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Environmental Technology Verification

Dust Suppressant Products

North American Salt Company's DustGard

Prepared by

Midwest Research Institute

RTI International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**DUST SUPPRESSANT**
APPLICATION:	**CONTROL OF DUST ON UNPAVED ROADS**
TECHNOLOGY NAME:	**DustGard**
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, permitters, and other interested parties; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Air Pollution Control Technology (APCT) Verification Center, a center under the ETV Program, is operated by RTI International (RTI) in cooperation with EPA's National Risk Management Research Laboratory. The APCT Center has evaluated the performance of a dust suppressant product for control of dust on an unpaved road.

ETV TEST DESCRIPTION

A field test program was designed by RTI and Midwest Research Institute (MRI) to evaluate the performance of dust suppressant products. Five dust suppressants manufactured or distributed by three firms were tested in this program. The field test for North American Salt Company's DustGard was conducted at Fort Leonard Wood, Missouri (FLW). A July 2003 test/QA plan for the field testing was developed and approved by EPA. The test/QA plan describes the procedures and methods used for the tests. The July 2003 version of the test/QA plan was based on an October 2002 version and a subsequent test/QA plan addendum (dated February 19, 2003). The goal of each test was to measure the performance of the products relative to uncontrolled sections of road over a 1-year period. Field testing was planned quarterly over a 1-year period; however, some logistical difficulties related to winter weather and then maintenance activities on the roads of interest arose, and the test/QA plan was revised (Rev 3) to address those issues. Test periods occurred per the test/QA plan for three roughly 6-month periods. Two of those test periods are summarized below and are considered most representative of product performance; the third testing period occurred after unexpected road maintenance, and those data may be seen in the verification report. The verification report also contains 90 percent confidence limits for the data collected during all of the test periods. Emissions measurements were made for total particulate (TP), particulate matter less than or equal to 10 micrometers (μm) in aerodynamic diameter (PM_{10}), and for particulate matter less than or equal to 2.5 μm in aerodynamic diameter ($PM_{2.5}$).

The host facility for the field test program, FLW, is a U.S. Army base. The test site used unpaved Roads P and PA in training area (TA) 236. Roads P and PA are the main access routes to TA 236 and are traveled by truck convoys, as well as traffic into and out of TA 236. DustGard was applied to test section E, located on Road PA; and test section F, located on Road P, was left untreated as the experimental control. Section 3.1 of the verification report provides a figure showing the test locations. Testing was conducted during October 2002, May 2003, and October 2003.

Table 1 presents test conditions for key parameters that may affect the performance of dust suppressants on unpaved roads.

Table 1. Test Conditions

Parameter	FLW, October 2003	FLW, May 2003
Initial application rate, l/m^2	2.5	2.5
Follow-up application rate, l/m^2	2.5	2.4
Time between application and testing, days	122	79
Precipitation during test week, cm	0.2	3.7
Precipitation during week before testing, cm	1.8	3.2
Precipitation between application and testing, total, cm	39	24
Soil moisture during test weeks, %—uncontrolled road	0.62–1.5	0.01-1.8
Soil moisture during test weeks, %—controlled road	1.9–3.5	0.20-0.42
Soil silt during test weeks, %—uncontrolled road	1.7–5.4	1.6-4.3
Soil silt during test weeks, %—controlled road	1.2 – 1.7	1.2-2.6

The DustGard product was analyzed using an array of chemical and toxicity tests. The results of these tests are included in the appendices to the verification report. A summary of the toxicity data is presented in Table 2.

Table 2. Toxicity Test Results

Species	Acute LC_{50} for survival	Chronic LC_{50} for survival	Chronic EC_{50}
Ceriodaphnia dubia	>1,000 mg/L (48-hr)	>1,000 mg/L (7-d)	>1,000 mg/L (7-d), reproduction
Fathead minnow	>1,000 mg/L (96-hr)	>1,000 mg/L (7-d)	>1,000 mg/L (7-d), growth
Americamysis bahia	>1,000 mg/L (96-hr)	>1,000 mg/L (7-d)	>1,000 mg/L (7-d), growth, fecundity

d = day
EC_{50} = effective concentration which affects 50% of sample population
hr = hour
LC_{50} = lethal concentration which kills 50% of sample population
LOEC = lowest observed effective concentration
mg/L = milligrams per liter
NOEC = no observed effect concentration

VERIFIED TECHNOLOGY DESCRIPTION

This verification statement is applicable to *North American Salt Company's DustGard*, which is a hygroscopic product made of magnesium chloride. The material safety data sheet (MSDS) for DustGard is retained in the RTI project files and is available at http://www.nasalt.com/msds/Magnesium%20Chloride%20(liquid).pdf [accessed July 2005].

VERIFICATION OF PERFORMANCE

The overall reduction in particulate matter emissions achieved by the DustGard dust suppressant compared to uncontrolled sections of road is shown in Table 3.

Table 2. Summary of Test Results

Test location and period	Average control efficiency, %			Noted events
	TP	PM_{10}	$PM_{2.5}$	
FLW, October 2003	86	>90	59	Rain events the day before test.[a]
FLW, May 2003	75	88	58	Rain events the morning of test.[b]

[a] All test sections were wet from rain the previous day. The uncontrolled section was heavily potholed and another section was used for the test. MRI used traffic to dry the road before testing.
[b] Rainfall in the morning meant that the uncontrolled section of the road was wet and another section was used for the test.

The APCT Center QA officer has reviewed the test results and quality control data and has concluded that the data quality objectives given in the generic verification protocol and test/QA plan have been attained. EPA and APCT Center QA staff have conducted technical assessments at the test organization and of the data handling. These confirm that the ETV tests were conducted in accordance with the EPA-approved test/QA plan.

This verification statement verifies the effectiveness of *North American Salt Company's DustGard* to control dust on unpaved roads as described above. Extrapolation outside that range should be done with caution and an understanding of the scientific principles that control the performance of the technologies. This verification focused on emissions. Potential technology users may obtain other types of performance information from the manufacturer.

In accordance with the generic verification protocol, this verification statement is valid, commencing on the date below, indefinitely for application of *North American Salt Company's DustGard* to control dust on unpaved roads.

Signed by Sally Gutierrez 9/25/2005

Sally Gutierrez, Director Date
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Signed by Andrew Trenholm 9/16/2005

Andrew R. Trenholm, Director Date
Air Pollution Control Technology Verification Center

Environmental Technology Verification

Dust Suppressant Products

North American Salt Company's DustGard

Prepared by:

RTI International
Midwest Research Institute

EPA Cooperative Agreement No. CR829434-01-1
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Notice

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* RTI International is a trade name of Research Triangle Institute.

