.

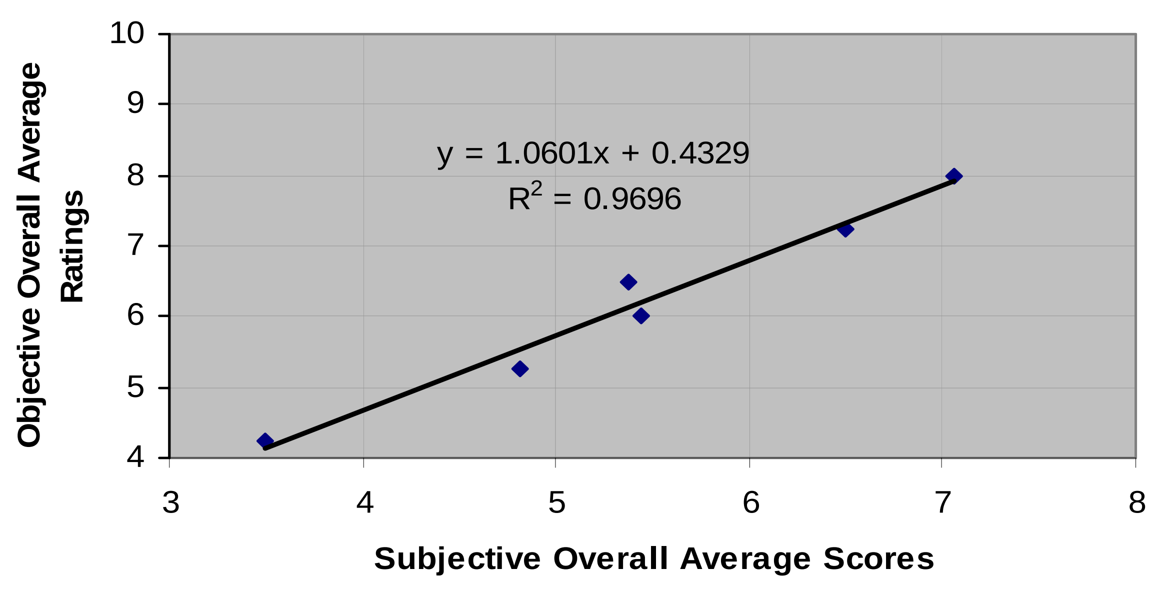


Figure 37. Plot. Correlation of results for dust.

Washboarding and Raveling Correlations

For wash boarding, Figure 38 shows a surprisingly good correlation at $R^2 = 0.7107$. This is also true for raveling shown in Figure 39 with a correlation value of $R^2 = 0.8179$. The reason this degree of correlation is surprising is that the pre-selected 7.6-m (25-foot) long monitoring areas were randomly selected such that information was not recorded from some of the perceived

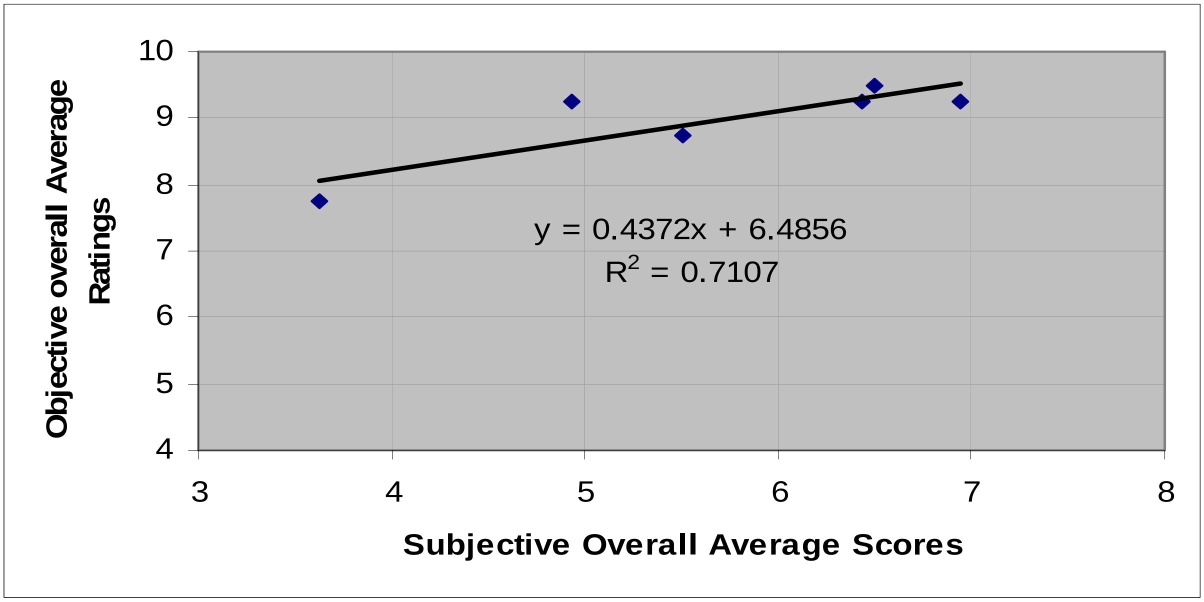


Figure 38. Plot. Correlation of results for washboarding.

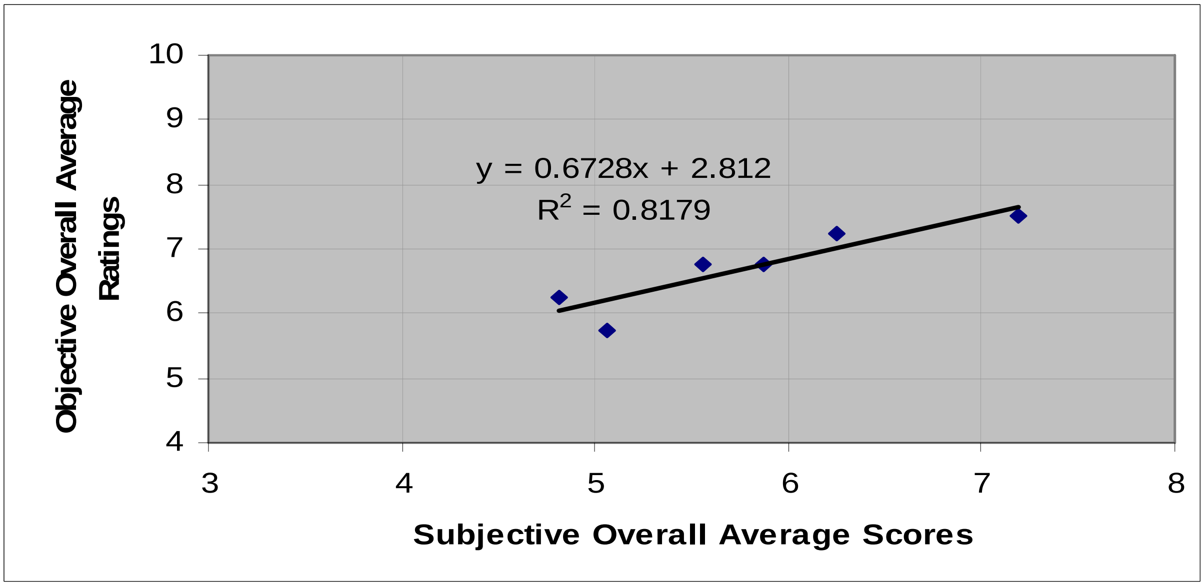


Figure 39. Plot. Correlation of results for raveling.

poorer performing areas within a particular section. This degree of correlation adds confidence that either the subjective method or objective method of evaluating these parameters could be chosen.

Rutting and Potholing Correlations

The correlation between the two methodologies using data from rutting and potholing, however, is quite poor. For the parameter of rutting, Figure 40 shows an $R^2 = 0.1362$, and for potholing Figure 41 shows $R^2 = 0.04$ which is essentially no correlation. These low R^2 values do not

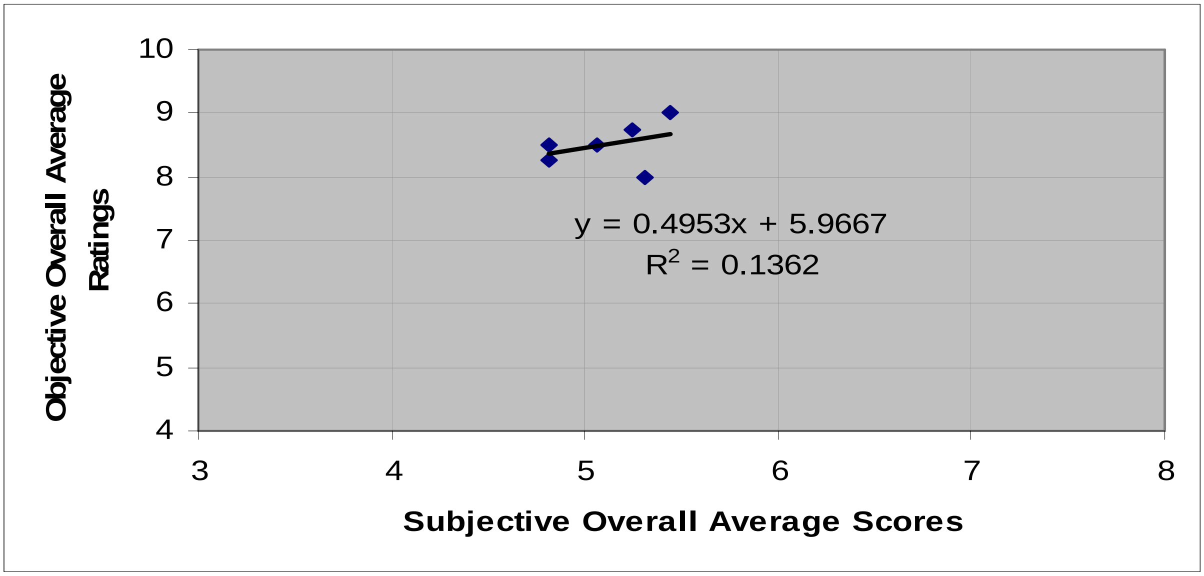


Figure 40. Plot. Correlation of results for rutting.

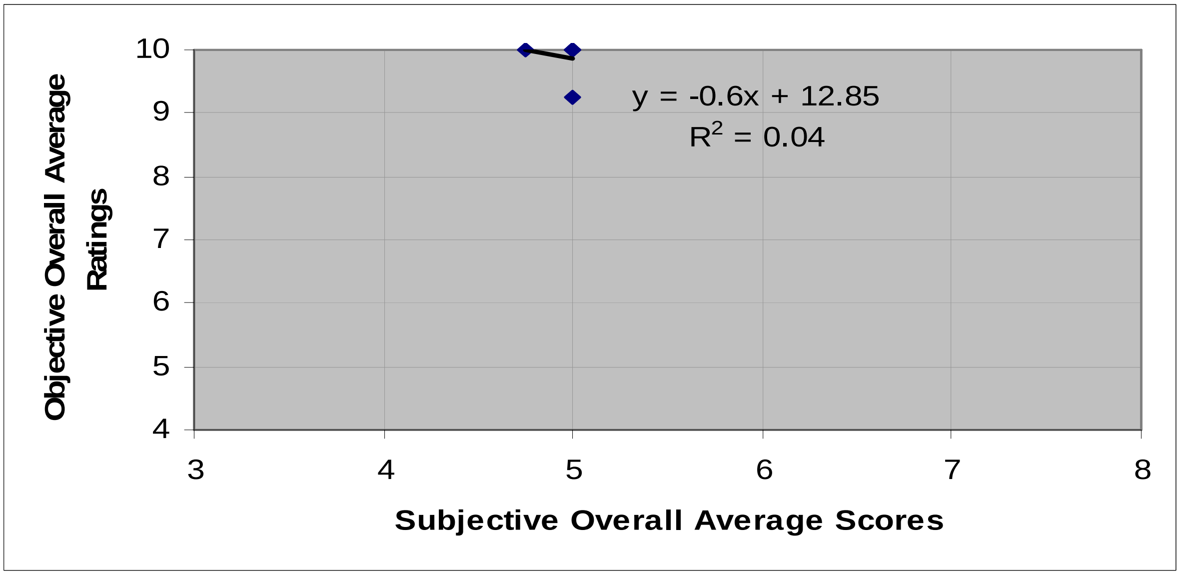


Figure 41. Plot. Correlation of results for potholing.

necessarily mean that the two monitoring methodologies do not give good answers, but rather the resulting values in the data set do not correlate. A data set that reported on a greater spread of rutting values, or one that measured significantly more potholes would have improved the likelihood of a better correlation.

