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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
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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.

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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.

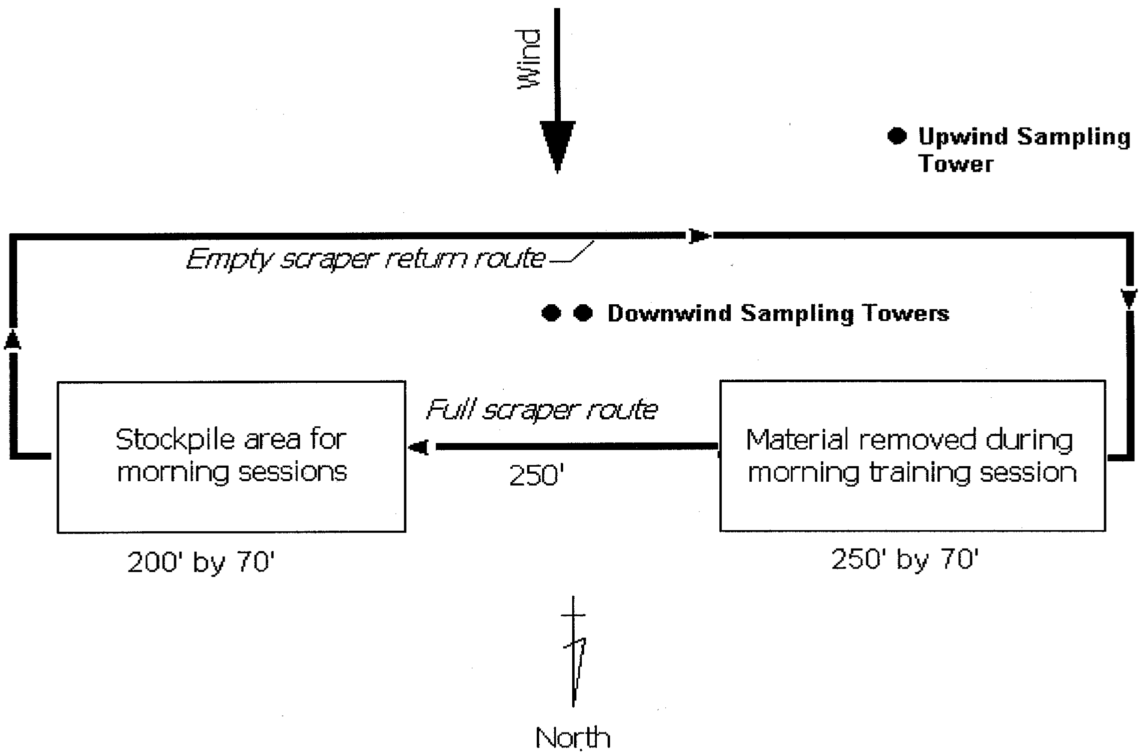
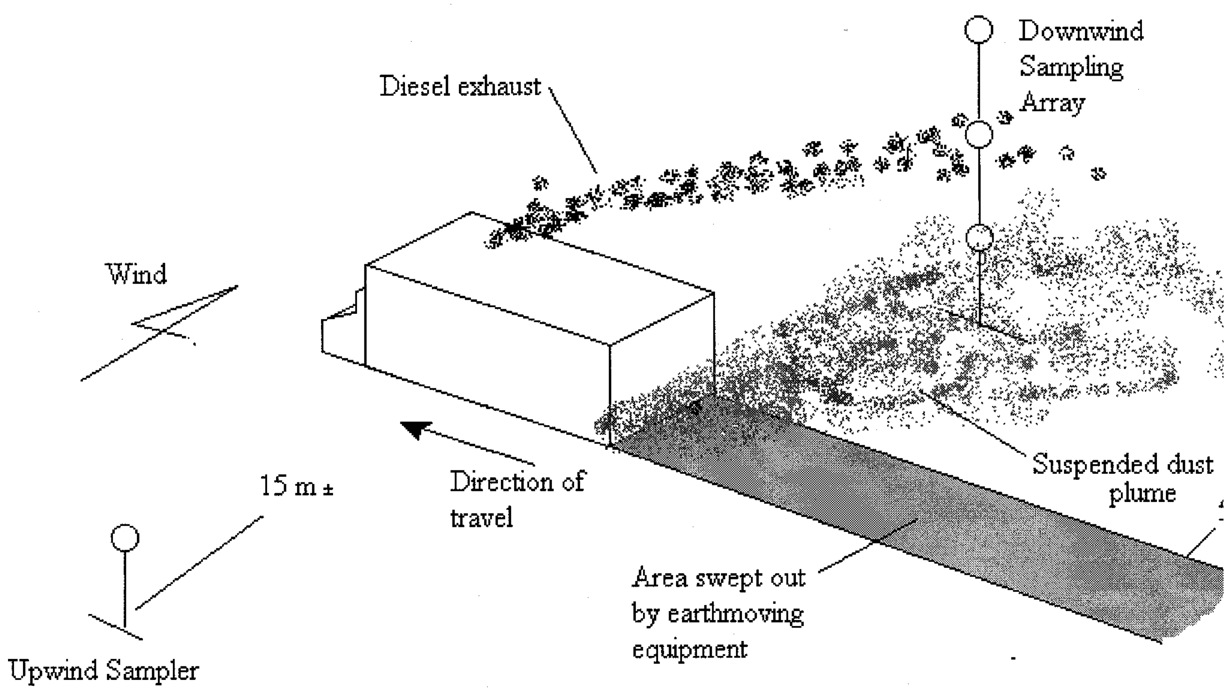


Figure 2-1. NCKTC overview.

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.



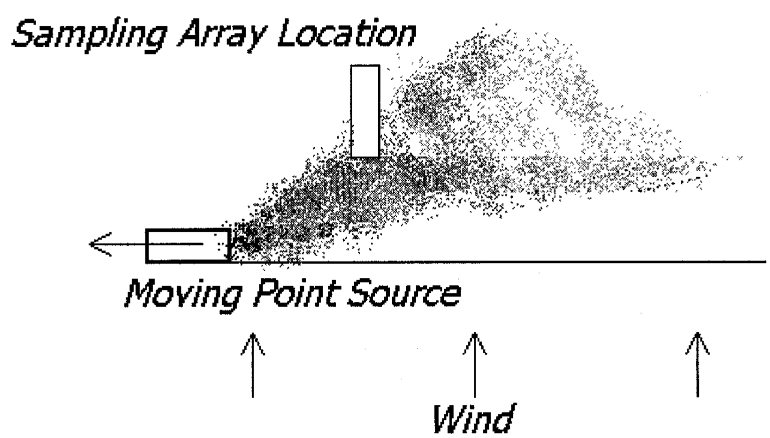


Figure 2-2. Schematic illustration of test procedure for moving point source (NCKTC).

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.

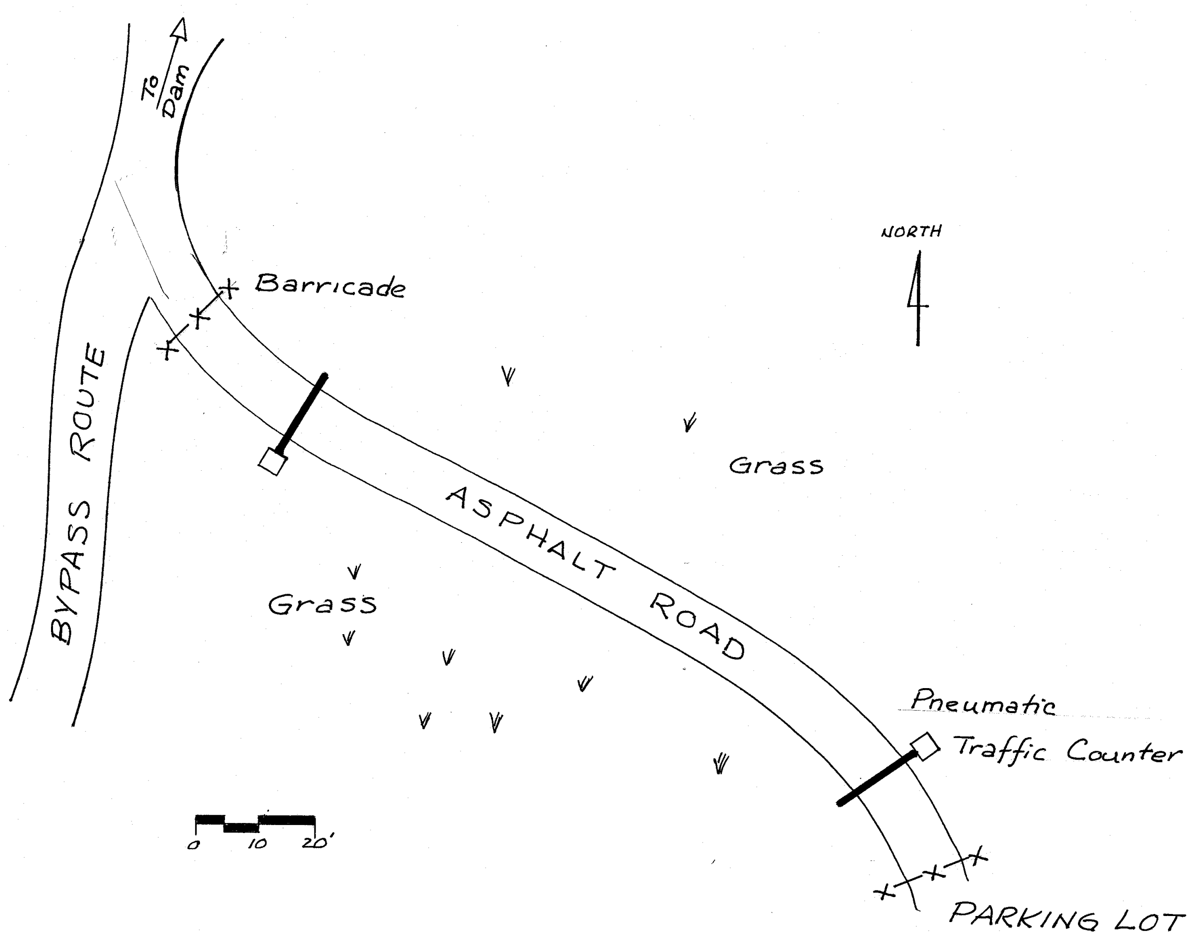


Figure 2-3. Overview of DFS test site.

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.

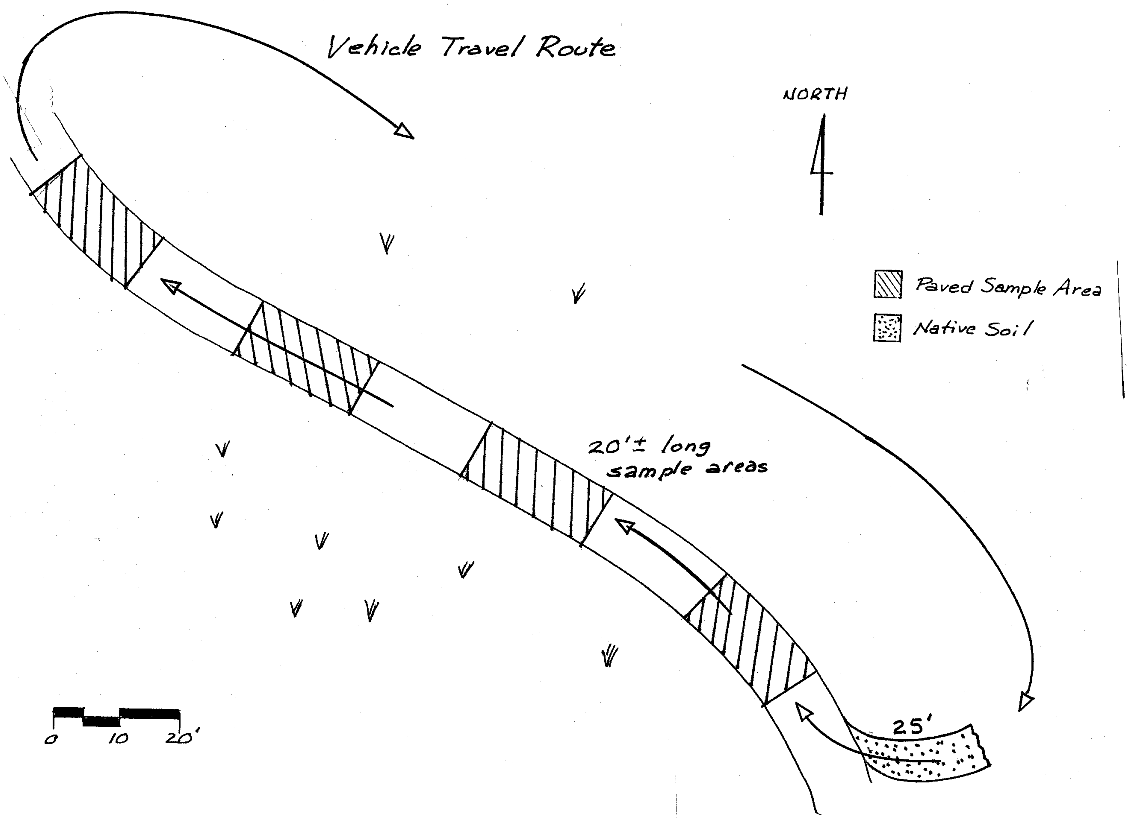


Figure 2-4. Trackout and sampling areas for Phase 1 (DFS).

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.

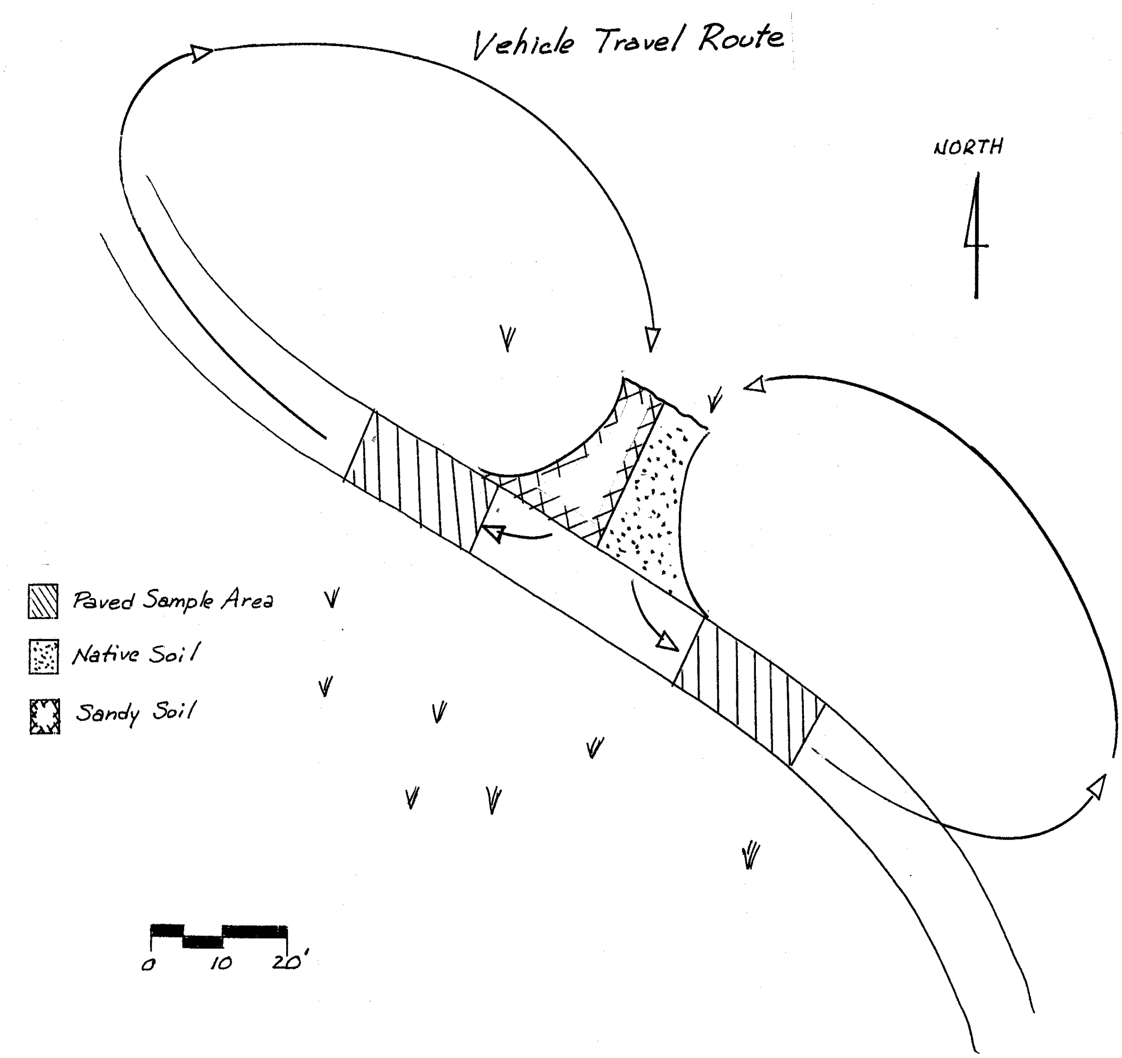


Figure 2-5. Trackout and sampling areas for Phase 2 (DFS).

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).

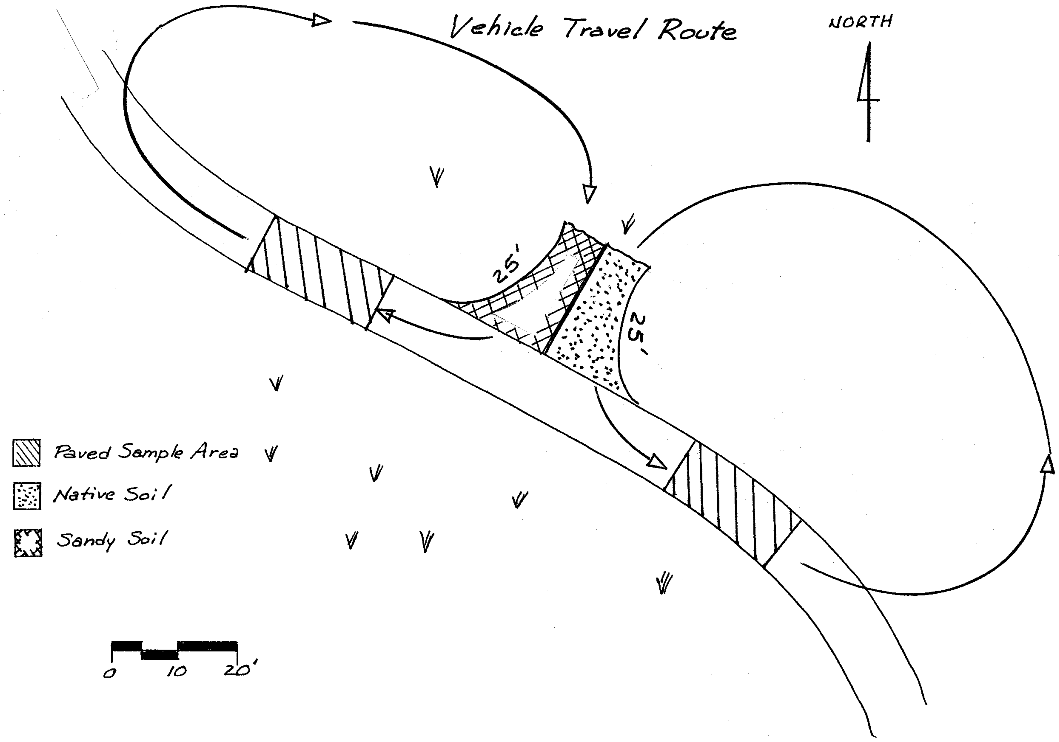


Figure 2-6. Trackout and sampling areas for Phase 3 (DFS).

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.

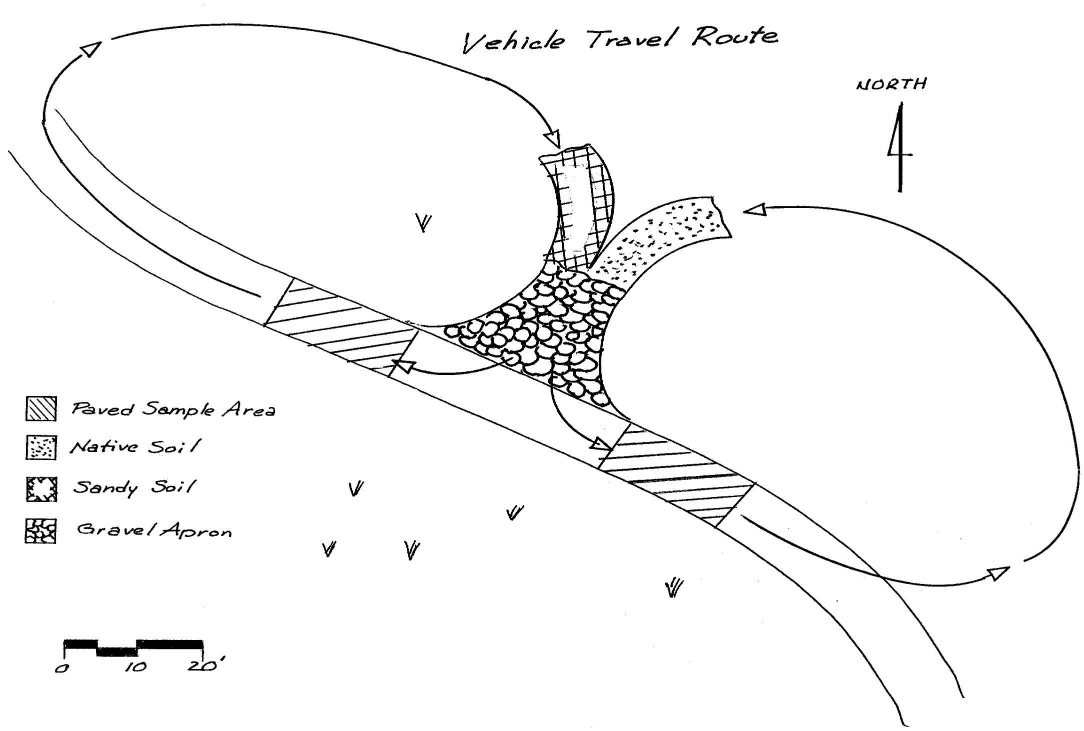


Figure 2-7. Trackout and sampling areas for Phase 4 (DFS).

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.

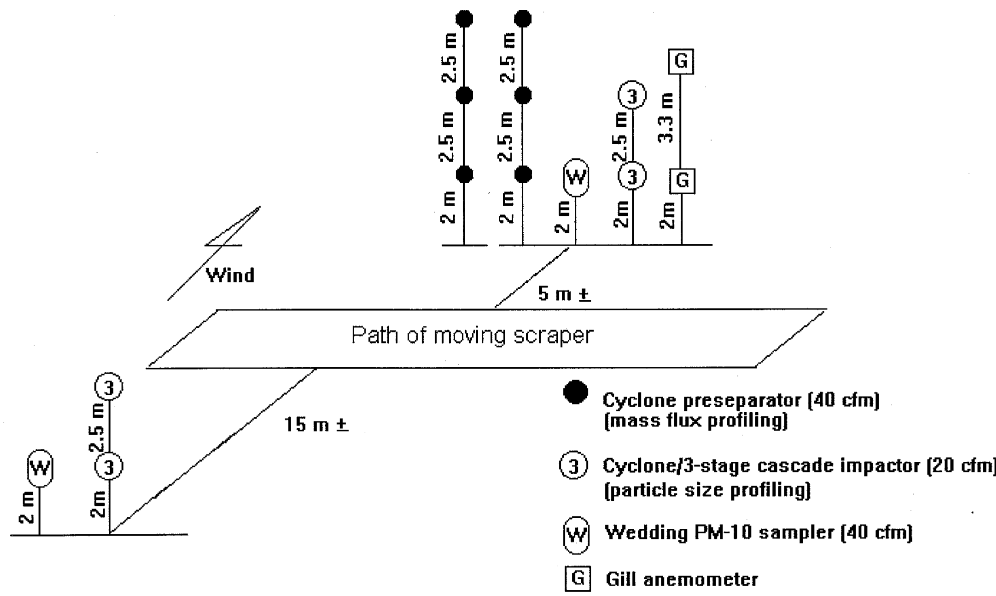


Figure 2-8. Sampler deployment at NCKTC.

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.

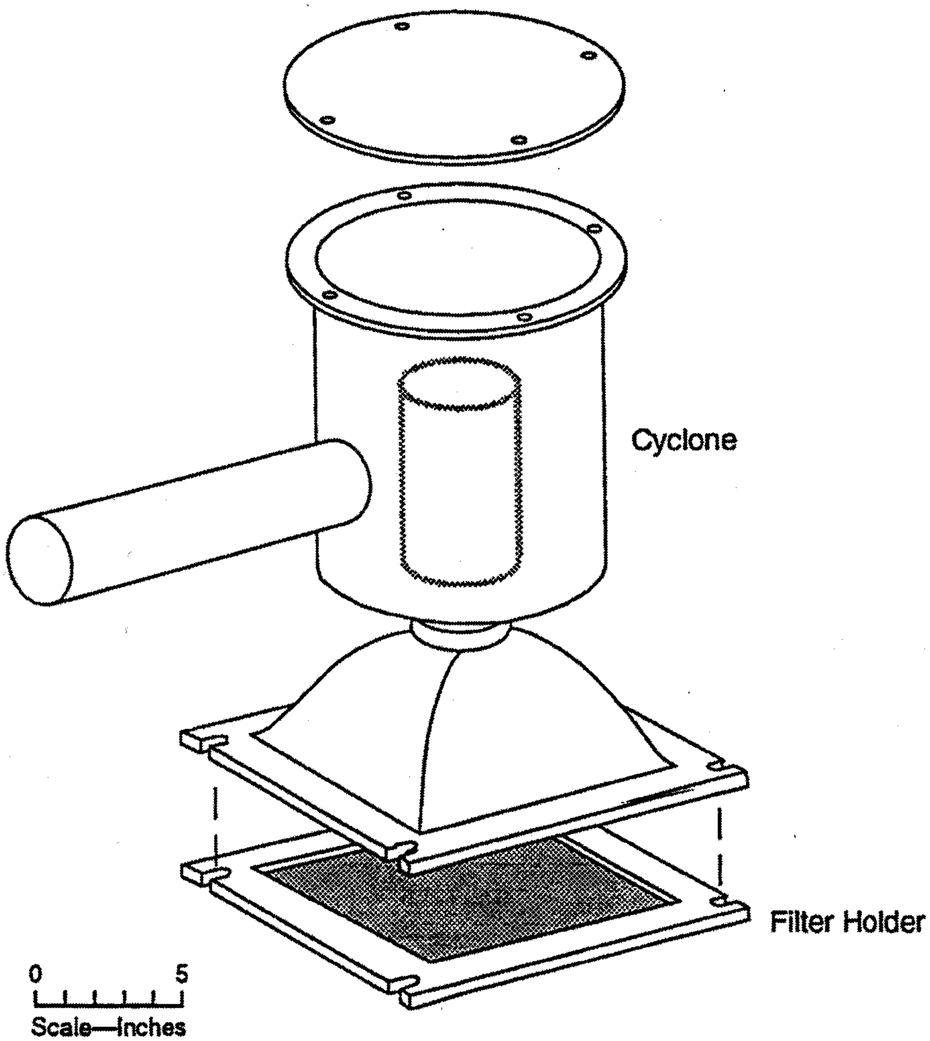


Figure 2-9. Cyclone preseparator operated at 40 cfm.

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.

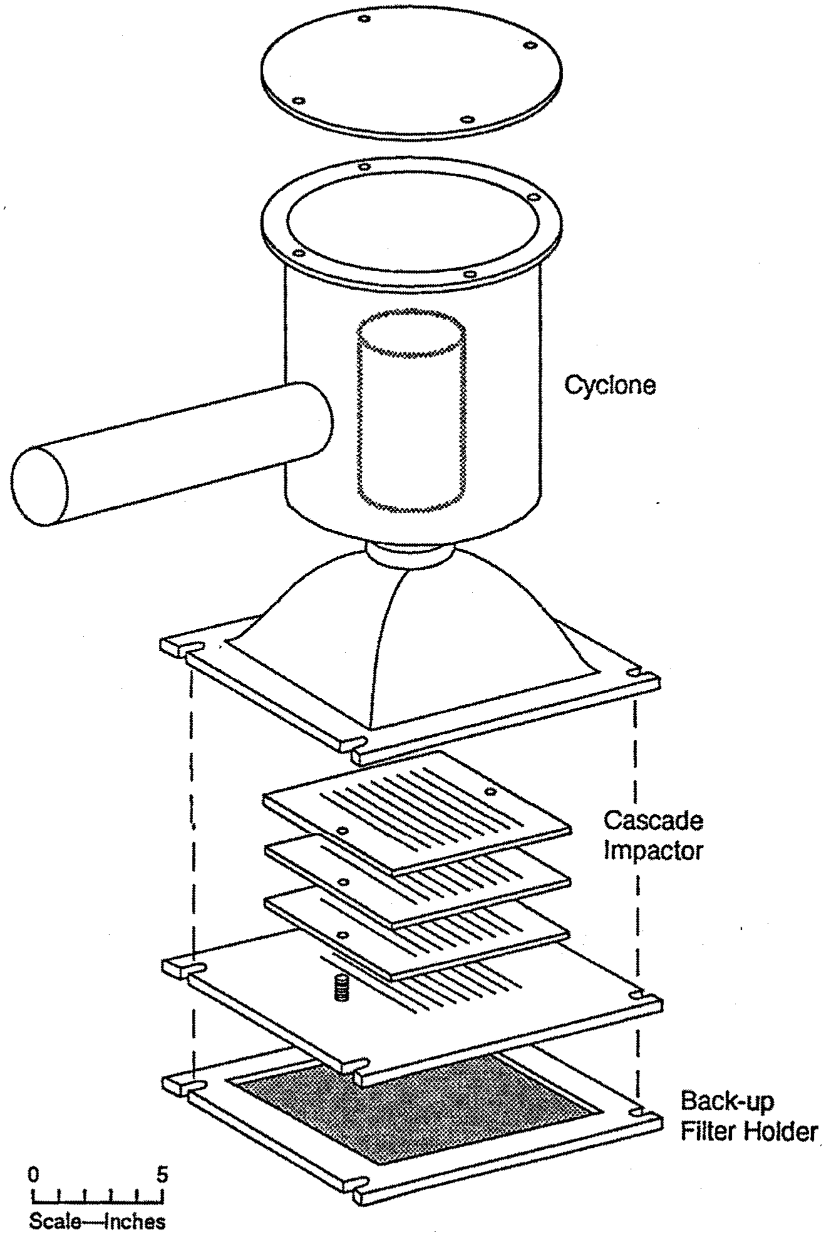


Figure 2-10. Cyclone preseparator – cascade impactor operated at 20 cfm.

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:

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

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:

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

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:

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

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

$$A = \int_0^H E\, dh \tag{2-5}$$

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:

$$e = \frac{A}{N} \tag{2-6}$$

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:

$$c = \frac{e_u - e_c}{e_u} \times 100\% \tag{2-7}$$

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:

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

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:

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

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:

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

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

$$sL = \frac{f(B_{full} - B_{empty}) + (B_{full} - B_{tare})}{a} \qquad (2\text{-}11)$$

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		Net PM 10 exposure (mg/cm²)
		m³/hr	ft³/min	
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.

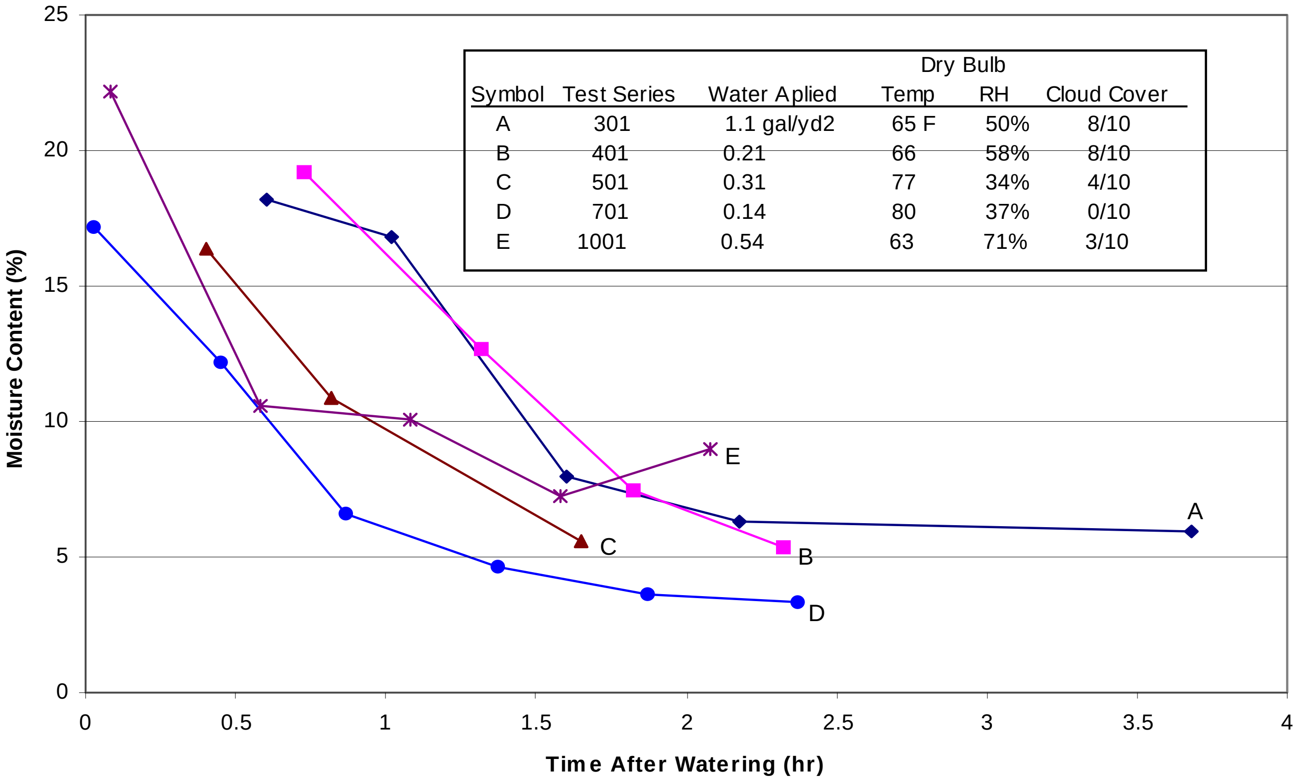


Figure 3-1. Decay of moisture content with time after watering (NCKTC).