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Abstract

Dust suppressant products used to control particulate emissions from unpaved roads are among the technologies evaluated by the Air Pollution Control Technology (APCT) Verification Center, part of the U.S. Environmental Protection Agency's Environmental Technology Verification (ETV) Program. The critical performance factor for dust suppressant verification is the dust control efficiency (CE). CE was evaluated in terms of total particulate (TP), particulate matter less than or equal to 10 micrometers (μm) in aerodynamic diameter (PM_{10}), and particulate matter less than or equal to 2.5 micrometers (μm) in aerodynamic diameter ($PM_{2.5}$).

North American Salt Company submitted the DustGard dust suppressant to the APCT Center for testing. The test and quality assurance (QA) plan, prepared in accordance with the Generic Verification Protocol (GVP), addressed the site-specific issues associated with these 1-year verification tests. The 1-year testing was conducted at Fort Leonard Wood, Missouri, during October 2002, May 2003, and October 2003. This verification report summarizes the results of the 1-year test. The verified CE will be based on all tests at each site, as specified in the test/QA plan. Test conditions were measured and documented.

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List of Acronyms and Abbreviations

ADT	average daily traffic
ANOVA	analysis of variance
APCT	air pollution control technology
BOD	biological oxygen demand
CE	control efficiency
cfm	cubic feet per minute
CI	confidence interval
cm	centimeters
COD	chemical oxygen demand
DQO	data quality objective
DPW	Directorate of Public Works
EC_{50}	effective concentration, 50 percent
EPA	U.S. Environmental Protection Agency
ETV	environmental technology verification
FLW	Fort Leonard Wood, Missouri
ft	feet
g	grams
g/mL	grams per milliliter
gal	gallons
GPS	global positioning system
GVP	generic verification protocol
hi-vol	high volume
in.	inches
km	kilometer
l or L	liters
lb	pounds
LC_{50}	lethal concentration, 50 percent
LOEC	lowest observed effective concentration
lpm	liters per minute
µg	micrograms
µm	micrometer
m	meters
mg	milligrams
min	minutes
ml	milliliters
mph	miles per hour
MRI	Midwest Research Institute
MSDS	material safety data sheet
NA	not applicable
NOEC	no observed effect concentration
PM	particulate matter
PM_{10}	particulate matter equal to or less than 10 µm in aerodynamic diameter
$PM_{2.5}$	particulate matter equal to or less than 2.5 µm in aerodynamic diameter
QA	quality assurance
QC	quality control

RSD	relative standard deviation
RTI	RTI International
s	seconds
TA	training area
TCLP	toxicity characteristic leaching procedure
TP	total particulate
WAF	water accommodated fractions
yd	yard

1.0 Introduction

The objective of the Air Pollution Control Technology (APCT) Verification Center, part of the U.S. Environmental Protection Agency's (EPA's) Environmental Technology Verification (ETV) Program, is to verify, with high data quality, the performance of air pollution control technologies. One such set of air pollution control technologies consists of products used to control dust emissions from unpaved roads. Dust suppressant products are, in general, designed to alter the roadway by lightly cementing the particles together or by forming a surface that attracts and retains moisture. Control of dust emissions from unpaved roads is of increasing interest, particularly related to attainment of the ambient particulate matter (PM) standard. EPA issued a new ambient standard for PM in 1997 that specifies new air quality levels for particulate matter less than or equal to 2.5 micrometers (μm) in aerodynamic diameter ($PM_{2.5}$).[1]

The APCT Center's verification of dust suppression products started with a preliminary 3-month testing program at Fort Leonard Wood, Missouri (FLW). The objective of this preliminary test program was to develop a cost-effective technique to measure the relative performance of dust suppressant products. The more common, but resource intensive, exposure profiling method to measure fugitive dust was compared to a mobile dust sampler. It was concluded that the mobile dust sampler could be used for future testing. A total of seven dust suppressant products were evaluated in the preliminary testing. Seven reports documenting the performance of these products were finalized in November 2002.[2]

After completion of the preliminary study, a 1-year field test program was designed by RTI and Midwest Research Institute (MRI) to evaluate the performance of dust suppressant products. Five dust suppressants manufactured or distributed by three firms were tested in this program. One of those dust suppressants was DustGard, developed by North American Salt Company. DustGard is a hygroscopic (attracts moisture) dust control and soil stabilization product made of magnesium chloride. The material safety data sheet (MSDS) for DustGard is retained in the RTI project files and is available on North American Salt Company's Web site (http://www.nasalt.com/msds/Magnesium%20Chloride%20(liquid).pdf) [accessed July 2005].

The field test program for DustGard was conducted at FLW. In July 2003, the test/quality assurance (QA) plan for the field testing was developed and approved by EPA.[3] The July 2003 version of the test/QA plan was based on an October 2002 version and a subsequent test/QA plan addendum (dated February 19, 2003). This test/QA plan describes the procedures and methods used for the tests. The goal of each test was to measure the performance of the products relative to uncontrolled sections of road over a 1-year period. Field testing was planned quarterly over a 1-year period; however, some logistical difficulties related to winter weather conditions and then maintenance activities on the roads of interest arose, and the test/QA plan was revised (Rev 3) to address those issues. Test periods occurred per the test/QA plan for three roughly 6-month periods, during October 2002, May 2003, and October 2003. Emissions measurements were made for total particulate (TP), particulate matter less than or equal to 10 μm in aerodynamic diameter (PM_{10}), and for $PM_{2.5}$.

This report contains only summary information and data from the 1-year test program, as well as the verification statement related to the dust control efficiency (CE) measured for DustGard during testing at FLW. Complete documentation of the FLW test results is provided in a separate test report[4] and a data quality audit report.[5] Those reports include the raw test data from product testing and supplemental testing, equipment calibration results, and QA and quality control (QC) activities and results. Complete documentation of QA/QC activities and results, raw test data, and equipment calibration results are retained in MRI's files for 7 years.

The results of the tests are summarized and discussed in Section 2. The conditions in which the tests were conducted are presented in Section 3, and references are presented in Section 4.

2.0 Summary and Discussion of Results

Verification tests were conducted over a 1-year period on North American Salt Company's DustGard dust suppressant as applied to unpaved roads at FLW. Original plans called for testing to occur on a quarterly basis; however, one quarterly test was abandoned due to persistently unfavorable wintertime weather at FLW.

The mobile dust sampling system used in this test program provides quantitative information on relative emissions levels. The mobile system consists of a high-volume (hi-vol) PM_{10} cyclone combined with a $PM_{2.5}$ cyclone. The sampler inlet sits above the densest portion of the dust plume, immediately behind the test vehicle. In this location, the sampler collects PM that is truly airborne. The hi-vol sampler is operated with a nozzle matched to the test vehicle's travel speed to best approximate isokinetic sampling. The test plan provides additional details on the construction and operation of the mobile sampler.