When the evaluation team was subjectively comparing the sections for rutting and potholing, they found very little differences between the sections, and this resulted in average scores that stayed very close to the score of five that was always assigned to the baseline section. That all the scores from the subjective method are close together hampered the use of linear regression for statistical analysis, especially when the sample consisted of only six data points. This is likely the primary reason for the low correlation between monitoring methods for the parameters of rutting and potholing. Other factors also influenced the data. One of the sections had an extremely reduced sampling area because a road section repaired after weather related damage did not contain stabilizer product and therefore were excluded from monitoring. Another factor was that for the parameter of potholing, the planned judging criteria for an anticipated numerous count of potholes did not fit the circumstances encountered of only three potholes in the entire study.

In summary, it appears that the two subjective and objective monitoring systems compare reasonably well. Each has it own strengths and weakness, and future monitoring efforts would benefit by clearly defining the desired goals of the monitoring effort before choosing a monitoring methodology. If time and resources are limited, then the subjective method still could be used to distinguish levels of performance. However, for more justifiable and defensible results, the objective method, even though more time consuming and data intensive, would be the better choice.

CHAPTER 8 – CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Earlier, this report stated that there were 987,518 km (613,365 mi) of road that serve Federal and Indian Lands, and that 83.6% of these miles are unpaved. The owners of these unpaved roads face a big challenge trying to keep them open and safe. Because funding to maintain these roads is often scarce, methods and products that allow the local agency to use native surfacing materials can prove to be very cost effective. Therefore, identifying methods to effectively control dust and prevent raveling, rutting, wash boarding, and potholing on varied native road surfacing materials should continue to be a goal of the FHWA Federal Lands Highway Division. Several conclusions can be drawn from this study.

Product Effectiveness

Under this 24-month study, six products were evaluated for road stabilization and dust control using both subjective and objective criteria. The ranking based on averaged normalized values of overall product performance for this non-plastic, crushed aggregate shown by higher score first was:

Lignosulphonate	(74)
Mag/Lig	(70)
Caliber	(68)
Permazyme	(64)
Terrazyme	(62)
Soil Sement	(56)

This Seedskadee NWR study was a follow-up to a previous 24-month study where these same products were used on a non-plastic granular base material at the Buenos Aires NWR. This previous study’s product performance ranking shown again by higher score first was:

Caliber	(83)
Mag/Lig	(77)
Lignosulphonate	(70)
Terrazyme	(66)
Soil Sement	(65)
Permazyme	(64)

Note that the averaged normalized scores for both studies allow for comparison directly within each project, but are only relatively comparable between projects. A clear conclusion is that the three highest ranked products are the same for both projects, although their order varies. Unfortunately, neither project employed an untreated control section to provide an absolute performance reference.

Subjective and Objective Monitoring Methods

The subjective monitoring method, first used at Buenos Aires and continued at Seedskadee, compared the performance of the products to each other based on visual observations of dusting, wash boarding, raveling, rutting, and potholing. The methodology is quick and easy, and it captures subtle difference in performance. It is accomplished by simply driving the project multiple times and observing and comparing performance. This method however does not track performance over time.

The objective measurements method, only used on the Seedskadee project, involves choosing, without bias, specific sites within each product section and making multiple depth measurements for raveling, wash boarding, rutting, and potholing. Using objective criteria, the measurements are transformed into ratings. The strengths of this method are that it provides abundant data and it can track performance over time. Its weaknesses are that it is time-consuming and physically challenging, and its ultimate accuracy is highly dependent on the specific sites that get measured. This newly developed objective system needs to have some adjustments made to the objective criteria so that the ratings more closely reflect a driver’s experience.

The two methodologies produced almost the same ordering of the products as to how well they performed. A correlation between the two methods was done, and reasonably good correlation was evident for dusting, wash boarding, and raveling. For rutting and potholing, correlation was poor but readily explainable. With a little more work on the objective method, correlation could improve and the subjective and objective methods could be reasonably interchangeable. The use of one system or the other should be based on the project’s objectives.

No One Best Product For All Applications

The product that will perform the best at any given site depends on a number of factors including the climate and traffic conditions at that site, the characteristics of the proposed surfacing material, and the method of product application. Road owners must do their due diligence to discover the most suitable and cost effective product for their area. New products continue to appear, and the industry continues to become more sophisticated in developing site specific products.

Silt Load Test and Dust Ratings

In this study, Silt Load Test results were plotted together with dust ratings through time. For five of the six products, the trends moved similarly. This was an expected result, however a sufficient amount of Silt Load Test data is critical because these discreet samples are averaged and compared to a non-discreet overall judgment on dust. The value of this comparison of Silt Load Test results and dust ratings is that the two ratings appeared to validate each other. Whether or not to use both tests in the future depends, again, on a project’s objectives.

Low Plasticity - A Key Signal

The materials used at both the Buenos Aires and Seedskadee projects were non-plastic materials. Those products that could bind together silty materials – Caliber, Lignosulfonate, and Mag/Lig – appeared to work better, whereas those products that tend to lower the plasticity index (PI) – the enzyme products and perhaps Soil Sement as well – worked less well. The lack of sufficient clay fines to glue the material together was especially noticeable on the Seedskadee project, and the material was improved the most by incorporating Lignosulfonate that actually increased the plasticity index. One result of studies at Buenos Aires and Seedskadee is that the CFLHD has increased its PI requirement in crushed aggregate base materials.

Full-Depth Stabilization

Surface applications of dust abatement and stabilization products can be done quickly, but their cost effectiveness could be scrutinized since they typically have shorter performance duration. After a short time the effect breaks down and they typically need re-application. In full depth stabilization, however, though the surface layer breaks down with use, underlying it is a fully stabilized roadway that resists further dusting, raveling, rutting, wash boarding, and potholing. This is the result seen at both the Buenos Aires and Seedskadee projects where no maintenance activities were performed on the roads for the two years during which they were monitored. Full depth stabilization may be the most significant contributor toward minimizing wash boarding and preventing rutting and potholing even though it did not prevent raveling and dusting.

Previous Study's Recommendations Still Valid

The recommendations made in the 2005 report *Road Stabilizer Product Performance - Buenos Aires National Wildlife Refuge* are still valid and are summarized in the next section.

RECOMMENDATIONS

Control Sections

Require a control section where no product is applied on any further product comparison studies so that the benefits of using rather than not using stabilizer products can be evaluated.

Increased Plasticity Index

Increase the specified plasticity index of crushed aggregate so that, despite the variability of test results, it is between 8% and 12%. As of this writing, CFLHD has already made this change.

Full depth Stabilization

Full depth Stabilization of native road materials can be cost effective and should be considered for use whenever conventional dust control methods are considered.

Buenos Aires Study's Recommendations

Recommendations from the Buenos Aires study are still valid. Because 83.6% of roads serving Federal and Indian Lands are unpaved, and there is a need to optimize use of maintenance funding, efforts to achieve the Buenos Aires recommendations should be strengthened. They are summarized here:

New Specifications are Needed that allow use of newer dust abatement and stabilization products. Products that are non-proprietary, such as magnesium chloride or lignosulphonate already have generic specifications. However, it is much more difficult to write generic specifications for the proprietary, brand-name products. The challenge that still needs to be addressed is how to produce generic specifications for product categories such as were defined by the USFS and used in these two studies. Proprietary, brand-name prodjucts can fit into these categories. Another method would be to define acceptable levels of product performance, regardless of product category.

Define an Optimum Stabilization Depth, or minimum depth that will allow for a cost effective treatment using available funds.

An Objective Method for tracking product performance over time that was needed was developed under this Seedskadee project, but it still can be improved and refined.

Track Cost Information for future comparisons, however, developing a precise economic comparison of various products is probably not feasible.

Develop a Product Class Selection Chart that starts with material composition and classification, considers climate, traffic, and environmental considerations, and finally leads to recommended prioritization of the product classes. A preliminary process that addresses this is proposed in the Appendix G.

Protect the Environment on future projects, by cooperating with not only the F&WS, but the other FLMAs as well to determine the environmental effects of using various stabilizer products.

Training for designers and construction inspection personnel on the application and use of these products can and should continue to be done.

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APPENDIX A – MONITORING AND MILEPOSTS PLAN

Table 14. Monitoring order and mileposts plan for field measurements.

					May-05		Aug-05		May-06		Aug-06	
Test Sec-tion	**Product Name**	**Road Width**	**Road Length (ft)**	**Road Length (mi)**	**Moni-toring Order**	**MPs for Sampling and Obj Measures**	**Moni-toring Order**	**MPs for Sampling and Obj Measures**	**Moni-toring Order**	**MPs for Sampling and Obj Measures**	**Moni-toring Order**	**MPs for Sampling and Obj Measures**
I	Terra Zyme	18	2882	0.546	I	.1,.2,.3,.4	III	.15,.25,.38,.48	VI	.05,.18,.33,.52	IV	.22,.35,.45,.5
II	Ligno sulfonate	18	2882	0.546	II	.1,.2,.3,.4	II	.15,.25,.38,.48	V	.05,.18,.33,.52	III	.22,.35,.45,.5
III	Perma-Zyme 11x	17.4	2882	0.546	III	.1,.2,.3,.4	I	.15,.25,.38,.48	IV	.05,.18,.33,.52	II	.22,.35,.45,.5
IV	Soil Sement	12	2882	0.546	IV	.1,.2,.3,.4	IV	.15,.25,.38,.48	III	.05,.18,.33,.52	I	.22,.35,.45,.5
V	DCA - 2000 Caliber	12	2882	0.546	V	.1,.2,.3,.4	V	.15,.25,.38,.48	II	.05,.18,.33,.52	VI	.22,.35,.45,.5
VI	DMC 820 Mag/Lig	18	3385	0.641	VI	.1,.2,.3,.4	VI	.15,.35,.5,.6	I	.05,.25,.45,.55	V	.18,.28,.48,.62

Notes:

Section V was damaged during Spring thaw in 2005, before May monitoring, and repaired before the August 2005 monitoring So as not to compromise the study, damaged sections were avoided.

MP 0.20 to 0.34	Damaged and repaired in July '05 with new material
MP 0.34 to 0.46	Damaged but regraded in July '05 using old treated material
MP 0.46 to 0.52	Damaged and repaired in July '05 with new material

All changes to planned MPs (above) are noted on the Objective Measurements and Locations Data Sheet.

APPENDIX B – OBJECTIVE RATING SYSTEM

BACKGROUND

The parameters evaluated in the Objective Rating System are the same as for the Comparative Visual System - dust, wash boarding, raveling, rutting and potholing that was developed for the Buenos Aires NWR project and used again in the Seedskadee NWR project. The 11-point system following was developed to mirror the Comparative Visual Rating System and its sensitivity to subtle differences in performance yet refer to objective criteria so that changes over time could be tracked.

Dust, wash boarding, raveling, rutting and potholing will be objectively evaluated at the Seedskadee National Wildlife Refuge based on the parameters identified and defined below. These parameters are loosely referenced from the December 2000 contract report entitled Pavement Management Systems: Standard Visual Assessment Manual for Unsealed Roads prepared by CSIR Transportek, Pretoria, South Africa. The parameters have been altered to fit within the conditions of the Seedskadee Stabilization Monitoring Study.

DUST

Assessment: The team will evaluate dust with driving safety being the major factor taken into account. Team members will follow behind a vehicle traveling at 25 mph to perform the analysis. They will rate visibility of the vehicle generating the dust based on the description parameters listed below. Four of the descriptions have 2 numbers associated with them. If, for example, several sections have “some loss of visibility,” sections given a 5 would be comparably a little worse than those given a 6.

Rating	Description
0	Vehicle generating dust cannot be seen - Must stop for dust to clear
1	Dangerous loss of visibility - Significant uneasiness at driving 25 mph
2	Dangerous loss of visibility - Significant uneasiness at driving 25 mph
3	Significant loss of visibility – Some uneasiness at driving 25 mph
4	Significant loss of visibility – Some uneasiness at driving 25 mph
5	Some loss of visibility – Little to no uneasiness at driving 25 mph
6	Some loss of visibility – Little to no uneasiness at driving 25 mph
7	Very little loss of visibility – No uneasiness at driving 25 mph
8	Very little loss of visibility – No uneasiness at driving 25 mph
9	A little low rising dust but no loss of visibility
10	No Dust

WASH BOARDING

Assessment: Wash boarding corrugations can be either “loose” or “fixed”. Loose corrugations consist of parallel alternating crests of loose, fine-sandy material and troughs of compacted material at right angles to the direction of travel. Fixed corrugations on the other hand consist of compacted crests and troughs of hard, fine sandy-gravel material. Wash boarding will be evaluated by measuring the number and depth of parallel troughs within a 25-foot length of roadway. Six trough measurements (divided equally between the 2 or 3 wheel paths) will be recorded and averaged. For Seedskadee Refuge monitoring, a measurement will occur at four locations within the approximate ½ mile test sections. These milepost locations will be determined prior to the monitoring event using random number selection. The four measurements will be averaged to assess their rating based on the description criteria listed below.