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:

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

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.

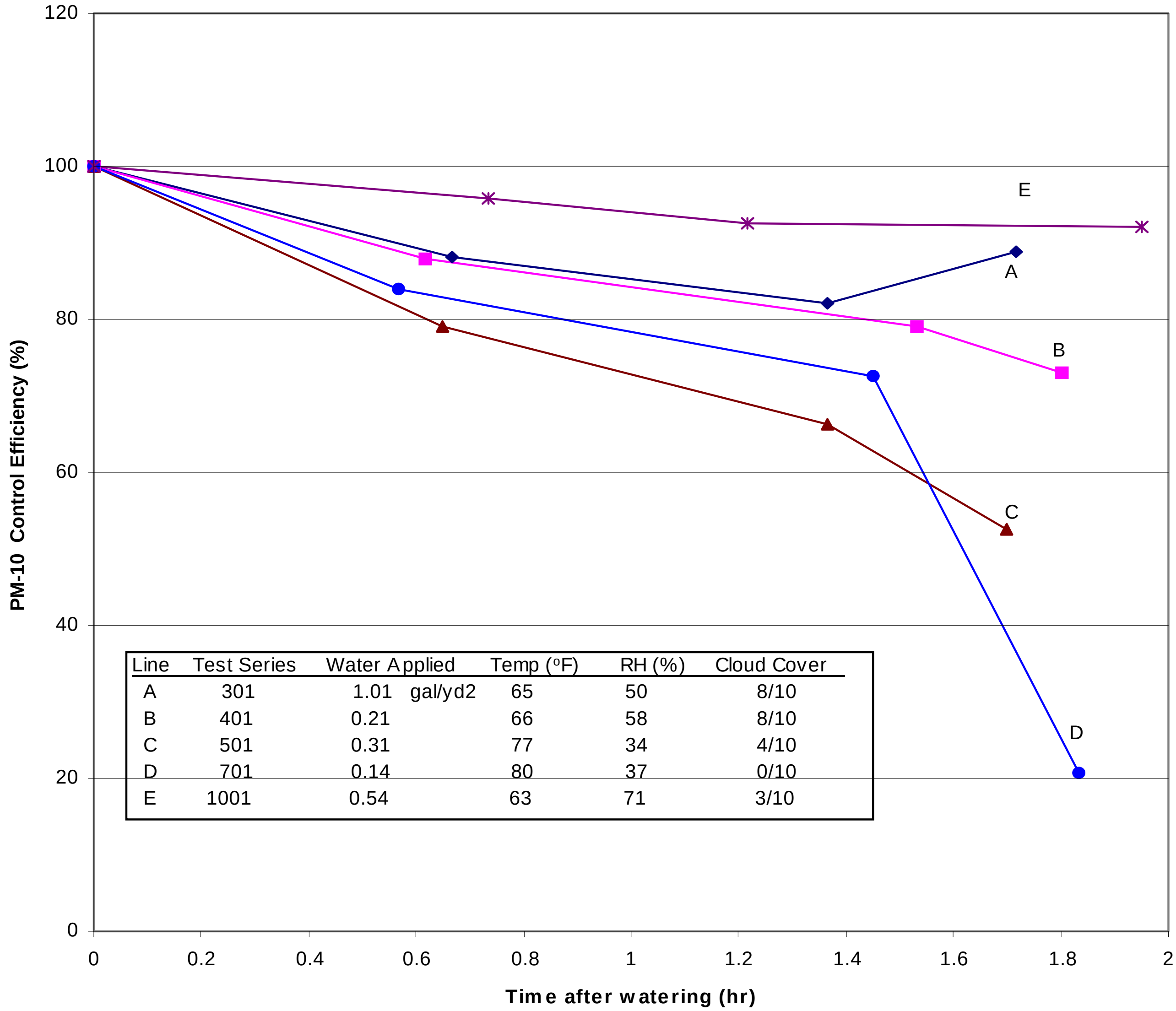


Figure 3-2. Decay of instantaneous control efficiency with time after watering (NCKTC).

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.

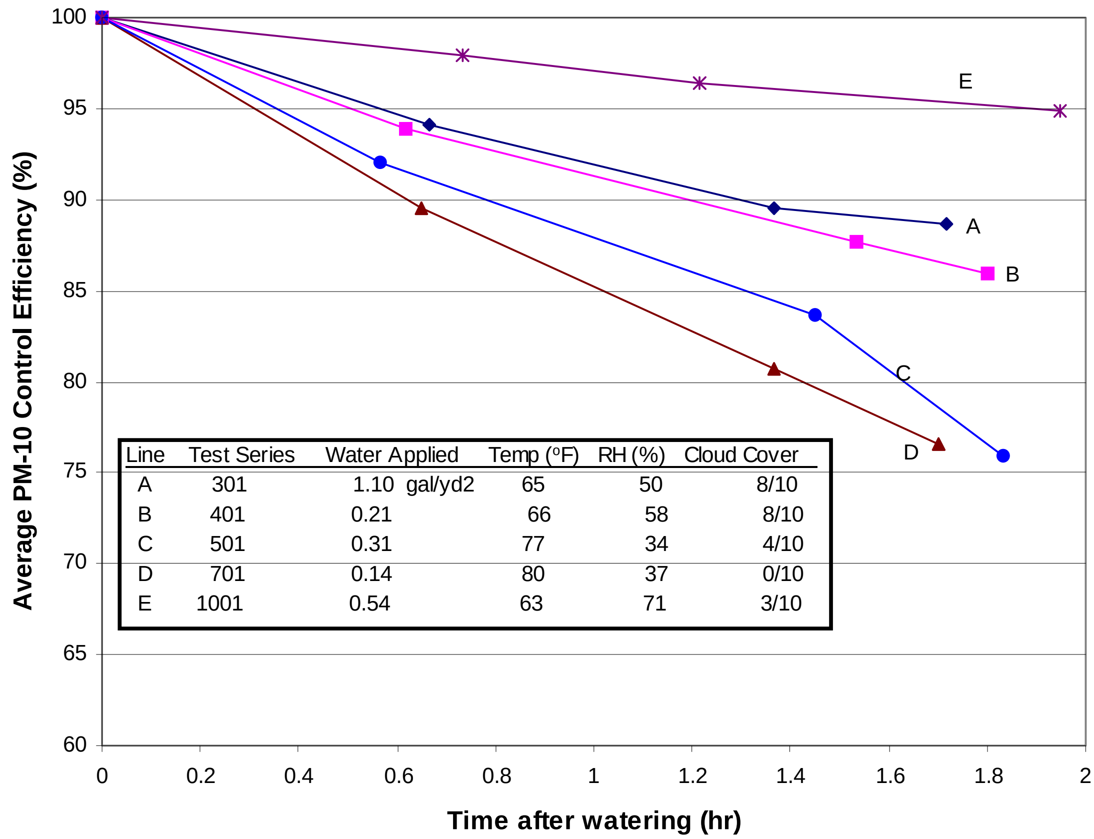


Figure 3-3. Decay of average control efficiency with time after watering (NCKTC).

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.

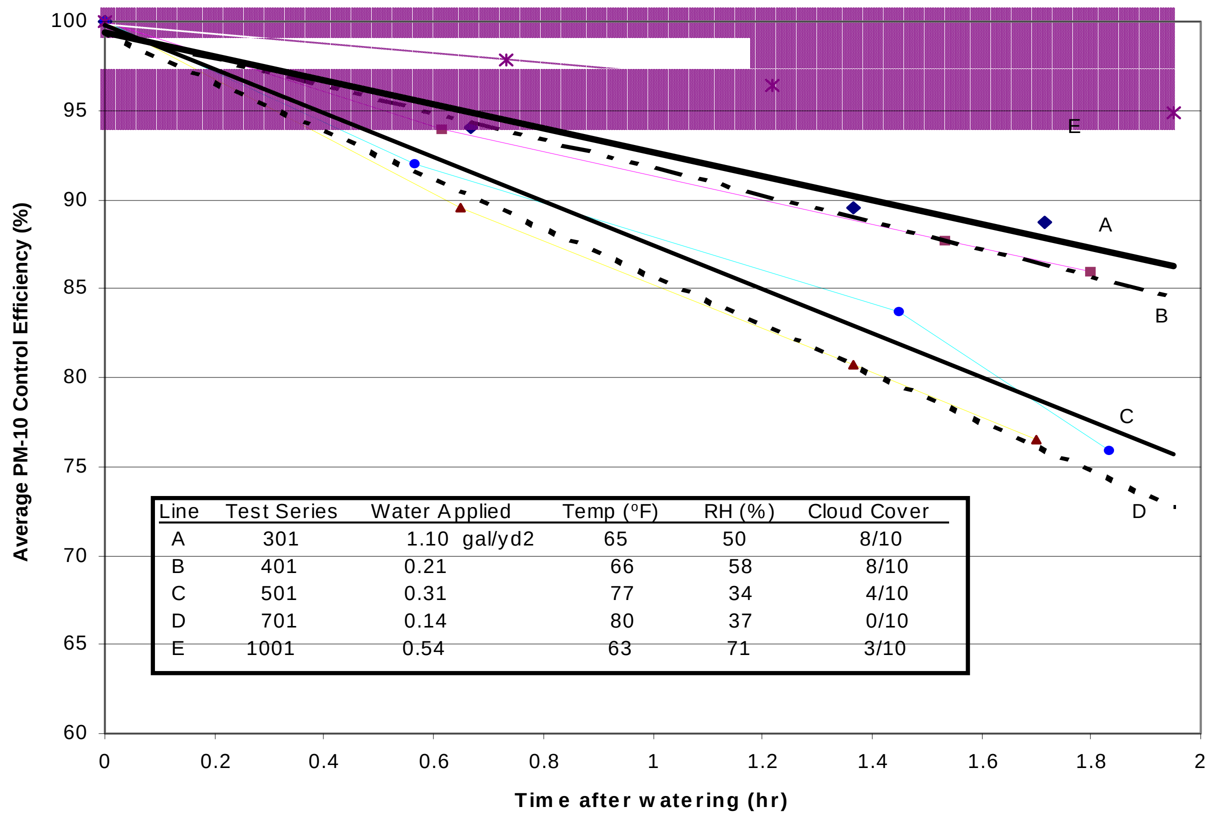


Figure 3-4. Best fit lines for average control efficiency decay with time after watering (NCKTC).

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:

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

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.

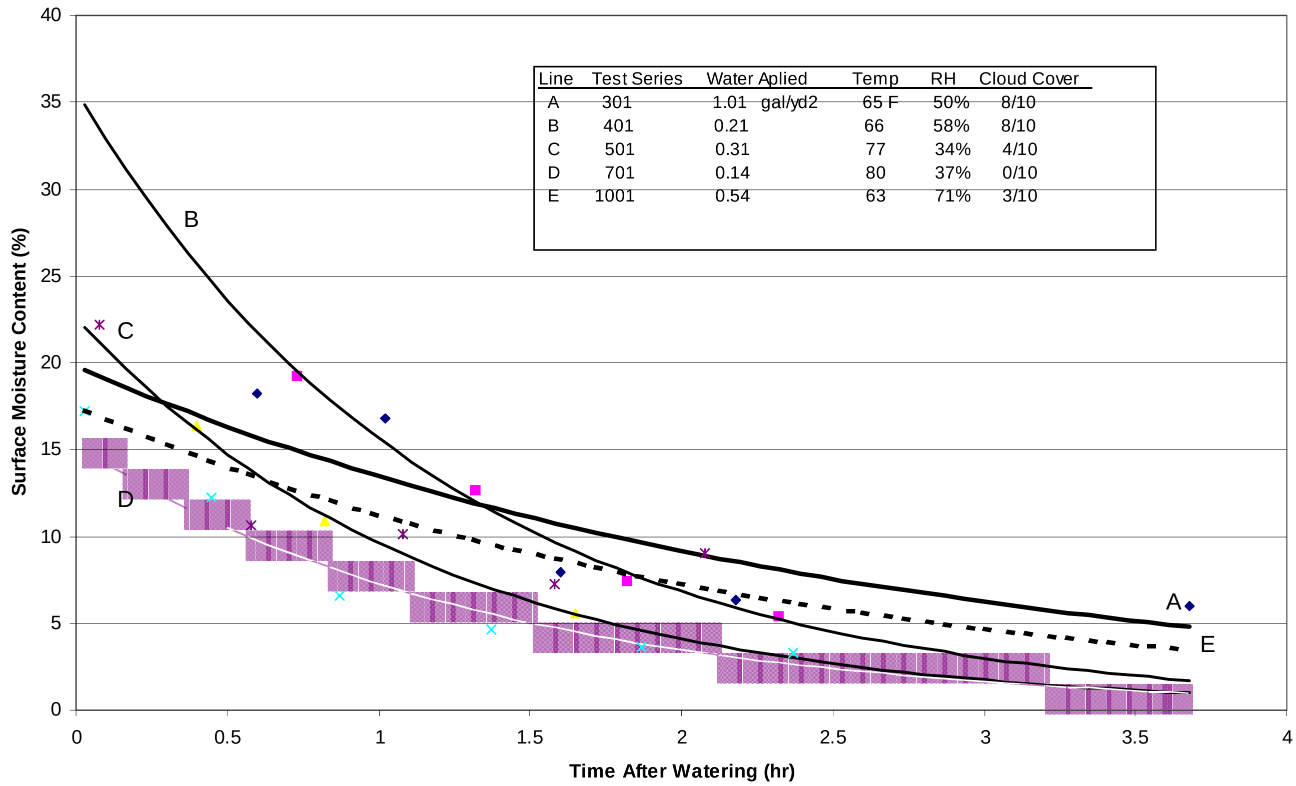


Figure 3-5. Exponential decay in surface moisture content with time after watering (NCKTC).

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]

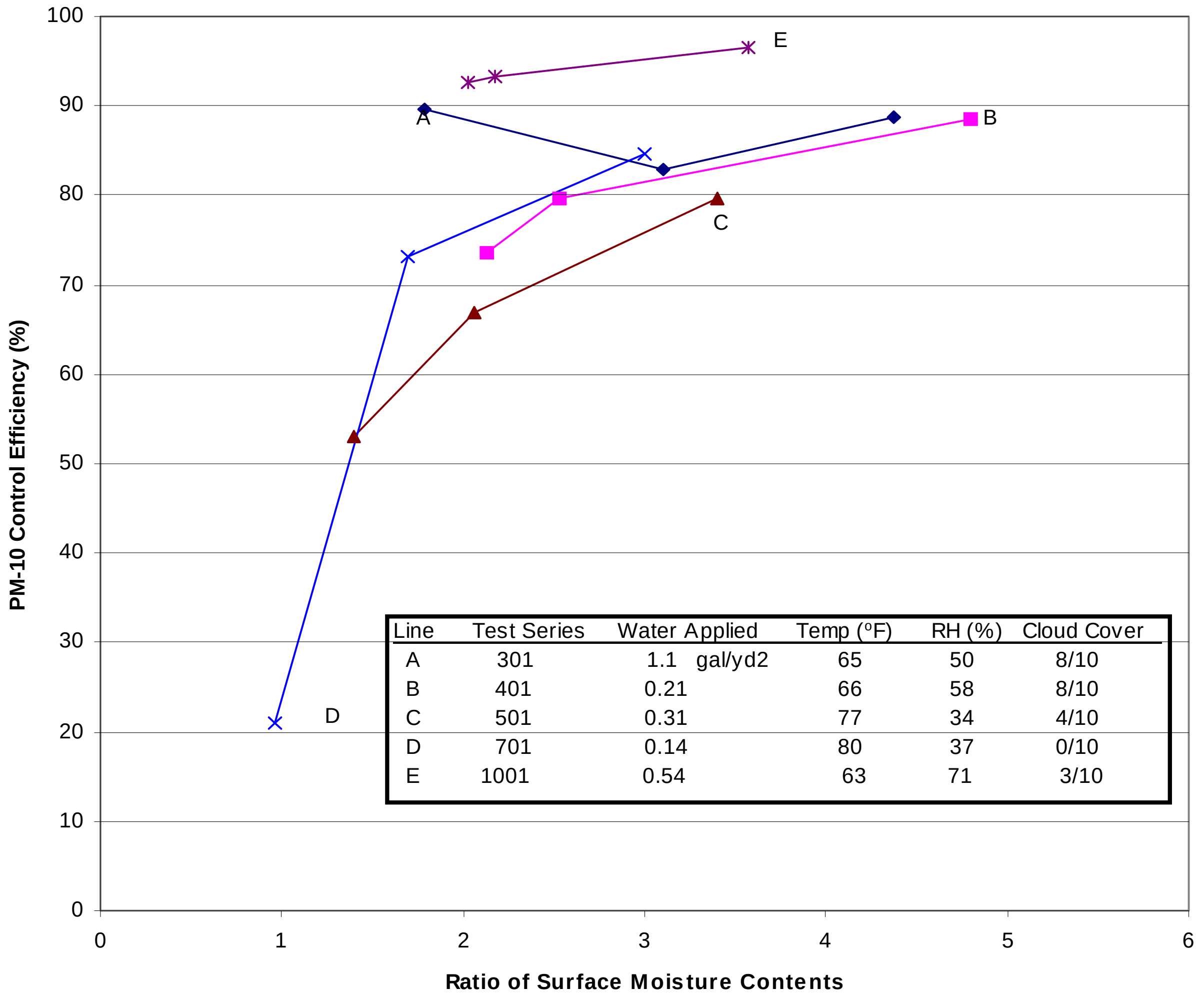


Figure 3-6. Instantaneous PM-10 control efficiency versus surface moisture content (NCKTC).

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

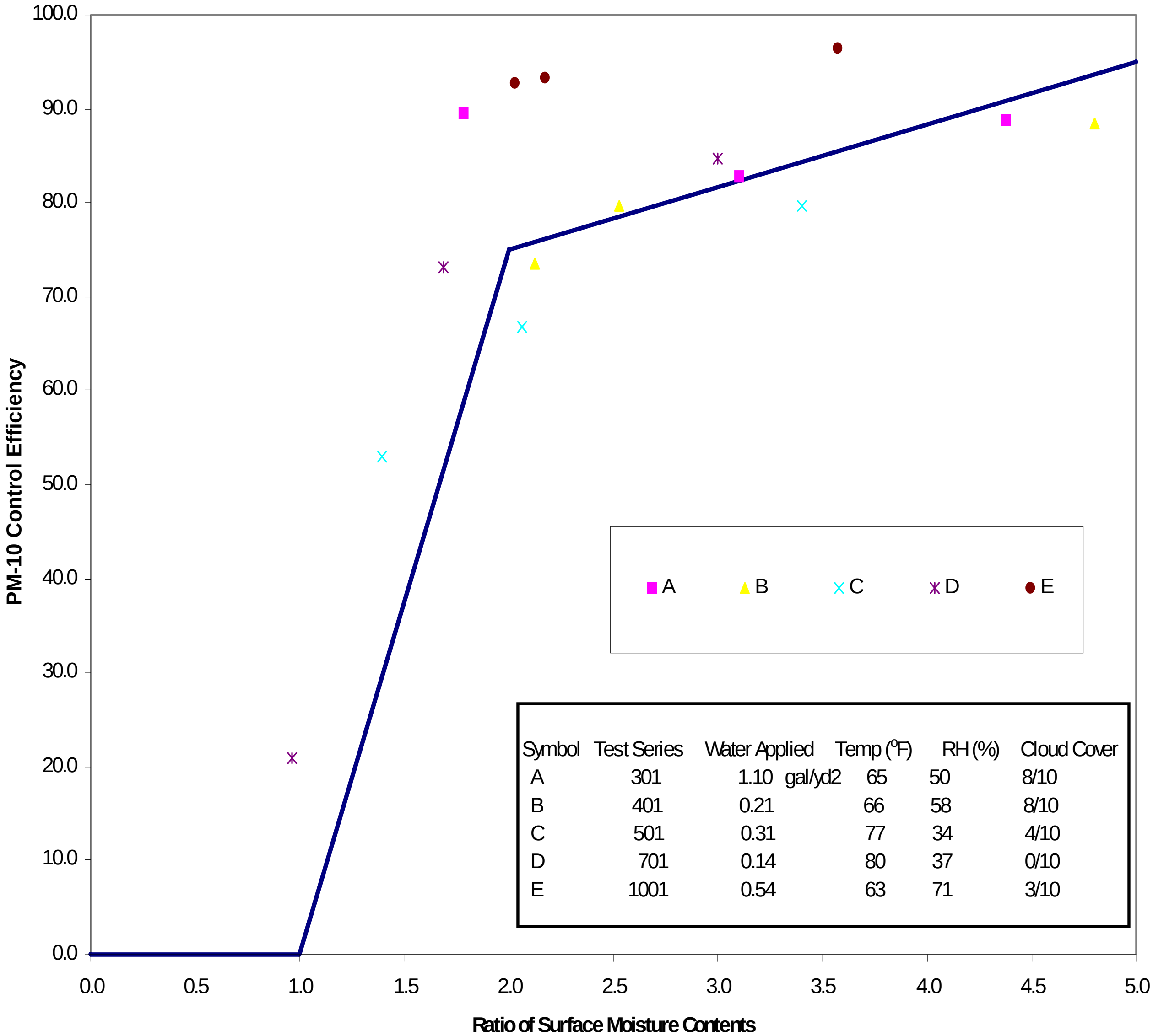


Figure 3-7. Comparison of instantaneous control efficiency with previously published function (NCKTC).

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

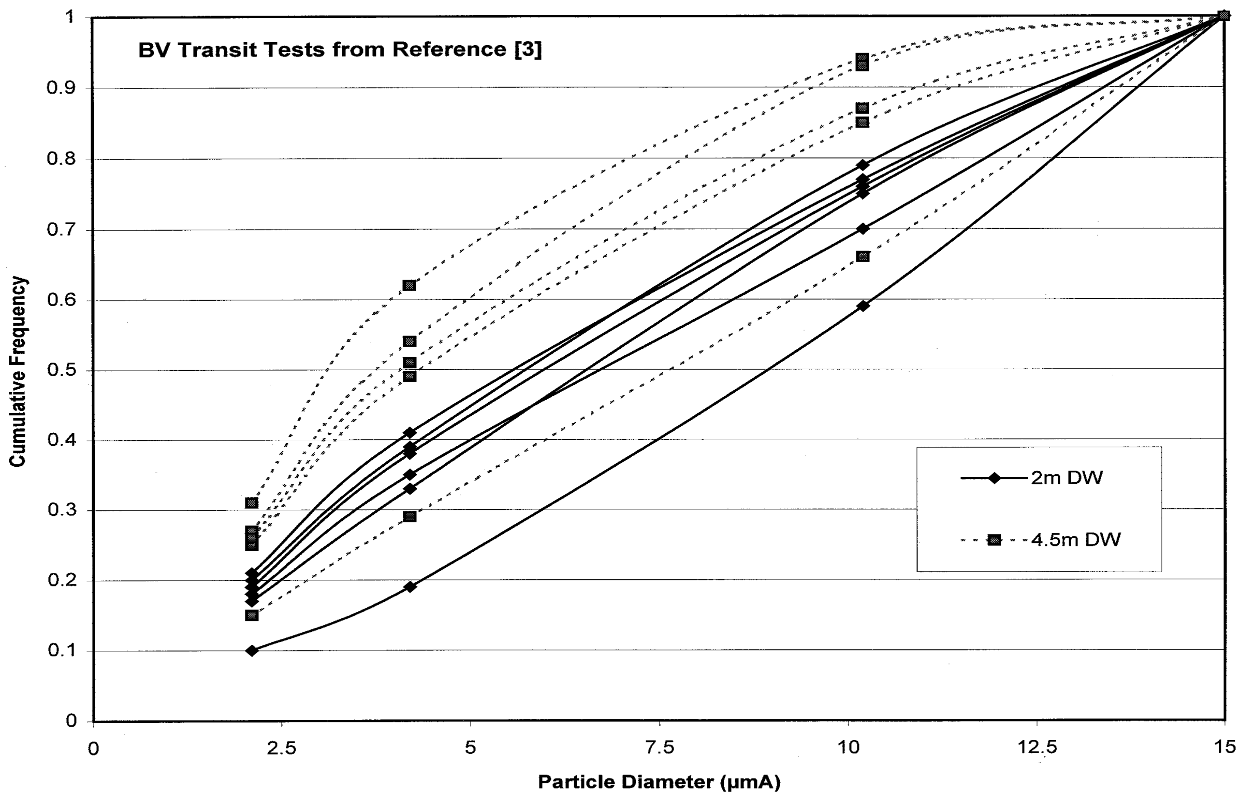


Figure 3-8. Particle size distributions for 1998 uncontrolled scraper transit emissions (BV runs) from reference 3.

(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

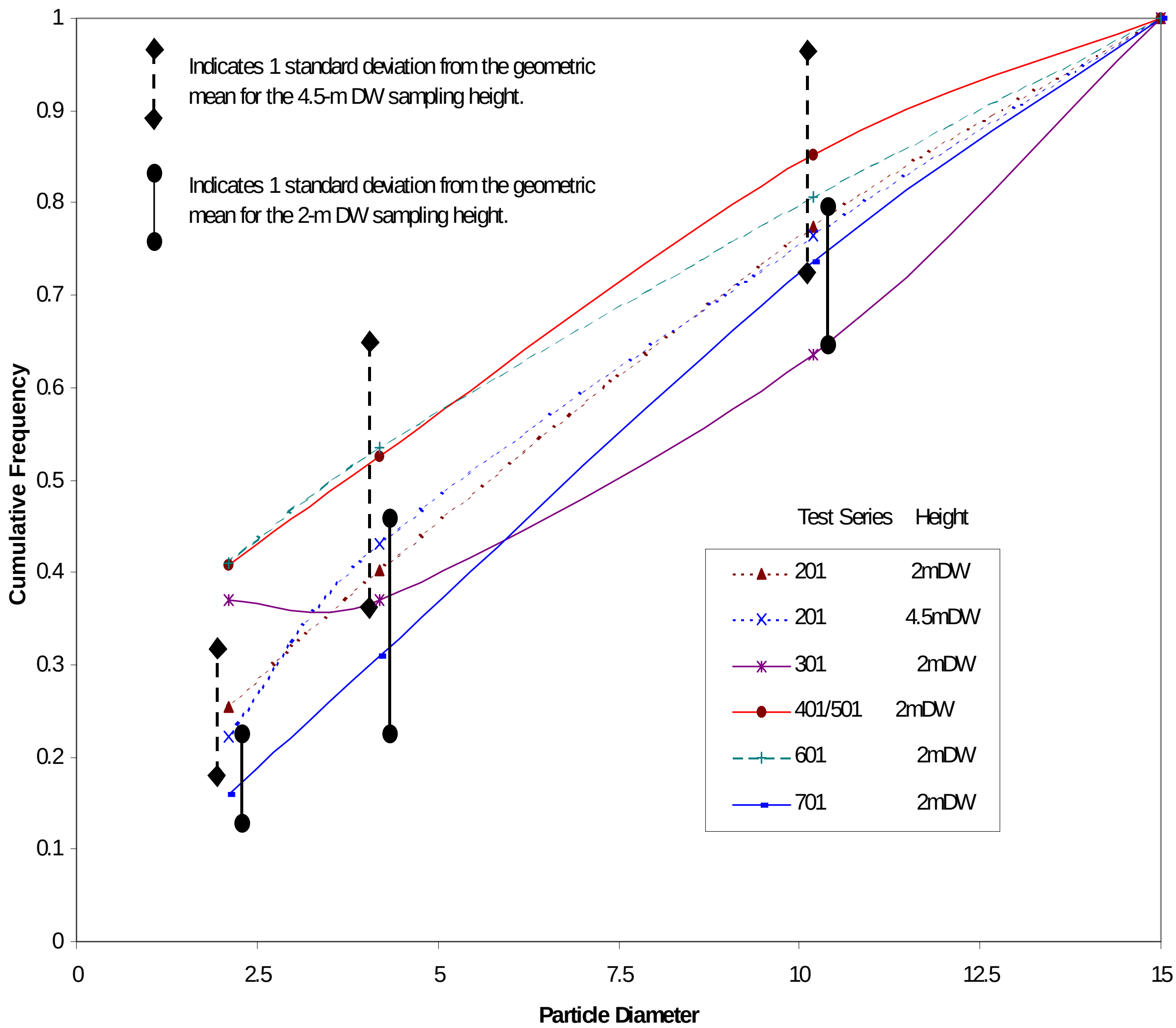


Figure 3-9. Comparison of particle size distributions for 1999 BY runs and 1998 BV runs.

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

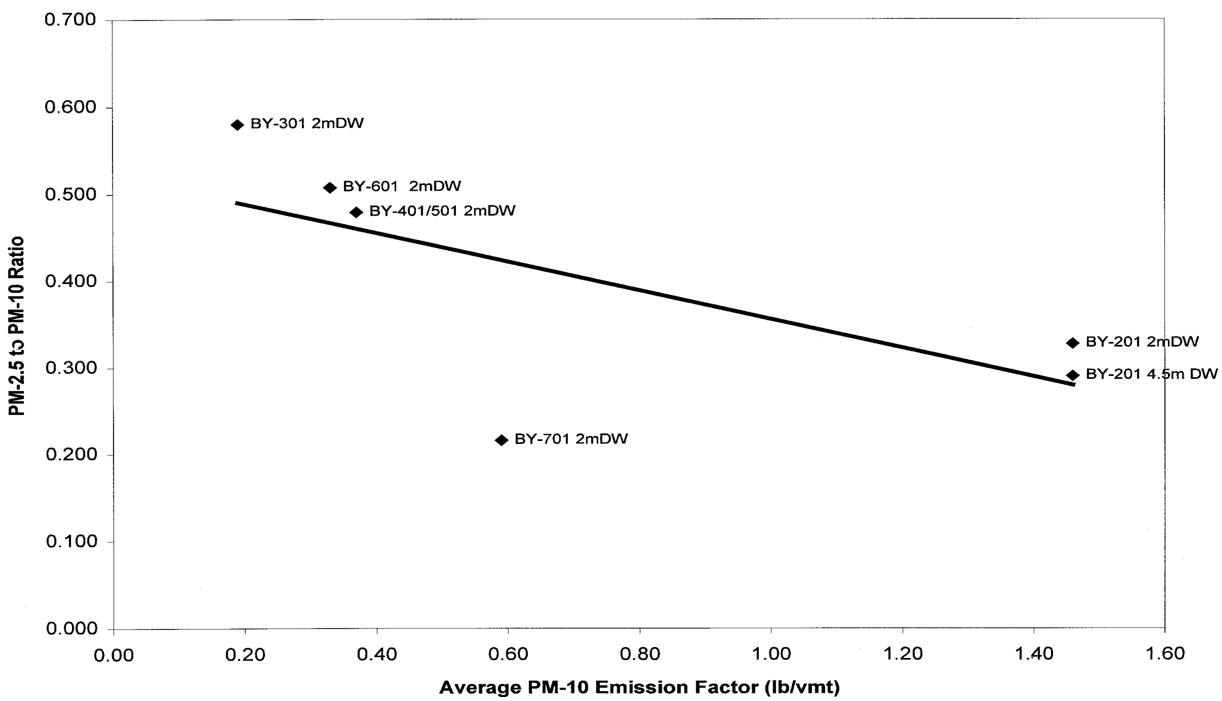


Figure 3-10. Correlation between PM-2.5/PM-10 ratio and PM-10 emission factor.

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,

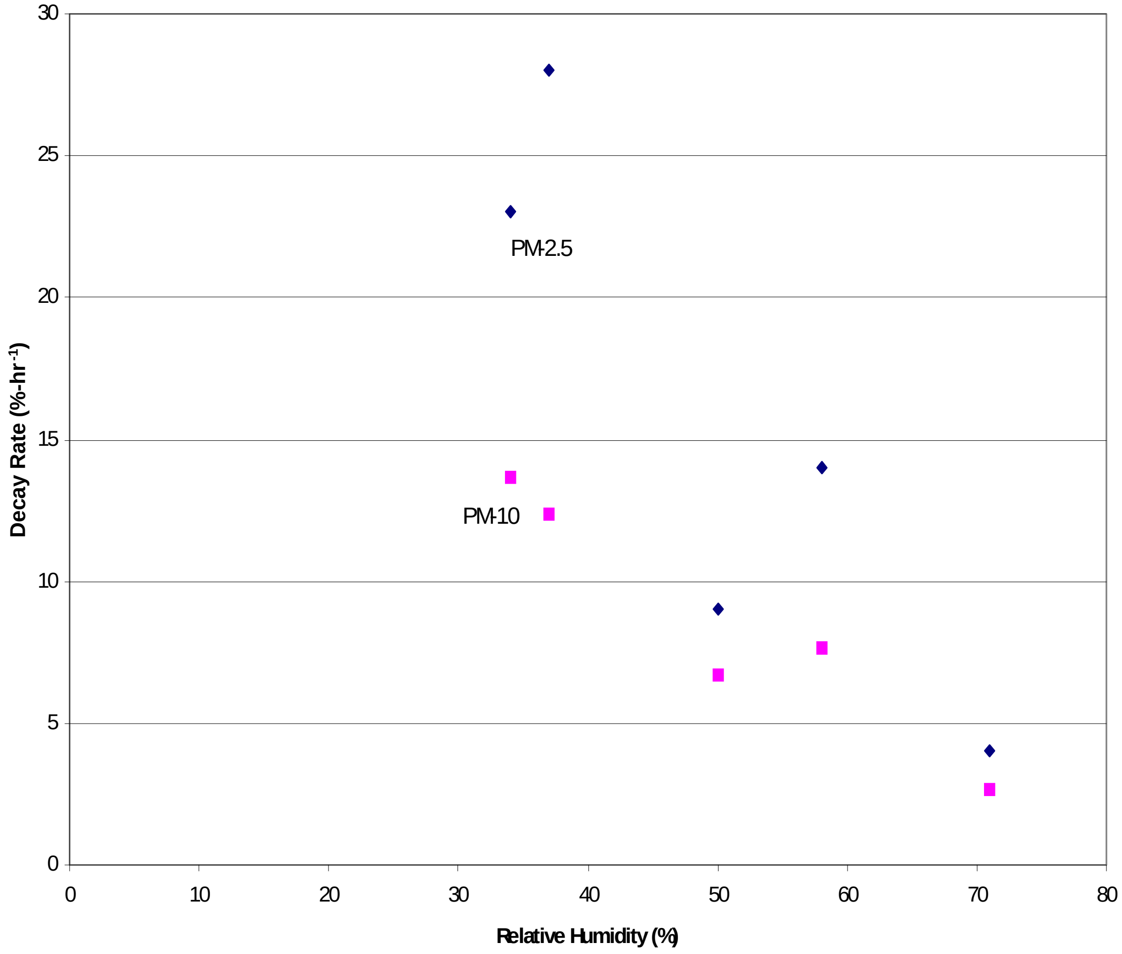


Figure 3-11. Average control efficiency decay rates for PM-10 and PM-2.5 versus relative humidity.