The results of the quarterly tests are summarized in Section 2.1. The results of laboratory toxicity tests on the product are included in Section 2.2. The results of QC checks performed during these quarterly tests are summarized in Section 2.3. Deviations from the test plan are discussed in Section 2.4.

2.1 Verification Results

Tables 1 and 2 present summary statistics for results from each test period. The mobile sampler provides a test result in terms of particulate mass collected per distance traveled [milligrams per 1,000 feet (mg/1,000 ft)]. The tables show the number of days after product application, the mean controlled and uncontrolled emissions values, and the resulting CEs. The relative standard deviation (RSD) for the emissions values is shown in parentheses.

The uncontrolled and controlled emissions values for the mobile dust sampler are means of five replicate measurements. Each of the five replicate measurements consisted of twelve passes over a 500-ft length test section of the treated road segment, to total approximately 6,000 ft of distance covered. Detection limits were set at two standard deviations above the average filter blank correction for sample mass. Values below the detection limits (quantification level) were included in the averaging process at half the detection limit.

Table 1 presents data for the test period when no unexpected road maintenance occurred between product application and testing. These data are considered the most representative of the product's performance. Table 2 presents data when unexpected road maintenance occurred. These data provide an example of performance under the described circumstances.

Table 1. Summary of Test Results for DustGard (No Road Maintenance)

Test period	Uncontrolled emissions, mg/1,000 ft *(RSD, %)*			Time since last application, days	Controlled emissions, mg/1,000 ft *(RSD, %)*			Control efficiency, %		
	TP	PM_{10}	$PM_{2.5}$		TP	PM_{10}	$PM_{2.5}$	TP	PM_{10}	$PM_{2.5}$
October 2003[a]	7.9	0.68	1.5	122	1.2	<0.07[b]	0.61	86	>90	59
	(59)	*(78)*	*(27)*		*(20)*	*(0.0)*	*(24)*			
May 2003[c]	9.1	1.2	0.71	79	2.3	0.14	0.29	75	88	58
	(14)	*(21)*	*(29)*		*(47)*	*(66)*	*(79)*			

[a] All test sections were wet from rain the previous day. The uncontrolled section was heavily potholed and another section was used for the test. MRI used traffic to dry the road before testing.
[b] All values were below the detection limit.
[c] Rainfall in the morning meant that the uncontrolled section of the road was wet and another section was used for the test.

Table 2. Summary of Test Results for DustGard (After Road Maintenance Occurred)

Test period	Uncontrolled emissions, mg/1,000 ft *(RSD, %)*			Time since last application, days	Controlled emissions, mg/1,000 ft *(RSD, %)*			Control efficiency, %		
	TP	PM_{10}	$PM_{2.5}$		TP	PM_{10}	$PM_{2.5}$	TP	PM_{10}	$PM_{2.5}$
October 2002[a]	9.5	2.3	2.5	129	12	1.2	<0.65[b]	[c]	46	>74
	(36)	*(55)*	*(41)*		*(16)*	*(10)*	*(0.0)*			

[a] Unexpected road maintenance activity occurred at FLW in September 2002 prior to the October 2002 test period. After consideration, it was decided to continue with planned testing; however, in retrospect, the treated surface evaluated during this test period was not representative, and control efficiency values from the test period should be viewed as conservatively low.
[b] All values were below the detection limit.
[c] No emissions reduction was observed.

The dust emissions CE is calculated as follows:

$$CE = 100 \times (e_{um} - e_{cm})/e_{um} \qquad \text{Eq. 1}$$

where

CE = control efficiency (percent)

e_{um} = uncontrolled emissions value, expressed as sample mass divided by the cumulative length of road traveled by the mobile sampler (mg/1,000 ft)

e_{cm} = controlled emissions value, expressed as sample mass divided by the cumulative length of road traveled by the mobile sampler (mg/1,000 ft).

Control efficiencies can vary considerably between test periods, and some of the variation can be related to two factors: (1) the time since the most recent application and (2) the application rate of the dust suppressant. A complete history of the test road treatment is given in Section 3.2. The time since the most recent application is shown in Tables 1 and 2, in addition to information on road maintenance activities and rainfall. Beyond the application rate and the time since application factors, additional variation can arise from changing site conditions. For example, unplanned road maintenance occurred, as noted in Table 2. In addition, precipitation before or during a field test could cause variation in both uncontrolled and controlled test results: measured emissions could change after precipitation so that back-to-back tests would not necessarily be "replicates" in the sense of having identical test conditions. MRI always attempted to dry the road with traffic to the point that it appeared visibly dry before beginning a test period.

2.2 Laboratory Toxicity Test Results

A sample of DustGard was taken when the product was applied at FLW. The product was sent to ABC Laboratories, Columbia, Missouri, and to Tri-State Laboratories, Inc., Youngstown, Ohio, for analysis. The following test methods were used in accordance with the test/QA plan:[3]

- **Environmental/Chemical Testing**
  - EPA Method 24[6] — Volatile Organics
  - EPA Method 405.1[7] — 5-day Biochemical Oxygen Demand (BOD) of product
  - EPA Method 410.4[8] — Chemical Oxygen Demand (COD)
  - EPA Method 1311[9] — Toxicity Characteristics Leaching Procedure (TCLP)
  - EPA Method 6010B[9] — Inorganics/Metals
  - EPA Method 6010B[9] — Title 22 Metals
  - EPA Method 8260B[9] — Volatile Organics
  - EPA Method 8270[9] — Semivolatile Organics
  - EPA Method 8270D[9] — Semivolatile Organics
  - EPA Method 8270D[9] — Pesticides and Herbicides

- **Effluent Toxicity Testing**
  - EPA600/4-90/027F[10] — Acute toxicity: Water fleas lethal concentration (LC_{50}), Fathead minnow LC_{50}, and Mysid shrimp LC_{50}
  - EPA/600/4-91/002[11] — Chronic Toxicity: Water fleas LC_{50}, Fathead minnow LC_{50}, and Mysid shrimp LC_{50}.

See Appendices A and B for the environmental and chemical test results, respectively.[12, 13] RTI also conducted Method 24 tests on the product samples;[14] see Appendix C for those results.

2.3 Discussion of QA/QC

The testing process was based on the approved *Generic Verification Protocol for Dust Suppression and Soil Stabilization Products* (GVP);[15] and the *Test/QA Plan for Testing of Dust Suppressant Products at Fort Leonard Wood, Missouri*, Rev 3 (July 24, 2003).[3] The MRI task leader and QA manager verified that the quality criteria specified in the test plan were effectively met for the overall test. Section 2.4 of this report discusses deviations from the test plan. Section 3.4 and A.4 of the test plan present the criteria. Assessments specified in Section 8 of the GVP were performed. Reconciliation of the data quality objectives (DQOs) with test results is summarized in Table 3. Data from all three test periods are included in the analysis, including those data collected during the test period following unexpected road maintenance.

