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Particulate Emission Measurements from Controlled Construction Activities

Prepared for

Office of Air Quality Planning and Standards

Prepared by

**National Risk Management
Research Laboratory
Research Triangle Park, NC 27711**

FOREWORD

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E. Timothy Oppelt, Director
National Risk Management Research Laboratory

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Particulate Emission Measurements from Controlled Construction Activities

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Abstract

This report summarizes the results of field testing of the effectiveness of control measures for sources of fugitive particulate emissions found at construction sites. Tests of the effectiveness of watering of temporary unpaved travel surfaces on PM-10 emissions were performed in Beloit, Kansas during September 1999. The tested operation was scraper transit. Tests of the effectiveness of paved and graveled access aprons on mud/dirt trackout from unpaved truck exit routes were performed in Grandview, Missouri during November 1999. In the latter tests, moisture content and soil type were varied to determine whether watering of exit routes, while reducing on-site emissions, might have an offsetting effect of increasing emissions attributable to mud/dirt trackout controls in place.

Contents

Figures

Tables

Acronyms and Abbreviations

ACE	Average control efficiency
acfm	Actual cubic feet per minute
DFS	Deramus Field Station (located in Grandview, Missouri)
DQO	Data quality objective
EPA	Environmental Protection Agency
ICE	Instantaneous control efficiency
IFR	Isokinetic flow ratio
MRI	Midwest Research Institute
NCKTC	North Central Kansas Technical College (located in Beloit, Kansas)
PM	Particulate matter
PM-X	Particulate matter less than X µm in aerodynamic diameter
QA	Quality assurance
RH	Relative humidity
sL	Silt loading
vmt	Vehicle miles traveled

Conversion Factors

Certain nonmetric units are used in this report for the reader's convenience. Readers who are more familiar with the metric system may use the following to convert to that system.

Nonmetric	Multiplied by	Yields metric
ft	0.3048	m
cfm	1.70	m^3/hr
yd^3	0.7646	m^3
ton	0.907	metric ton
lb	0.4536	kg

Chapter 1
Introduction

This report summarizes the results of field testing of the effectiveness of control measures for sources of fugitive particulate emissions found at construction sites. Tests of the effectiveness of watering of temporary unpaved travel surfaces on PM-10 emissions were performed in Beloit, Kansas during September 1999. The tested operation was scraper transit. Tests of the effectiveness of paved and graveled access aprons on mud/dirt trackout from unpaved truck exit routes were performed in Grandview, Missouri during November 1999. In the latter tests, moisture content and soil type were varied to determine whether watering of exit routes, while reducing on-site emissions, might have an offsetting effect of increasing emissions attributable to mud/dirt trackout from higher moisture soils, even with trackout controls in place.

Background

Historical Emission Factors

Although it has long been recognized that construction activity forms an important source of PM emissions throughout the United States, only limited research has been directed to its characterization. The background document[1] for AP-42, "Heavy Construction Activities," notes that the section remained unchanged from its original publication in 1975 for approximately 20 years because no new data had become available during that time. Furthermore, the data supporting the original 1975 section were based on a test method that could characterize only area-wide effects on air quality. The 1975 emission factor for construction activities had the form

$$e = 1.2 \text{ ton/acre-month of activity}$$

where e represents total suspended particulate (TSP) matter emissions.

The 1975 factor could neither distinguish overall variations in emissions between different phases (e.g., land clearing, earthmoving, general construction) nor rank in importance different emission categories (e.g., material handling, general vehicle travel). Instead, all emissions from a particular construction site were "smeared" uniformly in both a spatial and temporal sense. In other words, this assumed that all areas within the construction site emit at the same level and emissions are constant from beginning to end of a construction project.

To at least partially address shortcomings in the AP-42 estimation method for specific sites, a 1993 update[1] supplemented the single-valued factor given above with a "unit operation" approach. Under this approach, construction activities could be broken down into generic operations (such as truck travel over an unpaved surface, site preparation by graders or scrapers, or truck loading/dumping) and emissions from the generic operations could be estimated on the basis of factors in other sections of AP-42.

The unit operation approach itself had the following drawbacks:

1. Most of the factors had to be adapted from other industries – most notably, surface coal mining. Because of differences in how equipment is operated between different industries, there were concerns about how well emission factors based on tests in one industry can predict emission levels from another industry.

2. The measurement techniques used to characterize many of unit operations (in other industries) were generally not capable of successfully isolating an individual emission source. This was also true for the very limited amount of data actually collected at active construction sites.

3. Because of limitations in the underlying data sets, the factors included in AP-42 did not use a consistent set of source activity measures. For example, the factor for scraper loading was based on the distance that the equipment moves while the factor for unloading referred to the mass of material deposited.

Recent Field Studies

Subsequent application of the AP-42 estimation methods at several western U.S. construction sites[2] suggested that earthmoving activities could easily account for 70 to 90 percent of the PM-10 emissions estimated for any single construction site. The movement of aggregate materials forms another potentially important source of particulate emissions at construction sites throughout the United States. In many cases, bringing the site to final grade will necessitate either bringing material into the site for fill or shipping excess cut material off-site. Besides the cut/fill operations, a variety of other operations at construction sites require the loading, transport and unloading of aggregate material.

These studies reaffirmed the need to develop more specific emission factors for earthmoving and other construction operations in order to provide the greatest improvement in reliability of estimates. However, earthmoving activities present a serious challenge in terms of planning emission test programs. Because the goal of an earthmoving project is to alter the physical landscape, a pre-test site survey conducted 4 to 6 weeks prior to the start of field testing may not provide an accurate representation of the physical conditions that could be expected at the time testing begins. Beyond the fact that general site conditions are changing, individual earthmoving operations may restrict access for sampling purposes. For example, cuts involve concave cross-sections, which limit how close one can physically locate air sampling equipment near the open emission source.

In 1998, EPA sponsored a field testing program of earthmoving emissions at sites in Menlo and Beloit, Kansas.[3] To address the logistical difficulties in anticipating earthmoving tests at active construction sites, the program relied on "captive" operations in the sense that operations were largely controlled in orientation and sequencing during testing. The captive operations employed scrapers of the same type that are typically used at construction sites. The most important implications of the "captive" nature of the tests are that (a) sources are favorably oriented with respect to prevailing wind direction and (b) that the total operational cycle (loading, unloading, and transportation) represents a fairly short period of time to facilitate testing. Emissions were characterized from scraper loading ("cut"), unloading ("fill"), and transport operations at a heavy equipment vocational school in Beloit, Kansas and at a private feedlot in Menlo, Kansas. The 1998 test program[3] confirmed past studies that had found that a substantial fraction of PM (particulate matter) emissions from construction activities is related to movement of earth and other materials around the site.

Scope of the 1999 Field Study

Because of the generally short-term nature of travel routes at construction sites, operators throughout the United States commonly employ water to control PM rather than relying on more expensive and efficient chemical dust suppressants. Although PM emissions from watered unpaved roads have attracted attention since at least the early 1980s, only two tests of watering effectiveness had been conducted at construction sites, prior to the 1999 field study. In addition to the simple scarcity of data specifically referenced to construction sites, there have been concerns about how well test results from unpaved roadways can be applied to temporary travel routes at construction sites. Because temporary routes are not nearly as well constructed as roadways, available data may not accurately reflect the efficiency afforded by watering at construction sites.

The first half of the 1999 field testing program, described in the body of this report, built upon the 1998 program. MRI returned to North Central Kansas Technical College (NCKTC) in Beloit, Kansas and examined the control efficiency of water applied to the travel surface in controlling emissions from scrapers in transit. Testing spanned a range of common water application rates as well as a range of ambient conditions (such as relative humidity, cloud cover and solar radiation) that affect evaporation rates.

The second half of the 1999 program was conducted at MRI's Deramus Field Station (DFS) in Grandview, Missouri. These tests explored an unwelcome consequence of watering unpaved travel surfaces at construction sites—namely, the increase in mud/dirt trackout onto surrounding paved streets. For construction projects that require imported fill or the need to truck out excess cut material, watered travel routes increase the amount of mud and dirt carried from the site and deposited on the public paved roads adjacent to the construction site. Thereafter, all vehicles (and not just those associated with the construction project) can emit PM from the deposited material as it is abraded and entrained from the paved roads. Of particular interest is identifying the moisture level at which watering becomes "counterproductive"—in other words, the point at which any net decrease in on-site travel emissions is more than offset by an increase in off-site emissions from trackout.

The DFS facility provided a captive site for the testing of mud/dirt carryout. Again, "captive" is used to indicate that MRI could tightly control experimental variables such as the surface moisture content of the unpaved site access area as well as the number and type of vehicles leaving the site. The impact of trackout emissions was measured in terms of mass of mud/dirt per vehicle passing from the access apron to the paved test strip.

Organization of the Report

The remainder of this report is structured as follows. Chapter 2 describes the sampling and analysis procedures that were used in the field testing. Chapter 3 summarizes and discusses the results obtained. Chapter 4 discusses the quality assurance/quality control aspects of the program. Chapter 5 presents the conclusions drawn from the program, and the list of references follows. The appendices contain data generated during the program as well supporting information and documentation.

Chapter 2
Air Sampling Methodology

Test Sites and Overview of Tested Operations

As noted in Chapter 1, the field program to quantify watering effectiveness as a dust control was performed on "captive " operations at two different facilities. The first set of tests took place in September 1999 at the North Central Kansas Technical College (NCKTC) located near Beloit, Kansas. This is the same facility where MRI conducted emission tests of scraper operations in 1998. Figure 2-1 presents a general layout of the test site.

Testing at NCKTC was performed in conjunction with "hands-on" vocational training. As part of their training, each morning students operating up to five scrapers formed a cut of approximate dimensions 250 ft long, 70 ft wide, and 8 ft deep. The cut material was stockpiled at the location shown in Figure 2-1. After lunch, the students replaced the stockpiled material in the cut made during the morning.

The transit of empty scrapers (returning from the fill to the cut area) was selected as the source to be tested. Note that, in contrast to the 1998 program that focused on cut/fill operations, MRI requested that the empty scraper return route be placed to the south (upwind) of the cut/fill locations. In keeping with the goal of characterizing control of scraper transit emissions, this change prevented any confounding upwind source of PM emissions from overlapping the plume from the source of interest.

Water was applied by a pickup truck towing a 1,000-gal tank fitted with a pump and spray bar. To allow the entire 800-ft length of the return route in Figure 2-1 to be watered in two passes, traffic was halted for approximately 5 minutes. The amount of water applied was varied by towing the tank trailer at different speeds.

Scraper transit represents a "moving point" source that can be treated as a "line" source. Figure 2-2 shows not only a schematic of the operations but also the basis for the line source test methodology ("exposure profiling") described below in Air Sampling Test Methods.

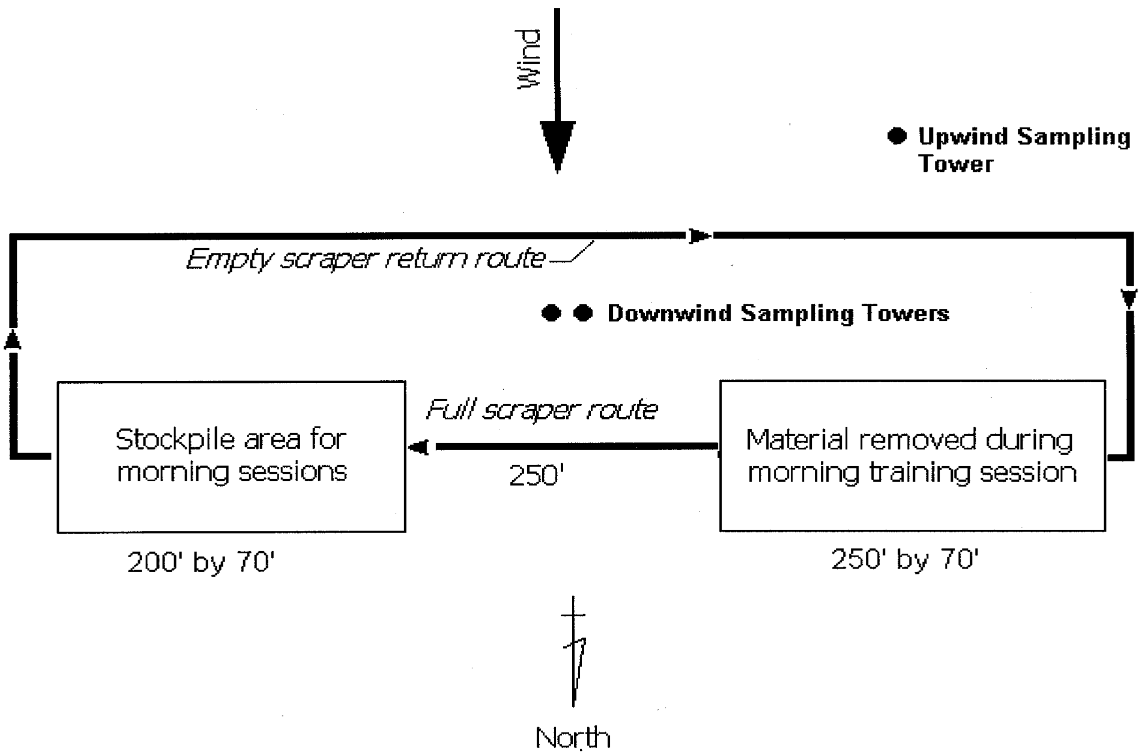

Figure 2-1. NCKTC overview.

As long as the distance traveled during transit operation is substantially greater than the downwind distance from path to the sampling array, then only a single vertical array of samplers ("tower") is necessary to characterize the PM plume. In other words, because the source is considered as uniformly emitting over the length of the operational pass, a vertical array is sufficient to characterize the vertical distribution of concentration and wind speed in the plume.

Two separate vertical sampling arrays ("towers") were used, so that tests could be staggered over the 2- to 3-hr morning/afternoon training sessions. This provided for more efficient tracking of control efficiency decay as the surface material along the travel route dried after watering. Three emission tests were conducted after each watering. Typically, "test 1" in a series began almost immediately after watering and utilized the first sampling tower. The second test began about 45 minutes later using the second sampling array. At approximately the midpoint of "test 2," MRI retrieved samples from "test 1" and began the third test on the first tower.

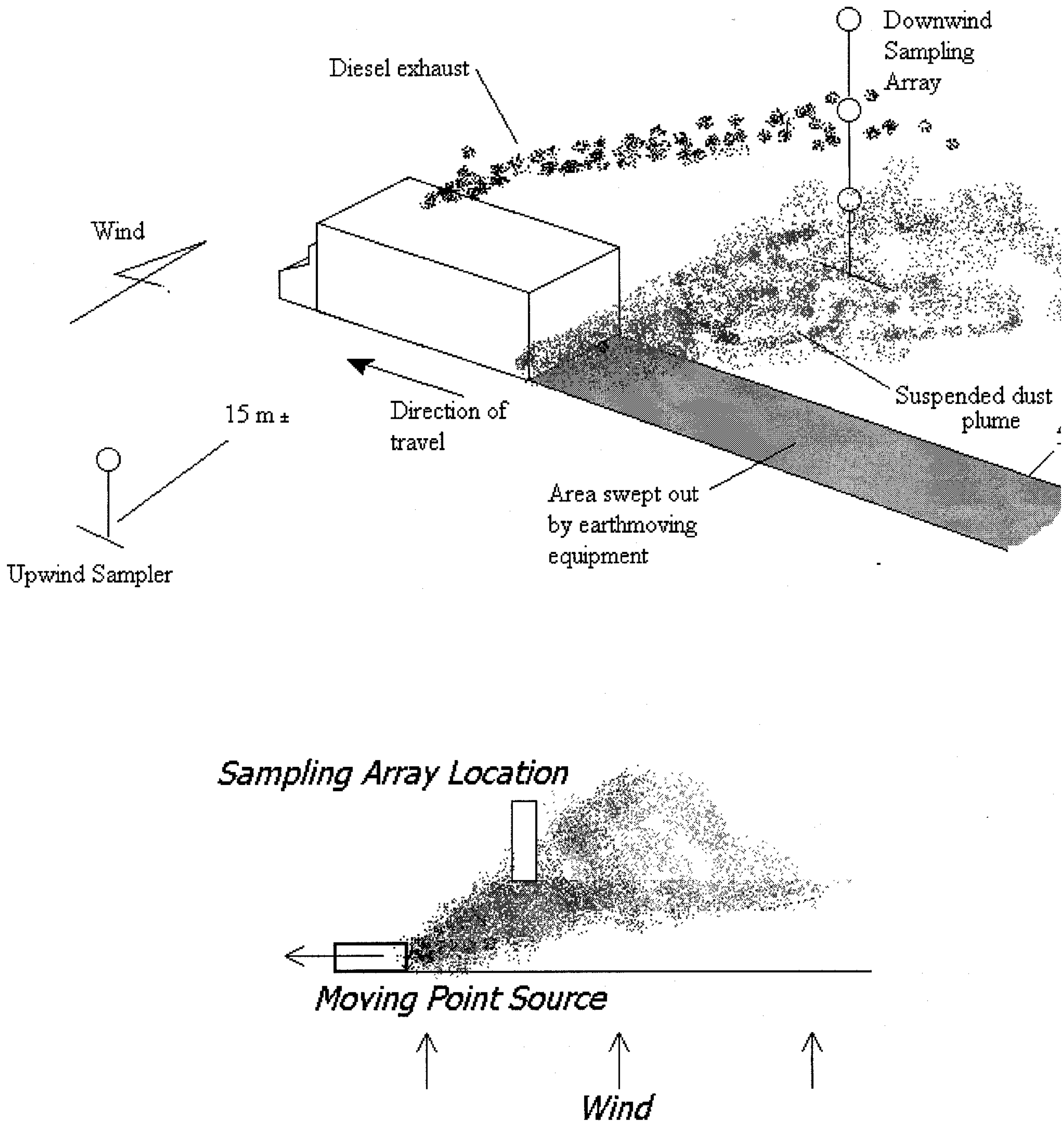

Figure 2-2. Schematic illustration of test procedure for moving point source (NCKTC).

In addition to the particulate concentration and wind measurements shown in Figure 2-2, a number of other samples were necessary to characterize the source conditions. These included surface samples from the scraper travel route and meteorological observations, described below in Ancillary Measurements.

