

U.S. Department
of Agriculture

Forest Service

**National Technology
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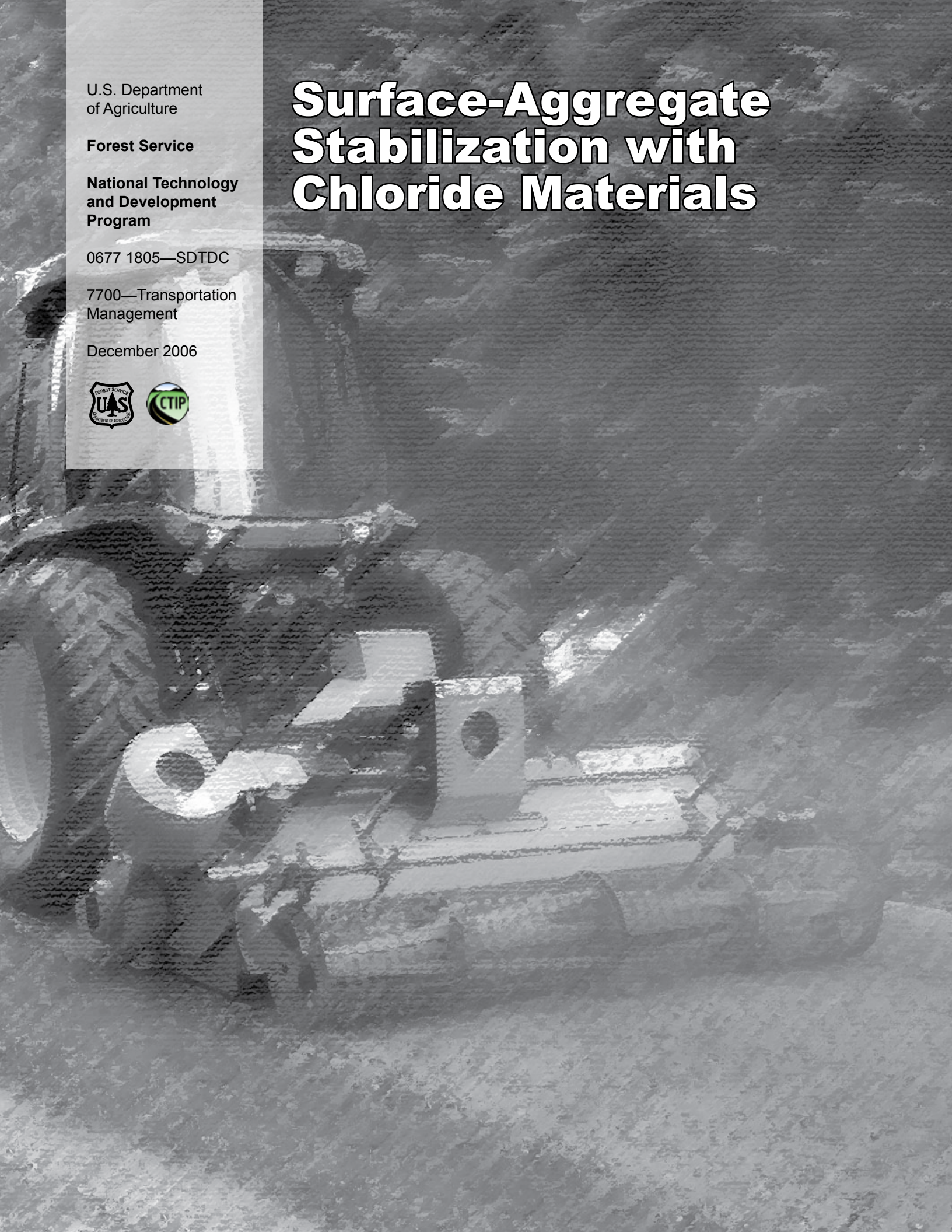
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7700—Transportation
Management

December 2006



Surface-Aggregate Stabilization with Chloride Materials



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by

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December 2006

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Table of Contents



Executive Summary	1
Introduction.....	3
Project Scope	4
Road Selection	7
Test Road Construction	7
Project Monitoring	
Road Surface Performance Monitoring.....	8
Soil, Water, and Tree Monitoring	9
Weather Monitoring	10
Construction Monitoring	10
Road Blading Maintenance.....	11
Road Use	11
Laboratory Testing of Aggregate and Chloride Materials	11
User Guide for Chloride Stabilization Projects	12
Cost and Performance Analysis	13
Intangible Benefits	16
Conclusions	
Treated Sections versus Untreated Sections	17
Treated Sections.....	18
Construction	19
Recommendations	
Design	21
Construction.....	21
Maintenance	22
Additional Studies	23
Acknowledgements.....	23

Surface-Aggregate Stabilization with Chloride Materials

Appendixes (on enclosed CD)

A—Project Characteristics and Performance

- 1—Project Area Map
- 2—Project Characteristic Summaries
- 3—Two-year Performance Curves
- 4—Project Characteristics and Performance Curves
- 5—Performance Life Ratios
- 6—Performance Equation (RESERVED)

B—Cost Analysis

- 1—Construction Cost Estimate
- 2—Blading Maintenance Costs
- 3—Construction and Maintenance Costs Analysis
- 4—Average Vehicle Speed
- 5—Road User Costs
- 6—Aggregate Loss by Vertical Survey
- 7—Aggregate Loss by Loss of Dust
- 8—Cost Benefit Summary and Analysis
- 9—Life Cycle Costs

C—Construction and Maintenance

- 1—Construction Specification
- 2—Chloride Quality and Quantity Assurance
- 3—Maintenance Methods

