PARTICULATE MATTER EMISSIONS FACTORS AND EMISSIONS INVENTORY FROM LEAF BLOWERS IN USE IN THE SAN JOAQUIN VALLEY

FINAL REPORT

Prepared for:

San Joaquin Valley Unified Air Pollution Control District
1990 Gettysburg Avenue
Fresno, CA 93726

Principal Investigator:

Mr. Dennis R. Fitz
College of Engineering
Center for Environmental Research and Technology
University of California, Riverside
Riverside, CA 92507

Participating Researchers:

David Pankratz, Mark Chitjian, James Bristow and Sally Pederson
College of Engineering
Center for Environmental Research and Technology
University of California
Riverside, CA 92521

January 27, 2006

DISCLAIMER

The statement and conclusions in the Report are those of the contractor and not necessarily those of the San Joaquin Valley Unified Air Pollution Control District. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

ACKNOWLEDGEMENTS

This research study was made possible by a group of individuals and organizations whose valuable contributions are greatly appreciated. We wish to thank the following organizations and individuals for their time and resources in contributing to the success of the measurement program:

1. The UC Kearney Research and Extension Center for allowing the use of their site in the San Joaquin Valley for some of measurements and particular thanks to Kearney staff members Laura Van der Staay, Bob Ray and Andy Padilla for being helpful and accommodating to the needs of the study.
2. Bob Giese and the staff of the UCR Physical Plant Building Services and Grounds Maintenance for allowing us to follow around the grounds maintenance crew and coordinating with us for the collection of samples from areas about to be leaf blown.
3. Joe Patricko, Paul Giering and Russell Vernon with the UCR Environmental Health and Safety Department for reviewing our planned activities, identifying the appropriate personal protective gear (PPG) and loaning us those PPGs.
4. Bourns, Inc. for allowing us to setup our sampling chamber in their parking lot.
5. Professor Mark Matsumoto in the UCR Chemical and Environmental Engineering Department for allowing us to use his sieve shaker.
6. Professor Arthur Winer with the UCLA School of Public Health for loaning his photoionization detector to the project.
7. Professor Marko Princevac in the UCR Mechanical Engineering Department for the loan of two DustTraks for use in the project.

TABLE OF CONTENTS

TABLES

FIGURES

1.0 EXECUTIVE SUMMARY

Particulate matter (PM) has been implicated as being responsible for a wide variety of adverse health effects that have been shown in epidemiological studies to contribute to premature deaths (Pope et al. 1995). To formulate effective mitigation approaches, the sources of the PM must be accurately known. Leaf blowers are an obvious source of particulate emissions. The emission rates, however, have never been quantitatively measured and there is no default emission factor in AP-42 for this source.

The San Joaquin Valley Unified Air Pollution Control District (District) funded the University of California at Riverside - College of Engineering Center for Environmental Technology (CE-CERT) to design a study and perform measurements and data analysis to determine particulate matter emissions from leaf blowers and to obtain a PM emission inventory from their operation in the District. This report presents a description of the PM measurement program and the study findings. This report does not address emissions from the blower motor itself or noise produced by the blower motor.

The approach used to measure emissions from leaf blowers and alternative devices (vacuums, rakes, and brooms) was to operate the devices over a measured area in a tent-like enclosure. In this enclosure the leaf blower (or other device) could be used in a normal manner while allowing the PM emissions to be confined for quantification. PM concentrations were measured with real-time sensors. Measurements were made for total suspended particulate matter (TSP), particulate matter (PM) with an aerodynamic diameter less than ten microns (PM_{10}) and particulate matter with an aerodynamic diameter less than 2.5 microns ($PM_{2.5}$). The amount of PM produced per unit area was then calculated by multiplying the concentration once it stabilized (when it became uniformly mixed) by the volume of the enclosure and dividing by the area treated.

To directly compare the PM emission characteristics of blowing, vacuuming, raking, and sweeping, the surface to be treated in the enclosure was loaded with surrogate debris. To develop the composition of this surrogate material, bulk samples were collected from areas on the University of California, Riverside (UCR) campus where leaf blowing was about to be conducted to determine the mass of soil and vegetative matter present where these cleaning activities are conducted. The test system was then used to measure emissions from leaf blowing over surfaces where leaf blowing is typically conducted and over surfaces where a surrogate mixture of soil (obtained from the San Joaquin Valley) and vegetative matter was deposited by our staff. A more limited number of emission tests were performed using the natural/indigenous material at the CE-CERT facility in Riverside and at the UC Kearney Agricultural Center in Parlier, CA.

Emission factors were developed for the following four categories:

1. Soil origin

2. Cleaning tool (i.e. leaf blower, leaf vacuum, rake and broom) on asphalt surfaces
3. Cleaning tool on concrete surfaces
4. Leaf blowing, raking or sweeping for specific grounds maintenance activities (i.e. cleaning grass clipping from along concrete path, gutter cleaning, asphalt parking lot and driveway cleaning, leaf blowing/raking on lawns and leaf blowing packed dirt parking lots)

Table 1 is a summary of the emission factors found from these measurements. These emission factors are provided in terms of mass emitted per square meter of surface cleaned. Several significant aspects of leaf blowing operations were observed:

- There was little difference between blowing and vacuuming with the model that was tested.
- Sweeping with a broom on concrete created significant PM emissions whereas sweeping asphalt did not.
- Raking leaves did not generate significant amounts of PM.

			Emission Factors		
Cleaning Action and Surface Cleaned	Number of Tests Performed	Type of Emission Factor Obtained from Tests	PM 2.5 (mg/m^2)	PM10 (mg/m^2)	TSP (mg/m^2)
Power Blowing or Vacuuming over concrete surfaces	12	Average emissions from leaf blowing	30	80	100
Power Blowing or Vacuuming over asphalt surfaces	21	Average emissions from leaf blowing	20	60	80
Push Broom on Asphalt Surface	3	Average emissions from sweeping	0	20	30
Push Broom on Concrete Surface	3	Average emissions from sweeping	20	80	110
Raking on Asphalt Surface	1	Average emissions from raking	0	0	0
Raking on Concrete Surface	3	Average emissions from raking	0	0	10
Raking Lawn	1	Average emissions from raking	0	1	1
Power Blowing Lawn	3	Average emissions from leaf blowing	1	2	3
Power Blowing Gutters	3	Average emissions from leaf blowing	9	30	50
Power Blowing Packed Dirt	1	Average emissions from leaf blowing	80	120	160
Power Blowing Cut Grass on Walkway	2	Average emissions from leaf blowing	2	6	9
Breakdown of Emissions by Power Blower Type on Asphalt and Concrete Surfaces					
Elec.Blower	4	Asphalt/CECERT	20	60	80
Gas Hand Held	3	Asphalt/CECERT	10	40	50
Gas Backpack	4	Asphalt/CECERT	20	60	80
Elec.Blower-Vac Mode	3	Asphalt/CECERT	40	120	150
Elec.Blower-Vac Mode - bag full	3	Asphalt/CECERT	20	70	90
Elec.Blower	4	Asphalt/Kearney	0	20	30
Elec.Blower	3	Concrete/CECERT	40	130	170
Gas Hand Held	3	Concrete/CECERT	10	40	50
Gas Backpack	3	Concrete/CECERT	30	70	70
Elec.Blower-Vac Mode	3	Concrete/CECERT	30	80	90

Table 1. Summary of emission factors.

A leaf blower fugitive dust emission inventory was prepared for the San Joaquin Valley (SJV) by multiplying emission factors by the estimated area subject to leaf blowing per unit of time. Census data was used to estimate the area over which leaf blowers were operated at residences; the emissions at commercial facilities were estimated to be one third of the residential emissions. A survey of leaf blowing operations was made to determine the area and frequency subject to leaf blowing by surface type for each of the ten census categories. The survey also indicated that weekly blower operation was typical except for the winter months when it was generally biweekly. Table 2 presents these annual PM emissions from leaf blowing operations. Please note that only those portions of Kern County within the boundaries of the District are included in the inventory.

	Fresno	Kern (SJVAPCD portion)	Kings	Madera	Merced	S.Joaquin	Stanislaus	Tulare	**Total**
PM 2.5 (tons/day)	0.07	0.05	0.01	0.01	0.02	0.05	0.04	0.03	**0.26**
PM 10 (tons/day)	0.13	0.09	0.02	0.02	0.03	0.09	0.08	0.06	**0.52**
TSP (tons/day)	0.17	0.12	0.02	0.03	0.04	0.12	0.10	0.08	**0.69**

Table 2. Annual emissions in the San Joaquin Valley from leaf blowing activities.

2.0 INTRODUCTION

Particulate matter (PM) has been implicated as being responsible for a wide variety of adverse health effects that have been shown in epidemiological studies to contribute to premature deaths (Pope et al. 1995). To formulate effective mitigation approaches, the sources of the PM must be accurately known. Receptor modeling has shown that PM_{10} of geologic origin is often a significant contributor to the concentrations in areas that are in non-attainment (Chow et al., 1992).

Leaf blowers are an obvious source of particulate emissions. The emission rates, however, have never been quantitatively measured and there is no default emission factor in AP-42 for this source. The San Joaquin Valley Air Pollution Control District (District) funded the University of California at Riverside - College of Engineering Center for Environmental Technology (CE-CERT) to design a study and perform measurements and data analysis to determine particulate matter emissions from leaf blowers and to obtain an emission inventory from their operation in the District. This report presents a description of the measurement program and the study findings.

2.1 Background

Receptor modeling has shown that PM_{10} of geologic origin is often a significant contributor to the concentrations in areas that are in non-attainment for federal PM10 air quality standards (Chow et al., 1992). These geologic sources are generally fugitive in nature and come from a wide variety of activities that disturb soil or re-entrain soil that has been deposited.

Botsford et al. (1996) estimated an emission rate for leaf blowers by making assumptions and applying engineering principles. These emission rate estimations have never been validated with actual measurements. Staff at the California Air Resources Board (California Air Resources Board, 2000) estimated leaf blower emission factors using the Botsford approach and the silt loadings determined by Venkatram and Fitz (1998). These silt loadings, however, were measured in gutters of paved roads, which is not a typical substrate that leaf blowers are used to clean. The ARB estimates have also not been validated by experimental measurements.

2.2 Project Objectives

The objective of this study is to develop an emission inventory for these sources using measured emission rates. The PM emission rates from typical leaf blowers and potentially lower emitting alternatives under typical actual and simulated conditions were quantified. These emission rates were then used to develop emission inventories for counties in the San Joaquin Valley.

2.3 Scope of Work

This study included the following tasks:

- Develop a measurement system for quantifying airborne particulate matter emissions produced during the process of sweeping, raking, blowing or vacuuming the ground from leaf blowing/vacuuming, raking or sweeping activities
- Determine the range of emissions and particle size (total suspended particulate matter (TSP), PM_{10} and $PM_{2.5}$) from leaf blowing/vacuuming, raking and sweeping operations over multiple surfaces and cleaning tasks
- Determine the types and amount of leaf blowing activities in the counties within the SJVUAPCD
- Use the emission factors and activity data to develop an emission inventory of airborne particulate matter from leaf blowing operation within the SJVUAPCD
- Include appropriate quality control and quality assurance activities in the project to obtain a viable set of data and results with known limits on the uncertainties

A quality integrated work plan (QIWP) was prepared for this program (Fitz, 2005) and is attached as Appendix A. This QWIP describes the project goals, approach and QC/QA steps to assure that viable results, meeting the project objectives, would be obtained.

3.0 EXPERIMENTAL METHODS AND STUDY DESIGN

The overall approach to measuring the PM emissions from leaf blowers involved operating the devices in a tunnel or enclosed space to confine the emissions while measuring the PM concentrations in real-time with an optical scattering sensor. Development of a suitable test chamber was a key component since no similar type of testing has been reported in the literature. The chamber needed to be large enough to operate the leaf blower for a representative amount of time and yet of manageable size and weight to easily move to various locations. The chamber was operated in a closed mode in which the test device was operated over defined area.

Because we needed to determine the total amount of PM generated, we needed to characterize the vertical and horizontal homogeneity of the PM concentrations in the chamber as a function of time to determine when the PM was adequately mixed, but before significant settling occurred. This was accomplished by separate tests in which the PM monitors were either placed along the horizontal or vertical extents of the test chamber. In addition, we needed to characterize the loss of PM from the test chamber since an absolute seal was impractical. To do this we released ethylene gas as a surrogate tracer for the PM and monitored its decay with a real-time analyzer. Once the full-length 20m test chamber was evaluated, we constructed and tested a half-length version that would be more easily moved to determine emission rates under actual use conditions.

In order to determine potential differences between various leaf removal practices on different surfaces, it was necessary to develop a surrogate mixture of soil and vegetative debris that would be representative of that found in actual practice. This was necessary so that the test device was the only variable. To characterize the debris we worked with grounds maintenance people at UCR and vacuumed up aliquots of debris that that were going to use a leaf blower to remove. These aliquots were sieved and weighed to determine the ratio of soil to vegetative debris and the size composition characteristics of the soil. Various soils from the San Joaquin Valley were used to form the surrogate in combination with locally-derived vegetative debris.

Testing was conducted primarily at the CE-CERT facility under controlled conditions using a debris surrogate. $PM_{2.5}$, PM_{10}, and TSP filter samples were collected during one test run each day to determine the response characteristics of the real-time optical analyzer with actual PM.

The remainder of this section describes the development of the approach as outlined while the following section describes the results obtained

3.1 Instrumentation

A description of the measurement and data logging instrumentation is presented in this section.

3.1.1 Real-Time PM Monitors – DustTraks

Real-time total suspended particulate matter (TSP), PM_{10} and $PM_{2.5}$ measurements were performed using Thermo Systems Inc. Model 8520 DustTrak Aerosol Monitors. These instruments use impactors to perform the size cuts and the PM concentrations are then determined by measuring the intensity of the 90^o scattering of light from a laser diode. The instruments are calibrated at the factory with Arizona road dust (NIST SRM 8632). The real-time data from this project were compared with the mass determinations from the filter collections on a daily basis to check their calibration factors for the specific aerosol present on this project. The instrument sample flow rates were set to 1.7 L/min. The instruments' time constants are adjustable from 1 to 60 seconds; they were set to one-second for this project. The instruments' zero responses were checked on a daily basis by placing a filter in line with their inlets and noting the responses.

- Real-Time PM Sampler Collocated Testing

The DustTraks were collocated in the test chamber and several tests were performed to determine instrument to instrument variability and to obtain correction factors to normalize the responses of the DustTraks to a single reference instrument. These tests included placing surrogate soil material in the chamber, blowing the material to the end of the chamber and observing the instrument responses. The collocated tests were performed for TSP, PM_{10} and $PM_{2.5}$ operation. The comparison results are presented in the Section 4.

3.1.2 Time-Integrated PM Measurements using Filter Samplers

Filter samples were collected using custom sampling systems designed by UCR for the collection of total suspended particulate matter TSP, PM_{10} and $PM_{2.5}$ samples. For the PM_{10} size-cuts Graseby-Andersen model 246B inlets were used, but modified such that a single filter could be directly attached to the inlet. These filter samplers operated at 16.7 L/min. For $PM_{2.5}$, size-cut Sensidyne model 240 cyclones sampling at approximately 110 L/min were used to provide the cutpoint. Two sample systems, each consisting of a rotary vane pump, needle valves and rotameters for flow control and measurement and TSP, PM_{10} and $PM_{2.5}$ inlets were used to collect samples on filter media at the same two locations that samples were collected using DustTraks.

The samples were collected on 47 mm Gelman Teflo filters with a 2.0 µm pore size. A Cahn Model 34 microbalance at the CE-CERT laboratory was used to determine the weight of the filters to within 1 µg before and after sampling. All filters were equilibrated at 23^oC and 40% relative humidity for at least 24 hours prior to weighing.

The results of this sampling were used to determine differences between the optical DustTrak method of determining PM and the mass collected on filter reference methods.

3.1.3 Wind Speed and Wind Direction

Prevailing winds for testing performed at CE-CERT were determined using a wind system located at a height of 5 meters at CE-CERT. A Climatronics F460 wind speed and wind direction monitoring system connected to a Campbell 10X data logger. This system measured and process winds into ten minute and hourly averages. The system has an accuracy of +\-5 degrees for wind direction and +/-5% wind speed accuracy for winds greater than 5 m/s. The wind system is shown in Figure 1.

Figure 1. Project wind system at CE-CERT.

For measurements performed at the UC Kearney facility, wind data were obtained from the SJVUAPCD site operated on the facility. The wind system is shown in Figure 2.

Figure 2. SJVUAPCD wind system at UC Kearney facility.

3.1.4 Propene Tracer Gas Measurements

The test chamber was not a completely sealed system. We were aware that there would be exchanges and losses of chamber air to the outside. Tracer gas was introduced into the chamber prior to each test run to assess the exchange amount. Approximately 3 liters of pure propene was placed in a bag (Figure 3) and released over the length of the chamber about two minutes prior to each run. Measurements for this tracer gas were performed using a RAE Systems ppbRAE hydrocarbon analyzer. The instrument determines the concentration of hydrocarbons using a 10.3 electron volt photoionization detector (PID). The instrument internally records the concentration and time data with a five second resolution. The instrument has a lower detection limit for propene (C_3H_6) of approximately 50 ppb. The three liters of propene introduced in the chamber created a concentration of about 37.5 ppm (37,500 ppb) for the 20m long chamber and 75 ppm for the 10 m long chamber, which was readily detectable by the PID. The instrument was placed at a height of 2m. It was placed at a distance of 6m in for the 20m chamber (Figure 4) and 2m in for the 10m chamber. The objective of the tracer was to look at the rate of change in tracer concentration with time. As a consequence, it was not necessary to accurately determine the amount of propene introduced into the chamber. The rate of change (i.e. tracer concentration decrease over time) for the propene is a surrogate for the amount of PM lost from the chamber to the outside due to incomplete sealing of the chamber. The tracer measurements were initially used to help validate the chamber method approach. The initial testing indicated that there was about a 1-2% per minute air exchange. This exchange was sufficiently low to not impact the chamber measurements. Exchange rates for all runs are presented in Section 3.