Rating	Description
0	Wash boarding troughs are > 60 mm deep
1	Wash boarding troughs are between 50 mm and 60 mm deep
2	Wash boarding troughs are between 40 mm and 50 mm deep
3	Wash boarding troughs are between 30 mm and 40 mm deep
4	Wash boarding troughs are between 25 mm and 30 mm deep
5	Wash boarding troughs are between 20 mm and 25 mm deep
6	Wash boarding troughs are between 15 mm and 20 mm deep
7	Wash boarding troughs are between 10 mm and 15 mm deep
8	Wash boarding troughs are between 5 mm and 10 mm deep
9	Wash boarding troughs are barely visible (< 5 mm deep)
10	Wash boarding is not visible

RAVELING

Assessment: Raveling will be evaluated by measuring the thickness of loose material. This is achieved by scraping a path through the material to the hard surface and measuring the thickness of the adjacent loose material with a straightedge and ruler. At each location, measure the maximum depths of material at the two outside wheel paths and at the center of the wheel paths, and average the numbers. Or where there are 3 wheel paths, measure the material depth only between the wheel paths. Do not measure uncompacted areas such as shoulders and ditches. For Seedskadee Refuge monitoring, a measurement will occur at four locations within the approximate ½ mile test sections. These milepost locations will be determined prior to the monitoring event using random number selection. The four measurements will be averaged to assess their rating based on the description criteria listed below.

Rating	Description
0	Loose material > 60 mm thick
1	Loose material between 50 mm and 60 mm thick
2	Loose material between 40 mm and 50 mm thick
3	Loose material between 30 mm and 40 mm thick
4	Loose material between 25 mm and 30 mm thick
5	Loose material between 20 mm and 25 mm thick
6	Loose material between 15 mm and 20 mm thick
7	Loose material between 10 mm and 15 mm thick
8	Loose material between 5 mm and 10 mm thick
9	Loose material is barely visible (< 5 mm thick)
10	Loose material is not visible

RUTTING

Assessment: Rutting will be evaluated by measuring the rut depth with a straightedge and ruler. For Seedskadee Refuge monitoring, a measurement will occur at four locations within the approximate ½ mile test sections. These milepost locations will be determined prior to the monitoring event using random number selection. The four location measurements will be averaged to assess their rating based on the description criteria listed below. At each location, a measurement will be made in at least the right and left wheel paths and averaged. Due to their high variability, the average of a number of readings may be necessary at each location in different directions and wheel paths.

Rating	Description
0	Rutting is > 60 mm thick
1	Rutting is between 50 mm and 60 mm thick
2	Rutting is between 40 mm and 50 mm thick
3	Rutting is between 30 mm and 40 mm thick
4	Rutting is between 25 mm and 30 mm thick
5	Rutting is between 20 mm and 25 mm thick
6	Rutting is between 15 mm and 20 mm thick
7	Rutting is between 10 mm and 15 mm thick
8	Rutting is between 5 mm and 10 mm thick
9	Rutting is barely measurable (< 5 mm thick)
10	Rutting is not measurable

POTHOLING

Assessment: Potholes will be evaluated by measuring the pothole depth with a straightedge and ruler. The number of potholes within a 25-foot length of roadway and their average depth will be recorded at each monitoring location. For Seedskadee Refuge monitoring, a measurement will occur at four locations within the approximate ½ mile test sections. These milepost locations will be determined prior to the monitoring event using random number selection. The four measurements will be averaged to assess their rating based on the description criteria listed below. If only a few potholes occur over the entire project, their locations will be noted and they will be measured during each monitoring event. They will be discussed separately in the final project report.

Rating	Description
0	Road is not passable for most passenger cars
1	Many potholes are evident > 100 mm deep
2	Many potholes are evident ranging from 80 to 100 mm deep
3	Many potholes are evident ranging from 65 to 80 mm deep
4	Some potholes are evident ranging from 50 to 65 mm deep
5	Some potholes are evident ranging from 35 to 50 mm deep
6	Some potholes are evident ranging from 20 to 35 mm deep
7	A few potholes are evident ranging from 10 to 20 mm deep
8	A few potholes are evident ranging from 5 to 10 mm deep
9	A few potholes are evident < 5 mm deep
10	Potholes are not evident

APPENDIX C – OBJECTIVE MEASUREMENTS AND LOCATIONS DATA

Table 15. Objective measurements and locations data for the 8-month monitoring event (May 2005).

Location - DCP - Silt						Washboarding Depths (mm)								Raveling Depths (mm)					Rutting Depths (mm)				Pothole Depths (mm)			
Section	MP	DCP Test Location	# Blows to 5" (127mm)	Silt Test 5/18/05 Sampling Time	Comment	1	2	3	4	5	6	Avg. Depth	Section Avg.	Rt	CL	Lt	Avg. Depth	Section Avg.	Rt. WP Avg.	Lt. WP Avg.	Avg. Depth	Section Avg.	# of Potholes	Avg. Depth	Section Avg.	Special Potholes & Other Comments
I - Terra-Zyme	0.10	LWP	15	4:30 PM	Curve to Lt.	0	0	0	0	0	0	0		40	23	22	28		0	0	0		0	0		
	0.20					0	0	0	0	0	0	0		14	10	13	12		0	0	0		0	0		
	0.30	CL	15	4:35 PM	Curve to Rt.	0	0	0	0	0	0	0		8	14	28	17		0	0	0		0	0		
	0.40				Curve to Lt.	0	0	0	0	0	0	0	0	30	16	5	17	19	0	0	0	0	0	0	0	
II - Ligno-sulfonate	0.10	RWP	21	4:50 PM		0	0	0	0	0	0	0		5	5	14	8		0	0	0		0	0		
	0.20					0	0	0	0	0	0	0		6	5	8	6.3		0	0	0		0	0		
	0.30	RWP	19	5:00 PM		0	0	0	0	0	0	0		16	6	12	11		0	0	0		0	0		
	0.40					0	0	0	0	0	0	0	0	10	4	15	9.7	8.8	0	0	0	0	0	0	0	
III - Perma-Zyme	0.10	LWP	15	5:08 PM		0	0	0	0	0	0	0		17	22	14	18		0	0	0		0	0		MP 0.43 pothole, 445 mm diameter, 50 mm to loose, 70 mm to hard surface.
	0.20					0	0	0	0	0	0	0		12	20	10	14		10	8	9		0	0		
	0.30	LWP	15	5:18 PM		0	0	0	0	0	0	0		17	12	14	14		10	12	11		0	0		
	0.40				Steep hill	0	0	0	0	0	0	0	0	18	6	16	13	15	37	22	30	12	0	0	0	
IV - Soil Sement	0.10	LWP	17	5:32 PM	Curve to Lt.	0	0	0	0	0	0	0		16	27	11	18		0	0	0		0	0		
	0.20					0	0	0	0	0	0	0		10	21	12	14		0	0	0		0	0		
	0.30	RWP	16	5:42 PM		0	0	0	0	0	0	0		15	23	10	16		0	0	0		0	0		
	0.40				Curve to Rt.	0	0	0	0	0	0	0	0	21	14	22	19	17	0	0	0	0	0	0	0	
V - Caliber	0.10	LWP	14	5:50 PM		0	0	0	0	0	0	0		14	24	16	18		0	0	0		0	0		
	0.20					0	0	0	0	0	0	0		11	17	25	18		0	0	0		0	0		
	0.32	LWP	17	5:59 PM	Moved monitoring to avoid damage.	0	0	0	0	0	0	0		17	23	15	18		0	0	0		0	0		
	0.41				Moved for damage. Area had no fines.	0	0	0	0	0	0	0	0	17	18	16	17	18	0	0	0	0	0	0	0	
VI - Mag/Lig	0.10	LWP	22	6:25 PM		0	0	0	0	0	0	0		15	13	14	14		0	0	0		0	0		
	0.20					0	0	0	0	0	0	0		16	8	6	10		0	0	0		0	0		
	0.30	RWP	14	6:35 PM	3 wheel paths	0	0	0	0	0	0	0		12		10	11		0	0	0		0	0		
	0.40					0	0	0	0	0	0	0	0	17	12	14	14	12	0	0	0	0	0	0	0	

Table 16. Objective measurements and locations data for the 11-month monitoring event (August 2005).

Location - DCP - Silt						Washboarding Depths (mm)								Raveling Depths (mm)					Rutting Depths (mm)				Pothole Depths (mm)			
Section	MP	DCP Test Location	# Blows to 5" (127mm)	Silt Test 5/18/05 Sampling Time	Comment	1	2	3	4	5	6	Avg. Depth	Section Avg.	Rt	CL	Lt	Avg. Depth	Section Avg.	Rt. WP Avg.	Lt. WP Avg.	Avg. Depth	Section Avg.	# of Potholes	Avg. Depth	Section Avg.	Special Potholes & Other Comments
I - Terra-Zyme	0.15	RWP	28	10:20 AM	Straight	8	10	8	5	8	0	6.5		10	6	11	9		0	0	0		0	0		Pothole in MP 0.48 measurement area, 270 mm diameter, 48 mm to loose, 68 mm to hard surface.
	0.25	LWP	30	10:45 AM	Straight	8	7	9	8	11	7	8.3		12	5	11	9.3		0	0	0		0	0		
	0.38	RWP	25	11:00 AM	Slight curve to Lt.	6	5	5	5	5	4	5		13	10	5	9.3		3	4	3.5		0	0		
	0.48	LWP	21	11:10 AM	Curve to Lt.	8	4	5	4	3	2	4.3	6	19	8	7	11	9.8	8	7	7.5	2.8	1	68	17	
II - Ligno-sulfonate	0.15	RWP	62	11:20 AM	Straight	0	0	0	0	0	0	0		6	6	7	6.3		3.5	0	1.8		0	0		
	0.25	LWP	41	11:30 AM	Straight just before curve Lt.	6	3	3	0	0	0	2		6	3	2	3.7		4.5	0	2.3		0	0		
	0.38	LWP	45	11:40 AM	Straight	0	0	0	0	0	0	0		11	9	7	9		0	4	2		0	0		
	0.48	RWP	46	11:50 AM	Straight	0	0	0	0	0	0	0	0.5	8	8	6	7.3	6.6	0	1.5	0.8	1.7	0	0	0	
III - Perma-Zyme	0.15	LWP	26	12:05 PM	Straight	10	12	11	17	15	15	13		13	13	19	15		6	5.5	5.8		0	0		MP 0.43 pothole, 420 mm diameter, 27 mm to loose, 47 mm to hard surface.
	0.25	RWP	25	12:15 PM	Straight	5	0	0	7	7	7	4.3		8	12	20	13		15	15	15		0	0		
	0.38	LWP	25	12:25 PM	Straight and on upper part of hill	0	0	0	0	0	0	0		10	16	14	13		13	9	11		0	0		
	0.48	RWP	32	12:35 PM	Straight just before boat ramp area	0	0	0	0	0	0	0	4.4	5	14	9	9.3	13	0	2.5	1.3	8.2	0	0	0	
IV - Soil Sement	0.15	LWP	29	1:10 PM	Straight	20	18	19	12	11	8	15		17	13	18	16		13	8	11		0	0		
	0.25	RWP	25	1:25 PM	Straight	0	0	0	0	0	0	0		9	10	13	11		6.5	6.5	6.5		0	0		
	0.38	LWP	26	1:40 PM	Straight	18	17	16	10	8	9	13		22	14	16	17		11	0	5.5		0	0		
	0.48	RWP	24	1:55 PM	Straight	0	0	0	0	0	0	0	6.9	22	13	15	17	15	0	0	0	5.6	0	0	0	
V - Caliber	0.15	LWP	33	2:05 PM	Straight	0	0	0	0	0	0	0		19	17	9	15		0	0	0		0	0		
	0.19	RWP	24	2:15 PM	Straight	0	0	0	0	0	0	0		3	18	9	10		12	9	11		0	0		
	0.38	RWP	33	2:20 PM	Straight. Regraded 1 month ago.	0	0	0	0	0	0	0		3	7	10	6.7		0	0	0		0	0		
	0.53	LWP	45	2:35 PM	On hill	0	0	0	0	0	0	0	0	3	11	2	5.3	9.3	13	10	12	5.5	0	0	0	
VI - Mag/Lig	0.15	LWP	29	3:15 PM	Straight	0	0	0	0	0	0	0		3	5	8	5.3		0	4	2		0	0		
	0.35	RWP	21	3:25 PM	Slight curve to Lt.	0	0	0	0	0	0	0		9	14	8	10		7.5	0	3.8		0	0		
	0.50	RWP	27	3:35 PM	Straight	0	0	0	0	0	0	0		7	10	8	8.3		4	0	2		0	0		
	0.60	LWP	31	3:45 PM	Straight	0	0	0	0	0	0	0	0	7	8	7	7.3	7.8	0	0	0	1.9	0	0	0	

Table 17. Objective measurements and locations data for the 20-month monitoring event (May 2006).