The second set of tests took place during November 1999 at MRI's Deramus Field Station (DFS). At DFS, another captive operation was established to explore the mud/dirt trackout aspects of road watering. Figure 2-3 presents an overview of the facility. The test vehicle traveled from an unpaved access area onto the asphalt road. After approximately 50 vehicle passes from the access area on to the paved road, a sample of the loose material present on the paved surface was collected. Testing spanned a range of soil surface moisture contents that would be expected for different watering rates. As was the case for the NCKTC tests, surface soil grab samples were collected over the test period to monitor the surface moisture content of the access area.

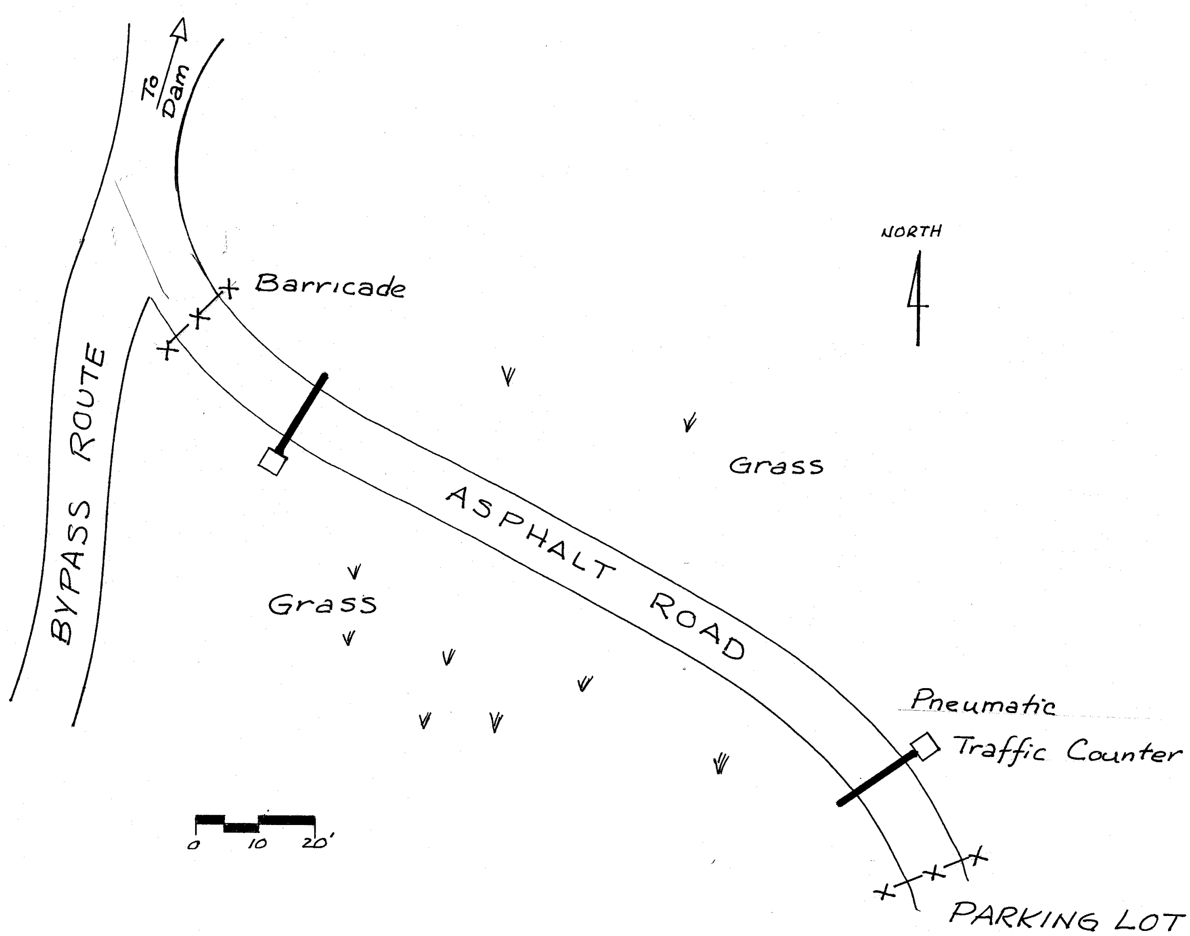

Figure 2-3. Overview of DFS test site.

The physical layout and driving patterns at the test site varied during different "phases" of the test program, as described below. The site was prepared by first removing the vegetative cover from three "access" areas adjacent to the asphalt road. Each area consisted of a strip that was 25 ft long and 12 ft wide, oriented at right angles to the road centerline. One access area was located near the southeast end of the 200-ft long road segment shown in Figure 2-3. The other two access areas were located on the north side of the road, near the mid-point of the segment.

Once the three access areas had been stripped of vegetation, MRI drove vehicles over two areas to condition the exposed soil. Thus, those two access areas represented the trackout potential attributable to the "native" soil in the area. This soil has a fairly high clay content. In contrast, MRI dug out the third access area to a depth of approximately 6 inches and replaced the native soil with a 50/50 mixture of native soil and sand. The soil/sand mixture was compacted before being driven over to generate a second set of trackout samples. A wooden border placed along the boundary within the adjacent access area prevented any mixing of the native soil and sand/soil mixture.

Prior to the start of a test, the access area was typically wetted using a garden hose and hand-held sprayer. Target watering application rates were 0.25 and 0.5 gal/yd.^{2} Because the access areas were approximately 25 ft long by 12 ft wide, this required roughly 8 or 16 gallons of water. The amount of water sprayed was estimated on the basis of application time and volumetric flow rate. (The volumetric flow was determined each morning by recording the time necessary to fill a 5-gal bucket.) Watered surfaces were allowed to "sit" for at least 1 minute before being driven on. During the tests, moisture analysis samples were composited from grab samples of surface soil taken from the access area approximately every 15 to 20 minutes.

Phase 1 was a preliminary series of tests to characterize the spatial distribution of mud/dirt trackout over the length of the road segment. Tests made use of the native soil access area at the southeast end of the road segment (see Figure 2-4). All trackout was generated by driving a full-size Chevrolet pickup truck (6100 lb gross vehicle weight) over the access area. Once 50 to 100 passes had been completed, samples were collected from four nominally 20-ft long strips of the asphalt road surface, beginning at the point where the last wheel of the pickup truck reached the pavement (approximately 10 ft down the road from the middle of the access area). The test strips were located on 40-ft centers, as shown in Figure 2-4. A second series of Phase 1 tests ("Phase 1A") was conducted by exiting the other native soil access area near the center of test road segment and traveling southwest on the test road. In that case, samples were collected from two 20-ft strips, again beginning at the point where the last wheel on the pickup truck reached the pavement.

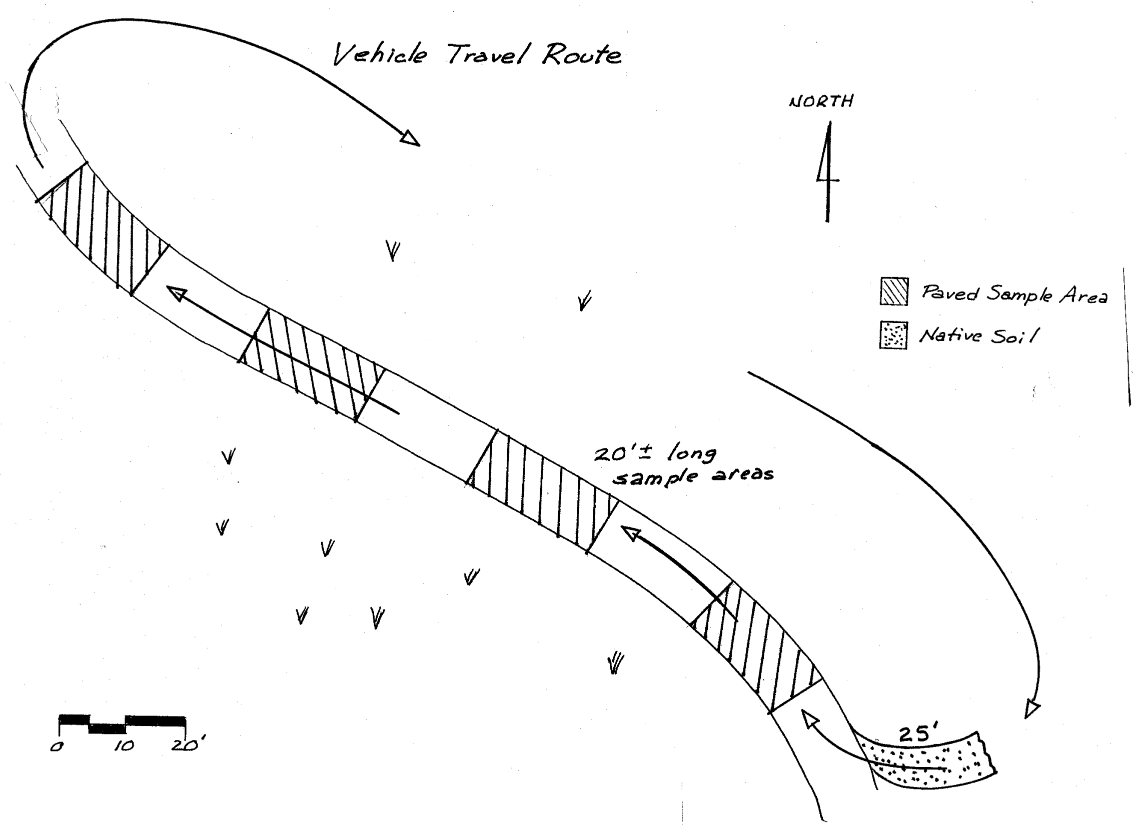

Figure 2-4. Trackout and sampling areas for Phase 1 (DFS).

Phase 2 involved uncontrolled (baseline) trackout from the sand/soil and native soil access areas at the midpoint of the test road. As shown in Figure 2-5, vehicles exiting the sand/soil and native soil areas traveled to the northwest and southeast, respectively, to avoid any cross-contamination. Paved road surface samples were collected from a 20-ft strip beginning at the point where the last vehicle wheel reached the pavement. Again, the Chevrolet pickup truck was used to generate the mud/dirt trackout. However, additional tests made use of a Ford dump truck with a gross vehicle weight of 28,000 lb.

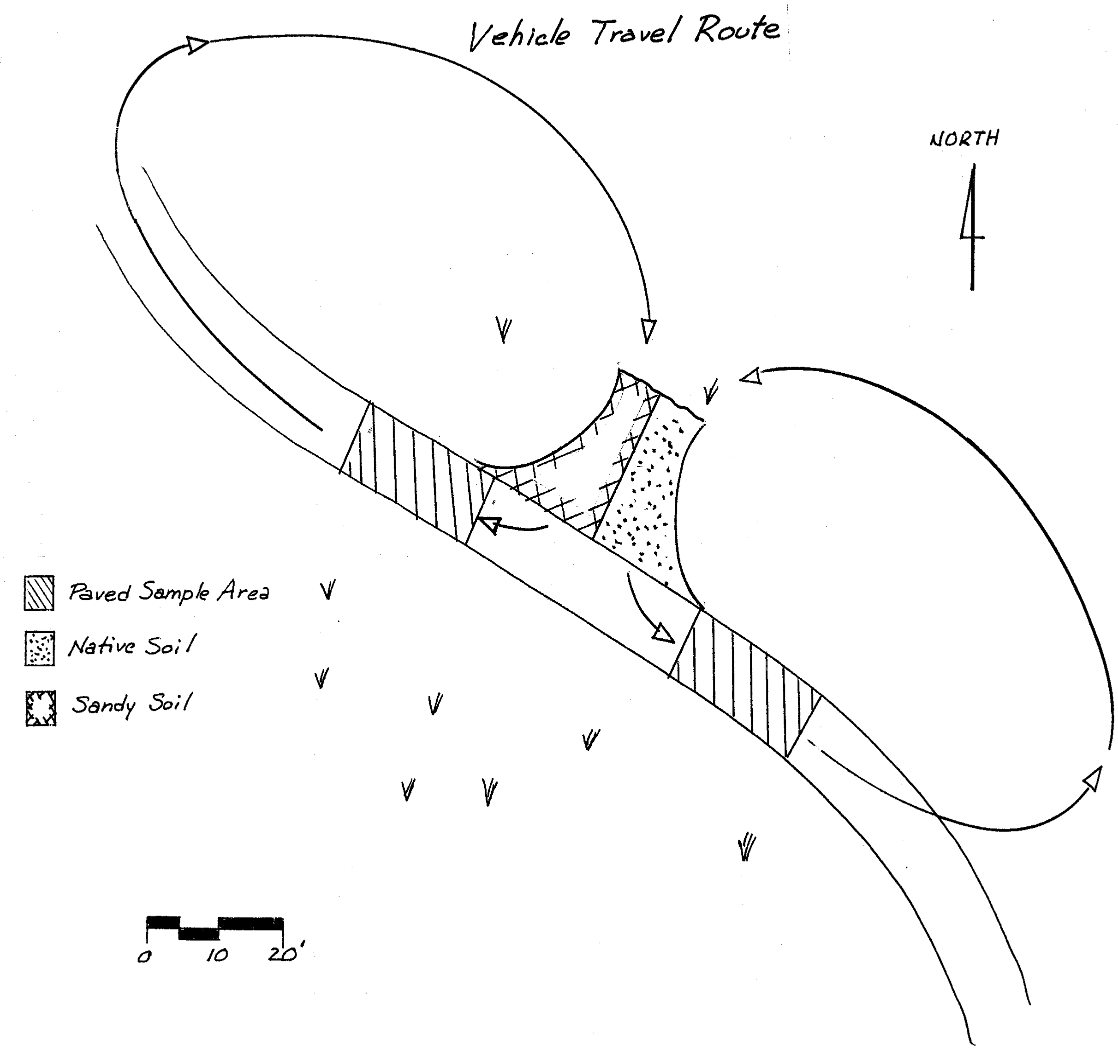

Figure 2-5. Trackout and sampling areas for Phase 2 (DFS).

Phase 3 tests examined the effectiveness of a 20-ft long paved apron (beginning at the point where all vehicle wheels had entered the roadway) in controlling mud/dirt trackout from both the sand/soil mixture and the native soil. As a practical matter, some Phase 2 and Phase 3 tests were conducted simultaneously. That is to say, the 20-ft long Phase 2 test surface also served as the 20-ft long paved apron for Phase 3. In this way, all Phase 3 tests referenced a clean paved apron. All passes were made with the full-size pickup truck. The paved road surface sample was collected from a 20-ft strip beginning at the end of the paved apron (see Figure 2-6).

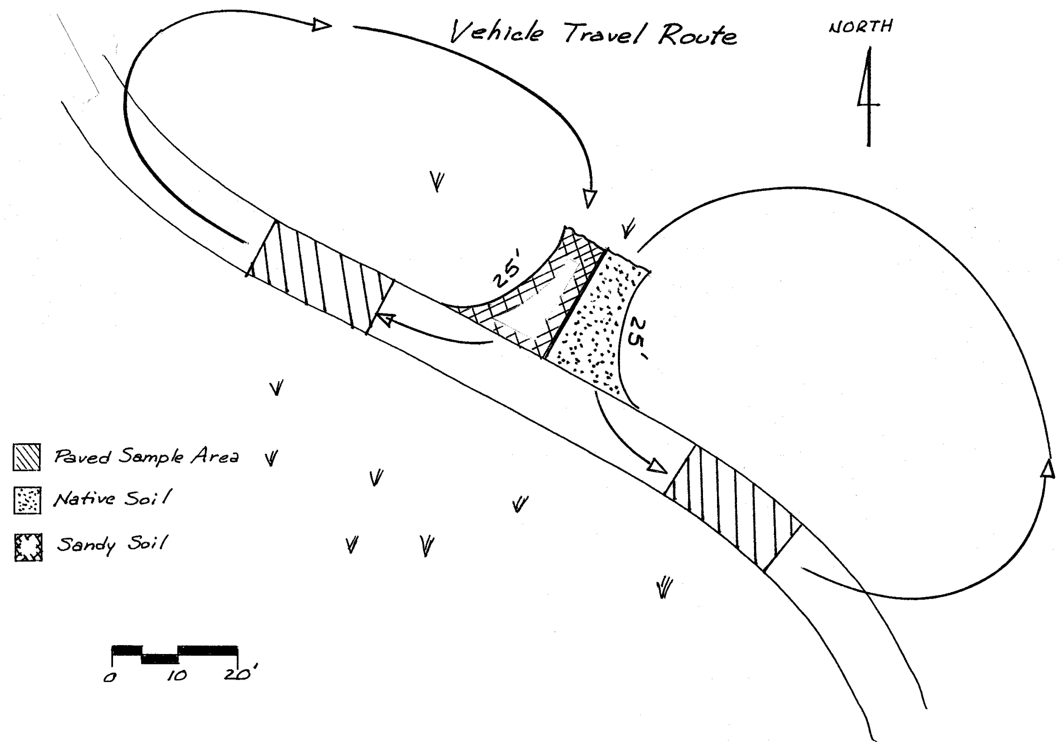

Figure 2-6. Trackout and sampling areas for Phase 3 (DFS).

Finally, Phase 4 evaluated the effectiveness of a 25-ft long gravel apron. The apron consisted of 2-inch washed limestone and was located atop the two access areas used in Phases 2 and 3. For that reason, new access areas were constructed from the native soil and the sand/soil mixture, as shown in Figure 2-7. All passes were made with the full-size pickup truck.

Air Sampling Test Methods

The test method employed at NCKTC – "exposure profiling" – has been recognized by EPA as the characterization technique most appropriate for the broad class of open anthropogenic dust sources, such as aggregate material transfer and vehicle travel over paved/unpaved surfaces. Because the method isolates a single emission source while not artificially shielding the source from ambient conditions (e.g., wind), the open source emission factors with the highest quality ratings in EPA's emission factor handbook, AP-42,[1] are typically based on this approach.