A plastic bag was placed in a three liter container and propene was then allowed to fill the bag.

Figure 3. Propene tracer gas preparation.

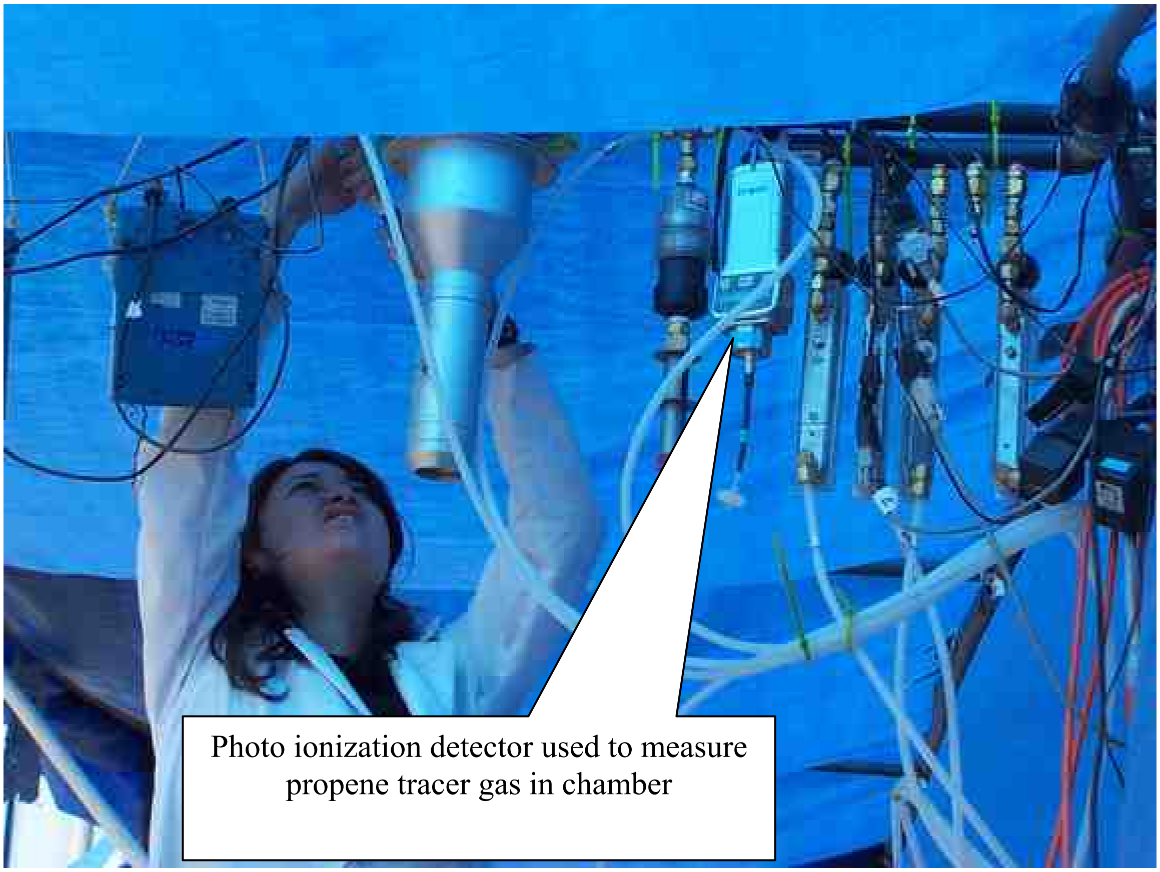


Photo ionization detector used to measure propene tracer gas in chamber

Figure 4. Photoionization analyzer in chamber used to measure propene tracer gas concentration.

3.1.5 Data Acquisition System

Data from the eight DustTraks were collected using a PC with LabVIEW software and appropriate RS-232 multiplexers. The logging and averaging periods for each channel will be set to one second. Data from the Climatronics WS/WD system were collected using a Campbell 10X data logger. Data from the RAE Systems ppbRAE propene analyzer were internally logged. At the conclusion of each set of tests, all data were transferred to a networked PC for storage and backup.

3.1.6 Leaf Blowers

There are several categories of leaf blowers. For this project, we procured one of each of the following: gasoline powered hand held, gasoline powered backpack and electric powered with blower and vacuum capability. We procured these from a home supply store. We selected the ones that are most popular and most likely of the style to be in use in the San Joaquin Valley. The leaf blowers used were identified as the most popular from a major supply store (Home Depot, 2005):

- Black & Decker Model BV 4000 Hand Held Electric Blower/Vacuum (Figure 5)
- Echo Model PB 261L Gas Backpack Blower (Figure 6)
- Homelite Model 30 cc Vac Attack II Gas Hand Held Blower (Figure 7)

Figure 5. Electric powered hand held blower/vacuum.

Figure 6. Gas powered hand held blower/vacuum.

Figure 7. Gas powered backpack blower.

3.1.7 Rakes and Brooms

A rake and push broom were procured for examining alternate methods to leaf blowers for this study. We procured one new broom (Figure 8) and rake (Figure 9) from a major home supply store.

Figure 8. Push broom used for study.

Figure 9. Rake used for study.

3.1.8 Surrogate Material Spreading

It was important to spread out the surrogate material, consisting of soil, grass clippings and leaves in a reasonably uniform manner prior to each leaf blowing run. Initially we tried to use a fertilizer spreader to spread our surrogate soil consisting of soil, grass clippings and leaves along ground inside the test chamber. This method did not work at all for the three items blended. It was also felt that it would tend to segregate the soil by size should we choose to use it just to disperse the soil. We switched to a bucket consisting of the soil, grass and leaves combined. The material was then shaken out of the bucket in the test area. Due to the differences in densities between the soil, grass and leaves, the material did not come out of the bucket in a uniform manner. We then switched to three buckets, one for the soil, a second for the grass clippings and a third for the leaves. This method was used to spread out the surrogate material for all runs.

3.1.9 Triple Beam Balance

A model 710-00 Ohaus triple beam balance was used to weigh soil and vegetative matter used in the tests. The balance had a resolution of 0.1 grams.

3.1.10 Sieve Shaker

A model Rx-29 Ro-tar sieve shaker was used to shake the sieves containing samples that were sieved into fractions and weighed. Five sieves were used to separate the samples into six fractions. The sieves were No. 3/8 (.375 inch, 9500 μm), No. 4 (4750 μm), No 18 (1000 μm), No. 40 (425 μm) and No. 200 (75 μm).

Sieving the soil for preparation for use in surrogate soil material was done by manually shaking the sieves. The finest sieve for this task was the No. 40, 425 μm. Soil passing through this sieve was then weighed and used for the surrogate soil.

3.2 Design and Evaluation of Test Chambers

Designing, constructing and testing a system for determining PM emission rates from leaf blower operations were the first tasks in the measurement program. Both an open test shelter (tunnel) and closed system (chamber) were considered for this project. The initial plan for the test chamber is shown in Figure 10. A test chamber configuration has several advantages over the tunnel. A major advantage of the chamber is there is no need to determine the air flow rate through the test apparatus. However, characterizing PM concentration differences throughout the tunnel becomes important as it is a closed system and it is the calculations will be based on accurately knowing the total amount of mass in the air in the test chamber. We initially pursued using the chamber method for the following reasons:

- We believed that we would be able to accurately quantify the entire amount of mass in the chamber
- It was likely that the higher and more stable concentrations within a test chamber could be more accurately and precisely determined than using a flow-through tunnel.
- The chamber method eliminates the need to quantify the air flow rate through the measurement system
- The chamber method does not need winds to be present or blowing at any particular speed or in any particular direction

The remainder of this section discusses the testing performed to assess the performance and operating characteristics of the chamber method.

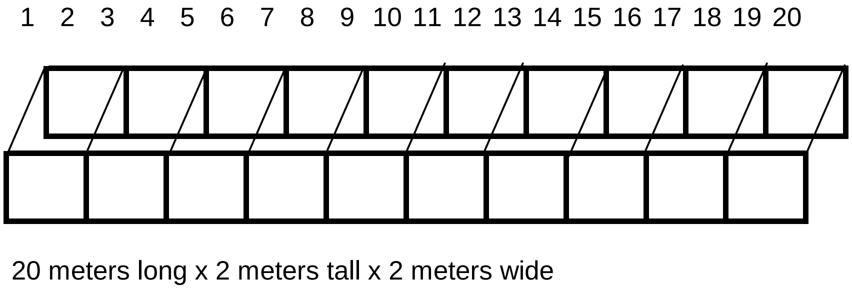


Figure 10. 20m test chamber.

3.2.1 Twenty Meter Long Test Chamber

The first chamber constructed was 2m wide, 2m high and 20m long. It was constructed using 1 inch PVC pipe and aluminum modular pipe and rail fittings. The chamber was enclosed using a polyethylene tarp. Figure 10 is a drawing of the chamber and Figure 11 shows photographs of the chamber.

Figure 11. Photographs of 20m test chamber.

3.2.2 Initial Evaluation of the 20m Chamber

Material was laid out as shown in Figure 12. A leaf blower was used to sweep the material to the end of the structure. Observations were made for the following:

- Losses along the length of the structure due to using round pipe at the bottom
- Losses under the length of the structure due to non flat surface – integrity between ground and pipe running along ground not maintained
- Creation of a copious of dust plume leading to an unsafe work environment
- Potential for high of gas powered leaf blower exhaust buildup in chamber leading to an unsafe work environment
- Ability/inability to sweep soil due to shape/dimensions of test chamber

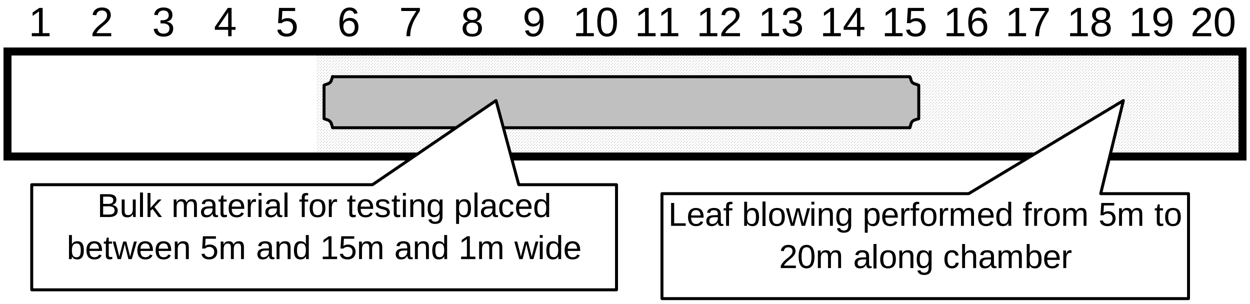


Figure 12. Top view of test chamber showing test material.

We found that uneven surfaces may create a problem sealing the chamber along the base. As shown in Figure 13, this problem was resolved by placing 1.5 inch OD PVC pipe on top of the excess tarp and using sand bags to hold down the pipe and tarp.

Figure 13. Addition of pipe and sandbags along base of chamber to eliminate leaks.

The range of the dust plume generated within the chamber varied from about 5 mg/m^3 to about 30 mg/m^3 (although one test did reach levels just over 100 mg/m^3). This range was within the 0.001-100 mg/m^3 range of the DustTraks. (Note: the DustTraks do continue to respond to concentrations above 100mg/m^3, but it's beyond the manufacturer's specified operating range.) The ranges of PM concentrations encountered within the chamber were not comfortable for staff to work in. The OSHA permissible exposure level (PEL) (level that a healthy individual can work in for eight hours) is 10 mg/m^3 and the CalOSHA level short-term exposure level (STEL) (level that a healthy individual can work in for fifteen minutes) is 20 mg/m^3. In order to provide a safe and comfortable working environment, staff working in the test chamber used the respiratory protection equipment shown in Figure 14.

Figure 14. Respiratory protection equipment used for chamber tests.

The initial chamber was 2m wide x 2m tall x 20m long. Most of the work performed in Riverside was done using this chamber. This length was originally chosen so that it would also be suitable for use as a tunnel. In order to have a more convenient size chamber for moving to multiple test locations in Riverside and at the UC Kearney agricultural facility near Fresno, the chamber was reduced in length to 10m (Figure 15). Chamber assessment tests were performed on both the 20m and 10m long chambers.

Figure 15. 10m test chamber.

3.2.3 Dust Plume Characterization

Initial test runs were performed using soil from three UC research areas in the San Joaquin Valley, Fresno, Madera and as well as material already present on the ground in the chamber. These tests were performed to check that the range of airborne particulate matter generated was within the range of operation of the DustTraks. As presented in Section 3.2.1, the plumes generated were well within the operating range of the DustTraks.

For the 20m chamber, we laid out surrogate material in a 10m^2 area (Figure 12). For the 10m chamber, we laid out half as much material and placed that material in a 5m^2 area (Figure 16).

Figure 16. Photographs showing surrogate material laid out in the 10m test chamber.

Additional testing was performed on the chamber to determine its mixing characteristics. Tests were performed to assess PM characteristics along the length of the chamber (horizontal gradients), PM characteristics in the vertical (vertical gradients) and changes in PM concentration with time (time to equilibrium).

Material was laid out in the 20m long chamber as shown in Figure 12. The impactors were removed from all eight DustTraks so that they were all measuring TSP. To determine the horizontal concentration gradients of PM, the DustTraks were placed at a height of 2m at the following distances in: 2m, 6m, 10m, 16m, 18m, and 20m (Figure 17). As shown in Figure 18, DustTraks were collocated at 10m and 16m. A leaf blower was used to blow the material to the end of the chamber (Figure 19). The DustTrak data were reviewed to determine plume characteristics across the chamber. This test was repeated several times. This test was also repeated with PM_{10} and $PM_{2.5}$ inlets on the DustTraks.

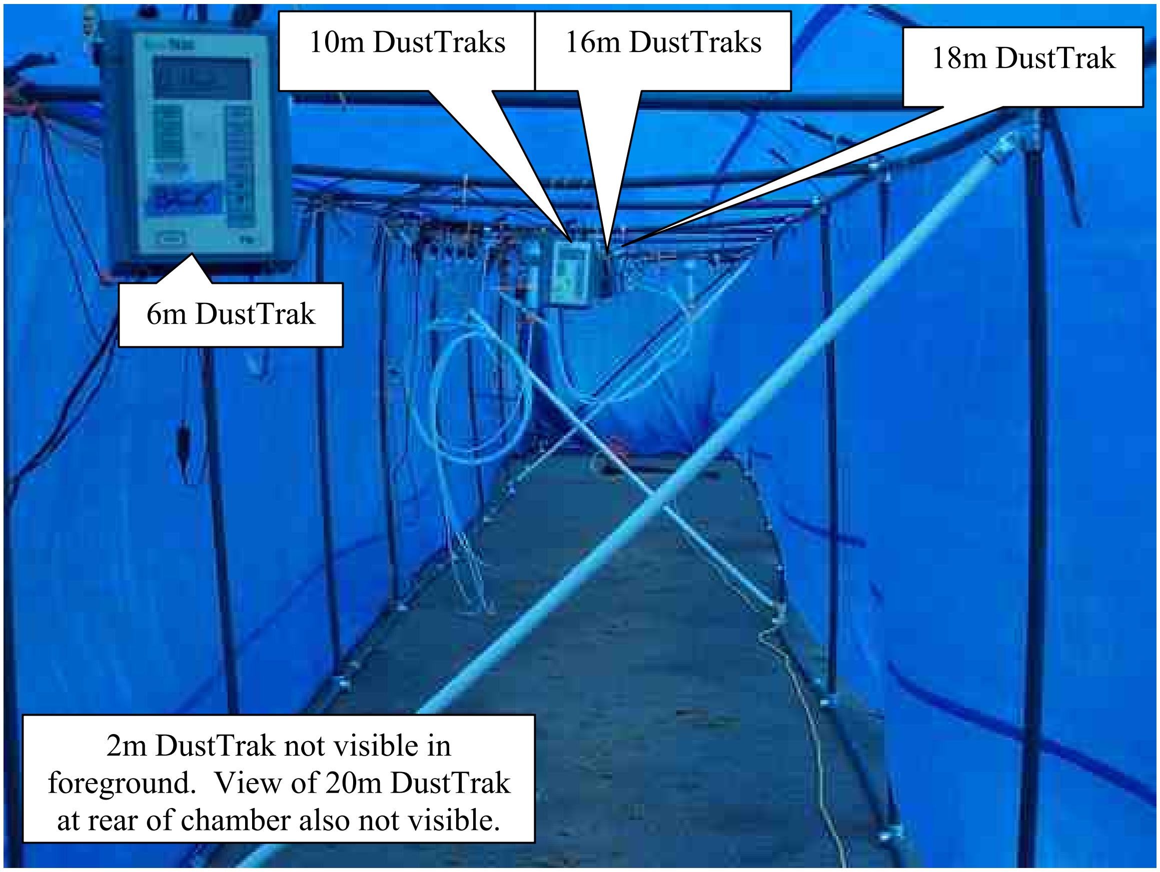


Figure 17. DustTrak locations in 20m test chamber for determining horizontal particulate matter distribution.