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.

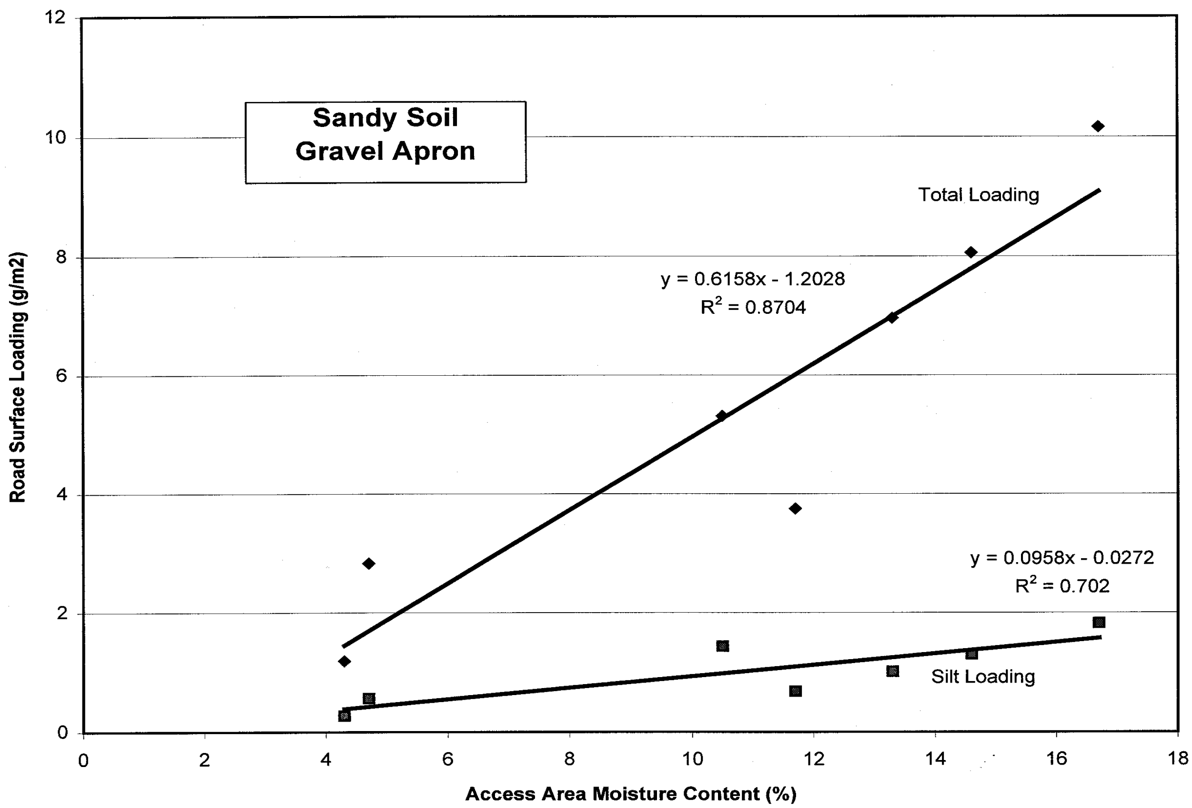


Figure 3-12. Correlation between loading and moisture content for sandy soil in conjunction with gravel apron (DFS).

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° 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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Appendix A

Emission Measurements from Controlled Construction Activities

Site-Specific Test Plan
Revision 1

Prepared for
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711
Office of Research and Development
Air Pollution Prevention and Control Division
(MD-61)

Attn: Charles C. Masser
Work Assignment Manager

Under Subcontract to
Pacific Environmental Services, Inc.

EPA Contract No. 68-D-70-002
Work Assignment No. 2-04
MRI Project No. 4813-02

October 6, 1999

Preface

This test plan was prepared for the U.S. Environmental Protection Agency by Midwest Research Institute (MRI) under Subcontract No. 68D7002-MRI, Work Assignment No. 2, from Pacific Environmental Services, Inc. The prime contract for this effort is EPA Contract 68-D-70-002, Work Assignment 2-04. Under this work assignment, MRI is providing assistance in characterizing construction-related particulate matter emissions and controls in terms of mass and particle size distribution.

Questions concerning this plan should be addressed to Dr. Chatten Cowherd, Work Assignment Leader, at (816) 753-7600, Ext. 1586.

MIDWEST RESEARCH INSTITUTE

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Director
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October 6, 1999

Document Control

This is an internally controlled document in accord with MRI's Standard Operating Procedures (SOPs) MRI-0055. Requests for controlled documents are to be made through Ms. Judy Kozak, MRI Document Control Coordinator.

Revision History

Revision 0: This site-specific test plan was prepared as a companion to the QAPP produced for the work assignment.

Revision 1: "October 6, 1999" Revised to incorporate corrections and changes in the text requested by EPA and PES.

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Section 1. Introduction

1.1 Summary

This test plan presents the testing approach that Midwest Research Institute (MRI) will use to characterize the amount and particle size distribution of particulate matter (PM) emissions from certain controlled construction-related activities. Specifically, the activities under consideration are those related to (a) the movement of large off-road construction equipment along temporary unpaved travel routes and (b) mud/dirt trackout from unpaved areas onto paved roads that border a construction site.

To address logistical difficulties, field testing of construction emissions will occur at "captive" operations in the sense that operations can be largely controlled during testing. Tests will be conducted at two locations:

- North Central Kansas (NCK) Technical College. This is a heavy equipment vocational training facility located in Beloit, Kansas. The effectiveness of watering as a control measure for unpaved travel routes will be tested at this site.

- Deramus Field Station. This 80-acre MRI facility is located in Grandview, Missouri. The effectiveness of two to four trackout controls on two soil types will be tested at this site.

Testing under this work assignment is planned for the period from August to October 1999. Testing of uncontrolled particulate emissions from construction-related activities was recently performed by MRI at both of these sites under a prior work assignment.

Past studies have found that a substantial fraction of PM emissions from construction activities is related to transport of earth and other materials around the site. Because of the generally short-term nature of travel routes at construction sites, operators throughout the United States commonly employ water to control PM emissions rather than relying on more expensive chemical dust suppressants.

Although PM emissions from watered unpaved roads has attracted attention since at least the early 1980s, only two watering tests have been conducted at construction sites. In addition to the simple scarcity of data specifically referenced to construction sites, there are concerns about how well watering tests of unpaved roads in other settings can be applied to the construction sites. Because temporary routes are not nearly as well constructed as conventional unpaved roadways, available data may not accurately reflect the efficiency afforded by watering at construction sites.

Mud/dirt trackout from construction sites constitutes a large component of construction dust emissions in urban areas, where tracked mud/dirt substantially raise the silt loadings on adjacent paved roadways. Trackout is observed to increase as soil moisture increases, but this effect has not been quantified. There are a variety of candidate methods for decreasing the accumulation of mud/dirt on tires or removing accumulated mud/dirt as vehicles exit a construction site. However, the control efficiency test data for these measures are limited.

1.2 Test Program Organization

Figure 1-1 presents the test plan organization, major lines of communication, and names/phone numbers of responsible individuals.

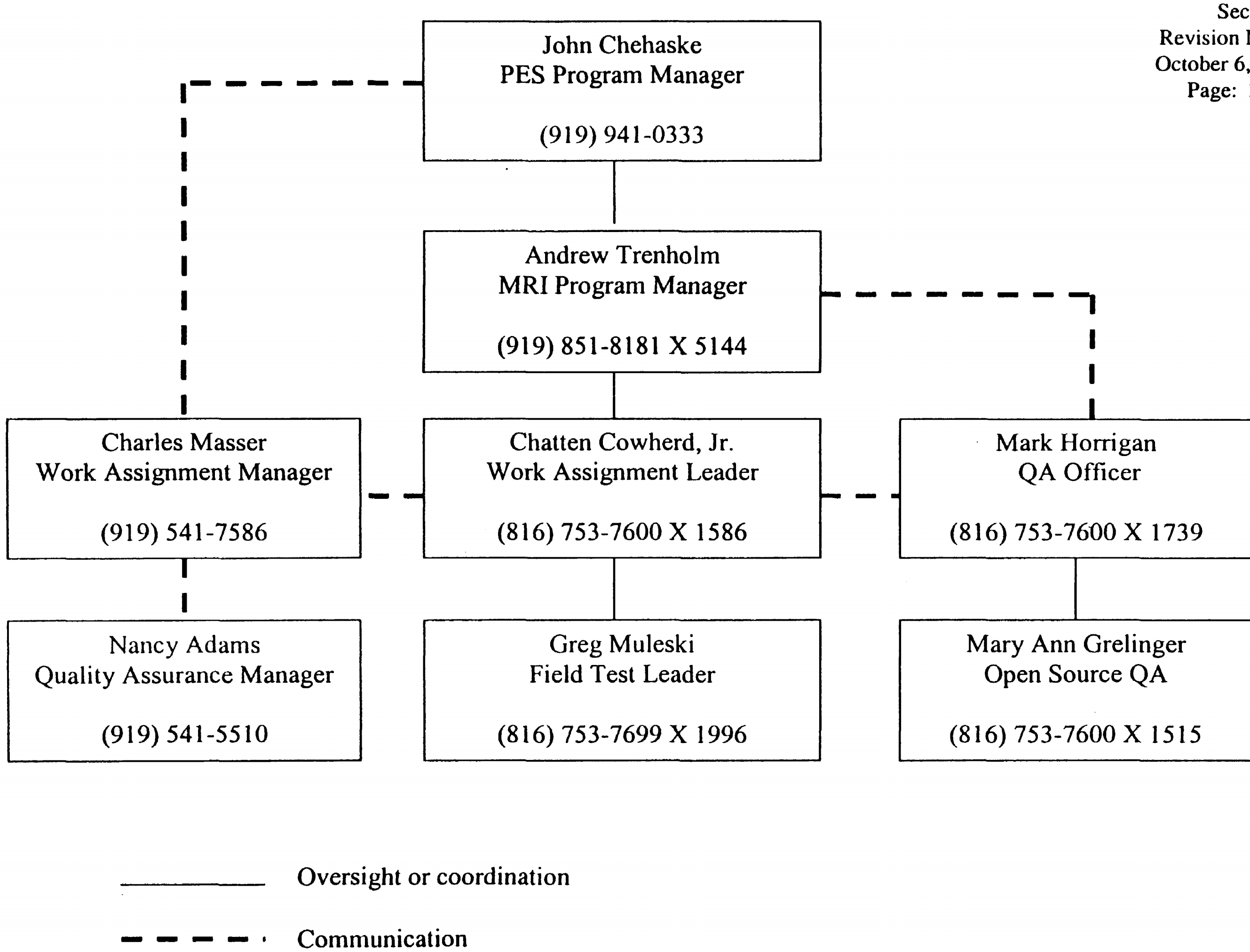

Figure 1-1. Project Organization Chart

Section 2.
Source Description

2.1 Process Description

Earthmoving operations constitute a large, if not dominant, source of particulate emissions at heavy construction sites. Numerous process "systems" are available for the purpose of earthmoving, and these systems often combine different machines. The *Caterpillar Performance Handbook*[3] lists the following options:

- Bulldozing with track-type tractors
- Load-and-Carry with wheel loaders
- Scrapers self-loading with elevator, auger, or push-pull configurations, or push-loaded by track-type tractors
- Articulated trucks loaded by excavators, track loaders or wheel loaders
- Off-highway trucks loaded by shovels, excavators or wheel loaders

Selection of a "spread" of equipment for use at a construction site depends on numerous factors, not the least of which includes the number and size of equipment readily available to the earthmoving contractor. The need to transport material into or out of the site also restricts what type of equipment can be used.

When different machine options are available, the most important consideration by the contractor involves the typical operating distance. General haul distances for earthmoving systems are shown in Figure 2-1, as found in the Caterpillar handbook.[3] As can be seen, scrapers can be economically operated over a wide range of haul distances and are the primary equipment used for alternating cuts and fills. Scrapers have important advantages in that they are highly mobile; can be operated under wide variety of underfoot conditions; and can accomplish the entire operation of digging, transporting, and unloading in a single cycle.

Figure 2-2 provides a schematic illustration of the earthmoving cycle for scrapers. During the loading or "cut" operation, a scraper generally travels approximately 100 to 200 ft while material is being loaded.[4] Once loaded, the scraper travels a haul route to a "fill" or a stockpiling location, where the material is unloaded. The scraper again travels approximately 100 to 200 ft during the unloading operation. The unloaded scraper then returns to the cut location along a haul route to repeat the loading/unloading cycle.

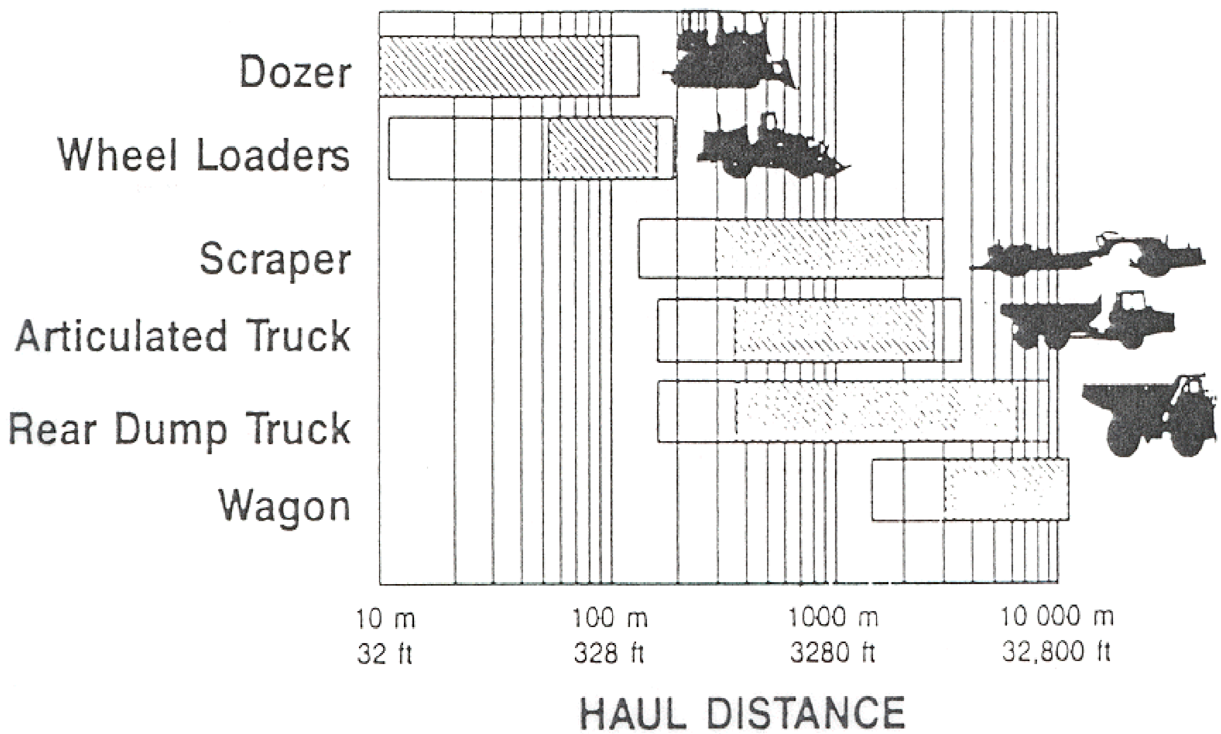

Figure 2-1. Typical Operating Distances for Earthmoving "Systems" Described in Reference 3

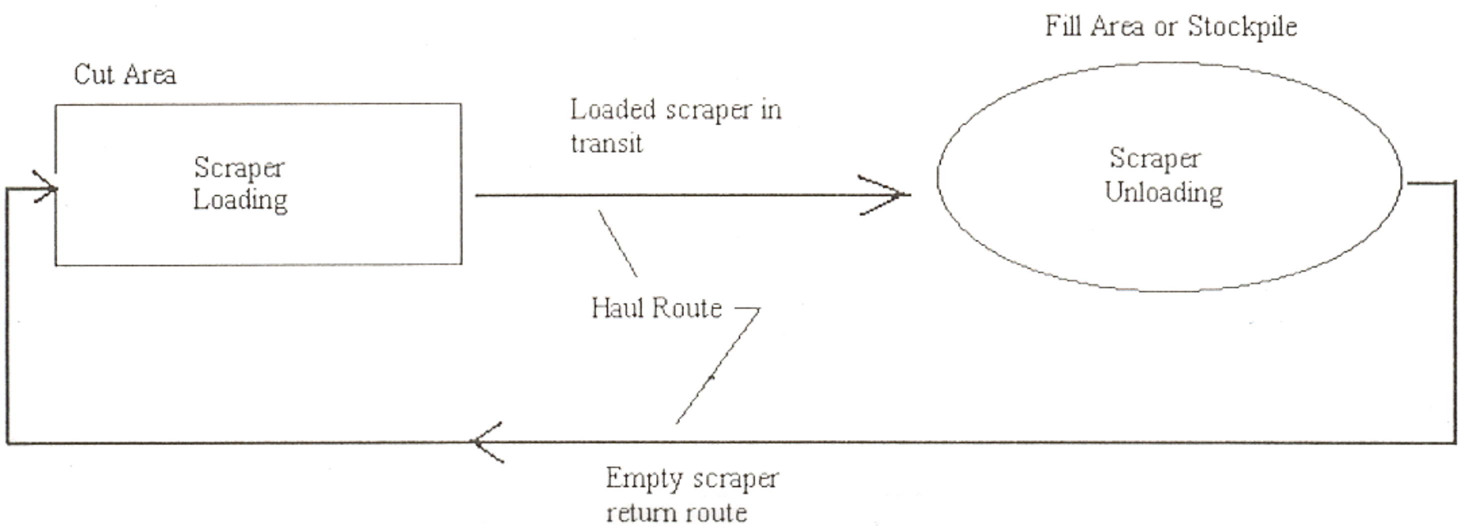

Figure 2-2. Schematic Operation of Scrapers for Earthmoving Activities

If the transported material is unloaded at a fill location, it can be compacted by bulldozers and other equipment. Should the unloading instead occur at a stockpile location, the material ultimately must be moved again. This typically involves a scraper again transporting the material to on-site fill location; however, the stockpile may require loading into trucks for transport to an off-site location.

Mud/dirt trackout constitutes a large component of construction dust emissions in urban areas. The mud/dirt that is tracked by vehicles exiting construction sites raises the silt loading on adjacent paved roads. This, in turn, causes elevated emissions from the paved roads as the mud/dirt is pulverized and resuspended by vehicular traffic. In some cases, surface watering for on-site control of construction dust may enhance trackout emissions.

2.2 Control Equipment Description

Because the construction-related PM sources under consideration are open emission sources, traditional pollution control devices such as cyclones and baghouses are not applicable. In general, water applied by gravity or pressurized trucks is the most commonly used dust control technique at construction sites. Water is frequently applied to the haul routes within a site.

Because temporary routes traveled by scrapers are not nearly as well constructed as conventional unpaved roadways, data from temporary routes will more accurately reflect the efficiency afforded by watering at construction sites. The frequency and amount of water added to the travel route per unit time will be varied to develop the basis for cost-effective strategies for dust control of unpaved travel routes within the construction industry.

Control measures for mud/dirt trackout usually consist of aprons or mechanical devices at the vehicle exit points. These measures are intended to remove the mud/dirt accumulations from tires as the vehicles exit the site onto adjacent paved roads.

Section 3.
Test Program

3.1 Objectives

This test program will develop particulate control efficiency for (a) watering of scraper travel routes and (b) application of two to four controls for mud/dirt trackout. Specific objectives, in descending order of priority, are:

- Develop uncontrolled and controlled PM-10 emission factors for watering of unpaved scraper travel routes.
- 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 include a gravel access apron and at least one stationary metallic device).

3.2 Test Matrix

Table 3-1 presents the overall design of the testing program. In the table, "mass flux profiling" refers to the method for determination of an individual emission factor/rate. The exposure profiling test method is discussed in detail in Section 5. The term "particle size profiling" is used to denote a test designed to characterize the particulate size distribution at two heights. Because of the need to collect adequate mass of the smaller size fractions, a single particle size test spans several mass flux tests. The particle sizing technique is also discussed in Section 5.

Emission tests at NCK Technical College will be conducted under a variety of meteorological conditions (e.g., temperature, wind speed, cloud cover) and operating conditions (e.g., weight and speed of vehicle equipment, number of vehicle passes per unit time, and time of day). Of particular interest is on-site collection of pan evaporation measurements so control efficiency decay rates for watering can be referenced to readily available meteorological data. Because control efficiency is greatest immediately after water is applied to the roadway and decays as the surface dries, testing will span a broad range of times after watering, so reliable average control efficiency data are obtained.

Table 3-1. Test Design

Operation	Travel surface	Pollutant	No. of tests	Test method	Approx. time (min) per test
NCK Tech. College					
Transit–Native Soil	Uncontrolled	PM-10 PM-2.5	3 1	Mass flux profiling Particle size profiling	15 75
	Watered: Appl. 1	PM-10 PM-2.5	3 1	Mass flux profiling Particle size profiling	30-60 120
	Watered: Appl. 1a	PM-10 PM-2.5	3 1	Mass flux profiling Particle size profiling	30-60 120
	Watered: Appl. 2	PM-10 PM-2.5	3 1	Mass flux profiling Particle size profiling	30-60 120
	Watered: Appl. 2a	PM-10 PM-2.5	3 1	Mass flux profiling Particle size profiling	30-60 120
Deramus Field Station					
Trackout–Native Soil	Uncontrolled • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
	Control 1	Surface loading		Manual cleaning	60 min
	• Moisture 1 • Moisture 2		3 3		
	Control 2 • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
	Control 3 • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
Trackout–Sandy Soil	Uncontrolled • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
	Control 1 • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
	Control 2 • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min
	Control 3 • Moisture 1 • Moisture 2	Surface loading	 3 3	Manual cleaning	60 min

At the Deramus Field Station, trackout from bare soil areas on to a paved roadway will be studied as a function of soil type, soil moisture and control method. The technique for trackout quantification is discussed in Section 4.

Section 4.
Sampling Locations

4.1 Sampling Locations

As noted earlier, testing will employ captive construction-related operations at two different facilities. The first set of tests will take place at the North Central Kansas Technical College (NCK Technical College) location near Beloit, Kansas. Figure 4-1 presents a general plant layout of the facility. Testing will be performed in conjunction with the "hands-on" training of students at NCK Technical College. During the captive earthmoving operation, students operating up to 5 scrapers will form a cut of approximate dimensions 300 ft long, 100 ft wide and 8 ft deep. When that cut is completed, the stockpiled material will be recovered and replaced.

AT NCK Technical College, there are seven scrapers available, as show below:

No. of units	Caterpillar model no.	Capacity (cu yd)	Type
3	621	21	Pan-type, single engine tractor
1	623	23	Elevating (paddle) type
3	613	11	Elevating (paddle) type

This test site affords an opportunity to examine the effect that different types of scrapers have on emission levels. To the extent practical, MRI will work with NCK Technical College staff to isolate individual scraper types during the testing. That is, if only three teams (two students each) are to train on scrapers on any given day, MRI will request that on one day the three pan scrapers be used and on the next day, the three Model 613 units be used. If NCK Technical College plans call for four teams, MRI will request that four elevating models be used.

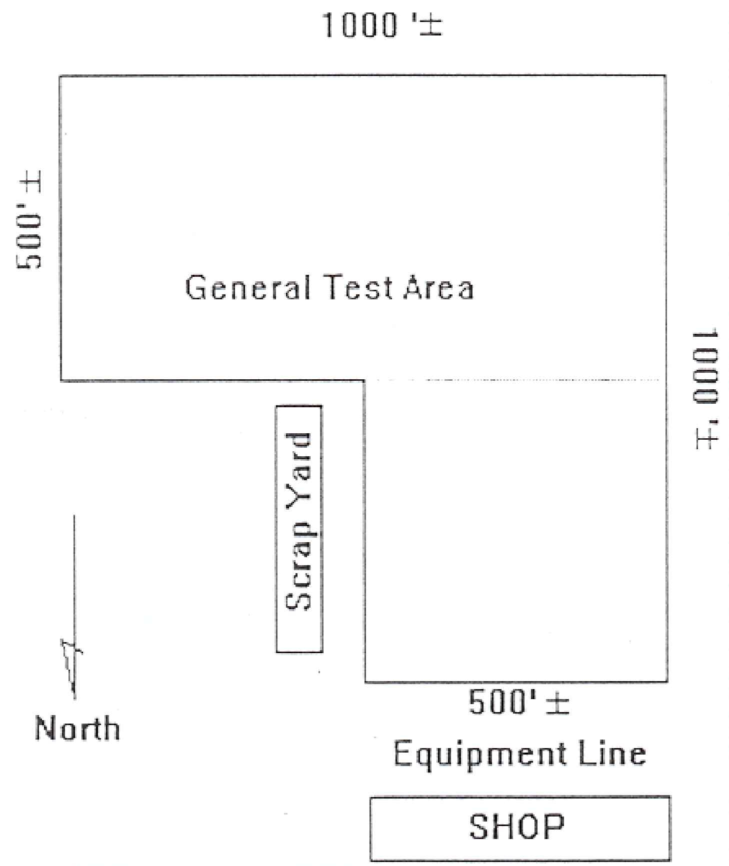

Figure 4-1. General Layout of Training Facility at North Central Kansas Technical College

The scraper in transit represents a “moving point” source that can be treated as a “line” source. Figure 4-2 shows not only a schematic of the operation but also the basis for the line source test methodology.

As long as the distance traveled during the transit operation is substantially greater than the downwind distance from the 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.

A captive test site at MRI Deramus Field Station (Grandview, Missouri) will be used to test mud/dirt trackout controls, in order to stage site conditions and trackout vehicles during the study. An asphalt-paved (or otherwise improved) linear test strip approximately 200 feet in length will be used to determine the amount of material that is tracked from the adjacent egress area (unpaved travel route at right angles to the paved test strip). The unpaved travel route will include two soil types (one high and one low clay content) for characterization of uncontrolled trackout (at varying moisture levels). In addition, from two to four trackout control methods will be investigated. They will include a gravel access apron and at least one stationary metallic device for removing the mud/dirt from vehicle tires.

4.2 Process Sampling Locations[a]

In addition to the particulate concentrations and wind speed measurements necessary (as described in Section 5) to determine emission rates, two other broad classes of information will be collected during the field exercise at NCK Technical College. The first class comprises operational features, such as the speed of the scraper. Because of the “captive” nature of the earthmoving being tested, the operational parameters will be established prior to the start of testing and will be controlled by the operators during test periods.

The second supplementary class consists of aggregate material properties of the unpaved travel surfaces. Of particular interest are the moisture and silt contents of the surface material. Up to six composite samples (edge-to-edge) will be collected to characterize the scraper transit surface soil at the NCK Technical College training facility. During watering tests, a composite sample for moisture analysis will be collected every 30 min. Each composite sample will consist of 10 increments, each 12 in by 12 in in area.

[a] The process is defined in terms of the operational parameters of the construction equipment and the properties of the travel surface which constitutes the source of entrained dust.

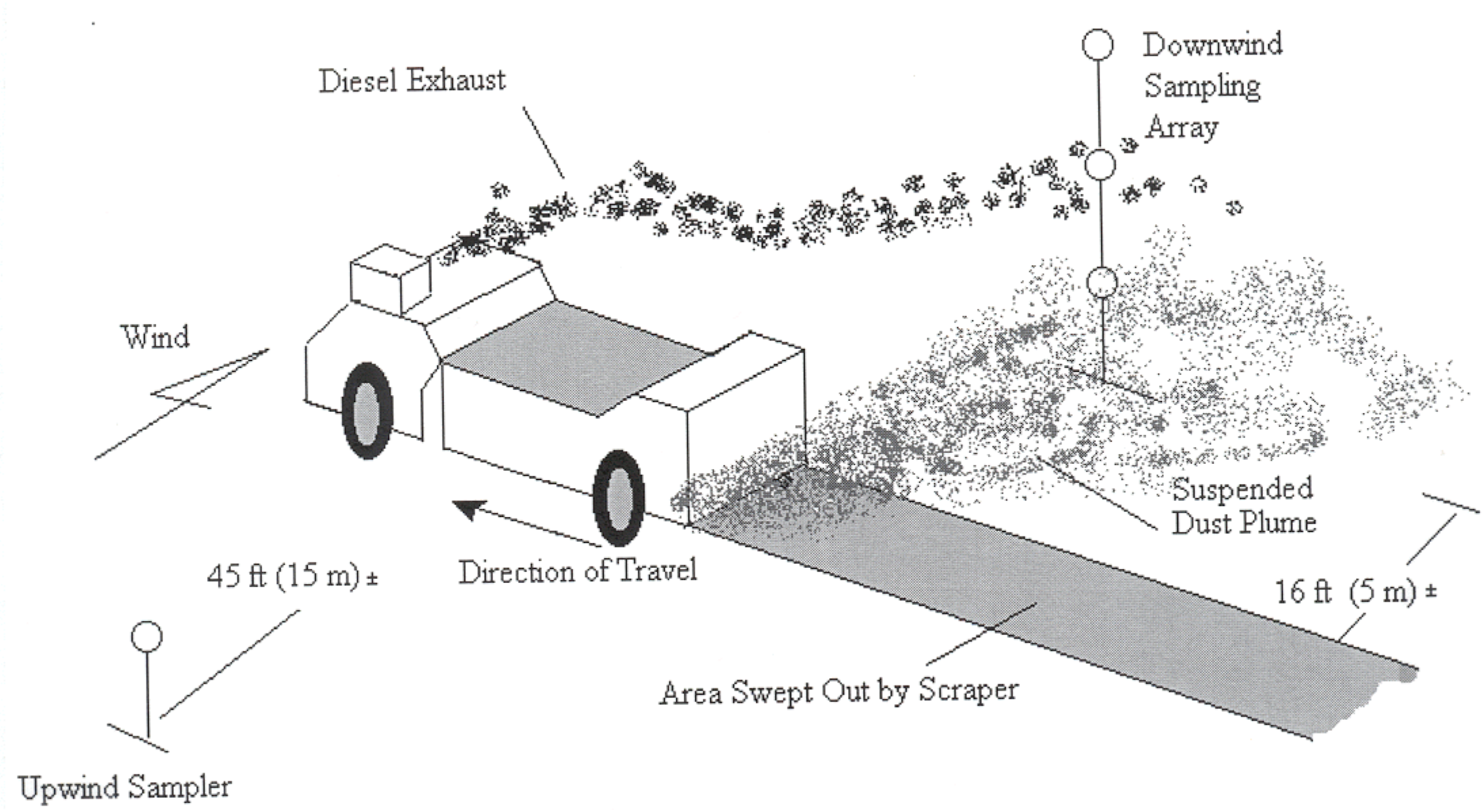

Figure 4-2. Schematic Illustration of Test Procedure for Moving Point Source

Sample collection and analysis will follow procedures contained in Appendices C.1 and C.2 in EPA's Compilation of Air Pollutant Emission Factors (AP-42).[5]

At the trackout test site at the Deramus Field Station, no emission testing will be performed, but the operational features of trackout vehicles (primarily a full-size pickup truck) will be documented. In addition, the aggregate material properties of the test soil surfaces, from which trackout originates, will be characterized, together with the silt loadings on the paved test strip. For each test soil, a composite sample consisting of six 12 in by 12 in increments will be collected for silt and moisture analysis. For "point" measurement silt loading on the paved test surface, each surface sample will be obtained by cleaning a lateral strip (edge-to-edge) of the surface. A combination of sweeping with a small broom and a vacuum cleaner (depending on surface loading) will be used to collect each surface sample.

Section 5. Sampling and Analytical Procedures

5.1 Test Methods

The exposure profiling test method will be used to quantify emissions from scrapers in transit under different watering cycles. This method has been recognized by EPA as the characterization technique most appropriate for the broad class of open anthropogenic dust sources, such as moving point sources. 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[5] are typically based on this approach.

The exposure profiling technique for emission testing of open particulate matter sources is based on an isokinetic profiling concept. The passage of airborne pollutant immediately downwind of the source is measured directly by means of simultaneous multi-point sampling of mass concentration and air flow (advection) over the cross section of the emission plume. Because both the emission rate and the air flow are non-steady, simultaneous multipoint sampling is required. This technique uses a mass flux measurement scheme testing rather than requiring indirect emission rate calculation through the application of a generalized atmospheric dispersion model. As noted in the previous section, the emission source—scrapers in transit—can be represented as a line source.

