Emission Tests of Paved Road Traffic at Minnesota Corn Processors Marshall, Minnesota, Facility

Revised Test Report

For
McVehil-Monnett Associates

MRI Project No. 310212.1.001

July 6, 2001

Emission Tests of Paved Road Traffic at Minnesota Corn Processors Marshall, Minnesota, Facility

Revised Test Report

For
McVehil-Monnett Associates
44 Inverness Drive East
Building C
Englewood, Colorado 80112

MRI Project No. 310212.1.001

July 6, 2001

Preface

This report presents the results from a field testing program conducted to evaluate emissions from paved roads at Minnesota Corn Processors' plant in Marshall, Minnesota. The report has been prepared under a contract with McVehil-Monnett Associates (MMA) and has been submitted to the state of Minnesota for review and comment. Dr. George McVehil is MMA's program manager. Dr. Gregory E. Muleski served as MRI's project leader and authored this report. The assistance of Mr. Ken Muhl in coordinating activities at the plant is gratefully acknowledged.

MIDWEST RESEARCH INSTITUTE

Dr. Gregory E. Muleski
Principal Environmental Engineer

Approved:

Paul C. Constant
Acting Director
Applied Engineer

July 6, 2001

Contents

Appendices

Figures

Tables

Section 1.
Introduction

The U. S. Environmental Protection Agency's (EPA's) *Compilation of Air Pollutant Emission Factors* (commonly referred to as "AP-42")[1] contains factors commonly used to estimate particulate matter (PM) emissions at industrial operations. EPA guidance[2] notes that AP-42 emission factors are best viewed as representative of long-term conditions for all facilities within a source category (i.e., a population average). Furthermore, the EPA guidance[2] also notes that test data supporting AP-42 factors are usually insufficient to fully indicate the effect of various source parameters on emission levels.

These points are particularly relevant to the paved road emission factor predictive equation presented in Section 13.2.1 of AP-42:

$$e = k\,(sL/2)^{0.65}\,(W/3)^{1.5} \tag{1-1}$$

e = particulate emission factor in pounds emitted per vehicle mile traveled (lb/vmt)

k = base emission factor
= 0.016 lb/vmt for particulate matter no greater than 10 microns in aerodynamic diameter (PM-10)
= 0.082 lb/vmt for total suspended particulate (TSP)

sL = surface "silt loading" which consists of mass of dried sub-200 mesh material per unit area of road surface (g/m^2)

W = average weight (ton) of vehicles traveling the road

The AP-42 emission factor model has been used to estimate PM emissions at Minnesota Corn Processors' (MCP's) plant in Marshall, Minnesota. However, in this instance, the AP-42 model has been applied to situations far beyond what is represented in the supporting data base. AP-42 states that Equation 1-1 is based on tests of emissions from freely flowing traffic moving at fairly constant speed and that no tests from slow-moving "stop-and-go" traffic are included in the data base. Traffic into and out of the MCP plant involves trucks queuing up to unload corn with frequents starts and stops. Furthermore, the plant enforces a strict speed limit of 5 mph when vehicles are moving; this is well below any of the vehicle travel speeds in the AP-42 data base.

This report presents particulate emission data specifically related to the Marshall plant. During April 2001, tests of both stop-and-go and slowly moving (5 mph) traffic were conducted at the plant. The site-specific data developed from the test program describe the actual PM emissions from paved roads at the Marshall facility better than the AP-42 factor.

It is important to note that the field program described in this report applied the exposure profiling method, which is **the same fundamental emission measurement methodology** used to develop the AP-42 data base. In other words, data generated from the field program described in this report are directly comparable to the test data supporting AP-42.

The remainder of this report is structured as follows. Section 2 presents a brief description of the test site as well as general test objectives and procedures. Section 3 provides detailed information on the test methodology. Section 4 presents and discusses the test results obtained. Section 5 lists the references cited. Appendix A presents quality assurance and quality control guidelines for the testing, while Appendix B presents detailed test results.

Section 2.
General Description of the Test Program

This section describes the test location site and lists the general objectives and procedures to be followed in the test program.

2.1 Description of the MCP Marshall Facility

Figure 2-1 presents a plan view of the Marshall facility. A previous emission inventory showed that over half of the AP-42 estimated paved road emission total for the facility is due to receipts of corn. However, corn trucks are often forced to wait in a queue up to four lanes wide before dumping. During this time, the trucks operate in a stop-and-go manner rather than in the freely moving condition inherent in the tests that underlie the AP-42 model.

The exposure profiling test method (as described in the next section) requires open space upwind and downwind of the source. With the exception of roads in the immediate vicinity of the corn receiving area, roadways at the Marshall plant are largely surrounded by buildings. As a practical matter, testing focused on the roadways aligned roughly northwest to southeast in Figure 2-1.

Specific test sites at the Marshall plant are discussed in Section 4.

2.2 Test Objectives

The overall purpose of the test program was to develop site-specific, measurement-based emission factors for paved roads at the Marshall facility. Specifically, the objectives were to develop measured emission factors that represent either (a) the stop-and-go nature of traffic at the Marshall facility or (b) the slowly moving (5 mph) traffic at the plant. Testing relied on the same exposure profiling test method used to develop the AP-42 data set. Road surface material samples were collected in connection with each test so that test results could be directly compared to the emission factor predicted from the AP-42 model (Equation 1-1).

Both emission sources of interest in this study—stop-and-go queuing and low-speed travel of trucks—can be represented as "line sources." Used in this context, a "line source" is an elongated source whose length is much greater than the distance from the source to the sampling array. All tests in the AP-42 paved road data are based on a line source representation of moving traffic.

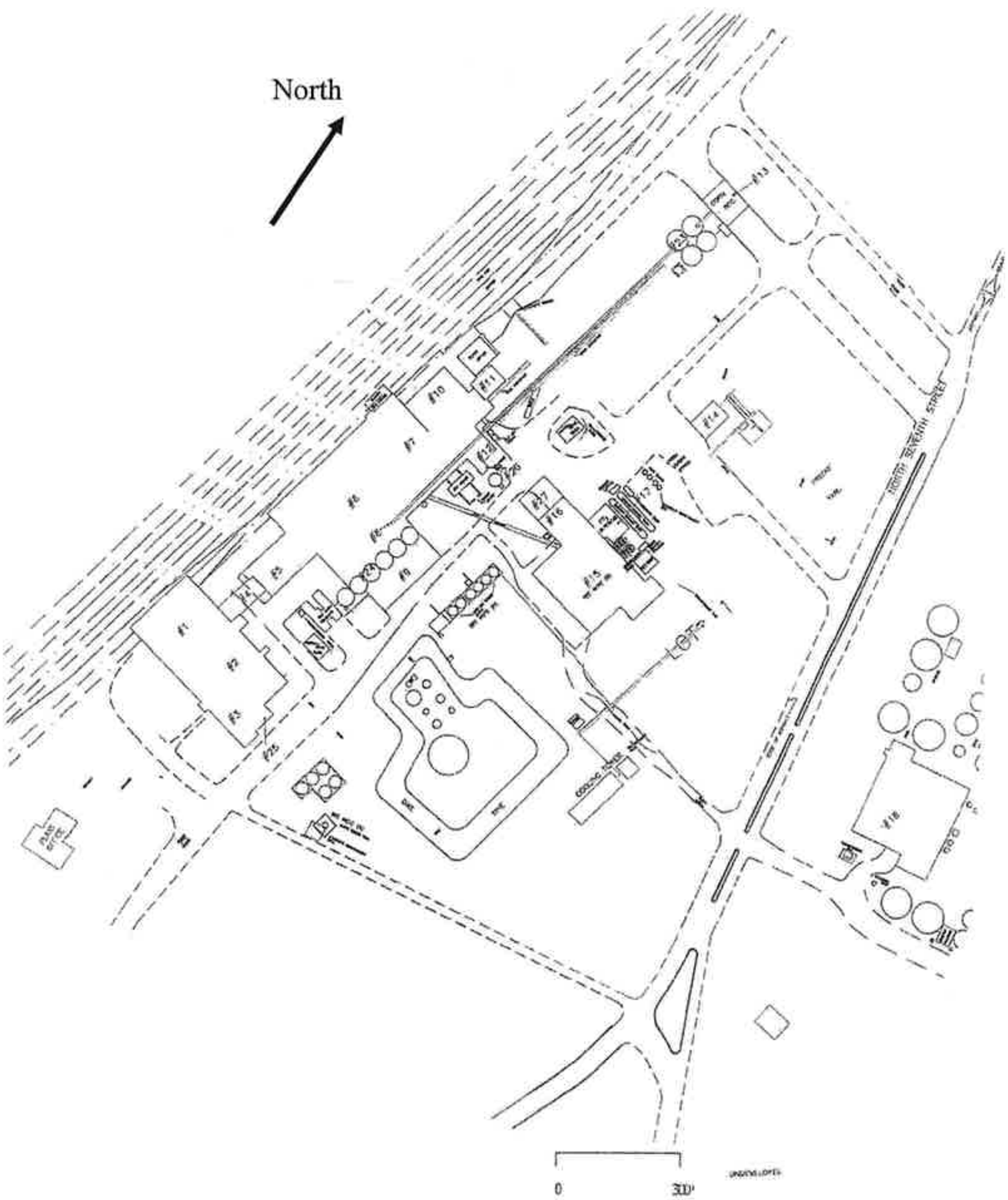
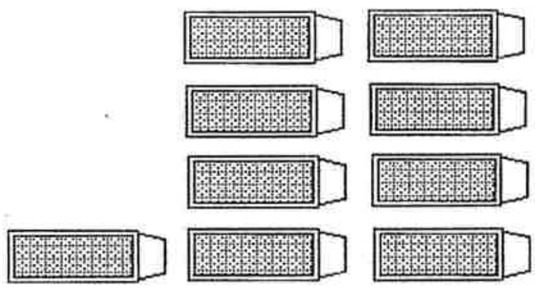