Location - DCP - Silt						Washboarding Depths (mm)								Raveling Depths (mm)					Rutting Depths (mm)				Pothole Depths (mm)			
Section	MP	DCP Test Location	# Blows to 5" (127mm)	Silt Test 5/18/05 Sampling Time	Comment	1	2	3	4	5	6	Avg. Depth	Section Avg.	Rt	CL	Lt	Avg. Depth	Section Avg.	Rt. WP Avg.	Lt. WP Avg.	Avg. Depth	Section Avg.	# of Potholes	Avg. Depth	Section Avg.	Special Potholes & Other Comments
I - Terra-Zyme	0.05	RWP	31	11:55 AM	Straight & adjacent to Kiosk	8	5	11	4	5	5	6.3		11	13	22	15		8	6	7		0	0		New pothole MP 0.47, 275mm diameter, 35mm to loose, 45mm to hard surface.
	0.18	LWP	33	11:10 AM	Straight	7	7	0	3	0	0	2.8		18	12	11	14		10	13	12		0	0		
	0.33	RWP	34	11:20 AM	End of curve Rt. & Turnout Lt.	8	5	2	0	0	0	2.5		20	16	28	21		10	8	9		0	0		MP 0.48 pothole, 435 mm diameter, 40 mm to loose, over 127 mm depth.
	0.52	LWP	27	11:30 AM	Gentle curve Rt.	3	4	5	5	4	3	4	3.9	13	10	23	15	16	12	16	14	10	0	0	0	
II - Ligno-sulfonate	0.05	RWP	37	11:40 AM	Slight curve Lt.	0	0	0	0	0	0	0		16	8	12	12		7	11	9		0	0		
	0.18	LWP	37	11:55 AM	Straight	0	0	0	0	0	0	0		12	8	16	12		9	4	6.5		0	0		
	0.33	RWP	31	1:05 PM	Straight	0	6	0	5	0	0	1.8		13	7	17	12		6	0	3		0	0		
	0.52	LWP	27	1:20 PM	Straight	0	0	0	0	0	0	0	0.5	13	12	13	13	12	0	3	1.5	5	0	0	0	
III - Perma-Zyme	0.05	RWP	28	1:55 PM	Straight	0	0	9	0	0	0	1.5		22	7	13	14		5	4	4.5		0	0		MP 0.43 pothole, 420 mm diameter, 39 mm to loose, 55 mm to hard surface.
	0.18	LWP	25	2:05 PM	Straight	12	12	13	10	12	12	12		22	11	26	20		9	7	8		0	0		
	0.33	RWP	35	2:15 PM	Straight	0	3	0	3	0	0	1		30	15	12	19		8	8	8		0	0		
	0.52	LWP	25	2:25 PM	Very wide Lt. to boat launch.	0	0	0	0	0	0	0	3.6	8	14	13	12	16	9	6	7.5	7	0	0	0	
IV - Soil Sement	0.05	RWP	17	2:40 PM	Straight	13	12	13	12	9	11	12		38	22	21	27		11	11	11		0	0		
	0.18	LWP	38	2:55 PM	Straight	11	9	15	14	10	8	11		18	14	27	20		0	0	0		0	0		
	0.33	RWP	21	3:05 PM	Straight	7	10	11	8	6	8	8.3		30	21	18	23		13	15	14		0	0		
	0.52	LWP	21	3:15 PM	Straight	12	9	12	10	10	10	11	10	25	26	19	23	23	11	10	11	8.9	0	0	0	
V - DCA 2000 Caliber	0.05	RWP	22	3:25 PM	Gentle Hill.	0	0	0	3	5	3	1.8		19	30	23	24		16	20	18		0	0		
	0.18	LWP	41	3:35 PM	Straight	0	8	5	0	0	0	2.2		17	20	17	18		10	7	8.5		0	0		
	0.35	RWP	24	3:45 PM	Straight. Regraded section.	0	0	0	0	0	0	0		20	15	20	18		7	8	7.5		0	0		
	0.54	LWP	46	4:00 PM	Very wide. Turnout on Lt.	0	0	0	0	0	0	0	1	10	10	12	11	18	7	7	7	10	0	0	0	
VI - DMC 820 (Lig/Mag)	0.05	LWP	24	10:20 AM	Straight	0	0	0	0	0	0	0		4	16	16	12		0	0	0		0	0		
	0.25	RWP	28	10:45 AM	Slight curve to Rt.	7	7	10	5	0	0	4.8		10	11	19	13		7	12	9.5		0	0		
	0.45	LWP	22	11:05 AM	Straight	8	7	10	7	4	5	6.8		10	17	16	14		10	2	6		0	0		
	0.55	RWP	25	11:20 AM	Straight	0	4	6	6	4	0	3.3	3.8	11	28	20	20	15	8	6	7	5.6	0	0	0	

Table 18. Objective measurements and locations data for the 23-month monitoring event (August 2006).

Location - DCP - Silt						Washboarding Depths (mm)								Raveling Depths (mm)					Rutting Depths (mm)				Pothole Depths (mm)			
Section	MP	DCP Test Location	# Blows to 5" (127mm)	Silt Test 5/18/05 Sampling Time	Comment	1	2	3	4	5	6	Avg. Depth	Section Avg.	Rt.	CL	Lt.	Avg. Depth	Section Avg.	Rt. WP Avg.	Lt. WP Avg.	Avg. Depth	Section Avg.	# of Potholes	Avg. Depth	Section Avg.	Special Potholes & Other Comments
I - Terra-Zyme	0.22	LWP	16	9:50 AM	Curve to Rt.	22	0	9	4	15	0	8.3		0	18	60	26		7	13	10		0	0		MP 0.47 pothole left, 280 mm diameter, 30 mm to loose, 50 mm to hard.
	0.35	RWP	14	10:00 AM	Straight just after curve Rt.	0	10	7	0	5	0	3.7		10	9	35	18		2	2	2		0	0		
	0.45	RWP	14	10:10 AM	Straight	7	9	7	0	0	0	3.8		28	19	10	19		7	7	7		0	0		MP 0.48 pothole left, 310 mm diameter, 20 mm to loose, 25 mm to hard.
	0.50	LWP	17	10:25 AM	Straight	17	17	16	10	15	15	15	7.7	8	19	29	19	20	10	15	13	7.9	0	0	0	
II - Ligno-sulfonate	0.22	RWP	22	10:35 AM	Straight	0	7	0	3	4	0	2.3		28	8	10	15		0	0	0		0	0		
	0.35	LWP	39	10:45 AM	Straight	0	0	14	10	10	0	5.7		15	10	11	12		0	0	0		0	0		
	0.45	RWP	23	10:50 AM	Slight curve Rt.	10	0	0	13	17	15	9.2		7	10	17	11		0	3	1.5		0	0		
	0.50	LWP	24	11:00 AM	Straight	0	0	0	10	0	0	1.7	4.7	11	10	15	12	13	7	0	3.5	1.3	0	0	0	
III - Perma-Zyme	0.22	RWP	22	11:10 AM	Straight	0	0	0	13	10	0	3.8		12	9	8	9.7		0	0	0		0	0		MP 0.43 pothole, 550 mm diameter, 30 mm to loose, 44 mm to hard surface.
	0.35	LWP	16	11:20 AM	Straight & on hill.	0	0	0	7	0	0	1.2		10	16	14	13		0	0	0		0	0		
	0.45	RWP	13	11:30 AM	Straight	15	15	12	9	7	7	11		18	12	18	16		0	0	0		0	0		
	0.50	LWP	13	11:40 AM	Very wide Lt to boat launch.	0	10	0	0	0	0	1.7	4.4	15	10	10	12	13	0	0	0	0	0	0	0	
IV - Soil Sement	0.22	RWP	17	12:40 PM	Straight	11	10	11	16	14	11	12		8	13	15	12		0	8	4		0	0		
	0.35	LWP	20	12:55 PM	Slight curve Rt. Shallow turnout Lt.	21	23	15	24	25	26	22		16	20	21	19		7	7	7		0	0		
	0.45	RWP	15	1:05 PM	Straight & deep Turnout Lt.	19	15	14	12	10	6	13		20	20	19	20		5	14	9.5		0	0		
	0.50	LWP	16	1:15 PM	Straight	17	17	19	27	25	24	22	17	10	15	17	14	16	15	13	14	8.6	0	0	0	
V - Caliber	0.02	RWP	17	1:30 PM	Straight & on hill.	0	0	0	0	0	0	0		10	15	15	13		12	11	12		0	0		
	0.08	LWP	19	3:50 PM	Straight & 100' beyond top of hill.	0	10	0	8	0	0	3		14	15	16	15		15	16	16		0	0		
	0.43	RWP	16	4:00 PM	Straight. Surface very hard.	0	0	0	0	0	0	0		0	9	10	6.3		0	10	5		0	0		
	0.53	LWP	21	4:10 PM	Straight & on hill, 2' cut on Lt.	0	0	0	0	0	0	0	0.8	20	30	0	17	13	30	19	25	14	0	0	0	
VI - Mag/Lig	0.18	RWP	15	2:40 PM	Straight	0	0	0	15	14	12	6.8		12	10	10	11		18	2	10		0	0		
	0.28	LWP	11	2:50 PM	Straight but 100' past curve Rt.	10	12	10	0	0	0	5.3		2	10	12	8		0	13	6.5		0	0		
	0.48	RWP	12	3:00 PM	Straight	10	9	8	6	7	6	7.7		10	11	16	12		8	10	9		0	0		
	0.62	LWP	15	3:10 PM	Straight	10	11	10	8	0	9	8	7	13	13	12	13	11	11	7	9	8.6	0	0	0	

APPENDIX D – 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 E – SILT LOADING CALCULATIONS

Table 19. Silt loading calculations for the 8-month monitoring event.
Wyoming RRP SEED 12(1)
Seedskdee National Wildlife Refuge Stabilization Project
Samples taken May 18, 2005

Section	1		2		3	
Product	Terrazyme		Lignosulfonate		Permazyme	
Milepost	0.1	0.3	0.1	0.3	0.1	0.3
Moisture (%)	**0.3**	**0.4**	**0.2**	**0.1**	**0.2**	**0.2**
Sample mass, (g)	4266.2	1765.2	1084.0	1010.6	1574.8	1561.0
Percent passing the No. 200 sieve	1.9%	0.9%	0.6%	0.2%	0.8%	0.6%
Mass passing the No. 200 sieve, (g)	81.1	15.9	6.5	2.0	12.6	9.4
Area (in^2)	1152	1152	1152	1152	1152	1152
Silt loading (g/in^2)	0.070	0.014	0.006	0.002	0.011	0.008
Silt loading (oz/ft^2)	**0.36**	**0.07**	**0.03**	**0.01**	**0.06**	**0.04**
(oz/ft2)	**Average = 0.21**		**Average = 0.02**		**Average = 0.05**	
RANK	**4**		**1**		**2**	

Section	4		5		6	
Product	Soil Sement		DCA 2000		DMC 820 (Lig/Mag)	
Milepost	0.1	0.3	0.1	0.3	0.1	0.3
Moisture (%)	**0.3**	**0.3**	**0.3**	**0.4**	**0.3**	**0.2**
Sample mass, (g)	4490.2	4098.2	4048.5	3324.8	2125.9	1509.3
Percent passing the No. 200 sieve	3.4%	3.8%	2.0%	3.4%	1.5%	0.6%
Mass passing the No. 200 sieve, (g)	152.7	155.7	81.0	113.0	31.9	9.1
Area (in^2)	1152	1152	1152	1152	1152	1152
Silt loading (g/in^2)	0.133	0.135	0.070	0.098	0.028	0.008
Silt loading (oz/ft^2)	**0.67**	**0.69**	**0.36**	**0.50**	**0.14**	**0.04**
(oz/ft2)	**Average = 0.68**		**Average = 0.43**		**Average = 0.09**	
RANK	**6**		**5**		**3**	

Conversion: 1 g/in^2 = 5.0794 oz/ft^2

Table 20. Silt loading calculations for the 11-month monitoring event.