As applied to line sources, the "exposure profiling" test method requires a vertically oriented array of sampling points. A vertical network of samplers (Figure 5-1) is positioned just downwind and upwind from the edge of the source. The downwind distance of approximately 5 m is far enough that interference with sampling due to vehicle-generated turbulence is minimal but close enough to the source that the vertical plume extent can be adequately characterized with a maximum sampling height of 5 to 7 m. In a similar manner, the approximate 15-m distance upwind from the source's edge is far enough from the source that (a) source turbulence does not affect sampling, and (b) a brief wind reversal would not substantially impact the upwind samplers. The 15-m distance is, however, close enough to the line of the moving point source to provide the representative background concentration values needed to determine the net (i.e., due to the source) mass flux.

The primary air sampling device in the exposure profiling portion of the field program will be a standard high-volume air sampler fitted with a cyclone preseparator (Figure 5-2).

UNCONTROLLED

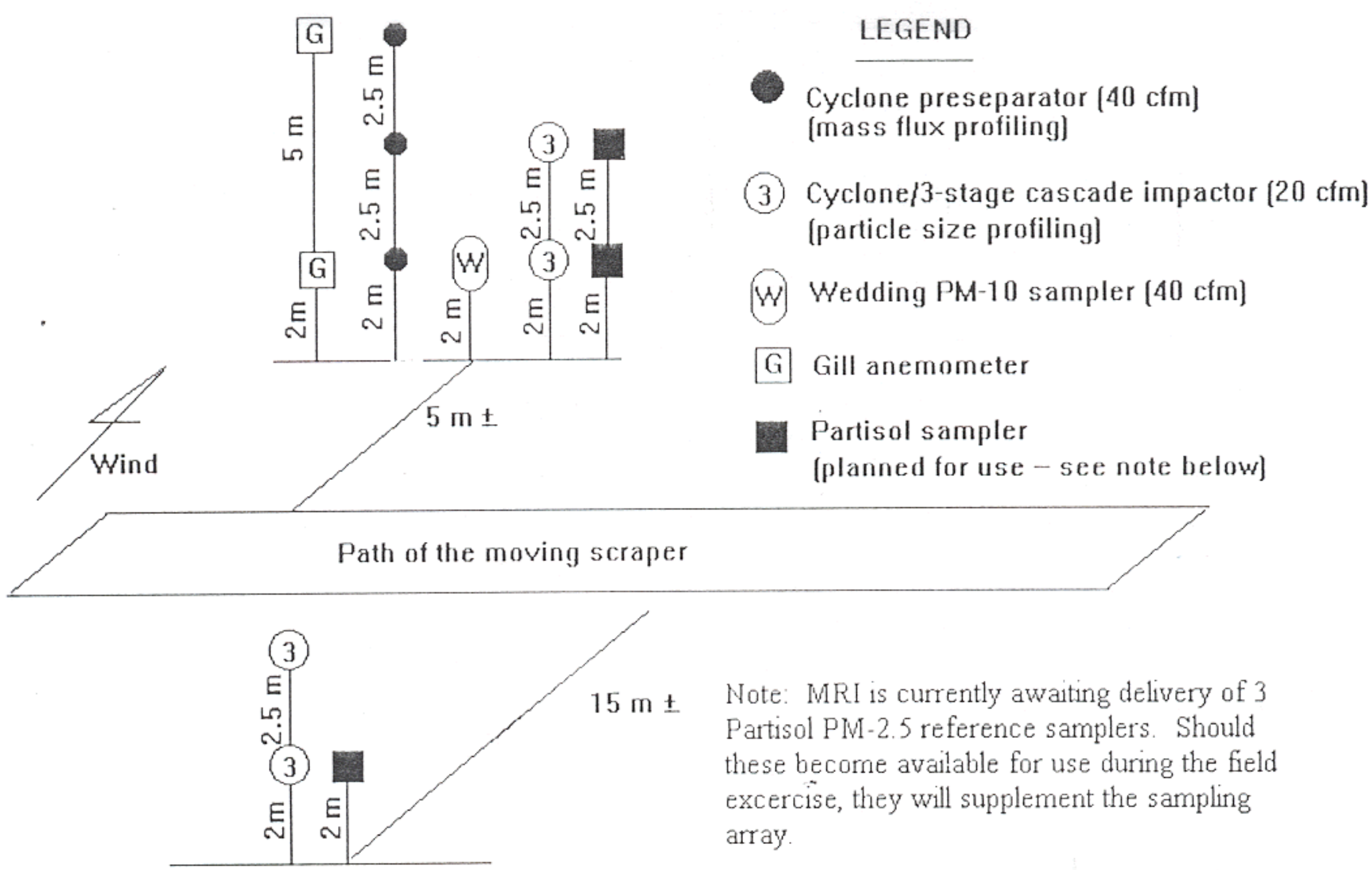

Figure 5-1. Sampling Equipment Deployment for Scraper Transit Tests

The cyclone exhibits an effective 50% cutoff diameter (D_{50}) of approximately 10 µmA when operated at a flow rate of 40 cfm (68 m^3/h).[6] Thus, mass collected on the 8- by 10-in backup filter represents a PM-10 sample. During each mass flux profiling test, a Wedding and Associates high-volume PM-10 reference sampler will be colocated with one cyclone sampler for comparison purposes.

As noted in connection with the test matrix given in Table 3-1, "mass flux profiling" describes tests that will be used to characterize mass emissions from scrapers in transit. In this technique, samplers of the type shown in Figure 5-2 are distributed over the effective height of the dust plume to determine the mass concentration of particulate at different heights in the plume. In this way, the shape of the emission plume is defined and the PM-10 emission factor is found by integrating the mass flux over the height of the plume in the manner described in Section 5.2.

The test matrix given in Table 3-1 also references "particle size profiling" tests to determine vertical profiles of particle size distribution data. This second sampling system supplements the mass exposure profiling system described above. The second system also uses a high-volume cyclone preseparator but in a different sampling configuration. Here, the cyclone is operated at a flow rate of 20 acfm over a 3-stage cascade impactor (see Figure 5-3). At that flow rate, the cyclone and 3 stages exhibit D_{50} cut points of 15, 10.2, 4.2, and 2.1 µmA. Particulate matter is collected on 4- by 5-in glass fiber impactor substrates and the 8- by 10-in glass fiber backup filter. To reduce particle "bounce" through the impactor, the substrates are sprayed with a grease solution that improves the adhesion of the impacted particles. To determine the sample weight of particulate collected on the interior surface, the interior surface is washed with distilled water into separate jar which is then capped and taped shut. Upon return to MRI's main laboratories, the entire wash solution will be passed through a Büchner-type funnel holding an 47-mm glass fiber filter under suction to ensure collection of all suspended material on the filter.

As noted in Section 3, a particle size profiling test will span three mass flux profiling tests. This recognizes that, because a cyclone/impactor combination samples at a slower flow rate and collects mass on more media, this type of sampler must be operated much longer than the 40-cfm cyclones used to define the plume shape in the mass flux profiling tests.

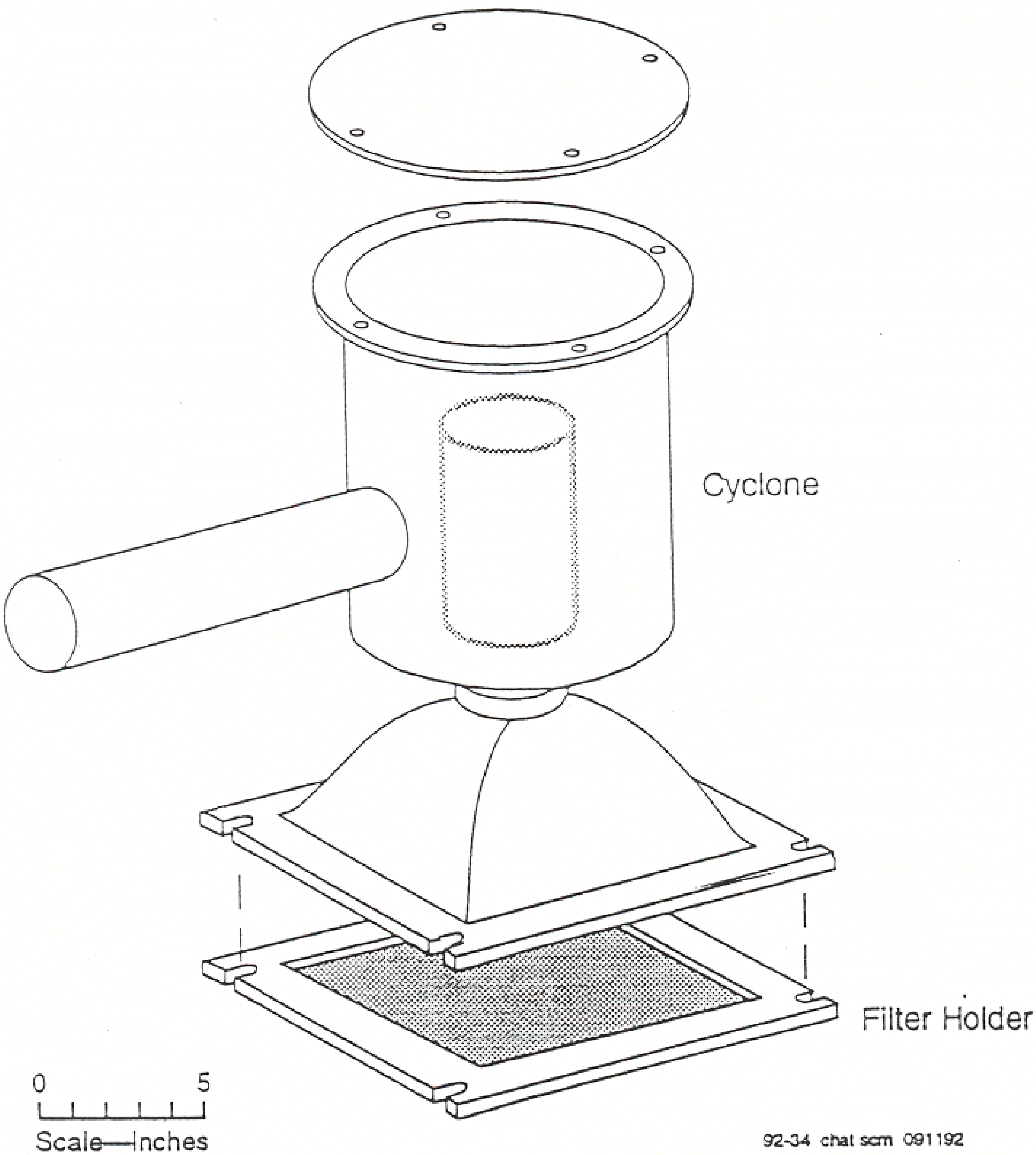

Figure 5-2. Cyclone Preseparator Operated at 40 cfm

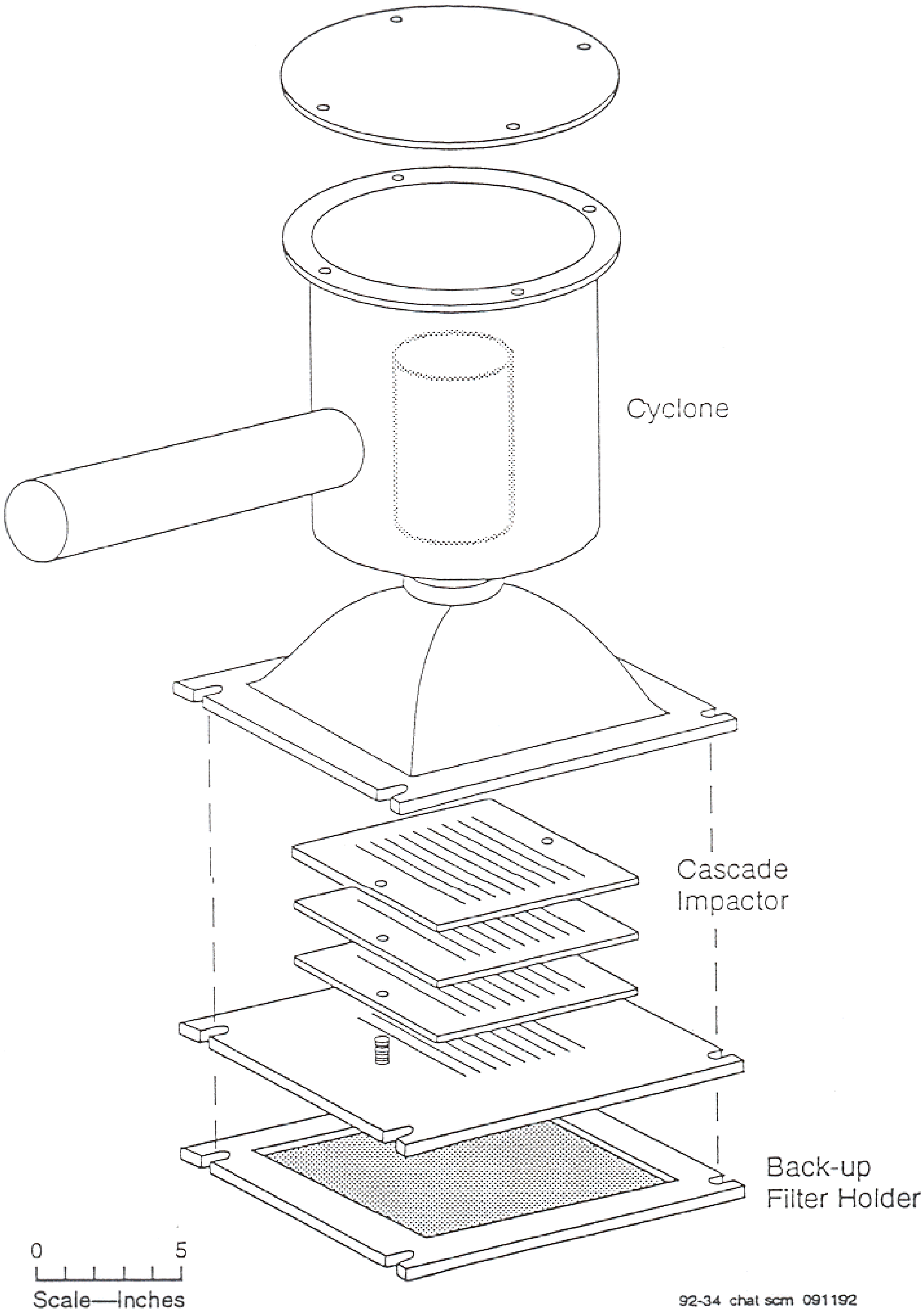

Figure 5-3. Cyclone Preseparator-Cascade Impactor Operated at 20 cfm

Besides the air sampling equipment, Figure 5-1 also shows that, throughout each test of scrapers in transit, wind speed will be monitored at two heights using R. M. Young Gill-type (model 27106) anemometers. Furthermore, an R. M. Young portable wind station (model 05305) will be used to record wind speed and direction at the 3.0 m height downwind. All wind data are to be accumulated into 5- to 15-min averages logged with a 26700 series R. M. Young "programmable translator."

Additional measurements are necessary to characterize the service environment for the watering tests of scrapers in transit. These measurements will include:

- volume of water applied per unit area of travel surface
- solar radiation
- cloud cover
- relative humidity
- pan evaporation

Note that these measurements are 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 the primary variable (moisture content) relates to environmental conditions. It should be noted that the evaporation rate from a travel surface is strongly enhanced by the movement of scrapers or other mobile equipment over the surface.

To determine the volume of water applied per unit area, a series of tared sampling pans will be placed across the test surface. These will consist of lightweight aluminum pans with an opening of approximately 32 square inches. The bottom of the pan will be lined with absorbent material to avoid splashing of the water. Once the water is applied, the sampling pans will be retrieved and reweighed. The volume of water will be determined by assuming water density of 1 g/cm^3. The application rate is found by dividing the volume of water by the top area of the pan.

Solar radiation during the test period will be monitored by a Weathertronics Model 3010 mechanical polygraph. This device produces a hard copy record of the intensity of direct and scattered solar radiation. Hourly visual observations of cloud cover (to the nearest tenth) will supplement the pyranograph results.

Dry and wet bulb temperatures (from which relative humidity is determined) from a sling psychrometer will be recorded hourly.

The standard "Class A" evaporation measurement procedure requires that 7.5 inches of water be maintained in a pan with very specific dimensions (10 inch high by 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 will make use of a galvanized steel tank with approximately the same dimensions as a Class A pan and will fill the tank with water to the same relative height (i.e., to 2.5 inch from the top). The tank will be deployed at the start of the testing exercise, and the water level will be measured each morning and evening during the sampling trip. A rain gauge will also be deployed in the immediate vicinity of the tank, and its contents will be read each morning and evening as well.

Trackout emissions of PM-10 and PM-2.5 will be projected from the quantity of mud/dirt per vehicle which passes from the egress area to the paved test strip, and its contribution to silt loading. The method for collection and analysis of surface loading (total and silt fraction) is described in Reference 5.

For the baseline (dry soil) uncontrolled condition (one series of tests for each soil type), the trackout quantity will be measured by collecting surface samples from the paved test strip at five regular distance intervals from the access end to the opposite end (200 ft length). The total trackout will be determined by integrating the measured surface loadings over the full length of the test strip.

For the other uncontrolled tests (with higher moisture levels on the unpaved travel route) and for tests of trackout controls, the total trackout quantity will be based on collection of surface materials in the immediate vicinity (within about 25 feet) of the trackout point, with a scaling factor for extrapolation. Reducing the paved area to be sampled will allow multiple access points for more effective back-to-back testing of several uncontrolled/controlled conditions. As stated in Section 3.1, the trackout control measures will include a gravel access apron and a stationary metallic device that spreads the tire tread to remove mud/dirt accumulations.

5.2 Data Reduction

To calculate emission rates in the exposure profiling technique, a conservation of mass approach is used. 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 calculation procedure are described below.

The concentration of particulate matter measured by a sampler is given by:

$$C = m / QT$$

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

$$IFR = Q / aU$$

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

This ratio is of interest in the sampling of total particulate, since isokinetic sampling ensures that particles of all sizes are sampled without bias. As such, the ratio is of greatest interest in the particle size profiling tests. Specially designed nozzles are available to maintain ±20% isokinetic sampling for wind speeds in the range of approximately 5 to 20 mph (when the samplers are operated at 20 acfm). Because the primary interest in this program is directed to PM-10 and PM-2.5 emissions, sampling under moderately nonisokinetic conditions should pose little difficulty. It is readily recognized that 10 µm (aerodynamic diameter) and smaller particles have weak inertial characteristics at normal wind speeds and therefore are relatively unaffected by anisokinesis.[7]

Nozzles are used on both the 20- and 40-cfm directional sampler units. However, because of the lower intake speed, the 20-cfm cyclone/impactors have more favorable isokinetic rations under typically encountered wind speeds. For this reason, only the total particulate results based on the samples collected in 20-cfm units will be reported and associated with an IFR value.

Exposure represents the net passage of mass through a unit area normal to the direction of plume transport (wind direction) and is calculated (at each downwind sampling height) by:

$$E = (C - C_b) U T$$

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

Because background concentrations are much smaller than source contributions to downwind concentrations (except when control efficiency is very high), linear interpolation and extrapolation are sufficient to characterize the vertical profile of background concentration for application to all downwind sampling heights.

The 4.5-m wind speed will be interpolated from the 2-m and 7-m measurements. The interpolation assumes a logarithmic wind profile of the form:

$$U(z) = K \ln (z/z_0)$$

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

Exposure values vary over the spatial extent of the plume. If exposure is integrated over the plume effective cross section, then the quantity obtained represents the total passage of airborne particulate matter due to the source. For a line source, a one-dimensional integration is used:

$$A1 = \int_{O}^{H} E \; dh$$

where	A1	=	integrated exposure for a line source (mass/length)
	E	=	net particulate exposure (mass/area)
	h	=	height above ground (length)
	H	=	vertical extent of the plume (length)

Because exposures are measured at discrete point within the plume, a numerical integration is necessary to determine the integrated exposure. For moving point (line) sources, exposure must equal zero at the vertical extremes of the profile (i.e., at the ground where the wind velocity equals zero and at the effective height of the plume where the net concentration equals zero). However, the maximum exposure usually occurs 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 a height of 1 m. The 1-m value of exposure is obtained by extrapolating the 2-m and 4.5-m values. The effective height H is found by vertically extrapolating the net (i.e., downwind minus upwind) concentrations to a value of zero.[b] Finally, the integration is performed using the trapezoidal rule.

The emission factor for particulate matter is determined from the integrated exposure by normalizing the emissions against some measure of source activity. For the tests of scrapers in transit, the integrated exposure will be divided by the number of equipment passes to obtain an emission factor in terms of mass emitted per equipment per unit distance traveled during the operation. For tests of loading and unloading, the “operational distance” traveled by the scrapers will be found by multiplying the total number of scraper passes by the mean distance traveled (see Sections 4.2 and 5.3) during loading or unloading. Both the operational distance and the total volume of earth loaded/unloaded will be used to normalize the emission factor. Both sets will be reported.

5.3 Process Data

As noted in connection with Section 4.2, operational features, such as the speed of the scraper, will be controlled by the “captive” nature of the earthmoving at the NCK Technical College test site.

[b] Because past testing at the Beloit site has shown that most of the dust plume lies below the 7 m sampling height, only minor uncertainties result from vertical extrapolation of the downwind concentration profile from the value at 7 m to the background (upwind value) above 7 m.

Section 6. QA/QC Activities

6.1 QC Procedure

The Quality Assurance Project Plan (QAPP) prepared for this test program is a separate document that describes all the QA/QC activities for the project.

6.2 QA Audits

As part of the QA program for this study, routine audits of sampling and analysis procedures are to be performed. The purpose of the audits is to demonstrate that measurements are made within acceptable control conditions for particulate source sampling and to assess the source testing data for precision and accuracy. Examples of items audited include gravimetric analysis, flow rate calibration, data processing, and emission factor calculation. The mandatory use of specially designed reporting forms for sampling and analysis data obtained in the field and laboratory aids in the auditing procedure.

Requirements for high-volume (hi-vol) sampler flow rates rely on the use of secondary and primary flow standards. The Roots meter is the primary volumetric standard and the BGI orifice is the secondary standard for calibration of hi-vol sampler flow rates. The Roots meter is calibrated and traceable to a NIST standard by the manufacturer. The BGI orifice is calibrated against the primary standard on an annual basis. Before going to the field, the BGI orifice is first checked to assure that it has not been damaged. In the field, the orifice is used to calibrate the flow rate of each hi-vol sampler. (For samplers with volumetric flow controllers, no calibration is possible and the orifice is used to audit the nominal 40 acfm flow rate.) Table 6-1 specifies the frequency of calibration and other QA checks regarding air samplers.

A second pre-test activity is the preparation of the hi-vol filters for use in the field. In this preparation, the filters are weighed under stable temperature and humidity conditions. After they are weighed and have passed audit weighing, the filters are packaged for shipment to the field. Table 6-2 outlines the general requirements for conditioning and weighing sampling media. Note, the audit weighing is performed by a second, independent analyst.

Table 6-1. Quality Assurance Procedures for Sampling Equipment

Activity	QC check/requirement
Maintenance • All samplers	Check motors, brushes, gaskets, timers, and flow measuring devices at each plant prior to testing. Repair/replace as necessary.
Calibration Volumetric flow controller	Prior to start of testing at each regional site, ensure that flow determined by orifice and the look-up table for each volumetric flow controller agrees within 7%. For 20 acfm devices (particle size profiling), calibrate each sampler against orifice prior to use at each regional site and every two weeks thereafter during test period. (Orifice calibrated against displaced volume test meter annually.)
Operation Timing	Start and stop all downwind samplers during time span not exceeding 1 min.
Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction changes by more than 30 degrees for 2 consecutive 5-min averaging periods. Suspend testing if mean wind direction (for two consecutive 5-min averaging periods) is more than 45 degrees from perpendicular to linear path of the moving point source. Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle for two consecutive 5-min averaging periods. Suspend testing if wind speed falls outside the acceptable range of 3 to 20 mph for two consecutive 5-min averaging periods.
Prevention of static deposition	Cover sampler inlets prior to and immediately after sampling.

Table 6-2. Quality Assurance Procedures for Sampling Media

Activity	QA check/requirement
Preparation	Inspect and imprint glass fiber media with identification numbers.
Conditioning	Equilibrate media for 24 h in clean controlled room with relative humidity of 40% (variation of less than ±5% RH) and with temperature of 23°C (variation of less than ±1°C).
Weighing	Weigh hi-vol filters to nearest 0.05 mg.
Auditing of weights	Independently verify final weights of 10% of filters and substrates (at least four from each batch). Reweigh entire batch if weights of any hi-vol filters deviate by more than ±2.0 mg. For tare weights, conduct a 100% audit by a second analyst. Reweigh any high-volume filter whose weight deviates by more than ±1.0 mg. Follow same procedures for impactor substrates used for sizing tests. Audit limits for impactor substrates are ±1.0 and ±0.5 mg for final and tare weights, respectively.
Correction for handling effects	Weigh and handle at least one blank for each 1 to 10 filters of each type used to test.
Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative. Check prior to each use with laboratory Class S weights.

As indicated in Table 6-2, a minimum of 10% field blanks will be collected for QC purposes. This involves handling at least 1 blank filter for every 10 exposed filters in an identical manner to determine systematic weight changes due to handling steps alone. These changes are used to mathematically correct the net weight gain due to handling. A field blank filter is loaded into a sampler and then immediately recovered without any air being passed through the media. Cyclone wash blanks are obtained by washing the devices after they have been cleaned. Blanks have been successfully used in many MRI programs to account for systematic weight changes due to handling.

After the particulate matter samples and blank filters are collected and returned from the field, the collection media are placed in the gravimetric laboratory and allowed to come to equilibrium. Each filter is weighed, allowed to return to equilibrium for an additional 24 h, and then a minimum of 10% of the exposed filters are reweighed by a second analyst. If a filter fails the audit criterion, the entire lot will be allowed to condition in the gravimetric laboratory an additional 24 h and then reweighed. The tare and first weight criteria for filters (Table 6-2) are based on an internal MRI study conducted in the early 1980s to evaluate the stability of several hundred 8- x 10-in glass fiber filters used in exposure profiling studies.

6.3 QA/QC Checks for Data Reduction and Validation

Whenever practical, all data collected in the study will be entered directly into bound laboratory notebooks and standard data forms. All data are to be recorded in notebooks or on standard data forms (examples are provided in the Appendix) using permanent black ink and signed/dated by sampling personnel. Notebooks and data forms are to be inspected for completeness and accuracy by the appropriate field supervisor at the end of each test. At that time, data forms are grouped by test number and bound into 3-ring binders.

The data analysis procedures to be used for this project are procedures that have been through several layers of validation in substantiating the performance of the method. It should be noted that blank-corrected sample mass is considered quantifiable (and usable for concentration calculation) only if it equals or exceeds three times the standard deviation for the net weight gain of the field blanks. The procedures for conversion of particulate concentrations to final end products are presented in Section 5.2.

The Field Team Leader or his/her designee will perform an independent check of the calculations in any computer data reduction program. The Field Team Leader or his/her designee will conduct an on-site spot check to assure that data are being recorded accurately. After the field test, the QA officer or his/her designee will check data input to assure accurate transfer of the raw data.

For this project, all records will be evaluated for the adherence to all procedures and requirements. The items that will be reviewed include:

- Gravimetric audit weighing for the assessment of the particulate data,
- Calibration and calibration criterion checks,
- The results of all blanks, and
- The validation of data process systems or procedures.

Selected data will be reconstructed, including tracing the calibration back to the primary standards. Any software (spreadsheets) used to determine numerical values will be checked by hand calculating all intermediate and final results for one run by referring to original sources of data (i.e., field filter logs, filter weight logs, run sheets, sampler look-up tables).

6.4 Sample Identification and Traceability

To maintain sample integrity, the following procedure will be used:

- Each filter will be issued a unique identification number. SOP MRI-8403 describes the numbering system that is employed to identify filter type, project, and other information.

- The sample number will be recorded in a sample logbook along with the date the sample is obtained. The sample number will be coded to indicate the sample location and test series.

- Other pertinent information to be recorded includes short descriptions of sample type or location, storage location, condition of sample, any special instructions, and signatures of personnel who receive the sample for analysis.

- In order to conduct traceability, all sample transfers will be recorded in a notebook or on forms. The following information will be recorded: the assigned sample codes, date of transfer, location of storage site, and the name of the person initiating and accepting the transfer.

All documented work will be reviewed by the project leader for completeness. The field technical coordinator and crew chief are responsible for assuring that all samples are accounted for and that proper traceability/tracking procedures are followed.

Section 7.
Reporting and Data Reduction Requirements

7.1 Report Format

The table of contents for the test report will be as shown in Table 7-1.

7.2 Data Reduction and Summary

Table 7-2 illustrates the summary format for the emission and particle size data collected during the field testing.

Table 7-1. Table of Contents for the Test Report

Table of Contents

Table 7-2. Summary Formats for Test Data

		PM-10 Emission Factor based on travel distance		PM-10 Emission Factor based on volume loaded/unloaded	
Scraper Operation	No. of Tests	Range	Mean	Range	Mean
Transit				NA	NA

		PM-2.5 to PM-10 Ratio	
Scraper Operation	No. of Tests	Range	Mean
Unloading			
Transit			

Section 8.
Plant Entry and Safety

8.1 Safety Responsibilities

The work assignment leader (C. Cowherd) and the field test leader (G. Muleski) are both responsible for ensuring compliance with plant entry, health, and safety requirements. The facility coordinator has the authority to impose or waive facility restrictions.

8.2 Safety Program

MRI has a comprehensive health and safety program that satisfies OSHA requirements. The Technical Safety and Security Manual, Chemical Hygiene Plan, and Field Operations Safety Manual include written procedures that cover: emergency procedures, safe work practices, material safety data sheets, employee information and training, medical monitoring, and use of personal protective equipment.

8.3 Safety Requirements

All MRI personnel will adhere to the host facility's procedures and safety requirements. In particular, MRI personnel will:

1. confine activities to the test area to the extent possible

2. obtain a daily pass, as required by the host facility

3. wear hard hat, safety shoes, and safety glasses at all times in accordance with host facility and MRI policy

4. have readily available first aid equipment and fire extinguisher

5. eat only in designated areas

Section 9. Personnel Responsibilities and Test Schedule

9.1 Test Site Organization

The key tasks and task leaders for MRI and the host facilities are as follows:

- Facility coordinator (L. Dietz for NCK Technical College)
- MRI work assignment leader (C. Cowherd)
- MRI field test leader (G. Muleski)

9.2 Test Preparation

Table 9-1 lists the preparations and responsibilities that are required for the field program. A schedule is also presented.

9.3 Test Personnel Responsibilities and Detailed Schedule

MRI personnel will arrive at the host facility or at DFS by 8 am during each potential test day during the field exercise. Upon arrival, the MRI field test leader will meet with the facility coordinator (only at NCK Technical College) and then with the test team to: review test plans for the day; communicate all necessary information ; and notify each other of any problem or delay. Table 9-2 provides a detailed test schedule.

Table 9-1. Test Preparations and Assignments

Preparation/Assignment	Responsibility
Preparation of sampling media	Field test leader
Transportation of sampling media and equipment to initial test site	Field test leader
On-site calibration of sampling equipment	Field test leader
Sample traceability (air and material samples)	Field test leader
Compilation of data forms by test number	Field test leader
Transportation of sampling media and equipment to second test site or MRI	Field test leader
Analysis of air and material samples	Field test leader
Data reduction and reporting formats	Field test leader
QA review	Senior QA officer or his designee
Report to management	Senior QA officer or his designee
Report preparation	Work assignment leader

Table 9-2. Testing Schedule

Date	Activity	Comments
7/26/99 - 7/30/99	Perform filter (tare) analysis	
	Prepare sampling equipment/supplies	
9/9/99 - 9/10/99	Load equipment and transport equipment to NCK Technical College	Schedule to coordinate with start of hands-on training fall semester
9/13/99	Establish on-site laboratory at NCK Technical College	
9/13/99 - 9/14/99	Conduct baseline uncontrolled tests at NCK Technical College	
9/14/99 - 9/24/99	Conduct controlled tests at NCK Technical College	
9/25/99	Return equipment and NCK Technical College samples to main MRI laboratories	
10/15/99	Establish test area at DFS	
10/18/99-10/25/99	Conduct baseline uncontrolled tests at DFS	
11/8/99 - 12/3/99	Conduct controlled tests at DFS	
12/13/99	Complete sample analyses	
12/23/99	Complete data reduction	

Section 10. References

1. Midwest Research Institute. *Prototype Test and Quality Assurance Plan for Construction Activities.* EPA Contract 68-D7-0002, Work Assignment No. 1. February 1998.

2. Midwest Research Institute. *Background Documentation for AP-42 Section 11.2.4, Heavy Construction Operations.* EPA Contract No. 68-D0-0123, Work Assignment No. 44. April 1993.

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4. Nichols, H. L, Jr. *Moving the Earth: The Workbook of Excavation*. Third Edition. McGraw-Hill, New York, NY. 1976.

5. US EPA. *Compilation of Air Pollutant Emission Factors.* AP-42. Fifth Edition. Research Triangle Park, NC. September 1995.

6. Baxter, T. E., D. D. Lane, C. Cowherd, Jr., and F. Pendleton. “Calibration of a Cyclone for Monitoring Inhalable Particulates.” *Journal of Environmental. Engineering*, 112(3), 468. 1986.

7. Davies, C. N. “The Entry of Aerosols in Sampling Heads and Tubes.” *British Journal of Applied Physics*, 2:921. 1968.

Appendix B

Emission Measurements from Construction Activities

Quality Assurance Project Plan
Revision 1

Prepared for
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711
Office of Research and Development
Air Pollution Prevention and Control Division
(MD-61)

Attn: Charles C. Masser,
Work Assignment Manager

Under Subcontract to
Pacific Environmental Services, Inc.

EPA Contract No. 68-D-70-002
Work Assignment 2-04
MRI Project No. 4813-02

October 6, 1999

Preface

This quality assurance project plan was prepared for the U.S. Environmental Protection Agency by Midwest Research Institute (MRI) under subcontract number 68D7002-MRI, Work Assignment No. 2, from Pacific Environmental Services, Inc. The prime contract for this effort is EPA Contract 68-D-70-002, Work Assignment 2-04. Under this work assignment, MRI is providing assistance in characterizing construction-related particulate matter emissions and controls in terms of mass and particle size distribution.