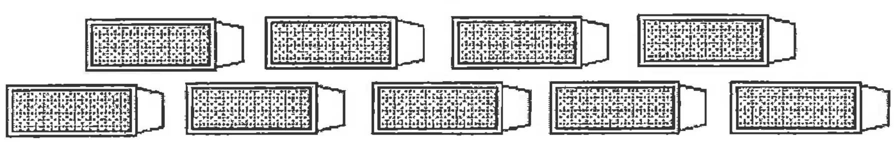
Figure 2-1. MCP Marshall Plant

Furthermore, trucks queued at Marshall represent a line source in that all emissions (whether travel- or exhaust-related) occur along the path of motion. Natural variability in wind conditions smears the emissions along the length of the queue.

Slight modifications of normal operations were made to facilitate testing at Marshall. For example, to better approximate a line source during test periods, trucks were queued in only two lanes rather than the customary three or four parallel lanes. This extended the source to accentuate the length in relationship to the distance to the samplers. To promote uniformity in emissions along the line source, trucks were (to the extent practical) "staggered" along two lanes rather than lining up wheel-to-wheel (Figure 2-2).



(a)



(b)

Figure 2-2. Illustration of How Truck Queue Was Modified for Testing Purposes: (a) Customary Truck Queue Over 4 Lanes; (b) Trucks "Staggered" Over 2 Lanes to Accentuate Length and Uniformity of "Line Source"

Section 3.
Test Methodology

This section discusses the exposure profiling sampling methodology employed in the program. MRI developed exposure profiling during the early 1970s and has applied the concept to a wide variety of open fugitive emission sources. AP-42 emission factors based on exposure profiling test results first appeared in 1976. Exposure profiling is EPA's preferred method to characterize emissions from fugitive dust sources. Open source emission factors based on the method typically have the highest quality ratings in AP-42.

3.1 Description of Exposure Profiling Test Method

The exposure profiling test method has been recognized by EPA as the technique most appropriate to characterize the broad class of open anthropogenic PM sources, such as material transfer and 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[1] are typically based on this approach.

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 emission rate and the air flow (i.e., ambient wind) are non-steady. This requires simultaneous multipoint sampling of mass concentration and air flow over the effective area of the emission plume. As noted above, the two emission sources of interest in this study—stop-and-go queuing and low-speed travel of trucks—can be represented as "line sources." When applied to line sources, the exposure profiling test method requires a vertically oriented array of sampling points.

The sampling deployment described below is fundamentally identical to that used to develop the test data base for the AP-42 emission factor equation. As such, the emission test data for slowly moving traffic at Marshall were reduced and analyzed in exactly the same manner as tests in the AP-42 data base. That is to say, the measured emission factor has been expressed in terms of mass emitted per unit of vehicle travel (e.g., lb/vmt). On the other hand, tests of trucks moving in a stop-and-go fashion were not associated with the passage of individual vehicles past the sampling array. Instead, emissions can be viewed as smeared along the length of the source, and the source strength was expressed in terms of the average emission rate (mass/length-time) during the test period.

Two vertical networks of samplers (Figure 3-1) were positioned just downwind and upwind from the edge of the source. 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 3-2). The cyclone exhibits an effective 50 percent cutoff diameter (D_{50}) of approximately 10 µmA when operated at a flow rate of 40 cfm (68 m^3/h).[3] Thus, mass collected on the 8- by 10-inch backup filter represents a PM-10 sample.

Besides the air sampling equipment, Figure 3-1 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) was used to record wind speed and direction at the 3.0 m height. All wind data were accumulated into 5-min averages logged with a 26700 series R. M. Young "programmable translator."

Sampling activities were subject to the quality assurance/quality control (QA/QC) guidelines discussed in detail in Appendix A. Note that these are the same QA/QC guidelines used to conduct the tests contained in the AP-42 paved road data base.

3.2 Data Analysis

To calculate measurement-based emission rates and emission factors 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 concentration of particulate matter measured by a sampler is given by:

$$C = m/QT \qquad (3\text{-}1)$$

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)

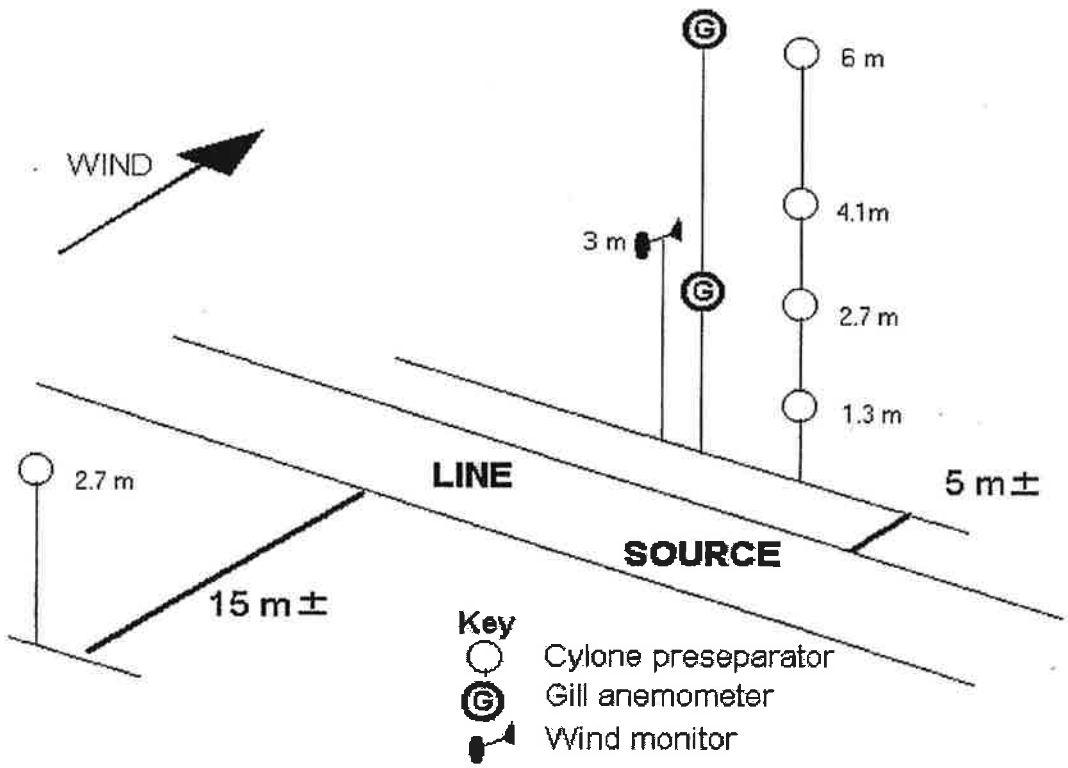


Figure 3-1. Sampler Deployment for Line Sources

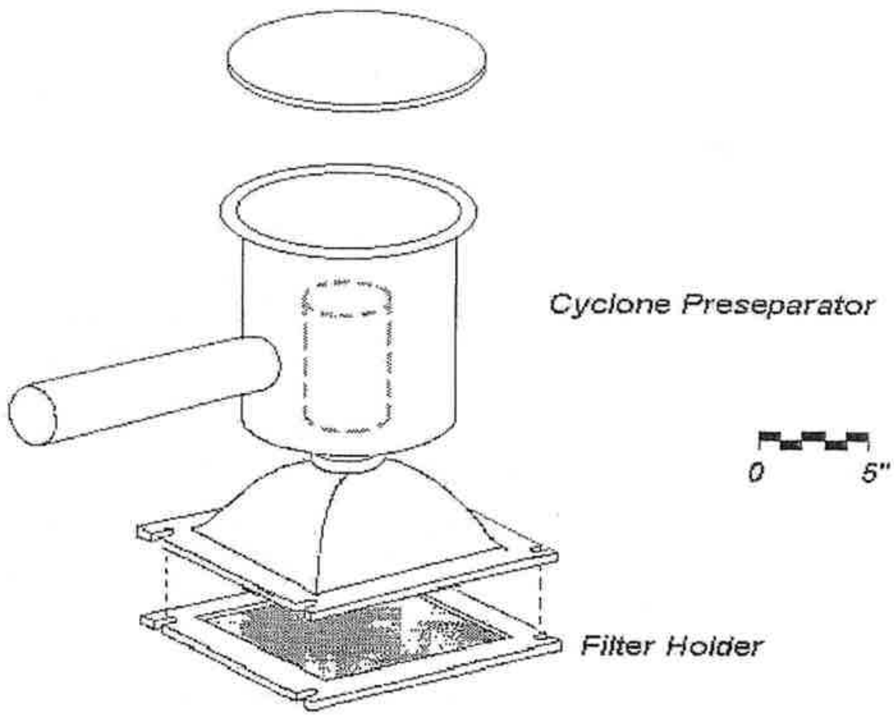


Figure 3-2. Cyclone Preseparator

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:

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

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. Because the primary interest is directed to PM-10, sampling under moderately nonisokinetic conditions poses 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 [4].