Wyoming RRP SEED 12(1)
Seedskdee National Wildlife Refuge Stabilization Project
Samples taken August 30, 2005

Section	1				2			
Product	Terrazyme				Lignosulfonate			
Milepost	0.15	0.25	0.35	0.48	0.15	0.25	0.38	0.48
Moisture (%)	**0.2**	**0.2**	**0.2**	**0.2**	**0.1**	**0.3**	**0.2**	**0.2**
Sample mass, (g)	5531.6	3927.9	2385.9	1958.7	1816.5	1457.8	3108.6	3466.8
Percent passing the No. 200 sieve	3.5%	2.8%	3.3%	5.7%	1.8%	3.0%	3.2%	3.3%
Mass passing the No. 200 sieve, (g)	193.6	110.0	78.7	111.6	32.7	43.7	99.5	114.4
Area (in^2)	864	864	864	864	864	864	864	864
Silt loading (g/in^2)	0.224	0.127	0.091	0.129	0.038	0.051	0.115	0.132
Silt loading (oz/ft^2)	**1.14**	**0.65**	**0.46**	**0.66**	**0.19**	**0.26**	**0.58**	**0.67**
Silt loading (oz/ft2)	**Average =0.73**				**Average = 0.43**			
RANK	**4**				**2**			

Section	3				4			
Product	Permazyme				Soil Sement			
Milepost	0.15	0.25	0.38	0.48	0.15	0.25	0.38	0.48
Moisture (%)	**0.2**	**0.2**	**0.2**	**0.2**	**0.4**	**0.3**	**0.2**	**0.2**
Sample mass, (g)	4818.5	2246.1	2775.1	3900.0	6760.1	3322.9	7022.4	4469.1
Percent passing the No. 200 sieve	3.6%	3.6%	3.2%	4.0%	6.3%	6.4%	6.3%	6.6%
Mass passing the No. 200 sieve, (g)	173.5	80.9	88.8	156.0	425.9	212.7	442.4	295.0
Area (in^2)	864	864	864	864	864	864	864	864
Silt loading (g/in^2)	0.201	0.094	0.103	0.181	0.493	0.246	0.512	0.341
Silt loading (oz/ft^2)	**1.02**	**0.48**	**0.52**	**0.92**	**2.50**	**1.25**	**2.60**	**1.73**
Silt loading (oz/ft2)	**Average = 0.73**				**Average = 2.02**			
RANK	**4**				**6**			

Section	5				6			
Product	DCA 2000				DMC 820 (Lig/Mag)			
Milepost	0.15	0.19	0.38	0.52	0.15	0.35	0.5	0.6
Moisture (%)	**0.2**	**0.1**	**0.1**	**0.2**	**0.2**	**0.1**	**0.1**	**0.1**
Sample mass, (g)	4815.5	1965.1	1511.1	1824.3	1524.8	1145.9	1194.9	1737.7
Percent passing the No. 200 sieve	3.5%	3.5%	1.0%	2.8%	3.3%	3.6%	2.3%	2.5%
Mass passing the No. 200 sieve, (g)	168.5	68.8	15.1	51.1	50.3	41.3	27.5	43.4
Area (in^2)	864	864	864	864	864	864	864	864
Silt loading (g/in^2)	0.195	0.080	0.017	0.059	0.058	0.048	0.032	0.050
Silt loading (oz/ft^2)	**0.99**	**0.40**	**0.09**	**0.30**	**0.30**	**0.24**	**0.16**	**0.26**
Silt loading (oz/ft2)	**Average = 0.45**				**Average = 0.24**			
RANK	**3**				**1**			

Conversion: 1 g/in^2 = 5.0794 oz/ft^2

Table 21. Silt loading calculations for the 20-month monitoring event.

Wyoming RRP SEED 12(1)
Seedskdee National Wildlife Refuge Stabilization Project
Samples taken May 18, 2006

Section	1				2			
Product	Terrazyme				Lignosulfonate			
Milepost	0.05	0.18	0.33	0.52	0.05	0.18	0.33	0.52
Moisture (%)	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Sample mass, (g)	4266.4	4346.6	5630.1	4581.1	2559.7	2581.6	2754.4	3507.1
Percent passing the No. 200 sieve	4.3%	5.7%	7.6%	6.6%	4.2%	5.2%	4.3%	6.0%
Mass passing the No. 200 sieve, (g)	183.5	247.8	427.9	302.4	107.5	134.2	118.4	210.4
Area (in^2)	864	864	864	864	864	864	864	864
Silt loading (g/in^2)	0.212	0.287	0.495	0.350	0.124	0.155	0.137	0.244
Silt loading (oz/ft^2)	**1.08**	**1.46**	**2.52**	**1.78**	**0.63**	**0.79**	**0.70**	**1.24**
Silt loading (oz/ft2)	**Average =1.71**				**Average = 0.84**			
RANK	**5**				**1**			

Section	3				4			
Product	Permazyme				Soil Sement			
Milepost	0.05	0.18	0.33	0.52	0.05	0.18	0.33	0.52
Moisture (%)	**0.0**	**0.1**	**0.0**	**0.1**	**0.1**	**0.1**	**0.1**	**0.0**
Sample mass, (g)	4042.3	4508.6	5028.1	4262.8	4815.2	3895.1	7077.2	6836.2
Percent passing the No. 200 sieve	5.4%	4.4%	5.2%	4.1%	6.5%	5.5%	6.6%	6.0%
Mass passing the No. 200 sieve, (g)	218.3	198.4	261.5	174.8	313.0	214.2	467.1	410.2
Area (in^2)	864	864	864	864	864	864	864	864
Silt loading (g/in^2)	0.253	0.230	0.303	0.202	0.362	0.248	0.541	0.475
Silt loading (oz/ft^2)	**1.28**	**1.17**	**1.54**	**1.03**	**1.84**	**1.26**	**2.75**	**2.41**
Silt loading (oz/ft2)	**Average = 1.25**				**Average = 2.06**			
RANK	**3**				**6**			

Section	5				6			
Product	DCA 2000				DMC 820 (Lig/Mag)			
Milepost	0.05	0.18	0.35	0.54	0.05	0.25	0.45	0.55
Moisture (%)	**0.0**	**0.0**	**0.0**	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**
Sample mass, (g)	3377.0	3477.5	3280.6	4492.8	4197.2	6045.7	7127.1	7425.3
Percent passing the No. 200 sieve	5.1%	4.6%	3.9%	4.5%	4.9%	5.2%	4.3%	4.5%
Mass passing the No. 200 sieve, (g)	172.2	160.0	127.9	202.2	205.7	314.4	306.5	334.1
Area (in^2)	864	864	864	864	1152	1152	1152	1152
Silt loading (g/in^2)	0.199	0.185	0.148	0.234	0.179	0.273	0.266	0.290
Silt loading (oz/ft^2)	**1.01**	**0.94**	**0.75**	**1.19**	**0.91**	**1.39**	**1.35**	**1.47**
Silt loading (oz/ft2)	**Average = 0.97**				**Average = 1.28**			
RANK	**2**				**4**			

Conversion: 1 g/in^2 = 5.0794 oz/ft^2

Table 22. Silt loading calculations for the 23-month monitoring event.

Wyoming RRP SEED 12(1)
Seedskdee National Wildlife Refuge Stabilization Project
Samples taken August 29, 2006

Section	1				2			
Product	Terrazyme				Lignosulfonate			
Milepost	0.22	0.35	0.45	0.50	0.22	0.35	0.45	0.50
Moisture (%)	**0.0**	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**	**0.0**	**0.0**
Sample mass, (g)	1046.3	2462.5	2149.5	2702.8	1989.5	2377.4	2002.2	2035.7
Percent passing the No. 200 sieve	1.5%	1.7%	2.8%	1.0%	0.6%	1.0%	0.8%	1.3%
Mass passing the No. 200 sieve, (g)	15.7	41.9	60.2	27.0	11.9	23.8	16.0	26.5
Area (in^2)	864	864	864	864	864	864	864	864
Silt loading (g/in^2)	0.018	0.048	0.070	0.031	0.014	0.028	0.019	0.031
Silt loading (oz/ft^2)	**0.09**	**0.25**	**0.35**	**0.16**	**0.07**	**0.14**	**0.09**	**0.16**
Silt loading (oz/ft2)	**Average =0.21**				**Average = 0.11**			
RANK	**3**				**1**			

Section	3				4			
Product	Permazyme				Soil Sement			
Milepost	0.22	0.35	0.45	0.50	0.22	0.35	0.45	0.50
Moisture (%)	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.1**	**0.1**
Sample mass, (g)	2360.9	2616.9	2915.7	5122.4	4335.9	7320.5	4047.2	5375.2
Percent passing the No. 200 sieve	1.1%	1.2%	1.2%	2.2%	4.9%	4.1%	4.5%	3.3%
Mass passing the No. 200 sieve, (g)	26.0	31.4	35.0	112.7	212.5	300.1	182.1	177.4
Area (in^2)	864	864	864	864	864	864	864	864
Silt loading (g/in^2)	0.030	0.036	0.040	0.130	0.246	0.347	0.211	0.205
Silt loading (oz/ft^2)	**0.15**	**0.18**	**0.21**	**0.66**	**1.25**	**1.76**	**1.07**	**1.04**
Silt loading (oz/ft2)	**Average = 0.30**				**Average = 1.28**			
RANK	**5**				**6**			

Section	5				6			
Product	DCA 2000				DMC 820 (Lig/Mag)			
Milepost	0.02	0.08	0.43	0.525	0.18	0.28	0.48	0.62
Moisture (%)	**0.1**	**0.0**	**0.1**	**0.2**	**0.1**	**0.0**	**0.0**	**0.0**
Sample mass, (g)	1986.1	3633.0	1980.4	1710.1	2173.2	1495.7	3389.6	3608.0
Percent passing the No. 200 sieve	1.0%	2.3%	1.4%	2.9%	0.5%	0.6%	1.0%	1.2%
Mass passing the No. 200 sieve, (g)	19.9	83.6	27.7	49.6	10.9	9.0	33.9	43.3
Area (in^2)	864	864	864	864	864	864	864	864
Silt loading (g/in^2)	0.023	0.097	0.032	0.057	0.013	0.010	0.039	0.050
Silt loading (oz/ft^2)	**0.12**	**0.49**	**0.16**	**0.29**	**0.06**	**0.05**	**0.20**	**0.25**
Silt loading (oz/ft2)	**Average = 0.27**				**Average = 0.14**			
RANK	**4**				**2**			

Conversion: 1 g/in^2 = 5.0794 oz/ft^2

Table 23. Gradation test averages from silt testing.

Sieve	Section I TerraZyme				Section II Lignosulfonate			
Size	8-month	11-month	20-month	23-month	8-month	11-month	20-month	23-month
3/4-in	100	100	100	100	100	100	100	100
1/2-in	98	98	97	98	100	99	97	98
3/8-in	93	93	94	93	98	96	93	94
# 4	78	79	82	79	88	85	83	80
# 8	60	66	69	62	67	70	70	61
# 10	55	62	66	59	61	66	67	56
# 16	43	53	57	47	44	54	57	44
# 30	27	39	44	32	24	37	41	27
# 40	18	30	35	23	15	28	32	18
# 50	11	21	26	15	7	18	23	11
# 200	1.4	3.8	6.1	1.8	0.4	2.8	4.9	0.9

	Section III PermaZyme				Section IV Soil Sement			
	8-month	11-month	20-month	23-month	8-month	11-month	20-month	23-month
3/4-in	100	100	100	100	100	100	100	100
1/2-in	99	98	99	96	96	98	97	95
3/8-in	95	95	96	90	90	95	94	90
# 4	81	81	84	71	74	81	81	74
# 8	59	65	69	53	59	66	67	59
# 10	54	61	66	49	55	63	64	56
# 16	40	51	56	39	45	54	55	46
# 30	22	36	42	25	32	41	42	35
# 40	14	27	32	18	24	33	33	27
# 50	7	19	24	11	17	24	24	19
# 200	0.7	3.6	4.8	1.4	3.6	6.4	6.2	4.2

	Section V Caliber				Section VI Mag/Lig			
	8-month	11-month	20-month	23-month	8-month	11-month	20-month	23-month
3/4-in	100	100	100	100	100	100	100	100
1/2-in	97	97	98	93	98	99	97	95
3/8-in	91	94	95	88	93	97	93	89
# 4	71	80	81	70	78	88	80	74
# 8	52	61	65	53	59	71	67	56
# 10	49	57	62	50	55	67	63	52
# 16	41	45	52	41	43	53	54	40
# 30	28	31	39	29	27	37	40	24
# 40	20	23	30	21	19	27	32	16
# 50	14	15	22	14	11	18	23	10
# 200	2.7	2.7	4.5	1.9	1.1	2.9	4.7	0.8

APPENDIX F – DYNAMIC CONE PENETROMETER DATA

Table 24. Dynamic cone penetrometer data and conversion to CBR values.