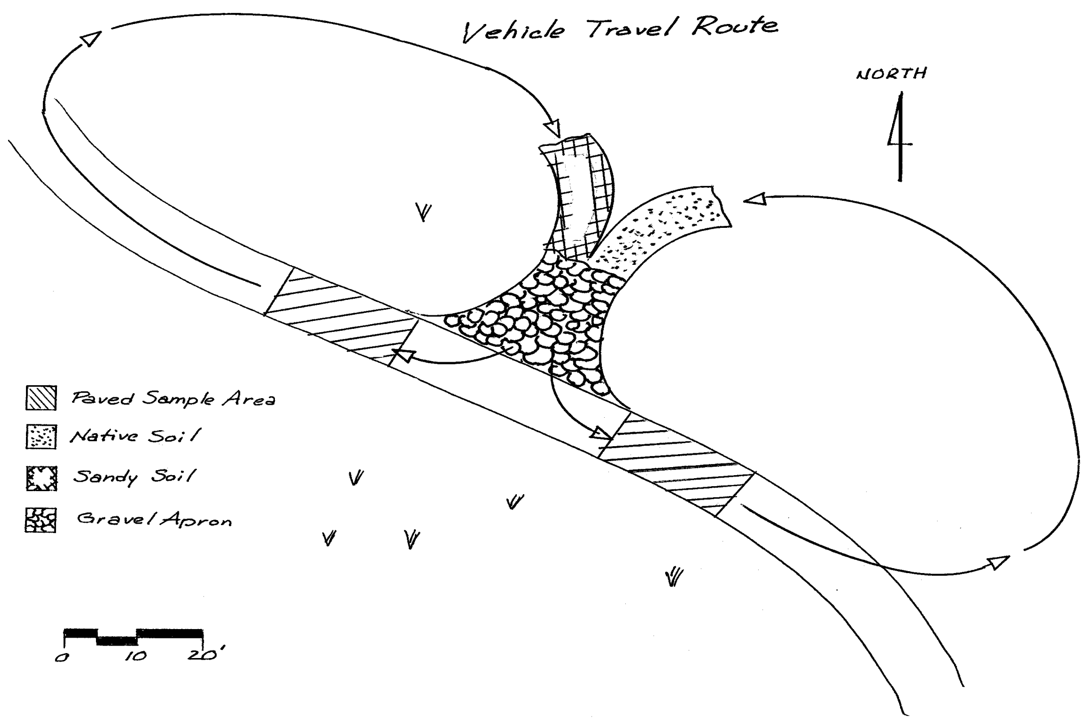

Figure 2-7. Trackout and sampling areas for Phase 4 (DFS).

The exposure profiling technique for source testing of open particulate matter sources is based on the same isokinetic profiling concept that is used in stack testing. The passage of airborne pollutant immediately downwind of the source is measured directly by means of simultaneous multipoint sampling over the cross section of the open dust source plume. This technique uses a mass flux measurement scheme similar to EPA Method 5 stack testing rather than requiring indirect emission rate calculation through the application of a generalized atmospheric dispersion model.

The exposure profiling technique relies on simultaneous multipoint measurement of both concentration and air flow (advection) over the effective area of the emission plume. The technique uses a mass flux measurement scheme. Unlike traditional stack sources, both the open dust source emission rate and the transport air flow are non-steady. This requires simultaneous multipoint sampling of mass concentration and air flow over the effective area of the emission plume. As noted in connection with Figure 2-2, line sources require only a vertical array of samplers. In the testing of scraper transit emissions at NCKTC, two vertical networks of samplers (Figure 2-8) were positioned just downwind (5 m) and upwind from the edge of the source.

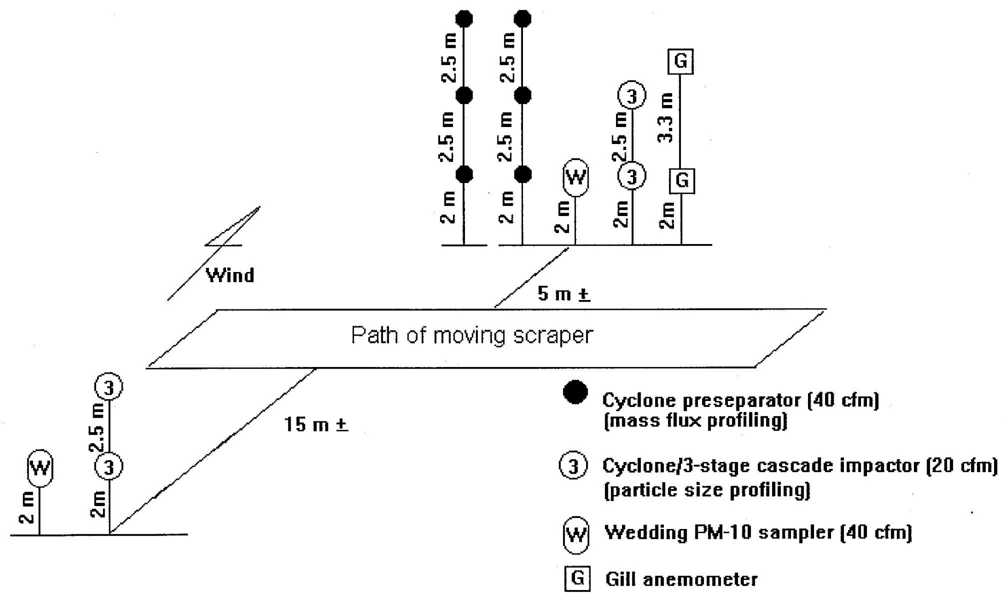

Figure 2-8. Sampler deployment at NCKTC.

The primary air sampling device in the exposure profiling portion of the field program was a standard high-volume air sampler fitted with a cyclone preseparator (Figure 2-9). The cyclone exhibits an effective 50 percent cutoff diameter (D_{50}) of approximately 10 umA when operated at a flow rate of 40 cfm (68 m^3/h).[4] Thus, mass collected on the 8- by 10-inch backup filter represents a PM-10 sample. During each mass flux profiling test, a Wedding and Associates high-volume PM-10 reference sampler was collocated with one cyclone sampler for comparison purposes. Additional detail is contained in the test and quality assurance (QA) plans prepared for the field exercise and presented in the Appendices A and B to this report.

The test plan also referenced particle size profiling tests to determine vertical profiles of particle size distribution. For this purpose, a second sampling system supplemented the mass exposure profiling system described above. The second system also used a high-volume cyclone preseparator but in a different sampling configuration. Here, the cyclone was operated at a flow rate of 20 acfm over a 3-stage cascade impactor (see Figure 2-10). At that flow rate, the cyclone and 3 stages exhibit D_{50} cut points of 15, 10.2, 4.2, and 2.1 µmA. Again, details are provided in the test and QA plans.

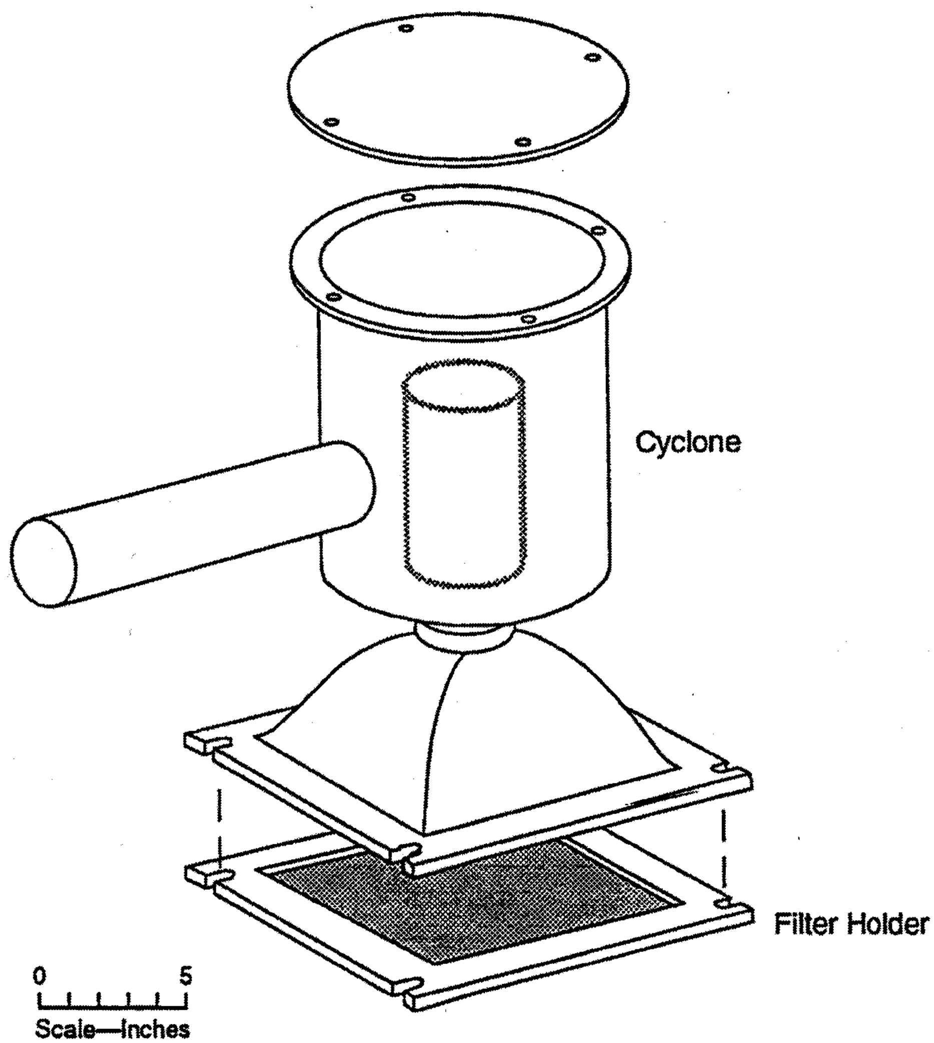

Figure 2-9. Cyclone preseparator operated at 40 cfm.

In addition to the air sampling equipment, Figure 2-4 also shows that, throughout each test, wind speed was monitored at two heights using R. M. Young Gill-type (model 27106) anemometers. Furthermore, an R. M. Young portable wind station (model 05305) recorded wind speed and direction at the 3.0-m height downwind. All wind data were accumulated into 5-min averages logged with a 26700 series R. M. Young programmable translator.

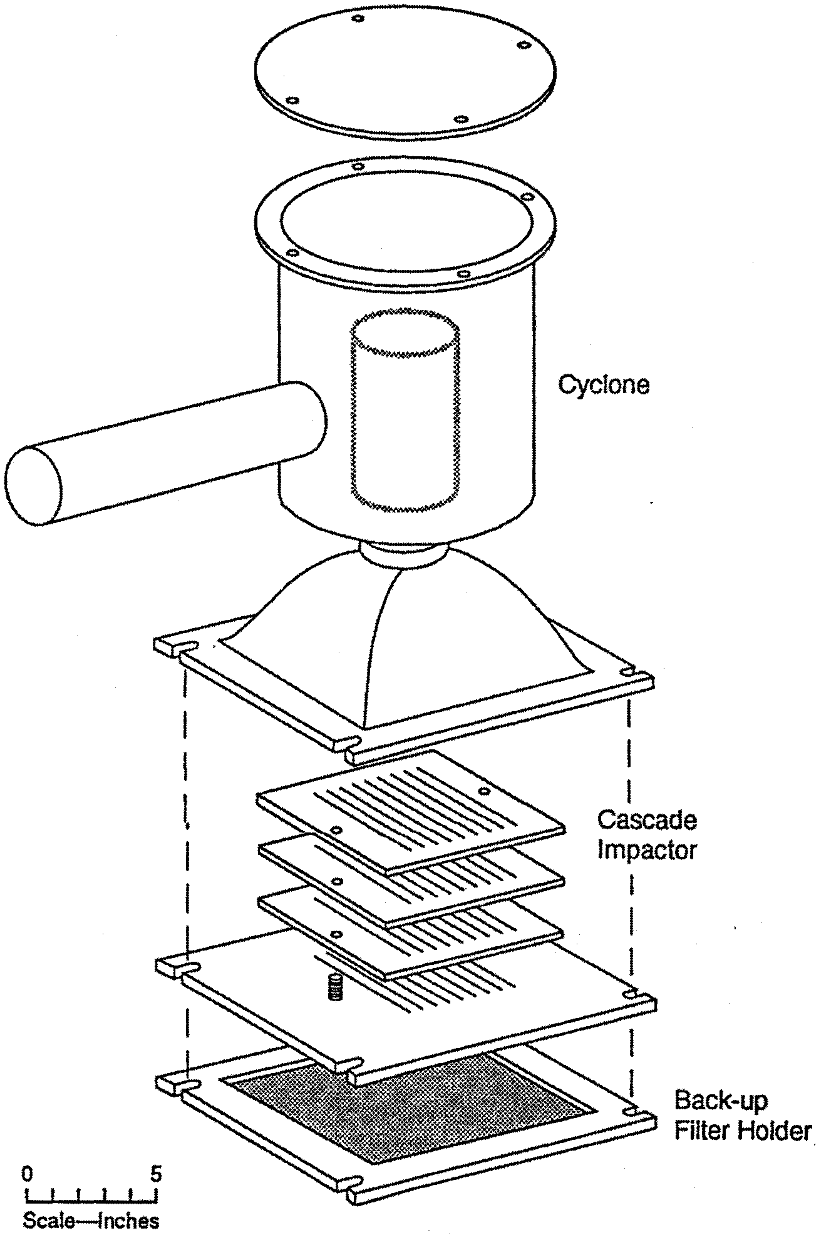

Figure 2-10. Cyclone preseparator – cascade impactor operated at 20 cfm.

Ancillary Measurements

In addition to aerometric measurements described in Section 2.2, a number of other samples/observations were necessary to characterize source conditions. The broad categories of interest include surface material properties, operating parameters, and ambient meteorological conditions.

At least one collected surface soil sample (from the unpaved scraper transit route at NCKTC or the unpaved access area at DFS) was associated with each test. Sample collection and analysis methods followed the guidelines given in Appendices C.1 and C.2 to AP-42. Soil samples taken from the unpaved travel surfaces at both NCKTC and DFS were collected with a dust pan and whisk broom, while the paved road surface dirt samples associated with the DFS tests were collected by broom sweeping followed by vacuuming.

Soil/road dust samples were analyzed for surface moisture content (by determining weight loss upon drying). During the watering tests at NCKTC, surface soil grab samples for moisture analysis were collected at least every half hour.

With the exception of those grab samples, all other samples (including the vacuum bag samples from DFS) underwent dry sieving to determine the sub-200 mesh fraction. Tables 2-1 and 2-2 present the procedures to determine moisture and silt contents, respectively.

Table 2-1. Moisture Content Determination

1.	Preheat the oven to approximately 110 °C (230 °F). Record oven temperature.
2.	Record the make, capacity, and smallest division of the scale.
3.	Weigh the empty laboratory sample containers which will be placed in the oven to determine their tare weight.
4.	Weigh containers with the lids on if they have lids. Record the tare weight(s). Check zero before each weighing.
5.	Weigh the laboratory sample(s) in the container(s). For materials with high moisture content, ensure that any standard moisture is included in the laboratory sample container. Record the combined weight(s). Check zero before each weighing.
6.	Place sample in oven and dry overnight. Materials composed of hydrated minerals or organic material like coal and certain soils should be dried for only 1-1/2 h.
7.	Remove sample container from oven and (a) weigh immediately if uncovered, being careful of the hot container; or (b) place the tight-fitting lid on the container and let cool before weighing. Record the combined sample and container weight(s). Check zero reading on the balance before weighing.
8.	Calculate the moisture as the initial weight of the sample and container minus the oven-dried weight of the sample and container divided by the initial weight of the sample alone. Record the value.

Additional measurements were necessary to characterize the service environment for the NCKTC watering tests. These measurements include the following:

Operating Parameters

- volume of water applied per unit area of travel surface
- travel speeds

Ambient Meteorological Conditions

- solar radiation
- cloud cover
- relative humidity
- pan evaporation

Note that these measurements were intended to provide a field representation of water application and evaporative conditions during testing. These are viewed as second-tier, semi-quantitative measurements to assess how well the primary variable (soil surface moisture content) relates to environmental conditions.

Table 2-2. Silt Content Determination

1.	Select the appropriate 20 cm (8-in) diameter, 5 cm (2-in) deep sieve sizes. Recommended U.S. Standard Series sizes are: 3/8 in, No. 4, No. 20, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be utilized. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available or if buildup on one particulate sieve during sieving indicates that an intermediate sieve should be inserted.
2.	Obtain a mechanical sieving device such as a vibratory shaker or a Roto-Tap without the tapping function.
3.	Clean the sieves with compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed (if possible) without handling the screen roughly.
4.	Obtain a scale (capacity of at least 1,600 g or 10 lb) and record make, capacity, smallest division, date of last calibration, and accuracy.
5.	Weigh the sieves and pan to determine tare weights. Check the zero before every weighing. Record weights on the form.
6.	After nesting the sieves in decreasing order with pan at the bottom, dump dried laboratory sample (preferably immediately after moisture analysis) into the top sieve. The sample should weigh between ~ 400 and 1,600 g (0.9 and 3.5 lb). This amount will vary for finely textured materials; 100 to 300 g may be sufficient with 90 percent of the sample passes a No. 8 (2.36 mm) sieve. Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.
7.	Place nested sieves into the mechanical sieving device and sieve for 10 min. Remove pan containing minus No. 200 and weigh. Repeat the sieving in 10-min intervals until the difference between two successive pan sample weighings (where the tare weight of the pan has been subtracted) is less than 3.0 percent. Do not sieve longer than 40 min.
8.	Weigh each sieve and its contents and record the weight on the form. Check the zero reading on the balance before every weighing.
9.	Collect the laboratory sample and place the sample in a separate container if further analysis is expected.
10.	Calculate the percent of mass less than the 200 mesh screen (75 mm). This is the silt content.

To determine the volume of water applied per unit area of soil surface along the scraper transit route at NCKTC, a series of tared sampling pans were placed across the test surface. These were light-weight aluminum pans with an opening of approximately 4 inches by 8 inches. The bottom of each pan was lined with absorbent material to avoid splashing of the water. Once the water was applied, the sampling pans were retrieved and reweighed. The volume of water was determined by assuming water density of 1 g/cm^3 and the application rate was found by dividing the volume of water by the top area of the pan.

Travel speeds were monitored by accumulating the elapsed time required for several scrapers to traverse a 100-ft distance in front of the sampling arrays.

Solar radiation during the test period was monitored by a Weathertronics Model 3010 mechanical pyranograph. This device produces a hard copy record of the intensity of direct and scattered solar radiation. Visual observations of cloud cover (to the nearest tenth) were taken at least hourly during test periods to supplement the pyranograph results. Dry and wet bulb temperatures (from which relative humidity is determined) from a sling psychrometer were also recorded at least hourly during tests.

The measurement of pan evaporation rate at NCKTC mimicked essential features of the standard "Class A" evaporation measurement procedure. The standard procedure requires that 7.5 inches of water be maintained in a pan with very specific dimensions (10 inches high with a 47.5-inch inside diameter), construction details (material, welding, etc.), and operational features (leveling, etc.). Given the goal to provide a semi-quantitative measure of ambient conditions, MRI deployed a 48-inch galvanized steel tank filled to 2 to 3 inches of the top with water. The tank was deployed early during the testing exercise and the water level was measured each morning that MRI crew members were present at the test site. A rain gauge was deployed in the immediate vicinity of the tank and its contents were read each morning.