Table 3. DQOs versus Final Control Efficiency Variability for DustGard

	Number of test periods	Final CE, fractional	90% confidence interval			DQO[a]	Is the half-width interval less than the DQO (i.e., DQO met)?
			Lower limit	Upper limit	Half width		
TP	3	0.45	0.33	0.57	0.12	0.13	Yes
PM_{10}	3	0.75	0.69	0.81	0.059	0.058	No[b]
$PM_{2.5}$	3	0.62	0.56	0.68	0.063	0.087	Yes

[a] Final CE DQO is interpolated from Table 6 of the test/QA plans using the equation:
Half width DQO = -0.2295 CE + 0.22972.
[b] For PM_{10}, the half width interval is greater than the DQO, i.e., the comparison for PM_{10} is a borderline failure.

Based on the overall DQO values, the $PM_{2.5}$ and TP half width intervals meet the DQO. The comparison for PM_{10} was a "borderline failure" to meet the DQO (i.e., 0.058 as compared to 0.059). However, this calculation results from one outlier test of five (CKO 215) occurring during a noted "drizzle" and, understandably, having no weighable catch.

The RTI quality manager has reviewed the above information (including the deviations from the test plan, noted in Section 2.4), has sampled the data against the specified criteria, and concurs with the MRI assessment; the DQOs were effectively met for the overall test. The APCT director has determined that the data are usable as intended in the planning documents.

2.4 Deviations from Test Plan

Significant deviations from the test/QA plan are discussed below and are shown in Table 4. Changes in the application dates are also summarized in the table.

The test/QA plan stated that background PM concentration values would be collected from an ambient PM monitor; however, the monitoring station in question collects only meteorological data and does not contain a PM monitor. Therefore, MRI operated a background PM sampler at the Range 12 building [located approximately 1 kilometer km east of the test section] where line electrical power was available.

Table 4. Summary of Test Event Deviations for FLW

Project activities	Planned date	Actual date	Test periods[a]
Unexpected road maintenance	Not planned	September 16, 2002	Not applicable (NA)
End of 1st test period	September 2002	October 12–14, 2002	5U, 5C
Suppressant Reapplication	September 2002	October 18–28, 2002	NA
End of 2nd test period	January 2003	Not performed because of consistently bad weather	None, per modified Test/QA Plan
Suppressant Reapplication	January 2003	March 8, 2003	NA
End of 3rd test period	April 2003	May 24–26, 2003	5U, 5C
Suppressant Reapplication	April 2003	June 14, 2003	NA
Road traffic increased with construction	Not planned	July 21–October 10, 2003	NA
End of 4th test period	July 2003	October 10–12, 2003	5U, 5C

Project activities	Planned date	Actual date	Test periods[a]

[a] 5U means five uncontrolled replicate measurements; 5C means five controlled replicate measurements.

The test/QA plan stated that the CE "will be determined relative to its decay over time and with traffic." Because the vendor chose to reapply the dust suppressant following each test period, this was not achievable. At least three test periods between applications would have been required to calculate a CE decay rate. Moreover, the decay rate would have changed from application to application because of the increasing inventory of dust suppressant in a specific road segment.

The projected schedule for the dust suppressant tests called for four quarters of planned tests starting in June 2002. The time between test periods was originally planned to be approximately 90 days, to represent seasonal differences in CE; however, not all of the planned four quarters of testing were conducted. Testing was conducted for three 6-month periods.

The test plan mentioned a pneumatic traffic counter and a data logger for on-site wind measurements; however, neither of these was deployed during the test program. Instead, training records supplied by the Army were used to estimate the total convoy traffic during the field program. Traffic data are described in Section 3.1.1. The Army supplied meteorological records for both the Forney Army Airfield (located within 5 km of the test site) and the Bailey wind station (located immediately west of the test site). Meteorological data are described in Section 3.1.2.

Deviations during the individual test periods are discussed in the following paragraphs.

October 2002 Test Period. Both the field tests and the reporting of results occurred later than originally called for in the test/QA plan. The delay in testing was directly due to the unexpected road maintenance during the week of September 16, 2002, at the request of a Directorate of Public Works (DPW) contractor. This action required a delay of approximately 2 weeks to assess the extent to which the treated surface had been affected and whether testing of the surface would produce results useful to the program. Based on anecdotal information from the grader operator as well as photographs of the surface, it was determined that the surface had been covered with loose material (pulled from the side of the road). Subsequent discussions between DPW, the product vendors, RTI, and MRI led to general agreement to continue with conducting a first series of tests in October 2002.

January 2003 Test Period. As noted above, persistently unfavorable winter weather during January and February 2003 forced the abandonment of the second quarterly test.

May 2003 Test Period. During the field audit conducted on May 26, 2003, it was determined that the $PM_{2.5}$ background monitor operated at a flow of approximately 9 liters per minute (lpm) [0.32 cubic feet per minute (cfm)] rather than the target of 16.7 lpm (0.59 cfm). Because the background concentration was used only to estimate the maximum contribution that ambient PM levels could contribute to the mass collected by the mobile sampler, the contribution for $PM_{2.5}$ was conservatively estimated using the PM_{10} background level. This point is discussed further in Section 3.1.

Another deviation concerned the location of the uncontrolled test section during the May 26, 2003, tests. On that day, a portion of uncontrolled test section (Section F in the test plan) was still damp from rain during the morning of May 25. For that reason, an uncontrolled 150-m (500-ft) section farther west along the same road was substituted.

October 2003 Test Period. Both the field tests and the reporting of results occurred later than originally called for in the test/QA plan. The delay in testing was due to rainfall over Labor Day weekend. Testing was rescheduled for Columbus Day weekend. No quarterly test report was prepared pending preparation of the final report.

Rainfall on the day before MRI's arrival left all sections damp. In addition, the uncontrolled test site (Section F) was so heavily potholed that the mobile sampler could not be safely operated at the designated vehicle speed. Uncontrolled tests were moved to an untreated section of the same road to the west that exhibited better drainage than Section F. As noted earlier, MRI used traffic to dry the road before beginning a test period.