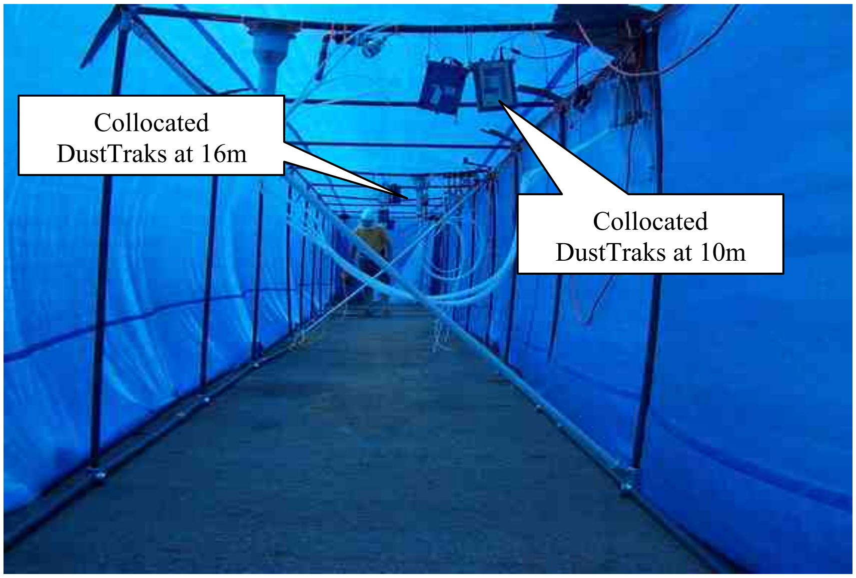


Figure 18. Collocated DustTraks at 10m and 16m for horizontal gradient tests.

Figure 19. Blowing operation for horizontal gradient tests.

To determine the vertical concentration gradients of the PM, three DustTraks were placed in the chamber at a distance of 10m at heights of 0.5m, 1.0m and 2m and three DustTraks were placed in at 16m at the same three heights (Figure 20). Two additional DustTraks were collocated at a height of 2m at the 10m distances in. The above tests were repeated with TSP, PM_{10} and $PM_{2.5}$ inlets to obtain vertical profile data.

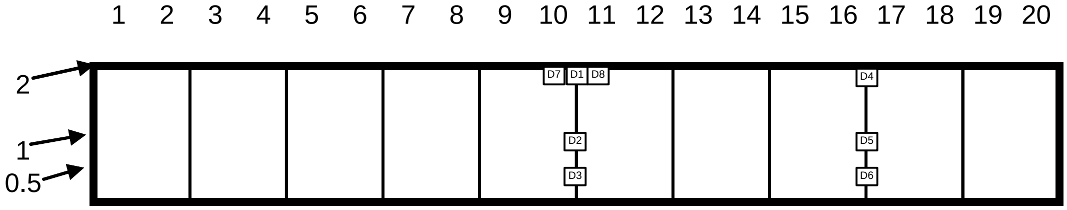


Figure 20. DustTrak locations in 20m test chamber for determining vertical particulate matter distribution.

A similar set of horizontal and vertical gradient tests were performed for the 10m long chamber. Four DustTraks were placed at a height of 2m at distances in of 2m, 4m, 6m and 8m. Four additional DustTraks were placed in at the distances, but a height of 1m. Figure 21 shows photographs of this setup. Three test runs were performed with the DustTraks setup to monitor TSP. Three additional tests were performed with the DustTraks setup for PM_{10} and an additional three tests with the DustTraks setup for $PM_{2.5}$.

Figure 21. DustTrak locations in 10m test chamber for determining horizontal and vertical particulate matter concentration gradients.

The findings from these tests were used to determine the minimum number and placement of PM samplers in order to perform subsequent tests. These tests also provided data as to the amount of time required following the leaf blowing for equilibrium to be obtained.

3.2.4 Ten Meter Long Test Chamber

Seventy-two runs were performed using surrogate material on asphalt and concrete surfaces using the 20m long chamber. The next phase of the project involved moving the chamber over surfaces that included unswept parking lots, curbs and grass surfaces. We felt that a 20m chamber was unnecessary (the length was originally chosen so that it could be used in the tunnel mode) and that it would be difficult to find locations that could accommodate the 20m long chamber. A 10m long chamber should give results equivalent to the 20m chamber, but it would be easier to find test locations and would also be easier to maneuver from test location to test location. For the evaluation of comparability a10m chamber was constructed from using half of the 20m long chamber. It had dimensions of 2m wide, 2m high and 10m long. Figure 22 is a drawing of the chamber and Figure 23 shows photographs of the chamber.

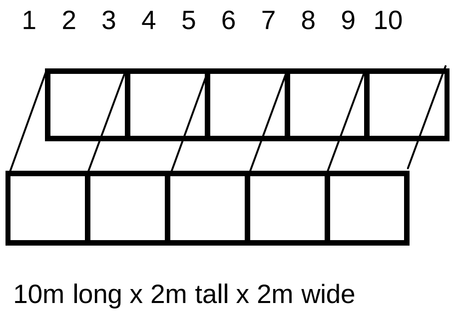


Figure 22. Drawing of 10m chamber.

Figure 23. Photographs of 10m chamber.

3.2.5 Sweeping Patterns in Test Chamber

Figure 12 shows the sweeping pattern in the 20m long chamber. Material was laid in a 10m2 area, one meter wide from 5m in to 15m in. The material was blown, raked or swept to the 20m end. For vacuuming runs, the vacuuming stopped at 15m.

Figure 24 shows the sweeping pattern in the 10m long chamber for the surrogate material. Material was laid in a $5m^2$ area, one meter wide from 2.5m in to 7.5m in. The material was blown, raked or swept to the 10m end. For vacuuming runs, the vacuuming stopped at 7.5m.

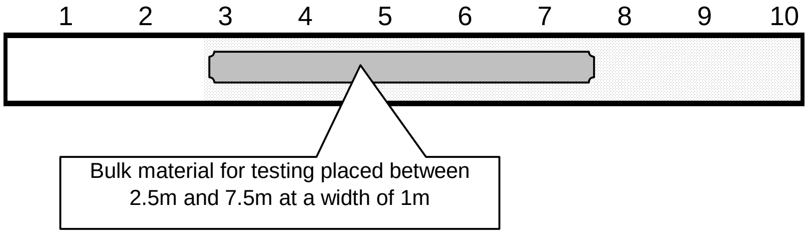


Figure 24. Surrogate material deployment pattern in 10m chamber.

Figure 25 shows the cleaning patterns used for the 10m chamber on indigenous surfaces. The 10m chamber was placed along the side of a recently mowed lawn, 0.3m on the lawn and 1.7m on the concrete surface next to the lawn. A leaf blower was used to blow the concrete surface sprinkled with grass clippings over a $9m^2$ area from 1m in the 10m end. The leaf blower was directed to blow material directly back on to the lawn. As shown in the next part of Figure 25, the 10m chamber was setup in a similar manner for cleaning a curb gutter. However, material was either raked or blown from 1m in to the 10m end for gutter cleaning. The 10m chamber was placed over lawns and packed dirt surfaces to obtain emission data from cleaning these surfaces. As shown in the last part of Figure 25, raking or blowing these surfaces was performed over the full 2m width from 1m in to the 10m end of the chamber.

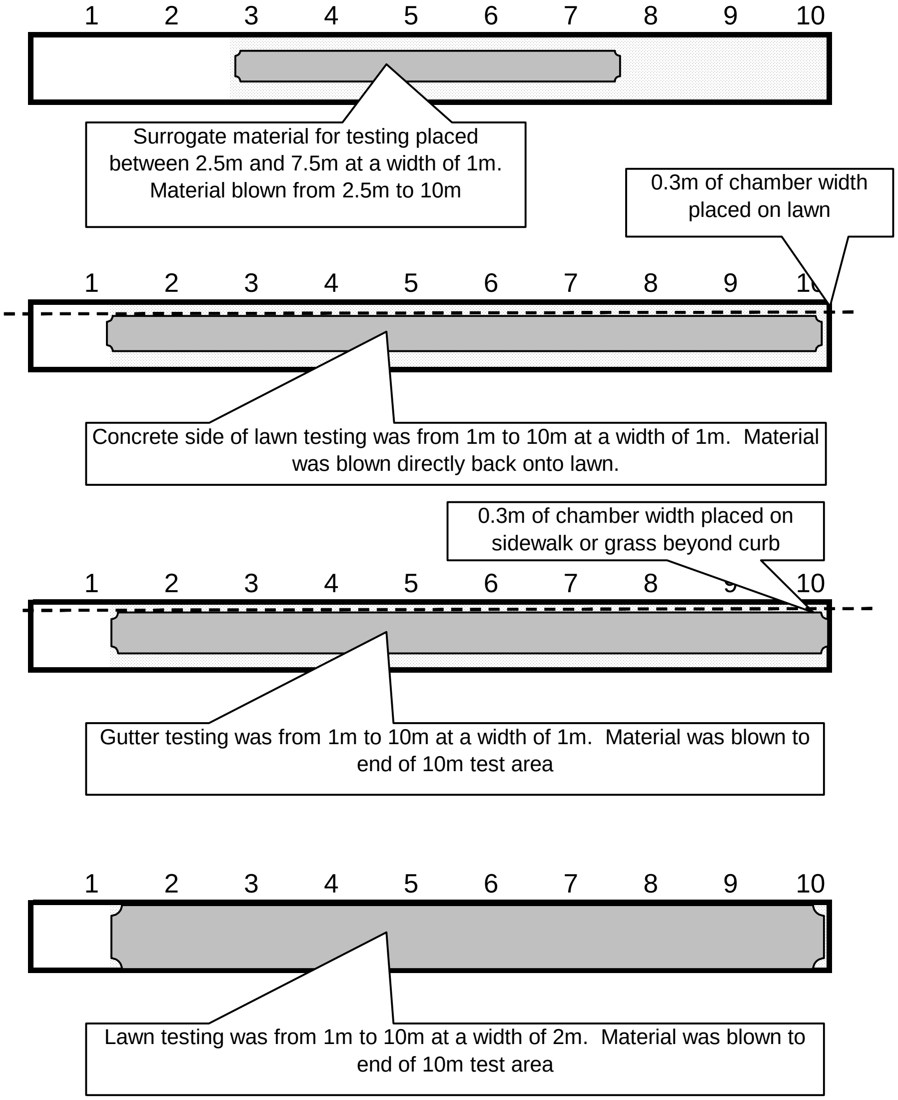


Figure 25. Cleaning patterns for natural/indigenous material with 10m chamber.

3.3 Surrogate and Actual Debris Selection, Preparation and Evaluation

Some tests were performed by placing the test chamber over a section of surface and blowing, sweeping or raking that ground. Other tests were performed by placing the chamber over a cleaned section of surface (either an asphalt or concrete surface), placing a measured amount of surrogate material down, then blowing, sweeping or raking that surface, as appropriate. The latter work was performed by placing known quantities of material on cleaned surfaces was critical for comparing different types of leaf blowers, raking and sweeping. In order to determine the appropriate amount of surrogate material to be placed on the cleaned surfaces, a series of measurements were performed on soils and surfaces to determine the range of their mass per unit area and soil/vegetative matter ratios.

Note: We used the terms "soil" and "vegetative matter" in this study as follows: We used dirt shoveled from near the surface of the ground for the soil material. This dirt was likely fairly rich in organic matter. We use the term "vegetative matter" to refer to leaves, grass, twigs, etc. that are on the surface of the ground (i.e. clippings from recently cut grass or leaves that have recently fallen from trees or been blown into the area).

- **Soil versus Vegetative Mass Ratio of Test Material**

One-meter square areas at selected locations around the UCR campus where leaf blowers are routinely used were vacuumed just prior to routine leaf blowing activities. Figure 26 shows photographs of several of these areas. The vacuumed material was separated via sieves into six size ranges from greater than about 1 cm (No. 3/8 inch sieve) to less than 75 µm (No. 200 sieve). We had expected a fairly clear distinction between soil material and vegetative matter from the sieving. The soil/vegetative distinction was not as clear between the sieve fractions as anticipated; there was a fair amount of vegetative matter in the finer sieve fractions and some soil material appeared in the larger sieve fractions. However, the sieving did provide sufficient data to determine the mass of soil material and its size (i.e. diameter based on sieving) as well as the mass of vegetative matter to use for creating surrogate samples. Details of the amount of material in each sieve fraction and the locations and types of areas samples were collected from are presented in Section 4.4. Based on the this work we prepared samples consisting of 120 grams of soil (mass after passing through a No. 40 (425 µm) sieve), 60 grams of leaves and 60 grams of grass clippings to be spread out in a 10 m^2 area in the 20m long chamber and half that amount to be spread in a 5m^2 area in the 10m long chamber.


Samples acquired from UCR prior to leaf blowing


Samples acquired from UC Kearney agricultural facility adjacent to location test chamber placed

Figure 26. Square meter areas vacuumed and analyzed just prior to leaf blowing.

- **Preparation of Surrogate Material**

Using the soil/vegetative ratio determined above, surrogate soils were prepared using the soils from three UC agricultural experimental facilities (Kearney, Five Points, and Shafter) and that supplied by the District from the Fresno and Madera areas. Separate samples with grass and leaf material were made for each of the soil samples. The material was spread out as shown in Figure 12 and a leaf blower was used to sweep the material to the end. Comparisons of the airborne PM levels were made between the three UC facilities and Fresno soils to identify any differences. The findings from this work are presented in Section 4.5.

For the emissions testing to determine emissions related to different types of blowers, brooms and rakes, only the soil from the UC Kearney facility in the San Joaquin Valley was used as it was desired to have just a single variable, the type of sweeper, for those emission determinations. However, as part of the study to determine emission factors for different materials, we performed significant testing using only one leaf blower to sweep over different surfaces with the indigenous soil and vegetative matter. Additional runs were also performed over indigenous soil and vegetative matter using a rake or broom, as appropriate.

3.3.1 Soil Silt Content

CE-CERT had soil from three agricultural facilities located in three different areas of the San Joaquin Valley from a previous study. These soils were used in the present study. We had aliquots of all of these soils analyzed for silt content using the following two methods.

- **AP-42 Soil Analysis Method**

The current protocol used by most agencies to estimate the amount dust entrained from agricultural tilling and from dirt roads is presented in AP-42 (EPA, 1995). Appendix C.2 of AP-42 describes a dry sieve protocol to determine the percentage of mass that passes through a No. 200 sieve (75µm) and to define this fraction the "silt content." Aliquots of soils from the three UC agricultural facilities in Shafter, Kearney, 5-Points were analyzed by this method.

- **Multisize Fraction Laboratory Analysis of Soils**

Aliquots of the above three soils (Shafter, Kearney, and 5 Points) were analyzed by methods to provide more comprehensive particle size information (in particular for the ~75 micron and smaller size diameters) than is provided by the Method AP-42 protocol.

ASTM Method D422 (ASTM, 1990) was used to determine the sand, silt and clay content in the under 75 µm size range. This is a wet sieve method that uses sedimentation of the soil (or a sieved fraction of the soil) to determine diameter of the soil particles.

	`	Shafter (percent passing)	Kearney (percent passing)	5 Points (Westside) (percent passing)
Method AP-42:				
Sieve Number	Sieve Grid Size			
20	850µm	100	100	100
40	425µm	99.5	99.8	99.1
60	250µm	85.2	91	91
100	150µm	69.3	78.3	72.5
200	75µm	45.4	60.7	37.7
Method D422:				
Gravel	(percent)	0	0	0
Sand	(percent)	55	39	62
Silt	(percent)	31	53	28
Clay (<0.002 mm)	(percent)	14	8	10
Moisture	(percent)	1.6	1.5	1.3

Table 3. Particle size analysis of various soil types used.

Aliquots of the three UC agricultural facility soils plus the Fresno and Madera soils provided by the

District were analyzed as part of this study. They were analyzed by the sieve method described in AP-42, except they were not baked prior to sieving. (We wanted the sieve data to reflect as-is conditions for these soils.) The findings from these analyses are presented in Table 4.

Top Sieve	none	3/8 inch	#4	#18	#40	#200
Bottom Sieve	3/8 inch	#4	#18	#40	#200	none
Bottom Sieve Mesh Size	>9,500µm	9,500µm	4,750µm	1,000µm	425µm	75µm
	(percent)	(percent)	(percent)	(percent)	(percent)	(percent)
Kearney	0	1	2	18	47	32
Shafter	0	1	12	22	49	16
Fresno	0	1	18	40	29	11
5 Points	5	7	24	19	33	11
Madera	14	7	6	14	45	14

* Sieve Range: Material passed through larger (top) sieve shown, but did not pass through smaller (bottom) sieve shown.

** Bottom Sieve Mesh Size: Value shown is grid mesh dimension of bottom sieve; the dimension that material did not pass through.

*** (percent): this is the percentage of total sample mass collected on bottom sieve except for last column where it is the percentage of sample collected after passing through the #200 sieve.

Table 4. Sieve analysis of the five soils used.

3.4 Data Processing and Validation

3.4.1 Data Handling

All testing was documented in the project logbook. A form was created to log filter data and document chain of custody. Additional forms were created to log collection of the $1m^2$ samples from areas planned to be blown as part of routine leaf blowing operations and logging the mass determined from each sieve fraction. In addition, all periods of data collection, including the specific sampling mode and any known problems with any of the instruments, were logged at a sufficient level of detail in order to preclude misdirection of data.