D—Project Photos, Power Point Presentation

- 1—Project Photos
- 2—PowerPoint® Presentation



E—Test Results

- 1—Aggregate Test Results
- 2—Chloride Mix Design Curves
- 3—Roadside Soil Chloride Content
- 4—Stream Water Quality
- 5—Chloride Content in Roadside Trees
- 6—Chloride Product Quality

F—Measurement Methods

- 1—Performance Measurement Form
- 2—Aggregate Loss Measurement
- 3—Tree Sampling
- 4—Chloride Mix Design Method
- 5—Aggregate Fracture

G—Supporting Analysis Spreadsheets

- 1—Traffic Count and Classification
- 2—Weather Summary
- 3—2003 and 2004 Condition Index, Traffic Speed, and Count Analysis
- 4—Condition Index versus Blading Needed-Critical

H—Unsurfaced Road Condition Index (URCI)

U.S. Army Corps of Engineers Special Report 87-15

I—Test Road Plan

J—Implementation Guide



Executive Summary

Road managers should consider chloride stabilization as a cost-effective method when selecting maintenance options and strategies for aggregate-surface roads. This stabilization technique also is a viable option for newly crushed aggregate. With proper maintenance, stabilized aggregate-surfaced roads have a projected life of 10 years, resulting in an annual maintenance cost savings of \$3,300 per mile when compared to untreated aggregate surfacing. Additional benefits of chloride stabilization include improved ride, reduced sedimentation in streams, reduced aggregate resource depletion, reduced inhalation health hazards, reduced vehicle maintenance, and increased road-user safety.

This publication provides Federal, State, county, and local road managers information on the performance and cost effectiveness of road-mixing high applications of calcium and magnesium chloride that are applied in a one-time construction process. Stabilization provides a much higher standard of road surface performance by improving ride quality and reducing dust, washboarding, and raveling (loose aggregate). Road managers can expect similar results when using this process with newly crushed aggregate.

The purpose of this project was to develop guidelines for chloride-stabilization and aggregate-surfacing materials in various environments. Road maintenance engineers monitored construction and maintenance costs, road surface deterioration, weather conditions, environmental effects, and construction materials for 2 years. The data collection and analysis provides a valuable tool for road managers.

Benefits and cost effectiveness of chloride stabilization were measured on 12 projects constructed in 2003 and monitored for two seasons in four Western States. Thirty-nine treated and 40 untreated sections were built with magnesium and calcium chloride mixed at two concentrations (1.5-percent and 2-percent pure chloride based on the dry weight of aggregate) with crushed aggregate surfacing 2 inches deep. Detailed periodic distress measurements of road surface conditions have shown significant reductions in dusting, raveling, and washboarding for the stabilized sections.

Construction costs for inplace stabilization are about \$8,000 to \$10,000 per mile depending on the chloride, construction process, and project location. Construction costs are offset by cost reductions for maintenance grading (blading), aggregate loss, and vehicle-use. Based on the projected life of the treated sections, the average annual savings for the 12 projects was \$3,300 per mile. The greatest savings are realized on projects where aggregate-surfacing replacement costs and average daily traffic volumes are high. Additional qualitative benefits are increased

Surface-Aggregate Stabilization with Chloride Materials

road-user safety, higher standard of road surface, reduced sedimentation in streams, reduced aggregate resource depletion, and reduced inhalation health hazard (dust). Cost analysis indicates treatment methods pay for themselves by the second season and, with proper maintenance treatments, will last 10 years.

After 2 seasons, monitoring indicates that, on average, treated surfacing needed blading after 25,500 vehicles, where untreated surfacing needed blading after only 3,200 vehicles; thus treated sections initial performance life was 8 times greater than untreated sections.

Based on 2 years of monitoring and analysis, chloride stabilization works well in moderately dry climates (semiarid), where daily traffic volumes are less than 250, and where crushed aggregate surfacing is well graded and has more than 11-percent minus #200 material. Performance is also influenced by the amount of 0.02-millimeter material and the plasticity index.

Performance of both magnesium chloride and calcium chloride was similar after 2 years. They are both hygroscopic (moisture absorbing) and deliquescent (moisture retaining). They attract moisture from air and promote greater density and capillary tension of fines in aggregate surfacing that helps bond the materials together. There are some significant construction advantages and resulting cost savings with dry or solid chlorides versus liquid chlorides. Although blade-mixing chlorides with a grader works, it costs more than mixing with a cross-shaft mixer or tractor-tiller.

Adverse environmental effects from the chloride on roadside trees and streams, along with lateral migration in the soil, were not shown to be a significant problem. Staff collected 96 soil samples, 20 water samples, and 202 tree samples and tested them for chloride content.

Thirty-six appendixes (on the enclosed CD) provide detailed cost and performance analysis, testing protocols and results, and construction and maintenance specifications. The information and tools in the appendixes will help road managers determine if stabilization is a cost-effective option.



Introduction

Each year, U.S. Department of Agriculture (USDA) Forest Service road managers maintain thousands of miles of unpaved roads by surface grading (blading). Blading is a high-cost activity typically done up to three times per year on heavily traveled roads. Aggregate-surface blading is a maintenance activity that also contributes to the increase of stream sediment and contamination and breakdown of expensive aggregate surfacing.

With road-surface stabilizers, the frequency of blading can be reduced significantly and results in financial savings and reduced environmental effects. Prior to this project, the USDA Forest Service's Northern Region completed a total of four projects that mixed calcium chloride into the road surface 2 inches deep. These projects had excellent results in stabilizing the aggregate-road surface and extending the service life between maintenance blading.