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

$$E = (C - C_b)\, U\, T \qquad (3\text{-}3)$$

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)

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:

$$A_1 = \int_0^H E\, dh \qquad (3\text{-}4)$$

where A_1 = 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 points within the plume, a numerical integration is necessary to determine the integrated exposure. For 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 the lowest sampling height. The integration is performed using the trapezoidal rule.

The measured 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 slowly moving traffic, the normalization process is the same as earlier tests supporting the AP-42 paved road emission factor model. In this case, the integrated exposure is divided by the number of vehicle passes during the emission test to express emissions in terms of mass emitted per vehicle distance traveled:

$$e = A_l / N \tag{3-5}$$

where e = measured emission factor (mass/vehicle-length)
A_l = integrated exposure for a line source (mass/length)
N = number of vehicle passes during the test

Emission measurements for the queued traffic can follow a different type of normalization. In this instance, emissions will be characterized in terms of PM mass emitted per time per unit length of the line source. In addition, the rate can be normalized to a single queue lane:

$$r = A_l / (T\ L) \tag{3-6}$$

where r = line source emission rate (mass/time-length)
A_l = integrated exposure for a line source (mass/length)
T = duration of sampling (time)
L = number of lanes used to queue traffic

Section 4.
Test Results and Discussion

This section presents and discusses the results from the field test program carried out at the Marshall MCP plant during April 2001.

4.1 Paved Road Emission Test Results

Nine PM-10 emission tests were conducted between April 17 through 24, 2001. The total comprises three tests of stop-and-go traffic and six tests of low-speed traffic. In addition, because of the low level of emissions encountered during the tests, a separate upwind sampling array was operated as Run CE-18 in conjunction with Run CE-19. This arrangement permitted far better definition of the net contribution of roadway emissions throughout the downwind plume height. As a result, greater confidence can be placed on the CE-19 results.

Table 4-1 lists the test site parameters associated with each run, and Table 4-2 presents traffic data. Test locations are shown in Figure 4-1. Note that the plant provided "drone" passes by loaded corn semi-trailers to supplement traffic during test periods.

Tests generally lasted 3 to 4 hr in order to collect adequate sample mass on both the upwind and downwind samplers. A minimally detectable (with a confidence level of 95%) PM-10 concentration of approximately 7 $\mu g/m^3$ was derived, based on the following:

- The average blank value (0.7 mg) plus two times the standard deviation (0.36 mg) of the blanks. This produces a value of 0.7 + 2 (0.36) = 1.4 mg.
- A nominal 40 cfm sampling rate
- A nominal minimum sampling duration of 3 hours

Table 4-3 lists measured concentrations and exposure values for the different sampling locations. The measured concentrations were all several times greater than the minimally detectable concentration value of 7 $\mu g/m^3$.

As discussed in preceding sections, the point values of exposure in Table 4-3 were integrated over the height of the plume to develop the emission rates and factors. Those results are shown in Table 4-4, together with the road surface silt loading data collected during the field exercise. Also shown are the AP-42 predicted emission factors calculated from Equation 1-1.

Table 4-1. Test Site Parameters[a]

Run No.	Source	Date	Start time	Duration (min)	Test site[a]	Mean wind speed[b] (mph)	Nominal wind direction[b]	Ambient temp. (°F)	Baro. pressure (in. Hg)
CE-1	Stop-and-go	04/17/01	13:31	144	1	3.14	NNE	54	29.6
CE-2	Stop-and-go	04/18/01	8:14	180	1	7.51	SSW	47	29.3
CE-11	Low Speed	04/18/01	8:20	174	2	7.59	SSW	46	29.2
CE-3	Stop-and-go	4/18/01	12:45	180	1	7.44	SSW	68	29.1
CE-12	Low Speed	4/18/01	12:46	179	2	7.44	SSW	66	29.2
CE-15[c]	Low Speed	4/19/01	14:26	118	3a	15.2	ESE	67	28.7
CE-16	Low Speed	4/20/01	8:33	289	3a	9.34	WNW	64	28.7
CE-17	Low Speed	4/20/01	8:51	271	3a	9.41	WNW	64	28.7
CE-18	Upwind[d]	4/24/01	8:09	418	1	5.52	SSW	55	29.3
CE-19	Low Speed	4/24/01	8:10	417	1	5.52	SSW	55	29.3

[a] Refer to Figure 4-1 for test site locations. Test site code refers to sites identified in the test plan.
[b] Wind conditions during test. Mean wind speed refers to speed measured at 5.4 m (17' 9") height during test. Nominal direction refers to cardinal direction most nearly perpendicular to line source.
[c] Run CE-13 was a run with blank filters; Run CE-14 was aborted due to poor wind conditions.
[d] Upwind background test conducted to better define net contribution from road during Run CE-19.

Table 4-2. Traffic During Tests

Run No.	Source	Avg. number of trucks[a] per hr	Average total number trucks in 2 lines	Corn receipts[b] (bu) during test	Number of vehicle passes[a] during test
CE-1	Stop-and-go	37.8	9.2	79,264	–
CE-2	Stop-and-go	32.0	9.8	91,458	–
CE-11	Low Speed	34.8	–	–	104
CE-3	Stop-and-go	47.0	8.9	89,164	–
CE-12	Low Speed	48.3	–	–	144
CE-15	Low Speed	29.5	–	–	58
CE-16	Low Speed	28.4	–	–	145
CE-17	Low Speed	28.8	–	–	138
CE-18	Upwind	–	–	–	–
CE-19	Low Speed	61.4	–	–	427

[a] Includes only corn trucks and other semis.
[B] Actual corn receipts during test.(i.e., not increased by "drone" passes used to increase truck queue).