Questions concerning this plan should be addressed to Dr. Chatten Cowherd, Work Assignment Leader, at (816) 753-7600, Ext. 1586.

MIDWEST RESEARCH INSTITUTE

Chatten Cowherd, Ph.D.
Work Assignment Leader

Approved:

Andrew Trenholm
Program Manager

Thomas J. Grant, Ph.D., P.E.
Director
Applied Engineering

October 6, 1999

UNCONTROLLED

EMISSION MEASUREMENTS FROM CONSTRUCTION ACTIVITIES

NORTH CENTRAL KANSAS TECHNICAL COLLEGE

QUALITY ASSURANCE PROJECT PLAN (QAPP)
REVISION 1

WORK ASSIGNMENT 2-04
EPA CONTRACT NO. 68-D-70-002
PES SUBCONTRACT NO. 68D70002
MRI WORK ASSIGNMENT NO. 2
MRI PROJECT NO. 4813-02

Approval for Midwest Research Institute:

Chatten Cowherd, Jr. — 10/7/99
Chatten Cowherd, Jr.
Work Assignment Leader
Date

Jack Balsinger — 07 October 1999
Jack Balsinger
Quality Assurance Officer
Date

Andrew Trenholm — 10/11/99
Andrew Trenholm
Program Manager
Date

Approval for Pacific Environmental Services

John T. Chehaske — 10-14-99
John Chehaske
Program Manager
Date

Approval for EPA:

Charles C Masser — Oct 18, 1999
Charles Masser
Technical Coordinator, ORD
Date

Nancy H. Adams — 10-15-99
Nancy Adams
Quality Assurance, ORD
Date

Distribution of QAPP:

EPA: Charles Masser, Nancy Adams
PES: John Chehaske
MRI: Chatten Cowherd, John Hosenfeld, Mark Horrigan, Gregory Muleski,
Mary Ann Grelinger, MRI QA Unit, MRI Archives

Revision History:

Revision 0: This QAPP was prepared as a companion to the site-specific test plan (dated June 12, 1998) produced for the work assignment. The QAPP was designed to be in compliance with the guidance document "EPA Guidance for Quality Assurance Project Plans" (EPA QA/G-5). To aid in the review of this document versus applicable guidance, this document has been structured to mimic the required classes and elements of QA/G-5. Sections 1 to 4 cover the classes A to B given in the guidance document.

Revision 1: October 6, 1999—Revised to incorporate changes in text requested by EPA and PES.

Contents

Figures

Tables

Section 1.
Project Management

1.1 Project/Task Organization (A4)

The key personnel participating in the project are listed in this section. For Midwest Research Institute (MRI), the Work Assignment Leader (WAL) is Dr. Chatten Cowherd and Dr. Greg Muleski is the Field Test Leader (FTL). The Quality Assurance Officer (QAO) for MRI is Mr. Mark Horrigan. Mr. Andrew Trenholm is the Program Manager (PgM) for the overall contract. All individuals except Mr. Trenholm are located at MRI's Kansas City office and any correspondence to them should be directed to

Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110
(816) 753-7500

Mr. Trenholm is located at MRI's North Carolina Office and correspondence to him should be directed to

Midwest Research Institute
Crossroads Corporate Park
5520 Dillard Road, Suite 100
Cary, North Carolina 27511
(919) 851-8181

A brief narrative of the project-specific roles and responsibilities is given below.

The program manager will assure corporate management that the work is conducted in accordance with the quality assurance (QA) requirements. As PgM, Mr. Trenholm:

- Evaluates staff credentials to ensure that they have the requisite training and experience necessary to complete the project.
- Ensures that the program is appropriately organized with effective lines of communication and that program responsibilities and authorities for making critical decisions are clearly understood.
- Ensures that the QAO is involved in the program from the planning stage through the issuance of the final report.

- Reviews QA Project Plans (QAPP) and project-specific Test Plan and Standard Operating Procedures (SOPs). Ensures that program QA requirements are addressed in the QAPP and SOPs. Ensures that the QAPP and SOPs are reviewed and approved as required.

- Ensures that the work is adequately and appropriately inspected by the WAL and that the results are reviewed.

- Reviews any audit reports from the QAO or the QA Unit and reviews and evaluates responses from the PL. Ensures that the actions taken are timely and appropriate.

- Reports project status, problems, and corrective actions as required by the contract, division Quality Management System (QMS), QA Program Plan, or QAPP. Reports program status to division and corporate management.

- Reports audits conducted or directed by the EPA to corporate management and the QA Unit. Prepares and routes responses to the audit reports through division management and the program QAO.

- Reviews work products and reports to ensure that QA goals were met. Approves technical reports.

Dr. Chatten Cowherd, the WAL, will have overall technical oversight of the project. Dr. Cowherd will have day-to-day responsibility for the project and will be responsible for conducting the work in accordance with the QA requirements. The WAL is responsible for assuring Department management that the work is conducted in accordance with the QA requirements, and he has the authority to override project staff on QA matters. As WAL, Dr. Cowherd:

- Evaluates staff credentials to ensure that they have the requisite training and experience necessary to complete the project.

- Ensures that the project is appropriately organized with effective lines of communication. Ensures that project responsibilities and authorities for making critical QA decisions are clearly understood.

- Ensures that the QAO is involved in the project from the planning stage through the issuance of the final report, is fully informed, and is kept apprised of program schedules.

- Coordinates the development of any required QAPPs and project specific SOPs. Anticipates problems and helps define prevention, detection, and remedial action systems. Ensures that program and work assignment QA requirements are addressed in the QAPP. Ensures that QAPPs, Test Plans, and SOPs are reviewed and approved as required.

- Approves, distributes, and enforces the QAPP and SOPs. Justifies and approves modifications to and deviations from the QAPP and SOPs.

- Justifies deviations from MRI's division QMS and SOPs. Obtains approval for deviations from division management.

- Routinely inspects the work and documents the results in the project records. Ensures that the work is adequately and appropriately inspected and that the results are reviewed. Reviews any audit/inspection reports from the QAO or the QA Unit. Ensures that any problems detected by inspection or audit are immediately communicated to the appropriate staff, that actions taken are timely and appropriate, and that the actions taken are documented in the project records.

- Reports problems and actions taken to the PgM and the QAO.

- Reports project status, problems, and corrective actions to appropriate management as required by the contract, division QMS, QA Program Plan, or QAPP. Reports project status to program management.

- Reviews work products and reports to ensure that QA objectives have been met. Ensures that critical data are adequately verified or validated. Approves all technical reports.

The WAL will be assisted by the Field Test Leader (FTL), Dr. Greg Muleski, who is responsible for providing oversight for the field testing program, coordination with the host facilities, and providing data interpretation and review. Dr. Muleski or his designee will have day-to-day responsibility for decisions made on-site during the field exercise.

The MRI program QAO will be Mr. Mark Horrigan who is independent of the technical management staff. He will conduct or direct audits as required, by corporate QA policy, the QAPP, or at the request of the EPA. The QAO:

- Assists in preparing all QAPPs.

- Reviews and approves the QAPP, and reviews project reports.

- Conducts or directs the conduct of systems, performance evaluation, and data audits as required and reviews reports as required by corporate policy, EPA, or the program management.

- Reports audit results along with any problems and corrective action requests to the WAL and PgM, and division management.

- Reports project QA status to division management, and the Manager of Quality Assurance.

The Manager of Quality Assurance reports to the Executive Vice President and Chief Operations Officer. The personnel of the QA Unit conduct general audits to assure corporate management and clients that work is conducted in accordance with the QAPP, MRI, and division QMS, and MRI corporate QA policy. The QA personnel have the authority to work directly with project management and staff on QA matters and to communicate directly with client's or subcontractor's QA staff.

The QA Unit's personnel have the authority to request immediate corrective action for noncompliance to the MRI program (the MRI QA plan, division QMS, and program QA requirements). Dr. Gene Podrebarac, Manager of Quality Assurance, provides QA oversight for corporate management for all programs. As a member of the QA Unit, Mr. Mark Horrigan, QAO, provides QA oversight for this program.

Project staff report to the WAL. Project staff are responsible for conducting work in accordance with division, program, and project QA requirements. They have the authority to request information and help for problems from the PL, the QAO, department management, and the QA Unit. Project staff and supervisors:

- Follow division QMS, the QA Program Plan, and any QAPP and SOPs.

- Obtain approval from the WAL for any deviations in the QA Program Plan, QAPP, or SOP.

- Report work assignment status to the WAL.

- Immediately report problems to the WAL and the QAO and help resolve the problems.

Figure 1-1 presents an organizational chart showing the management structure.

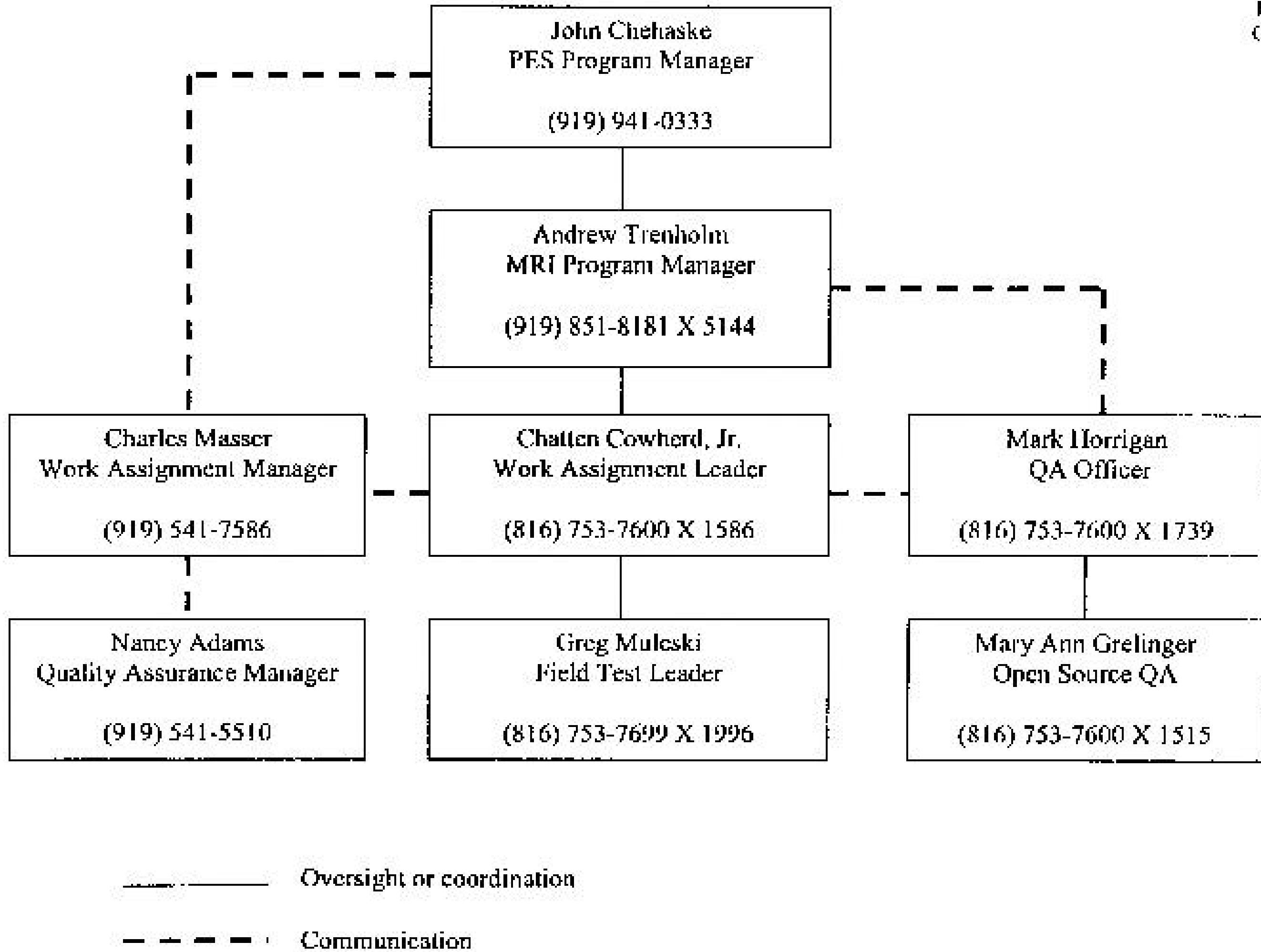

Figure 1-1. Project Organization Chart

1.2 Problem Definition/Background (A5)

An earlier scoping study [1] and AP-42 background document [2] identified several drawbacks in the limited information available for PM emissions from construction activities. In general, the PM information references total suspended particulate (TSP) and not the two size ranges of current regulatory interest—namely, PM-10 and PM-2.5.

A field program conducted during 1998 developed emission factor data for construction activities related to scraper operations. The current program will build upon the previous work. The present study will not only examine the effectiveness of watering in controlling on-site dust emissions but also implications of a watering program. Watering at construction sites can result in higher off-site PM emissions as material is tracked onto surrounding paved surfaces where it is available for resuspension by passing vehicles.

Because the emissions are not released through a stack, duct, or vent, standard EPA reference test methods do not apply. Furthermore, because source characterization requires (a) a shorter time duration for sampling and (b) encountering very high particulate concentrations, EPA reference methods for ambient monitoring as written in the CFR require modification when adapted for open source emission testing.

Note that, even though there are no directly applicable methods in the CFR, the test method to be used has undergone extensive evaluation and review. EPA/ORD since the 1970s has published approximately 10 test reports based on the exposure profiling method and performed a collaborative evaluation of the method during the 1980s. Furthermore, OAQPS recommends exposure profiling for the testing of open dust sources because the method isolates a single emission source while not artificially shielding the source from ambient conditions (e.g., wind). The EPA open source emission factors with the highest quality ratings are typically based on the exposure profiling method. In addition, the surface material sampling procedures to be followed are also based on the techniques included in AP-42 to characterize dust sources.

1.3 Project Task Description

The present study is directed toward the two major goals:

1. Characterize the PM-10 control efficiency of different amounts of water applied to scraper travel routes under various traffic (vehicle weight and traffic volume) and meteorological (temperature and evaporation rate) conditions.

2. Examine the amount of material tracked from areas treated with different amounts of water to paved surfaces.

Past studies have found that a substantial fraction of PM emissions from construction activities is related to transport of earth and other materials around the site. Because of the generally short-term nature of travel routes at construction sites, operators throughout the United States commonly employ water to control PM emissions rather than relying on more expensive chemical dust suppressants.

Although PM emissions from watered unpaved roads has attracted attention since at least the early 1980s, only two watering tests have been conducted at construction sites. In addition to the simple scarcity of data specifically referenced to construction sites, there are concerns about how well watering tests of unpaved roads in other settings can be applied to the construction sites. Because temporary routes are not nearly as well constructed as conventional unpaved roadways, available data may not accurately reflect the efficiency afforded by watering at construction sites.

Mud/dirt trackout from construction sites constitutes a large component of construction dust emissions in urban areas, where tracked mud/dirt substantially raise the silt loadings on adjacent paved roadways. Trackout is observed to increase as soil moisture increases, but this effect has not been quantified. There are a variety of candidate methods for decreasing the accumulation of mud/dirt on tires or removing accumulated mud/dirt as vehicles exit a construction site. However, the control efficiency test data for these measures are limited.

The first goal—namely, characterizing the effectiveness of water to control on-site dust emissions—requires that air emission sampling be conducted to compare the mass of PM emitted from controlled and uncontrolled travel routes. A scraper traveling over an unpaved route constitutes a “moving point” emission source that can be treated as a “line” source. That is to say, the source can be assumed to be uniformly emitting along the linear path of the scraper. Figure 1-2 shows not only a schematic of the operations but also the basis for the line source test methodology. As long as the distance traveled is substantially greater than the downwind distance from the 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.

Because the test method relies on ambient winds to carry emissions to the sampling array, acceptance criteria for wind speed/direction are necessarily based on the results from antecedent monitoring. That is to say, the immediate past record is used to determine acceptability for the current or upcoming period of time. As a practical matter, this requires that wind monitoring must be conducted immediately before starting a test. Testing does not begin unless the mean conditions remain in the acceptable ranges of:

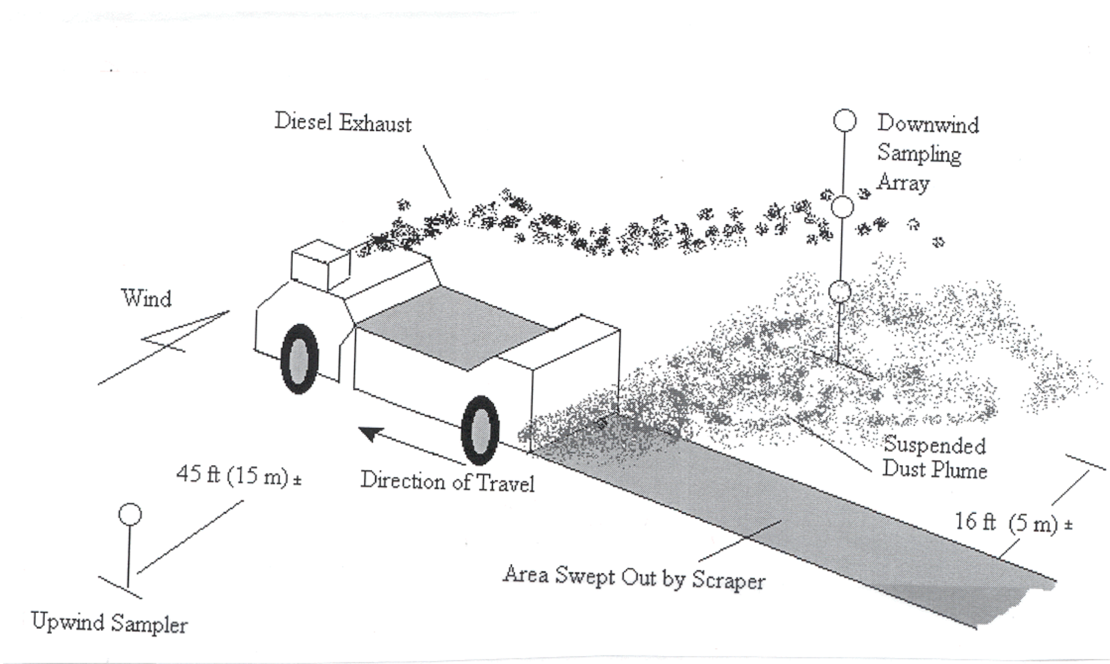

Figure 1-2. Schematic Illustration Test Procedure for Moving Point Source

1 Mean wind speed between 3 and 20 mph

2 Mean wind direction less than 45 degrees from the perpendicular to linear path of the moving point source

for at least two consecutive 5-minute averaging periods. Similarly, testing is suspended if the wind speed of direction move outside the acceptable ranges for two consecutive 5-minute averaging periods. Sampling may be restarted if acceptable conditions return. In that case, the same criterion of two consecutive acceptable 5-minute periods are followed to restart a test.

In a like manner, nozzles are added/removed or inlets reoriented if the mean wind speed of direction over two consecutive 5-minute averaging periods indicate the need for such action. These changes in sampler inlet conditions can be made at any time during a test. The actions are recorded on the run sheet. Nozzle placements are recorded on spaces in the middle of the example run sheet give in Appendix B of the site-specific test plan. Because reorientation applies equally to all samplers, that action is recorded in the general comment section at the bottom of the run sheet.

The second goal of characterizing off-site implications of watering requires comparison of the mass of mud/dirt carried onto paved surfaces. In this case, a surface sampling program will be used collect the mud/dirt samples for size analysis. The material is collected by vacuum cleaning predetermined areas of the roadway. A captive test site at MRI Deramus Field Station (Grandview, Missouri) will be used to test mud/dirt trackout controls, in order to control site conditions and vehicles during the study.

1.4 Quality Objectives (A7)

This test program will develop particulate control efficiency for (a) watering of scraper travel routes and (b) application of two to four controls for mud/dirt trackout. Specific objectives, in descending order of priority, are:

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

There is no way to directly assess the accuracy of the emission factor or the mass tracked onto a paved surface. The approach adopted here is to set goals for component measurements that are combined. For example, particle concentration and wind speed are multiplied together to produce point values of exposure, which are then integrated over height to develop the emission factor. Thus, data quality objectives (DQOs) are established for the wind speed and concentration measurements. Similarly, sample weights and sieve results are combined to develop the "silt loading" value (which represents the mass of sub-200 mesh material present per unit area of road surface). In that case, DQOs are established for weighing and sieving the samples.

The measurement approaches employed here will undoubtedly reduce the uncertainty associated with current estimates used in construction emission inventories. This statement is based on the fact that currently available estimation tools are based on very limited data, most of which has been collected outside the construction industry.

Because of the unsteady nature of ambient conditions and because emission levels will increase as the watered surface dries out, multiple tests cannot necessarily be considered replicate measurements. For this reason, precision DQOs for emission factors and silt loadings apply only to uncontrolled conditions.

The data quality goals are presented in Table 1-1.

1.5 Project Narrative (A8)

The overall objective for this work assignment is to provide improved information regarding the control of PM-10 and PM-2.5 emissions from construction activities. As discussed earlier and in the site-specific test plan (SSTP), previous studies have identified the limitations with available data and prioritized field testing needs. Because of logistical difficulties posed by the emission sources of interest in the work assignment, the field testing program relies on "captive" operations to control site conditions.

Unlike traditional emission sources, construction-related activities result in open dust sources. The exposure profiling method (as discussed in Section 2.2) is applicable to a wide class of anthropogenic emission sources. Because the method effectively isolates the dust contribution of a single emission source under investigation, exposure profiling is the EPA-preferred emission measurement technique for open sources. Furthermore, because mud/dirt trackout is a "precursor" to open dust emissions, neither traditional stack tests nor exposure profiling is directly applicable. For that reason, the second objective of the work assignment relies on measurement of the silt loading present on paved surfaces near trackout points.

Table 1-1. 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]	≥ 90
PM-2.5 concentration	High volume cascade impaction	± 15[f]	± 50[e]	≥ 90
Wind speed	Gill anemometer	± 10[g]	± 10[h]	≥ 90[i]
Wind direction	R. M. Young wind station	± 10[g]	-	≥ 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° 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-locate sample will be collected.

1.6 Special Training Requirements/Certification (A9)

This testing program will be conducted by personnel who have been trained in performing air sampling for the determination of emission measurements.

1.7 Documentation and Records (A9)

1.7.1 General Discussion

All data collected in the study will be entered directly into bound laboratory notebooks and standard data forms using permanent black ink and will be signed/dated by sampling personnel. Notebooks and data forms are to be inspected for completeness and accuracy by the appropriate field supervisor at the end of each test. At that time, data forms are grouped by test number and bound into 3-ring binders. Appendix A in the test plan [4] presented examples of the data forms to be used.

The work plan provided the reporting requirements for the work assignment. MRI will combine the results obtained at the two host facilities in one test report. The report will include hard copies of all data records specified in Section 1.6.2. The following information will be included:

Sample Collection Records: These will include run sheets that record the date, time, and location of sampling; sampler flow rates; operator; and key observations (comments). In addition, filter log sheets will clearly identify which filter or other collection media were used in specific samplers. Data forms are also used to record the location; method of collection; and any field splits of bulk (earth) material samples taken in connection with the emission tests.

Calibration Records: All sampler flow calibration records will be documented as to operator: time/date of calibration; transfer standard identifier (serial number); date and resulting of calibration of the transfer standard to the primary standard; key observations; QC results; and any problems/corrective actions taken.

Corrective Action Reports: These reports will be summarized and discussed in the final report as needed. If a corrective action report is directly applicable, it will be included in the data package.

Laboratory Analysis Records: Laboratory analyses are primarily gravimetric. Bound filter laboratory books are used to record the tare, final and audit weights of all air sample collection media. Specially designed data forms are used to record the sieve and pan weights used in the moisture and silt (minus-200 mesh) analyses for the bulk samples.

Personnel Training Files: These records are maintained by MRI's QA Unit. They are available for inspection but will not be supplied as part of the raw data.

General Field Procedures: Test procedures will be described and discussed in the report.

Waste Disposal: No hazardous/special wastes will be generated. Disposal of general solid waste (e.g., unused splits of bulk material samples) will be negligible. Thus, no records will be made part of the data packet.

1.7.2 Data Reporting Package Format and Documentation Control

In recording raw data, MRI will follow documentation practices (SOPs MRI-0055 and MRI-0056) to assure data of known and defensible quality. These also will include:

- Information will be entered on standard data forms using permanent black ink. See the test plan for example forms.
- Manual corrections will be made by drawing a line through the incorrect information, leaving the original information intact and legible. Corrections will be initialed, dated, and explained by the person making the correction.
- Corrections to any existing computer spreadsheet will involve modifying the file; saving it under a new file name; and leaving the original intact.
- All recorded data will be traceable to a sampling location, sampling time, instrument, operator, measurement method, calibration records, and final sample results.

The test report will discuss data collection, QA/QC and sample results. It will be accompanied by a series of appendices that contain the raw data and supporting information. The FTC will assemble the raw data files (hard copies and, as necessary, electronic versions). The FTC and WAL will jointly prepare the report. The WAL will review the data package and attach it to the report as an appendix.

1.7.3 Data Reporting Package Archiving and Retrieval

MRI will archive the data for the period of time required by EPA's contract with PES. The following record will be available:

- Personnel credentials

- Project procedures, reports, and plans
- All project internal correspondence, meeting minutes, etc.
- Hard copy of all raw data and field records

Section 2. Measurement/Data Acquisition (B)

Table 2-1 presents an overview of the testing program. In the table, "mass flux profiling" refers to the method for determination of an individual emission factor/rate. The exposure profiling test method is discussed in Section 2.2 of this QAPP and in even more detail in the site-specific test plan. The term "particle size profiling" is used to denote the test method designed to characterize the particulate size distribution at two heights. Because of the need to collect adequate mass of the smaller size fractions, a single particle size test spans several mass flux tests.

The third test method mentioned in Table 2-1—*manual cleaning*—refers to characterization of the loose surface material present on the paved road surface. The collection and analysis method are described in Appendices C.1 and C.2 of AP-42, respectively. Copies of those are included in the appendix to this QAPP.

2.1 Sampling Process Design (Experimental Design) (B1)

As discussed in the SSTP, past studies have found that a substantial fraction of PM (particulate matter) emissions from construction activities is related to transport of earth and other materials around the site. Because of the generally short-term nature of travel routes at construction sites, operators throughout the United States commonly employ water to control PM emissions rather than relying on more expensive chemical dust suppressants.

Mud/dirt trackout from construction sites constitutes a large component of construction dust emissions in urban areas, where tracked mud/dirt substantially raise the silt loadings on adjacent paved roadways. Trackout is observed to increase as soil moisture increases, but this effect has not been quantified. There are a variety of candidate methods for decreasing the accumulation of mud/dirt on tires or removing accumulated mud/dirt as vehicles exit a construction site. However, the control efficiency test data for these measures are limited.

Emission tests at NCK Technical College will be conducted under a variety of meteorological conditions (e.g., temperature, wind speed, cloud cover) and operating conditions (e.g., weight and speed of vehicle equipment, number of vehicle passes per unit time, and time of day). Of particular interest is on-site collection of pan evaporation measurements so control efficiency decay rates for watering can be referenced to readily available meteorological data. Because control efficiency is greatest immediately after water is applied to the roadway and decays as the surface dries, testing will span a broad range of times after watering, so reliable average control efficiency data are obtained.

Table 2-1. Test Design

Operation	Travel surface	Pollutant	No. of tests	Test method	Approx. time (min) per test
NCK Tech. College					
Transit-Native Soil	Uncontrolled	PM-10	3	Mass flux profiling	15
		PM-2.5	1	Particle size profiling	75
	Watered:	PM-10	3	Mass flux profiling	30-60
	Appl. 1	PM-2.5	1	Particle size profiling	120
	Watered:	PM-10	3	Mass flux profiling	30-60
	Appl. 1a	PM-2.5	1	Particle size profiling	120
	Watered:	PM-10	3	Mass flux profiling	30-60
	Appl. 2	PM-2.5	1	Particle size profiling	120
	Watered:	PM-10	3	Mass flux profiling	30-60
	Appl. 2a	PM-2.5	1	Particle size profiling	120
Deramus Field Station					
Trackout-Native Soil	Uncontrolled	Surface loading		Manual cleaning	60 min
	Moisture 1		3		
	Moisture 2		3		
	Control 1	Surface loading		Manual cleaning	60 min
	Moisture 1		3		
	Moisture 2		3		
	Control 2	Surface loading		Manual cleaning	60 min
	Moisture 1		3		
	Moisture 2		3		
	Control 3	Surface loading		Manual cleaning	60 min
	Moisture 1		3		
	Moisture 2		3		
Trackout-Sandy Soil	Uncontrolled	Surface loading		Manual cleaning	60 min
	Moisture 1		3		
	Moisture 2		3		
	Control 1	Surface loading		Manual cleaning	60 min
	Moisture 1		3		
	Moisture 2		3		
	Control 2	Surface loading		Manual cleaning	60 min
	Moisture 1		3		
	Moisture 2		3		
	Control 3	Surface loading		Manual cleaning	60 min
	Moisture 1		3		
	Moisture 2		3		

At the trackout test site at the Deramus Field Station, no emission testing will be performed, but the operational features of trackout vehicles will be documented. In addition, the aggregate material properties of the test soil surfaces, from which trackout originates, will be characterized.

Table 2-2 presents a projected schedule of activities during the test program.

Table 2-2. Testing Schedule

Date	Activity	Comments
7/26/99 - 7/30/99	Perform filter (tare) analysis	
	Prepare sampling equipment/supplies	
9/9/99 - 9/10/99	Load equipment and transport equipment to NCK Technical College	Schedule to coordinate with start of hands-on training fall semester
9/13/99	Establish on-site laboratory at NCK Technical College	
9/13/99 - 9/14/99	Conduct baseline uncontrolled tests at NCK Technical College	
9/14/99 - 9/24/99	Conduct controlled tests at NCK Technical College	
9/25/99	Return equipment and NCK Technical College samples to main MRI laboratories	
10/15/99	Establish test area at DFS	
10/18/99-10/25/99	Conduct baseline uncontrolled tests at DFS	
11/8/99 - 12/3/99	Conduct controlled tests at DFS	
12/13/99	Complete sample analyses	
12/23/99	Complete data reduction	

The general test methodology of mass flux profiling is described in the SSTP. Within this measurement framework, the critical and non-critical measurements described in Table 2-3 will be made. In this sense, “critical” denotes that these measurements are necessary to ensure that project objectives are met.

Table 2-3. Critical and Non-critical Measurements for Emission Factors

Measurement	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.

2.2 Sample Handling and Custody Requirements (B3)

The majority of environmental samples collected during the test program consists of particulate matter captured on a filter medium. Analysis will be gravimetric, as described in Section 2.4. SOP MRI-8403 describes the procedure, which is summarized below.

To maintain sample integrity, the following procedure will be used. Each filter will be stamped with a unique 7-digit identification number. A file folder is also stamped with the identification number and the filter is placed in the corresponding folder.

Particulate samples are collected on glass fiber filters (8 in by 10 in) or on glass fiber impaction substrates (4 in by 5 in). Prior to the initial (tare) weighing, the filter media are equilibrated for 24 h at constant temperature and humidity in a special weighing room. Impactor substrates are greased by spraying the collection surface with a solution of 140 g of stopcock grease in 1 L of reagent grade toluene. Thereafter, they undergo the same tare weighing steps, as do the filters.

During weighing, the balance is checked at frequent intervals with standard (Class S) weights to ensure accuracy. The filters remain in the same controlled environment for at least 24 hr until a second analyst reweighs them as a precision check. A minimum of ten percent (10%) of the filters and collection media used in the field will serve as blanks to account for the effects of handling. The QA guidelines pertaining to preparation of sample collection media are presented in Section 2.5.

The filters are placed in their folders. Groups of approximately 50 are sealed in heavy-duty plastic bags and stored in a heavy corrugated cardboard box equipped with a tight-fitting lid. Unexposed filters are transported to the field in the same truck as the sampling equipment and are then kept in the field laboratory.

Because the glass fiber impactor substrates are greased, they are not placed in the file folders for transport. Instead, they are stored in specially designed frames that keep the greased surfaces separate from one another and "face up." Cases that securely hold stacks of the frames are used to transport the substrates to and from the field.

Once they have been used, exposed filters are placed in individual glassine envelopes and then into numbered file folders. Groups of up to 50 file folders are sealed within heavy-duty plastic bags and then placed into a heavy-duty cardboard box fitted with a lid. Exposed and unexposed filters are always kept separate to avoid any cross-contamination. When exposed filters and the associated blanks are returned to the laboratory, they are equilibrated under the same conditions as the initial weighing. After reweighing, a minimum of 10% of each type are audited to check weighing accuracy.

In addition to filters and collection media described above, a second set of samples is collected to characterize the bulk material properties of the earth being moved. Of particular interest are the surface moisture and silt (mass fraction below 200 mesh upon dry sieving) contents. A composite sample consisting of a minimum of 3 increments will be collected from both the loaded and unloaded material for each test. Sample collection will follow procedures contained in Appendix C.1 in EPA's *Compilation of Air Pollutant Emission Factors* (AP-42) [5].

In order to ensure traceability, all filter and material sample transfers will be recorded in a notebook or on forms. The following information will be recorded: the assigned sample codes, date of transfer, location of storage site, and the names of the persons initiating and accepting the transfer. Data forms were included as an appendix to the site-specific test plan.

2.3 Analytical Methods Requirements (B4)

All analytical methods required for this testing program are inherently gravimetric in nature. That is, the final and tare weights are used to determine the net mass of particulate captured on filters and other collection media. The tare and final weights of blank filters are used to account for the systematic effects of filter handling. Finally, the determination of surface moisture and silt contents are also gravimetric in nature and are described in Appendix C.2 of EPA's *Compilation of Air Pollutant Emission Factors* (AP-42) [5]. The following procedures are followed whenever a sample-related weighing is performed:

- An accuracy check at the minimum of one level, equal to approximately the tare weight and actual weight of the sample or standard. Standard weights should be class S or better.