This project analyzes the use of calcium chloride and magnesium chloride as an aggregate-surface stabilizer with the following objectives:

- Refine a chloride stabilization process for crushed-aggregate road surfaces that road managers can implement to reduce blading maintenance, sediment generation, and road-surface defects, including dust, washboards, loose aggregate, and potholes.
- Determine long-term cost-effectiveness of the treatment in various conditions such as environment, traffic, road surface materials, road geometric, construction techniques, chloride types, and concentration percentage of the chloride treatment.
- Determine if streamwater quality and roadside vegetation are adversely affected.
- Develop tools for road managers to implement stabilization. These tools include:
 - Cost estimating guide.
 - Guidelines for predicting performance in various conditions.
 - Design guide for appropriate stabilization thickness, concentration percentage, product type, and construction process.
 - Construction specification.
 - Quality control and quality assurance procedures.
 - Maintenance procedures for blading.

Surface-Aggregate Stabilization with Chloride Materials

Project Scope

Staff engineers selected 12 roads in relatively dry-climate areas of Montana, Washington, Idaho, and Oregon. Appendix A1 shows the 12 roads plotted on an area map. Then, they divided each road into similar test sections ranging in length from 750 to 900 feet--79 test sections in all. For each project, the contractor constructed three types of sections, using four types of chlorides at concentration rates of 1.5- and 2.0-percent pure chloride salt based on the dry weight of aggregate. They mixed the treated sections with chloride using the blade and with a tractor-tiller (cross-shaft mixer). The contractor mixed at least one untreated control section with the blade or tractor-tiller to see if the construction process provided significant benefits by itself. They built at least one section to model the normal maintenance blading that is done on each road. Project locations are shown in figure 1 and project details are in the table 1.

Performance monitoring, measurements, and testing are a significant part of this project. Engineers measured road surface defects three to four times each season to determine the effective life of each test section. The treatment life and costs for aggregate loss, construction, maintenance, and road user costs are the primary inputs for a lifecycle cost analysis. They also measured environmental influences by testing chloride migration, roadside tree chloride concentration, and adjacent streams for streamwater contamination.

This publication provides project characteristics for the 12 projects, allowing forest road managers to determine if roads they want to stabilize are similar. These characteristics are traffic volume, ambient temperature, relative humidity, rainfall, road geometrics, aspect, canopy, and aggregate surface.



Figure 1—Project location map.

Surface-Aggregate Stabilization with Chloride Materials

Table 1—Project details

Project Number	Road Name	Project Location	Construction Date	Test Sections per Project	Number of Test Sections (Length from 750 to 900 ft)						Mixing Method	
					Untreated Control (a)	Normal Blading (b)	CaCl ₂ 94-percent Salt	CaCl ₂ 77-percent Salt	CaCl ₂ 36-percent Salt	MgCl ₂ 28-percent Salt	Tractor Tiller	Blade
1	Trout Creek	Western Montana	10/3/02	10	3	3	2		2		4	
2	Tucannon River	SE Washington	5/13/03	9	3	2		4			2	2
3	Miller Lake	South Central Oregon	5/14/03	4	1	1		2			2	
4	Williamson River	South Central Oregon	5/15/03	9	2	1	2	4			3	3
5	Wickiup Road	Central Oregon	5/16/03	8	2	2	2	2			4	
6	Conklin	Central Oregon	5/17/03	6	2	1	1	2			3	
7	Payette River	SW Idaho	5/18/03	4	1	1	2				2	
8	East Fork	Central Montana	5/28/03	8	2	2	2	2			4	
9	South Side	NW Montana	7/8/03	4	1	1				2		2
10	South Side II	Montana	7/9/03	4	1	1				2	2	
11	Deer Creek	Northern Idaho	7/9/03	4	1	1			2		2	
12	Snow Creek	Idaho	7/10/03	9	3	2			2	2	4	
Total Number of Sections				79	22	18	11	16	6	6	32	7

(a) An untreated control section is bladed, mixed, and compacted the same as treated sections except no chloride is added.

(b) Normal blading assimilates the traditional practice of blading to the bottom of all surface defects in the road surface, and then shaping to the desired crown.



Road Selection

The goal in road selection was to get a broad cross section of roads—that were in relatively dry climates—in three USDA Forest Service western regions. Within each road, test sections have similar aggregate, exposure, canopy, aspect, grade, and curvature. There were problems achieving similar test sections on three projects: the first segment of the Tucannon River Road had different aggregate; sections of the East Fork Road had minimal aggregate thickness; and road curvature and vehicle-speed variations were problems on the Conklin Road.

Test Road Construction

Moline Grading, Sandpoint, ID, was awarded a service contract for construction in September 2002. Oxford Inc., Moyie Springs, ID, provided, applied, and mixed all chloride materials. Moline Grading built the Trout Creek Road project as a pilot project in October 2002. They built the remaining 11 projects between mid May and early July 2003. The general construction process was as follows (see appendix D1 for photos of the construction process):

- Water all sections to assist the initial blading and shaping.
- Blade all sections to remove ruts, washboards, potholes, and process in loose aggregate. The road surface was shaped to a 4-percent crown.
- Water the road surface to ensure that the aggregate would be at optimum moisture during mixing where solid (dry) products were used. Do not apply water to the road surface prior to mixing liquid products for fear of exceeding optimum moisture.
- Apply and till chloride into the top 2 inches of aggregate for tractor-tiller mixed sections. Lightly shape the surface to ensure a 4-percent crown and then compact with a loaded watertruck. Note that the construction specification in appendix C1 requires a pneumatic roller, which is more proficient and cost effective on longer projects. Apply a light surface application of chloride to the finished surface.
- Build, size, and flatten windrows for blade-mixed sections. Base the size of the windrow on a 2-inch compacted depth times a 1.25-swell factor. Spread chloride materials on the flattened windrow and mix by moving material from one side of the road to the other, two times. Then, shape the mixed surfacing to a 4-percent crown and compact with a loaded watertruck. Note that the construction specification in appendix C1 requires a pneumatic roller, which is more proficient and cost effective on longer projects. Finally, spread a light surface application of chloride on the finished surface.
- Use application rates shown in table 2 for stabilization and surface application.