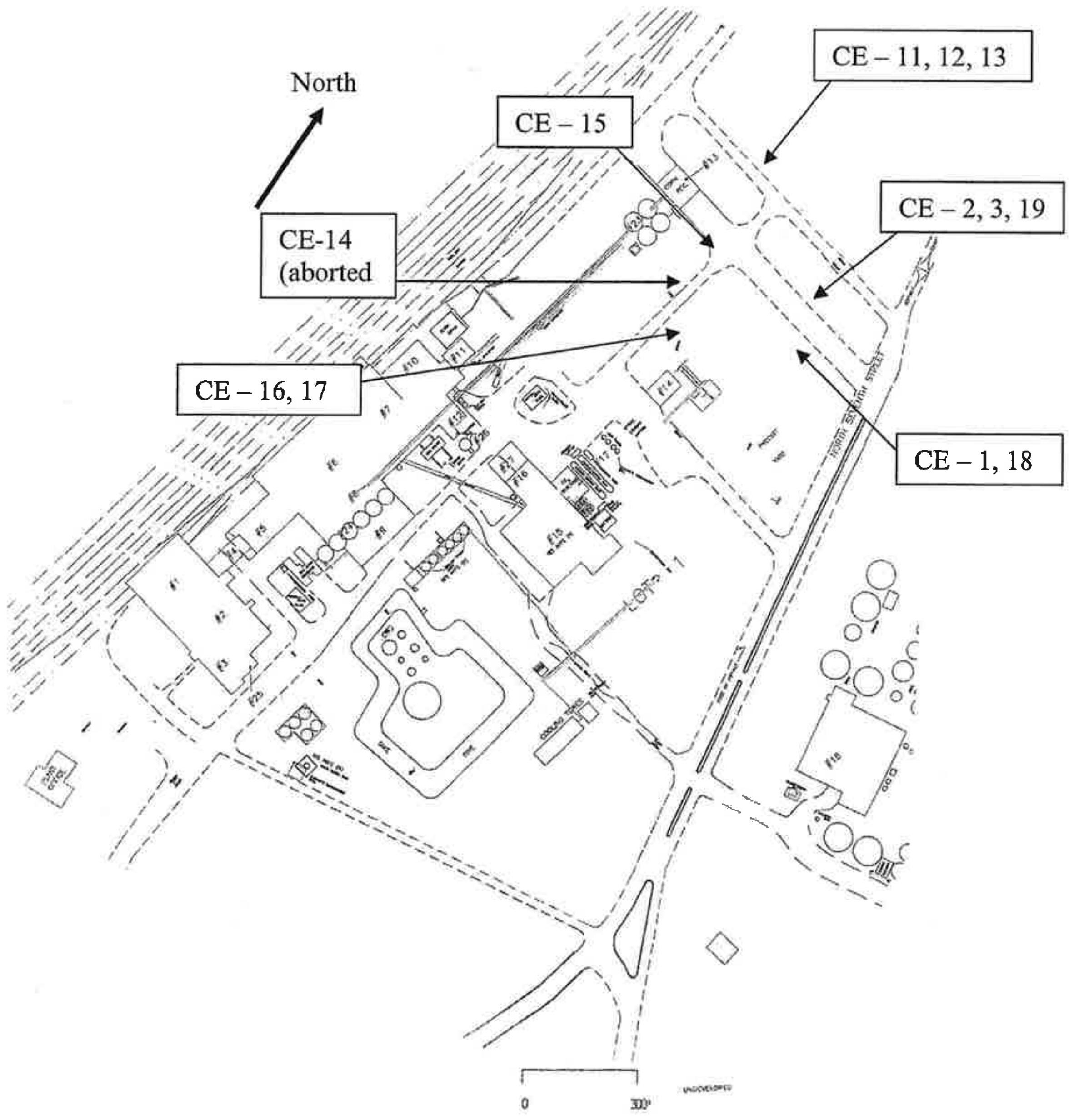


Figure 4-1. Test Site Downwind Sampling Locations

Table 4-3. Plume Sampling Data

Run	Sampler height (m) / location[a]	Downwind PM-10 concentration (μg/m³)	Net PM-10 concentration (μg/m³)	Wind speed (mph)	PM-10 exposure (mg/cm²)
CE-1	1.3 DW	66.8	38.0	0.50	0.00736
	2.7 DW	42.2	13.4	1.86	0.00960
	4.1 DW	36.1	7.4	2.63	0.00751
	6.0 DW	57.2	28.4	3.34	0.0366[b]
	3.0 UW	28.8			
CE-2	1.3 DW	80.4	32.0	5.14	0.0795
	2.7 DW	79.8	31.5	6.36	0.0966
	4.1 DW	60.0	11.7	7.05	0.0397
	6.0 DW	50.1	1.8	7.69	0.00655
	3.0 UW	48.3			
CE-11	1.3 DW	82.3	10.6	5.18	0.0257
	2.7 DW	84.9	13.2	6.42	0.0395
	4.1 DW	204.0	132.3	7.12	0.440
	6.0 DW	103.7	32.0	7.77	0.116
	2.0 UW	71.7			
CE-3	1.3 DW	80.4	42.9	4.79	0.0991
	2.7 DW	59.7	22.1	6.15	0.0655
	4.1 DW	51.4	13.8	6.93	0.0461
	6.0 DW	42.9	5.3	7.64	0.0196
	3.0 UW	37.6			
CE-12	1.3 DW	85.3	11.3	4.79	0.0261
	2.7 DW	86.4	12.5	6.15	0.0369
	4.1 DW	87.8	13.9	6.93	0.0461
	6.0 DW	78.6	4.7	7.64	0.0172
	2.0 UW	73.9			
CE-15	1.3 DW	68.7	16.2	12.6	0.0649
	2.7 DW	65.4	13.0	14.0	0.0574
	4.1 DW	54.3	1.9	14.7	0.00877
	6.0 DW	46.1	0[c]	15.4	0[c]
	3.0 UW	52.4			
CE-16	1.3 DW	71.6	40.2	4.65	0.145
	2.7 DW	40.0	8.5	7.06	0.0465
	4.1 DW	54.2	22.7	8.43	0.148
	6.0 DW	39.3	7.8	9.69	0.0589
	3.0 UW	31.5			
CE-17	1.3 DW	40.6	9.1	4.62	0.0306
	2.7 DW	43.9	12.5	7.08	0.0641
	4.1 DW	40.3	8.8	8.48	0.0545
	6.0 DW	37.2	5.7	9.76	0.0403
	3.0 UW	31.5			
CE-18	1.3 UW	21.5	–	4.46	0.108
	2.7 UW	21.5	–	5.01	0.121
	4.1 UW	17.7	–	5.32	0.106
	6.0 UW	19.7	–	5.60	0.124
CE-19	1.3 DW	30.5	9.0	4.46	0.0450
	2.7 DW	29.6	8.1	5.01	0.0451
	4.1 DW	38.5	20.7	5.32	0.123
	6.0 DW	28.8	9.1	5.60	0.0568

[a] DW = downwind, UW = upwind
[b] Plume height of 10 m assumed for integration. See discussion in text.
[c] No net mass attributed to test source. Zero value assumed in integration.

Table 4-4. Measurement-Based PM-10 Emission Rates/Factors

Run	Traffic rate[a] (veh/hr)	Mean vehicle[a] weight (tons)	Silt loading (g/m^2)	Measured line source emission rate (g/mile-s)	Measured per vehicle[a] emission factor (lb/vmt)	AP-42 predicted emission factor (lb/vmt)
CE- 1	37.8	36	1.16	0.28[b]	0.059	0.46
CE- 2	32.0	36	0.86	0.56[b]	0.14	0.38
CE-11	34.8	12	1.34	1.54	0.34	0.10
CE- 3	47.0	39	0.86	0.60[b]	0.10	0.43
CE-12	48.3	13	1.34	0.31	0.051	0.11
CE-15	29.5	40	1.91	0.52	0.14	0.76
CE-16	28.4	40	1.41	0.64	0.17	0.62
CE-17	28.8	40	2.93	0.35	0.091	1.0
CE-19	61.4	38	0.76	0.30	0.041	0.39

[a] Includes only corn trucks and other semi-trailers. Vehicle weights based on the following values (lbs) in MCP's Title V application:

	Empty	Loaded
Straight Truck	10,000	26,000
Tandem	19,000	45,000
Semi	27,000	80,000

[b] Based on 2 lines of queued traffic.

4.2 Discussion of Test Results

Before discussing the test results, it should be noted that the measured emission factors and rates for stop-and-go traffic presented in Table 4-4 should be considered conservatively high (i.e., greater than the actual values). During the first test (CE-1), it was determined that the queued traffic proved to be a more formidable wind break than had been anticipated. A conservatively high plume height of 10 m was assumed to develop the measurement-based emission factor/rate for run CE-1. During subsequent tests of stop-and-go traffic, the aerometric equipment was deployed at the upwind location. There, the anemometers measured higher (i.e., unblocked) wind speeds that would have been experienced on the downwind side of the queue. Because higher wind speeds were multiplied by the downwind measured concentrations, conservatively high values resulted for the exposure and the measurement-based emission factor/rates.

All nine measured emission factors in Table 4-4 are well below the AP-42 predicted emission factor of 0.453 lb/vmt currently applied in the MCP Marshall inventory. Because there is only a 0.2% ($=1 / 2^{9}$) probability that all nine measurement-based emission factors would be below that value by chance alone, one can be highly confident that AP-42 substantially overpredicts emissions for the source conditions present at the Marshall plant. The average measurement-based emission factors determined during the testing are shown below in Table 4-5.

Table 4-5. Average Measured PM_10 Emission Factors

	Measured PM-10 emission factor (lb/vmt)	
	Average	Standard deviation
Stop-and-go traffic (n=3)	0.100	0.041
Slowly moving traffic (n=6)	0.139	0.110
Overall (n=9)	0.126	0.092

On average, the measured emission factors are less than one-third of the 0.453 lb/vmt value currently applied in the Marshall inventory. The degree of overprediction does not improve markedly even if the measured silt loading values and test-specific vehicle weights are substituted in the AP-42 emission factor model (Table 4-4). Figure 4-2 plots the ratio of the measured-to- AP-42 prediction against silt loading. Note that (a) there is no discernible trend for the prediction to improve at higher silt loading values and (b) the (geometric) mean overprediction is a factor of roughly 3.7. Furthermore, all but one of the nine AP-42 estimates are greater than the measured value. There is less than 2% probability that this situation would occur by chance alone.

The degree of overprediction is not particularly surprising when one considers that *reentrained road dust is not nearly as dominant in the tests reported here as compared to the AP-42 emission factor data base.* Figure 4-3 plots the measured emission factors against silt loading. As can be seen, unlike the AP-42 data base, there is no significant relationship between measured emission factor and silt loading.

The exposure profiles provide additional evidence that traffic at Marshall does not produce extensive amounts of reentrained dust. At low vehicle speeds, the reentrained road dust would be expected to produce a maximum PM-10 exposure at a height of 1 to 2 m. Figure 4-4 plots the net PM-10 exposure versus height for the six slowly moving traffic tests. For the most part, profiles were either flat over the plume height or showed peak values near the 4.1-m height. (It is likely that diesel exhaust accounts for the 4.1-m peak.) This is particularly true for run CE-11; that run produced the highest measurement-based emission factor in Table 4-4, but its profile is definitely not influenced by reentrained road dust.