Data collected on the data logging PC were transferred to a networked PC for storage and backup on a daily basis.

Power failures, instrument or computer failures, operator intervention for maintenance and calibration, deviation of the instrument calibration results outside the acceptable limits, deviations of the QC checks outside the acceptable ranges, problems with the sample runs, or other problems are all factors can potentially compromise data validity. The Project Team identified those periods during which specific data may be considered unreliable by the use of data flags. When these factors occurred it was recorded in the project logbook and communicated directly to those performing the data validation and analysis. The data were inspected graphically and all discrepancies and inconsistencies were resolved by discussion within the project team and/or by reference to the raw data and the project logbook.

3.4.2 Data Validation

Data validation followed guidelines described by the U.S. Environmental Protection Agency (U.S. EPA, 1978, 1980). All data were screened for outliers that were not within the physically reasonable (normal) ranges. Next, the following steps were taken:

1. Data were flagged when deviations from measurement assumptions had occurred.
2. Computer file entries were checked for proper date and time.
3. Measurement data resulting from instrument malfunctions were invalidated.
4. Data were corrected for calibrations or interference biases.

Meteorological, propene tracer and DustTrak data were reviewed as time series plots and using computer based outlier screening routines. Rapidly changing, anomalous or otherwise suspect data were examined with respect to other data. Computer based outlier programs were used to screen the data from the eight DustTraks for anomalies (e.g. $PM_{2.5} > PM_{10}$, etc).

Data were not invalidated unless there was an identifiable problem or the measurement result was physically impossible.

3.4.3 Data Analysis

The filter sampler data were used to develop correction factors between the mass concentrations reported by the DustTraks and the concentrations determined by those determined from the filter data. These correction factors were used to adjust the data measured by the DustTraks for the airborne particulate matter used in this project.

Emission factors were calculated for the sweeping activities. We collected data to enable calculation of emissions in terms of airborne mass (TSP, PM_{10} and $PM_{2.5}$) per unit area swept, airborne mass per unit time swept and airborne mass per unit mass swept. The emission factors reported here are in terms of emissions per unit area cleaned. These findings have been tabulated in Section 4. Comparisons of the emission factors were made to better understand variables effecting emissions as well as to perform a level 2 validation of the data.

3.4.4 Data Precision, Accuracy and Completeness

- **Accuracy**

The accuracy of the filter samplers was determined from a performance audit conducted during the study. The audit consisted of determining the flow rate for each of the six samplers and comparing those flow rates to the flow rates used by the measurement team. The percent difference for each of the six filter samplers was calculated using the following equation:

$$\%Dif. = [(Y - X)/X] \times 100$$

In this equation, X is the test value and Y is the corresponding instrument response.

- **Precision**

The precision of the DustTraks was determined from collocating two additional DustTraks. The differences between the collocated instruments were determined using the following equation:

$$\%Dif. = 2(A - B)/(A + B) \times 100$$

In this equation, A is the value from the instrument A and B is the corresponding instrument value reported from collocated instrument B. A series of replicate collocation checks were assimilated and an average and standard deviation from the entire set of collocated data were calculated.

- **Minimum Detection Limits**

The minimum detection limits (MDLs) are defined as a statistically determined value above which the reported concentration can be differentiated, at a specific probability, from a zero concentration. For this study, the gas analyzers (PID instrument used for measuring propene) and DustTraks were all operated well above their MDLs.

- **Completeness**

Completeness was determined from the collected data generated during the study using the following equation:

$$Completeness = (D_x - D_c)/D_c * 100$$

Where D_x is the number of samples for which valid results were reported and D_c is the number of samples that were scheduled to be collected. The provisional completeness objective for this study was 90% for each instrument for each sampling run. The data completeness are presented in Section 4.

4.0 MEASUREMENTS AND RESULTS

Measurements to determine emission factors were performed during August and September 2005. This section presents the results from those measurements.

4.1 Study Dates and Conditions

Measurements were performed during August and September 2005. Development of the test chambers and most of the testing using surrogate soils was performed at the UCR CE-CERT facility in Riverside. Table 5 summarizes the study activities and meteorological conditions.

Date	Operating Time (PDT)	Activity	Winds	
			WS (m/s)	WD (deg)
8/3/2005	NA	Collected one 1m^2 samples from asphalt area at CE-CERT where 20m chamber will be placed		
8/8/2005	14:00-16:00	Collocated comparison of DustTraks in chamber		
8/9/2005	6:00-8:00	Collected five 1m2 samples from areas around UCR gardening activities		
8/9/2005	9:00-15:00	Collocated comparison of DustTraks in chamber		
8/10/2005	6:30-8:00	Collected six 1m^2 samples from areas around UCR gardening activities		
8/11/2005	6:20-7:30	Collected three 1m^2 samples from areas around UCR gardening activities		
8/16/2005	NA	Chamber development		
8/17/2005	13:00-15:00	Chamber vertical and horizontal gradient assessment - three test runs		
8/18/2005	11:00-16:10	Chamber vertical and horizontal gradient assessment - four test runs		
8/19/2005	10:00-17:00	Chamber vertical and horizontal gradient assessment - five test runs		
8/23/2005	14:00-15:00	Two surrogate material runs		
8/24/2005	8:00-12:00	Six surrogate material runs	1.3	E, then W
8/25/2005	6:00-12:00	Twelve surrogate material runs	1.3	E, then W
8/26/2005	6:00-8:00	Eight surrogate material runs	0.6	E, then W
8/30/2005	6:00-12:00	Twelve surrogate material runs	1.1	SE, then W
8/31/2005	5:00-13:00	Seventeen surrogate material runs	1.0	SE, then W
9/2/2005	5:00-14:00	Fifteen surrogate material runs	1.2	E, then W
9/6/2005	5:00-9:00	Nine surrogate material runs	0.5	NE
9/8/2005	7:00-13:00	Nine indigenous surface runs at CE-CERT	1.4	SE, then W
9/13/2005	5:00-14:00	Fourteen indigenous surface runs at Kearney	1.7	var
9/13/2005	NA	Collected three 1m^2 samples from areas adjacent to where 10m chamber was setup		
9/14/2005	5:00-13:00	Nine indigenous surface runs and four surrogate material runs at Kearney	1.7	var
9/14/2005	NA	Collected three 1m^2 samples from areas adjacent to where 10m chamber was setup		

* Surrogate Material Run: Test using mixture of sieved soil, grass and leaves as described in Section 3.3.

** Indigenous Material Run: Test perofrmed by placing chamber over undesturbed surface and cleaning that surface as described in Sections 3.2 and 3.3.

Table 5. Summary of study activities and meteorological conditions.

Measurements of emissions from blowing and raking on surfaces with natural/indigenous material, including asphalt parking lot, grass lawn and street gutter were performed at the

CE-CERT facility September 6-8, 2005. Additional measurements of emissions from blowing, raking or sweeping on surfaces with indigenous material, concrete walkways adjacent to a mowed lawn, grass lawns, asphalt driveways, street gutter and packed dirt parking lot were performed at the UC Kearney agricultural facility in Parlier on September 12-14, 2005.

Our staff followed grounds maintenance crews around the UCR campus between August 9 and 11 and collected 23 debris samples from areas that were about to be leaf blown.

Most of the measurement work was performed between 5 am and 2 pm PDT. This working period proved to be best for the following reasons. The UCR grounds maintenance crews complete their cleaning work by about 7 am daily. For test runs we found that the stronger afternoon winds resulted in fairly high air exchanges between the chamber and outside air. Additionally, the higher afternoon temperatures and radiant heating of the test chamber created uncomfortable working conditions in the test chamber.

4.2 Test Chamber Characteristics

As described in Section 3.2.2, a series of tests were performed on the 20m and 10m chambers to determine horizontal and vertical gradients and time to equilibrium.

4.2.1 Twenty Meter Test Chamber Horizontal Characteristics

Figure 27 shows the responses of the eight DustTraks spaced out at the horizontal distances shown in the legend (e.g. 2M is the DustTrak at two meters, 16M-coll = is the collocated DustTrak at sixteen meters). All eight DustTraks were at a height of two meters.

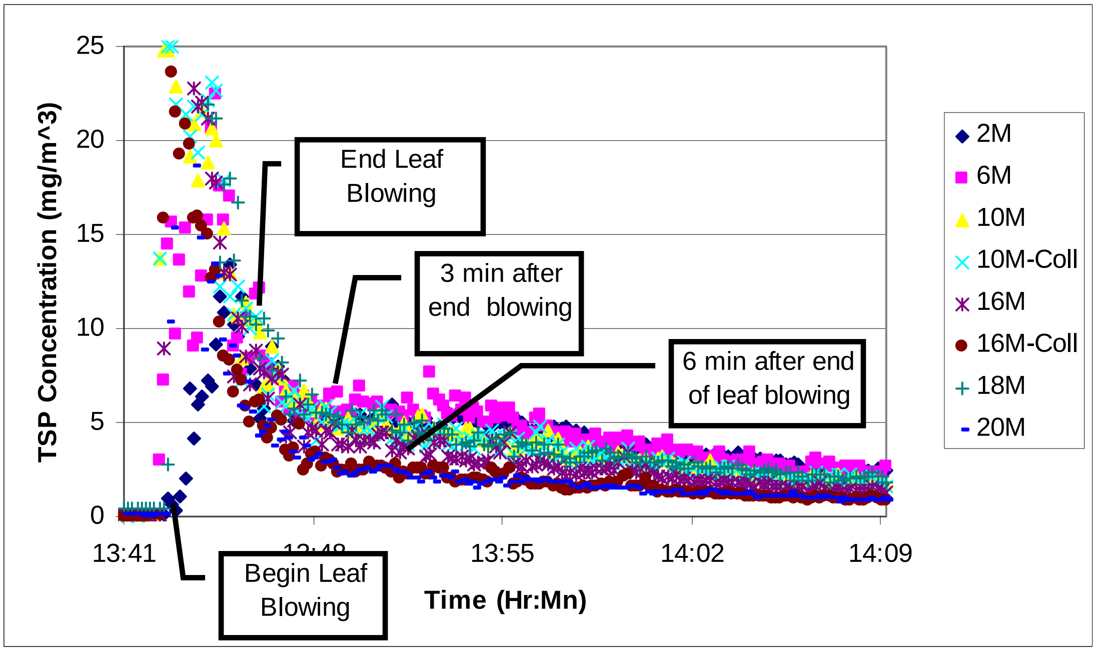


Figure 27. Time series of DustTrak TSP responses for horizontal distribution characterization.

As can be seen in the figure, the DustTraks show some initially high concentrations (greater than 25 mg/m^3) during the leaf blowing operation. The high concentrations observed during the leaf blowing are the spikes caused as the leaf blowing kicks up short-lived plumes of dust around each DustTrak. The PM concentrations in the chamber during this period are neither uniform, nor in equilibrium The TSP concentration at all distances (the measured locations within the chamber) rapidly drop to a more common value at the end of the leaf blowing operation. The rapid drop off to similar values indicates the suspended mass within the chamber is mixing and becoming more uniform. The concentrations become fairly uniform at about three to six minutes after the end of the leaf blowing. The concentration continues to drop off at a near constant rate over the next twenty minutes to about half of their values at three minutes after the end of leaf blowing. The tracer gas concentrations, not shown here, consistently dropped off at a rate of about one percent per minute, indicating that very little of the ambient mass was lost due to leaks in the chamber. As can be seen in the figure, although the eight DustTraks do track each other, there are some differences in the concentrations observed along the length.

Table 6 shows horizontal concentration profiles (averaged between 6 and 6.5 minutes after the end of leaf blowing) for additional runs with the eight DustTraks equipped with TSP, PM_{10} and $PM_{2.5}$ inlets and located at the six horizontal locations shown. As can be seen in this table, there is some run-to-run variability. Because we only had eight DustTraks, and these needed to be divided into two with TSP, inlets, two with PM_{10} inlets and two with $PM_{2.5}$ inlets, plus use the remaining two for collocated quality control or as backups, as appropriate, it was necessary to determine locations and methods that would allow us to perform the requisite measurements with these instruments. We performed calculations to determine the error in the data if we placed DustTraks only at 10m and 16m and used the average of readings between those two locations to be equivalent to the average concentration along the horizontal length of the chamber. These calculations showed the error to be 12% or less for the nine test runs. We felt that these errors were within the uncertainties of our measurements; indicating that placing the DustTraks at 10m and 16m and using the average concentrations for each of the three size cuts as the average concentration along the length of the chamber would provide accurate results.

Run	Size	21976 2 Meters	21975 6 Meters	85200674 10 Meters	21569 10 Meters	85200677 16 Meters	21955 16 Meters	21668 18 Meters	21667 20 Meters
0819_1	PM2.5	1.7	1.9	2.4	2.6	2.8	2.2	3.4	3.7
0819_2	PM2.5	2.5	1.7	2.3	2.6	4.1	3.0	5.1	5.2
0819_3	PM2.5	1.7	1.3	1.6	1.5	2.0	1.7	2.6	3.6
0817_1	TSP	2.9	3.7	2.5	2.4	2.8	3.7	2.0	1.6
0817_2	TSP	4.5	5.3	3.9	3.6	3.6	4.4	2.7	1.9
0817_3	TSP	5.6	6.8	4.4	4.2	4.3	4.1	3.6	2.6
0818_1	PM10	7.1	9.9	5.6	8.9	6.9	6.5	4.8	9.4
0818_2	PM10	5.1	7.5		8.0	6.1	5.2	6.1	4.9
0818_3	PM10	5.7	6.4	4.7	7.4	6.3	5.9	5.7	5.0

Table 6. Concentration data (mg/m^3) from tests to determine horizontal gradient in 20m chamber.

4.2.2 Twenty Meter Test Chamber Vertical Characteristics

Figure 28 shows the responses of the eight DustTraks at heights of 0.5m, 1m and 2m. Three DustTraks were at these heights at a distance of 10m in and another three were at these heights at a distance of 16m in. The remaining two DustTraks were collocated at a height of 2m and a distance in of 10m. All DustTraks were setup to measure TSP.

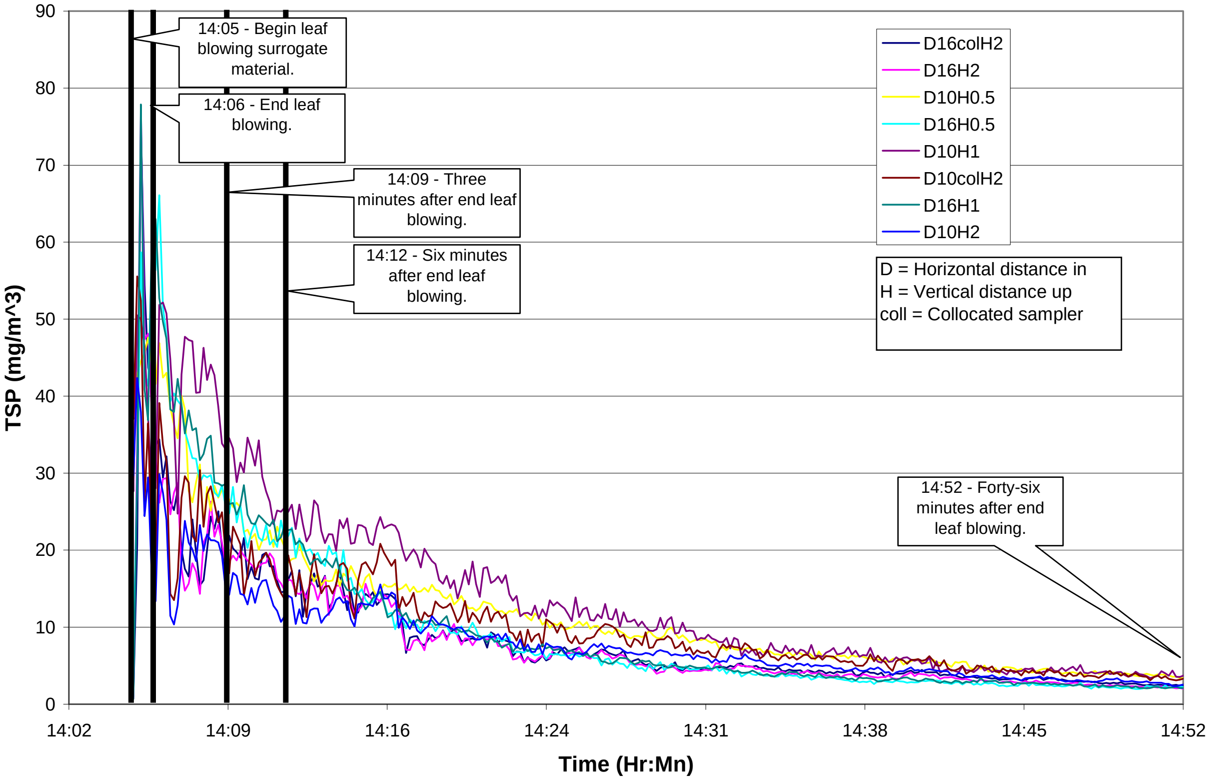


Figure 28. Time series of DustTrak responses for vertical distribution characterization.