Surface-Aggregate Stabilization with Chloride Materials

Table 2—Calcium-chloride and magnesium-chloride application rates

Chloride Product Type and Concentration	Chloride for Stabilization Percentage by Weight of Dry Aggregate		Surface Application
	1.5%	2%	
Calcium-Chloride Solid (94 percent)	3.23 lb/sy*	4.31 lb/sy*	1.06 lb/sy*
Calcium-Chloride Solid (77 percent)	3.94 lb/sy*	5.26 lb/sy*	1.30 lb/sy*
Calcium-Chloride Liquid (36 percent)	0.74 gal/sy**	0.99 gal/sy**	0.24 gal/sy**
Magnesium-Chloride Liquid (28 percent)	1.01 gal/sy**	1.35 gal/sy**	0.33 gal/sy**

* Pounds per square yard

** Gallons per square yard.

Project Monitoring Road Surface Performance Monitoring

The contractor built 40 untreated control sections using the same methods as treated sections, except chloride materials were not used.

Road engineers used the comprehensive unsurfaced road condition index (URCI), developed by the U.S. Army Corps of Engineers, to monitor road surface performance (see appendix H). The URCI is a road management tool for scheduling maintenance and avoiding costly repairs. Similar but less measurement-intensive methods are used by many low-volume road agencies. The distress types or defects rated for this project are:

- Corrugations (washboards).
- Dust.
- Potholes.
- Ruts.
- Loose aggregate.

Each distress type measured is categorized into three severity levels (low, medium, and high) and the extent of each level is measured in square feet. Each measured distress level is converted into a value and subtracted from 100 to get the condition index. A defect-free road has a condition index of 100. Appendix F1 shows the field form used for road surface performance measurements and provides additional clarifications on the measurement process including minor modifications to make the URCI process more measurement intensive and to allow index values less than zero. Performance curves for each project are in appendix A3.



An example of the Tucannon River Road project performance curve is shown in figures 2 and 3 (see figures folder on enclosed CD). For additional information on URCI, refer to appendix H.

Prior to construction, engineers took aggregate loss measurements using a vertical survey grid on two sections of each project, one treated and one untreated. The final measurements are scheduled for 2006. Appendix F2 provides a protocol for the measurement process. It is assumed that all loss is from the road surface and not from intermixing with the subgrade since all roads have been arterials for many years and the subgrades are stable. Appendix B6 shows the initial aggregate-loss survey data for each project.

Engineers measured road surfacing strengths with a Clegg hammer. Strengths for treated and untreated sections had such a broad and overlapping range that the test was dropped from the monitoring program in August 2004.

The engineers observed road surface conditions to determine if blading was needed and to determine reasonable vehicle speed on each section. Vehicle speed is important because it influences user costs and provides another indication of road serviceability. Reasonable vehicle speeds and corresponding thresholds for blading needed and blading critical are on performance curves to provide a better description of the extent of deterioration that was taking place during each season. A 25-percent reduction in vehicle speed correlates with blading needed and a 40-percent reduction in vehicle speed correlates with blading critical. These thresholds are the basis for figuring maintenance and user costs.

Soil, Water, and Tree Monitoring

Engineers took 48 soil samples, from both treated and untreated sections on the road shoulder, before construction on each project. After two seasons, they took 48 additional samples on these same sections to see if there was a significant change in chloride concentration. Data in appendix E3 shows a rise in soil chloride levels that are below the thresholds for concern.

Before and after treatment of the Tucannon River Road, engineers measured chloride levels in the Tucannon River. Umatilla National Forest fisheries biologist, Dell Groat, arranged for sampling and testing of river water. The river varied 15 to 20 feet from the road shoulder. Results shown in appendix E4 indicate there is no significant change in calcium- or chloride-ion levels in the water after treatment.

Surface-Aggregate Stabilization with Chloride Materials

Weather Monitoring

On 4 projects, before construction, staff sampled 101 conifers close to the road and adjacent to a treated and an untreated test section. Locations of trees ranged from 5 to 50 feet from the road shoulder. Staff took duplicate samples from the same trees after two growing seasons to see if there was a significant increase in chloride concentration. Data from tree samples in appendix E5 indicates the chloride level increased, but is not a significant long-term threat to vegetation survival. USDA Forest Service Northern Region plant pathologist, Blakey Lockman, provided the sampling, testing protocol, and review of the results and conclusions. Photos of each section were taken before treatment in 2003 and two growing seasons after treatment in fall 2004. There was no discernible difference between the photo sets.

Onsite gauges measured relative humidity and temperature on all 12 projects. Gauges measured onsite rainfall on six projects. During 2003, staff gathered data on the other six projects using nearby remote automated weather stations. In 2004, all projects had onsite rainfall gauges. Onset Computer Corporation manufactured the onsite weather monitoring equipment. A summary of weather data is provided in appendixes A2 and G2 by project and year.

The data for spring, summer, and fall begins and ends when the average air temperature for 3 consecutive days reaches 32 degrees Fahrenheit. Deterioration of the road surface essentially stops when temperatures drop below freezing unless snowplowing takes place. Snowplowing on the Trout Creek Road removed substantial amounts of loose aggregate on the road surface and flattened the crown so much that pothole failures occurred the following season.

Precipitation during the spring, summer, and early fall was light in 2003 and heavy in 2004. About two-thirds of this precipitation occurred during the hot summer months as isolated thunderstorms dropping 0.3 to 0.5 inches of rain over a 1-hour period.