Figure 4-5 compares exposure values upwind and downwind of the test road during Run CE-18, -19. Again, the profile shows a peak at the 4.1-m height and there is no evidence that reentrained dust from the road surface is the dominant emission mechanism.

Figure 4-6 plots the measured PM-10 emission factors against the mean vehicle weight during the exposure profiling tests. In contrast to the prediction of higher emissions with heavier vehicles based on AP-42 emission factor model (Equation 1-1), the figure shows that there is no relationship between measured emission levels and vehicle weight. This provides further evidence that Equation 1-1 is not capable of describing the measurement-based emission factors obtained at MCP.

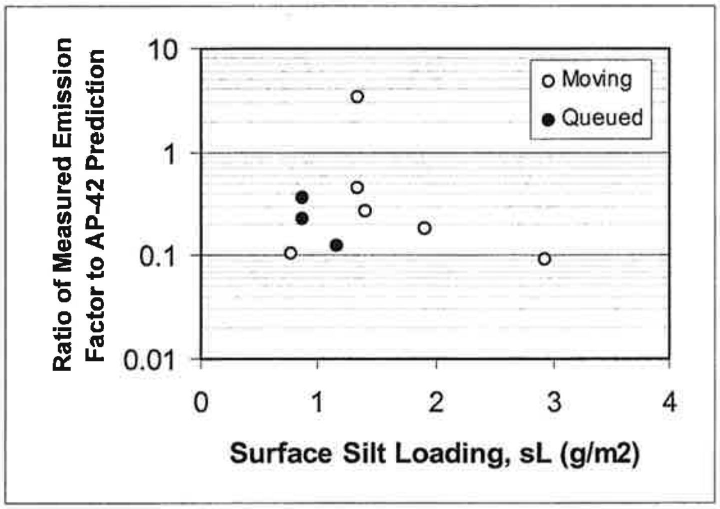


Figure 4-2. Ratio of Measured PM-10 Emission Factor to AP-42 Prediction versus Silt Loading