3.0 Test Conditions

3.1 General Test Site Conditions

The test/QA plan documents the site and road sections used during dust suppressant testing. The host facility for the field test program is a U.S. Army base. The test site used unpaved Roads P and PA in training area (TA) 236. Roads P and PA are the main access routes to TA 236 and are traveled by truck convoys, as well as traffic into and out of TA 236. Test sections A, B, C, and D are located on Road PA, while test section E is located along Road P. DustGard was applied to test section E. Other products tested during this program were applied to the other test sections. The sixth test section (F), also located on Road P, was left untreated as the experimental control. Figure 1 shows the test locations at FLW.[3]

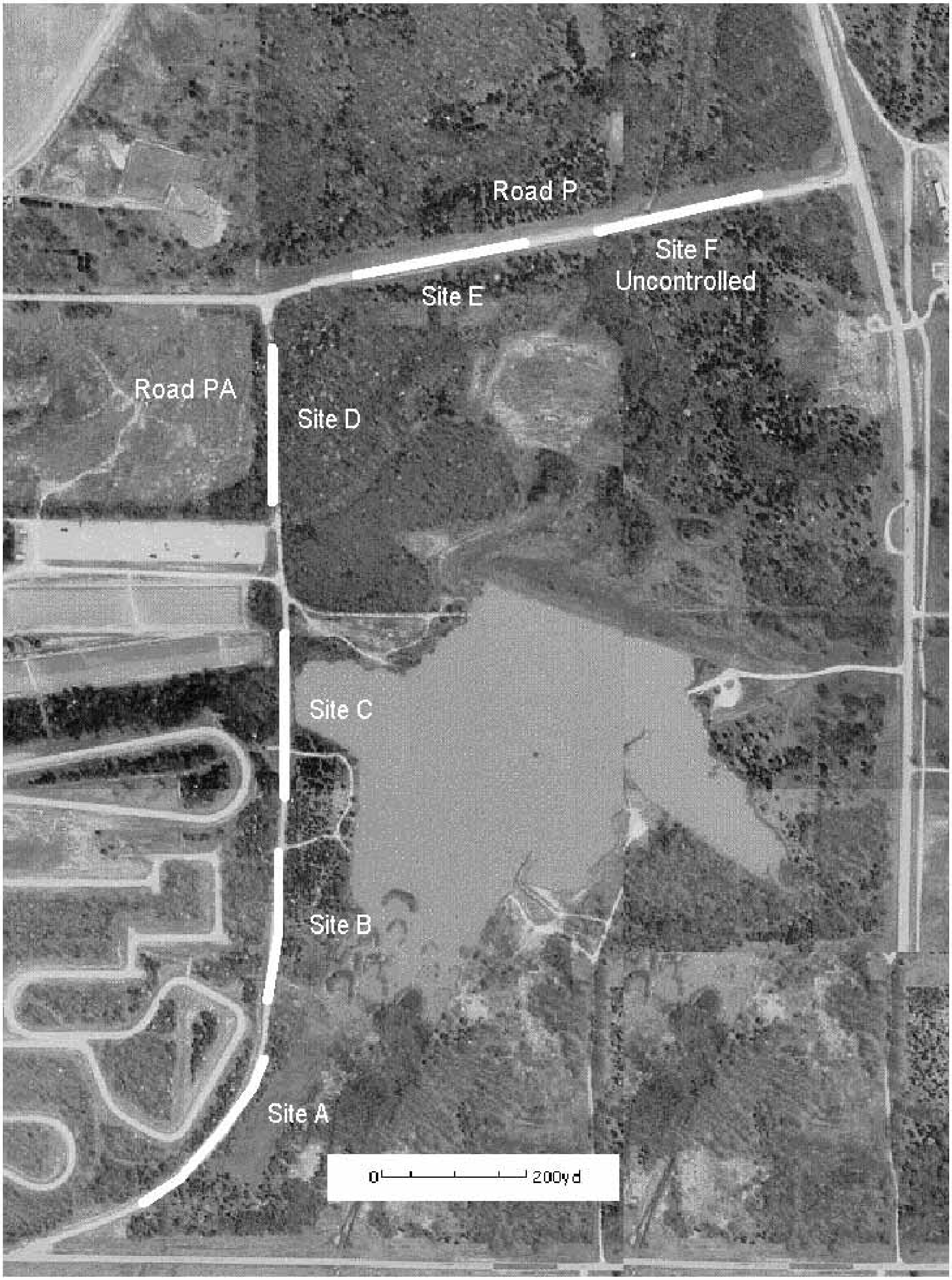

Figure 1. Test locations at FLW

3.1.1 Traffic

All sections of the test site at FLW were exposed to military traffic, consisting of 2.5- and 5-ton trucks, as well as sport-utility type vehicles (such as Chevrolet Blazers). This traffic occurred during training days (typically Monday through Friday). Based on records supplied by the Army, an estimated 3,650 convoy vehicles traveled over the test surface during the entire field program. This does not include other Army-related traffic, for which records are not kept. Furthermore, additional light-duty vehicular traffic took place due to recreational use of the fort during weekends. Finally, an additional 60 passes by a Ford F-250 pickup occurred during each of the test periods. (Note that testing took place on days with no scheduled Army training activities.)

From July 21, 2003, to the final test period in October 2003, the DustGard test section at FLW experienced additional traffic associated with construction activities in TA 236. This traffic, which occurred Monday through Friday, averaged 40 loaded (27 ton) dump truck passes, 40 empty (11 ton) dump truck passes, and 30 to 50 car and pickup passes per day.

3.1.2 Area Climatic Conditions

Table 5 presents a weekly weather summary over the entire verification period (i.e., from June 2002 when the product was first applied until the final set of tests in October 2003). These data were collected at Forney Airfield, which is located approximately 5 km (3 miles) north-northeast from the test section. (Note that the Forney station operating hours were 0600–2100 Monday through Friday, 0700–1500 Saturday, and 1100–1900 Sunday. The temperature extremes are officially valid for those timeframes.) A summary of the precipitation for all the test periods is shown in Table 6.

Table 5. Weekly Weather for FLW

Site weather				
Week beginning	Air temp, °C (°F)		Precipitation, cm (in.)	
	Maximum	Minimum	Liquid	Frozen
06/02/02	32 (90)	13 (56)	2.2 (0.88)	0 (0)
06/09/02	31 (87)	14 (58)	1.2 (0.48)	0 (0)
06/16/02	33 (91)	13 (56)	0 (0)	0 (0)
06/23/02	33 (92)	19 (66)	0.61 (0.24)	0 (0)
06/30/02	33 (92)	20 (68)	2.0 (0.79)	0 (0)
07/07/02	36 (97)	20 (68)	1.0 (0.41)	0 (0)
07/14/02	35 (95)	18 (64)	0.03 (0.01)	0 (0)
07/21/02	37 (98)	19 (67)	2.6 (1.0)	0 (0)
07/28/02	37 (99)	21 (69)	0.03 (0.01)	0 (0)
08/04/02	36 (97)	16 (61)	0.2 (0.07)	0 (0)
08/11/02	31 (87)	18 (64)	4.1 (1.6)	0 (0)
08/18/02	33 (92)	20 (68)	0.89 (0.35)	0 (0)
08/25/02	29 (85)	17 (62)	0 (0)	0 (0)
09/01/02	31 (88)	17 (63)	0 (0)	0 (0)
09/08/02	32 (90)	14 (58)	0 (0)	0 (0)