Data Reduction

The calculation of emission rates in the exposure profiling method used at NCKTC relies on a conservation of mass approach. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) is obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross-section of the plume. Exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement, or equivalently, the net particulate mass passing through a unit area normal to the mean wind direction during the test. The steps in the exposure profiling calculation procedure are discussed below.

Concentration of particulate matter measured by a sampler is given by:

$$C = \frac{m}{QT} \tag{2-1}$$

where C = particulate concentration (mass/volume)
m = net mass collected on the filter or substrate (mass)
Q = volumetric flow rate of the sampler (volume/time)
T = duration of sampling (time)

The wind speed profile was developed from the two Gill anemometer data. The profile assumes a logarithmic shape given by:

$$U(z) = K \ln\left(\frac{z}{z_0}\right) \tag{2-2}$$

where U(z) = wind speed (length/time)at height z (length)
K = proportionality constant (length/time)
z_0 = roughness height of ground surface (length)

K and z_0 are the two parameters used to fit the profile.

The isokinetic flow ratio (IFR) is the ratio of a directional sampler's intake velocity to the mean wind speed approaching the sampler. It is given by:

$$IFR = \frac{Q}{(aU)} \tag{2-3}$$

where Q = volumetric flow rate (volume/time)
a = sampler intake area (area)
U = approach wind speed (length/time)

The IFR is of interest in the sampling of total particulate, because isokinetic sampling (i.e., IFR = 1) ensures that particles of all sizes are sampled without bias. As such, the ratio is of most interest in the particle size profiling tests. Specially designed nozzles were available to maintain isokinetic properties (with $\pm$ 20 percent) for wind speeds in the range of 5 to 20 mph when the samplers were operated at 20 acfm. Because the primary interest in this program was directed toward PM-10 and PM-2.5 emissions, sampling under moderately non-isokinetic conditions posed little difficulty. It is widely recognized that 10 µmA and smaller particles have weak inertial characteristics at normal ambient wind speeds and therefore are relatively unaffected by anisokinesis.[5]

Exposure was calculated by:

$$E = (C - C_b) U T \tag{2-4}$$

where E = net particulate matter exposure (mass/area)
C = downwind concentration (mass/volume)
C_b = background concentration (mass/volume)
U = approach wind speed (length/time)
T = duration of sampling (time)

Exposure varies with height over the extent of the plume. When exposure values are integrated over the effective cross-section of the plume, the quantity obtained represented the total passage of airborne particulate matter due to the road

$$A = \int_0^H E \, dh \qquad (2\text{-}5)$$

where A = integrated exposure (mass/length)
E = particulate exposure (mass/area)
h = height (length)

and the integration extended from 0 to the effective height "H" of the plume.

Because exposures are measured at discrete heights of the plume, a numerical integration is necessary to determine A. The exposure is set equal to zero at the vertical extremes of the profile (i.e., at the ground where the wind velocity equaled zero and at the effective height of the plume where the net concentration equaled zero). However, the maximum exposure usually occurred below a height of 1 m, so that there is a sharp decay in exposure near the ground. To account for this sharp decay, the value of exposure at the ground level is set equal to the value at 1 m (as extrapolated from the 2-m and 4.5-m values). The integration is then performed using the trapezoidal rule. The emission factor is then found by dividing the integrated exposure by the number of vehicle passes during sampling:

$$e = \frac{A}{N} \qquad (2\text{-}6)$$

where e = particulate emission factor in terms of mass per vehicle-distance-traveled (mass/length)
A = integrated exposure (mass/length)
N = number of vehicle passes during sampling (vehicles)

The control efficiency due to watering was determined by the percent reduction from the average uncontrolled emission factor:

$$c = \frac{e_u - e_c}{e_u} \times 100\% \qquad (2\text{-}7)$$

where c = instantaneous control efficiency (%)
e_u = average uncontrolled emission factor (mass/length)
e_c = controlled test emission factor (mass/length)

It is important to note that the efficiency determined for a specific test represents an "instantaneous" control efficiency (ICE) that is applicable to a particular time after control application. Another important measure of control performance is “average” control efficiency (ACE) which is related to instantaneous control efficiency in the following way:

$$C(T) = \frac{\int_0^T c(t)dt}{T} \tag{2-8}$$

where C(T) = average control efficiency during period ending T hours after watering (%)
c(t) = instantaneous control efficiency t hours after watering (%)
T = time period over which average control efficiency is determined (hours)

In practical terms, if the ICE for a test series shows a linear decay over time, such as:

$$c(t) = 100 - mt \tag{2-9}$$

where c(t) = instantaneous control efficiency at time t
m = decay rate

Then the corresponding average control value is also linear, but with half the decay rate:

$$C(T) = 100 - \frac{m}{2}T \tag{2-10}$$

where all variables are as defined above

For the DFS portion of the program, the primary results involved the surface loading and surface silt loading. The (total) surface loading is the mass of sample collected divided by the surface area sampled. The surface silt loading represents the amount of loose material less than 200 mesh present per unit area on the paved surface. Silt loading “sL” is found as

$$sL = \frac{f\left(B_{full} - B_{empty}\right) + \left(B_{full} - B_{tare}\right)}{a} \tag{2-11}$$

where sL = silt loading (mass/area)
f = fraction of recovered material less than 200 mesh (mass)
B_{full} = weight of the full vacuum bag (mass)
B_{empty} = weight of the empty vacuum bag after sample recovery (mass)
B_{tare} = initial (tare) weight of the vacuum bag before sampling (mass)
a = paved road area swept (area)

Chapter 3
Test Site Results

This section presents and discusses the results from the two-part field testing program. The watering tests of scraper transit conducted at NCKTC are discussed first, and the DFS mud/dirt carryout tests are discussed second. In spite of weather-related delays (from rain and variable winds), the number of tests performed at both sites exceeded the targets set in the Site-Specific Test Plan.

Watering Control of Scraper Transit Emissions

A total of 19 mass flux profiling tests were conducted at NCKTC during September 1999. Table 3-1 presents the test site parameters associated with each run. Note that the 19 tests are distributed over two uncontrolled test "series" (201, 601) and five controlled test "series" (301, 401, 501, 701, 1001)." The tests in the uncontrolled series were conducted simultaneously. Controlled tests were staggered in time after watering to track the decay in control efficiency as the scraper travel surface dried. Table 3-1 also shows the vehicle passes by the type of scraper in use during the test. NCKTC operates three basic models of Caterpillar scrapers:

Model	Type	Nominal Capacity	Empty Weight
613	Elevating ("paddle")	11 yd^3	16 ton
621	Pan	20 yd^3 (heaped)	33 ton
623	Elevating ("paddle")	22 yd^3	36 ton

All tests, whether controlled or uncontrolled, were conducted on the same stretch of the return route at the approximate mid-point. Note that, because of the orientation of the operation with respect to the prevailing wind direction, all scrapers were empty when they passed the sampling array (see Figure 2-1). The overall mean travel speed measured during the tests was 11 mph. No significant differences in travel speed were found between westbound and eastbound traffic or between watered and unwatered surfaces.

The results of the tests of scraper transit emissions are given in Tables 3-2, 3-3, and 3-4. Table 3-2 presents wind speeds at the heights of the 40 cfm cyclone samplers.

Table 3-3 contains the individual PM-10 exposure values at each sampling height in the downwind vertical array. As discussed in Section 2, the point values of exposure are integrated over the height of the plume to develop the PM-10 emission factors, which are given in Table 3-4. Appendix C presents detailed spreadsheets for the BY runs and Appendix D presents an example calculation.

Table 3-1. Test Site Parameters

Run no.	u/c[a]	Equipment[b]	Date	Start time	Duration (min)	Operational passes	Air temp (°F)	Barometric pressure (in. Hg)
BY-201	u	Cat 613	9/15/99	12:49	26	20	75.0	28.80
		Cat 621				14		
BY-202	u	Cat 613	9/15/99	12:54	16	15	76.0	29.00
		Cat 621				11		
BY-301	c	2-Cat 613	9/16/99	9:05	78	40	64.5	28.90
		3-Cat 621				60		
BY-302	c	2-Cat 613	9/16/99	9:46	80	42	64.5	28.90
		3-Cat 621				63		
BY-303	c	2-Cat 613	9/16/99	10:28	38	36	67.0	28.90
		3-Cat 621				24		
BY-401	c	2-Cat 613	9/17/99	9:13	61	37	59.5	28.80
		3-Cat 621				56		
BY-402	c	2-Cat 613	9/17/99	10:03	70	41	69.0	28.90
		3-Cat 621				59		
BY-403	c	2-Cat 613	9/17/99	10:21	67	40	69.0	28.90
		3-Cat 621				57		
BY-501	c	2-Cat 613	9/17/99	12:59	73	40	75.0	28.90
		3-Cat 621				73		
BY-502	c	2-Cat 613	9/17/99	13:38	81	45	78.0	28.90
		3-Cat 621				73		
BY-503	c	2-Cat 613	9/17/99	14:19	38	19	78.0	28.90
		3-Cat 621				34		
BY-601	u	2-Cat 613	9/22/99	9:28	56	36	58.0	28.78
		2-Cat 621				35		
		623				18		
BY-602	u	2-Cat 613	9/22/99	9:28	56	36	58.0	28.78
		2-Cat 621				35		
		623				18		
BY-701	c	Cat 613	9/22/99	12:42	61	2	78.8	28.88
		2-Cat 621				45		
		623				22		
BY-702	c	Cat 613	9/22/99	13:09	92	5	80.0	28.92
		2-Cat 621				57		
		623				27		

(continued)

Table 3-1. (continued)

Run no.	u/c[a]	Equipment[b]	Date	Start time	Duration (min)	Operational passes	Air temp (°F)	Barometric pressure (in. Hg)
BY-703	c	2-Cat 613	9/22/99	13:50	76	6	80.0	28.92
		2-Cat 621				44		
		623				20		
BY-1001	c	3-Cat 613	9/23/99	8:44	81	41	58.8	28.50
		2-Cat 621				48		
		623				24		
BY-1002	c	2-Cat 613	9/23/99	9:26	54	30	58.5	28.50
		2-Cat 621				29		
		623				16		
BY-1003	c	2-Cat 613	9/23/99	10:14	46	30	72.0	28.55
		2-Cat 621				25		
		623				14		

[a] Uncontrolled/controlled test.
[b] All passes were by empty scrapers.

Table 3-2. Isokinetic Correction Parameters (By Runs)

	Wind speed						Profiler		
	2 m		4.5 m		7 m		isokinetic flow ratios		
Run	(cm/s)	(ft/min)	(cm/s)	(ft/min)	(cm/s)	(ft/min)	2m	4.5 m	7 m
BY-201	111	218	135	265	147	290	4.28	3.51	3.24
BY-202	103	202	124	244	135	266	4.53	3.82	3.51
BY-301	240	473	292	575	320	630	1.96	1.62	1.48
BY-302	307	604	377	743	416	818	1.50	1.24	1.14
BY-303	298	586	369	727	408	803	1.58	1.27	1.16
BY-401	211	415	266	523	295	582	2.23	1.76	1.60
BY-402	312	613	396	780	442	869	1.48	1.19	1.07
BY-403	346	680	437	860	486	957	1.37	1.07	0.98
BY-501	289	569	364	716	405	797	1.61	1.51	1.38
BY-502	274	539	340	669	376	740	1.74	1.89	1.72
BY-503	260	512	319	627	350	690	1.79	1.49	1.84
BY-601	254	501	326	642	364	717	1.85	1.43	1.29
BY-602	254	501	326	642	364	717	1.81	1.43	1.29
BY-701	365	719	464	913	517	1017	1.27	1.02	0.92
BY-702	372	732	475	935	532	1046	1.28	0.99	0.90
BY-703	384	756	488	960	544	1072	1.24	0.97	0.88
BY-1001	160	315	205	403	229	451	2.93	2.27	2.08
BY-1002	151	297	186	367	206	406	3.05	2.52	2.28
BY-1003	148	291	181	357	200	394	3.20	2.59	2.36

Table 3-3. Plume Sampling Data

Run	Sampling height (m)	PM-10 Sampling rate m³/hr	PM-10 Sampling rate ft³/min	Net PM 10 exposure (mg/cm²)
BY-201	2	69.35	40.82	0.3253
	4.5	68.93	40.57	0.2131
	7	69.67	41.01	0.0428
BY-202	2	67.98	40.01	0.1571
	4.5	69.08	40.66	0.0635
	7	69.28	40.78	0.0378
BY-301	2	68.88	40.54	0.0246
	4.5	69.10	40.67	0.0815
	7	69.05	40.64	0.0586
BY-302	2	67.38	39.66	0.1353
	4.5	68.62	40.39	0.0406
	7	68.99	40.61	0.0694
BY-303	2	68.81	40.50	0.0450
	4.5	68.40	40.26	0.0319
	7	68.98	40.60	0.0126
BY-401	2	68.79	40.49	0.0606
	4.5	68.32	40.21	0.0671
	7	68.96	40.59	0.0345
BY-402	2	67.47	39.71	0.1779
	4.5	68.72	40.45	0.0423
	7	69.01	40.62	0.0492
BY-403	2	69.15	40.70	0.1631
	4.5	68.57	40.36	0.2022
	7	69.78	41.07	0.0290
BY-501	2	68.15	40.11	0.1942
	4.5	69.16	40.71	0.0417
	7	69.54	40.93	0.0712
BY-502	2	69.59	40.96	0.3009
	4.5	69.01	40.62	0.1590
	7	69.76	41.06	0.0720

(continued)

Table 3-3. (continued)

Run	Sampling height (m)	PM-10 Sampling rate m³/hr	PM-10 Sampling rate ft³/min	Net PM 10 exposure (mg/cm²)
BY-503	2	68.06	40.06	0.2397
	4.5	69.16	40.71	0.0542
	7	69.54	40.93	0.0000
BY-601	2	68.57	40.36	0.2514
	4.5	67.94	39.99	0.1128
	7	68.52	40.33	0.0302
BY-602	2	66.99	39.43	0.1182
	4.5	68.01	40.03	0.0567
	7	68.52	40.33	0.0015
BY-701	2	68.03	40.04	0.1026
	4.5	69.13	40.69	0.0120
	7	69.50	40.91	0.0145
BY-702	2	69.71	41.03	0.2549
	4.5	69.06	40.65	0.0000
	7	69.88	41.13	0.0000
BY-703	2	69.56	40.94	0.5428
	4.5	69.13	40.69	0.0843
	7	69.64	40.99	0.0173
BY-1001	2	68.62	40.39	0.0173
	4.5	67.84	39.93	0.0150
	7	69.84	41.11	0.0343
BY-1002	2	67.41	39.68	0.0180
	4.5	68.57	40.36	0.0190
	7	68.79	40.49	0.0180
BY-1003	2	69.16	40.71	0.0295
	4.5	68.60	40.38	0.0146
	7	69.18	40.72	0.0206

Table 3-4. Emission Factors

Run	Test conditions	Silt content (%)	Moisture content (%)	PM-10 emission factor (lb/VMT)
BY-201	uncontrolled	7.9	3.8	1.798
BY-202	"	10.8	4.6	1.133
BY-301	1.1 gal/yd²	14.9	17.5	0.164
BY-302	"	"	12.4	0.251
BY-303	"	"	7.14	0.153
BY-401	0.21 gal/yd²	9.58	19.2	0.168
BY-402	"	"	10.1	0.297
BY-403	"	"	8.51	0.386
BY-501	0.31 gal/yd²	5.87	13.6	0.296
BY-502	"	"	8.24	0.485
BY-503	"	"	5.58	0.687
BY-601	uncontrolled	7.32	7.08	0.491
BY-602	"	"	7.08	0.225
BY-701	0.14 gal/yd²	9.4[a]	12.0	0.224
BY-702	"	"	6.46	0.391
BY-703	"	"	3.86	1.154
BY-1001	0.54 gal/yd²	9.4[a]	14.3	0.052
BY-1002	"	"	8.68	0.098
BY-1003	"	"	8.12	0.107

[a] Mean silt content found for site.

Table 3-4 also presents the soil surface moisture value associated with each test. These values are averages of appropriate point values (from grab samples) along the decay curves shown in Figure 3-1.

Discussion of the Watering Test Results

Control efficiency was determined as the percent reduction in the emission factor for each test compared to the mean uncontrolled emission factor. The mean uncontrolled PM-10 emission factor of 1.46 lb/vmt was based on test series 201-202. Note that the other uncontrolled test series (601-602) was not included in determining the mean, because the 601 test series had been performed after rain at the site. Although the route had visibly appeared uncontrolled during the test, gravimetric analysis of the 601-series filters resulted in emission factors substantially below those from the 201 series. The moisture content of the 601 series was also almost twice that for the 201 series.