Construction Monitoring

Staff monitored construction equipment time and developed a cost guide, appendix B1, for the stabilization process. They also used construction costs in each project's cost analysis. A preliminary cost analysis is in appendix B8.

During construction, several quality assurance methods ensured that the chloride application rate specified was met and that liquid chloride materials met the minimum specified concentration. These methods are provided in appendix C2.



Road Blading Maintenance

The engineering staff monitored blading maintenance on treated sections on three projects during the first two seasons. Unfortunately, the results of this monitoring were not typical because of equipment breakdowns and unusual weather conditions. Treated-section blading on the other four projects was done under dry summer conditions and was not monitored. More controlled blading and monitoring was done in 2005 to illustrate the benefits of correct maintenance techniques. These maintenance techniques are in appendix C3.

Road Use

Staff collected vehicle traffic counts on all 12 projects. The South Side Road had the lowest seasonal average daily traffic (25), and the Middle Fork Payette River Road had the highest (157). Four of the 12 roads had peak daily traffic counts of over 400 vehicles with the greatest count being 922. The primary operating season is from April to November and is defined by freezing road conditions or snowfall. Cumulative traffic and average daily traffic are shown on performance graphs in appendix A3. The raw data used to generate the graphs is provided in appendix G1. Numerous traffic counter equipment problems occurred in 2003 and estimates had to be made on some projects during the performance period. Equipment and data were improved significantly in 2004 but estimated values were still necessary during certain time periods on some projects.

Forest road managers provided traffic classification and generally fit it into the three categories:

- Light vehicles including light-duty trucks (79 percent).
- Two-axle trucks and light-duty trucks with trailers (16 percent).
- Trucks with more than two axles (5 percent).

Laboratory Testing of Aggregate and Chloride Materials

Road-surfacing aggregate on 11 of the 12 projects is good quality, well-graded crushed aggregate. Gradation tests show from 48 to 72 percent passing the #4 sieve, and 11.1 to 17.2 percent passing the #200 sieve. These gradations perform well in semiarid climates because they capture the chloride ions in a relatively impervious gradation. Impervious gradations prevent rains from flushing chloride ions in the aggregate down into the subgrade. Less amount of minus #200 would be necessary if the minus-#40 materials were plastic. Aggregates on all projects are

Surface-Aggregate Stabilization with Chloride Materials

User Guide for Chloride Stabilization Projects

nonplastic, including the Payette River Road aggregate that was treated with 2.5-percent bentonite clay in 1999. Aggregate quality test results are in appendixes A2 and E1.

Engineers based the percentage of chloride used for stabilization on prior stabilization projects. The 1.5- and 2-percent chloride salt concentrations--by weight of aggregate surfacing--is similar to concentrations obtained by annual dust abatement treatments over a 4- to 6-year period. An indication of the optimum chloride content for a particular aggregate can be determined by running moisture density tests with various percentages of chloride, similar to an asphalt mix design. Experience with this approach is limited, but the optimum chloride content may be where density increases begin to level off and the mixture becomes relatively impermeable. Appendix E2 provides curves on three projects that represent a cross section of all projects and appendix F4 shows the mix-design test method. The modified Marshall hammer method provides higher and more realistic moisture density results for aggregate materials than the proctor method. It is easier to perform and is more repeatable than American Association of State Highway and Transportation Officials or American Society for Testing and Materials procedures.

Two samples of each chloride type were laboratory-tested to verify concentration percentage, impurities (sulfates and nitrates), and hazardous waste (arsenic and lead). Test methods are in appendix C2 and the results are in appendix E6.

The information provided in the appendixes is valuable for road managers considering chloride stabilization as an option for improving road surface performance.

The first step in a chloride stabilization project is to estimate the length of performance that can be expected for the project conditions.

- Compare the proposed project's characteristics with project characteristics listed in appendix A2.
- Select the project(s) with the closest project characteristics and look at the selected project(s) performance curves in appendix A3 to see if the results are desirable.
- Use performance equations as another option to predict performance. If additional monitoring is approved, these performance equations can be developed (appendix A6). The equations will permit more accurate life prediction because each project variable can be considered.



The second step is to perform a cost analysis.

- Perform a preliminary construction cost estimate using appendix B1.
- Tabulate the savings in annual blading maintenance, road user cost, and aggregate loss using appendixes B2, B5, and B7.
- Attempt to quantify intangible benefits for sedimentation, resource damage, road user safety, dust health hazard, and public opinion.
- Obtain price quotes for chloride materials from regional chloride manufacturers (appendix B1) and refine the construction cost estimate if the project is feasible.
- Complete the cost benefit analysis using appendix B8 as a guide.

The third step is to prepare the contract package.

- Visit the project, dig holes to confirm depths of aggregate surfacing and measure road crowns. Take representative samples for testing of gradation, Atterberg limits, and mix design. Using project data, check the original performance estimate and cost analysis.
- Review, and if necessary, edit the construction specification in appendix C1.
- Use the PowerPoint® presentation in appendix D2 to explain the process to management if necessary.

Cost and Performance Analysis

Treated-section performance for each project is most easily seen by viewing the graphs of cumulative traffic versus condition index in appendixes A3 and A4. These graphs show significant road surface performance benefits during 2003 and 2004. Several trends are:

- Sections untreated show an initial rapid deterioration due to high-speed traffic. After a significant number of defects develop, vehicle speed decreases and the deterioration rate decreases.
- Thresholds for blading needed and blading critical are based on reductions in vehicle speed, road manager comments, and visual observations of monitoring personnel. Appendix G4 shows correlations between the condition index and reasonable vehicle speed for each project. A 25-percent reduction in vehicle speed correlates with blading needed and a 40-percent reduction in vehicle speed correlates with blading critical. To visualize the significance of reductions in the condition index, the information was plotted on the performance curves in appendixes A3 and A4.