- The observed mass of the calibration weight (not including the tare weight) must be within 1.0% of the reference mass.

- If the balance calibration does not pass this test at the beginning of the weighing, the balance should be repaired or another balance should be used. If the balance calibration does not pass this test at the end of the weighing, the samples or standards should be reweighed using a balance that can meet these requirements.

2.4 Quality Control Requirements (B5)

Routine audits of sampling and analysis procedures are to be performed. The purpose of the audits is to demonstrate that measurements are made within acceptable control conditions for particulate source sampling and to assess the source testing data for precision and accuracy. Examples of items audited include gravimetric analysis, flow rate calibration, data processing, and emission factor calculation. The mandatory use of specially designed reporting forms for sampling and analysis data obtained in the field and laboratory aids in the auditing procedure.

To prepare hi-vol collection media (filters and impactor substrates) for use in the field, filters and substrates are weighed under stable temperature and humidity conditions. After they are weighed and have passed audit weighing, the filters are packaged for shipment to the field. Table 2-4 outlines the general requirements for conditioning and weighing sampling media. Note that the audits weights are performed by a second, independent analyst.

Table 2-4. Quality Control Procedures for Sampling Media

Activity	QC check/requirement
Preparation	Inspect and imprint glass fiber media with identification numbers.
Conditioning	Equilibrate media for 24 h in clean controlled room with relative humidity of 40% (variation of less than ±5% RH) and with temperature of 23 °C (variation of less than ±1 °C).
Weighing	Weigh hi-vol filters to nearest 0.05 mg.
Auditing of weights	Independently verify final weights of 10% of all filters and substrates used in the field either to collect samples or as blanks (at least four from each batch). Reweigh entire batch if weights of any hi-vol filters deviate by more than ±2.0 mg. For tare weights, conduct a 100% audit by a second analyst after an additional 24 h of equilibration. Reweigh any high-volume filter whose weight deviates by more than ±1.0 mg. Follow same procedures for impactor substrates used for sizing tests. Audit limits for impactor substrates are ±1.0 and ±0.5 mg for final and tare weights, respectively.
Correction for handling effects	Weigh and handle at least one blank for each 1 to 10 filters of each type used to test.
Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative. Check prior to each use with laboratory Class S weights.

As indicated in Table 2-4, a minimum of 10% field blanks will be collected for QC purposes. This involves handling at least 1 blank filter for every 10 exposed filters in an identical manner to determine systematic weight changes due to handling steps alone. These changes are used to mathematically correct the net weight gain for the effects of handling. A field blank filter is loaded into a sampler and then immediately recovered without any air being passed through the media. This technique has been successfully used in many MRI programs to account for systematic weight changes due to handling.

After the particulate matter samples and blank filters are collected and returned from the field, the collection media are placed in the gravimetric laboratory and allowed to come to equilibrium. Each filter or substrate is weighed, allowed to return to equilibrium for an additional 24 h, and then a minimum of 10% of the exposed filters are reweighed by a second analyst. If a filter or substrate fails the audit criterion, the entire lot will be allowed to condition in the gravimetric laboratory an additional 24 h and then reweighed. The tare and first weight criteria for filters (Table 2-2) are based on an internal MRI study conducted in the early 1980s to evaluate the stability of several hundred 8- x 10-in glass fiber filters used in exposure profiling studies.

Because the test method relies on ambient winds to carry emissions to the sampling array, acceptance criteria for wind speed/direction are necessarily based on the results from antecedent monitoring. That is to say, the immediate past record is used to determine acceptability for the current or upcoming period of time. As a practical matter, this requires that wind monitoring must be conducted immediately before starting a test. Testing does not begin unless the mean conditions remain in the acceptable ranges of:

1. Mean wind speed between 3 and 20 mph.

2. Mean wind direction less than 45 degrees from the perpendicular to linear path of the moving point source.

for at least two consecutive 5-minute averaging periods. Similarly, testing is suspended if the wind speed or direction move outside the acceptable ranges of two consecutive 5-minute averaging periods. Sampling may be restarted if acceptable conditions return. In that case, the same criterion of two consecutive acceptable 5-minute periods are followed to restart a test.

2.5 Instrument/Equipment Testing, Inspection and Maintenance Requirements (B6)

Inspection and maintenance requirements for sampling equipment are provided in Table 2-5. Note that because the cyclone preseparator is cleaned between individual tests, only limited maintenance is required.

2.6 Instrument Calibration and Frequency (B7)

Calibration and frequency requirements for the balances used in the gravimetric analyses are given in Table 2-4.

Requirements for high-volume (hi-vol) sampler flow rates rely on the use of secondary and primary flow standards. The Roots meter is the primary volumetric standard and the BGI orifice is the secondary standard for calibration of hi-vol sampler flow rates. The Roots meter is calibrated and traceable to a NIST standard by the manufacturer. The BGI orifice is calibrated against the primary standard on an annual basis. Before going to the field, the BGI orifice is first checked to assure that it has not been damaged. In the field, the orifice is used to calibrate the flow rate of each hi-vol sampler. (For samplers with preset volumetric flow controllers, no calibration is possible but the orifice is used to audit the nominal 40 acfm flow rate.) Table 2-5 specifies the frequency of calibration and other QC checks regarding air samplers.

Table 2-6 outlines the QC checks employed for miscellaneous instrumentation needed.

Table 2-5. Quality Control and Calibration Procedures for Sampling Equipment

Activity	QC check/requirement
Maintenance • All samplers	Check motors, brushes, gaskets, timers, and flow measuring devices at each plant prior to testing. Repair/replace as necessary.
Calibration • Volumetric flow controller	Prior to start of testing at each regional site, ensure that flow determined by orifice and the look-up table for each volumetric flow controller agrees within 7%. For 20 acfm devices (particle size profiling), calibrate each sampler against orifice prior to use at each regional site and every two weeks thereafter during test period. (Orifice calibrated against displaced volume test meter annually.)
Operation • Timing	Start and stop all downwind samplers during time span not exceeding 1 min.
• Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction changes by more than 30 degrees for 2 consecutive 5-min averaging periods. Suspend testing if mean wind direction (for two consecutive 5-min averaging periods) is more than 45 degrees from perpendicular to linear path of the moving point source. Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle for two consecutive 5-min averaging periods. Suspend testing if wind speed falls outside the acceptable range of 3 to 20 mph for two consecutive 5-min averaging periods.
• Prevention of static deposition	Cover sampler inlets prior to and immediately after sampling.

Table 2-6. Quality Control and Calibration Procedures for Miscellaneous Instrumentation

Instrumentation	QC check/requirement[a]
Digital manometers	Compare reading against water-in-tube manometers over range of operating pressures using “Y” connectors and flexible tubing. Do not use units which differ by more than 7%.
Digital barometer	Compare against mercury-in-tube barometer. Do not use if more than 0.5 in Hg difference in reading.
Thermometer (mercury or digital)	Compare against NIST-traceable mercury-in-glass. Do not use if more than 3.0 C difference.
Gill anemometer	Conduct 4-point calibration of each unit over the range of 2 to 20 mph both before going to the field and upon return of the equipment to MRI’s main laboratories. Use factory-specified anemometer drive device for calibration.
Watches/stopwatches	The field test leader will compare an elapsed time (> 1 hr) recorded by his watch against the US Naval Observatory master clock. Do not use if more than 3% difference. All crew members will synchronize watches (to the nearest minute) at the start of each test day.

[a] Activities performed prior to going to the field, except as noted.

2.7 Inspection/Acceptance Requirements for Supplies and Consumables (B8)

The primary supplies and consumables for this field exercise consist of the air and substrate sample collection media as well as vacuum cleaner bags. Prior to stamping and initial weighing (Table 2-4), each filter is visually inspected and is discarded for use if any pin-holes, tears, or other damage is found. Similarly, vacuum bags are examined for tears or other damage before tare weighing.

2.8 Data Acquisition Requirements (B9)

In addition to the field samples, MRI will also collect information on the physical size and operational parameters of equipment used in the field exercise. To the extent practical, physical characteristics will be obtained from the manufacturer or the manufacturer’s literature. Physical dimensions will be measured and recorded.

2.9 Data Management (B10)

After return to MRI’s main laboratories, raw data will be transferred from data sheets into computer spreadsheet programs to perform the calculations (described in Section 5.2 of the site-specific test plan) leading to net concentrations. In addition to raw data, the spreadsheet also contains cells for data derived from field measurements (such as flow rates determined from “look-up” tables using air temperatures and pressures). Cell formulas are included on the spreadsheet so that the reader can readily determine how a value is calculated. Validation activities are discussed in Section 4.0.

Section 3. Assessment/Oversight

The quality of the project and associated data are assessed within the project by the WAL, project personnel and peer reviewers. Oversight and assessment of the overall project quality are accomplished through the review of data, memos, audits, and reports by the program and division management and, independently, by the QAO.

3.1 Assessments and Response Actions (C1)

The effectiveness of implementing the QAPP and associated SOPs for a project are assessed through project reviews, field inspections, audits, and data quality assessment.

3.1.1 Project Reviews

The review of project data and the writing of project reports are the responsibility of the WAL who also is responsible for the conduct of the first complete assessment of the project. Although the project's data have been reviewed by the project personnel and assessed as to whether the data meet the measurement quality objectives, it is the WAL who must assure that overall the project activities meet the measurement and data quality objectives. The second review process is a technical peer review conducted by a technically qualified person who is familiar with the technical aspects of the project but not involved in the conduct of project activities. The peer reviewer is to present to the project leader an accurate and independent appraisal of the technical aspects of the project.

The division management will assure that the project management systems are established and functioning as required by division procedures and corporate policy. The division management is the final reviewer before the QAO and is responsible for assuring EPA that contractual requirements have been met. The QAO will conduct the final review of the report before submittal to EPA.

3.1.2 Field Inspections

Field inspections may be conducted by the WAL or QA field auditor. Inspections assess project activities that are considered important or critical to the requirements of the project. These critical activities may include, but are not limited to, sample collection and preservation, method development or validation, sample preparation, sample analysis, or data reduction. Field inspections are assessed with respect to the QAPP, SOPs, or other established methods, and are reported to the WAL and QAO. Any deficiencies or problems found during the in-phase inspections must be investigated with the results and responses or corrective actions reported in a Corrective Action Report (CAR), as discussed later in this section.

3.1.3 Audits

Independent systematic checks to determine the quality of the data will be performed during the conduct of this project. These checks will consist of a system and data audits as described below. In addition, the internal quality control measurements will be used to assess the performance of the analytical methodology. The combination of these audits and the internal quality control data allows the assessment of the overall data quality for this project.

The QAO is responsible for ensuring that audits are conducted as required by the QAPP. The WAL is responsible for evaluating corrective action reports, taking appropriate and timely corrective actions, and informing the QAO and PgM of the action taken. The QAO is then responsible for ensuring that the corrective action was taken.

The system audit will be conducted by the QAO prior to the start of the project activities. This audit will evaluate all components of the data gathering and management system to determine if these systems have been properly designed to meet the quality assurance objectives for this study. The system audit includes a careful review of the experimental design, the test plan, and the procedures. This review includes personnel qualifications, adequacy, and safety of the facilities and equipment, SOPs, and the data management system.

The system audit starts with the review of the QAPP, the SSTP, and the associated procedures and experimental design to ensure that they can meet the data quality objectives for the study. During the system audit, the QAO will inspect project activities and determine the laboratory's adherence to the SOPs and the QAPP. The QAO reports any area of nonconformance to the project leader and division management through an audit report. The audit report may contain corrective action recommendations. If so, follow-up inspections may be required and should be performed by the QAO to ensure corrective actions are taken. The system audit ends with a review of the report and an audit of the records at the completion of the study.

The data audit, an important component of a total system audit, is a critical evaluation of the measurement, processing, and evaluation steps to determine if systematic errors have been introduced. During the data audit, the QAO, or his designee, will randomly select data to be followed through the analysis and data processing. The scope of the data audit is to verify that the data handling system is correct and to assess the quality of the data generated.

The data audit, as part of the system audit, is not an evaluation of the reliability of the data presentation. The review of the data presentation is the responsibility of the WAL and the peer reviewer.

3.1.4 Amendments and Revisions to the QAPP

This QAPP is designed to be a working tool for the staff conducting the study as well as the management of MRI and EPA. As a working document, it may become necessary to amend or revise the QAPP to reflect current activities. When there is a requirement to update the QAPP to correct minor discrepancies that have no effect on the overall conduct of the study or typing errors, an amendment (Figure 3-1) will be prepared and submitted to the EPA WAM, and the MRI WAL for approval. The format of the amendment record will be an assigned amendment number to the chapter/section where the statement will be changed, the original statement, the reason for the change, and the amended statement. The amended statement will use crossed-out text for deletions and red-lined text for additions. The effective date of the amendment will be the date of the submitted amendment unless otherwise noted.

When the changes involve major changes in the conduct of the study (i.e., changes in the design, collection, or processing of samples or data), a revision of the affected chapter in the QAPP will be required. When a chapter is revised, the entire chapter will be replaced.

3.2 Corrective Action

Corrective action is the process that occurs when the results of an audit or quality control measurement are shown to be unsatisfactory, as defined by the data quality objectives or by the measurement objectives for each task. The corrective action process involves the WAL and the QAO. In cases involving the analytical process, the corrective action also will involve the analyst. A written report (Figure 3-2) is required on all corrective actions.

The WAL will consult with appropriate staff having expertise in areas where difficulties are experienced and will propose solutions to situations requiring corrective action. Program management will be involved in the problem-solving discussions and may have input into final decisions.

QUALITY ASSURANCE PROJECT PLAN AMENDMENT RECORD

QAPP Title/Date: Quality Assurance Project Plan for ______________________

____

Origin Location: Midwest Research Institute

WAL: ____

PgM: ____

QAO: ____

EPA WAM: ____

No.	Section	Description
1		Statement: Reason: Amendment:
2		Statement: Reason: Amendment:
3		Statement: Reason: Amendment:
4		Statement: Reason: Amendment:

Figure 3-1. QAPP Modification Record

Project No.: __________

Date: __________

Corrective Action Report

Project Title/Description: ______________________________

Description of Problem:

____
____
____
____
____
____
____

Originator: ______________ Date: __________

Investigation and Results:

____
____
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____

Investigator: ______________ Date: __________

Corrective Action Taken:

____
____
____
____

Originator: _ Date:

Reviewer/Approval: ______________ Date: __________

Cc: Project leader, Program Manager, Division Manager, QA Unit

MRI-QA\CAR Form.DOC

Figure 3-2. Corrective Action Report

There are two types of corrective actions:

- **Immediate** corrective action is a quick response to improper procedures such as malfunctioning equipment. The need for such an action is usually identified by the analyst as a result of calibration checks and internal quality control sample analysis. The WAL, who will be notified of the problem immediately, will then take and document appropriate action. The WAL is responsible for and is authorized to halt the work if it is determined that a serious problem exists.

- **Long-term** corrective action is used to prevent the recurrence of unanticipated problems. The need for such action may be identified by audits. The long-term corrective action steps consist of:

  — Definition of the problem

  — Investigation to determine the cause

  — Determination of the appropriate corrective action

  — Implementation of the corrective action

  — Verification of the effectiveness of the corrective action by a follow-up inspection.

The WAL is responsible for and is authorized to implement any procedures to prevent the recurrence of problems.

3.3 Reports to Management (C2)

The status of the project will be reported to the WAL on a weekly basis by the project staff. Any problems found during the analytical process requiring corrective action will be reported immediately by the project staff to the WAL and the quality assurance officer through the investigation and corrective action documentation. The results of the in-phase inspection by the project or program management will be documented in the project files and reported to the QAO. In-phase inspections conducted by the QAO will be reported to management in the same manner as other audits.

Results of system audits, in-phase inspections, performance evaluations, and data audits conducted by the QAO will be routed to the WAL for review, comments, and corrective action, and forwarded to management. An assessment of the data will be sent for management review. The performance evaluations, control issues, and corrective action responses covered by the audit reports will be reviewed and approved by the program manager, section manager, and division management. The results of all assessments, audits, inspections, and corrective actions for the project will be summarized and included in a quality assurance/quality assessment section in the final report.

The reporting requirements are a draft final report and a final report submitted as part of the contractual obligation. Electronic deliverables in the form of data tables will also be submitted.

Section 4.
Data Validation and Usability (D)

4.1 Data Review, Validation, and Verification Requirements (D1)

The data analysis procedures to be used for this project are procedures that have been passed through several layers of validation in substantiating the performance of the method. The procedure for calculation of a raw particulate concentration requires a sample mass and an associated sampler flow rate. It should be noted that blank-corrected sample mass is considered quantifiable (and usable for concentration calculation) only if it equals or exceeds three times the standard deviation for the net weight gain of the field blanks. The procedures for conversion of particulate concentrations to final end products are presented in Section 5.2 of the site-specific plan.

The FTL or his/her designee will conduct an on-site spot check to assure that data are being recorded accurately. After the field test, the QAO or his designee will check data input to assure accurate transfer of the raw data. The FTL or his designee will perform an independent check of any computer data reduction program through an independent hand-calculation of at least one test run. The FTL will report their findings to the WAL.

4.2 Validation and Verification Methods (D2)

For this project, all records will be evaluated for the adherence to all procedures and requirements. The items that will be reviewed include:

- Gravimetric audit weighing for the assessment of the particulate data
- Calibration and calibration criterion checks
- Results of all blanks
- Validation of data process systems or procedures
- Traceability and sample tracking

Selected data will be reconstructed, including tracing the calibration back to the primary standards. Any software (spreadsheets) used to determine numerical values will be checked by hand calculating all intermediate and final results for one run by referring to original sources of data (i.e., field filter logs, filter weight logs, run sheets, look-up tables for volumetric flow controllers).

4.3 Reconciliation with User Requirements (D3)

The data generated during the field exercise will be evaluated with respect to the user requirements to estimate PM-10 and PM-2.5 emissions from controlled and uncontrolled scraper travel and mud/dirt trackout. Recommendations for revisions to current AP-42 emission estimation methods will be presented in the test report.

Section 5. References

1. Midwest Research Institute. *Prototype Test and Quality Assurance Plan for Construction Activities*. EPA Contract 68-D7-0002, Work Assignment No. 1. February 1998.

2. Midwest Research Institute. *Background Documentation for AP-42 Section 11.2.4, Heavy Construction Operations*. EPA Contract No. 68-D0-0123, Work Assignment No. 44. April 1993.

3. Midwest Research Institute. *Emission Factor Documentation for AP-42 Section 13.2.2—Unpaved Roads*. Draft Report. EPA Contract No. 68-D2-0159, Work Assignment 4-02. September 1997.

4. Midwest Research Institute. *Emission Measurements of Particulate Mass and Size Emission Profiles from Construction Activities—Site-Specific Test Plan*. EPA Contract No. 68-D-98-027, Work Assignment 1-04. June 1998.

5. U.S. EPA. *Compilation of Air Pollutant Emission Factors*. AP-42, Fifth Edition. Research Triangle Park, NC. September 1995.

6. Baxter, T. E, D. D. Lane, C. Cowherd, Jr., and F. Pendleton. "Calibration of a Cyclone for Monitoring Inhalable Particulates." *Journal of Environmental Engineering*, 112(3), 468. 1986.

Appendix C

North Central Kansas Technical College
Sampling Data

BY Watering Tests Beloit Kansas NCKTC September 1999

Run	Date	Sampler Location	ample ID	Sampler tart Tim	ample top Ti	Sampler Run Time (min)	vg. Temp (deg. F)	Avg. B.P. (in. Hg)	Flowrate (ft^3/min)	Avg. Filter Pressure (in. H2O)	Po/Pa	Filter Number	Tare Wt. (mg)	Final Wt. (mg)	Net Wt. (mg)	Wt. after Blank Correctio	PM10 Conc. (ug/m^3)	Upwind Conc. (ug/m^3)	Net PM10 Conc. (ug/m^3)	Mean Wind Speed (mph)	PM10 Exposure (mg/cm^2)	Notes
BY-201	09/15/99	Cyclone 2m DW	75	12:49	13:31	26	75	28.80	40.82	24.10	0.939	9982019	4411.50	4469.50	58.00	56.86	1892	11	1881	2.48	0.3253	No upwind samplers operated. Background concentration based on average value measured during
		Cyclone 4.5m DW	70	12:49	13:31	26	75	28.80	40.57	22.90	0.942	9982018	4404.05	4435.85	31.80	30.66	1026	11	1015	3.01	0.2131	field exercise.
		Cyclone 7m DW	67	12:49	13:31	26	75	28.80	41.01	24.00	0.939	9982017	4408.05	4415.15	7.10	5.96	197	11	186	3.29	0.0428	
		Wedding 2m DW	424U	12:50	15:07	121	75	28.90	41.40	24.60	0.937	9982016	4404.00	4474.85	70.85	69.71	491	11	480			Impactors and Wedding run longer than 40 cfm cyclones to collect adequate mass.
		Wedding 2m UW	599U	not run																		
BY-202	09/15/99	Cyclone 2m DW	78	12:54	13:27	17	75	28.80	40.01	23.10	0.941	9982023	4354.05	4384.25	30.20	29.06	1509	11	1498	2.30	0.1571	No upwind samplers operated. Background concentration based on average value measured during
		Cyclone 4.5m DW	66	12:54	13:27	17	75	28.80	40.66	22.70	0.942	9982022	4389.25	4400.45	11.20	10.06	514	11	503	2.77	0.0635	field exercise.
		Cyclone 7m DW	74	12:54	13:27	17	75	28.80	40.78	23.55	0.940	9982021	4420.15	4426.90	6.75	5.61	286	11	275	3.02	0.0378	
BY-301	09/16/99	Cyclone 2m DW	75	9:05	10:23	78	64.5	28.90	40.54	23.03	0.941	9982033	4386.70	4390.25	3.55	2.41	27	5	22	5.37	0.0246	Background taken as average of 3 upwind sampler concentrations.
		Cyclone 4.5m DW	70	9:05	10:23	78	64.5	28.90	40.67	22.73	0.942	9982032	4379.75	4386.70	6.95	5.81	65	5	60	6.53	0.0815	
		Cyclone 7m DW	67	9:05	10:23	78	64.5	28.90	40.64	22.80	0.942	9982031	4400.70	4405.80	5.10	3.96	44	5	39	7.16	0.0586	
		Wedding 2m DW	424U	9:05	11:06	121	64.5	28.90	40.000			9982034	4361.05	4367.00	5.95	4.81	35	5	30			No filter pressure reading taken on DW Wedding. Default value of 40 acfm used.
		Wedding 2m UW	599U	9:12	13:54	282	65	28.90	40.46	23.60	0.940	9982035	4381.55	4385.20	3.65	2.51	8					
BY-302	09/16/99	Cyclone 2m DW	78	9:46	11:06	80	64.5	28.90	39.66	23.05	0.941	9982038	4384.40	4394.25	9.85	8.71	97	5	92	6.86	0.1353	Background taken as average of 3 upwind sampler concentrations.
		Cyclone 4.5m DW	66	9:46	11:06	80	64.5	28.90	40.39	22.15	0.944	9982037	4412.85	4416.50	3.65	2.51	27	5	22	8.44	0.0406	
		Cyclone 7m DW	74	9:46	11:06	80	64.5	28.90	40.61	22.20	0.944	9982036	4390.10	4394.90	4.80	3.66	40	5	35	9.30	0.0694	
BY-303	09/16/99	Cyclone 2m DW	75	10:28	11:06	38	64.5	28.90	40.50	23.45	0.940	9982041	4382.50	4386.75	4.25	3.11	71	5	66	6.66	0.0450	Background taken as average of 3 upwind sampler concentrations.
		Cyclone 4.5m DW	70	10:28	11:06	38	64.5	28.90	40.26	22.50	0.943	9982040	4367.35	4370.35	3.00	1.86	43	5	38	8.26	0.0319	
		Cyclone 7m DW	67	10:28	11:06	38	64.5	28.90	40.60	23.05	0.941	9982039	4393.35	4395.30	1.95	0.81	19	5	14	9.13	0.0126	
BY-401	09/17/99	Cyclone 2m DW	75	9:14	10:14	60	64.2	28.80	40.49	23.65	0.940	9982044	4406.00	4413.25	7.25	6.11	89	9	80	4.72	0.0606	Background taken as average of 3 upwind sampler concentrations.
		Cyclone 4.5m DW	70	9:14	10:14	60	64.2	28.80	40.21	22.70	0.942	9982043	4382.20	4388.75	6.55	5.41	79	9	70	5.94	0.0671	Same Wedding used on 401 and 501 series.
		Cyclone 7m DW	67	9:14	10:14	60	64.2	28.80	40.59	23.30	0.941	9982042	4399.20	4403.20	4.00	2.86	41	9	32	6.61	0.0345	
		Wedding 2m DW	424U	9:13	15:00	256	69.6	28.90	41.33	23.90	0.939	9982051	4378.10	4390.35	12.25	11.11	37	9	28			
		Wedding 2m UW	599U	9:25	15:34	369	72.4	28.88	40.88	23.00	0.941	9982052	4367.00	4373.05	6.05	4.91	11					
BY-402	09/17/99	Cyclone 2m DW	78	10:03	11:13	70	69	28.85	39.71	24.10	0.939	9982047	4394.30	4406.85	12.55	11.41	145	9	136	6.97	0.1779	Background taken as average of 3 upwind sampler concentrations.
		Cyclone 4.5m DW	66	10:03	11:13	70	69	28.85	40.45	22.90	0.942	9982046	4378.15	4382.05	3.90	2.76	34	9	25	8.86	0.0423	
		Cyclone 7m DW	74	10:03	11:13	70	69	28.85	40.62	23.05	0.941	9982045	4381.00	4385.00	4.00	2.86	36	9	27	9.88	0.0492	
BY-403	09/17/99	Cyclone 2m DW	75	10:21	11:28	67	69	28.90	40.70	23.40	0.941	9982048	4392.40	4403.30	10.90	9.76	126	9	117	7.73	0.1631	Background taken as average of 3 upwind sampler concentrations.
		Cyclone 4.5m DW	70	10:21	11:28	67	69	28.90	40.36	22.90	0.942	9982049	4393.25	4403.90	10.65	9.51	124	9	115	9.77	0.2022	
		Cyclone 7m DW	67	10:21	11:28	67	69	28.90	41.07	20.50	0.948	9982050	4388.25	4391.25	3.00	1.86	24	9	15	10.87	0.0290	
																			0			
BY-501	09/17/99	Cyclone 2m DW	78	12:59	14:12	73	78	28.90	40.11	23.25	0.941	9982057	4356.85	4371.45	14.60	13.46	162	9	153	6.47	0.1942	Background taken as average of 3 upwind sampler concentrations.
		Cyclone 4.5m DW	66	12:59	14:12	73	78	28.90	40.71	23.35	0.941	9982056	4372.85	4376.95	4.10	2.96	35	9	26	8.14	0.0417	Same Wedding used on 401 and 501 series.
		Cyclone 7m DW	74	12:59	14:12	73	78	28.90	40.93	23.35	0.941	9982055	4380.30	4385.60	5.30	4.16	49	9	40	9.06	0.0712	
		Wedding 2m DW	424U														37					
		Wedding 2m UW	599U																			
BY-502	09/17/99	Cyclone 2m DW	75	13:38	14:59	81	78	28.90	40.96	23.75	0.940	9982060	4375.05	4398.30	23.25	22.11	235	9	226	6.12	0.3009	Background taken as average of 3 upwind sampler concentrations.
		Cyclone 4.5m DW	70	13:38	14:59	81	78	28.90	40.62	23.10	0.941	9982059	4384.25	4395.20	10.95	9.81	105	9	96	7.60	0.1590	
		Cyclone 7m DW	67	13:38	14:59	81	78	28.90	41.06	23.40	0.941	9982058	4372.15	4377.85	5.70	4.56	48	9	39	8.41	0.0720	
BY-503	09/17/99	Cyclone 2m DW	78	14:19	14:57	38	78	28.90	40.06	23.50	0.940	9982063	4402.45	4421.40	18.95	17.81	413	9	404	5.82	0.2397	Background taken as average of 3 upwind sampler concentrations.
		Cyclone 4.5m DW	66	14:19	14:57	38	78	28.90	40.71	23.15	0.941	9982062	4373.25	4378.05	4.80	3.66	84	9	75	7.13	0.0542	
		Cyclone 7m DW	74	14:19	14:57	38	78	28.90	40.93	23.35	0.941	9982061	4386.00	4387.00	1.00	-0.14	-3	9	-12	7.84	-0.0097	
BY-601	09/22/99	Cyclone 2m DW	75	9:28	10:24	56	58	28.78	40.36	22.90	0.942	9982068	4387.60	4408.40	20.80	19.66	307	13	294	5.69	0.2514	Background based on 2m UW Wedding because of negative catches on upwind C/ls.
		Cyclone 4.5m DW	70	9:28	10:24	56	58	28.78	39.99	22.90	0.942	9982067	4400.80	4409.30	8.50	7.36	116	13	103	7.29	0.1128	No DW Wedding run on this test. Sampler never started.
		Cyclone 7m DW	67	9:28	10:24	56	58	28.78	40.33	23.45	0.940	9982066	4419.05	4422.60	3.55	2.41	38	13	25	8.15	0.0302	
		Wedding 2m DW	424U	Not run																		
		Wedding 2m UW	599U	9:03	15:38	335	67.6	28.88	40.64	23.60	0.940	9982064	4405.85	4412.10	6.25	5.11	13					
BY-602	09/22/99	Cyclone 2m DW	78	9:28	10:24	56	60	28.78	39.50	23.00	0.941	9982074	4404.40	4415.00	10.60	9.46	151	13	138	5.69	0.1180	Background based on 2m UW Wedding because of negative catches on upwind C/ls.
		Cyclone 4.5m DW	66	9:28	10:24	56	60	28.78	40.10	23.10	0.941	9982073	4416.60	4421.85	5.25	4.11	65	13	52	7.29	0.0565	
		Cyclone 7m DW	74	9:28	10:24	56	60	28.78	40.40	22.35	0.943	9982072	4383.10	4385.15	2.05	0.91	14	13	1	8.15	0.0015	
BY-701	09/22/99	Cyclone 2m DW	78	12:42	13:43	61	78.8	28.88	40.04	24.15	0.939	9982071	4394.25	4401.60	7.35	6.21	90	13	77	8.17	0.1026	Background based on 2m UW Wedding because of negative catches on upwind C/ls.
		Cyclone 4.5m DW	66	12:42	13:43	61	78.8	28.88	40.69	23.65	0.940	9982070	4403.90	4406.45	2.55	1.41	20	13	7	10.37	0.0120	
		Cyclone 7m DW	74	12:42	13:43	61	78.8	28.88	40.91	23.60	0.940	9982069	4389.90	4392.50	2.60	1.46	21	13	8	11.56	0.0145	
		Wedding 2m DW	424U	12:42	15:10	148	78.8	28.89	41.53	25.05	0.936	9982087	4410.35	4422.40	12.05	10.91	63	13	50			
		Wedding 2m UW	See 601 test series																			
BY-702	09/22/99	Cyclone 2m DW	75	13:09	14:41	92	80	28.91	41.03	23.40	0.941	9982086	4402.00	4417.80	15.80	14.66	137	13	124	8.32	0.2549	Background based on 2m UW Wedding because of negative catches on upwind C/ls.
		Cyclone 4.5m DW	70	13:09	14:41	92	80	28.91	40.65	23.50	0.940	9982085	4375.00	4376.00	1.00	-0.14	-1	13	-14	10.63	-0.0376	
		Cyclone 7m DW	67	13:09	14:41	92	80	28.91	41.13	23.65	0.940	9982084	4379.30	4380.20	0.90	-0.24	-2	13	-15	11.89	-0.0447	

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BY-703	09/22/99	Cyclone 2m DW	75	13:50	15:06	76	80	28.90	40.94	24.55	0.938	9982083	4377.65	4406.60	28.95	27.81	316	13	303	8.59	0.5299	Background based on 2m UW Wedding because of negative catches on upwind C/Is.
		Cyclone 4.5m DW	70	13:50	15:06	76	80	28.90	40.69	23.25	0.941	9982082	4384.00	4389.60	5.60	4.46	51	13	38	10.91	0.0843	
		Cyclone 7m DW	67	13:50	15:06	76	80	28.90	40.99	23.35	0.941	9982081	4394.25	4397.15	2.90	1.76	20	13	7	12.18	0.0173	
BY-1001	09/23/99	Cyclone 2m DW	75	8:44	10:05	81	58.8	28.50	40.39	22.53	0.942	9982094	4311.70	4316.00	4.30	3.16	34	11	23	3.58	0.0180	Background based on 2m UW Wedding. No upwind C/Is operated (out of substrates).
		Cyclone 4.5m DW	70	8:44	10:05	81	58.8	28.50	39.93	23.15	0.940	9982095	4329.50	4333.40	3.90	2.76	30	11	19	4.58	0.0190	Extrapolation yields unrealistic plume height. Value set equal to that from BY-1003
		Cyclone 7m DW	67	8:44	10:05	81	58.8	28.50	41.11	23.30	0.940	9982096	4301.70	4305.40	3.70	2.56	27	11	16	5.13	0.0180	
		Wedding 2m DW	424U	8:44	11:00	136	65.4	28.52	41.00	23.95	0.938	9982098	4328.60	4334.10	5.50	4.36	28	11	17			
		Wedding 2m UW	599U	8:55	13:23	300	65.4	28.52	40.32	24.10	0.938	9982097	4381.20	4386.10	4.90	3.76	11					
BY-1002	09/23/99	Cyclone 2m DW	78	9:26	10:20	54	65.2	28.51	39.68	23.00	0.941	9982093	4332.30	4336.15	3.95	2.81	46	11	35	3.38	0.0173	Background based on 2m UW Wedding. No upwind C/Is operated (out of substrates).
		Cyclone 4.5m DW	66	9:26	10:20	54	65.2	28.51	40.36	22.15	0.943	9982092	4319.50	4322.85	3.35	2.21	36	11	25	4.17	0.0150	Extrapolation yields unrealistic plume height. Value set equal to that from BY-1003
		Cyclone 7m DW	74	9:26	10:20	54	65.2	28.51	40.49	22.90	0.941	9982091	4327.05	4332.05	5.00	3.86	62	11	51	4.61	0.0343	
BY-1003	09/23/99	Cyclone 2m DW	75	10:14	11:00	46	72	28.55	40.71	23.97	0.938	9982088	4388.35	4393.90	5.55	4.41	83	11	72	3.31	0.0295	Background based on 2m UW Wedding. No upwind C/Is operated (out of substrates).
		Cyclone 4.5m DW	70	10:14	11:00	46	72	28.55	40.38	23.20	0.940	9982089	4326.00	4329.25	3.25	2.11	40	11	29	4.06	0.0146	Extrapolation yields unrealistic plume height. Value set equal to that from BY-1003
		Cyclone 7m DW	67	10:14	11:00	46	72	28.55	40.72	23.63	0.939	9982090	4337.80	4341.50	3.70	2.56	48	11	37	4.48	0.0206	

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GF 4x5 greased substrate

No	Final	Tare	Net (mg)
9988001	1012.35	1012.29	0.06
9988002	986.20	986.06	0.14
9988003	990.25	990.32	-0.07
9988004	987.80	987.49	0.31
9988005	987.65	987.49	0.16
9988006	985.70	985.55	0.15
9988007	975.10	974.64	0.46
9988008	991.50	990.86	0.64
9988009	975.85	975.55	0.30
9988010	964.05	963.66	0.39
9988011	976.60	976.42	0.18
		Average=	**0.247**
		Std Dev=	**0.199**

Quartz 8x10 Blanks

	Tare	Final	Cyclone	Wedding	Imp Bus
9982009	4384.45	4385.15	0.70		
9982008	4387.70	4390.15	2.45		
9982007	4386.20	4386.95	0.75		
9982026	4399.10	4400.75	1.65		
9982025	4379.50	4381.35	1.85		
9982024	4420.45	4421.75	1.30		
9982100	4310.85	4313.60	2.75		
9982099	4332.70	4333.50	0.80		
9982015	4401.05	4403.15		2.10	
9982006	4376.95	4376.60		-0.35	
9982010	4364.40	4365.05		0.65	
9982001	4385.60	4386.55			0.95
9982002	4392.20	4392.80			0.60
9982003	4359.20	4359.55			0.35
9982004	4391.35	4391.90			0.55
		Mean	**1.53**	**0.80**	**0.61**
		Std Dev	**0.787**	**1.232**	**0.250**
			n=8	n=3	n=4
		Overall	**1.14**		
		n=15	**0.855**		

Appendix D.
Example Calculation -- Run BY-201

This example calculation is based on run BY-201, which was a test of scraper loading emissions conducted at the North Central Kansas Technical College. The test was conducted on September 15, 1999, began at 12:49 p.m. and ended at 13:31 p.m. However, the test was halted at 13:05 p.m. because of poor winds. It was then restarted again at 13:21 p.m. and finished accordingly at 13:31 p.m. Thus, the test duration was 26 minutes. The average temperature during the test was 75 F and the barometric pressure was 28.80 in Hg [information taken from Run Sheet]. During the test, there were 34 scraper passes [information taken from vehicle log].