(continued)

Table 5. (continued)

Week beginning	Site weather			
	Air temp, ºC (°F)		Precipitation, cm (in.)	
	Maximum	Minimum	Liquid	Frozen
09/15/02	31 (87)	17 (63)	3.6 (1.4)	0 (0)
09/22/02	27 (81)	8 (46)	0 (0)	0 (0)
09/29/02	32 (89)	16 (60)	0.58 (0.23)	0 (0)
10/06/02	20 (68)	5 (41)	0.48 (0.19)	0 (0)
10/13/02	18 (64)	1 (33)	0.56 (0.22)	0 (0)
10/20/02	19 (67)	2 (36)	5.1 (2.0)	0 (0)
10/27/02	11 (52)	0 (32)	4.1 (1.6)	0 (0)
11/03/02	22 (71)	2 (36)	1.8 (0.72)	0 (0)
11/10/02	18 (64)	-2 (28)	1.7 (0.65)	0 (0)
11/17/02	18 (65)	0 (32)	0 (0)	0 (0)
11/24/02	16 (61)	-6 (21)	0.03 (0.01)	0 (0)
12/01/02	15 (59)	-9 (15)	1.7 (0.68)	16 (6.2)
12/08/02	11 (52)	-4 (24)	0.38 (0.15)	0 (0)
12/15/02	18 (65)	1 (33)	3.7 (1.4)	0 (0)
12/22/02	4 (40)	-12 (11)	3.4 (1.4)	34 (14)
12/29/02	18 (65)	-7 (19)	1.3 (0.52)	0.8 (0.3)
01/05/03	21 (70)	-6 (22)	0.43 (0.17)	0 (0)
01/12/03	6 (43)	-14 (7)	0.33 (0.13)	4.8 (1.9)
01/19/03	13 (56)	-19 (-2)	0.43 (0.17)	4.3 (1.7)
01/26/03	19 (67)	-10 (14)	0.38 (0.15)	0 (0)
02/02/03	23 (74)	-15 (5)	0.68 (0.27)	7.9 (3.1)
02/09/03	14 (57)	-4 (24)	2.7 (1.1)	2 (0.9)
02/16/03	12 (54)	-6 (22)	2.1 (0.83)	0.3 (0.1)
02/23/03	4 (40)	-14 (6)	1.7 (0.66)	18 (7.2)
03/02/03	24 (76)	-7 (20)	0.051 (0.02)	0 (0)
03/09/03	25 (77)	-8 (17)	1.7 (0.66)	0 (0)
03/16/03	22 (72)	4 (39)	3.6 (1.4)	0 (0)
03/23/03	25 (77)	0 (32)	2 (0.7)	0 (0)
03/30/03	29 (85)	2 (35)	0.03 (0.01)	0 (0)
04/06/03	27 (81)	0 (32)	4.7 (1.8)	0 (0)
04/13/03	29 (85)	9 (48)	0.91 (0.36)	0 (0)
04/20/03	22 (71)	5 (41)	4.2 (1.7)	0 (0)
04/27/03	30 (86)	10 (50)	1.7 (0.67)	0 (0)
05/04/03	30 (86)	14 (57)	2.3 (0.92)	0 (0)
05/11/03	26 (79)	9 (48)	3.2 (1.3)	0 (0)
05/18/03	26 (79)	9 (48)	2.1 (0.83)	0 (0)
05/25/03	31 (87)	9 (48)	1.6 (0.63)	0 (0)
06/01/03	25 (77)	9 (48)	3.7 (1.4)	0 (0)
06/08/03	28 (83)	13 (56)	6.6 (2.6)	0 (0)
06/15/03	29 (84)	14 (57)	2 (0.6)	0 (0)
06/22/03	32 (90)	13 (56)	2.6 (1.0)	0 (0)
06/29/03	34 (94)	19 (66)	0 (0)	0 (0)
07/06/03	34 (93)	17 (63)	1.2 (0.46)	0 (0)
07/13/03	36 (96)	21 (69)	3.9 (1.5)	0 (0)

(continued)

Table 5. (continued)

Site weather				
Week beginning	Air temp, ºC (°F)		Precipitation, cm (in.)	
	Maximum	Minimum	Liquid	Frozen
07/20/03	35 (95)	14 (58)	0.03 (0.01)	0 (0)
07/27/03	37 (98)	17 (63)	4.0 (1.6)	0 (0)
08/03/03	33 (91)	18 (64)	0.1 (0.04)	0 (0)
08/10/03	34 (94)	18 (65)	0.03 (0.01)	0 (0)
08/17/03	39 (102)	21 (69)	1.5 (0.59)	0 (0)
08/24/03	37 (98)	21 (69)	4.2 (1.6)	0 (0)
08/31/03	28 (82)	12 (54)	6.4 (2.5)	0 (0)
09/07/03	31 (87)	14 (57)	2.0 (0.78)	0 (0)
09/14/03	29 (84)	7 (45)	3.3 (1.3)	0 (0)
09/21/03	29 (85)	11 (52)	3.8 (1.5)	0 (0)
09/28/03	20 (68)	4 (39)	1.7 (0.68)	0 (0)
10/05/03	24 (76)	8 (47)	1.8 (0.72)	0 (0)
10/12/03	23 (74)	8 (46)	0.2 (0.07)	0 (0)

Table 6. Summary of Precipitation for all Test Periods at FLW

Parameter	Weekly precipitation range, cm
Precipitation during test week	0.2–3.7
Precipitation during week before testing	0.58–3.2
Precipitation between application and testing, total	17–39

3.1.3 Background Particulate Concentration

During the test period, TP and PM_{10} background concentrations were measured approximately 1 km (0.6 miles) east of the test site. Background concentration data are presented in Table 7.

Table 7. Measured Background PM Concentrations at FLW

Date	Concentration, µg/m^3	
	PM_{10}	TP
10/12/02	7.1	14
10/13/02	6.5	16
10/14/02	9.1	28
5/24/03	19	23
5/26/03	19	38
10/11/03	13	19
10/12/03	5.7	7.9
10/13/03	7.2	14
Average	11	20
Maximum	19	38

Because of the previously mentioned problem with the $PM_{2.5}$ background monitor at FLW (see Section 2.4), it was not possible to measure background $PM_{2.5}$ concentrations accurately. Therefore, the $PM_{2.5}$ concentration was assumed equal to the PM_{10} concentration value. This yielded a conservatively high estimate for the contribution of background PM concentrations to the $PM_{2.5}$ sample mass catches at FLW.