Surface-Aggregate Stabilization with Chloride Materials

The performance equation in appendix A6 will be completed if additional monitoring is approved. This work cannot be completed until more treated sections need blading. The equation allows road managers to make an estimated prediction on the performance life given their specific project conditions. The primary basis for this prediction model is the life ratios in appendix A5. Life ratio is defined as the amount of traffic on treated sections divided by the amount of traffic on untreated sections prior to blading being needed. Essentially, the ratio is a number that represents how much longer the initial performance life of the treated sections is versus the untreated sections prior to maintenance blading. The ratios in table 3 range from a low of 4 to a high of 57.

Table 3—Life ratios for each project

Project	Traffic Volume Prior to Blading Needed		Life Ratio
	Treated	Untreated	
Trout Creek	21,000	2,000	11
Tucannon	50,000	10,000	5
Miller Lake	10,200	2,800	4
Williamson	9,000	1,200	8
Wickiup	32,000	3,000	11
Conklin	17,000	3,000	6
Payette	52,500	5,000	11
East Fork	50,000	6,700	7
South Side	12,000	700	17
South Side II	20,000	350	57
Deer Creek	22,000	2,700	8
Snow Creek	11,000	1,000	11
Average	25,558	3,204	8

Staff developed construction costs for the four chloride products mixed by blade and tractor-tiller. They also developed costs for a 5-mile-long project located within 35 miles of Missoula, MT, Boise, ID, and Bend, OR. The format provided in appendix B1 serves as a cost guide. The construction times for each equipment operation came from detailed monitoring during test-project construction. Chloride costs came from regional suppliers shown in appendix B1. Follow directions on the spreadsheet to perform project estimates.



Blade maintenance costs in appendix B2 are based on the blading cost per mile and number of bladings needed over the 2003 and 2004 performance period. Cost-per-mile data was available from forest road managers and the actual equipment hours required for various road surface conditions. For consistency in the analysis, the blading cost per mile was based on the cost that correlated with the condition index for blading needed for each project. The number of bladings needed is based on staying above the blading needed line on performance curves provided in appendix A3. As expected, blading frequency is strongly influenced by traffic volumes, vehicle speed, and aggregate-surfacing quality.

The average condition index for normally bladed versus untreated control sections was very similar as shown in appendix G3. This indicates there are little long-term performance benefits from compaction while doing routine blading on untreated aggregate surfacing. Results were inconsistent, but an overall average showed a slight increase in condition index and vehicle speeds for the compacted segments over those not compacted. These increases in performance probably do not justify compaction's added expense. Greater increases in performance can probably be obtained by watering during blading.

Staff used the World Bank Roads Economic Decision Model for determining road-user costs in appendix B5. Variables in this model include road roughness, vehicle speeds and types, terrain, and road surface. Appendix B4 provides average vehicle speed throughout the season for each project for both untreated and treated sections. This analysis was based on only one vehicle, which was described as a "goods vehicle" driven in mountainous terrain on an aggregate surface. This vehicle has a 4,000-pound gross weight, a new cost of \$14,000, and is driven 20,000 miles per year. Fuel costs are \$1.14 per gallon. Increasing vehicle and fuel costs to current values and selecting a mix of vehicles that included trucks would show an even greater user-cost savings for vehicles traveling over treated road surfaces.

Staff will determine aggregate replacement costs by conducting an identical vertical survey at the initial sites in 2005. Aggregate loss is expected to be a significant cost factor for untreated road segments. Initial survey measurements for aggregate loss are shown in appendix B6. An estimated loss, based on loss of dust from the aggregate, is in appendix B7. This estimate is based on the 1973 Iowa Highway Research Board Project HR-151 test results and assumes that aggregate loss is proportional to dust loss.

Surface-Aggregate Stabilization with Chloride Materials

Intangible Benefits

The cost benefit summary and analysis, appendix B8, compares all costs for untreated and treated sections on the 12 projects. This analysis cannot be finished until more treated sections need blading and the aggregate loss survey is completed. Preliminary results indicate that the treatment cost is recovered during the second season for some projects. The graph in figure 4 (from figures folder) compares the life cycle cost benefits of both untreated and treated sections of all projects. This graph is based on 2 years of actual performance and long-term projections that depend on annual maintenance practices on treated sections that have been used successfully by others. Figures 5 and 6 (from figures folder) show the cumulative cost by year for both treated and untreated sections on 2 of the 12 projects.

There are five intangible benefits that may, in many cases, be more important than actual costs.

Sediment Reduction

Research by Randy Foltz, USDA Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory, Moscow, ID, and others has shown that if road blading is reduced, sediment that reaches streams is reduced. This project shows that blading is reduced when road surfaces are stabilized. When sediment is reduced, costs are reduced or eliminated for design, construction, and maintenance of sediment control structures.

Resource Damage from Aggregate Sources

Road surface stabilization clearly reduces the need for aggregate replacement. Less aggregate usage would conserve aggregate resources that are scarce in many areas and save funds currently spent for locating new sources, preparing pit development plans, securing necessary permits, and developing and restoring the site.

Road User Safety

Chloride materials are an effective dust abatement product, as well as a stabilization agent. Less dust reduces vehicle accidents, which reduce costs associated with vehicle repair and medical expenses. Less dust also decreases loss of life.

Dust Inhalation of Airborne Particulate

Public health costs are less when a known health hazard, such as dust, is reduced. The extent of the benefit is based on the amount of vehicular traffic on a road, the number of vehicle occupants, and the number of individuals exposed for longer periods in roadside residences and campgrounds.