The following table shows the filter net weights calculated for the 2, 4.5 and 7m cyclone samplers:

Sampler Location	(Note 1) Filter No.	(Note 2) Tare weight (mg)	(Note 2) Final weight (mg)	Net Weight (mg)	(Note 3) Blank–corrected net weight (mg)
Cyclone 40 cfm 2 m DW	9982019	4411.50	4469.50	58.00	56.86
Cyclone 40 cfm 4.5 m DW	9982018	4404.05	4435.85	31.80	30.66
Cyclone 40 cfm 7 m DW	9982017	4408.05	4415.15	7.10	5.96

Notes
1. Information taken Field Filter Log.
2. Information taken from filter weigh books.
3. The blank-corrected net weights are based on an average blank value of –1.14 mg. Blank filter statistics are contained in Appendix C, which presents spreadsheets for the BY runs.

The following table illustrates how the sampling flow rates are determined using the look-up tables.

Sampler Location	VFC ID	(Note 1) Filter Pressure (in H20)	Filter Pressure (in Hg)	(Note 2) P_o/P_a	(Note 3) Flow rate (acfm)	PM-10 Concentration (ug/m^3)
Cyclone 40 cfm 2 m DW	75	24.10	1.77	0.939	40.82	1892
Cyclone 40 cfm 4.5 m DW	70	22.90	1.68	0.942	40.57	1026
Cyclone 40 cfm 7 m DW	67	24.00	1.76	0.939	41.01	197

Notes:
1. Average of pressures shown on Run Sheet.
2. Value represents 1 – (filter pressure/barometric pressure). For example, for 2 m sampler, 0.939 = 1-(1.77/28.80).
3. Flow rate determined from Look Up table using previous column and ambient temperature. Look Up table for 2m unit attached.

As shown in Appendix C, the upwind PM-10 concentration is 11 ug/m3 and the following plume sampling data are obtained:

Sampler Location	PM-10 Concentration (ug/m3)	(Note 1) Net PM-10 Concentration (ug/m3)	(Note 2) Mean Wind Speed (mph)	(Note 3) Net PM-10 Exposure (mg/cm2)
Cyclone 40 cfm 2 m DW	1892	1881	2.48	0.3253
Cyclone 40 cfm 4.5 m DW	1026	1015	3.01	0.2131
Cyclone 40 cfm 7 m DW	197	186	3.29	0.0428

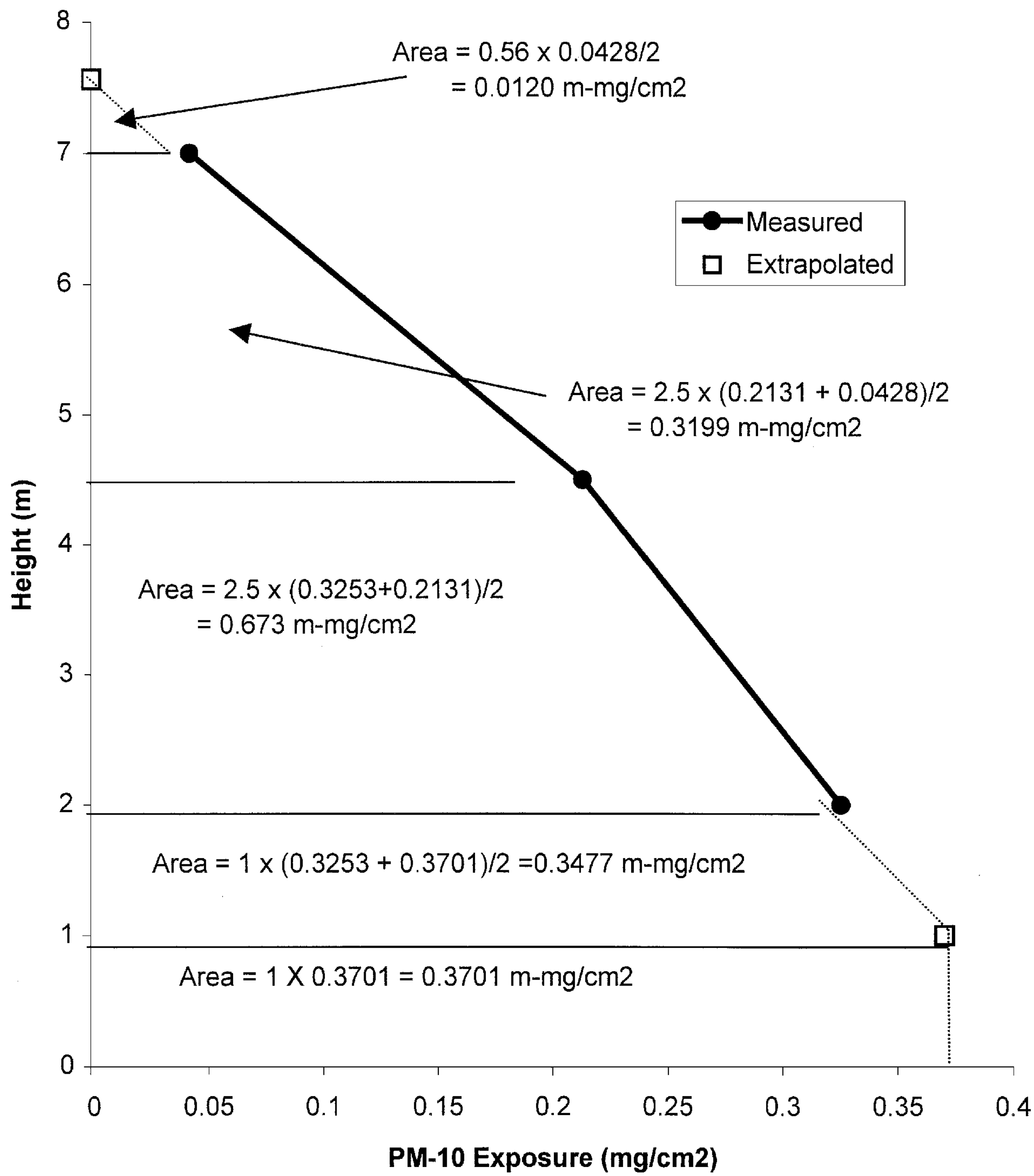
Notes
1. Upwind concentration values presented in Appendix F.
2. Average of 5-min average wind speeds recorded during test. Value at 4.5 m interpolated using the logarithmic profile described in Section 2.4 of the report.
3. Exposure represents product of wind speed, concentration, and test duration. See Section 2.4 of the report.

As discussed in Section 2.4, a numerical integration scheme is used to determine the integrated exposure and emission factor.
Extrapolation of the 4.5 and 7 m net concentrations to a value of zero leads to an estimated plume height of H = 7.56 m. The attached figure plots the exposure values and shows how the trapezoidal rule is applied to obtain the intrgrated exposure value:

A = 0.3701 + 0.3477 + 0.673 + 0.3199 + 0.0120
= 1.723 m-mg/cm^2
= 61.1 lb/mi

The emission factor e is found by dividing the integrated exposure by the number of scraper passes:

e = 61.1 / 34 vehicles
= 1.80 lb/veh-mi


Area = 0.56 x 0.0428/2
= 0.0120 m-mg/cm2
Measured
Extrapolated
Area = 2.5 x (0.2131 + 0.0428)/2
= 0.3199 m-mg/cm2
Area = 2.5 x (0.3253+0.2131)/2
= 0.673 m-mg/cm2
Area = 1 x (0.3253 + 0.3701)/2 =0.3477 m-mg/cm2
Area = 1 X 0.3701 = 0.3701 m-mg/cm2
Height (m)
PM-10 Exposure (mg/cm2)
0
1
2
3
4
5
6
7
8
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

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Fugitive Emission Testing
Run Sheet

BY-201

Run No(s). Beloit
MRI Project No. 104813.1.002.03

Date 9-15-99
Recorded by [illegible] + ABP

Site NCKTC @ [illegible] uncontrolled test

Temperature 75 @ 1245 ___ @ ___ (w 59 Temp) Barometric pressure 28.9 @ 1245 ___ @ ___ (Baro Press)

Sampler	Sampler Location	Sampler ID	*Start Time	*Stop Time	Back Plate Pressure (in H_2O)	Filter/B.P. Pressure (in. H_2O)	Nozzle/ Time
Partisol	not run						
Cyc/Imp						@ @	/ /
Cyc/Imp						@ @	/ /
Wedding						@ @	

Sampler	Sampler Location	Sampler ID	*Start Time	*Stop Time	Back Plate Pressure (in H_2O)	Filter/B.P. Pressure (in. H_2O)	Nozzle/ Time
Partisol	N.A.						
Cyc/Imp	4.5m	8585	1250 ~~1350~~	1305 restart @ 1321	0.57	~~0.57~~ ABP @ ___ @	/ /
Cyc/Imp	2m	98-5	1250 ~~1350~~	1305	0.60	~~0.60~~ ABP @ ___ @	/ /
Cyclone	7m	67	1249 ~~1349~~		stop 13:31	23.7 @ 1257 ~~1357~~ 24.3 @ 1327	/ /
Cyclone	4.5	70				22.9 @ 22.9 @	/ /
Cyclone	2m **	75				24.1 @ 1257 ~~1357~~ @	/ /
Wedding			1250 ~~1350~~		13:31	24.2 @ 1250 ~~1350~~ 25.0 @ 1507 ABP	

NO UPWINDS RUN

Comments
201 on East Tower 202 on West Tower
all Start 30° E of South —

0.58 98-6
0.57 8585
0.58 98-7
0.60 98-5

* initial start @ 1249 - 1250 (all)
stop @ 1305 (all) - shut down because of poor winds
restart @ 1321 (all)
stop @ 1331 (cyclones only shut down) - cyclone impactors are left running + wedding
stop cyclone impactors + wedding @ 15:07

** Pressure Umbilical on #3 not working — need to read

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MIDWEST RESEARCH INSTITUTE
Fugitive Emission Testing
Vehicle Log

BY-201, 202

Site: Beloit Run 201

Date 9-15-99

Project No. 104813.1.002.03

Recorded by DG

Road Location ______

Sampling Start Time 1250

Stop Time ______

Counter Start Count 1250

Stop Count ______

Annotations: 1305 shut down BY201 202 restart 1321 — off @1527 — doing other work between now refill — now 2 min. the cont.

Vehicle Type *	Vehicle Wt.	Axles / Wheels	1	2	3	4	5	6	7	8	9	10	Total
613 Scraper		2/4	𝍸	𝍸	||||	𝍸	|						
621 Scraper		2/4	𝍸	||||	𝍸								
		/											
		/											

Comments: 1254 tower 202 start 5-613's 3-621's not included w/run 201

Site Sketch: WIND ... to E @ 1303

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Midwest Research Institute
Fugitive Emission Testing
Field Filter Log

Site: Beloit   Date 9-14-99
Project No. 104813.1.002.03 BY-201   Recorded by DG

Sampling Array ID	Sampler Type/Height	Filter Type	Filter ID	Checks/Date Unloaded		Comments
U-1	Partisol	47mm Teflon	9985002	✓	9-15	Used as blank
U-2	Cyc/Imp 2m	8x10 quartz	9982011			BY 401
		4x5 glass fiber S-3	9988014			"
		4x5 glass fiber S-2	9988015			"
		4x5 glass fiber S-1	9988016			"
U-3	Cyc/Imp 4.5m	8x10 quartz	9982012			"
		4x5 glass fiber S-3	9988017			"
		4x5 glass fiber S-2	9988018			"
		4x5 glass fiber S-1	9988019			"
U-4	Wedding 2m	8x10 quartz	9982015	✓	9-15	Blank
D-1	Cyc/Imp 2m	8x10 quartz	9982013	✓	9-15	
		4x5 glass fiber S-3	9988020	✓	9-15	
		4x5 glass fiber S-2	9988021	✓	9-15	
		4x5 glass fiber S-1	9988022	✓	9-15	
D-2	Cyc/Imp 4.5m	8x10 quartz	9982014	✓	9-15	
		4x5 glass fiber S-3	9988023	✓	9-15	
		4x5 glass fiber S-2	9988024	✓	9-15	
		4x5 glass fiber S-1	9988025	✓	9-15	
D-3	Cyclone 7m	8x10 quartz	9982017	✓	9-15	
	Cyclone 4.5m	8x10 quartz	9982018	✓	9-15	
	Cyclone 2m	8x10 quartz	9982019	✓	9-15	
D-4	Wedding 2m	8x10 quartz	9982016	✓	9-15	

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TARE

Filter Analysis Log

Filter No.	First Weigh			Audit (1)					Audit (2)			
	Weight (mg)	By	Date	Weight (mg)	Δ (mg)	Meets QC?	By	Date	Weight (mg)	Meets QC?	By	Date
9982001	* ~~4388.80~~	DA	9-9-99	4386.00	0.40	yes	CK	9.10.99				
002	4392.20			4391.80	0.40							
* 003	~~4359.70~~			4359.10	0.10							
004	4391.35			4390.60	0.75							
005	4390.60			4390.25	0.35							
006	4376.95			4376.25	0.70							
007	4386.20			4386.00	0.20							
008	4387.70			4387.35	0.35							
009	4384.45			4384.25	0.20							
010	4364.40			4364.15	0.25							
011	4373.70			4373.20	0.50							
012	4394.90			4395.00	0.10							
013	4378.05			4378.00	0.05							
014	4408.85			4408.70	0.15							
015	4401.05			4400.65	0.40							
016	4404.00			4403.70	0.30							
017	4408.05			4407.85	0.20							
018	4404.05			4403.80	0.25							
019	4411.50			4411.25	0.25							
020	~~4420.15~~	NO FILTER										
021	4420.15	DA	9-9-99	4419.85	0.30	yes	CK	9.10.99				
022	4389.25			4389.20	0.05							
023	4354.05			4353.65	0.40							
024	4420.45			4420.20	0.25							
025	4379.50			4378.85	0.65							
026	4399.10			4398.80	0.30							
027	4379.05			4378.70	0.35							
028	4416.05			4415.80	0.25							
029	4385.50			4386.00	0.50							
030	4406.00			4405.75	0.75							
031	4400.70			4400.35	0.35							
032	4379.75			~~4400~~ *	0.30							

Comments:

* 9982001 4385.60 9-9-99
003 4359.20 9-9-99

Figure 3. Filter Analysis Log

* 4379.45

MRI-QAU\MRI-8403 FORMS.DOC

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0 ^ 10 GMH

FINAL

Filter Analysis Log

Filter No.	First Weigh: Weight (mg)	First Weigh: By	First Weigh: Date	Audit (1): Weight (mg)	Audit (1): Δ (mg)	Audit (1): Meets QC?	Audit (1): By	Audit (1): Date	Audit (2): Weight (mg)	Audit (2): Meets QC?	Audit (2): By	Audit (2): Date
9982001	4386.55	AY	9-27-99									
002	4392.80											
003	4359.55											
004	4391.90			4391.40	0.50	YES	DA	9-28-99				
005	NO FILTER											
006	4376.60											
007	4386.95											
008	4390.15											
009	4385.15											
010	4365.05											
011	4376.85											
012	4397.05											
013	4406.65			4406.25	0.40	YES	DA	9-28-99				
014	4422.35			4422.15	0.20	YES	DA	9-28-99				
015	4403.15											
016	4474.85											
017	4415.15											
018	4435.85											
019	4469.50			4468.90	0.60	YES	DA	9-28-99				
020	NO FILTER											
021	4426.90			4426.75	0.15	YES	DA	9-28-99				
022	4400.45											
023	4384.25											
024	4421.75											
025	4381.35											
026	4400.75											
027	4380.60			4380.10	0.50	YES	DA	9-28-99				
028	4417.90											
029	4387.80											
030	4407.60			4407.40	0.20	YES	DA	9-28-99				
031	4405.80			4405.50	0.30	YES	DA	9-28-99				
032	4386.70											

Comments:

Figure 3. Filter Analysis Log

 LOOKUP TABLE FOR ASI/GMW VFC S/N P01575 Calibrated 07/23/1992

TEMPERATURE °F Flow rate ft3/min (actual)

Po/Pa	48	52	56	60	64	68	72	76	80	84	88	92	96	Po/Pa
0.930	39.48	39.61	39.75	39.89	40.03	40.16	40.30	40.43	40.57	40.70	40.84	40.97	41.10	0.930
0.931	39.52	39.66	39.80	39.93	40.07	40.21	40.34	40.48	40.61	40.75	40.88	41.02	41.15	0.931
0.932	39.57	39.70	39.84	39.98	40.12	40.25	40.39	40.52	40.66	40.79	40.93	41.06	41.20	0.932
0.933	39.61	39.75	39.89	40.02	40.16	40.30	40.43	40.57	40.71	40.84	40.97	41.11	41.24	0.933
0.934	39.65	39.79	39.93	40.07	40.21	40.34	40.48	40.62	40.75	40.89	41.02	41.15	41.29	0.934
0.935	39.70	39.84	39.98	40.12	40.25	40.39	40.53	40.66	40.80	40.93	41.07	41.20	41.33	0.935
0.936	39.74	39.88	40.02	40.16	40.30	40.44	40.57	40.71	40.84	40.98	41.11	41.25	41.38	0.936
0.937	39.79	39.93	40.07	40.21	40.34	40.48	40.62	40.75	40.89	41.02	41.16	41.29	41.43	0.937
0.938	39.83	39.97	40.11	40.25	40.39	40.53	40.66	40.80	40.94	41.07	41.21	41.34	41.47	0.938
0.939	39.88	40.02	40.16	40.30	40.43	40.57	40.71	40.85	40.98	41.12	41.25	41.39	41.52	0.939
0.940	39.92	40.06	40.20	40.34	40.48	40.62	40.75	40.89	41.03	41.16	41.30	41.43	41.57	0.940
0.941	39.97	40.11	40.25	40.39	40.52	40.66	40.80	40.94	41.07	41.21	41.34	41.48	41.61	0.941
0.942	40.01	40.15	40.29	40.43	40.57	40.71	40.85	40.98	41.12	41.26	41.39	41.53	41.66	0.942
0.943	40.06	40.20	40.34	40.48	40.62	40.75	40.89	41.03	41.17	41.30	41.44	41.57	41.71	0.943
0.944	40.10	40.24	40.38	40.52	40.66	40.80	40.94	41.07	41.21	41.35	41.48	41.62	41.75	0.944
0.945	40.15	40.29	40.43	40.57	40.71	40.84	40.98	41.12	41.26	41.39	41.53	41.67	41.80	0.945
0.946	40.19	40.33	40.47	40.61	40.75	40.89	41.03	41.17	41.30	41.44	41.58	41.71	41.85	0.946
0.947	40.24	40.38	40.52	40.66	40.80	40.94	41.07	41.21	41.35	41.49	41.62	41.76	41.89	0.947
0.948	40.28	40.42	40.56	40.70	40.84	40.98	41.12	41.26	41.39	41.53	41.67	41.80	41.94	0.948
0.949	40.33	40.47	40.61	40.75	40.89	41.03	41.17	41.30	41.44	41.58	41.71	41.85	41.99	0.949
0.950	40.37	40.51	40.65	40.79	40.93	41.07	41.21	41.35	41.49	41.62	41.76	41.90	42.03	0.950
0.951	40.41	40.56	40.70	40.84	40.98	41.12	41.26	41.39	41.53	41.67	41.81	41.94	42.08	0.951
0.952	40.46	40.60	40.74	40.88	41.02	41.16	41.30	41.44	41.58	41.72	41.85	41.99	42.13	0.952
0.953	40.50	40.65	40.79	40.93	41.07	41.21	41.35	41.49	41.62	41.76	41.90	42.04	42.17	0.953
0.954	40.55	40.69	40.83	40.97	41.11	41.25	41.39	41.53	41.67	41.81	41.95	42.08	42.22	0.954
0.955	40.59	40.74	40.88	41.02	41.16	41.30	41.44	41.58	41.72	41.85	41.99	42.13	42.27	0.955
0.956	40.64	40.78	40.92	41.06	41.20	41.35	41.48	41.62	41.76	41.90	42.04	42.18	42.31	0.956
0.957	40.68	40.83	40.97	41.11	41.25	41.39	41.53	41.67	41.81	41.95	42.08	42.22	42.36	0.957
0.958	40.73	40.87	41.01	41.15	41.30	41.44	41.58	41.72	41.85	41.99	42.13	42.27	42.41	0.958
0.959	40.77	40.92	41.06	41.20	41.34	41.48	41.62	41.76	41.90	42.04	42.18	42.32	42.45	0.959
0.960	40.82	40.96	41.10	41.24	41.39	41.53	41.67	41.81	41.95	42.09	42.22	42.36	42.50	0.960
0.961	40.86	41.01	41.15	41.29	41.43	41.57	41.71	41.85	41.99	42.13	42.27	42.41	42.55	0.961
0.962	40.91	41.05	41.19	41.34	41.48	41.62	41.76	41.90	42.04	42.18	42.32	42.45	42.59	0.962
0.963	40.95	41.10	41.24	41.38	41.52	41.66	41.80	41.94	42.08	42.22	42.36	42.50	42.64	0.963
0.964	41.00	41.14	41.28	41.43	41.57	41.71	41.85	41.99	42.13	42.27	42.41	42.55	42.69	0.964
0.965	41.04	41.18	41.33	41.47	41.61	41.75	41.90	42.04	42.18	42.32	42.46	42.59	42.73	0.965
0.966	41.09	41.23	41.37	41.52	41.66	41.80	41.94	42.08	42.22	42.36	42.50	42.64	42.78	0.966
0.967	41.13	41.27	41.42	41.56	41.70	41.85	41.99	42.13	42.27	42.41	42.55	42.69	42.83	0.967
0.968	41.18	41.32	41.46	41.61	41.75	41.89	42.03	42.17	42.31	42.45	42.59	42.73	42.87	0.968
0.969	41.22	41.36	41.51	41.65	41.79	41.94	42.08	42.22	42.36	42.50	42.64	42.78	42.92	0.969
0.970	41.26	41.41	41.55	41.70	41.84	41.98	42.12	42.27	42.41	42.55	42.69	42.83	42.97	0.970
0.971	41.31	41.45	41.60	41.74	41.89	42.03	42.17	42.31	42.45	42.59	42.73	42.87	43.01	0.971
0.972	41.35	41.50	41.64	41.79	41.93	42.07	42.22	42.36	42.50	42.64	42.78	42.92	43.06	0.972
0.973	41.40	41.54	41.69	41.83	41.98	42.12	42.26	42.40	42.54	42.69	42.83	42.97	43.10	0.973
0.974	41.44	41.59	41.73	41.88	42.02	42.16	42.31	42.45	42.59	42.73	42.87	43.01	43.15	0.974
0.975	41.49	41.63	41.78	41.92	42.07	42.21	42.35	42.50	42.64	42.78	42.92	43.06	43.20	0.975
0.976	41.53	41.68	41.82	41.97	42.11	42.26	42.40	42.54	42.68	42.82	42.96	43.11	43.24	0.976
0.977	41.58	41.72	41.87	42.01	42.16	42.30	42.44	42.59	42.73	42.87	43.01	43.15	43.29	0.977
0.978	41.62	41.77	41.91	42.06	42.20	42.35	42.49	42.63	42.78	42.92	43.06	43.20	43.34	0.978
0.979	41.67	41.81	41.96	42.10	42.25	42.39	42.54	42.68	42.82	42.96	43.10	43.24	43.38	0.979

$$\text{Flow Rate (@ 75°F)} = (75-72)\left(\frac{40.85-40.71}{76-72}\right) + 40.71 = 40.82 \ \frac{ft^3}{min}$$

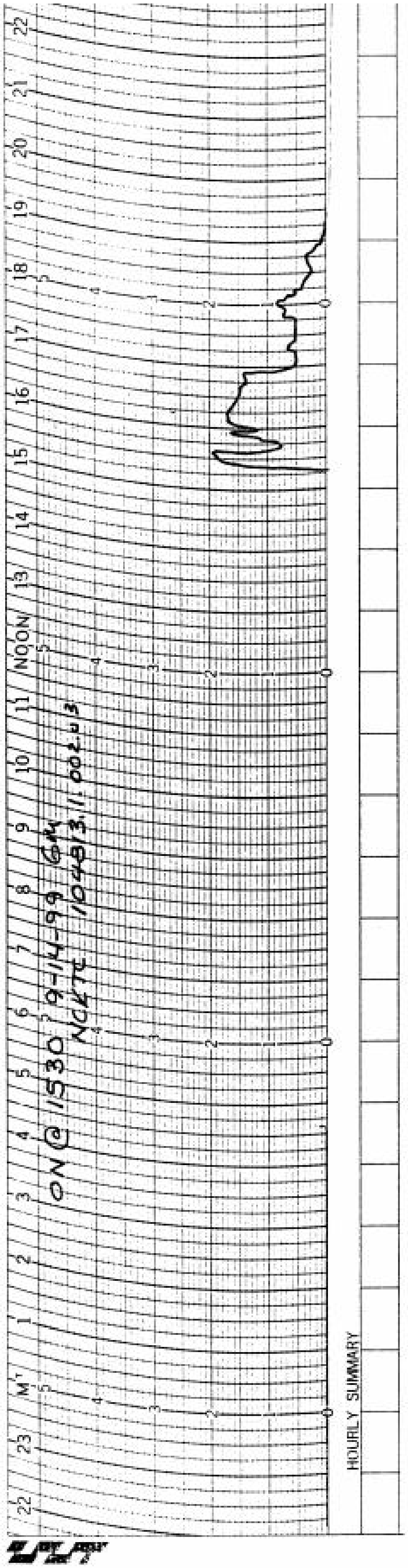
Appendix E

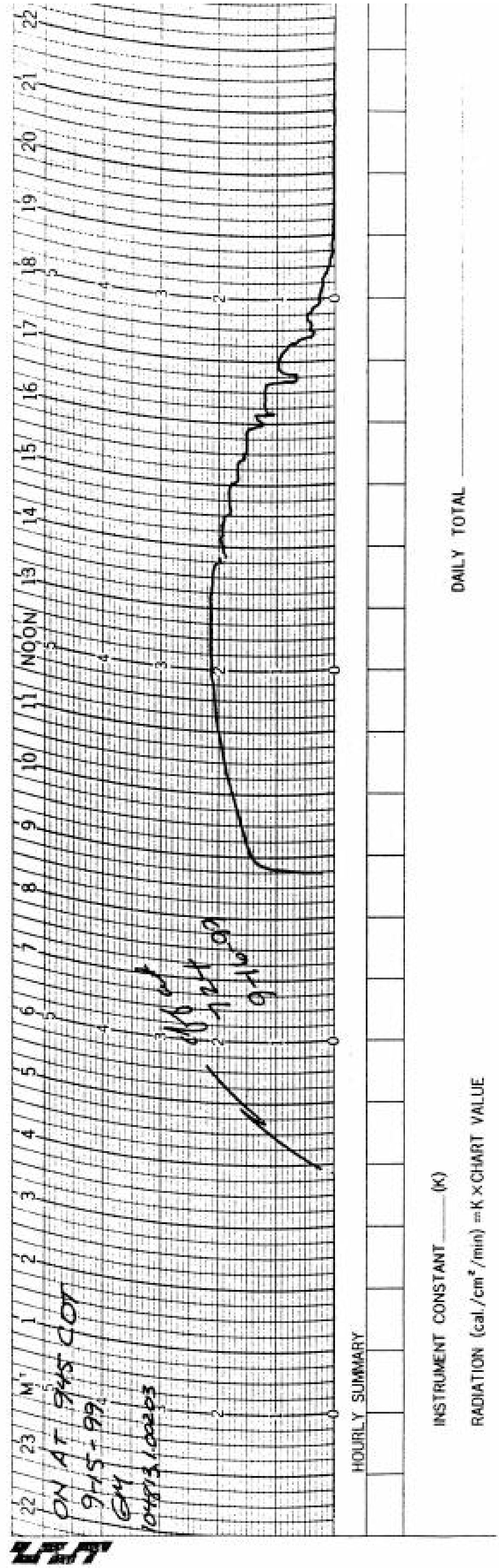
Second-Tier Meteorological Observations

Meterological Data (in CDT)

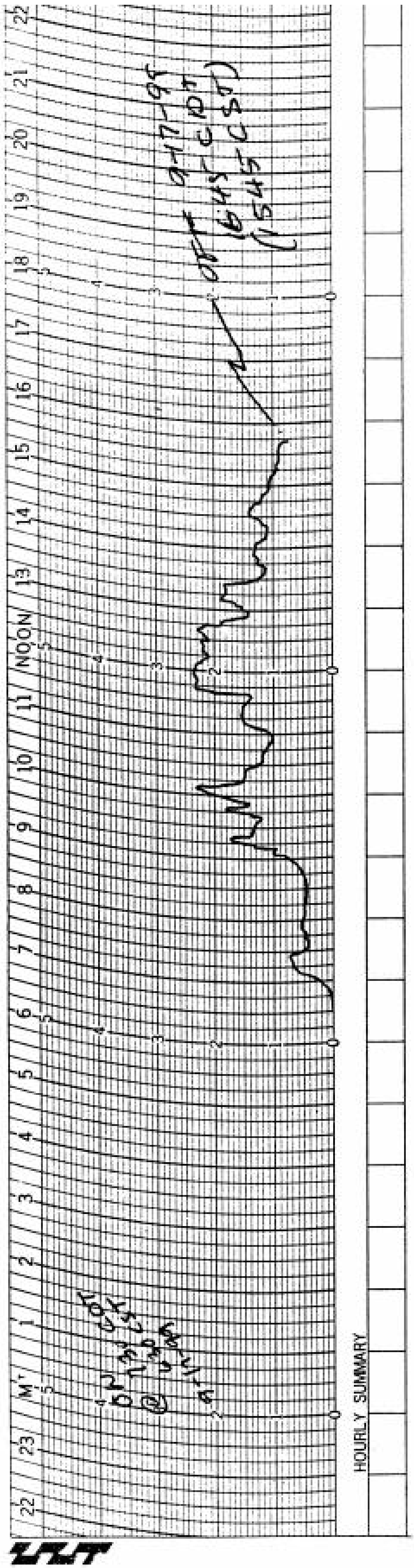
Date	Barometric Pressure	Dry Bulb	Wet Bulb	Cloud Cover	Water Height in Evap. Pan (in.)	Rain Gauge	Wind
9/14/99	28.80@1245	75.0@1245	59.0@1245				wind to E @ 1303
9/15/99	28.80@1000	63.0@1000	53.0@1000	0.1@0945		0" @ 0945	wind E to ESE around 10 mph
	29.00@1400	76.0@1400	60.0@1400				
	28.90@1525	76.0@1525	59.0@1525				
9/16/99	28.90@0835	54.0@0835	50.0@0835	0.8@0835	20 11/16 @ 0730	0" @ 0730	
	28.90@0931	62.0@0931	54.0@0931	0.7@0931			
	28.90@1017	67.0@1017	55.0@1017	0.8@1017			
	28.95@1130	66.0@1130	55.0@1130	0.8@1130			
9/17/99	28.80@0845	59.5@0845	54.5@0845	0.9@0845	20 9/16 @ 0730	0" @ 1645	
	28.80@1000	67.0@1000	56.0@1000	1.0@1000	20 3/8 @1645		
	28.90@1057	69.0@1052	58.0@1052	0.7@1052			
	28.90@1240	72.0@1238	58.0@1238	0.6@1238			
	28.90@1321	78.0@1322	59.5@1322	0.4@1322			
		76.0@1411	59.5@1411	0.5@1411			
9/22/99	28.75@0850	51.0@0850	49.0@0850	0.0@0850	19 13/16 @ 0745	0.25" @ 0745	
	28.75@0930	58.0@0938	52.0@0938	0.0@0938			
	28.80@1006	62.0@1006	55.0@1006	0.0@1006			
	28.95@1048	68.0@1047	58.0@1047	0.0@1047			
	28.80@1224	77.0@1224	61.0@1224	0.0@1224			
	28.80@1253	78.5@1253	62.0@1253	0.0@1253			
	28.95@1326	79.0@1326	62.0@1326	0.0@1326			
	28.90@1405	81.0@1400	63.0@1400	0.0@1400			
	28.90@1429	82.5@1429	64.0@1429	0.0@1429			
9/23/99	28.50@0852	58.0@0852	56.0@0852	0.3@0852	19 1/2 @0745	0" @ 0745	
	28.50@0920	59.5@0920	55.0@0920	0.3@0920	19 3/8 @1500	0" @ 1500	
	28.50@0950	64.5@0950	58.0@0950	0.3@0950			
	28.55@1020	67.5@1019	59.0@1019	0.3@1019			
	28.55@1043	71.0@1043	60.0@1043	0.3@1043			
	28.55@1102	43.0@1104	61.0@1104	0.3@1104			