The vertical profiles shown in Figure 28 show similar responses to the horizontal profiles discussed in Section 4.2.1. Very high concentrations (greater than 25 mg/m3, up to a peak of just over 75 mg/m3 in this example) are present during the leaf blowing as short-lived plumes pass over the DustTraks. The concentrations drop off rapidly and the concentrations at the three heights and two horizontal locations approach each other at the end of the blowing, indicating that the airborne particulate matter are mixing and becoming uniform along both the horizontal and vertical axes. The vertical profile tests were performed several times in the 20m chamber with the DustTraks equipped with TSP, PM_{10} and $PM_{2.5}$ inlets. The results for those tests are shown in Table 7.

		Distance 6			Distance 16				
Run	Size	Height 0.5M	Height 1M	Height 2M	Height 0.5M	Height 1M	Height 2M	Height 2M	Height 2M
0902_1	PM10	6.0	6.9	4.9	18.6	18.4	20.0	20.6	17.2
0902_2	PM10	4.7	5.8	4.1	22.0	22.9	25.7	24.1	20.0
0903_3	PM10	9.5	11.1	9.0	12.6	12.0	11.1	11.1	9.9
0902_4	PM2.5	2.3	3.9	3.4	1.4	1.9	3.2	3.2	2.1
0902_5	PM2.5	1.6	3.3	2.7	0.9	1.8	2.5	2.9	2.0
0902_6	PM2.5	1.9	2.2	2.3	1.9	1.9	2.0	2.5	1.8
0902_7	TSP	9.6	11.7	11.8	13.3	9.1	7.5	8.1	7.9
0902_8	TSP	7.8	11.5	11.6	11.3	8.5	8.6	9.8	9.3
0902_9	TSP	7.7	9.6	9.5	13.5	7.3	8.1	9.0	8.9

Table 7. Concentration data (mg/m^3) from tests to determine vertical gradient in 20m chamber.

As can be seen in the table, there is some variations in the concentrations with height and distance in. Because of logistic concerns regarding placing the DustTraks at heights other than 2m and because the differences in concentration along the vertical were similar to the measurement uncertainty, the DustTraks were placed at a height of 2m for subsequent tests with the 20m long chamber.

4.2.3 Ten Meter Test Chamber Horizontal and Vertical Characteristics

Our understandings of the horizontal and vertical profiles in the 20m long chamber were used to simplify the setup and testing of the 10m chamber. For the 10m chamber, pairs of DustTraks were placed at horizontal distances of 2m, 4m, 6m and 8m in. One DustTrak from each pair was placed at a height of 1m and the second was placed at a height of 2m. This setup allowed us to perform vertical and horizontal gradient testing at the same time. Testing of the 10m chamber was performed on a concrete surface using surrogate material. The surrogate material was spread out and blown using the manner presented in Section 3.2.5. Separate tests were performed with the DustTraks equipped with TSP, PM_{10} and $PM_{2.5}$ inlets. Figure 29 shows a time series for one of the tests with the DustTraks equipped with PM_{10} inlets.

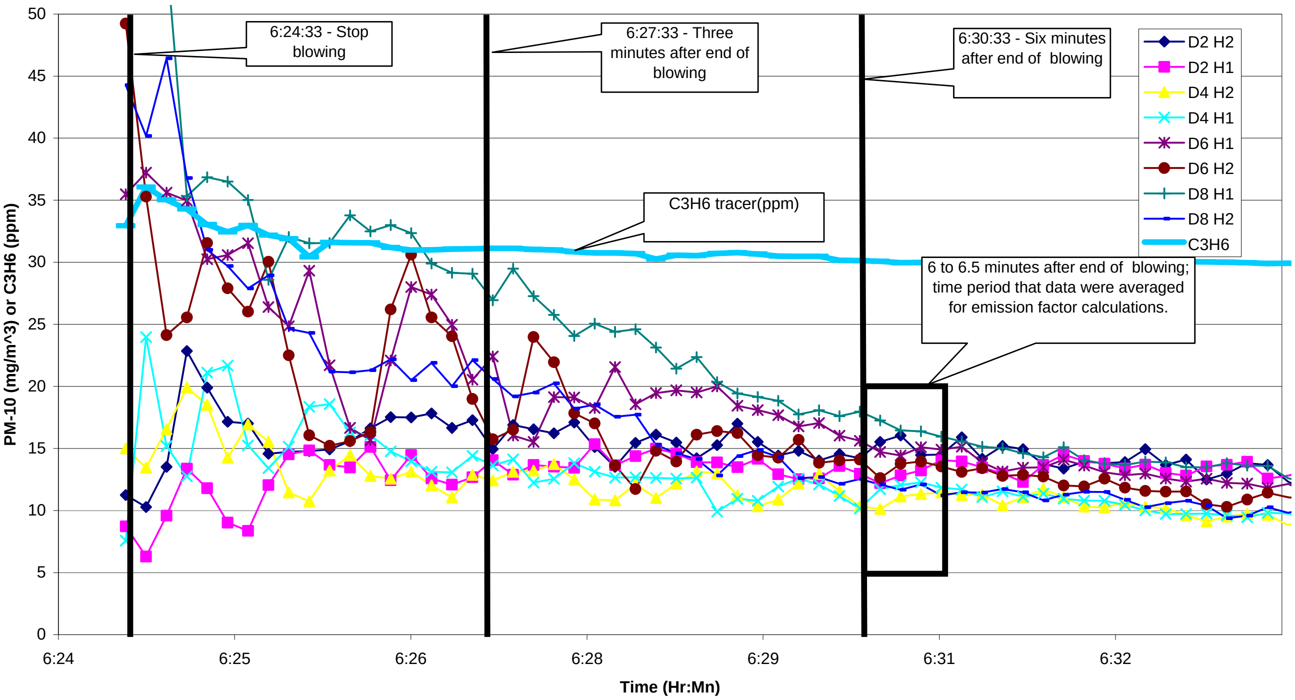


Figure 29. Time series of DustTrak responses for horizontal and vertical distribution characterization in 10m chamber.

The above figure shows that the concentration differences between the sampling locations drops off substantially 3.5 minutes (6:28 am) after the end of leaf blowing. The differences continue to decrease over the following five minutes shown in the figure. Also note that the tracer gas concentration is declining more slowly, indicating that particles are settling to surfaces. Table 8 presents the results from subsequent test runs for TSP, PM10 and $PM_{2.5}$ averaging the concentration data between 6.0 and 6.5 minutes after completing the blowing operation. Although there was some variability between which DustTrak was highest or lowest for a specific run, indicating incomplete and inconsistent mixing, these data indicate that there was sufficient mixing and repeatability within our experimental error to place the DustTraks in similar locations to those selected for the 20m chamber. For the subsequent test runs, three DustTraks (one each TSP, PM_{10} and $PM_{2.5}$) were placed at a height of 2m two meters in; three additional DustTraks (one each TSP, PM_{10} and $PM_{2.5}$) were placed at a height of 2m six meters in; and collocated PM_{10} and $PM_{2.5}$ DustTraks were placed at heights of 2m six meters in.

		Distance 2M		Distance 4M		Distance 6M		Distance 8M	
Run	Size	Height 1M	Height 2M	Height 1M	Height 2M	Height 1M	Height 2M	Height 1M	Height 2M
0906_1	PM10	12.7	15.3	11.3	10.5	14.9	13.5	17.2	12.1
0906_2	PM10	12.0	11.2	11.7	11.7	14.1	13.4	15.6	12.3
0906_3	PM10	6.1	7.1	7.7	7.6	9.3	9.7	12.8	11.5
0906_4	PM2.5	2.3	1.7	2.4	1.3	1.8	1.3	1.8	1.4
0906_5	PM2.5	1.7	1.9	2.8	1.4	2.1	1.6	2.5	1.2
0906_6	PM2.5	2.0	1.9	2.6	1.5	3.0	1.8	2.9	1.5
0906_7	TSP	5.9	6.7	5.5	7.5	9.5	8.2	11.4	6.0
0906_8	TSP	5.9	5.7	5.8	4.5	7.6	4.7	12.5	4.0
0906_9	TSP	9.3	6.6	10.8	4.4	14.4	4.8	11.7	4.2

Table 8. Vertical and horizontal concentration gradient data (mg/m^3) averaged between 6.0 and 6.5 minutes for 10m chamber.

The average concentrations obtained between 6 and 6.5 minutes after the end of blowing was used to calculate the emissions for subsequent runs.

4.3 DustTrak Calibration Factors

As presented in Section 3.1.1, there were two parts for obtaining the DustTrak calibration factors. The first part was collocation of DustTraks. This was done to obtain calibration factors normalizing the DustTrak responses to each other. The second was collocation of filter based particulate matter samplers for one run each day to check the calibration factors for each size range against a reference mass measurement method.

Figure 30 presents a time series for the eight DustTraks collocated at a height of 2m and in a distance of 6m in the 10m long chamber for three separate test runs. The DustTraks all had their inlets removed for TSP sampling for this collocated test. As shown in the figure, the test ran up to twenty minutes after the end of the leaf blowing. The first five minutes after the end of leaf blowing were excluded from the analysis to allow, time for mixing and a homogeneous ambient PM plume to be present around the collocated samplers. The average concentrations for the eight samplers between minute five and ten, ten and fifteen and fifteen and twenty were determined. One DustTrak was selected to be the reference DustTrak. The ratio of the reference DustTrak averages to the averages for the other seven were determined. This approach was performed for multiple runs with DustTraks set for TSP, PM$_{10}$ and PM$_{2.5}$ monitoring. Table 9 presents the calibration factors obtained from these data for the three particle cut sizes.

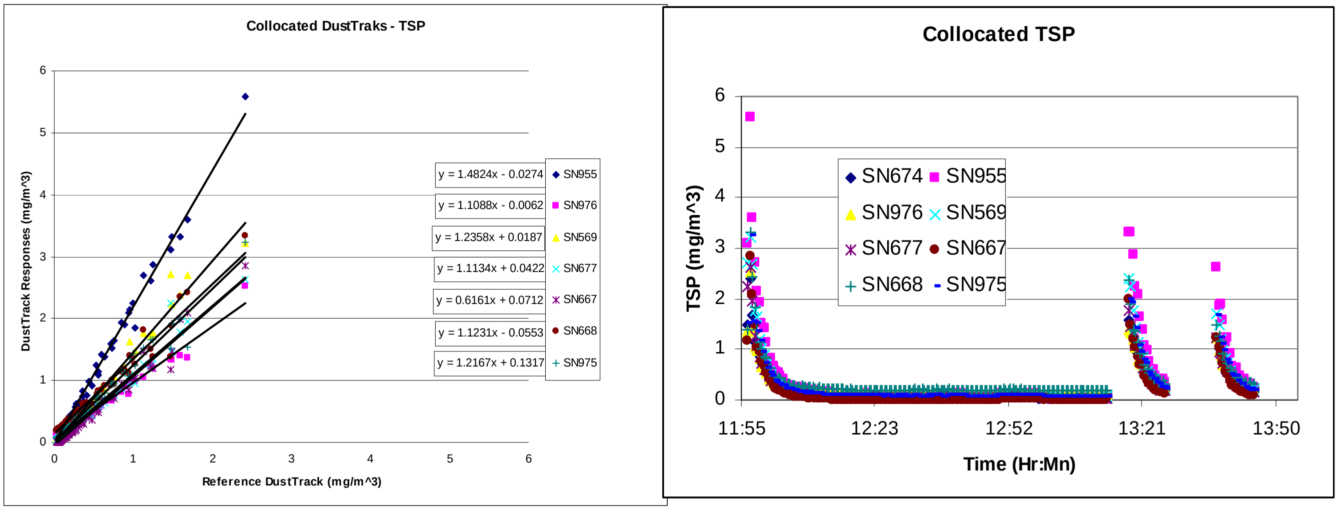


Figure 30. Correlation (all three tests) and time-series plots for eight DustTraks collocated in 10m chamber.

Serial Number	85200677	21955	85200674	21667	21975	21976	21668	21569
PM-2.5	1	1.00	0.84	1.24	0.94	1.00	1.00	1.01
PM-10	1	0.68	0.71	0.83	0.62	0.75	0.81	0.96
TSP	1	0.76	0.93	1.03	0.85	1.14	0.87	0.71

Table 9. Collocated DustTrak mean response ratios.

The collocation of filter samplers were used to check the calibration factors for the DustTraks' optical response to a mass response for the specific soil material used on the project.

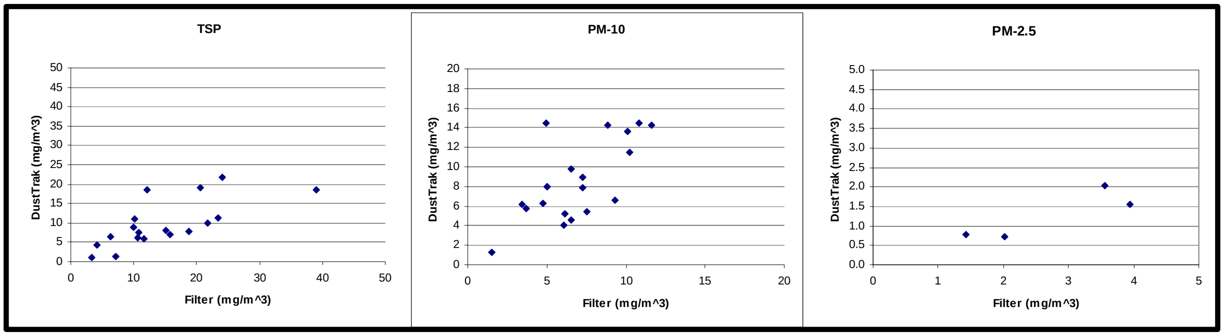


Figure 31. Collocated DustTrak and filter sampler comparisons.

As can be seen in Figure 31, there is significant scatter in these comparison data. The filter samplers were started at the same time that the leaf blowing was initiated. This included sampling during a period prior to homogeneous mixing in the chamber, which will enhance the amount of scatter. Hence these sampling numbers are used only to confirm that the DustTraks were providing data in the correct range, not to obtain calibration factors. The data indicate that the DustTraks were providing data within an acceptable range.

4.4 Determination of the Composition of Debris for Leaf Blower Testing

Twenty-three samples were collected from areas that were about to be leaf blown or swept. They were collected by vacuuming 1 m^2 areas in the manner described in Section 3.3. Fourteen of these were from areas around UCR that were being cleaned by the campus gardening. The remaining nine were from areas around CE-CERT (three samples) and the UC Kearney facility (six samples) that were immediately adjacent to locations where the test chamber was setup to blow, rake or sweep indigenous debris.

Table 10 presents the total mass and mass for each of the six size fractions. As can be seen in the table, the total mass ranged over two orders of magnitude, from 2 to 377 grams. The mass in each size fraction are presented as percentages in Table 11 to more readily identify the differences between the size fractions and to compare samples from one location to the next.

Sample	Location	Sample Description	Total Mass (grams)	> 3/8 fraction (grams)	< 3/8, > #4 fraction (grams)	< #4, > #18 fraction (grams)	< #18, > #40 fraction (grams)	< #40, > #200 fraction (grams)	< #200 fraction (grams)
1	UCR	Asphalt Driveway - General cleaning	377.3	2.8	24.8	136.5	74.2	104.8	34.3
2	UCR	Concrete Walkway - Lawn trimmings	49.5	0.9	0.5	8.3	32.3	4.8	2.7
3	UCR	Textured Concrete Walkway - Lawn trimmings	10.4	0.4	1.1	5.0	2.5	1.1	0.2
4	UCR	Concrete Walkway - General cleaning	36.1	9.9	8.8	14.6	1.9	0.8	0.1
5	UCR	Brinks - General cleaning	55.2	11.5	19.6	12.3	5.4	4.9	1.5
11	UCR	Concrete Walkway - General cleaning	24.2	11.9	7.3	1.5	1.1	1.7	0.8
12	UCR	Concrete Walkway - General cleaning	10.5	0.5	0.5	4.4	1.3	2.5	1.4
13	UCR	Concrete Steps - General cleaning	16.2	6.9	2.9	3.6	1.5	1.2	0.2
14	UCR	Concrete Walkway - General cleaning	4.6	1.0	0.7	0.5	0.4	1.4	0.6
15	UCR	Concrete Walkway - Lawn trimmings	14.6	2.8	1.2	6.4	3.2	1.1	0.0
16	UCR	Concrete Walkway - Lawn trimmings	36.6	12.1	5.9	13.0	4.0	1.5	0.1
21	UCR	Asphalt Parking Lot - Lawn trimmings	26.2	1.9	3.6	17.3	3.1	0.2	0.0
22	UCR	Concrete Walkway - Lawn trimmings	2.3	0.0	0.2	0.9	0.8	0.3	0.1
23	UCR	Concrete Walkway - General cleaning	22.6	4.3	6.2	8.8	2.3	0.7	0.2
24	CE-CERT	Asphalt Parking Lot - General cleaning	75.2	9.4	11.2	13.5	12.1	20.8	8.2
25	CE-CERT	Lawn - Leaves and debris	109.7	0.0	4.3	34.9	37.1	26.1	7.2
26	CE-CERT	Gutter - Debris	30.9	0.3	2.1	9.6	7.9	7.5	3.5
27	Kearney	Concrete Walkway - Lawn trimmings	2.8	0.0	0.0	0.4	0.5	1.8	0.2
28	Kearney	Gutter - Debris	96.8	0.1	3.2	19.8	29.6	42.1	2.0
29	Kearney	Lawn - Leaves and debris	5.0	0.0	0.0	1.1	2.3	1.6	0.1
30	Kearney	Asphalt Driveway - General cleaning	12.2	0.0	0.7	3.4	2.7	4.3	1.1
31	Kearney	Packed Dirt and Gravel Parking - General cleaning	50.0	21.6	6.5	8.0	5.4	6.3	2.3
32	Kearney	Lawn - Leaves and debris	35.0	9.1	4.1	7.7	4.2	9.1	0.8
		Average	48	5	5	14	10	11	3
		Minimum	2	0	0	0	0	0	0
		Maximum	377	22	25	136	74	105	34
		Median	26	2	3	8	3	2	1
		Standard Deviation	77	6	6	28	17	23	7

Table 10. Mass per sieve size for samples collected from area to be leaf blown.