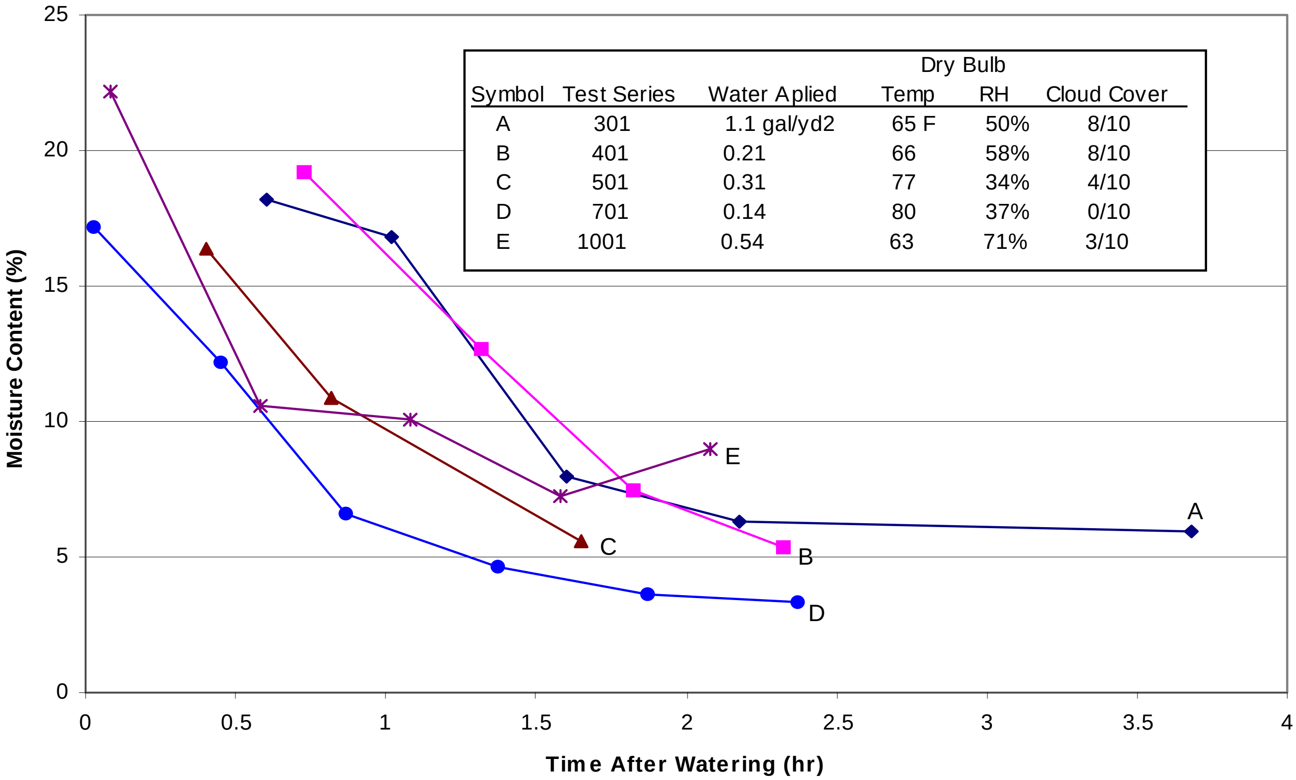

Figure 3-1. Decay of moisture content with time after watering (NCKTC).

Figure 3-1 presented a time history of the moisture content after watering. Figure 3-2 provides a similar time history, except that the (instantaneous) control efficiency is plotted against the mid-point time for each test. Figure 3-3, on the other hand, plots **average** control efficiency values. Note that, due to the integration process described in Chapter 2, average control efficiency values result in a "smoother" time history.

Fitting the Figure 3-3 data to least-squares lines of the form:

$$C(t) = B - mt \qquad (3\text{-}1)$$

where C(t) = average control efficiency (%)
B = intercept (%)
m = decay rate (%-hr^{-1})
t = time after watering (hr)

provides a means to explore decay rates in terms of service environment variables. Table 3-5 lists the test series and decay rates, and Figure 3-4 shows the lines of best fit.

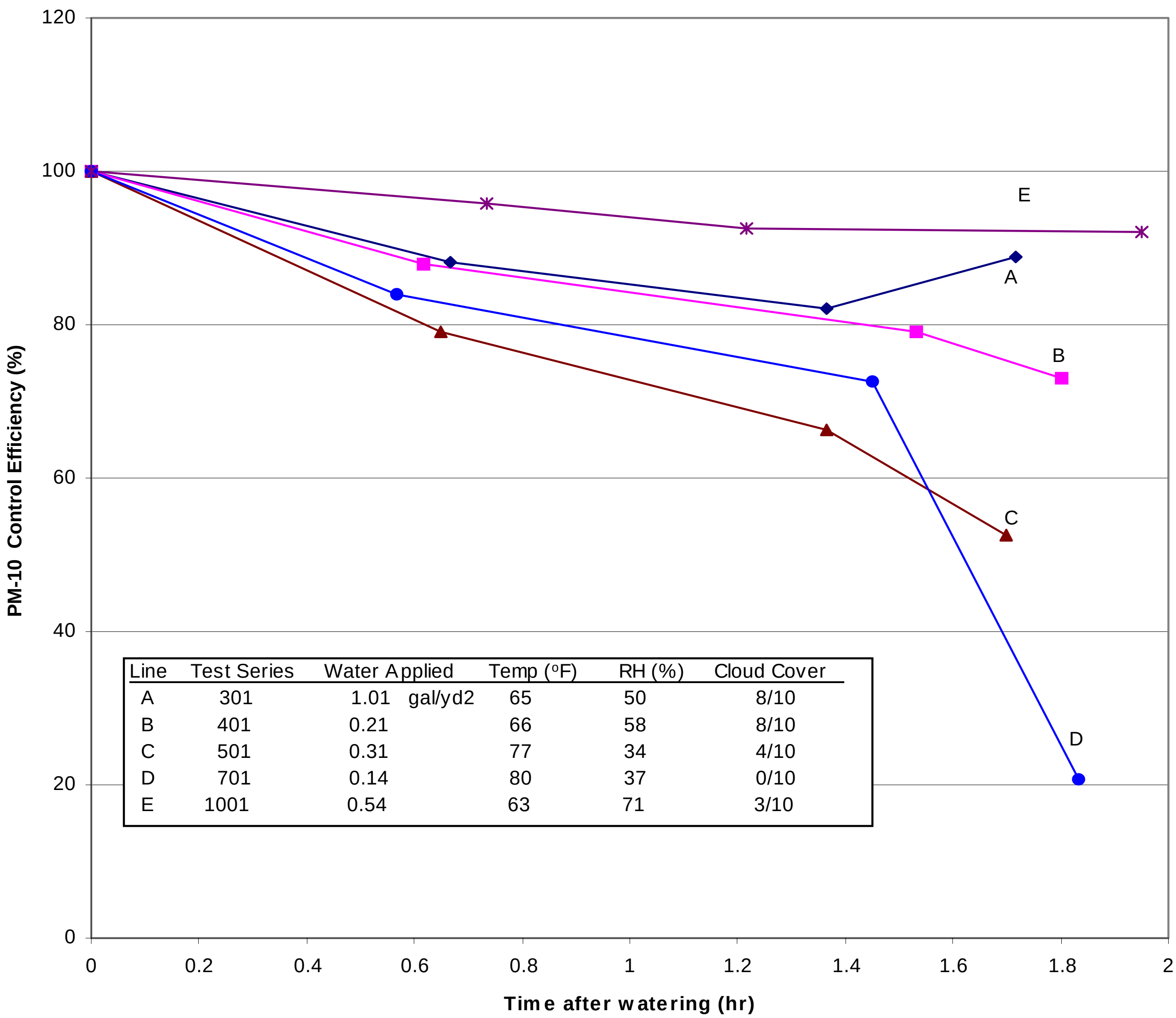

Figure 3-2. Decay of instantaneous control efficiency with time after watering (NCKTC).

Also given in Table 3-5 are measures of the service environment in which water acted as a control measure. Service environment variables include ambient variables such as amount of water applied, ambient temperature, relative humidity, cloud cover, and solar radiation. Recall that these are viewed as second-tier, semi-quantitative measurements to assess how well the primary variable (surface moisture content) relates to environmental conditions. Appendix E contains a listing of the second-tier measurements.

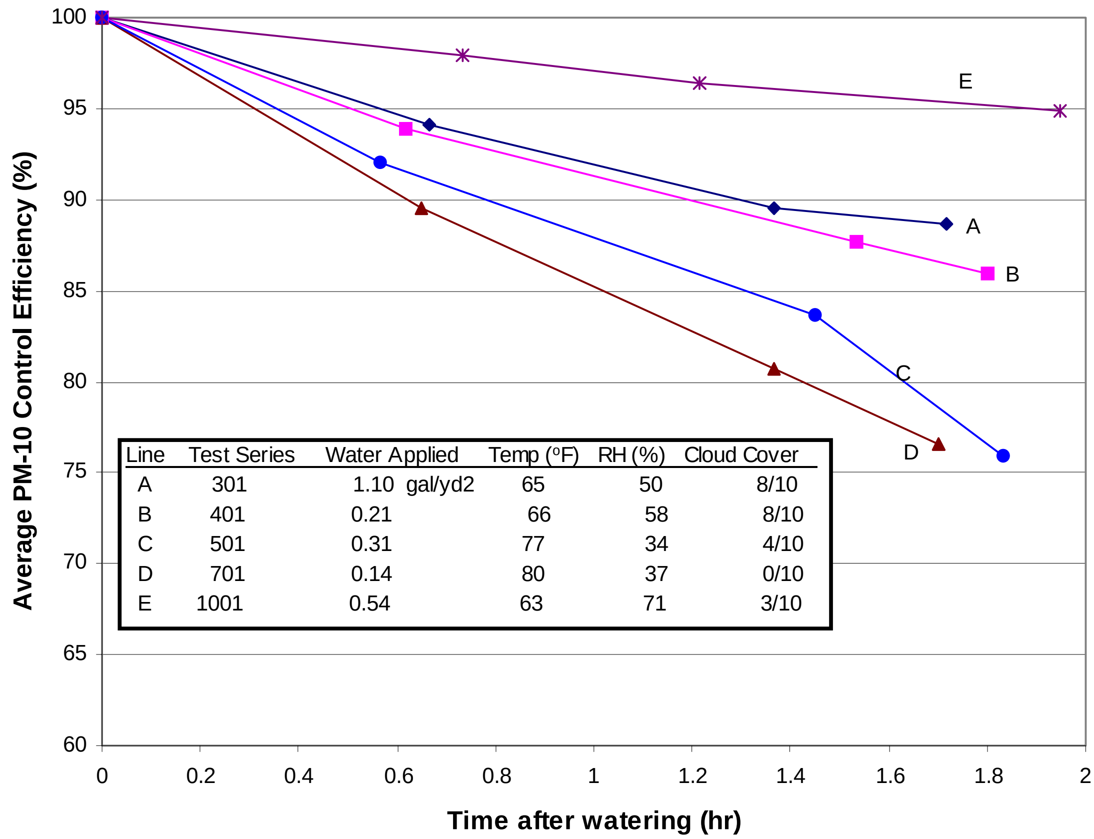

Figure 3-3. Decay of average control efficiency with time after watering (NCKTC).

Table 3-5. Decay Rates Fitted by Least-Squares Linear Regression

Test series	Water applied (gal/yd^2)	Dry bulb temp. (°F)	Wet bulb temp. (°F)	Relative humidity (%)	Cloud cover (tenths)	Traffic volume[a] (veh/hr)	Intercept, B (%)	Decay rate (%—hr^{-1})	r^2
301	1.10	65	55	50	8	84	99.4	6.71	0.9717
401	0.21	66	57	58	8	88	99.5	7.68	0.9917
501	0.31	77	59	34	4	88	99.4	13.70	0.9957
701	0.14	80	62	37	0	60	99.8	12.40	0.9835
1001	0.54	63	57	71	3	86	99.9	2.65	0.9930

[a] Average value of operating passes per unit time over the three tests in each test series.

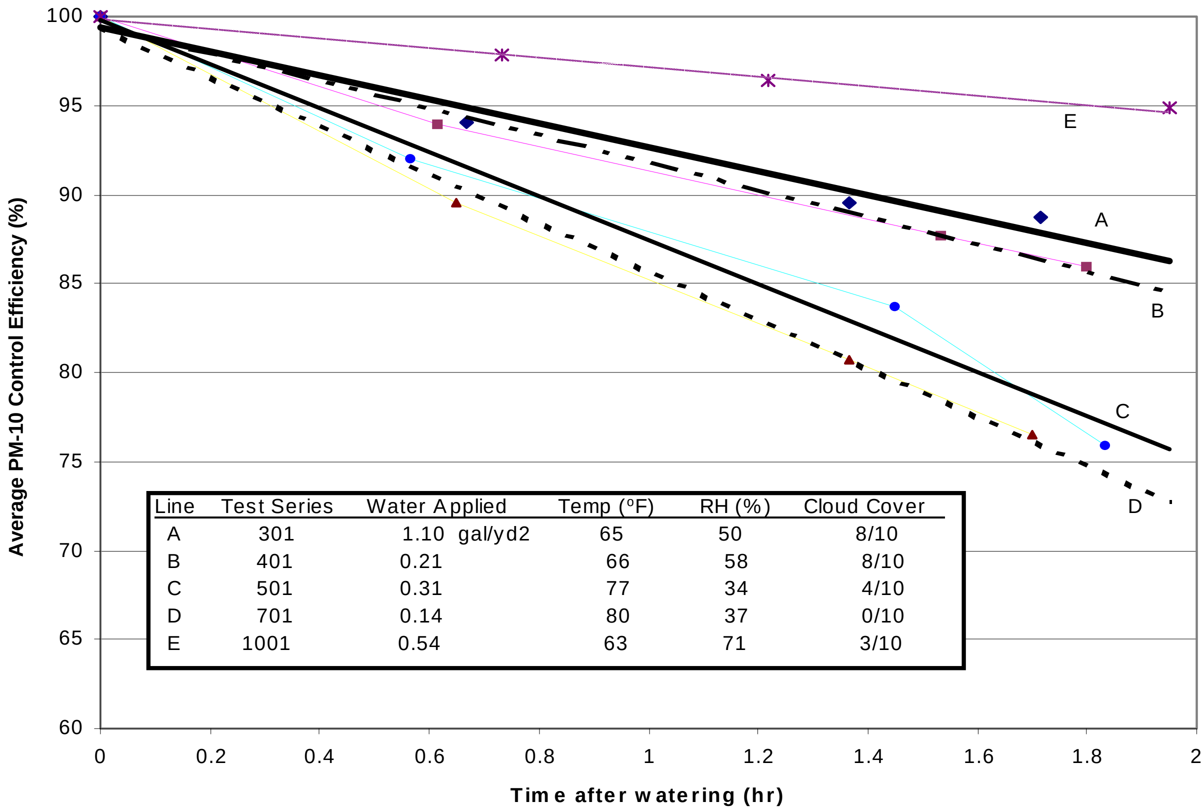

Figure 3-4. Best fit lines for average control efficiency decay with time after watering (NCKTC).

Table 3-6 presents the correlation matrix for the decay rate “m” against the different measures of the service environment.

Table 3-6. Correlation Matrix

	PM-10 decay rate	Water applied	Dry bulb temp.	Wet bulb temp.	Relative humidity	Cloud cover	Traffic rate
PM-10 decay rate	1	- 0.494	0.239	0.195	- 0.964	- 0.334	0.124
Water applied	- 0.494	1	- 0.402	- 0.689	0.263	0.517	0.273
Dry bulb temp.	0.239	- 0.402	1	0.893	- 0.053	0.484	- 0.647
Wet bulb temp.	0.195	- 0.689	0.893	1	0.05	0.248	- 0.774
Relative humidity	- 0.964	0.263	- 0.053	0.05	1	0.301	- 0.271
Cloud cover	- 0.334	0.517	0.484	0.248	0.301	1	- 0.606
Traffic rate	0.124	0.273	- 0.647	- 0.774	- 0.271	- 0.606	1

Table 3-6 shows that the PM-10 control efficiency decay rate is strongly correlated with relative humidity. A least-squares regression of decay rate against relative humidity results in:

$$m^* = 22.8 - 0.283\,(RH) \tag{3-2}$$

where m* = estimated decay rate (%-hr^{-1})
RH = relative humidity (%)

The r^2 value for Equation 3-2 is 0.929.

Soil surface moisture content provides an alternate variable that might be used as a basis for tracking the emission factor and control efficiency data developed from the field tests. However, there is no readily available “starting point” for the moisture content for which one could reasonably assume 100 percent control at time zero (i.e., when the road had just been watered). To illustrate this point, Figure 3-5 shows exponential decay functions fitted to the moisture time histories shown earlier as Figure 3-1. Extrapolated time-zero moisture values vary from 15 to 36 percent. Clearly, one could reasonably expect that the higher initial moisture contents should be associated with the higher water application rates. However, the extrapolations in Figure 3-5 do not generally follow that trend.

Figure 3-6 plots the instantaneous control efficiency against the surface moisture content associated with each test. The important aspects to notice about the figure are the steep slope at fairly low moisture values and the more shallow slope at high moisture levels. This is in keeping with past studies[6,7] which found that control efficiency data can be successfully fitted by a bilinear function, based on a “normalized” surface moisture value. The normalization is performed by dividing by the uncontrolled (unwatered) surface moisture content for the unpaved travel route. In this case, the BY moisture data are normalized by 4 percent, which is the mean moisture value from BY-201 and 202. Figure 3-7 compares the data collected in this study against a bilinear fit proposed in an EPA guidance document.[7] In general, the BY data match relatively well with the EPA guidance model, showing a sharp rise in control efficiency as the surface moisture content is raised to twice the uncontrolled value and a much slower rise beyond that moisture level. Use of the EPA function to predict the watering data is conservative in the sense that the predicted control efficiency values are somewhat lower than the observed values.

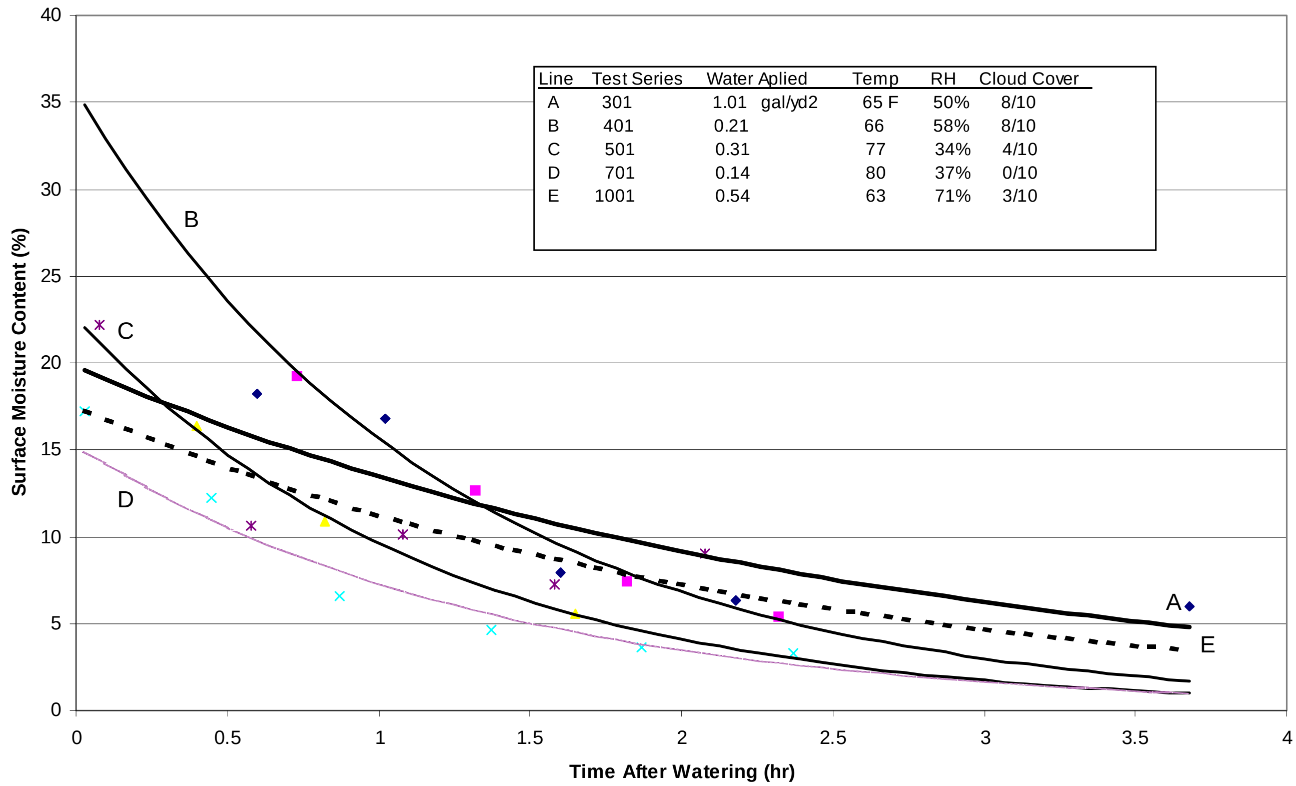

Figure 3-5. Exponential decay in surface moisture content with time after watering (NCKTC).