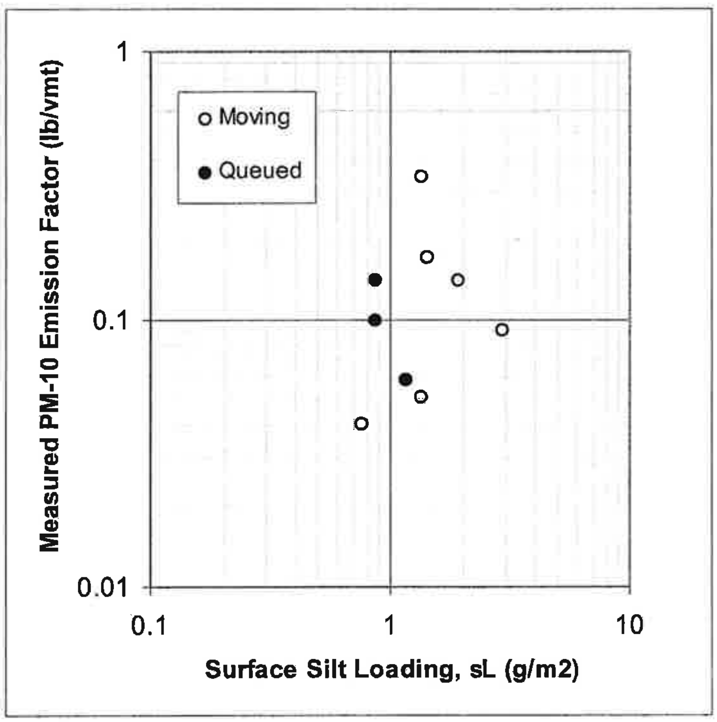


Figure 4-3. Measured PM-10 Emission Factor Versus Silt Loading

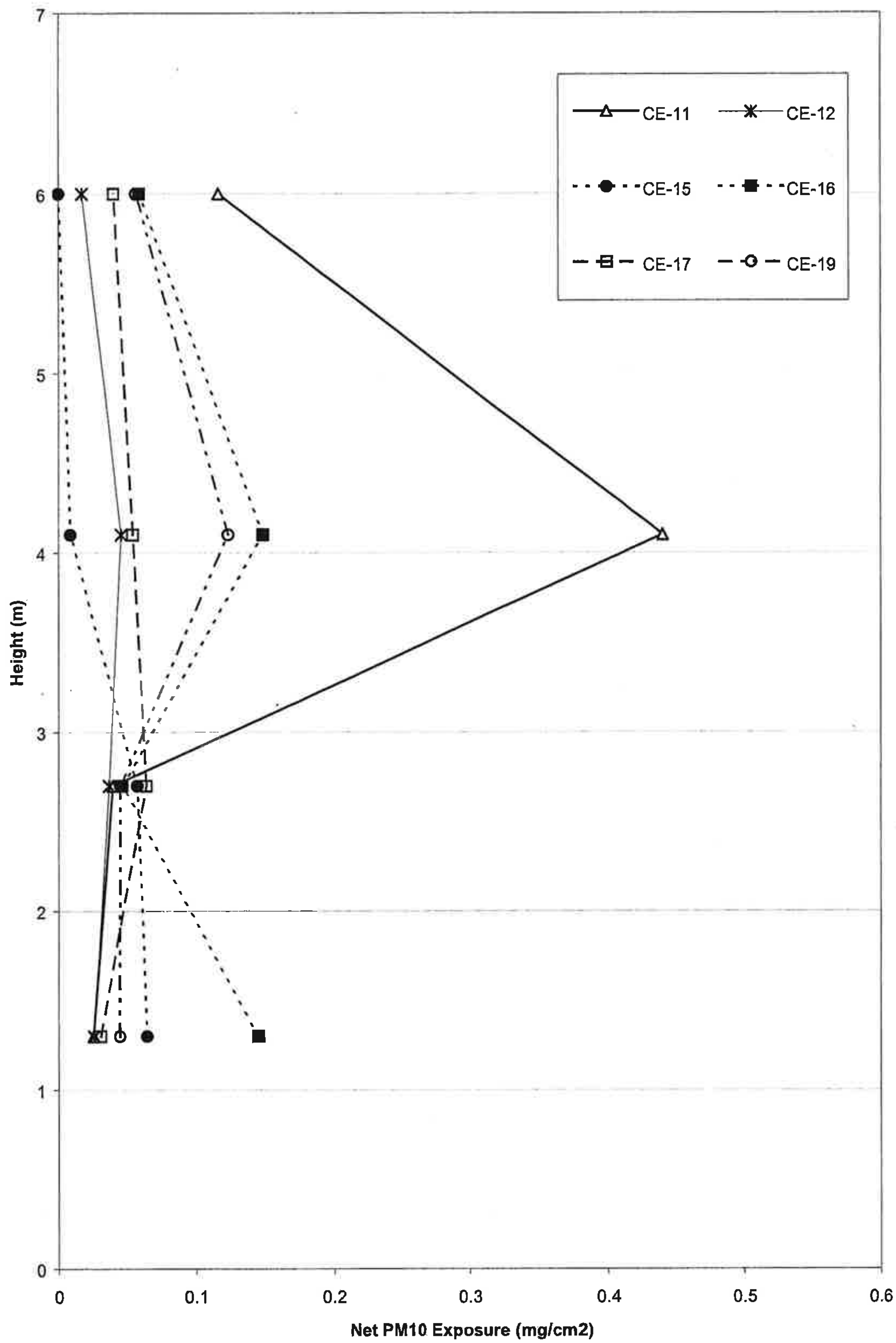


Figure 4-4. Moving Traffic PM-10 Exposure Profiles

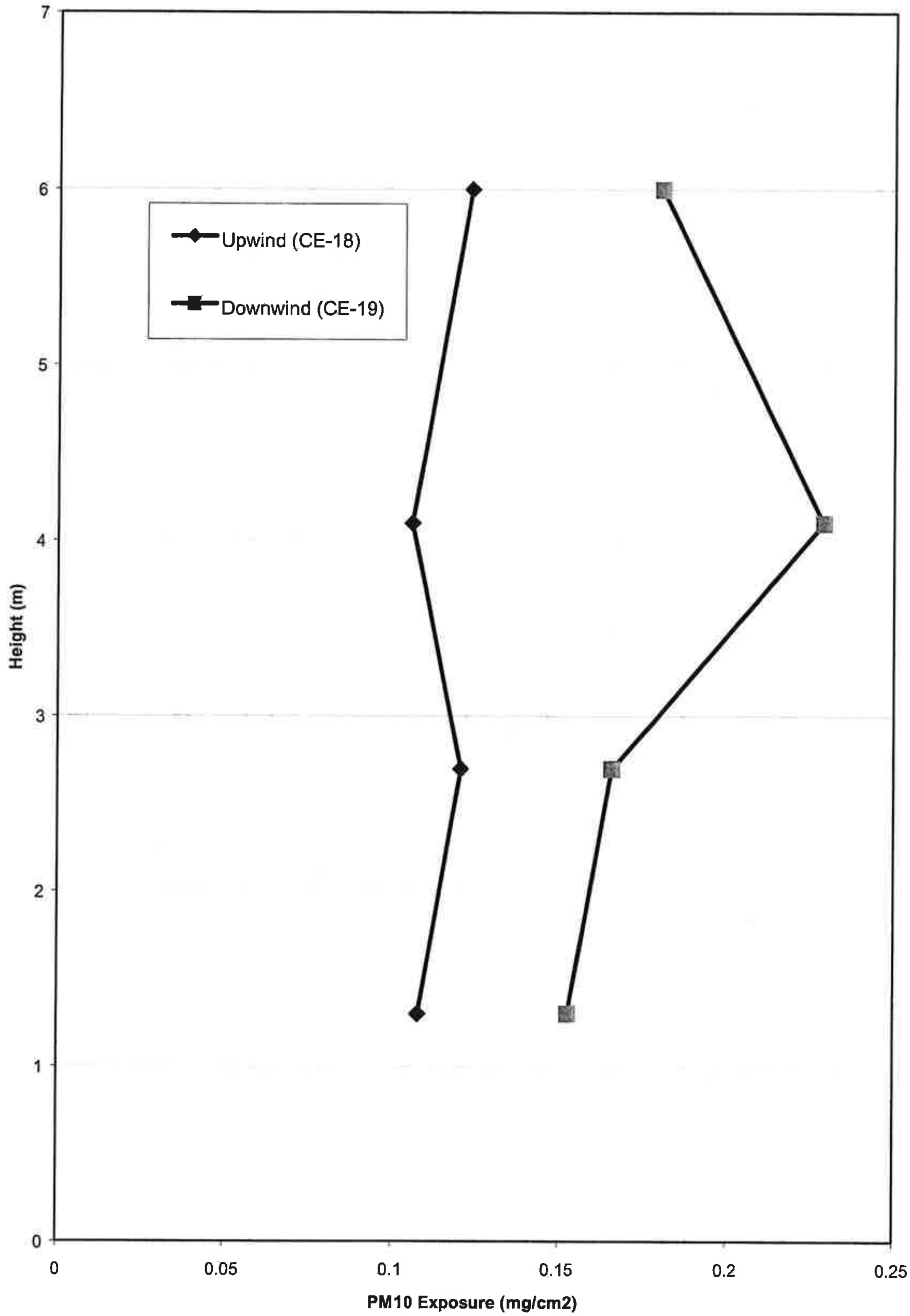


Figure 4-5. Upwind and Downwind PM-10 Exposures for Runs CE-18, -19

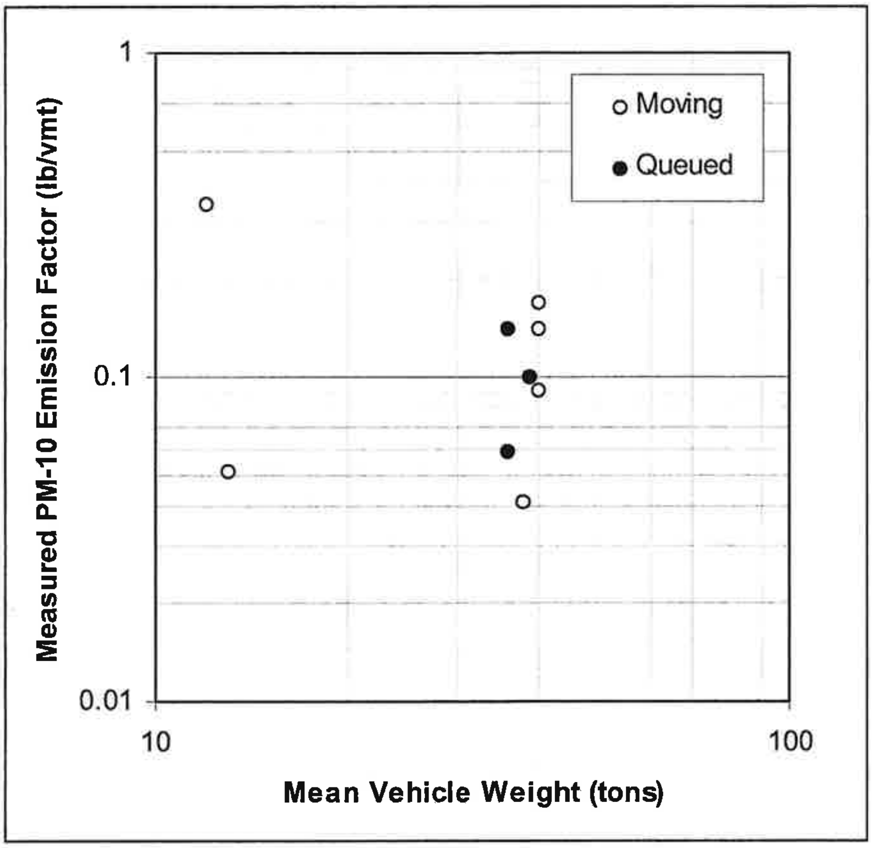


Figure 4-6. Measured PM-10 Emission Factors versus Mean Vehicle Weight

Section 5. References

1. USEPA. *Compilation of Air Pollutant Emission Factors.* AP-42. Fifth Edition. Office of Air Quality Planning and Standards. U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1995.

2. USEPA. *Procedures for Preparing Emission Factor Documents.* EPA-454/R-95-015. Office of Air Quality Planning and Standards. U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1997.

3. Baxter, T.E. et al. "Calibration of a Cyclone for Monitoring Inhalable Particulates," Journal of Environmental Engineering. 112(3), 468. 1986.

4. Davies, C. N. "The Entry of Aerosols in Sampling Heads and Tubes." British Journal of Applied Physics. 2:921, 1968.

Appendix A

Quality Assurance/Quality Control Procedures

A.1 Sample Handling and Traceability Requirements

The majority of environmental samples collected during the test program consist of particulate matter captured on a filter medium. Analysis is gravimetric, as described in the following paragraphs.

To maintain sample integrity, the following procedure was used. Each filter was stamped with a unique 7-digit identification number. SOP (standard operating procedure) MRI-8403 describes the numbering system that is employed. 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 (or quartz) 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 hr at constant temperature and humidity in a special weighing room. Temperature and humidity levels are given in Table A-1. The room contains a hygrothermograph to provide a permanent record of equilibration conditions. The chart is changed weekly and recalibrated (as necessary) against wet and dry bulb thermometers. Those thermometers are checked annually against traceable units.

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 until a second analyst reweighs them as a precision check. A minimum of ten percent (10%) (with an absolute minimum of three blanks per test site) of the filters used in the field serve as blanks to account for the effects of handling. The QA guidelines pertaining to preparation of sample collection media are presented in Section A-3.

The filters are placed in their like-numbered 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.

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 main MRI laboratory in Kansas City, they are equilibrated under the same conditions as the initial weighing. After reweighing, a minimum of 10% of each type is audited to check weighing accuracy.

In order to ensure traceability, all filter and material sample transfers are recorded in a notebook or on forms. The following information are recorded: the assigned sample codes, date of transfer, location of storage site, and the names of the persons initiating and accepting the transfer.

A.2 Analytical Method Requirements

All analytical methods required for this testing program are inherently gravimetric in nature. That is to say, 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.

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 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 a weighing, the samples or standards should be reweighed using a balance that can meet these requirements.

A.3 Quality Control Requirements

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 filters for use in the field, 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 A-1 outlines the general requirements for conditioning and weighing sampling media. Note that a second, independent analyst performs the audit weights.

Table A-1. 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. 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.
Collection of blanks	Conduct at least one complete blank test for every 1 to 9 emission tests. A minimum of 3 blank filters is necessary for each test site/source combination.
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 A-1, a minimum of 10% field blanks are collected for QC purposes. This is accomplished by conducting one blank test for every 1-to-9 emission tests conducted. A blank test is conducted in exactly the same manner as an emission test except that no air is passed through the filters after they are loaded into the sampling devices. Instead, they are immediately recovered and handled the same as any exposed filter from an actual emission test. Blank runs are labeled in the same manner as other tests, although the run sheets indicate that a blank test was conducted.

Handling blank filters in an identical manner to all sample filters allows one to determine systematic weight changes due to handling steps alone. 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 is weighed, allowed to return to equilibrium for an additional 24 hr, and then a minimum of 10% of the exposed/blank filters are reweighed. If a filter fails the audit criterion, the entire lot is allowed to condition in the gravimetric laboratory an additional 24 hr and then reweighed. The tare and first weight criteria for filters (Table A-1) 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.

A.4 Instrument/Equipment Testing, Inspection and Maintenance

Inspection and maintenance requirements for sampling equipment are provided in Table A-2. Material presented in italics discusses how these requirements were met during the study.

A.5 Instrument Calibration and Frequency

Calibration and frequency requirements for the balances used in the gravimetric analyses are given in Table A-1.

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 A-2 specifies the frequency of calibration and other QA checks regarding air samplers.