Conclusions

Treated Sections versus Untreated Sections

Public Opinion

Poorly maintained public roads generate negative public opinion. Public complaints require valuable employee resources that adversely affect the Government workforce's overall productivity.

The following conclusions are from field observations and data collected during construction and monitoring of this project throughout the 2003 and 2004 seasons.

- Economic benefits of stabilization are greatest on projects well suited for stabilization, that have high traffic volumes, and that have high costs for aggregate replacement.
- The average initial performance period for the treated sections lasted eight times longer than the untreated sections: sections treated required blading after 25,500 vehicles, and untreated sections required blading after 3,200 vehicles.
- Average speed on treated sections was 37 miles per hour and the average speed on untreated sections was 26 miles per hour for the 2-year period.
- Four of the 39 treated sections needed blading for part of the 2003 season.
- Blading became critical on several untreated sections during the same 2003 season.
- Forty untreated sections needed blading 95 percent of the time during the 2003 season.
- Rate of deterioration decreases as more defects develop in the road surface and traffic speed decreases.
- Visual observations indicate treated sections reduced the dust by approximately 90 percent, thus reducing inhalation health hazard.
- Condition of all test sections improved after periods of wet weather and over the winter season. Treated sections improved more than untreated sections.

Surface-Aggregate Stabilization with Chloride Materials

Treated Sections

- During the first 2 years of monitoring, 13 of 39 treated sections needed blading. Six of these sections had construction problems or the crown was removed by snowplowing. The predominant failure mode in the other seven sections was potholing, washboarding, and rutting. All the pothole problems existed where the crown was less than 2 percent due to snowplowing or at the centerline where the crown was flattened by traffic.
- No distinct difference in performance existed between the four different products: magnesium chloride liquid, calcium chloride liquid, and calcium chloride solid at 77- and 94-percent salt concentration.
- After the 2004 season, no significant difference in performance was noticed on 2-percent chloride content versus 1.5 percent. A greater difference in performance may be evident in year 2005.
- Chloride stabilization does not improve resistance to surface erosion or pothole formation. Road crown is the primary deterrent to the formation of potholes and surface erosion.
- Poor performance was noted on all treated test sections that potholed due to either a low or flattened crown. Water in potholes may leach chloride from the treated surface.
- Aggregate materials on 11 of 12 projects performed well when stabilized. Miller Creek Road was the exception because there was 14-percent 3/4- by 1-1/2-inch material that caused raveling. All other projects were essentially 3/4-inch minus and dense graded with a minus #200 range of 11.2 to 17.1 percent and no plasticity. Dense-graded aggregates with this amount of minus #200 work well because chloride ions are held within a relatively impervious medium. Minus #200 contents between 8 and 12 percent may also work well if minus #40 fraction was plastic.
- No correlation existed between project performance and gradations plotted on the 0.45 power curve. Curves for each projects' aggregate gradation are provided in appendix E1.
- In dryer climates, treated road surfaces may dust in early spring before spring rains. These surfaces regain their treated appearance (wet look), and harden-up when rains come or when the surface is watered.



Construction

- All project and construction characteristics influence the performance of chloride-treated aggregate surfaces. The most significant appear to be aggregate characteristics, climate, traffic volume, and moisture content when maintenance blading. If additional monitoring is approved, the relative significance will be reflected in appendix A6 (performance equation) after the 2005 season.
- The average daily minimum humidity appears to correlate with performance of the chloride-treated sections. The East Fork project was very successful and had an average daily minimum humidity of 26 percent. The three projects in central Oregon that had minimum average daily humidity below 23 percent had marginal performance but also had porous gradations. Periodic summer rains improve performance on impervious surfacing but decrease performance on porous surfacing materials. Other relative humidity and temperature statistics do not appear to be good performance predictors. Projects located next to streams or that had thick roadside vegetation to provide shade, performed better than those in more arid climates.
- Blading-treated sections when moisture is below optimum decreases stabilization effectiveness. Allowing the bladed surface to remain loose and dust will reduce long-term performance. The wet-blading—as explained in appendix C3, will pull enough chloride and fines to the road surface to create a dried crust that will last as long as the original treatment.
- There is no significant difference in the performance of untreated normally bladed sections and untreated compacted control sections. This indicates the following:
 - Compaction has no long-term benefits in maintenance blading.
 - Normal blading practices used during test-section construction removed all road surface defects was as effective as milling or blade-mixing 2 inches deep. However, this blading costs \$284 per mile and probably removed many more defects and built better crowns than the typical maintenance blading. On 8 of the 12 roads the average maintenance blading contract costs \$157 per mile. During the second season most contract-bladed untreated sections developed defects more rapidly than blading done during test-section construction.

Surface-Aggregate Stabilization with Chloride Materials

- Superior performance of treated sections over untreated control sections indicates that the good performance is due to stabilization agents and not the stabilization construction process.
- Aggregate roads should be stabilized with chloride in early spring when road surface moisture content and humidity are high and late spring rains will keep the surface wet while traffic flushes fines to the surface. The fines form a hard crust when dry.
- Blade-mixing consistency is very dependent on operator capability and machine condition.
- Blade-mixed sections deteriorated more rapidly than tractor-tiller mixed sections, due to treatment depth inconsistencies and nonuniform mixing. A minimum depth of 2.5 inches is recommended for blade mixing.
- Blade mixing a 2.5-inch depth of aggregate surfacing is not practical where road widths are less than 18 feet, because the loose berm covers too much of the road width.
- Blade mixing liquid chlorides is not practical on roads with grades over 2 percent because the product will run in distributor wheel tracks to sag vertical curves or off the road surface.
- Blade-mixing operations require more quality assurance and technical expertise to ensure the correct amount of aggregate is mixed with chloride and that the treated thickness is uniformly mixed to the specified depth.
- Traffic delays and construction interruptions with blade mixing are more significant than with tractor-tiller mixing for all chloride products.