Particle Size Data for Watered and Unwatered Travel Routes

In addition to the mass flux profiling tests used to determine control efficiency values, the NCKTC portion of the field program collected particle size information for the particulate emissions. These data supplement the particle size data from the BV tests conducted during the 1998 test program[3]. Figure 3-8 presents the data collected at the 2- and 4.5-m downwind sampling locations during six 1998 scraper transit tests. The figure plots the cumulative fraction of PM less than the size shown on the horizontal axis. Note that the fraction is based on particles up to 15 mm in aerodynamic diameter, which is the 50 percent cutpoint for the cyclone operated at 20 acfm.[4]

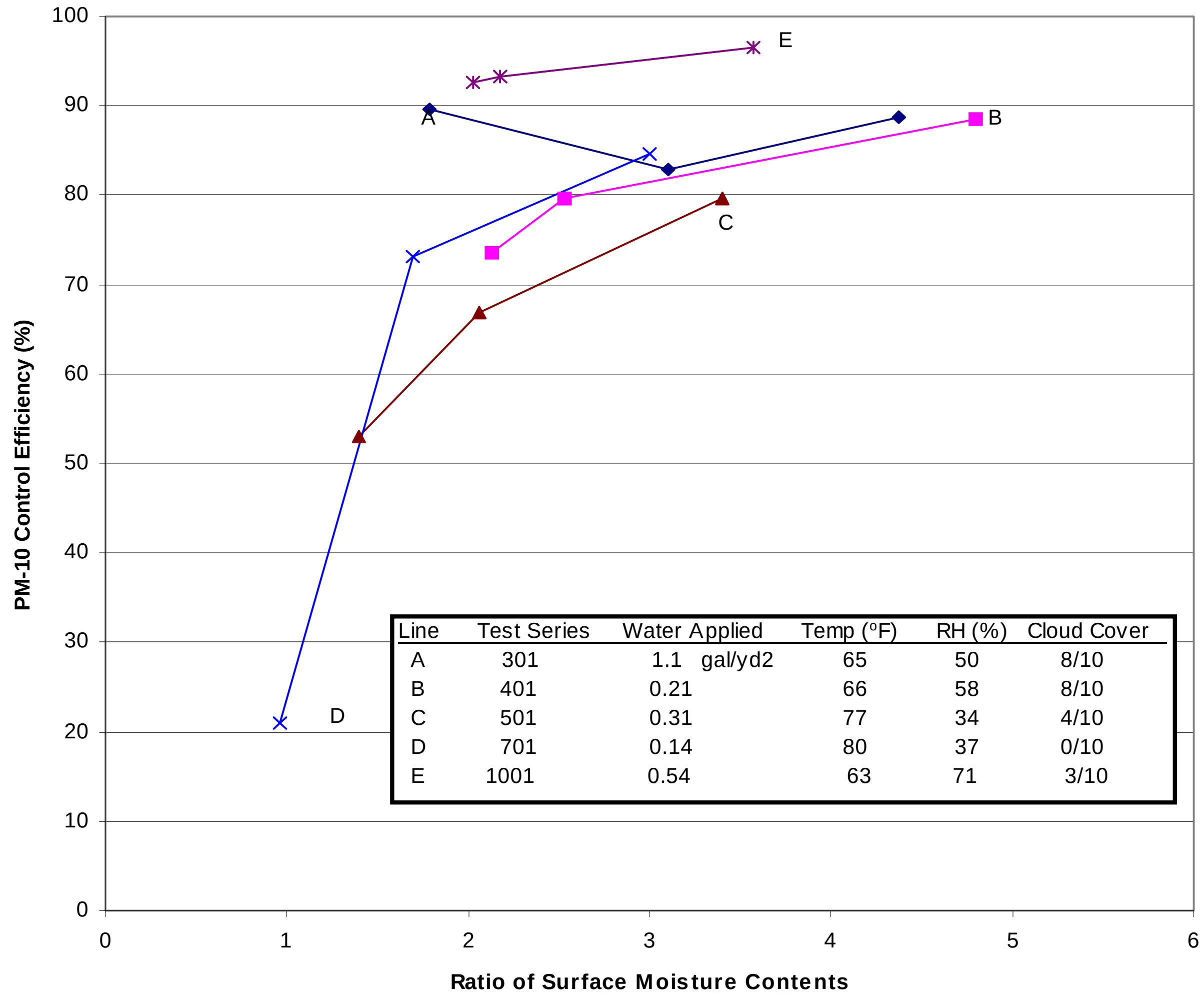

Figure 3-6. Instantaneous PM-10 control efficiency versus surface moisture content (NCKTC).

Before discussing the new particle size information, it is important to recall the key difference between the two data sets. The 1998 tests referenced uncontrolled conditions while the 1999 program was directed toward control performance characterization.

Consequently, in 1998 the downwind monitors encountered much higher downwind concentrations and thus could collect adequate sample mass in a relatively brief period of time. In 1999, on the other hand, the watered surfaces resulted in much lower downwind concentrations, thus posing a problem in collecting adequate sample mass. In general, only the 2-m downwind cyclone/cascade impactor combination collected

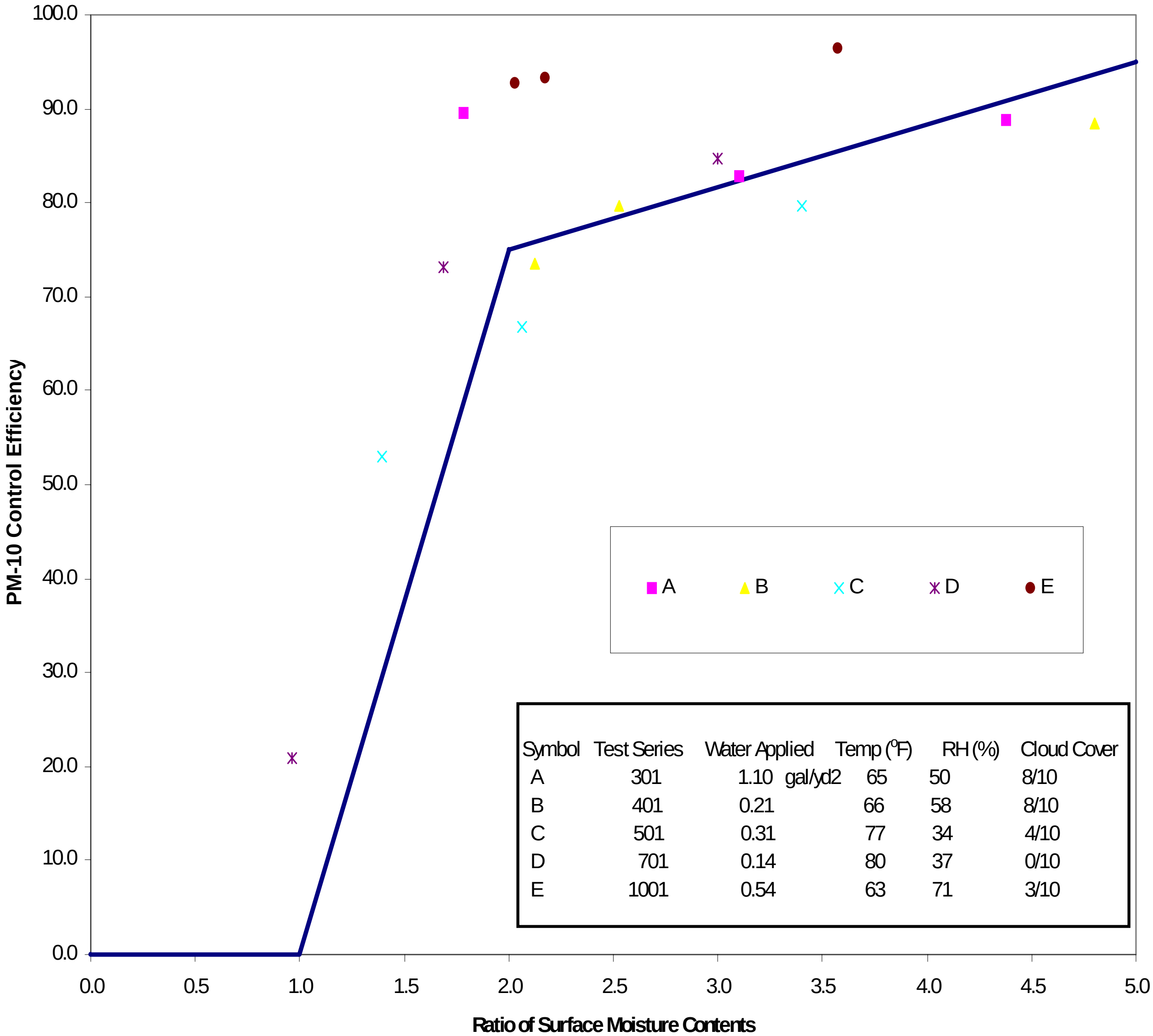

Figure 3-7. Comparison of instantaneous control efficiency with previously published function (NCKTC).

adequate sample mass for the controlled test series. Appendix F contains detailed data for the impactor tests.

Figure 3-9 compares particle size data collected during the 1999 tests at NCKTC with the data collected in 1998. Solid and dashed lines indicate tests conducted on surfaces which had or had not been watered, respectively. The vertical lines in Figure 3-9 indicate 1 standard deviation bounds on the geometric mean from the 1998 (BV) tests

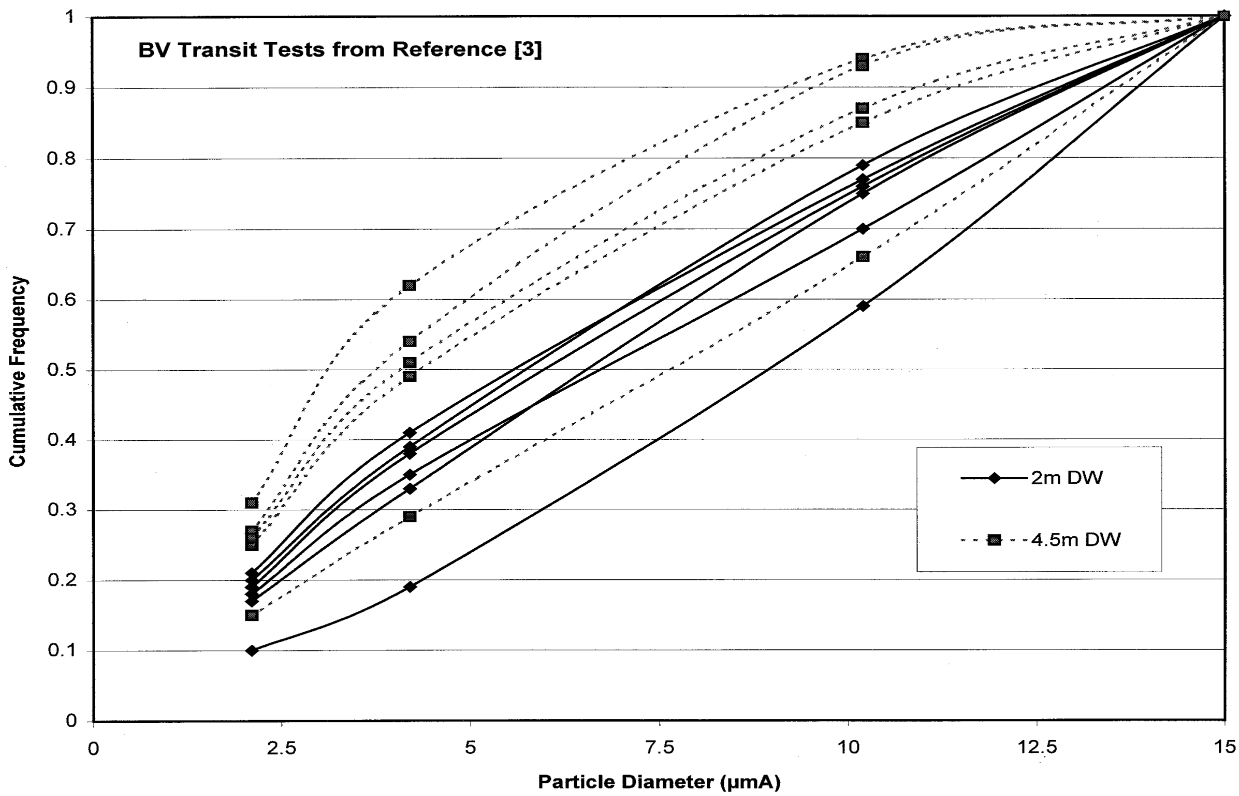

Figure 3-8. Particle size distributions for 1998 uncontrolled scraper transit emissions (BV runs) from reference 3.

(i.e., the data from Figure 3-8). The lefthand and righthand lines are for the 4.5-m and 2-m downwind sampling heights, respectively. In spite of difficulties collecting adequate sample mass, the 1999 particle size data generally compare well with BV data.

An additional series of analyses were performed on the PM-2.5-to-PM-10 ratio (as approximated by catches associated with the third impactor stage (50 percent cutpoint of 2.1 μm in aerodynamic diameter) and the first stage (50 percent cutpoint of 10.2 μm in aerodynamic diameter). The variation in the PM-2.5/PM-10 ratio was explored in terms of variations in the following variables.

- mean PM-10 emission factor for a test series
- average control efficiency decay rate
- volume of water applied

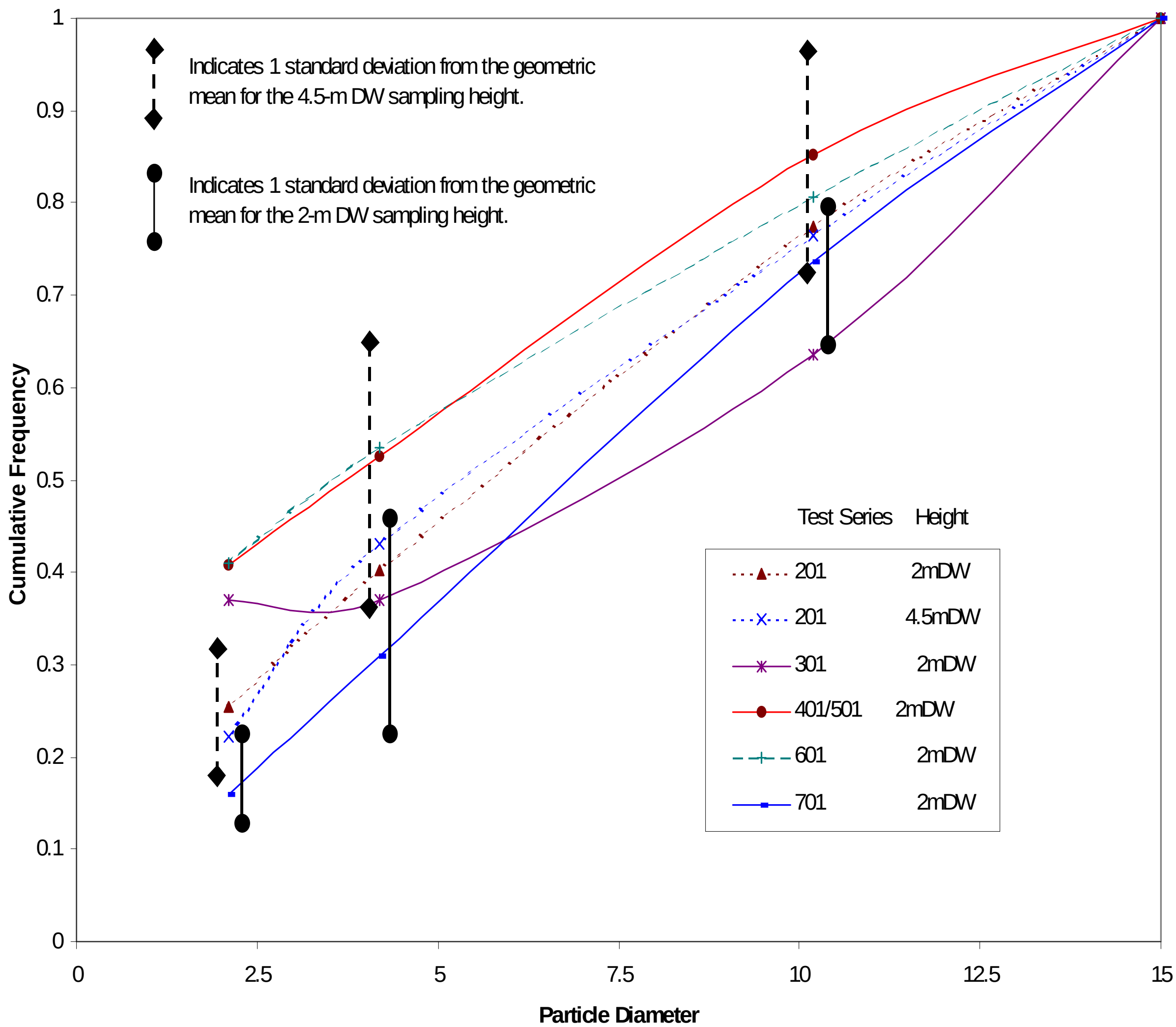

Figure 3-9. Comparison of particle size distributions for 1999 BY runs and 1998 BV runs.