Sample	> 3/8 fraction (percent)	< 3/8, > #4 fraction (percent)	< #4, > #18 fraction (percent)	< #18, > #40 fraction (percent)	< #40, > #200 fraction (percent)	< #200 fraction (percent)
1	1	7	36	20	28	9
2	2	1	17	65	10	5
3	3	11	49	24	11	2
4	27	24	40	5	2	0
5	21	35	22	10	9	3
11	49	30	6	4	7	3
12	5	4	41	12	24	13
13	42	18	22	9	8	1
14	22	15	11	8	31	13
15	19	8	43	22	7	0
16	33	16	35	11	4	0
21	7	14	66	12	1	0
22	0	10	38	37	13	3
23	19	27	39	10	3	1
24	13	15	18	16	28	11
25	0	4	32	34	24	7
26	1	7	31	26	24	11
27	0	1	14	18	62	6
28	0	3	20	31	44	2
29	0	0	21	46	32	1
30	0	6	28	22	35	9
31	43	13	16	11	13	5
32	26	12	22	12	26	2
Average	15	12	29	20	19	5
Minimum	0	0	6	4	1	0
Maximum	49	35	66	65	62	13
Median	7	11	28	16	13	3
Std. Dev.	16	10	14	15	15	4

Table 11. Percent mass per sieve size for samples collected from area to be leaf blown.

Our initial results from this work was used to determine the surrogate soil blend used for this project; 12 grams of soil (weighed after passing through the #40 sieve), 6 grams of grass clippings and 6 grams of leaves all per meter square of surface. The mass passing through the #40 (425µm) sieve is the equivalent to the sum of the masses in the right two columns in Table 11. As can be seen, in Table 11, the average mass that passed through the final two sieve stages was (11+3) 14 grams. The average amount of material that did not pass through the 425µm sieve was 34 grams, considerably more than the 12 grams total of grass clippings and leaves that we deployed per square meter for our surrogate. However, since our main purpose for this vegetative matter (which is not directly a source of TSP, PM_{10} or $PM_{2.5}$) was to provide a target for our leaf blower, placing too little or too much of this coarse size material down does not affect our emission factor results.

4.5 Emission Factor Measurements

Our test chambers were used for eighty-five tests using surrogate material and thirty-two tests over natural/indigenous material surfaces. Three different leaf blowers were used, one leaf blower was configured for vacuuming for several tests as well as for blowing mode, a push broom was used for several runs and raking was also performed for several runs. Table 5 shows the number of test runs by date and location. Table 12 presents the test run information by cleaning operation, cleaning implement and location.

Run Number	Material	Surface	Blower	DustTrak	Log Page	Run Number in logbook	Time of Run
	material below is as follows: grams of soil (+soil source and sieve grid size in microns)+ grams of grass cuttings + grams of leaves + volume of propene						
0824_1	Shafter <425; 120+60+60+ 1/2 l C3H6	asphalt	Elec Blow	3 sizes at D=6,16	25	1	8:32
0824_2	5 Points <425; 120+60+60+ 1/2 l C3H6	asphalt	Elec Blow	3 sizes at D=6,16	25	2	9:20
0824_3	Kearney <425; 120+60+60+ 1 l C3H6	asphalt	Elec Blow	3 sizes at D=6,16	27	3	9:52
0824_4	Fresno <425; 120+60+60+ 1 l C3H6	asphalt	Elec Blow	3 sizes at D=6,16 + filters	27	4	10:28
0824_5	Kearney <425; 120+60+60+ 1 l C3H6	asphalt	Hand Gas	3 sizes at D=6,16	27	5	11:20
0824_6	Kearney <425; 120+60+60+ 1 l C3H6	asphalt	Backpack	3 sizes at D=6,16	27	6	11:48
0825_1	Kearney <425; 120+60+60+ C3H6	asphalt	Elec Blow	3 sizes at D=6,16	27	1	6:02
0825_2	Kearney <425; 120+60+60+ C3H6	asphalt	Elec Blow	3 sizes at D=6,16	29	2	6:34
0825_3	Kearney <425; 120+42 g grass+78 g leaves+ C3H6	asphalt	Hand Gas	3 sizes at D=6,16	29	3	7:05
0825_4	Kearney <425; 120+60+60+ C3H6	asphalt	Hand Gas	3 sizes at D=6,16	29	4	7:39
0825_5	Kearney <425; 120+60+60+ C3H6	asphalt	Backpack	3 sizes at D=6,16 + filters	29	5	7:58
0825_6	Kearney <425; 120+60+60+ C3H6	asphalt	Backpack	3 sizes at D=6,16	30	6	8:54
0825_7	0	asphalt	Backpack	3 sizes at D=6,16	30	7	9:29
0825_8	0	asphalt	Backpack	3 sizes at D=6,16	30	8	9:46
0825_9	Kearney <425; 120+60+60+ C3H6	asphalt	Broom	3 sizes at D=6,16	30	9	10:06
0825_10	Kearney <425; 120+60+60+ C3H6	asphalt	Broom	3 sizes at D=6,16	30	10	10:36
0825_11	Kearney <425; 120+60+60	asphalt	Broom	3 sizes at D=6,16	30	11	11:01
0825_12	Kearney <425; 120+60+60+ C3H6	asphalt	Rake	3 sizes at D=6,16	30	12	11:34
0826_1	Kearney <425; 120+60+60+ C3H6	asphalt	Elec Vac	3 sizes at D=6,16	31	1	6:37
0826_2	Kearney <425; 120+60+60+ C3H6	asphalt	Elec Vac	3 sizes at D=6,16	31	2	7:03
0826_3	Kearney <425; 120+60+60+ C3H6	asphalt	Elec Vac	3 sizes at D=6,16	31	3	7:30
0826_4	Kearney <425; 120+60grass+60pine needles+ C3H6	asphalt	Elec Vac Bag Full	3 sizes at D=6,16	31	4	8:20
0826_5	Kearney <425; 120+60+60+ C3H6	asphalt	Elec Vac Bag Full	3 sizes at D=6,16 + filters	31, 32	5	9:10
0826_6	Kearney <425; 120+60+60+ C3H6	asphalt	Elec Vac Bag Full	3 sizes at D=6,16	31	6	9:47
0826_7	Kearney <425; 120+60+60+ C3H6	asphalt	Backpack	3 sizes at D=6,16	31	7	10:14
0826_8	Kearney <425; 120+60+60+ C3H6	asphalt	Backpack	3 sizes at D=6,16	31	8	10:30

* Material: e.g.: “Shafter <425” is the fraction of soil from Shafter that passed through a sieve with 425µm openings; “120+60+60” indicates 120 g of th sieved soil, plus 60 g of grass clippings and 60 g of leaves were deployed for the cleaning; and “½ l C3H6” indicates that 0.5 liter of propene tracer gas was released in the chamber

** DustTrak: e.g.: "3 sizes at D = 6, 16" indicates that DustTraks for all three size fractions (TSP, PM10 and PM2.5) were in the chamber and one set of TSP, PM10 and PM2.5 were placed at a distance of 6 meters in and a second set was placed at a distance of 16 meters in.

Table 12 (part 1 of 4). Summary of test run conditions and equipment.

Run Number	Material	Surface	Blower	DustTrak	Log Page	Run Number in logbook	Time of Run
0830_1	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	3 sizes at D=6,16	33	1	6:21
0830_2	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	3 sizes at D=6,16	35	2	6:48:30
0830_3	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	3 sizes at D=6,16	35	3	7:11:50
0830_4	2.5C3H6	concrete	Elec Blow	3 sizes at D=6,16	35	4	7:34:25
0830_5	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Hand Gas	3 sizes at D=6,16	35	5	7:57:25
0830_6	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Hand Gas	3 sizes at D=6,16	35	6	8:25:10
0830_7	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Hand Gas	3 sizes at D=6,16	35	7	9:05:38
0830_8	2.5C3H6	concrete	Hand Gas	3 sizes at D=6,16	37	8	9:34:28
0830_9	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Backpack	3 sizes at D=6,16	37	9	9:57:40
0830_10	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Backpack	3 sizes at D=6,16	37	10	10:21:40
0830_11	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Backpack	3 sizes at D=6,16	37	11	10:56:24
0830_12	2.5C3H6	concrete	Backpack	3 sizes at D=6,16	37	12	11:26:05
0831_1	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Broom	3 sizes at D=6,16	39	1	6:01:20
0831_2	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Broom	3 sizes at D=6,16	39	2	6:26:34
0831_3	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Broom	3 sizes at D=6,16	41	3	6:55:37
0831_4	2.5C3H6	concrete	Broom	3 sizes at D=6,16	41	4	7:16:07
0831_5	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Rake	3 sizes at D=6,16	41	5	7:41:31
0831_6	2.5C3H6	concrete	Rake	3 sizes at D=6,16	41	6	8:02:18
0831_7	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Rake	3 sizes at D=6,16	41	7	8:22:38
0831_8	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Rake	3 sizes at D=6,16	41	8	8:49:58
0831_9	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Vac	3 sizes at D=6,16	41	9	9:12:44
0831_10	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Vac	3 sizes at D=6,16	41	10	9:37:29
0831_11	2.5C3H6	concrete	Elec Vac	3 sizes at D=6,16	43	11	10:01:11
0831_12	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Vac	3 sizes at D=6,16	43	12	10:28:43
0831_13	Five Points <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	3 sizes at D=6,16	43	13	10:57:10
0831_14	Five Points <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	3 sizes at D=6,16	43	14	11:21:33
0831_15	Shafter <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	3 sizes at D=6,16	43	15	11:43:20
0831_16	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	3 sizes at D=6,16	43	16	12:05:04
0831_17	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	3 sizes at D=6,16	43	17	12:06:31

Table 12 (part 2 of 4). Summary of test run conditions and equipment.

Run Number	Material	Surface	Blower	DustTrak	Log Page	Run Number in logbook	Time of Run
0902_1	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	PM10 at D=6,16 and H=.5,1,2	45	1	6:28:15
0902_2	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	PM10 at D=6,16 and H=.5,1,2	45	2	6:49:32
0902_3	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	PM10 at D=6,16 and H=.5,1,2	47	3	7:13:32
0902_4	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	PM2.5 at D=6,16 and H=.5,1,2	47	4	7:34:27
0902_5	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	PM2.5 at D=6,16 and H=.5,1,2	47	5	7:52:08
0902_6	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	PM2.5 at D=6,16 and H=.5,1,2	47	6	8:10:44
0902_7	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	TSP at D=6,16 and H=.5,1,2	47	7	8:29:07
0902_8	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	TSP at D=6,16 and H=.5,1,2	47	8	8:48:10
0902_9	Kearney <425; 120+60+60+ 2.5C3H6	concrete	Elec Blow	TSP at D=6,16 and H=.5,1,2	47	9	9:07:11
0902_10	Kearney <425; 120g + 2.5C3H6	concrete	Elec Blow	TSP at D=16 and H=2 + Filter	49	10	9:48:32
0902_11	Kearney <425; 240g	concrete	Elec Blow	TSP at D=16 and H=2 + Filter	49	11	10:09:43
0902_12	Kearney <425; 240g + 2.5C3H6	concrete	Elec Blow	PM10 at D=16 and H=2 + Filter	51	12	10:47:20
0902_13	Kearney <425; 240g	concrete	Elec Blow	PM10 at D=16 and H=2 + Filter	51	13	11:13:24
0902_14	Kearney <425; 250g + 2.5C3H6	concrete	Elec Blow	PM2.5 at D=16 and H=2 + Filter	51	14	11:46:48
0902_15	Kearney <425; 240g	concrete	Elec Blow	PM2.5 at D=16 and H=2 + Filter	51	15	12:11:24
	Above runs are 20m chamber; below runs are 10m chamber						
0906_1	Kearney <425; 60+30+30+ 2.5C3H6	concrete	Elec Blow	PM10 at D=2,4,6,8 and H=1,2	53	1	6:23:58
0906_2	Kearney <425; 60+30+30+ 2.5C3H6	concrete	Elec Blow	PM10 at D=2,4,6,8 and H=1,2	53	2	6:51:51
0906_3	Kearney <425; 60+30+30+ 2.5C3H6	concrete	Elec Blow	PM10 at D=2,4,6,8 and H=1,2	53	3	7:09:59
0906_4	Kearney <425; 60+30+30+ 2.5C3H6	concrete	Elec Blow	PM2.5 at D=2,4,6,8 and H=1,2	55	4	7:32:38
0906_5	Kearney <425; 60+30+30+ 2.5C3H6	concrete	Elec Blow	PM2.5 at D=2,4,6,8 and H=1,2	55	5	7:50:26
0906_6	Kearney <425; 60+30+30+ 2.5C3H6	concrete	Elec Blow	PM2.5 at D=2,4,6,8 and H=1,2	55	6	8:07:56
0906_7	Kearney <425; 60+30+30+ 2.5C3H6	concrete	Elec Blow	TSP at D=2,4,6,8 and H=1,2	55	7	8:26:49
0906_8	Kearney <425; 60+30+30+ 2.5C3H6	concrete	Elec Blow	TSP at D=2,4,6,8 and H=1,2	55	8	8:43:17
0906_9	Kearney <425; 60+30+30+ 2.5C3H6	concrete	Elec Blow	TSP at D=2,4,6,8 and H=1,2	55	9	9:02:18
0908_1	Lawn at CE-CERT + 2.5 C3H6	Lawn	Elec Blow	3 sizes at D=2,6	57	1	7:43:02
0908_2	Asphalt Driveway + 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	57	2	8:27:43
0908_3	Asphalt Driveway + 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	57	3	8:48:45
0908_4	Asphalt Driveway + 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	57	4	9:29:16
0908_5	Asphalt Driveway + 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	57	5	9:53:40
0908_6	Lawn at CE-CERT + 2.5 C3H6	Lawn	Elec Blow	3 sizes at D=2,6	59	6	11:01:58

Table 12 (part 3 of 4). Summary of test run conditions and equipment.

Run Number	Material	Surface	Blower	DustTrak	Log Page	Run Number in logbook	Time of Run
0908_7	Lawn at CE-CERT + 2.5 C3H6	Lawn	Elec Blow	3 sizes at D=2,6	59	7	11:20:40
0908_8	Gutter at CE-CERT + 2.5 C3H6	Asphalt gutter	Elec Blow	3 sizes at D=2,6 + filters	59	8	12:01:07
0908_9	Gutter at CE-CERT + 2.5 C3H6	Asphalt gutter	Elec Blow	3 sizes at D=2,6	59	9	12:26:25
0913_1	Grass clipping on concrete at Kearney + 2.5 C3H6	concrete	Elec Blow	3 sizes at D=2,6	65	1	6:56:56
0913_2	Grass clipping on concrete at Kearney + 2.5 C3H6	concrete	Elec Blow	3 sizes at D=2,6	65	2	7:15:20
0913_3	Grass clipping on concrete at Kearney + 2.5 C3H6	concrete	Elec Blow	3 sizes at D=2,6	65	3	7:58:44
0913_4	Grass clipping on concrete at Kearney + 2.5 C3H6	concrete	Elec Blow	3 sizes at D=2,6	65	4	8:19:20
0913_5	Gutter at Kearney + 2.5 C3H6	asphalt	rake	3 sizes at D=2,6	65	5	8:59:30
0913_6	Gutter at Kearney + 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	65	6	9:21:15
0913_7	Gutter at Kearney + 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	65	7	9:40:44
0913_8	Gutter at Kearney + 2.5 C3H6	asphalt	Rake	3 sizes at D=2,6	65	8	10:28:07
0913_9	Gutter at Kearney + 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6 + filters	67	9	11:07:34
0913_10	Gutter at Kearney + 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	67	10	11:29:11
0913_11	Grass clipping on concrete at Kearney + 2.5 C3H6	concrete	Broom	3 sizes at D=2,6	67	11	12:07:48
0913_12	Grass clipping on concrete at Kearney + 2.5 C3H6	concrete	Broom	3 sizes at D=2,6	67	12	12:26:04
0913_13	Lawn at Kearney + 2.5 C3H6	Lawn	Elec Blow	3 sizes at D=2,6	67	13	13:04:29
0913_14	Lawn at Kearney + 2.5 C3H6	Lawn	Elec Blow	3 sizes at D=2,6	67	14	13:23:25
0914_1	Asphalt Driveway at Kearney+ 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	69	1	6:42:24
0914_2	Asphalt Driveway at Kearney+ 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	69	2	7:03:59
0914_3	Asphalt Driveway at Kearney+ 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	69	3	7:32:00
0914_4	Kearney <425; 60+30+30+ 2.5C3H6	asphalt	Elec Blow	3 sizes at D=2,6	71	4	7:58:45
0914_5	Kearney <425; 60+30+30+ 2.5C3H6	asphalt	Elec Blow	3 sizes at D=2,6	71	5	8:33:42
0914_6	Asphalt Driveway at Kearney+ 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	71	6	9:04:40
0914_7	Asphalt Driveway at Kearney+ 2.5 C3H6	asphalt	Broom	3 sizes at D=2,6	71	7	9:41:34
0914_8	Asphalt Driveway at Kearney+ 2.5 C3H6	asphalt	Broom	3 sizes at D=2,6	73	8	10:04:42
0914_9	Asphalt Driveway at Kearney+ 2.5 C3H6	asphalt	Elec Blow	3 sizes at D=2,6	73	9	10:27:39
0914_10	Lawn at Kearney + 2.5 C3H6	Lawn	rake	3 sizes at D=2,6	73	10	11:06:20
0914_11	Lawn at Kearney + 2.5 C3H6	Lawn	Elec Blow	3 sizes at D=2,6	73	11	11:22:44
0914_12	Packed Dirt Parking Lot + 2.5 C3H6	Packed Dirt	Elec Blow	3 sizes at D=2,6	73	12	11:59:38
0914_13	Packed Dirt Parking Lot + 2.5 C3H6	Packed Dirt	Elec Blow	3 sizes at D=2,6	75	13	12:20:40

Table 12 (part 4 of 4). Summary of test run conditions and equipment.