Estimates made of the contributions to net sampler catches at FLW by background concentrations of TP and PM_{10} are also conservatively high because estimates assume a 30-minute (min) sampling period. As noted in the test/QA plan, the hi-vol sampler is activated only when passing over the test section; 12 passes over a 500 ft-test section at 25 mph is only 160 s or 2.7 min. The conservatively high estimates of background contributions to sampler catches at FLW are compared to blank filter data in Table 8. Background mass contributions were estimated by multiplying background concentration times flow rate and sampling time to arrive at a mass collected that could have been contributed by ambient air.

Table 8. Estimated Background Contribution to Sampler Catch at FLW Compared to Mean Blank Filter Data

	Weight, mg		
	TP	**PM_{10}**	**$PM_{2.5}$**
Average estimated background contribution	0.67	0.37	0.0055
Average blank filter weight	2.5	2.2	0.029

The estimated background contributions are significantly lower than the mean blank filter masses collected at FLW. Thus, background PM contributed negligibly to the net catches for the mobile sampler.

3.2 Application of Dust Suppressant

MRI observed and documented all steps in the various applications of the dust suppressant to the road test section. DustGard is applied as received and requires no mixing with water for application. The road may be “prewetted” with water if the surface is not already wetted from antecedent precipitation. Table 9 presents the application intensity as determined through use of sampling pans located on a grid each time the product was applied.

Table 9. Application History

Date	Application intensity		Comments
	Mean, l/m^2 (gal/yd^2) [a]	Standard deviation, l/m^2 (gal/yd^2)	
June 7, 2002	2.5 (0.54)	0.91 (0.20)	Applied in two passes, centerline of road less heavily treated than are sides.
October 26, 2002	2.5 (0.55)	0.77 (0.17)	Applied in two passes, centerline treatment slightly less than sides.
March 8, 2003	2.4 (0.52)	0.85 (0.19)	Applied in two passes, centerline of road less heavily treated than are sides.
June 13, 2003	2.5 (0.56)	0.29 (0.06)	Applied in three passes, centerline of road less heavily treated than are sides.

[a] The mean is based on the total amount applied to the surface of the road summed over all passes.

The same driver and truck applied the product each time at FLW. Treatment of the 270-m (900-ft) road segment required approximately 0.5 man-hour, when allowances are made for placing and collecting the sampling pans. Figure 2 shows application of DustGard product at FLW.

Figure 2. Application of DustGard product at FLW

3.3 Conditions During Dust Suppressant Test Runs

Table 10 presents the dates and times when dust suppressant testing was conducted at FLW, including the length of road measured and meteorological conditions during each test run. As discussed previously, Table 5 presents the climatic conditions for the week during which the dust emissions tests were conducted.

Table 10. Test Run Parameters

Run	Test section	Date	Test start time	Total distance, m (ft)	Temperature, °C (°F)	Barometric pressure, mm Hg (in. Hg)
CKO-2	Uncontrolled	10/12/02	10:36	1,800 (6,000)	22 (72)	745 (29.4)
CKO-13	Uncontrolled	10/12/02	16:50	1,800 (6,000)	23 (74)	744 (29.3)
CKO-23	Uncontrolled	10/13/02	17:14	1,800 (6,000)	13 (56)	753 (29.6)
CKO-24	Uncontrolled	10/14/02	9:28	1,800 (6,000)	13 (55)	749 (29.5)
CKO-35	Uncontrolled	10/14/02	16:21	1,800 (6,000)	19 (66)	747 (29.4)
CKO-211	Uncontrolled	5/24/03	16:15	1,800 (6,000)	24 (75)	733 (28.8)
CKO-212	Uncontrolled	5/24/03	16:40	1,800 (6,000)	26 (78)	733 (28.8)
CKO-230	Uncontrolled	5/26/03	16:16	1,800 (6,000)	26 (78)	735 (29.0)
CKO-231	Uncontrolled	5/26/03	16:45	1,800 (6,000)	26 (78)	735 (29.0)
CKO-232	Uncontrolled	5/26/03	17:08	1,800 (6,000)	24 (76)	737 (29.0)
CKO-1022	Uncontrolled	10/12/03	15:35	1,800 (6,000)	24 (76)	734 (28.9)
CKO-1028	Uncontrolled	10/13/03	11:07	1,800 (6,000)	21 (69)	729 (28.7)
CKO-1029	Uncontrolled	10/13/03	11:28	1,800 (6,000)	23 (73)	729 (28.7)
CKO-1030	Uncontrolled	10/13/03	11:49	1,800 (6,000)	23 (74)	729 (28.7)
CKO-1031	Uncontrolled	10/13/03	12:12	1,800 (6,000)	24 (76)	730 (28.8)
CKO-30	DustGard, E	10/14/02	14:21	1,800 (6,000)	20 (68)	747 (29.4)
CKO-31	DustGard, E	10/14/02	14:50	1,800 (6,000)	20 (68)	747 (29.4)
CKO-32	DustGard, E	10/14/02	15:12	1,800 (6,000)	20 (68)	747 (29.4)
CKO-33	DustGard, E	10/14/02	15:35	1,800 (6,000)	20 (68)	747 (29.4)
CKO-34	DustGard, E	10/14/02	15:58	1,800 (6,000)	20 (68)	747 (29.4)
CKO-213	DustGard, E	5/24/03	17:05	1,800 (6,000)	26 (78)	732 (28.8)
CKO-214	DustGard, E	5/24/03	17:33	1,800 (6,000)	23 (74)	732 (28.8)
CKO-215	DustGard, E	5/24/03	18:14	1,800 (6,000)	21 (70)	732 (28.8)
CKO-233	DustGard, E	5/26/03	17:37	1,800 (6,000)	26 (78)	737 (29.0)
CKO-234	DustGard, E	5/26/03	18:06	1,800 (6,000)	23 (74)	734 (28.9)
CKO-1017	DustGard, E	10/12/03	13:13	1,800 (6,000)	22 (72)	734 (28.9)
CKO-1018	DustGard, E	10/12/03	13:33	1,800 (6,000)	25 (77)	734 (28.9)
CKO-1019	DustGard, E	10/12/03	13:56	1,800 (6,000)	24 (76)	732 (28.8)
CKO-1020	DustGard, E	10/12/03	14:16	1,800 (6,000)	25 (77)	732 (28.8)
CKO-1021	DustGard, E	10/12/03	14:39	1,800 (6,000)	26 (78)	733 (28.8)

Road surface samples were collected on a section each day that section was tested. The surface samples were analyzed for moisture and silt (i.e., fraction passing 200 mesh upon dry sieving). Table 11 presents the moisture and silt content results.