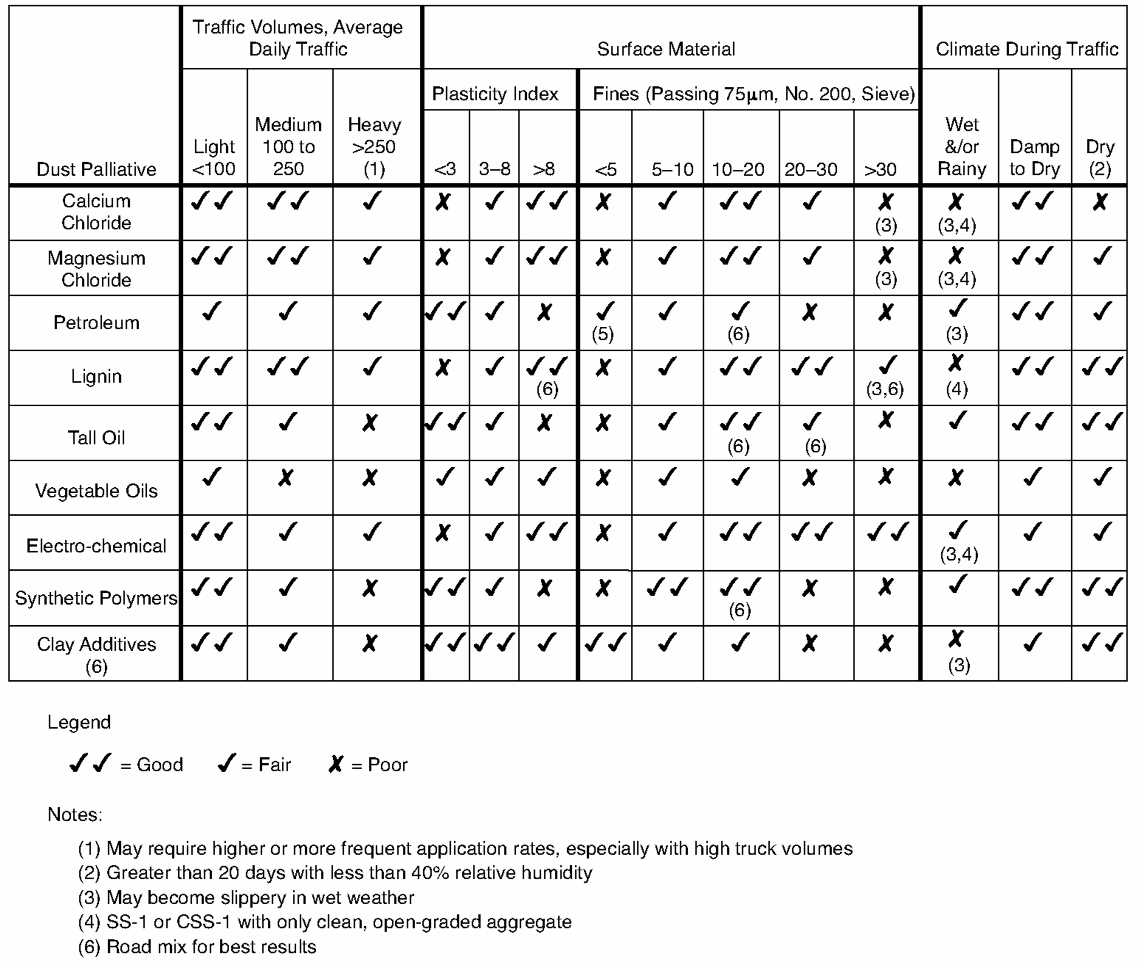
Section	10/20/2004 Monitoring					5/18/2005 Monitoring					8/30/2005 Monitoring					5/18/2006 Monitoring					8/29/2006 Monitoring				
	MP	# Blows to 5" (127mm)	DCP Index mm/blow	CBR %	Avg CBR %	MP	# Blows to 5" (127mm)	DCP Index mm/blow	CBR %	Avg CBR %	MP	# Blows to 5" (127mm)	DCP Index mm/blow	CBR %	Avg CBR %	MP	# Blows to 5" (127mm)	DCP Index mm/blow	CBR %	Avg CBR %	MP	# Blows to 5" (127mm)	DCP Index mm/blow	CBR %	Avg CBR %
I - Terra-Zyme	0.10	21	6	40	28	0.10	15	8	30	30	0.15	28	5	50	50	0.05	31	4	60	58	0.22	16	8	30	29
	0.40	9	14	15		0.30	15	8	30		0.25	30	4	60		0.18	33	4	60		0.35	14	9	25	
											0.38	25	5	50		0.33	34	4	60		0.45	14	9	25	
											0.48	21	6	40		0.52	27	5	50		0.50	17	7	35	
II - Ligno-sulfonate	0.10	26	5	50	43	0.10	21	6	40	38	0.15	62	2	100	85	0.05	37	3	80	68	0.22	22	6	40	53
	0.40	17	7	35		0.30	19	7	35		0.25	41	3	80		0.18	37	3	80		0.35	39	3	80	
											0.38	45	3	80		0.33	31	4	60		0.45	23	6	40	
											0.48	46	3	80		0.52	27	5	50		0.50	24	5	50	
III - Perma-Zyme	0.10	19	7	35	28	0.10	15	8	30	30	0.15	26	5	50	53	0.05	28	5	50	53	0.22	22	6	40	28
	0.40	12	11	20		0.30	15	8	30		0.25	25	5	50		0.18	25	5	50		0.35	16	8	30	
											0.38	25	5	50		0.33	35	4	60		0.45	13	10	20	
											0.48	32	4	60		0.52	25	5	50		0.50	13	10	20	
IV - Soil Sement	0.10	10	13	16	21	0.10	17	7	35	33	0.15	29	4	60	53	0.05	17	7	35	49	0.22	17	7	35	34
	0.40	14	9	25		0.30	16	8	30		0.25	25	5	50		0.18	38	3	80		0.35	20	6	40	
											0.38	26	5	50		0.33	21	6	40		0.45	15	8	30	
											0.48	24	5	50		0.52	21	6	40		0.50	16	8	30	
V - DCA 2000 Caliber	0.10	11	12	18	17	0.10	14	9	25	30	0.15	33	4	60	63	0.05	22	6	40	63	0.02	17	7	35	35
	0.50	9	14	15		0.30	17	7	35		0.25	24	5	50		0.18	41	3	80		0.08	19	7	35	
											0.38	33	4	60		0.35	24	5	50		0.43	16	8	30	
											0.48	45	3	80		0.54	46	3	80		0.53	21	6	40	
VI - DMC 820 (Mag/Lig)	0.10	10	13	16	18	0.10	22	6	40	33	0.15	29	4	60	53	0.05	24	5	50	48	0.18	15	8	30	25
	0.60	13	10	20		0.30	14	9	25		0.35	21	6	40		0.25	28	5	50		0.28	11	12	18	
											0.50	27	5	50		0.45	22	6	40		0.48	12	11	20	
											0.60	31	4	60		0.55	25	5	50		0.62	15	8	30	

APPENDIX G – DUST CONTROL CATEGORY SELECTION PROCESS

Traditionally, to identify an acceptable dust control or roadway stabilization product the process has been based on a perspective that examines its specific and individual acceptability or suitability for the application. Products that have been used in the past with a known positive history are given more consideration than those that have not been used. Anecdotal experiences shared by trusted associates of success or failures more often contribute to the decision to use a product rather than fact sheets and promotional brochures offered by manufacturers and distributors. One misapplication can create a dark cloud over a product that ten successful applications cannot dispel.

The fact is that not every product works for all situations. Some products do have a broad range of effectiveness while others are have narrow applicability. Misapplications can result in slippery surfaces, lack of uniform mixing, continued instability and dusting, loss of product in the ditches, complaints from the public and mis-spent funds. Managers of unsurfaced roadways want to be able to confidently select an effective product, know that it is cost effective, and never have a failure. The USFS report *Dust Palliative Selection and Application Guide*(6) tabulates the effectiveness of dust palliative categories as shown in Table 25.

Table 25. Product selection chart. (USFS)



	Traffic Volumes, Average Daily Traffic			Surface Material								Climate During Traffic		
				Plasticity Index			Fines (Passing 75μm, No. 200, Sieve)							
Dust Palliative	Light <100	Medium 100 to 250	Heavy >250 (1)	<3	3–8	>8	<5	5–10	10–20	20–30	>30	Wet &/or Rainy	Damp to Dry	Dry (2)
Calcium Chloride	✓✓	✓✓	✓	✗	✓	✓✓	✗	✓	✓✓	✓	✗ (3)	✗ (3,4)	✓✓	✗
Magnesium Chloride	✓✓	✓✓	✓	✗	✓	✓✓	✗	✓	✓✓	✓	✗ (3)	✗ (3,4)	✓✓	✓
Petroleum	✓	✓	✓	✓✓	✓	✗	✓ (5)	✓	✓ (6)	✗	✗	✓ (3)	✓✓	✓
Lignin	✓✓	✓✓	✓	✗	✓	✓✓ (6)	✗	✓	✓✓	✓✓	✓ (3,6)	✗ (4)	✓✓	✓✓
Tall Oil	✓✓	✓	✗	✓✓	✓	✗	✗	✓	✓✓ (6)	✓ (6)	✗	✓	✓✓	✓✓
Vegetable Oils	✓	✗	✗	✓	✓	✓	✗	✓	✓	✗	✗	✗	✓	✓
Electro-chemical	✓✓	✓	✓	✗	✓	✓✓	✗	✓	✓✓	✓✓	✓✓	✓ (3,4)	✓	✓
Synthetic Polymers	✓✓	✓	✗	✓✓	✓	✗	✗	✓✓	✓✓ (6)	✗	✗	✓	✓✓	✓✓
Clay Additives (6)	✓✓	✓	✗	✓✓	✓✓	✓	✓✓	✓	✓	✗	✗	✗ (3)	✓	✓✓

Legend

✓✓ = Good ✓ = Fair ✗ = Poor

Notes:

(1) May require higher or more frequent application rates, especially with high truck volumes
(2) Greater than 20 days with less than 40% relative humidity
(3) May become slippery in wet weather
(4) SS-1 or CSS-1 with only clean, open-graded aggregate
(6) Road mix for best results

While this table has been a standard reference since it was published in 1999, there is a need to reexamine the selection process from the perspective of not whether a category will work for a specific site, but what categories will work for a particular site. Therefore, the following process is proposed that prioritizes the families of dust palliative categories based on the conditions of traffic, climate, plasticity index, percent fines, environmental impact, cost, and application rate.

Step 1: The initial USFS list shown in Table 25 was expanded to include all of the families of products, plus Environmental Impact, Relative Cost and Application Rate.

Step 2: Numerical values of 1, 2, or 3 were assigned to each of the site condition attributes representing good, fair, or poor product performance; or low, medium, or high impact or cost. This new and expanded information is shown in Table 26. For easier visualization, green was associated with "1", yellow with "2", and pink with "3".

One can easily see that some products may be effective for a specific climate, but not effective for a specific level of traffic, while others are effective for both. Similar observations can be seen for the material attributes. Therefore, it was necessary to "optimize" each product's effectiveness for all of the attributes.

Step 3: For each of the 17 families of products, the numerical values associated with the three climate conditions and the three traffic levels were multiplied and sorted from low to high to produce Table 27. Similarly, the numerical values associated with the three plasticity index values and the five percent fines amounts were multiplied and sorted from low to high to produce Table 28.

Note that in these tables, a value of "1" represents a product that would be highly recommended for a particular combination of attributes, whereas a "9" would not. One can see for instance in Table 27 that there are six families of products with a value of "1" for a Dry Climate and a Light Traffic. On the other hand in that same Table 27 for a Wet or Rainy Climate and a Heavy Traffic there are no highly recommended products with a value of "1". Instead the best options are four products with a value of "4", indicating they may work, but not to the full level desired.