Table A-3 outlines the QC checks employed for miscellaneous instrumentation needed. Material presented in italics discusses how these requirements were met during the study.

A.6 Inspection/Acceptance Requirements for Supplies and Consumables

The primary supplies and consumables for this field exercise consist of the air filter and collection media. Prior to stamping and initial weighing (Table A-1), each filter is visually inspected and is discarded for use if any pin-holes, tears, or other damage is found.

A.7 Data Acquisition Requirements

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

Table A-2. Quality Assurance Procedures for Sampling Equipment

Activity	QA check/requirement[a]
Maintenance • All samplers	Check motors, brushes, gaskets, timers, and flow measuring devices at each plant prior to testing. Repair/replace as necessary. *Sampling devices were cleaned and checked prior to loading truck and upon arrival at plant.*
Calibration • Volumetric flow controller (VFC)	Prior to start of testing at each regional site, ensure that flow determined by calibration orifice and the look-up table for each volumetric flow controller agrees within 7%. Alternately, develop a separate calibration curve for each VFC. For 20 acfm devices (particle size profiling), calibrate each sampler against the orifice prior to use for each regional site and every two weeks thereafter during test period. (Orifice calibrated against displaced volume test meter annually.) *VFC calibration records have been included in copy of field data sheets. Calibration curves developed for each VFC are included on diskette with field data and data reduction.*
Operation • Timing	Start and stop all downwind samplers during time span not exceeding 1 min. *All downwind samplers were started / stopped within 1 minute.*
• Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction dictates. *Wind direction relative to line source monitored immediately before and throughout test. Rotation of sampling arrays noted on field run sheets.* Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle. *Wind speed throughout range of sampling heights monitored immediately before and throughout the test. Use of nozzles indicated on field run sheets.*
• Prevention of static deposition	Cover sampler inlets prior to and immediately after sampling. *Samplers were uncovered immediately before start of test and filters recovered immediately after end of test.*

[a] "Mean" denotes a 5-min average.

Table A-3. Quality Assurance for Miscellaneous Instrumentation

Instrumentation	QA check/requirement[a]
Digital manometers	Compare reading against water-in-tube manometers over range of operating pressures, using "Y" or "T" connectors and flexible tubing. Do not use units which differ by more than 7%. *Two units were used during tests. Maximum deviations for unit Y7543 and unit Y7542 were 2.8 and 4.8%, respectively.*
Digital barometer	Compare against mercury-in-tube barometer. Do not use if more than 0.5 in Hg difference in reading. *Deviation of altimeter/barometer Y-1253 was 0.19 in Hg (0.66% deviation).*
Thermometer (mercury or digital)	Compare against NIST-traceable mercury-in-glass. Do not use if more than 3.0 C difference. *Two units used during tests. Deviation for Hg-in-glass unit was 0.7 °F (0.4 °C) high and for electronic unit SN 8935833 was 0.7 °F (0.4 °C) low.*
Gill anemometers and wind station	Conduct a 4-point calibration of each unit over the range of 2 to 20 mph both before the field exercise and upon return to MRI's main laboratories. Use factory-specified devices for calibration of wind speed and direction. *Calibration records have been supplied as part of field run sheets.*
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. *Crew chief watch was checked against 27 hr elapsed time, with deviation of 0.04% Crew member watches and wind data acquisition device were reset to crew chief watch each day.*

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

Table A-4. Criteria for Suspending or Terminating an Exposure Profiling Test

A test may be suspended or terminated if:[a]

1. Rainfall ensues during equipment setup or when sampling is in progress. (Exception made in the case of a source protected by a roof or other enclosure).
2. Mean wind speed during sampling moves outside the 4 to 20 mph acceptable range for more than 20% of the sampling time.
3. The angle between the mean wind direction and the perpendicular to the measurement plane exceeds 45° for more than 20% of the sampling time.
4. Daylight is insufficient for safe equipment operation. (Exception made in case of adequate artificial lighting.)
5. Source conditions deviates from predetermined criteria (e.g., loading equipment malfunction, water splashing, truck spills).

[a] "Mean" denotes a 5-min average.