Table 11. Road Surface Properties

Test section	Date	Moisture content, %	Silt content, %
Uncontrolled	10/12/02[a]	0.4	1.6
	10/13/02[a]	0.63	1.5
	10/14/02[a]	0.75	1.7
	5/24/03	1.8	4.3
	5/26/03	0.01	1.6
	10/12/03	1.4	3.0
	10/13/03	1.5	5.4
	10/13/03	0.62	1.7
DustGard	10/14/02[a]	0.74	2.0
	5/24/03	0.42	2.6
	5/26/03	0.20	1.2
	10/12/03	3.5	1.2
	10/12/03	1.9	1.7

[a] Unexpected road maintenance activity occurred at FLW in September 2002 prior to the October 2002 test period.

4.0 References

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Appendix A

Environmental Testing Results

A copy of ABC Laboratories' summary report for aquatic toxicity testing on dust suppression products[12] is retained in the RTI International project files. The results for Dustgard are summarized below.

Solution Preparation

Solutions were prepared on a weight-to-volume basis for all compounds.

Test Design

Where preliminary testing indicated no mortality at concentrations of 1,000 milligram per liter (mg/L), abbreviated or limit studies were performed. Acute studies run as limit tests were conducted with a control and a single concentration at 1,000 mg/L. Chronic studies were conducted with a control and three test levels: 250, 500, and 1,000 mg/L. All other studies were conducted with five or six test levels and a control.

Statistical Analysis

Statistical analysis of the concentration versus effect data was performed using a custom computer program, ToxCalc. This program is designed to calculate the lethal concentration, 50 percent (LC_{50}) / effective concentration, 50 percent (EC_{50}) statistic and its 95 percent confidence interval (CI), as applicable, using the appropriate EPA recommended analysis. Statistical significance of comparison of means for *Ceriodaphnia dubia*, fathead minnow, and *Americamysis bahia* survival and reproduction, growth, and fecundity was determined by hypothesis testing using either Fisher's Exact test or Dunnett's test. Point estimate testing to calculate the LC_{50} or EC_{50} were determined with the Trimmed Spearman-Karber method.

Generally, the statistical approach was as follows: analysis of each endpoint between samples was evaluated by first analyzing the data for normality and homogeneity of variances with Shapiro-Wilk's Test and Kolmogorov D's Test before comparison of means. If the data were normally distributed and the variances were homogeneous, then analysis of variances (ANOVA) was used for the weight data, along with Fisher's Exact Test or Dunnett's procedure for comparing the means. Survival data were analyzed using Fisher=s Exact test, and growth or reproduction data were analyzed using Dunnett's. If the assumptions of normality or homogeneity of variance were not met, transformations of the survival data were employed to allow the use of parametric procedures. If transformations (e.g., arc sine-square root transformation) of the survival data still did not meet assumptions of normality and homogeneity, then the nonparametric test, Steel's Many-One Rank Test, was used to analyze these data.

47551 *Ceriodaphnia dubia* Acute Tests (July 18–20, 2002)

This test was conducted as a limit test with levels of control and 1,000 mg/L. Mortality was 0 percent in both the control and the 1,000 mg/L concentration. The 48-hour LC_{50} for survival was greater than (>) 1,000 mg/L. The no observed effect concentration (NOEC) was 1,000 mg/L and the lowest observed effective concentration (LOEC) was >1,000 mg/L.

47552 Fathead Minnow Acute Tests (July 15–19, 2002)

This test was conducted as a limit test with levels of control and 1,000 mg/L. Mortality was 0 percent in both the control and the 1,000 mg/L concentration. The 96-hour LC_{50} for survival was >1,000 mg/L. The NOEC was 1,000 mg/L and the LOEC was >1,000 mg/L.

47553 *Americamysis bahia* Acute Tests (July 15–19, 2002)

This test was conducted as a limit test with levels of control and 1,000 mg/L. Mortality was 0 percent in both the control and the 1,000 mg/L concentration. The 96-hour LC_{50} for survival was >1,000 mg/L. The NOEC was 1,000 mg/L and the LOEC was >1,000 mg/L.

47554 *Ceriodaphnia dubia* Chronic Tests (August 6–13, 2002)

This test was conducted as a multi-concentration test with levels of control, 250, 500, and 1,000 mg/L. Mortality was 0 percent in the control and all test levels. The 7-day LC_{50} for survival was >1,000 mg/L. For survival, the NOEC was 1,000 mg/L and the LOEC was >1,000 mg/L. The 7-day EC_{50} for reproduction was >1,000 mg/L. For reproduction, the NOEC was 1,000 mg/L and the LOEC was >1,000 mg/L.

47555 Fathead Minnow Chronic Tests (August 6–13, 2002)

This test was conducted as a multi-concentration test with levels of control, 250, 500, and 1,000 mg/L. Mortality was 0 percent in the control. Mortality was 3, 3, and 0 percent in the 250, 500, and 1,000 mg/L test levels, respectively. The 7-day LC_{50} for survival was >1,000 mg/L. For survival, the NOEC was 1,000 mg/L and the LOEC was >1,000 mg/L. The 7-day EC_{50} for growth was >1,000 mg/L. For growth, the NOEC was 1,000 mg/L and the LOEC was >1,000 mg/L.

47556 *Americamysis bahia* Chronic Tests (July 23–30, 2002)

This test was conducted as a multi-concentration test with levels of control, 250, 500, and 1,000 mg/L. Mortality was 15 percent in the control. Mortality was 15, 18, and 30 percent in the 250, 500, and 1,000 mg/L test levels, respectively. The 7-day LC_{50} for survival was >1,000 mg/L. For survival, the NOEC was 1,000 mg/L and the LOEC was >1,000 mg/L. The 7-day EC_{50} for growth was >1,000 mg/L. For growth, the NOEC was 1,000 mg/L and the LOEC was >1,000 mg/L. The 7-day EC_{50} for fecundity was >1,000 mg/L. For fecundity, the NOEC was 1,000 mg/L and the LOEC was >1,000 mg/L.

Appendix B

Chemical Testing Results

Tri-State Laboratories' analysis report of five dust suppression products[13] is retained in the RTI International project files. The results for DustGard are included on the pages that follow.

Appendix C

Method 24 Results

Table C-1 shows the results of the Method 24 analysis conducted by RTI International.[14]

Table C-1. Summary of EPA Method 24 Analysis for DustGard

Sample ID	ASTM D1475 Density, g/mL	ASTM D2369 Total volatiles, wt %	ASTM D3792 Water, wt %
DustGard	1.244	45.60	0.00

NOTE: Each value is the average of two measurements.