4.5.1 Measurement Locations

The bulk of the testing was conducted in Riverside at the UCR CE-CERT facility using the surrogate debris mixtures consisting of vegetative matter and soil from the UC facilities in the San Joaquin Valley and that supplied by the District, as discussed in the previous section. The 20m test chamber was used to perform most of this surrogate testing on asphalt and concrete surfaces. Figure 32 shows the chamber locations for these tests. Figure 33 shows the inside of the chamber during several of the test runs. Table 13 lists the tests and the concentration data taken at six minutes after the end of blowing for these runs.

Figure 32. Photographs showing 20m chamber for surrogate tests.

Figure 33. Photographs showing inside of 20m chamber during testing.

								Distance A			Distance B				
Run	Chamber	Material	Blower	Location	Clean Pattern	Clean Area (m^2)	Clean Time (mm:ss)	PM 2.5 (mg/m^3)	PM10 (mg/m^3)	TSP (mg/m^3)	PM 2.5 (mg/m^3)	PM 2.5 (mg/m^3)	PM10 (mg/m^3)	PM10 (mg/m^3)	TSP (mg/m^3)
0823_1	20M	A4	A	A1	A	10	01:50	2.1	4.9	0.0	1.6	1.1	5.6	7.6	5.6
0823_2	20M	A6	A	A1	A	10	01:10	1.6	5.5	0.0	1.9	1.2	9.3	10.8	8.7
0824_1	20M	A5	A	A1	A	10	00:48	0.7	2.6	3.9	1.8	1.2	8.3	7.9	9.1
0824_2	20M	A3	A	A1	A	10	02:18	0.7	2.3	4.3	1.1	0.7	7.3	5.9	6.1
0824_3	20M	A1	A	A1	A	10	01:20	1.0	3.4	5.4	1.7	1.4	9.5	8.0	8.2
0824_4	20M	A1	A	A1	A	10	01:00	1.4	5.0	8.8	1.7	1.1	4.3	11.1	7.2
0824_5	20M	A1	C	A1	A	10	01:10	0.7	2.0	3.2	1.0	0.7	2.7	5.6	3.8
0824_6	20M	A1	D	A1	A	10	01:30	2.8	7.7	13.2	2.4	1.9	6.4	9.7	7.0
0825_1	20M	A1	A	A1	A	10	01:10	2.8	8.2	14.3	7.2	5.6	20.9	21.8	26.2
0825_2	20M	A1	A	A1	A	10	00:40	2.1	13.2	10.7	6.6	5.1	8.5	18.0	25.3
0825_3	20M	A1	C	A1	A	10	01:10	2.2	5.7	9.8	3.4	1.9	8.7	11.1	13.2
0825_4	20M	A1	C	A1	A	10	01:20	1.8	6.0	7.5	2.6	2.1	10.6	10.1	12.3
0825_5	20M	A1	D	A1	A	10	01:10	3.8	8.4	13.8	4.3	2.9	10.8	13.4	14.6
0825_6	20M	A1	D	A1	A	10	01:20	2.1	8.7	12.8	3.6	3.2	13.2	12.7	12.3
0825_7	20M	AC	D	A1	A	10	01:30	1.0	3.2	5.6	1.3	1.1	4.9	4.2	3.6
0825_8	20M	AC	D	A1	A	10	01:20	0.7	1.7	3.3	1.0	0.7	2.6	2.6	2.7
0825_9	20M	A1	E	A1	A	10	04:30	0.7	1.8	3.4	0.6	0.4	1.9	2.0	2.2
0825_10	20M	A1	E	A1	A	10	04:40	0.8	2.6	5.7	0.9	0.6	2.7	4.6	3.4
0825_11	20M	A1	E	A1	A	10	03:20	0.6	3.0	5.4	0.8	0.5	2.0	4.8	3.1
0825_12	20M	A1	F	A1	A	10	02:40	0.2	0.2	0.4	0.2	0.1	0.2	0.4	0.2
0826_1	20M	A1	B	A1	A	10	04:00	9.9	14.6	23.9	11.9	9.0	32.8	33.2	37.8
0826_2	20M	A1	B	A1	A	10	03:00	5.1	7.2	11.9	4.6	3.4	13.2	13.5	13.4
0826_3	20M	A1	B	A1	A	10	02:50	5.9	7.8	11.0	3.9	3.0	11.8	11.7	13.4
0826_4	20M	A1	B1	A1	A	10	02:40	4.5	7.5	10.5	3.0	2.3	7.8	8.7	8.0
0826_5	20M	A1	B1	A1	A	10	03:30	5.9	12.9	19.2	4.1	3.2	10.9	14.0	12.9
0826_6	20M	A1	B1	A1	A	10	02:00	3.4	5.9	9.6	2.4	1.9	6.8	6.8	6.6
0826_7	20M	AC	D	A1	A	10	00:30	5.6	17.0	31.0	5.5	4.3	15.9	28.0	21.6
0826_8	20M	AC	D	A1	A	10	00:30	2.5	6.2	11.0	2.9	2.4	7.9	13.1	8.6
0830_1	20M	A1	A	B1	A	10	01:20	4.6	9.6	15.8	9.3	6.0	25.4	28.9	38.0
0830_2	20M	A1	A	B1	A	10	01:25	4.2	7.9	12.9	7.0	5.2	23.5	19.5	23.9
0830_3	20M	A1	A	B1	A	10	01:38	7.1	12.6	20.0	4.4	3.5	15.4	14.7	18.0
0830_4	20M	AC	A	B1	A	10	00:50	1.4	1.7	2.6	1.0	0.7	1.9	2.1	2.3
0830_5	20M	A1	C	B1	A	10	01:55	3.1	6.0	7.9	1.9	1.1	5.4	6.6	6.5
0830_6	20M	A1	C	B1	A	10	02:02	3.2	5.5	7.6	1.9	1.4	6.4	7.0	6.2
0830_7	20M	A1	C	B1	A	10	02:27	3.7	5.7	7.4	3.9	3.4	13.5	10.5	12.5
0830_8	20M	AC	C	B1	A	10	01:07	0.2	0.2	0.3	0.1	0.1	0.2	0.2	0.2
0830_9	20M	A1	D	B1	A	10	01:18	3.9	5.5	7.2	5.7	4.8	15.5	14.1	15.8
0830_10	20M	A1	D	B1	A	10	01:17	3.6	4.0	6.7	5.5	3.7	11.9	13.9	14.0
0830_11	20M	A1	D	B1	A	10	01:15	4.4	6.5	6.3	3.0	2.5	7.9	5.9	5.8
0830_12	20M	AC	D	B1	A	10	00:55	0.5	0.4	0.4	0.3	0.2	0.4	0.3	0.4
0831_1	20M	A1	E	B1	A	10	02:33	1.3	3.6	5.3	2.3	1.5	11.0	11.2	15.7
0831_2	20M	A1	E	B1	A	10	03:31	1.9	6.4	9.5	3.2	2.2	15.7	15.2	19.2
0831_3	20M	A1	E	B1	A	10	03:25	2.3	6.3	9.9	3.8	3.0	19.5	16.1	20.0
0831_4	20M	AC	E	B1	A	10	02:51	0.8	1.8	2.5	0.5	0.4	2.1	2.1	3.1
0831_5	20M	A1	F	B1	A	10	03:14	0.1	0.3	0.5	0.1	0.1	0.4	0.4	0.5
0831_6	20M	AC	F	B1	A	10	01:52	0.1	0.2	0.3	0.1	0.1	0.2	0.2	0.3
0831_7	20M	A1	F	B1	A	10	03:57	0.2	0.4	0.8	0.1	0.1	0.3	0.4	0.6
0831_8	20M	A1	F	B1	A	10	02:59	0.3	0.8	1.3	0.2	0.1	0.9	0.8	0.9
0831_9	20M	A1	B	B1	A	10	03:29	7.0	12.4	19.0	3.4	2.2	7.9	8.8	8.2
0831_10	20M	A1	B	B1	A	10	02:42	7.3	11.3	13.9	4.3	2.6	9.2	8.6	9.2
0831_11	20M	AC	B	B1	A	10	01:59	1.1	1.8	2.4	0.9	0.5	1.7	1.8	1.8
0831_12	20M	A1	B	B1	A	10	02:57	5.7	8.1	5.1	2.9	2.5	8.1	5.4	13.8
0831_13	20M	A3	A	B1	A	10	01:28	3.8	6.4	4.9	4.1	3.0	13.1	8.6	11.0
0831_14	20M	A3	A	B1	A	10	01:17	2.8	3.9	4.6	2.0	1.6	6.8	3.5	4.2
0831_15	20M	A5	A	B1	A	10	01:07	2.5	4.1	4.9	1.3	0.9	3.2	2.5	2.4
0831_16	20M	A5	A	B1	A	10	01:27	3.7	5.3	6.2	2.1	0.9	2.9	4.8	4.2
0831_17	20M	A1	A	B1	A	10	01:07	5.3	7.8	10.0	2.3	1.5	5.0	6.1	5.1

Table 13 (part 1 of 2). Emission test airborne particulate matter concentrations.

								Distance A			Distance B				
Run	Chamber	Material	Blower	Location	Clean Pattern	Clean Area (m^2)	Clean Time (mm:ss)	PM 2.5 (mg/m^3)	PM10 (mg/m^3)	TSP (mg/m^3)	PM 2.5 (mg/m^3)	PM 2.5 (mg/m^3)	PM10 (mg/m^3)	PM10 (mg/m^3)	TSP (mg/m^3)
0908_1	10M	C	A	C1	B	18	01:46	0.1	0.1	0.2	0.1	0.1	0.3	0.3	0.2
0908_2	10M	C	A	D1	C	10	01:43	0.7	2.7	4.1	1.2	1.5	4.3	4.2	3.6
0908_3	10M	C1	A	D1	C	10	01:20	0.3	1.0	1.0	0.5	0.7	2.1	2.2	1.8
0908_4	10M	C	A	D2	C	10	02:11	0.5	1.7	2.1	1.0	1.5	3.4	3.7	2.7
0908_5	10M	C1	A	D2	C	10	01:02	0.2	0.8	1.0	0.3	0.5	1.4	1.6	0.9
0908_6	10M	C	A	C2	B	18	01:15	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.2
0908_7	10M	C1	A	C2	B	18	01:11	0.1	0.2	0.2	0.1	0.2	0.3	0.3	0.3
0908_8	10M	C	A	D3	D	5.4	00:57	0.1	0.5	0.8	0.3	0.6	0.9	1.1	1.1
0908_9	10M	C1	A	D3	D	5.4	00:48	0.3	1.2	1.5	0.6	1.1	1.9	1.8	1.8
0913_1	10M	C	A	B2	E	9	00:46	0.3	1.6	3.4	0.7	0.8	2.6	3.0	3.7
0913_2	10M	C1	A	B2	E	9	00:48	0.1	0.5	1.2	0.3	0.4	1.2	1.2	1.4
0913_3	10M	C	A	B3	E	9	00:58	0.1	0.2	0.5	0.1	0.1	0.4	0.4	0.6
0913_4	10M	C1	A	B3	E	9	00:44	0.1	0.3	0.6	0.1	0.2	0.6	0.7	1.0
0913_5	10M	C	F	D4	D	9	01:28	0.1	0.4	0.7	0.1	0.2	0.6	0.7	0.7
0913_6	10M	C	A	D4	D	9	00:58	2.5	9.0	20.9	5.0	6.3	13.2	21.9	26.7
0913_7	10M	C1	A	D4	D	9	00:46	0.9	3.4	9.0	2.9	3.3	7.1	10.9	13.0
0913_8	10M	C	F	D5	D	9	01:31	0.1	0.4	0.9	0.2	0.3	1.0	1.1	0.9
0913_9	10M	C	A	D5	D	9	00:50	0.9	2.9	3.7	2.1	2.4	6.8	8.0	7.4
0913_10	10M	C1	A	D5	D	9	00:37	0.4	1.3	2.2	0.6	0.7	1.2	2.0	1.9
0913_11	10M	C	E	B3	E	9	01:36	0.1	1.3	1.9	0.9	1.0	2.4	2.8	2.7
0913_12	10M	C1	E	B3	E	9	01:11	0.2	0.7	1.0	0.5	0.6	1.4	1.6	1.6
0913_13	10M	C	A	C4	B	18	00:44	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
0913_13	10M	C1	A	C4	B	18	00:52	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2
0914_1	10M	C	A	A2	B	18	00:49	0.7	3.4	7.4	1.7	2.2	6.6	6.3	10.6
0914_2	10M	C1	A	A2	B	18	00:31	0.3	1.4	3.2	0.8	1.4	3.1	3.2	5.2
0914_3	10M	A1	A	A2	A	6.5	00:34	0.4	2.1	5.1	0.7	1.1	3.6	3.4	6.3
0914_4	10M	A1	A	A2	A	5	00:40	0.4	2.5	5.4	0.7	0.9	3.8	3.5	5.1
0914_5	10M	A1	A	A2	A	5	00:31	0.4	2.0	4.5	0.8	0.9	3.9	4.0	4.9
0914_6	10M	A1	A	A2	A	5	00:32	0.1	0.3	0.6	0.1	0.0	0.6	0.5	0.6
0914_7	10M	C	E	A3	B	18	03:11	4.2	17.6	23.2	4.0	0.0	14.0	15.2	11.8
0914_8	10M	C1	E	A3	B	18	02:21	4.9	16.9	19.8	5.1	0.0	16.4	19.2	14.8
0914_9	10M	C1	A	A3	B	18	00:20	15.0	25.5	47.8	16.0	0.0	34.9	40.9	35.9
0914_10	10M	C	F	C5	B	18	02:20	0.1	0.4	0.7	0.1	0.0	0.3	0.4	0.5
0914_11	10M	C	A	C5	B	18	00:20	0.6	2.4	5.6	0.7	0.0	1.8	2.1	2.3
0914_12	10M	C	A	E	B	18	00:35	23.7	39.1	67.7	40.0	0.0	67.1	74.9	78.0
0914_13	10M	C1	A	E	B	18	00:48	27.1	41.5	65.9	50.1	0.0	85.6	95.9	132.0

Chamber

10M	10 meter long chamber *** Distance A= 2 meters, Distance B = 6 meters
20M	20 meter long chamber *** Distance A= 6 meters, Distance B = 16 meters

Material

A		120 g Surrogate Dirt < 425 micron, 60 g grass, and 60 g leaves
	1	Surrogate: Kearny
	2	Surrogate: Other
	3	Surrogate: Five Points
	4	Surrogate: Fresno
	5	Surrogate: Shafter
	6	Surrogate: Madera
	C	Control
B		60 g Surrogate Dirt < 425 micron, 60 g grass, and 60 g leaves
	1	Surrogate: Kearny
	2	Surrogate: McKitrick
	3	Surrogate: Five Points
	4	Surrogate: Fresno
	5	Surrogate: Shafter
	C	Control
C		Soil/Dirt/Grass cuttings, etc., as is at the time time chamber was set up
	1	Control

Blower

A	Electric Blower in blow mode
B	Electric Blower in vacuum mode 1 Vaccum full
C	Gas hand held blower
D	Gas Backpack Blower
E	Push Broom
F	Rake

Location

A		Asphalt
	1	CE-CERT
	2	Kearny Site 1
	3	Kearny Site 2
B		Cement/Sidewalk/Driveway
	1	CE-CERT
	2	Kearny Site 1
	3	Kearny Site 2
	4	Kearny Site 3
C		Lawn
	1	CE-CERT Site 1
	2	CE-CERT Site 2
	3	CE-CERT Site 3
	4	Kearny Site 1
	5	Kearny Site 2
	6	Kearny Site 3
D		Gutter
	1	CE-CERT Site 1
	2	CE-CERT Site 2
	3	CE-CERT Site 3
	4	Kearny Site 1
	5	Kearny Site 2
E		Packed Dirt Parking Lot

Cleaning Pattern

A	In 20 meter chamber: 5 m^2 to 15 m^2, 1 meter wide In 10 meter chamber: 2.5 m^2 to 7.5 m^2, 1 meter wide
B	Full 2 meter width from 1 meter into chamber
C	Gutter onto grass
D	Gutter
E	Sidewalk onto grass

Table 13 (part 2 of 2). Emission test airborne particulate matter concentrations.