Recommendations

Road managers should consider chloride stabilization as a cost-effective method when selecting maintenance options and strategies for aggregate-surface roads. This publication discusses the performance characteristics and economic benefits that can be expected when chloride is used as a stabilizing agent. The average performance life of the treated sections were eight times greater than the untreated sections. Over the projected 10-year life of the treated sections, a savings of \$3,300 per mile can be realized in maintenance costs when compared to not stabilizing the road surface. Additional nonmonetary benefits of chloride stabilization include reduced stream sedimentation, reduced inhalation health hazards, and increased road-user safety.

The following are additional recommendations when using chloride products as a stabilizer on aggregate surfaced roads.



Design

- Only allow blade mixing on roads wider than 18 feet. Delete blade mixing option in Section 311.06 (appendix C1) for projects with road widths less than 18 feet.
- Use minimum treatment depths of 2 inches for tractor-tiller mixing and 2.5 inches for blade mixing.
- When stabilizing with chloride materials, use the following road-surface crown-construction requirements to avoid pothole problems:
 - 4-percent minimum crown for roads with grades over 2 percent.
 - 5- to 6-percent crown for roads with grades under 2 percent.
- Follow the recommended aggregate characteristics shown in table 4. Performance of aggregate with preferred characteristics will exceed the acceptable characteristics, which are typical of most sections treated on the 12 projects.

Table 4—Recommended aggregate characteristics

Characteristic	Preferred	Acceptable
Maximum Size	3/4 inch	1 inch
Percent Pass #4	55 to 65	50 to 70
Percent Pass #200 (Nonplastic)	14 to 17	12 to 17
Percent Pass #200 (Plastic)	12 to 15	8 to 15
Plasticity Index	2 to 9	Nonplastic
Los Angeles Abrasion	Less than 30	Less than 40
Percent Fracture, one face	Greater than 85 percent	Greater than 75 percent

Construction

Tractor-tiller mixing:

- Add additional water to the road surface prior to spreading dry chloride to get close to optimum moisture. Mix both into the aggregate surfacing at the same time.
- Mix liquid products into the road surface immediately after application to prevent liquid from running off road surface.
- Evaluate the loose mixing depth continuously, using a 1.25 swell factor times the specified compacted thickness.
- Follow quality and quantity assurance methods contained in appendix C2.

Surface-Aggregate Stabilization with Chloride Materials

Blade mixing:

- Do not use blade mixing on roads less than 18-feet wide.
- Blade cutting edge height should not vary more than 1/2 inch to ensure that mixing is consistent and that crowns are properly built.
- Do not use motorgraders with carbide mold boards for mixing.
- Measure and size windrows to obtain the desired chloride percentage.
- Continuously monitor mixed material for uniformity and consistency.
- Follow quality and quantity assurance methods contained in appendix C2.

Liquid chloride:

- Be more cautious with magnesium chloride than calcium chloride liquid because magnesium chloride contains more water due to a lower salt concentration.
- Do not blade-mix liquid products on roads with grades over 2 percent.
- Use tractor-tiller mixed liquid products right behind the distributor on grades over 2 percent.
- Use caution when adding water during blading. Too much water prior to adding liquid products will cause the mixed aggregate to be over optimum moisture. Liquid products should not be used when rain is imminent.
- Delay the final application of magnesium chloride liquid on the compacted road surface at least 1 week after construction to avoid product runoff into ditches.
- Spray the final surface application in two passes to help control runoff.
- Follow quality and quantity assurance methods contained in appendix C2.

Maintenance

- Maintain stabilized roads each spring with light blading to recreate the 4- to 6-percent crown.
- Blade according to procedures in appendix C3, Maintenance Methods.
- After 4 to 6 years, consider the need for a chloride dust abatement application to ensure a 10-year life.



Additional Studies

During the first 2 years of this study, engineers recognized many unforeseen critical areas of work but were beyond the scope, time, and resources available. With additional funding and monitoring, the following areas could be developed:

- Determine the initial performance life of all the treated sections since five of the projects did not need blading in the first 2 years of monitoring.
- Develop performance life-prediction equation (appendix A5) based on all 12 projects, not just the 7 projects where the treated sections needed blading.
- Evaluate performance of the four chloride types used on the project.
- Evaluate performance of the 2-percent chloride content versus the 1.5-percent content.
- Monitor performance of recommended blading practices (wet blading versus dry blading).
- Finish long-term performance and cost analysis.
- Evaluate long-term performance of treated sections that are bladed wet annually in the spring.

Acknowledgements

We would like to express appreciation to the eight USDA Forest Service road managers and their assistants for logistical and technical support. Special thanks to Peter Bolander, USDA Forest Service Pacific Northwest Region materials engineer, and William Vischer, Northern Region materials engineer, for their technical contributions throughout the study and especially for their review of the final report.

For additional information on this chloride stabilization project, contact San Dimas Technology & Development Center (SDTDC) by phone at 909-599-1267.

This publication is the result of a partnership between the USDA Forest Service technology and development program and the U.S. Department of Transportation Federal Highway Administration (FHWA) Coordinated Federal Lands Highway Technology Improvement Program.

SDTDC's national publications are available on the Internet at <http://www.fs.fed.us/eng/pubs/>.

USDA Forest Service and U.S. Department of the Interior Bureau of Land Management employees also can view SDTDC's videos, CDs, and individual project pages on their internal computer network at <http://fsweb.sdtc.wa.fs.fed.us/>.

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