Step 4: For each of the 17 families of products, the numerical values associated with the six environmental impacts, cost, and application rates were averaged and sorted from low to high to produce an Overall Cost Factor in Table 29.

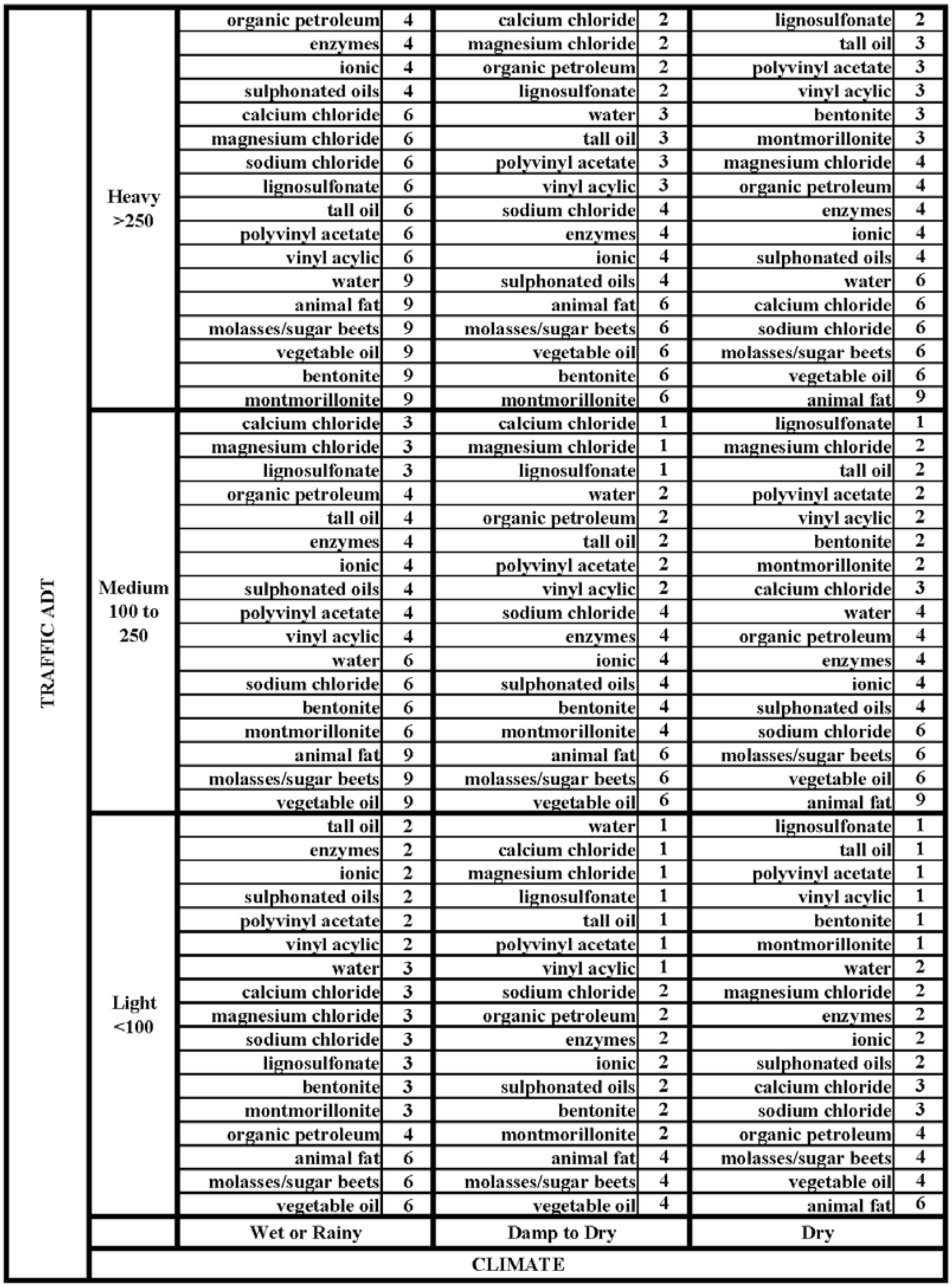
Up to this point, no calculations have been necessary for a person selecting a product for their specific site, however for the next steps it will be required when the calculated values for the traffic levels and climate are combined with those for the plasticity index and percent fines, and the overall cost factor.

Step 5: Select the particular blocks from Tables 27 and 28 along with the Overall Cost Factor block that show the 17 family of products associated with the specific site conditions, and average and sort their values from low to high. The products with the lowest values are recommended as best optimized for use based on all of the combined conditions.

Table 26. Expanded and revised product selection chart.

Family	Product	Climate			Traffic ADT			Material								Environmental Impact						Relative Cost	Application Rate
		Wet or Rainy	Damp to Dry	Dry	Light <100	Medium 100 to 250	Heavy >250	Plasticity Inde1			% Fines -#200					Stability (No Leach)	Surface Water (No Harm)	Ground Water (No Harm)	Plants (No Harm)	Animals (No Harm)	Humans (No Harm)		
								<3	3-8	>8	<5	5-10	10-20	20-30	>30								
Water	water	3	1	2	1	2	3	2	2	1	2	1	1	1	2	3	1	1	1	1	1	1	3
Water Absorbing	calcium chloride	3	1	3	1	1	2	3	2	1	3	2	1	2	3	3	2	2	2	2	2	2	3
	magnesium chloride	3	1	2	1	1	2	3	2	1	3	2	1	2	3	3	2	2	2	2	2	2	3
	sodium chloride	3	2	3	1	2	2	3	2	2	3	2	1	2	3	3	2	2	2	2	2	2	3
Organic Petroleum	asphalt emulsions	2	1	2	2	2	2	1	2	3	1	2	2	3	3	3	3	3	3	2	2	3	3
	cutback asphalt	2	1	2	2	2	2	1	2	3	1	2	2	3	3	3	3	3	3	2	2	3	3
	dust oil	2	1	2	2	2	2	1	2	3	1	2	2	3	3	3	3	3	3	2	2	3	3
	modified AC emulsions	2	1	2	2	2	2	1	2	3	1	2	2	3	3	3	3	3	3	2	2	3	3
Organic Non-Petroleum	animal fats	3	2	3	2	3	3	2	2	2	3	3	2	3	3	3	3	3	1	1	2	2	3
	lignosulfonate	3	1	1	1	1	2	3	2	1	3	2	1	1	2	2	2	2	2	2	2	2	3
	molasses sugar beet	3	2	2	2	3	3	2	2	2	3	2	2	3	3	3	1	1	1	1	1	3	3
	tall oil emulsions	2	1	1	1	2	3	1	2	3	3	2	1	2	3	3	2	2	2	2	2	2	3
	vegetable oils	3	2	2	2	3	3	2	2	2	3	2	2	3	3	3	1	1	1	1	1	2	3
Electrochemical	enzymes	2	2	2	1	2	2	3	2	1	3	2	1	1	1	2	2	2	1	1	1	1	1
	ionic	2	2	2	1	2	2	3	2	1	3	2	1	1	1	2	2	2	1	1	1	2	1
	sulphonated oils	2	2	2	1	2	2	3	2	1	3	2	1	1	1	2	2	2	1	1	1	2	1
Synthetic Polymer	polyvinyl acetate	2	1	1	1	2	3	1	2	3	3	1	1	3	3	1	2	2	1	1	1	3	2
	vinyl acrylic	2	1	1	1	2	3	1	2	3	3	1	1	3	3	1	2	2	1	1	1	3	2
Clay Additives	bentonite	3	2	1	1	2	3	1	1	2	1	2	2	3	3	1	2	1	1	1	1	2	2
	montmorillonite	3	2	1	1	2	3	1	1	2	1	2	2	3	3	1	2	1	1	1	1	2	2

Table 27. Traffic level versus climate conditions product ranking.

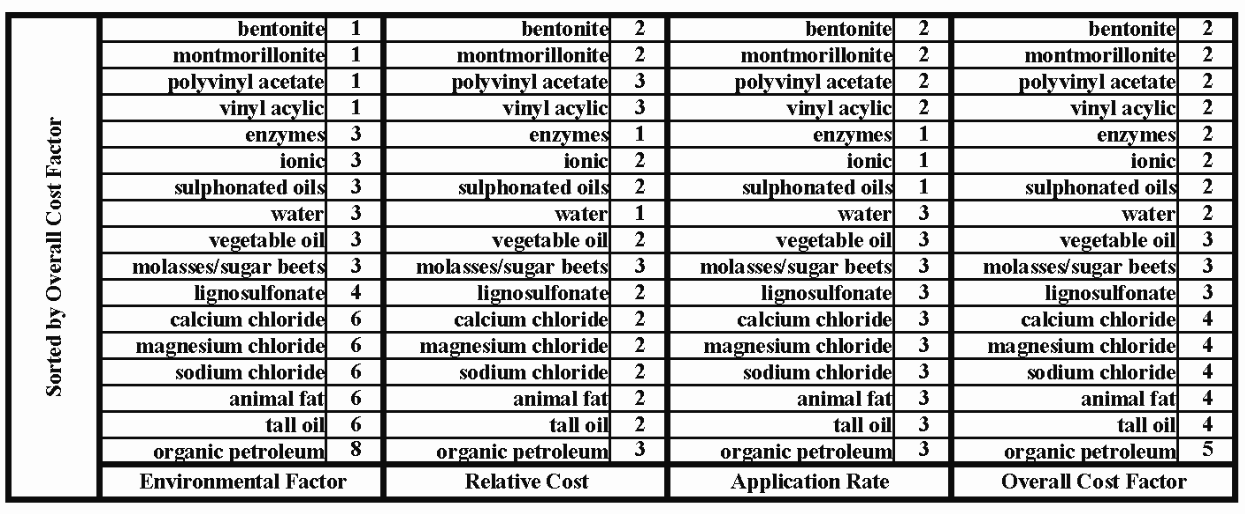


TRAFFIC ADT	Heavy >250	organic petroleum	4	calcium chloride	2	lignosulfonate	2
		enzymes	4	magnesium chloride	2	tall oil	3
		ionic	4	organic petroleum	2	polyvinyl acetate	3
		sulphonated oils	4	lignosulfonate	2	vinyl acylic	3
		calcium chloride	6	water	3	bentonite	3
		magnesium chloride	6	tall oil	3	montmorillonite	3
		sodium chloride	6	polyvinyl acetate	3	magnesium chloride	4
		lignosulfonate	6	vinyl acylic	3	organic petroleum	4
		tall oil	6	sodium chloride	4	enzymes	4
		polyvinyl acetate	6	enzymes	4	ionic	4
		vinyl acylic	6	ionic	4	sulphonated oils	4
		water	9	sulphonated oils	4	water	6
		animal fat	9	animal fat	6	calcium chloride	6
		molasses/sugar beets	9	molasses/sugar beets	6	sodium chloride	6
		vegetable oil	9	vegetable oil	6	molasses/sugar beets	6
		bentonite	9	bentonite	6	vegetable oil	6
		montmorillonite	9	montmorillonite	6	animal fat	9
	Medium 100 to 250	calcium chloride	3	calcium chloride	1	lignosulfonate	1
		magnesium chloride	3	magnesium chloride	1	magnesium chloride	2
		lignosulfonate	3	lignosulfonate	1	tall oil	2
		organic petroleum	4	water	2	polyvinyl acetate	2
		tall oil	4	organic petroleum	2	vinyl acylic	2
		enzymes	4	tall oil	2	bentonite	2
		ionic	4	polyvinyl acetate	2	montmorillonite	2
		sulphonated oils	4	vinyl acylic	2	calcium chloride	3
		polyvinyl acetate	4	sodium chloride	4	water	4
		vinyl acylic	4	enzymes	4	organic petroleum	4
		water	6	ionic	4	enzymes	4
		sodium chloride	6	sulphonated oils	4	ionic	4
		bentonite	6	bentonite	4	sulphonated oils	4
		montmorillonite	6	montmorillonite	4	sodium chloride	6
		animal fat	9	animal fat	6	molasses/sugar beets	6
		molasses/sugar beets	9	molasses/sugar beets	6	vegetable oil	6
		vegetable oil	9	vegetable oil	6	animal fat	9
	Light <100	tall oil	2	water	1	lignosulfonate	1
		enzymes	2	calcium chloride	1	tall oil	1
		ionic	2	magnesium chloride	1	polyvinyl acetate	1
		sulphonated oils	2	lignosulfonate	1	vinyl acylic	1
		polyvinyl acetate	2	tall oil	1	bentonite	1
		vinyl acylic	2	polyvinyl acetate	1	montmorillonite	1
		water	3	vinyl acylic	1	water	2
		calcium chloride	3	sodium chloride	2	magnesium chloride	2
		magnesium chloride	3	organic petroleum	2	enzymes	2
		sodium chloride	3	enzymes	2	ionic	2
		lignosulfonate	3	ionic	2	sulphonated oils	2
		bentonite	3	sulphonated oils	2	calcium chloride	3
		montmorillonite	3	bentonite	2	sodium chloride	3
		organic petroleum	4	montmorillonite	2	organic petroleum	4
		animal fat	6	animal fat	4	molasses/sugar beets	4
		molasses/sugar beets	6	molasses/sugar beets	4	vegetable oil	4
		vegetable oil	6	vegetable oil	4	animal fat	6
		Wet or Rainy		Damp to Dry		Dry	
	CLIMATE						

Table 28. Plasticity index versus percent minus #200 product ranking.