A slight negative correlation (significant at the 10 percent level, but not at the 5 percent level) between emission factor and PM-2.5/PM-10 ratio was found, as shown in Figure 3-10. This indicates that, as emissions increase, the ratio of PM-2.5 to PM-10 decreases. That is, higher emission levels (i.e., either uncontrolled or several hours after watering) are associated with higher fractions of mass in the 2.5 to 10 µmA size range. This is to be expected because when the road is highly controlled immediately after the water is applied, emissions consist almost entirely of diesel exhaust emissions in submicron size range. As the road surface dries, increasing amounts of coarse road dust are emitted while the diesel exhaust emissions remain constant. This discussion points out an obvious – but still worth mentioning – feature of watering: water controls only surface dust and not diesel exhaust emissions. Because diesel exhaust is a far

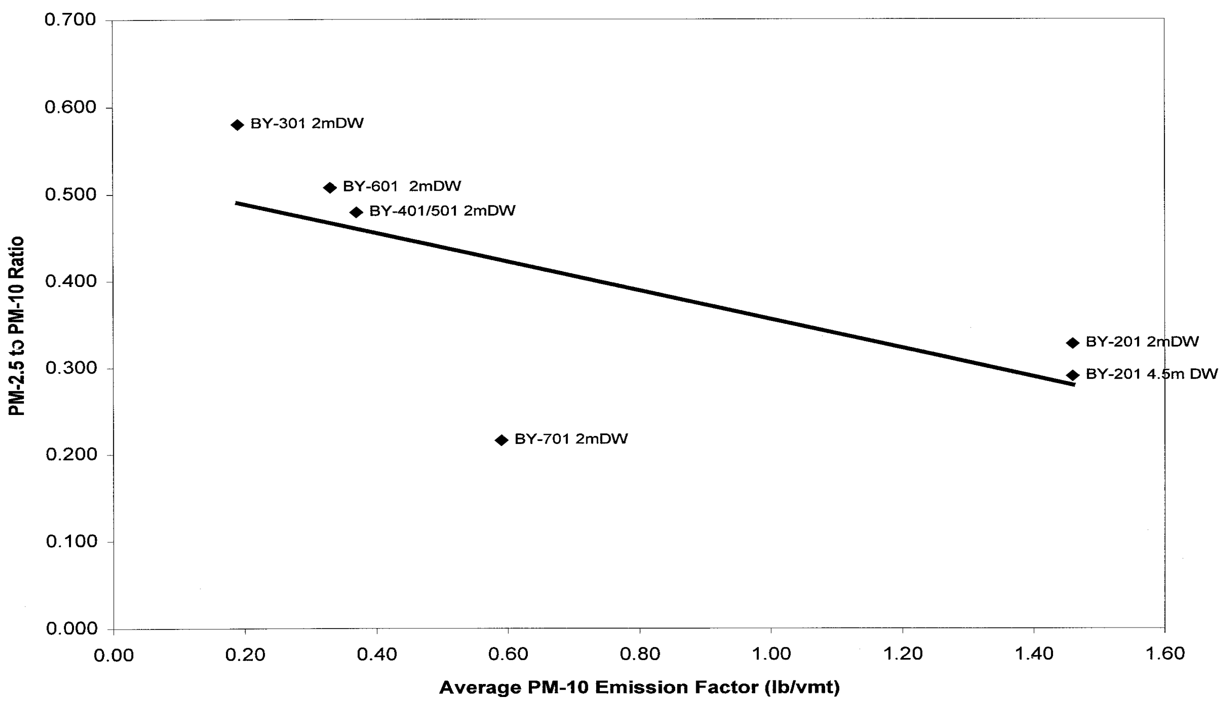

Figure 3-10. Correlation between PM-2.5/PM-10 ratio and PM-10 emission factor.

more important component of PM-2.5 emissions than of PM-10 emissions and because diesel exhaust is unaffected by watering, these observations lead to the logical conclusion that watering scraper routes should give lower control efficiency for PM-2.5 than for PM-10.

As noted earlier, in order to collect adequate sample mass on the various media, the cyclone/impactors were operated over the entire test series. As a result, it is not possible to develop a time history of PM-2.5 control efficiency in the manner that PM-10 efficiency was presented in Figures 3-2 to 3-4. Instead, PM-2.5 control efficiency is based on the average controlled emission factor determined over the test series.

Based on both the BV and BY test data, the average PM-2.5-to-PM-10 ratio for uncontrolled tests is 0.267. When combined with the mean uncontrolled PM-10 emission factor of 1.46 lb/vmt, this leads to a mean uncontrolled PM-2.5 emission factor of 0.39 lb/vmt. Because of difficulties collecting adequate sample mass on the impactor substrates and backup filters during the watered tests, only impactor data from the

401/501 and 701 test series are considered reliable. When the two sets of watered test data are combined, an average PM-2.5-to-PM-10 ratio of 0.374 is obtained. These ratios are used to develop the scaled emission factors shown in Table 3-7.

Table 3-7. PM-2.5 Control Efficiency Values

Test series	Average PM-10 emission factor[a] (lb/vmt)	Average PM-2.5 emission factor[a] (lb/vmt)	Average PM-2.5 control efficiency[b] (%)	Average PM-2.5 control efficiency decay rate[c] (% - hr^{-1})
201	1.46	0.39	–[d]	–[d]
301	0.189	0.072	82	9
401	0.284	0.11	72	14
501	0.489	0.18	54	23
701	0.590	0.22	44	28
1001	0.0857	0.032	92	4

[a] PM-10 emission factor found by averaging emission factors in Table 3-4 over each test series. PM-2.5 factors found by scaling average PM-10 factors by 0.267 or 0.374, for uncontrolled or watered tests, respectively.

[b] PM-2.5 control efficiency based on percent reduction in average PM-2.5 emission factor from average uncontrolled PM-2.5 factor (i.e., 0.39 lb/vmt).

[c] Average decay rate based on assumed linear decay from 100% control at time zero and nominal 2-hour test period for test series.

[d] Uncontrolled test series.

Average control efficiency decay rates for PM-10 (from Table 3-5) and PM-2.5 are compared against relative humidity in Figure 3-11. Control efficiency for PM-2.5 decayed at least 30 percent more quickly than did PM-10 control efficiency in each case. In most instances, the rate of decay was at least 50 percent faster. The difference between PM-10 and PM-2.5 control efficiency decay rates was greater for low relative humidity values. In other words, under dry conditions, watering appears to be far more effective in controlling coarse PM rather than fine PM emitted during scraper travel operations.

Mud/Dirt Trackout Study Test Results

As noted in the Introduction, the second part of the field testing program explored an unwelcome consequence of watering unpaved surfaces at construction sites—namely, the increase in mud/dirt trackout onto surrounding paved streets. Testing employed a captive site at MRI's Deramus Field Station (DFS). The captive nature of the operation meant that one could tightly control experimental variables such as the moisture level of the access area and the number and type of vehicles leaving the site. The impact of trackout emissions was measured in terms of mass of mud/dirt deposited onto the paved test area.

Table 3-8 presents test site parameters associated with the DFS field exercise. Tests were conducted during an unseasonably warm period in November 1999. In the table,

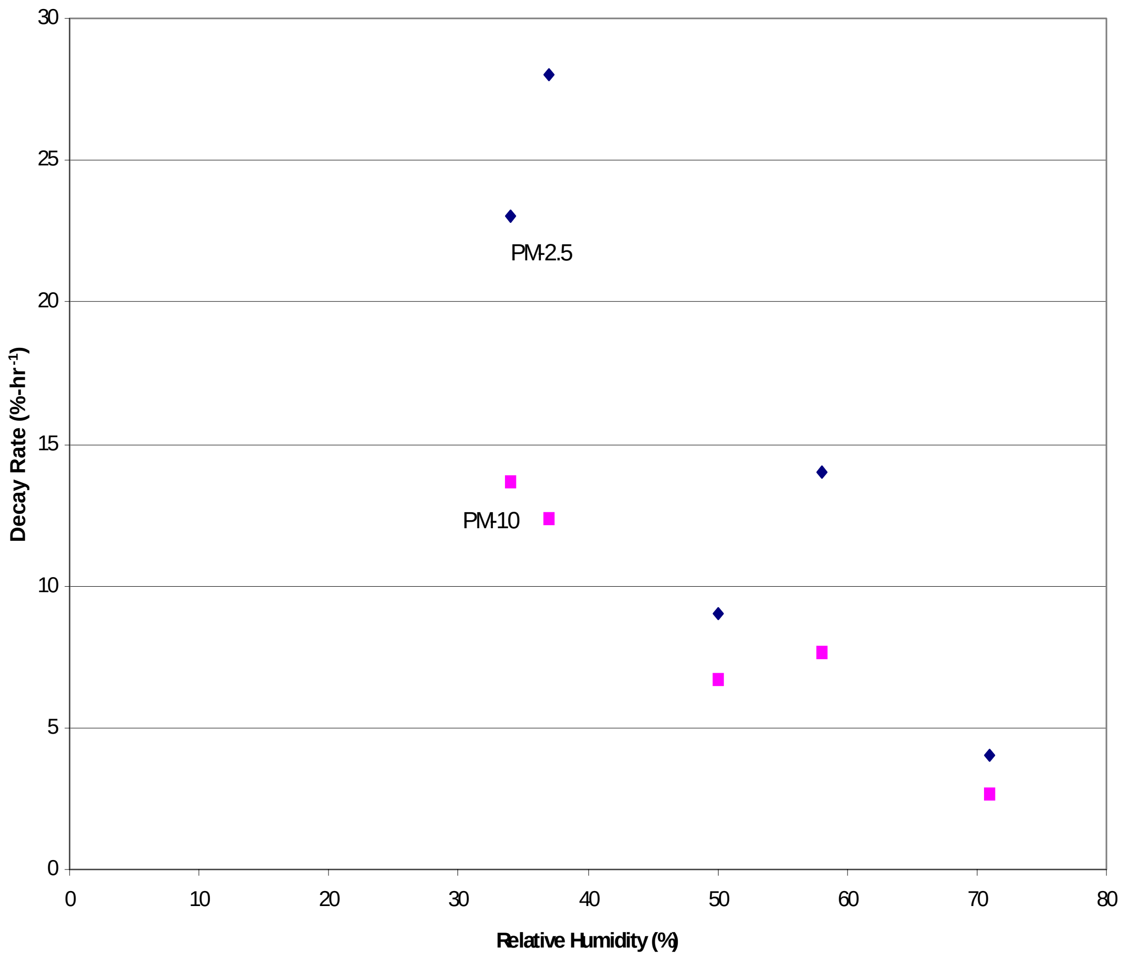

Figure 3-11. Average control efficiency decay rates for PM-10 and PM-2.5 versus relative humidity.

tests are referenced by a numerical code of the form “x-y” where “x” indicates the phase and “y” indicates a sequential number to uniquely identify tests within a specific phase.

A total of 58 paved road surface samples were collected during the field exercise. Table 3-9 presents the analysis results for those samples. In the table, the average moisture content refers to average of the two to four composite samples collected while captive traffic traveled over the access area during a given test. A thorough listing of the sample data collected at DFS is provided in Appendix G.

Table 3-8. Trackout Study Test Parameters

Test ID	Date	Vehicle	Type of test	Vehicle start time	Duration (min)	Operational passes	Air Temp (°F)
1-1	11/8/99	pickup	calibration	1600	45	100	73.9
1-2	11/9/99	pickup	calibration	1323	60	100	75
1-3	11/9/99	pickup	calibration	1533	26	50	73.5
1A-1	11/10/99	pickup	calibration	950	19	50	61
2-1	11/10/99	pickup	uncontrolled	1027	19	50	63
2-2	11/10/99	pickup	uncontrolled	1440	18	50	70
2-3	11/10/99	pickup	uncontrolled	1531	19	50	67.5
2-4	11/10/99	pickup	uncontrolled	1621	18	50	65
2-5, 3-1	11/11/99	pickup	uncont./paved apron	1143	26	50	57
2-6, 3-2	11/11/99	pickup	uncont./paved apron	1340	16	50	61
2-7, 3-3	11/11/99	pickup	uncont./paved apron	1422	21	50	60
2-8, 3-4	11/11/99	pickup	uncont./paved apron	1519	18	54	59
2-9, 3-5	11/11/99	pickup	uncont./paved apron	1610	18	50	58
2-10, 3-6	11/12/99	pickup	uncont./paved apron	923	15	50	61
2-11, 3-7	11/12/99	pickup	uncont./paved apron	953	22	50	63
2-12, 3-8, & 1A-2	11/12/99	pickup	uncont./pav.apr./calib.	1045	17	50	65
2-13, 3-9	11/12/99	pickup	uncont./paved apron	1126	15	50	68
2-14, 3-10	11/12/99	pickup	uncont./paved apron	1344	19	50	70
2-15, 3-11	11/12/99	pickup	uncont./paved apron	1420	14	50	73
2-16, 3-12	11/12/99	pickup	uncont./paved apron	1523	18	50	72
2-17	11/15/99	dump truck	uncontrolled	1431	61	50	62
2-18	11/15/99	dump truck	uncontrolled	1430	61	50	62
2-19	11/16/99	dump truck	uncontrolled	956	60	50	40
2-20	11/16/99	dump truck	uncontrolled	958	58	50	40
4-1	11/17/99	pickup	gravel apron	953	21	50	N/A
4-2	11/17/99	pickup	gravel apron	1030	16	50	N/A
4-3	11/17/99	pickup	gravel apron	1104	16	50	N/A
4-4	11/17/99	pickup	gravel apron	1248	17	50	N/A
4-5	11/17/99	pickup	gravel apron	1330	21	50	N/A
4-6	11/17/99	pickup	gravel apron	1421	22	50	N/A
4-7	11/17/99	pickup	gravel apron	1535	22	50	N/A
4-8	11/17/99	pickup	gravel apron	1613	20	50	N/A
4-9	11/18/99	pickup	gravel apron	905	24	50	62
4-10	11/18/99	pickup	gravel apron	938	27	50	63
4-11	11/18/99	pickup	gravel apron	1025	23	50	65
4-12	11/19/99	pickup	gravel apron	901	19	50	38
4-13	11/19/99	pickup	gravel apron	948	18	50	39

Table 3-9. Surface Loading Results (DFS)

Test ID	Average moisture content (%)	Soil type	Vehicle type	Distance (ft) from access point	Total loading (g/m^2)	Silt loading (g/m^2)
1-1	4.6	native	pickup	10	1.54	0.26
1-1	4.6	native	pickup	50	0.20	0.03
1-1	4.6	native	pickup	90	0.57	0.06
1-1	4.6	native	pickup	130	0.21	0.02
1-2	9.5	native	pickup	10	2.27	0.16
1-2	9.5	native	pickup	50	1.32	0.13
1-3	21.4	native	pickup	130	4.40	0.35
1-3	21.4	native	pickup	90	2.96	0.19
1-3	21.4	native	pickup	50	6.40	0.61
1-3	21.4	native	pickup	10	7.88	0.40
1A-1	24.1	native	pickup	5	13.67	0.90
1A-1	24.1	native	pickup	45	12.03	0.97
2-1	5.5	sandy	pickup	5	2.48	0.44
2-2	12.1	sandy	pickup	5	6.81	0.72
2-3	7.9	sandy	pickup	5	4.02	0.54
2-4	17.4	sandy	pickup	5	7.34	0.93
2-5	9.4	sandy	pickup	5	4.73	0.99
3-1	9.4	sandy	pickup	25	1.80	0.45
2-6	14.5	native	pickup	5	9.33	1.52
3-2	14.5	native	pickup	25	2.78	0.50
2-7	19.3	sandy	pickup	5	4.00	0.87
3-3	19.3	sandy	pickup	25	2.31	0.66
2-8	25.0	native	pickup	5	16.52	1.46
3-4	25.0	native	pickup	25	11.48	0.76
2-9	16.7	sandy	pickup	5	3.66	0.83
3-5	16.7	sandy	pickup	25	2.20	0.45
2-10	20.1	native	pickup	5	9.34	1.59
3-6	20.1	native	pickup	25	6.59	1.01
2-11	18.4	sandy	pickup	5	1.57	0.33
3-7	18.4	sandy	pickup	25	1.30	0.24
1A-2	19.7	native	pickup	45	8.46	0.87
3-8	19.7	native	pickup	25	8.37	0.94
2-12	19.7	native	pickup	5	13.29	1.62
2-13	20.5	sandy	pickup	5	2.17	0.50
3-9	20.5	sandy	pickup	25	1.87	0.34
2-14	23.8	native	pickup	5	6.86	1.57
3-10	23.8	native	pickup	25	4.28	0.85
2-15	19.2	sandy	pickup	5	5.00	0.49
3-11	19.2	sandy	pickup	25	3.56	0.49
2-16	32.5	native	pickup	5	6.21	0.95
3-12	32.5	native	pickup	25	4.08	0.63
2-17	14.7	native	dump truck	5	19.07	4.12
2-18	14.7	sandy	dump truck	5	8.37	2.29
2-19	20.5	native	dump truck	5	13.46	3.00
2-20	17.6	sandy	dump truck	5	11.41	3.41

(continued)

Table 3-9. (continued)

Test ID	Average moisture content (%)	Soil type	Vehicle type	Distance (ft) from access point	Total loading (g/m^2)	Silt loading (g/m^2)
4-1	11.7	sandy	pickup	5	3.75	0.68
4-2	22.6	native	pickup	5	6.07	1.83
4-3	13.3	sandy	pickup	5	6.96	1.01
4-4	27.5	native	pickup	5	3.45	1.04
4-5	14.6	sandy	pickup	5	8.06	1.30
4-6	29.1	native	pickup	5	9.56	2.70
4-7	16.7	sandy	pickup	5	10.16	1.82
4-8	32.1	native	pickup	5	7.41	1.77
4-9	4.7	sandy	pickup	5	2.83	0.56
4-10	13.5	native	pickup	5	2.73	0.70
4-11	4.3	sandy	pickup	5	1.19	0.27
4-13	14.1	native	pickup	5	5.41	1.88
4-12	10.5	sandy	pickup	5	5.31	1.43

Discussion of the Mud/Dirt Trackout Results
Several considerations are necessary to place the DFS trackout results in the proper context. First, because only limited traffic was present at the site, primary emphasis was placed on the total loading in the immediate vicinity of the access point rather than the spatial distribution of silt loading along the road. Had additional traffic been present, the mud/dirt trackout material would have been more finely ground and more uniformly "smeared" along the roadway. In other words, additional traffic would have crushed the deposited material and carried it down (and across) the road.