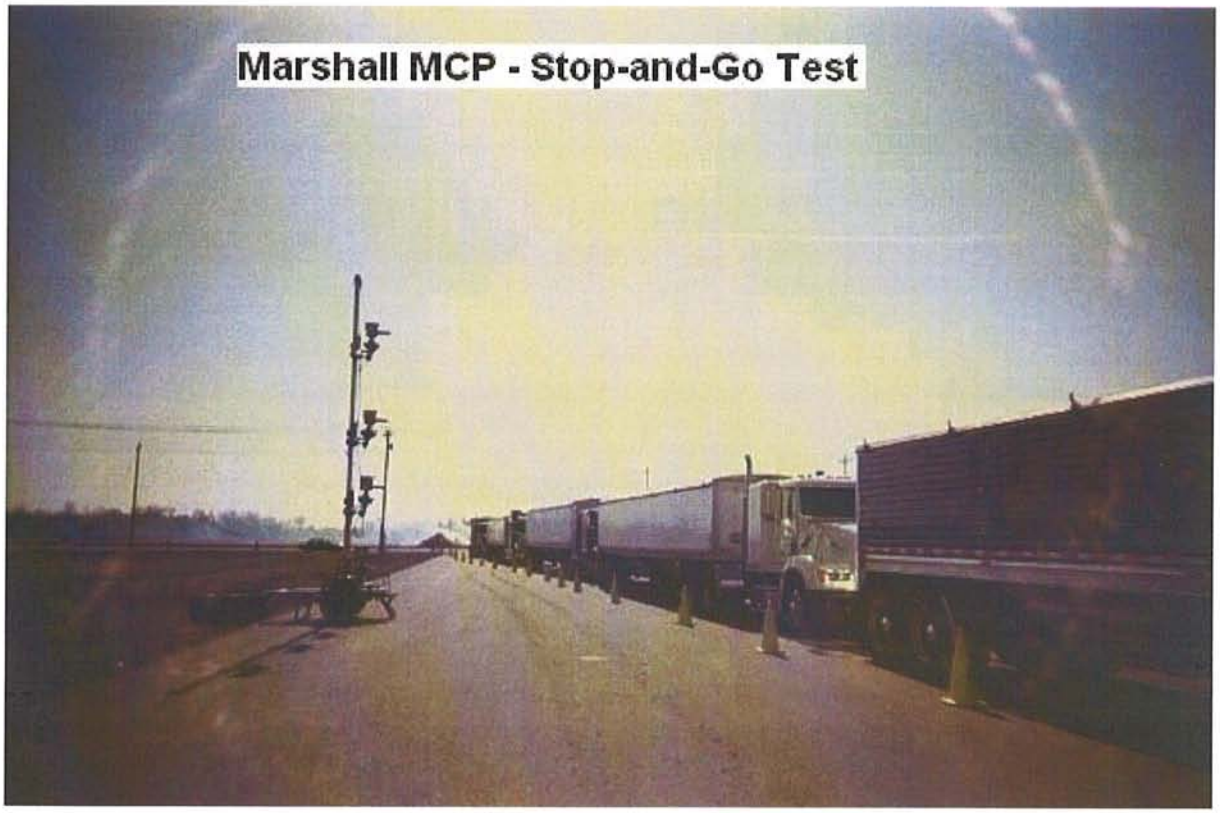
Appendix B

Detailed Test Data

Run	Date	Sampler Location	Sampler ID	Sampler Start Time	Sampler Stop Time	Duration (min)	Avg. Temp. (deg F)	Avg. B.P. (in. Hg)	Avg. Filter Pressure (in. H2O)	Filter Number	Tare Wt. (g)	Final Wt. (g)	Non-blank Corrected (mg)	Blank Corrected* (mg)	Flow rate VFC (acfm) or URG	Downwind (raw) Conc. (ug/m3)	Net Conc. (ug/m3)	Wind Speed (mph)	PM-10 Exposure (mg/cm2)
CE-1	04/17/01	Cyclone 1.3 DW	66	13:31	15:35	144 *	54	29.58	21.03	121002	4.3795	4.3901	10.60	9.90	36.35	66.8	38.0	0.50	0.00736
		Cyclone 2.7 DW	74	13:31	15:35	144 *	54	29.58	20.23	121003	4.3575	4.3646	7.10	6.40	37.23	42.2	13.4	1.86	0.00960
		Cyclone 4.1 DW	75	13:31	15:35	144 *	54	29.58	20.73	121004	4.3917	4.3979	6.20	5.50	37.32	36.1	7.4	2.63	0.00751
		Cyclone 6.0 DW	76	13:31	15:35	144 *	54	29.58	20.30	121005	4.3736	4.3830	9.40	8.70	37.33	57.2	28.4	3.34	0.03658
		Cyclone UW	77	13:29	15:35	143 **	54	29.58	20.90	121001	4.3552	4.3602	5.00	4.30	36.93	28.8			
				* Includes 20 min additional time (start: 16:02, stop: 16:22)					** Includes 17 min additional time (start: 16:04, stop: 16:21)										
CE-2	04/18/01	Cyclone 1.3 DW	66	8:14	11:14	180	46.67	29.25	20.15	121011	4.3700	4.3856	15.60	14.90	36.38	80.4	32.0	5.14	0.07952
		Cyclone 2.7 DW	74	8:14	11:14	180	46.67	29.25	20.40	121012	4.3593	4.3751	15.80	15.10	37.12	79.8	31.5	6.36	0.09663
		Cyclone 4.1 DW	75	8:14	11:14	180	46.67	29.25	20.30	121013	4.3595	4.3716	12.10	11.40	37.28	60.0	11.7	7.05	0.03973
		Cyclone 6.0 DW	76	8:14	11:14	180	46.67	29.25	20.50	121014	4.3780	4.3882	10.20	9.50	37.21	50.1	1.8	7.69	0.00655
		Cyclone UW	77	8:08	11:12	184	46.67	29.25	20.15	121015	4.3705	4.3805	10.00	9.30	36.94	48.3			
CE-11	04/18/01	Cyclone 1.3 DW	70	8:20	11:14	174	46	29.23	19.25	121007	4.3735	4.3890	15.50	14.80	36.49	82.3	10.6	5.18	0.02571
		Cyclone 2.7 DW	78	8:20	11:14	174	46	29.23	20.15	121008	4.3816	4.3974	15.80	15.10	36.12	84.9	13.2	6.42	0.03947
		Cyclone 4.1 DW	71	8:20	11:14	174	46	29.23	20.70	121009	4.3810	4.4185	37.50	36.80	36.61	204.0	132.3	7.12	0.43984
		Cyclone 6.0 DW	67	8:20	11:14	174	46	29.23	20.65	121010	4.3652	4.3852	20.00	19.30	37.77	103.7	32.0	7.77	0.11615
		Cyclone UW	69	8:04	11:12	188	46	29.23	20.55	121006	4.3822	4.3972	15.00	14.30	37.48	71.7			
CE-3	4/18/01	Cyclone 1.3 DW	66	12:45	15:45	180	68	29.10	20.60	121022	4.3685	4.3848	16.30	15.60	38.05	80.4	42.9	4.79	0.09906
		Cyclone 2.7 DW	74	12:45	15:45	180	68	29.10	20.95	121023	4.3804	4.3929	12.50	11.80	38.81	59.7	22.1	6.15	0.06554
		Cyclone 4.1 DW	75	12:45	15:45	180	68	29.10	20.95	121024	4.3765	4.3874	10.90	10.20	38.97	51.4	13.8	6.93	0.04608
		Cyclone 6.0 DW	76	12:45	15:45	180	68	29.10	21.05	121025	4.3731	4.3823	9.20	8.50	38.89	42.9	5.3	7.64	0.01957
		Cyclone UW	77	12:50	15:50	180	68	29.10	20.55	121021	4.3683	4.3764	8.10	7.40	38.64	37.6			
CE-12	4/18/01	Cyclone 1.3 DW	70	12:46	15:45	179	65.5	29.23	20.87	121017	4.3681	4.3851	17.00	16.30	37.71	85.3	11.3	4.79	0.02607
		Cyclone 2.7 DW	78	12:46	15:45	179	65.5	29.23	20.57	121018	4.3793	4.3964	17.10	16.40	37.44	86.4	12.5	6.15	0.03690
		Cyclone 4.1 DW	71	12:46	15:45	179	65.5	29.23	21.10	121019	4.3781	4.3957	17.60	16.90	37.98	87.8	13.9	6.93	0.04611
		Cyclone 6.0 DW	67	12:46	15:45	179	65.5	29.23	21.13	121020	4.3834	4.3997	16.30	15.60	39.15	78.6	4.7	7.64	0.01719
		Cyclone UW	69	12:42	15:45	183	65.5	29.23	20.97	121016	4.3727	4.3883	15.60	14.90	38.90	73.9			
CE-15	4/19/01	Cyclone 1.3 DW	76	14:26	16:24	118	67	28.70	21.90	121038	4.3474	4.3571	9.70	9.00	39.22	68.7	16.2	12.64	0.06491
		Cyclone 2.7 DW	75	14:26	16:24	118	67	28.70	21.80	121039	4.3829	4.3922	9.30	8.60	39.33	65.4	13.0	13.95	0.05739
		Cyclone 4.1 DW	74	14:26	16:24	118	67	28.70	22.15	121040	4.3700	4.3778	7.80	7.10	39.11	54.3	1.9	14.70	0.00877
		Cyclone 6.0 DW	66	14:26	16:24	118	67	28.70	21.90	121041	4.3877	4.3943	6.60	5.90	38.33	46.1	0	15.39	0
		Cyclone UW	77	13:08	16:25	197	67	28.70	21.60	121036	4.3589	4.3710	12.10	11.40	38.97	52.4			
CE-16	4/20/01	Cyclone 1.3 DW	76	8:33	13:22	289	64	28.68	21.50	121042	4.4038	4.4274	23.60	22.90	39.06	71.6	40.2	4.65	0.14481
		Cyclone 2.7 DW	75	8:33	13:22	289	64	28.68	21.60	121043	4.3734	4.3869	13.50	12.80	39.13	40.0	8.5	7.06	0.04651
		Cyclone 4.1 DW	74	8:33	13:22	289	64	28.68	21.20	121044	4.3653	4.3833	18.00	17.30	39.01	54.2	22.7	8.43	0.14846
		Cyclone 6.0 DW	66	8:33	13:22	289	64	28.68	21.00	121045	4.3680	4.3810	13.00	12.30	38.23	39.3	7.8	9.69	0.05890
		Cyclone UW	77	8:31	13:23	289 *	64	28.68	20.95	121037	4.3688	4.3795	10.70	10.00	38.83	31.5			
						* Includes time off from 9:10 to 9:13													
CE-17	4/20/01	Cyclone 1.3 DW	78	8:51	13:22	271	64	28.68	21.30	121046	4.3508	4.3633	12.50	11.80	37.88	40.6	9.1	4.62	0.03061
		Cyclone 2.7 DW	70	8:51	13:22	271	64	28.68	21.10	121047	4.3590	4.3726	13.60	12.90	38.26	43.9	12.5	7.08	0.06408
		Cyclone 4.1 DW	71	8:51	13:22	271	64	28.68	21.75	121048	4.3650	4.3776	12.60	11.90	38.47	40.3	8.8	8.48	0.05448
		Cyclone 6.0 DW	67	8:51	13:22	271	64	28.68	21.80	121049	4.3656	4.3776	12.00	11.30	39.64	37.2	5.7	9.76	0.04030
		Cyclone UW	77	8:31	13:23	289 *	64	28.68	20.95	121037	4.3688	4.3795	10.70	10.00	38.83	31.5			
						* Includes time off from 9:10 to 9:13													
CE-18	4/24/01	Cyclone 1.3 DW	76	8:09	15:07	418	55	29.25	21.45	121050	4.3591	4.3694	10.3000	9.60	37.65	21.5		4.46	0.10782
		Cyclone 2.7 DW	75	8:09	15:07	418	55	29.25	21.40	121051	4.3545	4.3648	10.3000	9.60	37.73	21.5		5.01	0.12063
		Cyclone 4.1 DW	74	8:09	15:07	418	55	29.25	20.95	121052	4.3934	4.4020	8.6000	7.90	37.63	17.7		5.32	0.10569
		Cyclone 6.0 DW	66	8:09	15:07	418	55	29.25	20.45	121053	4.3926	4.4019	9.3000	8.60	36.92	19.7		5.60	0.12352
CE-19	4/24/01	Cyclone 1.3 DW	78	8:10	15:07	417	55	29.25	20.80	121056	4.4035	4.4174	13.9000	13.20	36.59	30.5	9.0	4.46	0.04497
		Cyclone 2.7 DW	70	8:10	15:07	417	55	29.25	20.30	121057	4.3881	4.4017	13.6000	12.90	36.97	29.6	8.1	5.01	0.04511
		Cyclone 4.1 DW	71	8:10	15:07	417	55	29.25	20.80	121058	4.3894	4.4070	17.6000	16.90	37.21	38.5	20.7	5.32	0.12326
		Cyclone 6.0 DW	67	8:10	15:07	417	55	29.25	21.25	121059	4.3975	4.4112	13.7000	13.00	38.29	28.8	9.1	5.60	0.05678

Blank Filter Data (Runs CE-13, -20).

Filter number	Tare Wt. (g)	Final Wt. (g)	Net Wt. (mg)
121027	4.3378	4.3387	0.9
121028	4.3487	4.3494	0.7
121029	4.3246	4.3249	0.3
121030	4.3248	4.3254	0.6
121031	4.3183	4.3188	0.5
121054	4.3860	4.3868	0.8
121060	4.3921	4.3935	1.4
121061	4.4029	4.4038	0.9
121062	4.3950	4.3952	0.2
		Mean	**0.7**
		Std Dev	**0.36**


Marshall MCP - Stop-and-Go Test


Marshall MCP - Freely Moving Test