PLASTICITY INDEX (PI)	>8	water	2	water	1	water	1	water	1	enzymes	1
		bentonite	2	calcium chloride	2	calcium chloride	1	lignosulfonate	1	ionic	1
		montmorillonite	2	magnesium chloride	2	magnesium chloride	1	enzymes	1	sulphonated oils	1
		calcium chloride	3	lignosulfonate	2	lignosulfonate	1	ionic	1	water	2
		magnesium chloride	3	enzymes	2	enzymes	1	sulphonated oils	1	lignosulfonate	2
		organic petroleum	3	ionic	2	ionic	1	calcium chloride	2	calcium chloride	3
		lignosulfonate	3	sulphonated oils	2	sulphonated oils	1	magnesium chloride	2	magnesium chloride	3
		enzymes	3	polyvinyl acetate	3	sodium chloride	2	sodium chloride	4	sodium chloride	6
		ionic	3	vinyl acylic	3	tall oil	3	animal fat	6	animal fat	6
		sulphonated oils	3	sodium chloride	4	polyvinyl acetate	3	molasses/sugar beets	6	molasses/sugar beets	6
		sodium chloride	6	molasses/sugar beets	4	vinyl acylic	3	tall oil	6	vegetable oil	6
		animal fat	6	vegetable oil	4	animal fat	4	vegetable oil	6	bentonite	6
		molasses/sugar beets	6	bentonite	4	molasses/sugar beets	4	bentonite	6	montmorillonite	6
		vegetable oil	6	montmorillonite	4	vegetable oil	4	montmorillonite	6	organic petroleum	9
		tall oil	9	organic petroleum	6	bentonite	4	organic petroleum	9	tall oil	9
		polyvinyl acetate	9	animal fat	6	montmorillonite	4	polyvinyl acetate	9	polyvinyl acetate	9
		vinyl acylic	9	tall oil	6	organic petroleum	6	vinyl acylic	9	vinyl acylic	9
	3 - 8	bentonite	1	water	2	water	2	water	2	enzymes	2
		montmorillonite	1	polyvinyl acetate	2	calcium chloride	2	lignosulfonate	2	ionic	2
		organic petroleum	2	vinyl acylic	2	magnesium chloride	2	enzymes	2	sulphonated oils	2
		water	4	bentonite	2	sodium chloride	2	ionic	2	bentonite	3
		calcium chloride	6	montmorillonite	2	lignosulfonate	2	sulphonated oils	2	montmorillonite	3
		magnesium chloride	6	calcium chloride	4	tall oil	2	bentonite	3	water	4
		sodium chloride	6	magnesium chloride	4	enzymes	2	montmorillonite	3	lignosulfonate	4
		animal fat	6	sodium chloride	4	ionic	2	calcium chloride	4	calcium chloride	6
		lignosulfonate	6	organic petroleum	4	sulphonated oils	2	magnesium chloride	4	magnesium chloride	6
		molasses/sugar beets	6	lignosulfonate	4	polyvinyl acetate	2	sodium chloride	4	sodium chloride	6
		tall oil	6	molasses/sugar beets	4	vinyl acylic	2	tall oil	4	organic petroleum	6
		vegetable oil	6	tall oil	4	bentonite	2	organic petroleum	6	animal fat	6
		enzymes	6	vegetable oil	4	montmorillonite	2	animal fat	6	molasses/sugar beets	6
		ionic	6	enzymes	4	organic petroleum	4	molasses/sugar beets	6	tall oil	6
		sulphonated oils	6	ionic	4	animal fat	4	vegetable oil	6	vegetable oil	6
		polyvinyl acetate	6	sulphonated oils	4	molasses/sugar beets	4	polyvinyl acetate	6	polyvinyl acetate	6
		vinyl acylic	6	animal fat	6	vegetable oil	4	vinyl acylic	6	vinyl acylic	6
	<3	organic petroleum	1	polyvinyl acetate	1	tall oil	1	water	2	organic petroleum	3
		bentonite	1	vinyl acylic	1	polyvinyl acetate	1	tall oil	2	tall oil	3
		montmorillonite	1	water	2	vinyl acylic	1	organic petroleum	3	enzymes	3
		tall oil	3	organic petroleum	2	water	2	lignosulfonate	3	ionic	3
		polyvinyl acetate	3	tall oil	2	organic petroleum	2	enzymes	3	sulphonated oils	3
		vinyl acylic	3	bentonite	2	bentonite	2	ionic	3	polyvinyl acetate	3
		water	4	montmorillonite	2	montmorillonite	2	sulphonated oils	3	vinyl acylic	3
		animal fat	6	molasses/sugar beets	4	calcium chloride	3	polyvinyl acetate	3	bentonite	3
		molasses/sugar beets	6	vegetable oil	4	magnesium chloride	3	vinyl acylic	3	montmorillonite	3
		vegetable oil	6	calcium chloride	6	sodium chloride	3	bentonite	3	water	4
		calcium chloride	9	magnesium chloride	6	lignosulfonate	3	montmorillonite	3	animal fat	6
		magnesium chloride	9	sodium chloride	6	enzymes	3	calcium chloride	6	lignosulfonate	6
		sodium chloride	9	animal fat	6	ionic	3	magnesium chloride	6	molasses/sugar beets	6
		lignosulfonate	9	lignosulfonate	6	sulphonated oils	3	sodium chloride	6	vegetable oil	6
		enzymes	9	enzymes	6	animal fat	4	animal fat	6	calcium chloride	9
		ionic	9	ionic	6	molasses/sugar beets	4	molasses/sugar beets	6	magnesium chloride	9
		sulphonated oils	9	sulphonated oils	6	vegetable oil	4	vegetable oil	6	sodium chloride	9
		<5		5 - 10		10 - 20		20 - 30		>30	
		% - # 200									

Table 29. Environmental, cost, and application rate product ranking.

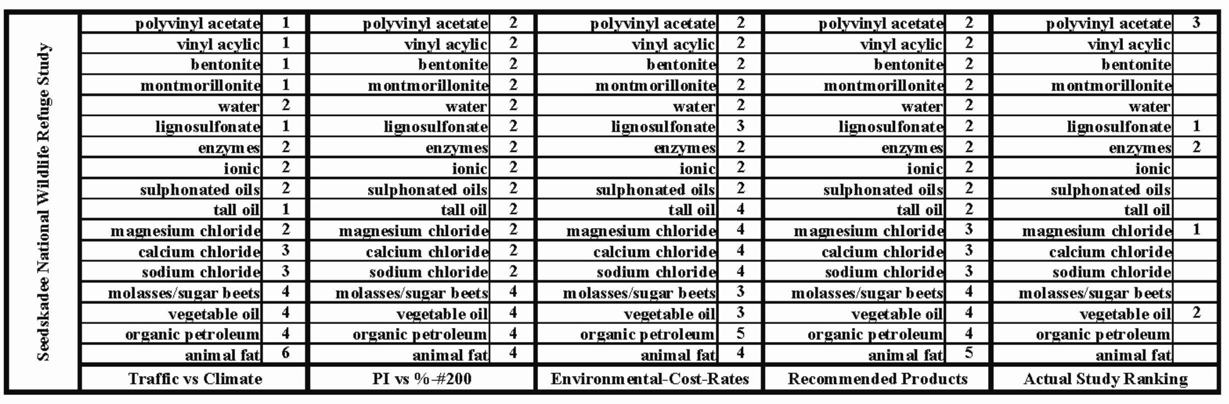


Sorted by Overall Cost Factor	bentonite	1	bentonite	2	bentonite	2	bentonite	2
	montmorillonite	1	montmorillonite	2	montmorillonite	2	montmorillonite	2
	polyvinyl acetate	1	polyvinyl acetate	3	polyvinyl acetate	2	polyvinyl acetate	2
	vinyl acylic	1	vinyl acylic	3	vinyl acylic	2	vinyl acylic	2
	enzymes	3	enzymes	1	enzymes	1	enzymes	2
	ionic	3	ionic	2	ionic	1	ionic	2
	sulphonated oils	3	sulphonated oils	2	sulphonated oils	1	sulphonated oils	2
	water	3	water	1	water	3	water	2
	vegetable oil	3	vegetable oil	2	vegetable oil	3	vegetable oil	3
	molasses/sugar beets	3	molasses/sugar beets	3	molasses/sugar beets	3	molasses/sugar beets	3
	lignosulfonate	4	lignosulfonate	2	lignosulfonate	3	lignosulfonate	3
	calcium chloride	6	calcium chloride	2	calcium chloride	3	calcium chloride	4
	magnesium chloride	6	magnesium chloride	2	magnesium chloride	3	magnesium chloride	4
	sodium chloride	6	sodium chloride	2	sodium chloride	3	sodium chloride	4
	animal fat	6	animal fat	2	animal fat	3	animal fat	4
	tall oil	6	tall oil	2	tall oil	3	tall oil	4
	organic petroleum	8	organic petroleum	3	organic petroleum	3	organic petroleum	5
	Environmental Factor		Relative Cost		Application Rate		Overall Cost Factor	

The results of an example are shown in Table 30 using this Seedskadee study's specific site conditions of:

Traffic Level: Light (10 to 15 ADT)
Climate: Dry
PI: 3 – 8 (actual was 4)
Percent -#200: 1 – 20 (actual was 12).

Table 30. Seedskadee NWR specific site product ranking recommendations.



Seedskadee National Wildlife Refuge Study	polyvinyl acetate	1	polyvinyl acetate	2	polyvinyl acetate	2	polyvinyl acetate	2	polyvinyl acetate	3
	vinyl acylic	1	vinyl acylic	2	vinyl acylic	2	vinyl acylic	2	vinyl acylic	
	bentonite	1	bentonite	2	bentonite	2	bentonite	2	bentonite	
	montmorillonite	1	montmorillonite	2	montmorillonite	2	montmorillonite	2	montmorillonite	
	water	2	water	2	water	2	water	2	water	
	lignosulfonate	1	lignosulfonate	2	lignosulfonate	3	lignosulfonate	2	lignosulfonate	1
	enzymes	2	enzymes	2	enzymes	2	enzymes	2	enzymes	2
	ionic	2	ionic	2	ionic	2	ionic	2	ionic	
	sulphonated oils	2	sulphonated oils	2	sulphonated oils	2	sulphonated oils	2	sulphonated oils	
	tall oil	1	tall oil	2	tall oil	4	tall oil	2	tall oil	
	magnesium chloride	2	magnesium chloride	2	magnesium chloride	4	magnesium chloride	3	magnesium chloride	1
	calcium chloride	3	calcium chloride	2	calcium chloride	4	calcium chloride	3	calcium chloride	
	sodium chloride	3	sodium chloride	2	sodium chloride	4	sodium chloride	3	sodium chloride	
	molasses/sugar beets	4	molasses/sugar beets	4	molasses/sugar beets	3	molasses/sugar beets	4	molasses/sugar beets	
	vegetable oil	4	vegetable oil	4	vegetable oil	3	vegetable oil	4	vegetable oil	2
	organic petroleum	4	organic petroleum	4	organic petroleum	5	organic petroleum	4	organic petroleum	
	animal fat	6	animal fat	4	animal fat	4	animal fat	5	animal fat	
	Traffic vs Climate		PI vs %-#200		Environmental-Cost-Rates		Recommended Products		Actual Study Ranking	

One can see that further development is still needed since the products recommended under this optimizations selection process do not track well with the actual observed product performance. The process appears to be sound, but the initial numerical values in Table 26 may need to be revisited and revised as more information of product performance is documented.

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