Furthermore, the area used to calculate total and silt loading values was based on a nominal width of 12.5 ft for each of the 20-ft long sampling strips. This approach was taken (rather than using the actual pavement width for each strip) because the only traffic on the test road was that supplied for purposes of testing. Mud/dirt was carried out along the vehicle tracks and was not smeared over the full road width. That is to say, for this sampling program, a linear measurement was more appropriate than an area measurement.

Because of the interest in control effectiveness, emphasis was placed on a relative measurement–namely, the percent reduction in total loading in the immediate vicinity of the access point. That is to say, the absolute mass of material tracked out should not be construed as necessarily representative of mud/dirt trackout from typical construction sites. Tests at DFS were conducted with fairly light-duty vehicles traveling over relatively short stretches of watered access areas. One would reasonably expect "typical" amounts of mud and dirt trackout to be much higher than that measured here because of the contributions of larger vehicles (with more weight and wheels) and longer travel distances at construction site access areas.

Additionally, the sampling method required cleaning the road surface. Thus, there was no cumulative buildup of material on the roadway during the test exercise. Again, this lowers the DFS silt and total loading results, as compared to what one would expect at an actual construction site.

These points are illustrated when one compares the DFS results to those from an earlier study.[8] That 1994 study evaluated mud/dirt trackout onto a 1200 ft-long arterial road segment from a construction site with extensive haulage of earth from the site. During the approximate 3-month duration of the 1994 study, more than 5,000 vehicles left the construction site. Those vehicle passes were supplemented by approximately 500,000 vehicle passes which further crushed and spread the trackout along the arterial road.

The 1994 report[8] presents a geometric mean silt loading between 2 to 4 g/m^2 for uncontrolled conditions, a value several times higher than the corresponding value of 0.67 g/m^2 calculated from Table 3-9. Even more importantly, on-site roads in the 1994 study were not watered to control dust. Had the trackout been from watered roads, the 1994 study would have produced even higher silt loading values.

Examination of the data in Table 3-9 began by determining the correlation coefficient between total loading values and moisture content of the access areas when data were grouped by both soil type (native soil, soil/sand mixture) and control treatment (uncontrolled, gravel apron, paved apron). Thus, six combinations (two soils and three controls) were of interest.

A significant (5-percent level) correlation was found for only one combination of test conditions – a gravel apron in conjunction with the sand/soil mixture. None of the other combinations exhibited a discernible trend between moisture of the access area surface and the amount of mud/dirt tracked onto the paved road. This was an unexpected finding because one can reasonably expect that more material would be tracked out from wetter access areas.

One other factor may affect the DFS trackout results. As one would expect, the access areas became increasingly compacted as the surface was repeatedly watered and driven over. Toward the end of the test program, both the native soil and the sand/soil mixture had a hard crust several millimeters thick. It appeared that most trackout during later tests was due to wetted loose material on the surface being carried out during the first few passes.

For the five combinations of test conditions that did not produce significant correlations, the surface loading values were simply averaged. Summary statistics for those cases are shown in Table 3-10. Note that, for the uncontrolled conditions, the native soil produced roughly twice as much trackout on average as did the sand/soil mixture.

Table 3-10. Summary Statistics for Loading Values

Soil type	Control measure	Sample size	Total loading (g/m^2)[a]
Native soil	Uncontrolled	7	11.0 ± 3.8
	Gravel apron	6	5.8 ± 2.5
	Paved apron	6	6.3 ± 3.2
Sand/soil mixture	Uncontrolled	10	4.2 ± 1.9
	Gravel apron	6	_[b]
	Paved apron	7	2.2 ± 0.8

[a] Entries represent arithmetic mean ± standard deviation.
[b] This source condition exhibited a significant correlation between loading and moisture content.

Table 3-11 presents control efficiencies based on percent reduction in mean loading values. Little variation in control efficiency was seen, with values ranging from 42 to 48 percent. The 46 percent control for a gravel apron in conjunction with the native soil compares fairly well with the 1994 study[8] finding of 56 to 58 percent control for a gravel apron. (The 1994 result is based on reduction in silt loading rather than total loading.)

Table 3-11. Control Efficiency Values

Soil type	Control measure	Total loading control efficiency
Native	Gravel apron	46%
	Paved apron	42%
Sandy	Gravel apron	_[a]
	Paved apron	48%

[a] This source condition exhibited a significant correlation between loading and moisture content. See discussion in text.

The most surprising finding from the DFS study was the relatively poor performance of the gravel apron in combination with the sandy soil. As noted above, this combination produced a statistically significant correlation between surface loading and access area moisture content. That relationship is illustrated in Figure 3-12 for both total loading and silt loading.

What is important to note in Figure 3-12 is that, for an access area moisture content higher than 8 percent, the relationship predicts a total loading value at least comparable to the mean uncontrolled value of 4.2 g/m^2 in Table 3-10. In other words, the gravel apron results in no net control when the sandy soil moisture content higher than about 8 percent. Moreover, for moisture contents higher than about 8 percent, the 25-foot long gravel apron appeared to aggravate the amount of mud/dirt trackout from the sandy soil access area.

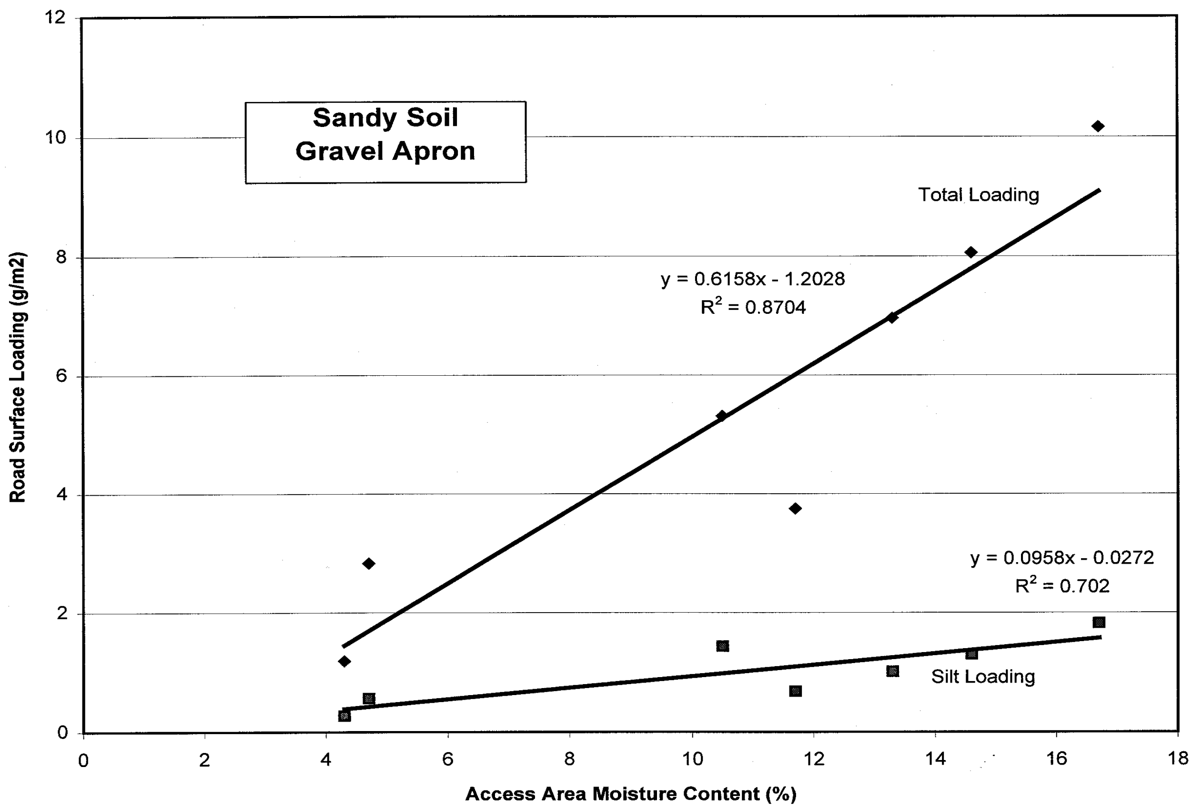

Figure 3-12. Correlation between loading and moisture content for sandy soil in conjunction with gravel apron (DFS).

A further examination as to whether the gravel apron compounds trackout from the sandy soil area was conducted. This involved culling 26 total loading data associated with an access area moisture content of at least 8 percent from Table 3-9. The distribution of tests is as follows:

	Sand/Soil Mixture	Native Soil
Uncontrolled Tests	8	7
Gravel Apron Tests	5	6
Totals	13	13

The uncontrolled and gravel apron test results were combined for each soil type and then ranked lowest to highest to perform a Mann-Whitney "U" test [9] The U test used the sum of ranks to test the null hypothesis that, for moisture levels higher than 8 percent, trackout for the gravel apron is the same as that for uncontrolled. The null hypothesis is tested against the alternative hypothesis that trackout from the two surfaces is different. For both the sandy and the clay soils, the null hypothesis is rejected at the 5 percent level of significance. In other words, for both soil types, total loading trackout with the gravel apron was significantly different than when no apron is used if the access area moisture content was at least 8 percent.

Chapter 4
Quality Assurance/Quality Control Activities

This section discusses the quality control and quality assurance activities performed to ensure that the data collected during this test program were of known and acceptable quality (see Table 4-1). Additionally, the data collected during these activities and conclusions derived from the data are assessed to ensure that conclusions are made with respect to the program specific quality objectives. The goals for this work assignment are:

- Develop uncontrolled and controlled PM-10 emission factors for watering of unpaved scraper travel routs.

- Determine the PM-2.5 fraction of the PM-10 emissions from scraper travel routes, with and without watering.

- Determine mud/dirt trackout rates from uncontrolled, unpaved soil surfaces onto a paved roadway

- Determine mud/dirt trackout rates after application of each control measure.

To achieve these goals, Data Quality Objectives were established for the wind speed, the concentration measurements, and the silt load. Each of the DQO control parameters is described in the following section.

Quality Control

In order to ensure the quality of the work being performed, procedures were established to control critical processes that would allow assessment of the data with respect to the Data Quality Objectives. The control of the test activities in the field was established in the test plans that governed the positioning of the sampling array, the movement and operating parameters of the construction equipment. By monitoring the meteorological conditions and adjusting the field activities accordingly, the acceptability of the sampling activity in meeting the wind speed and direction objective was maintained and the integrity of the sample data was ensured.

The quality control activities for the sampling media and field measurement are defined as either critical or non-critical (see Table 4-2). To ensure that the data collected are of known quality, the sampling media were prepared in accordance with the quality control requirements given in Table 2-4 of the QA Plan (Appendix B). In addition, the sampling equipment was calibrated for the collection of critical data prior to acquiring the field data. The calibration requirements for the sampling equipment and miscellaneous instrumentation are given in QA Plan (Appendix B, Tables 2-5 and 2-6, respectively).

During the review of the quality control data and calibration documentation, the critical calibration measurements were found to be documented and to meet the quality control objectives. The sampling media were weighed and audited as required prior to use in the field.

Table 4-1. Data Quality Objectives

Measurement	Method	Accuracy (%)	Precision (%)	Completeness (%)
PM-10 emission factor	Mass flux profiling	_[a]	± 45[b]	_[c]
PM-10 concentration	High volume samplers	± 10[d]	± 40[e]	^{3} 90
PM-2.5 concentration	High volume cascade impaction	± 15[f]	± 50[e]	^{3} 90
Wind speed	Gill anemometer	± 10[g]	± 10[h]	^{3} 90[i]
Wind direction	R. M. Young wind station	± 10[g]	_	^{3} 90[i]
Filter weights	Analytical balance	± 10[j]	± 10[k]	100
Moisture content	Weight loss upon drying	± 10[j]	± 10[l]	_[m]
Silt Content	Dry sieving	± 10[j]	± 10[l]	_[m]
Silt Loading	Vacuum sampling of road surface	_[n]	± 50[o]	_[p]

[a] Because the emission factor is calculated from particle concentrations and wind speed, the approach taken here is to set goals for the component measurements.
[b] Refers to the range percent of replicate measurements made of uncontrolled conditions. See discussion in text.
[c] At least one set of replicate measurements will be conducted for scrapers traveling over uncontrolled surface.
[d] Based on audit of volumetric flow controller.
[e] Based on range percent of co-located samplers. At least one test with co-located samplers will be conducted for the uncontrolled transit tests.
[f] Based on pre- and post-test settings of flow rate.
[g] Based on calibration with manufacturer-recommended device.
[h] Based on pre- and post-test co-locations of both unit in a steady air flow.
[i] Refers to percentage of time during testing that wind lies within acceptable range of 3 to 30 mph and ±45^{o} from perpendicular to linear path of moving point source.
[j] Based on Class S calibration weights.
[k] Based on independent audit weights.
[l] Based on independent analysis of a riffle-split sample.
[m] At least one sample from each test site will be riffle split for duplicate analysis. (This assumes that at least one paved road sample obtained has a mass ≥ 800 g).
[n] Because silt loading is calculated, the approach taken here is to set goals for the component measurements.
[o] Refers to percent range of embedded co-located paved road surface loading samples.
[p] At least one embedded co-located sample will be collected.

Data Audit

The data collected during the field activities and the emission factor calculations were audited as required by the QA Unit. The data were evaluated with respect to the measurement objectives as presented in the QA plan. The majority of the data audited for these activities met the data quality objectives presented in Table 4-1.

Data Assessment
In assessing the data generated on this work assignment, the quality control process and results were validated with respect to the DQO. The technical staff conducted an internal assessment of the overall data quality generated during this work assignment. In addition, an independent external assessment of the program was conducted by the QA Officer. These assessments were performed in accordance with the requirements cited in the Site Specific Test Plan and the QA Plan.

Three of the four DQOs were accomplished through activities during the field exercise; verification was by work assignment personnel. The first DQO was the wind speed that was verified to be between 3 and 20 mph during the sampling process using a calibrated Gill anemometer. Next, the wind direction was checked using an R. M. Young wind station to ensure that it was less than 45^o from the perpendicular to the moving point source. In meeting the requirements of the third DQO, field personnel manually recorded the number of vehicular passes and the speed (100 ft per time). When the field activity included the use of water to reduce the dust emissions, the number of passes to distribute water and the rate (speed per distance) at which the truck traveled were recorded.

The final DQO requirement for ensuring the quality of the results was the concentration factor. The concentration factor included the sampling rate (m^3/min) using calibrated samplers, sampling media, silt load (mass per unit area) by sieving, and soil moisture. The data assessment included a review of the calibration data, media preparation, sample collection data, and sample analysis. The validation included the accuracy and precision data generated by the calibration procedures and results obtained from split (silt load) and co-located samples.

The assessment of the results and documentation found that the data generated for this report were traceable, of known quality, and supportive of the conclusions cited in this report. The field test activities, the results, and the conclusions cited herein were found to validate the Data Quality Objectives as presented in the scope of the work assignment.

Table 4-2. Critical and Non-Critical Measurements for Emission Factors

Measurements	Comments
Critical	
• Filter weights • Sampler flow rates • Wind speed	These three variables are used to calculate the mass flux over the plume area and the emission factor.
• Volume of earth moved • Number of scraper passes	These measurements are necessary to normalize the mass flux and obtain an emission factor. The scraper count will be tallied during the test by individual equipment ID. The total volume will be determined by multiplying the count for an individual unit by its manufacturer-rated capacity.
Non-critical	
• Elapsed time	Even though this quantity is needed to determine concentrations, its effect is multiplied out in determining the emission factor. Furthermore, in determining PM-2.5 to PM-10 ratios, only the relative filter catches are necessary.
• Pressure drop across filter • Barometric pressure • Ambient temperature	These three variables are used to determine the sampling rate for a high-volume sampler equipped with a volumetric flow controller (VFC). However, flow rate varies only slightly over the possibly encountered range of each variable.
• Wind direction • Horizontal wind speed	These variables are of interest primarily to ensure that conditions are suitable for testing. In this way, the measurements are useful for operational decisions but do not affect the calculated emission factor.
• Moisture content • Silt content	These measurements deal with the earthen material being handled. They do not affect the calculated emission factor.

Chapter 5
Summary and Conclusions

The following conclusions can be drawn from the field testing results and data comparisons generated in this study:

1. As expected, PM-10 control efficiency afforded by watering of unpaved scraper travel routes decays (from 100 percent) with time after water application. Using the mean uncontrolled PM-10 emission factor (1.46 lb/vmt) as a basis for control efficiency calculation, the measured decay rates in the average control efficiency vary from 2.65 to 13.7 percent/hr, for traffic rates in the range of 60 to 88 vehicles/hour.

2. The PM-10 control efficiency decay rate is strongly negatively correlated with relative humidity. These results are consistent with the effects of humidity on evaporation rate. A weak correlation exists for this data set between PM-10 control efficiency decay rate and water application rate.

3. The observed decay in instantaneous PM-10 control efficiency with soil surface moisture content ratio closely matches the previously published bilinear function. Doubling of the uncontrolled moisture content of a soil surface produces a PM-10 control efficiency of approximately 75 percent. In general, use of the EPA model leads to conservatively low estimates of control efficiency.

4. Because watering reduces only surface dust emissions and not diesel exhaust emissions, PM-2.5 control efficiency decayed much more quickly than for PM-10. The difference between PM-10 and PM-2.5 decay rates was greater for low relative humidity values. In other words, under dry conditions, watering appears to be far less effective in controlling fine PM rather than coarse PM emitted during scraper travel operations.

5. When a pickup truck was used for mud/dirt trackout, the trackout rate from the mixture of sand and native (clay) soil was strongly positively correlated with the soil moisture content. However, there was little effect of the moisture content on the rate of trackout from the native soil alone. This may have resulted from the increased ability of the native soil to be compacted during the trackout process. This implies that soil compaction itself is an effective trackout control measure.

6. The average control efficiency afforded by the paved apron ranged from 42 percent for the native soil to 48 percent for the sand-soil mixture, based on reductions in total trackout rate onto the paved road. The control efficiency afforded by the paved apron ranged from 34 percent for the sand-soil mixture to 43 percent for the native soil alone.

7. Based on the reduction in the total trackout, the average control efficiency afforded by the gravel apron was 46 percent for the native soil but insignificant for the sand-soil mixture.

8. As compared to the total trackout rate, the silt trackout rate gives a poorer indication of control efficiency afforded by paving or graveling because of lack of roadway traffic at the captive test site. Such traffic tends to grind the tracked soil and increase the silt component.

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