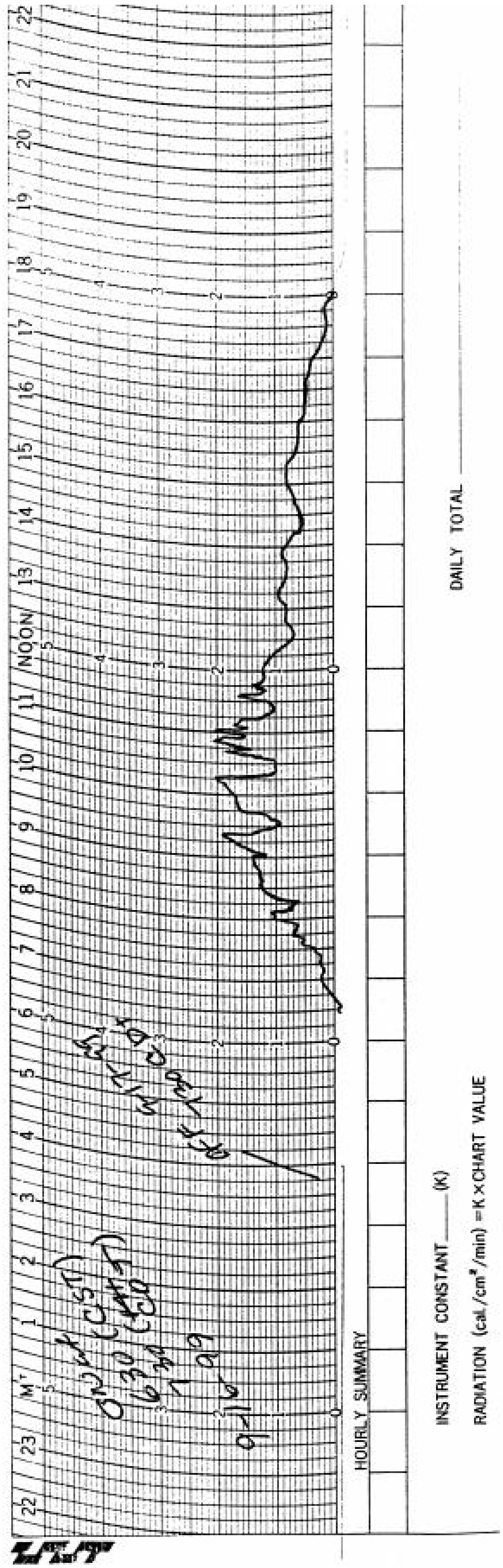
UNCONTROLLED





UNCONTROLLED





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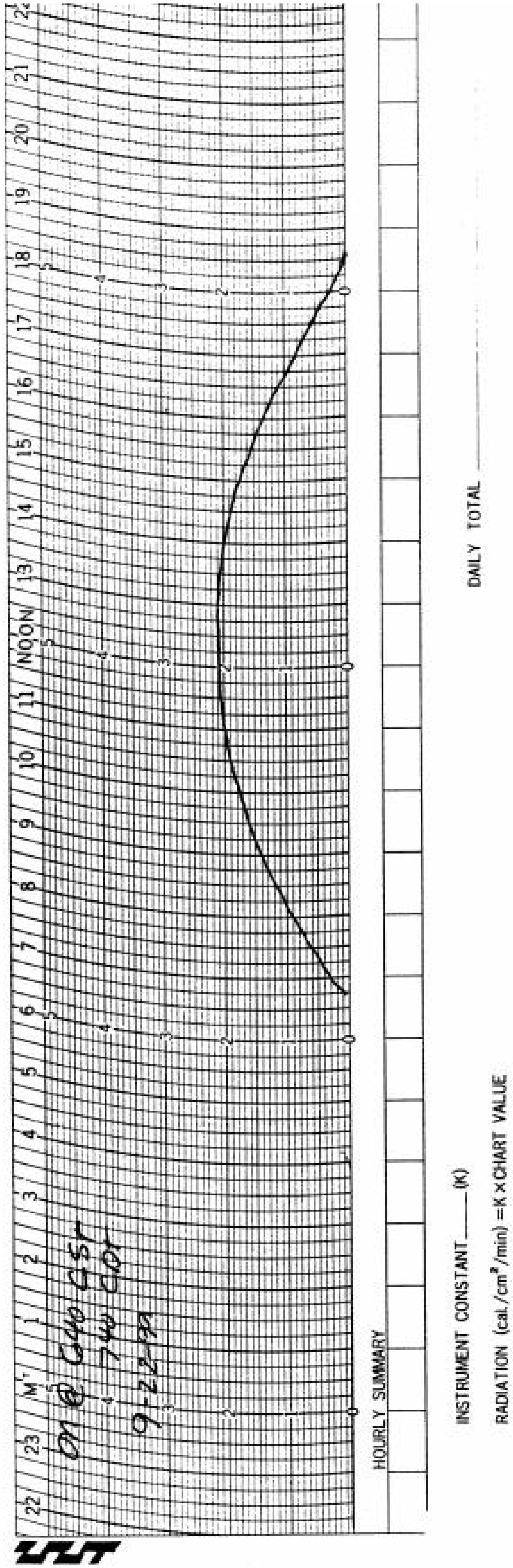

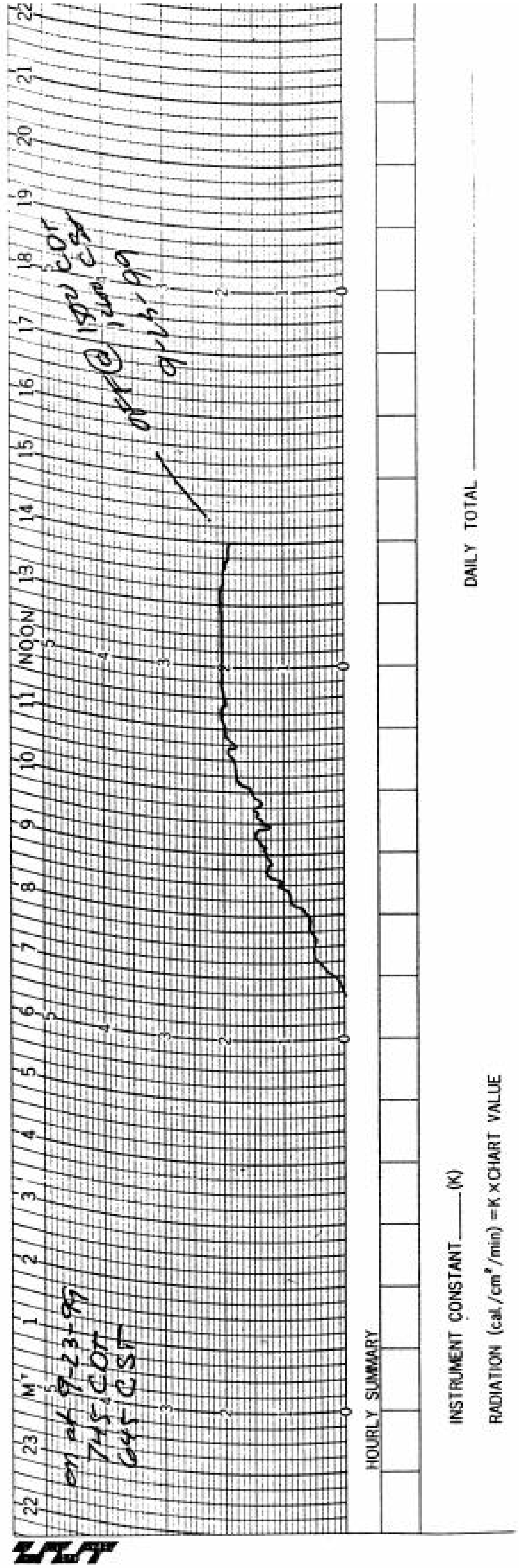

Appendix F

Particle Sizing Data

U N C O N T R O L L E D

BY Loading Runs
BYImpact.xls

Run	Date	Sampler Location	Sampler ID	Sampler Start Time	Sampler Stop Time	Sampler Run Time (min)	Avg. Temp. (deg. F)	Avg. B.P. (in. Hg)	Flowrate (ft^3/min)
BY-201	09/15/99	Cyc/Imp 2m DW	98-5	12:50	13:31	137	75	28.80	20.0
		Cyc/Imp 4.5m DW	8585	12:50	13:31	137	75	28.80	20.5
BY-301	09/16/99	Cyc/Imp 2m UW	98-7	9:12	13:54	282	65	28.90	19.9
		Cyc/Imp 4.5m UW	98-6	9:12	13:54	282	65	28.90	20.1
		Cyc/Imp 2m DW	98-5	9:05	11:06	121	64.5	28.90	19.5
		Cyc/Imp 4.5m DW	8585	9:05	11:06	121	64.5	28.90	20.0
BY-401/501	09/17/99	Cyc/Imp 2m UW	98-7	9:25	15:34	369	72.4	28.88	20.2
		Cyc/Imp 4.5m UW	98-6	9:25	15:34	369	72.4	28.88	20.4
		Cyc/Imp 2m DW	98-5	9:13	15:00	256	72.4	28.88	19.8
		Cyc/Imp 4.5m DW	8585	9:13	15:00	256	72.4	28.88	20.4
BY-601/701	09/22/99	Cyc/Imp 2m UW	98-7	9:03	15:38	335	67.6	28.88	20.0
		Cyc/Imp 4.5m UW	98-6	9:03	15:38	335	67.6	28.88	20.2
BY-601		Cyc/Imp 2m DW	98-5	9:11	10:52	101	59.8	28.78	19.4
		Cyc/Imp 4.5m DW	8585	9:11	10:52	101	59.8	28.78	19.9
BY-701	09/22/99	Cyc/Imp 2m DW	98-5	12:42	15:10	148	78.8	28.85	20.1
		Cyc/Imp 4.5m DW	8585	12:42	15:10	148	78.8	28.85	20.6

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Run	Sampler Location	Stage Number	Blank Corrected	Cumulative Mass Fraction by Stage
BY-201	Cyc/Imp 2m DW	S-1	24.46	**0.77**
		S-2	40.21	**0.40**
		S-3	16.20	**0.25**
		Backup	27.46	
			108.34	
	Cyc/Imp 4.5m DW	S-1	13.14	**0.76**
		S-2	18.58	**0.43**
		S-3	11.67	**0.22**
		Backup	12.36	
			55.76	
BY-301	Cyc/Imp 2m UW	S-1	0.00	**1.00**
		S-2	0.00	**1.00**
		S-3	0.04	**0.91**
		Backup	0.41	
			0.45	
	Cyc/Imp 4.5m UW	S-1	0.00	**1.00**
		S-2	0.00	**1.00**
		S-3	0.00	**1.00**
		Backup	0.71	
			0.71	
	Cyc/Imp 2m DW	S-1	0.45	**0.64**
		S-2	0.33	**0.37**
		S-3	0.00	**0.37**
		Backup	0.46	
			1.25	
	Cyc/Imp 4.5m DW	S-1	0.02	**0.98**
		S-2	0.00	**0.98**
		S-3	0.00	**0.98**
		Backup	1.16	
			1.18	
BY-401/501	Cyc/Imp 2m UW	S-1	0.10	**0.96**
		S-2	0.45	**0.79**
		S-3	0.03	**0.77**
		Backup	2.01	
			2.60	
	Cyc/Imp 4.5m UW	S-1	0.00	**1.00**
		S-2	0.22	**0.82**
		S-3	0.00	**0.82**
		Backup	1.01	
			1.23	
	Cyc/Imp 2m DW	S-1	1.58	**0.85**
		S-2	3.48	**0.53**
		S-3	1.25	**0.41**
		Backup	4.36	
			10.68	
	Cyc/Imp 4.5m DW	S-1	0.00	**1.00**
		S-2	0.43	**0.88**
		S-3	0.00	**0.88**
		Backup	3.06	
			3.49	
BY-601/701	Cyc/Imp 2m UW	S-1	0.00	**1.00**
		S-2	0.00	**1.00**
		S-3	0.00	**1.00**

		Backup	0.21	
			0.21	
	Cyc/Imp 4.5m UW	S-1	0.00	**1.00**
		S-2	0.00	**1.00**
		S-3	0.00	**1.00**
		Backup	0.41	
			0.41	
BY-601	Cyc/Imp 2m DW	S-1	1.93	**0.81**
		S-2	2.73	**0.53**
		S-3	1.25	**0.41**
		Backup	4.11	
			10.03	
	Cyc/Imp 4.5m DW	S-1	0.00	**1.00**
		S-2	0.00	**1.00**
		S-3	0.00	**1.00**
		Backup	0.96	
			0.96	
BY-701	Cyc/Imp 2m DW	S-1	2.18	**0.74**
		S-2	3.51	**0.31**
		S-3	1.24	**0.16**
		Backup	1.31	
			8.25	
	Cyc/Imp 4.5m DW	S-1	0.38	**0.42**
		S-2	0.27	**0.00**
		S-3	0.00	**0.00**
		Backup	0.00	
			0.66	

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Filter No. (4x5)	Final Wt. (mg)	Tare Wt (mg)	Difference (mg)
9988001	1012.35	1012.29	0.06
9988002	986.20	986.06	0.14
9988003	990.25	990.32	-0.07
9988004	987.80	987.49	0.31
9988005	987.65	987.49	0.16
9988006	985.70	985.55	0.15
9988007	975.10	974.64	0.46
9988008	991.50	990.86	0.64
9988009	975.85	975.55	0.30
9988010	964.05	963.66	0.39
9988011	976.60	976.42	0.18
			0.247
			0.199

Filter No. (8x10)	Final Wt. (mg)	Tare Wt (mg)	Difference (mg)
9982001	4386.55	4385.60	0.95
9982002	4392.80	4392.20	0.60
9982003	4359.55	4359.20	0.35
9982004	4391.90	4391.35	0.55
			0.61
			0.250

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Run	Sampler Location	Particulate Concentration (ug/m^3) less than stated size 2.1 um	Particulate Concentration (ug/m^3) less than stated size 10.2 um
BY-201	Cyc/Imp 2m DW	353.9	1080.9
	Cyc/Imp 4.5m DW	159.3	549.2
BY-301	Cyc/Imp 2m UW	2.6	2.5
	Cyc/Imp 4.5m UW	4.4	4.0
	Cyc/Imp 2m DW	6.7	10.0
	Cyc/Imp 4.5m DW	16.9	11.6
BY-401/501	Cyc/Imp 2m UW	9.6	11.9
	Cyc/Imp 4.5m UW	4.8	5.3
	Cyc/Imp 2m DW	30.1	62.7
	Cyc/Imp 4.5m DW	21.1	19.3
BY-601/701	Cyc/Imp 2m UW	1.1	-4.1
	Cyc/Imp 4.5m UW	2.2	-2.2
BY-601	Cyc/Imp 2m DW	71.8	141.5
	Cyc/Imp 4.5m DW	16.8	6.9
BY-701	Cyc/Imp 2m DW	15.6	72.4
	Cyc/Imp 4.5m DW	-1.1	2.1

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b	m	p	Set Flow Rate Delta P	Std Flowrate	Actual Flowrate
-0.0785	0.00148	2.07	0.60	19.30	**20.0**
0.0823	0.00107	2.07	0.60	19.81	**20.5**
0.0344	0.00119	2.07	0.60	19.64	**19.9**
0.0917	0.00105	2.07	0.60	19.82	**20.1**
-0.0785	0.00148	2.07	0.60	19.30	**19.5**
0.0823	0.00107	2.07	0.60	19.81	**20.0**
0.0344	0.00119	2.07	0.60	19.64	**20.2**
0.0917	0.00105	2.07	0.60	19.82	**20.4**
-0.0785	0.00148	2.07	0.60	19.30	**19.8**
0.0823	0.00107	2.07	0.60	19.81	**20.4**
0.0344	0.00119	2.07	0.60	19.64	**20.0**
0.0917	0.00105	2.07	0.60	19.82	**20.2**
-0.0785	0.00148	2.07	0.60	19.30	**19.4**
0.0823	0.00107	2.07	0.60	19.81	**19.9**
-0.0785	0.00148	2.07	0.60	19.30	**20.1**
0.0823	0.00107	2.07	0.60	19.81	**20.6**

Appendix G

Deramus Field Station Sampling Data

UNCONTROLLED

Master

	Phase	Number of Passes	Percent Moisture					Soil	Vehicle	Type of Test	Distance From Access	Area sampled (ft²)	Bag	Tare Weight (g)	Final Weight (g)	Difference (g)	Empty Bag (g)	Nonrecoverable mass (g)	Total loading (g/m)	f	sL_{lower}	sL_{upper}	silt content	10 mesh (%)	20 mesh (%)	40 mesh (%)	100 mesh (%)	140 mesh (%)	200 mesh (%)	Pan (%)
			1st	2nd	3rd	4th	Ave.																							
1	phase 1-1	100	4.2	4.9			4.6	native	pickup	calibration	10	250	9901	59.9	177.3	117.4	62.5	2.6	1.54	0.15	0.23	0.26	0.17	30.4	14.1	11.6	19.6	4.6	4.6	15.0
2	phase 1-1	100	4.2	4.9			4.6	native	pickup	calibration	50	250	9902	61.5	76.8	15.3	61.8	0.3	0.20	0.14	0.03	0.03	0.16	12.9	19.4	23.0	18.7	8.6	2.9	14.4
3	phase 1-1	100	4.2	4.9			4.6	native	pickup	calibration	90	250	9903	60.4	103.6	43.2	61.4	1.0	0.57	0.09	0.05	0.06	0.11	44.0	19.3	14.4	11.0	1.5	1.2	8.6
4	phase 1-1	100	4.2	4.9			4.6	native	pickup	calibration	130	250	9904	62.0	77.8	15.8	62.7	0.7	0.21	0.08	0.02	0.02	0.12	20.0	28.6	25.0	12.9	3.6	2.1	7.9
5	phase 1-2	100	14.3	10.4	7.2	6.0	9.5	native	pickup	calibration	10	250	9905	62.4	235.1	172.7	65.6	3.2	2.27	0.05	0.12	0.16	0.07	34.7	20.9	21.2	13.3	3.6	1.2	5.1
6	phase 1-2	100	14.3	10.4	7.2	6.0	9.5	native	pickup	calibration	50	250	9906	61.3	161.9	100.6	63	1.7	1.32	0.08	0.11	0.13	0.10	22.3	19.6	21.2	23.3	2.8	2.7	8.1
7	phase 1-3	50	25.0	18.9	20.4		21.4	native	pickup	calibration	130	250	9907	61.4	396.5	335.1	63.3	1.9	4.40	0.08	0.33	0.35	0.08	9.2	20.0	30.5	26.4	4.4	1.9	7.5
8	phase 1-3	50	25.0	18.9	20.4		21.4	native	pickup	calibration	90	250	9908	61.3	286.7	225.4	62.5	1.2	2.96	0.06	0.18	0.19	0.07	26.4	24.0	21.8	18.8	1.6	1.4	6.1
9	phase 1-3	50	25.0	18.9	20.4		21.4	native	pickup	calibration	50	250	9909	61.3	549.0	487.7	63.9	2.6	6.40	0.09	0.58	0.61	0.10	16.9	22.9	23.9	19.7	5.3	2.2	9.1
10	phase 1-3	50	25.0	18.9	20.4		21.4	native	pickup	calibration	10	250	9910	61.5	661.6	600.1	62.8	1.3	7.88	0.05	0.39	0.40	0.05	17.5	27.4	25.2	21.4	1.9	1.6	4.9
11	phase 1A-1	50	23.6	24.6			24.1	native	pickup	calibration/uncontrolled	5	250	9911	61.2	1102.9	1041.7	62.6	1.4	13.67	0.06	0.88	0.90	0.07	37.2	26.7	14.4	11.9	1.7	1.7	6.4
12	phase 1A-1	50	23.6	24.6			24.1	native	pickup	calibration/uncontrolled	45	250	9912	61.2	978.2	917.0	64.8	3.6	12.03	0.08	0.93	0.97	0.08	50.6	17.6	11.7	7.6	3.4	1.3	7.7
13	phase 2-1	50	6.1	5.1	5.2		5.5	sandy	pickup	uncontrolled	5	250	9913	61.1	249.7	188.6	62.7	1.6	2.48	0.17	0.43	0.44	0.18	16.5	19.9	20.2	20.2	3.0	3.0	17.2
14	phase 2-2	50	14.1	10.0			12.1	sandy	pickup	uncontrolled	5	250	9914	60.9	580.0	519.1	63.7	2.8	6.81	0.10	0.69	0.72	0.11	20.0	24.2	27.6	12.6	4.0	1.4	10.1
15	phase 2-3	50	8.8	8.3	6.6		7.9	sandy	pickup	uncontrolled	5	250	9915	60.0	366.6	306.6	61.7	1.7	4.02	0.13	0.52	0.54	0.13	21.2	25.0	23.2	14.5	1.6	1.7	12.9
16	phase 2-4	50	17.6	17.1			17.4	sandy	pickup	uncontrolled	5	250	9916	61.1	620.7	559.6	64.2	3.1	7.34	0.12	0.90	0.93	0.13	25.0	22.5	23.1	12.1	3.6	1.6	12.2
17	phase 2-5	50	11.1	10.0	7.2		9.4	sandy	pickup	uncontrolled	5	250	9917	59.0	419.3	360.3	62	3.0	4.73	0.20	0.96	0.99	0.21	13.7	20.7	25.5	14.9	2.8	2.0	20.4
18	phase 3-1	50	11.1	10.0	7.2		9.4	sandy	pickup	paved apron	25	250	9918	60.5	197.9	137.4	61.6	1.1	1.80	0.25	0.44	0.45	0.25	13.9	21.6	20.9	15.2	1.7	2.1	24.5
19	phase 2-6	50	17.4	12.1	14.0		14.5	native	pickup	uncontrolled	5	250	9919	60.9	771.8	710.9	64.4	3.5	9.33	0.16	1.48	1.52	0.16	26.1	19.9	16.3	15.7	3.4	2.8	15.9
20	phase 3-2	50	17.4	12.1	14.0		14.5	native	pickup	paved apron	25	250	9920	60.3	272.2	211.9	61.9	1.6	2.78	0.17	0.48	0.50	0.18	20.0	20.8	15.9	19.0	3.3	3.7	17.2
21	phase 2-7	50	19.4	19.5	19.1		19.3	sandy	pickup	uncontrolled	5	250	9921	60.9	365.7	304.8	64.5	3.6	4.00	0.21	0.83	0.87	0.22	17.9	18.5	23.0	14.9	2.9	2.1	20.8
22	phase 3-3	50	19.4	19.5	19.1		19.3	sandy	pickup	paved apron	25	250	9922	61.2	237.3	176.1	63.4	2.2	2.31	0.27	0.63	0.66	0.28	10.1	17.9	22.3	17.6	2.1	2.4	27.4
23	phase 2-8	54	24.2	25.7			25.0	native	pickup	uncontrolled	5	250	9923	62.3	1321.1	1258.8	67.2	4.9	16.52	0.08	1.40	1.46	0.09	26.8	23.9	18.6	16.2	3.5	2.5	8.5
24	phase 3-4	54	24.2	25.7			25.0	native	pickup	paved apron	25	250	9924	62.2	936.6	874.4	66.7	4.5	11.48	0.06	0.71	0.76	0.07	48.8	20.4	10.8	10.0	2.0	1.8	6.2
25	phase 2-9	50	17.0	18.7	14.5		16.7	sandy	pickup	uncontrolled	5	250	9925	59.5	338.5	279.0	61.2	1.7	3.66	0.22	0.81	0.83	0.23	18.7	20.5	20.2	13.8	2.6	2.2	22.1
26	phase 3-5	50	17.0	18.7	14.5		16.7	sandy	pickup	paved apron	25	250	9926	57.7	225.0	167.3	59	1.3	2.20	0.20	0.43	0.45	0.20	18.5	23.7	20.1	14.5	1.8	1.8	19.7
27	phase 2-10	50	15.7	24.5			20.1	native	pickup	uncontrolled	5	250	9927	58.0	770.0	712.0	60.6	2.6	9.34	0.17	1.56	1.59	0.17	15.6	24.0	19.3	17.6	3.8	3.1	16.7
28	phase 3-6	50	15.7	24.5			20.1	native	pickup	paved apron	25	250	9928	57.9	560.1	502.2	61.2	3.3	6.59	0.15	0.97	1.01	0.15	24.2	24.6	16.2	15.2	2.5	2.6	14.7
29	phase 2-11	50	19.3	17.4			18.4	sandy	pickup	uncontrolled	5	250	9929	54.9	174.7	119.8	55.9	1.0	1.57	0.21	0.32	0.33	0.21	12.5	22.2	22.9	16.0	3.7	2.3	20.5
30	phase 3-7	50	19.3	17.4			18.4	sandy	pickup	paved apron	25	250	9930	55.0	153.7	98.7	55.6	0.6	1.30	0.18	0.24	0.24	0.19	14.9	22.1	23.1	17.7	2.0	2.0	18.3
31	phase 1A-2	50	16.8	22.6			19.7	native	pickup	calibration	45	250	9931	55.3	699.7	644.4	59.1	3.8	8.46	0.10	0.82	0.87	0.10	42.8	20.2	12.8	10.6	2.1	1.7	9.7
32	phase 3-8	50	16.8	22.6			19.7	native	pickup	paved apron	25	250	9932	55.8	693.9	638.1	58.4	2.6	8.37	0.11	0.91	0.94	0.11	39.4	22.5	12.1	11.2	1.9	2.0	10.8
33	phase 2-12	50	16.8	22.6			19.7	native	pickup	calibration/uncontrolled	5	250	9933	55.6	1068.4	1012.8	58.4	2.8	13.29	0.12	1.59	1.62	0.12	26.1	23.5	16.2	16.6	2.8	2.8	12.0
34	phase 2-13	50	22.8	18.2			20.5	sandy	pickup	uncontrolled	5	250	9934	55.7	221.2	165.5	58.3	2.6	2.17	0.22	0.47	0.50	0.23	18.3	20.5	20.4	13.6	3.2	2.1	21.8
35	phase 3-9	50	22.8	18.2			20.5	sandy	pickup	paved apron	25	250	9935	55.7	198.5	142.8	57.4	1.7	1.87	0.17	0.32	0.34	0.18	27.4	20.7	19.2	10.6	3.6	1.5	16.9
36	phase 2-14	50	31.2	16.3			23.8	native	pickup	uncontrolled	5	250	9936	55.6	578.6	523.0	60.3	4.7	6.86	0.22	1.53	1.57	0.23	19.1	20.2	16.4	15.6	3.4	3.0	22.2
37	phase 3-10	50	31.2	16.3			23.8	native	pickup	paved apron	25	250	9937	55.5	381.7	326.2	59.6	4.1	4.28	0.19	0.80	0.85	0.20	22.9	22.8	14.9	15.1	2.6	2.9	18.8
38	phase 2-15	50	19.2	19.1			19.2	sandy	pickup	uncontrolled	5	250	9938	58.9	439.8	380.9	63	4.1	5.00	0.09	0.44	0.49	0.10	27.5	26.9	20.0	15.5	0.0	1.3	8.8
39	phase 3-11	50	19.2	19.1			19.2	sandy	pickup	paved apron	25	250	9939	57.9	329.3	271.4	59.5	1.6	3.56	0.13	0.47	0.49	0.14	27.6	21.8	19.9	13.1	2.5	1.7	13.3
40	phase 2-16	50	35.6	29.4			32.5	native	pickup	uncontrolled	5	250	9940	57.3	530.4	473.1	59.5	2.2	6.21	0.15	0.92	0.95	0.15	32.5	22.2	12.9	12.8	2.3	2.4	14.9
41	phase 3-12	50	35.6	29.4			32.5	native	pickup	paved apron	25	250	9941	57.7	368.3	310.6	59.6	1.9	4.08	0.15	0.61	0.63	0.15	34.3	21.9	12.1	13.8	1.1	1.9	14.9
42	phase 2-17	50	19.8	12.8	11.5		14.7	native	dump truck	uncontrolled	5	250	9942	57.8	1511.0	1453.2	61	3.2	19.07	0.21	4.09	4.12	0.22	24.2	16.8	15.7	15.4	3.5	3.0	21.4
43	phase 2-18	50	19.8	12.8	11.5		14.7	sandy	dump truck	uncontrolled	5	250	9943	57.8	695.8	638.0	60.8	3.0	8.37	0.27	2.26	2.29	0.27	10.7	16.0	21.0	19.0	2.9	3.2	27.0
44	phase 2-19	50	21.2	14.8	25.5		20.5	native	dump truck	uncontrolled	5	250	9944	55.6	1081.2	1025.6	59.3	3.7	13.46	0.22	2.96	3.00	0.22	22.9	19.4	14.6	15.3	3.1	2.7	22.0
45	phase 2-20	50	15.6	26.1	11.2		17.6	sandy	dump truck	uncontrolled	5	250	9945	55.9	925.4	869.5	59	3.1	11.41	0.30	3.38	3.41	0.30	14.1	17.6	19.8	14.1	2.5	2.3	29.6
46	phase 4-1	50	13.2	10.2			11.7	sandy	pickup	gravel apron	5	250	9946	55.3	341.2	285.9	58.2	2.9	3.75	0.17	0.65	0.68	0.18	8.8	16.9	24.7	27.9	2.2	2.2	17.3
47	phase 4-2	50	24.2	21.0			22.6	native	pickup	gravel apron	5	250	9947	55.6	518.5	462.9	59.2	3.6	6.07	0.30	1.80	1.83	0.30	13.2	17.0	15.5	17.5	3.7	3.4	29.7
48	phase 4-3	50	14.4	12.1			13.3	sandy	pickup	gravel apron	5	250	9948	55.7	586.0	530.3	58.2	2.5	6.96	0.14	0.98	1.01	0.14	17.5	18.4	25.0	21.1	2.3	1.7	14.1
49	phase 4-4	50	29.1	25.9			27.5	native	pickup	gravel apron	5	250	9949	55.5	318.6	263.1	58.5	3.0	3.45	0.29	1.01	1.04	0.30	10.1	17.6	16.1	18.9	3.7	4.2	29.3
50	phase 4-5	50	17.2	11.9			14.6	sandy	pickup	gravel apron	5	250	9950	57.2	671.4	614.2	60.2	3.0	8.06	0.16	1.27	1.30	0.16	14.3	19.5	23.1	23.5	2.2	1.7	15.7
51	phase 4-6	50	30.2	28.0			29.1	native	pickup	gravel apron	5	250	9951	56.7	785.5	728.8	60.3	3.6	9.56	0.28	2.67	2.70	0.28	15.3	16.9	15.8	16.7	3.8	3.5	27.9
52	phase 4-7	50	17.7	15.7			16.7	sandy	pickup	gravel apron	5	250	9952	62.6	836.7	774.1	66.5	3.9	10.16	0.17	1.77	1.82	0.18	15.8	19.3	20.3	21.9	2.5	2.6	17.5
53	phase 4-8	50	33.9	30.2			32.1	native	pickup	gravel apron	5	250	9954	62.6	627.6	565.0	66.6	4.0	7.41	0.23	1.73	1.77	0.24	17.4	19.8	15.3	17.3	3.7	3.1	23.3
54	phase 4-9	50	4.8	5.1	4.3		4.7	sandy	pickup	gravel apron	5	250	9955	61.6	277.5	215.9	63.8	2.2	2.83	0.19	0.53	0.56	0.20	13.2	20.8	25.0	18.9	2.0	1.4	18.8
55	phase 4-10	50	11.4	16.0	13.1		13.5	native	pickup	gravel apron	5	250	9956	62.3	270.3	208.0	64.5	2.2	2.73	0.25	0.68	0.70	0.26	16.4	24.0	16.1	13.7	2.2	2.6	25.0
56	phase 4-11	50	4.1	4.4			4.3	sandy	pickup	gravel apron	5	250	9957	61.7	152.4	90.7	63.1	1.4	1.19	0.21	0.25	0.27	0.22	15.9	22.8	19.8	17.5	1.7	1.2	21.1
57	phase 4-12	50	15.8	12.3			14.1	native	pickup	gravel apron	5	250	9958	62.3	474.5	412.2	65.4	3.1	5.41	0.34	1.86	1.88	0.35	6.3	14.5	17.5	18.8	4.6	4.0	34.3
58	phase 4-13	50	12.8	8.1			10.5	sandy	pickup	gravel apron	5	250	9959	61.9	466.7	404.8	64.7	2.8	5.31	0.26	1.40	1.43	0.27	7.6	15.5	19.9	24.3	3.1	3.2	26.4