As discussed by in Section 3.2, the average between the concentrations determined at the 10m and 16m sampling locations are being used to calculate the emission factors. The emission factors are calculated using the following equation:

$$EF = [((C10_{ave,t=6} + C16_{ave,t=6})/2) \times V_{chamber}] / A_{debris} \qquad (1)$$

Where EF (mass/unit area) is the emission factor, C10 and C16 are the concentrations (mass per volume) determined at those respective distances, V is the volume of the chamber and A is the area that the surrogate debris was spread over. Equation 1 and the data from Table 13 were used to obtain the emission factors shown in the following tables.

Table 14 presents the average emission factors for test runs conducted to look at the differences between soil types used in the surrogate matrix. There were no significant differences between the soils tested.

Soil Source	Surface Cleaned	PM 2.5 (mg/m^2)	PM10 (mg/m^2)	TSP (mg/m^2)
Shafter	Asphalt	10	40	50
Five Points	Asphalt	10	40	40
Five Points	Concrete	20	60	50
Shafter	Concrete	10	30	40
Kearney	Concrete	20	50	60
Fresno	Asphalt	10	40	40
Madera	Asphalt	10	60	70
Average		10	50	50

Basis: 10m^2 cleaned in an 80m^3 chamber
All emissions are from cleaning with an electric leaf blower

Table 14. Leaf blowing emission factors for various soils tested.

The emission factor data obtained for testing using surrogate soil (from Kearney) on an asphalt surface are presented in Table 15. The emission factor data obtained for testing using surrogate soil (from Kearney) on a concrete surface are presented in Table 16.

The 10m chamber was used for twenty-three test runs over natural/indigenous surfaces. Nine of these runs were performed at the UCR CE-CERT facility and twenty-three were performed at the UC Kearney facility. Table 17 lists these thirty-two test runs, the surface type of surface cleaned, the cleaning tool and the area cleaned.

Blower Type	Surface Cleaned	Number of Tests	PM 2.5 (mg/m^2)	PM10 (mg/m^2)	TSP (mg/m^2)
Elec.Blower	Asphalt/CECERT	4	20	60	80
Gas Hand Held	Asphalt/CECERT	3	10	40	50
Gas Backpack	Asphalt/CECERT	4	20	60	80
Push Broom	Asphalt/CECERT	3	0	20	30
Rake	Asphalt/CECERT	1	0	0	0
Elec.Blower-Vac Mode	Asphalt/CECERT	3	40	120	150
Elec.Blower-Vac Mode - bag full	Asphalt/CECERT	3	20	70	90
Elec.Blower	Asphalt/Kearney	4	0	20	30
Average (all)			10	50	70
Average (power blowers/vacuums only)			20	60	80

Basis: 10m^2 cleaned in an 80m^3 chamber, except for last four which were 5m^2

Table 15. Emission factors for blowing, vacuuming, raking and sweeping on asphalt surfaces.

Blower Type	Number of Tests	PM 2.5 (mg/m^2)	PM10 (mg/m^2)	TSP (mg/m^2)
Elec.Blower	3	40	130	170
Gas Hand Held	3	10	40	50
Gas Backpack	3	30	70	70
Push Broom	3	20	80	110
Rake	3	0	0	10
Elec.Blower-Vac Mode	3	30	80	90
Average (all)		20	70	80
Average (power blowers/vacuums only)		30	80	100

All cleaning was performed on concrete surfaces at
CE-CERT with surrogate soil

Table 16. Emission factors for blowing, vacuuming, raking and sweeping on concrete surfaces.

Surface Cleaned	Cleaning Tool	Area Cleaned (m^2)	Cleaning Time (sec/m^2)	PM 2.5 (mg/m^2)	PM10 (mg/m^2)	TSP (mg/m^2)
Lawn - CE-CERT	Elec. Leaf Blower	18	6	0.2	0.5	0.5
Asphalt Driveway - CE-CERT	Elec. Leaf Blower	10	10	4	14	15
Asphalt Driveway - CE-CERT - control	Elec. Leaf Blower	10	8	2	6	5
Asphalt Driveway - CE-CERT	Elec. Leaf Blower	10	13	3	10	10
Asphalt Driveway - CE-CERT - control	Elec. Leaf Blower	10	6	1	4	4
Lawn - CE-CERT	Elec. Leaf Blower	18	4	0.2	0.3	0.5
Lawn - CE-CERT - control	Elec. Leaf Blower	18	4	0.2	0.5	0.6
Gutter - CE-CERT	Elec. Leaf Blower	5.4	11	2	5	7
Gutter - CE-CERT - control	Elec. Leaf Blower	5.4	9	3	12	12
Grass on Concrete Walkway - Kearney	Elec. Leaf Blower	9	5	2	9	16
Grass on Concrete Walkway - Kearney - control	Elec. Leaf Blower	9	5	1	4	6
Grass on Concrete Walkway - Kearney	Elec. Leaf Blower	9	6	0	1	2
Grass on Concrete Walkway - Kearney - control	Elec. Leaf Blower	9	5	0	2	4
Gutter - Kearney	Elec. Leaf Blower	9	6	18	50	106
Gutter - Kearney - Control	Elec. Leaf Blower	9	5	8	23	49
Gutter - Kearney	Elec. Leaf Blower	9	6	7	21	25
Gutter - Kearney - Control	Elec. Leaf Blower	9	4	2	6	9
Lawn - Kearney	Elec. Leaf Blower	18	2	0.1	0.2	0.3
Lawn - Kearney - control	Elec. Leaf Blower	18	3	0.1	0.2	0.3
Asphalt Driveway - Kearney	Elec. Leaf Blower	18	3	3	11	20
Asphalt Driveway - Kearney - control	Elec. Leaf Blower	18	2	1	5	9
Asphalt Driveway - Kearney	Elec. Leaf Blower	18	1	39	67	93
Lawn - Kearney	Elec. Leaf Blower	18	1	2	5	9
Packed Dirt Parking Lot - Kearney	Elec. Leaf Blower	18	2	76	118	162
Packed Dirt Parking Lot - Kearney - control	Elec. Leaf Blower	18	3	92	141	220
Gutter - Kearney	Rake	9	10	0.4	2.2	3.2
Gutter - Kearney	Rake	9	10	1	3	4
Lawn - Kearney	Rake	18	8	0	1	1
Grass on Concrete Sidewalk - Kearney	Push Broom	9	11	2.0	8.1	10.3
Grass on Concrete Sidewalk - Kearney - control	Push Broom	9	8	2	5	6
Asphalt Driveway - Kearney	Push Broom	18	12	11	35	39
Asphalt Driveway - Kearney - control	Push Broom	18	8	13	37	38
Average (all, except controls)			**7**	**9**	**19**	**28**
Average (power blowers only, not including controls)			**5**	**11**	**22**	**33**
Average of power blowing lawns				**1**	**2**	**3**
Average of power blowing gutters				**9**	**25**	**46**
Average of power blowing cut grass on walkway				**2**	**6**	**9**

Table 17. Emission factors for leaf blowing natural/indigenous surfaces.

4.6 Data Accuracy, Precision and Completeness

The results from the collocated DustTrak data from all of the test runs with valid data are presented in Table 18. The precision is within the variability of the individual tests.

Particle Cut Size	Number of Data Pairs	Average Difference (percent)	Standard Deviation of Difference (percent)
PM-10	93	-14	27
PM-2.5	85	-7	19

Table 18. Collocated DustTrak data.

A performance audit of the flow rates for the six filter samplers was performed. The auditor found all samplers flow rates to be within the project goal of +/-10%. The audit report is included as Appendix B of this report.

The study had a very high level of data completeness. Out of the 56 filter samples attempted 48 viable samples were collected. The lost eight samples were due to tearing of the filter media in the sample holders. The project required six DustTraks. We were able to obtain two additional DustTraks. These additional DustTraks were collocated with selected primary DustTraks to provide quality control precision data. They were also ready to be used as backups should there by a failure in a primary sampler. All eight DustTraks were operational for all but the last study day. We had one DustTrak fail about half way through the final study day. One of the backup collocated DustTraks was used in place of the failed DustTrak for these final runs.

5.0 EMISSION FACTORS

The emission factors obtained have been reviewed to better understand these numbers. As shown in Table 17, the values for TSP obtained from leaf blowing lawns were 0.5, 0.5, 0.3 and 9 mg/m^3. The reason for this large range can be seen in the following figure:

Photograph of chamber set on lush foliage lawn

Photograph of chamber set on lean foliage lawn

Figure 34. Photographs showing lawns with lush and lean foliage.

The photograph on the left is from the lush foliage lawn from one test location that had low PM emissions from leaf blowing. The photograph on the right in Figure 34 is from a lawn with bare spots used for the test that had the high PM emissions from leaf blowing. Since both lawns and representative of those in the SJV, the range of emission factors from blowing lawns will also vary accordingly.

We observed a significant variation in emissions from asphalt. As shown in Table 17, blowing asphalt driveways at the UC Kearney resulted in emission for TSP of 20 and 93 μg/m^3. Although a variation of a factor of five is not unusual, this variation was observed by simply moving the chamber 2m to the side from the first test location to obtain the second test location. One possible explanation for this was that the asphalt driveway was slightly curved or sloped to better enable water run off and our second (higher emission numbers) sampling location was at a low spot where water drained, carrying sediments.

As shown Tables 15 and 16, there was a range of emission factors obtained from the different leaf blowers and leaf vacuums as well as from raking and sweeping. Due to the variability of emissions from one test to the next, there were no significant differences between the power leaf blowing and vacuuming methods that were clearly identifiable above the measurement uncertainty. As an example, the three test runs for leaf vacuuming off of asphalt surfaces (Table 15) had the highest emission factors for asphalt surfaces, but the three test runs for the leaf vacuuming off of concrete surfaces (Table 15) provided emission factors that were in the middle of the emission factor range for concrete surfaces. To best represent the range or real-world conditions in the composite emission factor, we averaged the concrete surface emission factor data from power leaf blowing and vacuuming operations into a single emission factor, and did the same for the asphalt surface blowing/vacuum emission factors. These emission factors, along with emission factors from raking lawns and power blowing gutters, packed dirt, and cut grass on walkways are compiled in Table 19.

Cleaning Action and Surface Cleaned	Number of Tests Performed	Type of Emission Factor Obtained from Tests	Emission Factors		
			PM 2.5 (mg/m^2)	PM10 (mg/m^2)	TSP (mg/m^2)
Power Blowing or Vacuuming over concrete surfaces	12	Average emissions from leaf blowing	30	80	100
Power Blowing or Vacuuming over asphalt surfaces	21	Average emissions from leaf blowing	20	60	80
Push Broom on Asphalt Surface	3	Average emissions from sweeping	0	20	30
Push Broom on Concrete Surface	3	Average emissions from sweeping	20	80	110
Raking on Asphalt Surface	1	Average emissions from raking	0	0	0
Raking on Concrete Surface	3	Average emissions from raking	0	0	10
Raking Lawn	1	Average emissions from raking	0	1	1
Power Blowing Lawn	3	Average emissions from leaf blowing	1	2	3
Power Blowing Gutters	3	Average emissions from leaf blowing	9	30	50
Power Blowing Packed Dirt	1	Average emissions from leaf blowing	80	120	160
Power Blowing Cut Grass on Walkway	2	Average emissions from leaf blowing	2	6	9

Table 19. Summary of emission factors.

The highest emission factors were from power blowing packed dirt surfaces. The packed dirt surfaces had both the same fine particulate matter deposited on its surface that the asphalt and concrete surfaces had, plus it was composed of a dirt surface that could be disrupted and entrained in the air due to the leaf blowing.

The second highest TSP emission value and one of the highest PM_{10} and $PM_{2.5}$ emission values was from broom sweeping on a concrete surface. As can be seen in the table, the emission factors for broom sweeping on an asphalt surface are among the lower PM emitters. The broom operator was able to move the surrogate material along the concrete surface quite rapidly with the broom; resulting in emissions similar to those obtained with power leaf blowers. When sweeping the porous asphalt surface, the operator swept at a similar rate, but the bristles of the broom did not thoroughly penetrate the porous surface. We presume that a significant portion of the dirt material that was laid out was pushed into the voids in the porous asphalt surface. This deposited mass was no longer being pushed along and potentially entrained in the air.

For all surfaces and operations, raking resulted in the lowest emissions.

The TSP and PM_{10} emission factors were similar in magnitude. The $PM_{2.5}$ emission factors were between one fifth and two thirds the emission rate of PM_{10}.

6.0 EMISSION INVENTORY

The emission inventory was developed using the emission factors and activity information based on the number of residential units cleaned, the area cleaned and the frequency of cleaning. The emissions at commercial facilities were estimated to be one third of the residential emissions.

Data on the area typically cleaned and the time spent at each task was gathered from interviews with operators and observation of operators at work. Several residences, single family and multiple unit, and commercial locations were visited to estimate areas requiring cleaning. From this data, the area cleaned and the time spent per task were determined for each unit of typical residence and commercial location. Tasks that were observed included cleaning of planter areas (similar to “packed dirt”), lawn surfaces and asphalt and concrete driveways and sidewalks. The area cleaned was determined to be approximately constant from spring through fall, with a 50% reduction of activity in winter. Tables 20 and 21 show areas cleaned for non-winter and winter months respectively (winter is defined as January-March).

	Area (m^2/unit)			
Housing Type	Planter	Lawn	Asphalt	Concrete
1 unit, detached	22.0	277.8	20.0	22.0
1 unit, attached	22.0	277.8	20.0	22.0
2 units	14.0	138.9	11.0	14.0
3 or 4 units	10.0	92.6	10.0	10.0
5 to 9 units	5.7	39.7	5.0	5.7
10 to 19 units	4.3	19.8	2.9	4.3
20 to 49 units	2.7	9.3	1.5	2.7
50 or more units	1.4	4.0	0.7	1.4
Mobile home	5.0	5.0	5.0	5.0
Boat, RV, van, etc.	0.0	0.0	0.0	0.0

Table 20. Area cleaned per week, non-winter months.

	Area (m^2/unit)			
Housing Type	Planter	Lawn	Asphalt	Concrete
1 unit, detached	11.0	138.9	10.0	11.0
1 unit, attached	11.0	138.9	10.0	11.0
2 units	7.0	69.4	5.5	7.0
3 or 4 units	5.0	46.3	5.0	5.0
5 to 9 units	2.9	19.8	2.5	2.9
10 to 19 units	2.1	9.9	1.4	2.1
20 to 49 units	1.3	4.6	0.8	1.3
50 or more units	0.7	2.0	0.4	0.7
Mobile home	2.5	2.5	2.5	2.5
Boat, RV, van, etc.	0.0	0.0	0.0	0.0

Table 21. Area cleaned per week, winter months.

For each season, s, the following calculation determined a seasonal emission factor for each housing type, h. For each housing type, the typical area cleaned for each task was multiplied by the emission factor for that task, t. The number of units of each housing type was determined from field H30, number of units in structure, from the 2000 US Census. The resulting emissions for each task were summed over all tasks to produce an overall emission factor for each housing type. This calculation was repeated for each season.

$$A_{hts} \text{ x } EF_t = EF_{hts}$$

$$\sum EF_{hts} = EF_{hs}$$

We estimated that leaf blowers are used at a frequency of once per week for all residential applications. For single-family residences, we estimated that one-half of the residences use leaf blowers in some capacity to aid cleaning of the yard, either self-maintained or professionally maintained. For multiple-unit housing we assumed that professional perform yard maintenance on a weekly basis. Table 22 summarizes the key emission factors used for the emission inventory calculations. These factors are from the data shown previously in Table 19. Specifically, the four entries used are blowing/vacuuming on concrete and asphalt, power blowing lawn, and power blowing packed dirt (for planters).

Using Tables 20-22, the stated assumptions, and the equations above, we calculated the emission rates for all residential classifications by multiplying the emission factor by the area estimated for each of the four tasks and summing the four tasks. Tables 23 shows the results for non-winter months and Table 24 shows the results for winter months.

	Emission Factors (mg/m^2)			
	Planter	Lawn	Asphalt	Concrete
PM 2.5	80.0	1.0	20	30
PM 10	120.0	2.0	60	80
TSP	160.0	3.0	80	100

Table 22. Emission factors by task.

Housing Type	Emissions (mg/week/unit)		
Total:	PM 2.5	PM 10	TSP
1 unit, detached	1,549	3,078	4,077
1 unit, attached	1,549	3,078	4,077
2 units	1,899	3,738	4,937
3 or 4 units	1,393	2,785	3,678
5 to 9 units	768	1,522	2,005
10 to 19 units	548	1,068	1,402
20 to 49 units	333	642	841
50 or more units	175	337	440
Mobile home	655	1,310	1,715
Boat, RV, van, etc.	0	0	0

Table 23. Emissions by housing type, non-winter months.

Housing Type	Emissions (mg/week/unit)		
Total:	PM 2.5	PM 10	TSP
1 unit, detached	774	1,539	2,038
1 unit, attached	774	1,539	2,038
2 units	949	1,869	2,468
3 or 4 units	696	1,393	1,839
5 to 9 units	384	761	1,002
10 to 19 units	274	534	701
20 to 49 units	166	321	421
50 or more units	88	168	220
Mobile home	328	655	858
Boat, RV, van, etc.	0	0	0

Table 24. Emissions by housing type, winter months.

Finally, seasonal emissions are determined for each county by multiplying the number of units of each housing type, by the emissions by housing type, for that season, to arrive at the emissions for that county for that season.

$$U_{hc} \times EF_{hs} = E_{hsc}$$

$$\sum E_{hsc} = E_{sc}$$

Emissions from commercial locations were assumed to be one third of the total emissions from residential locations. Overall total emissions were obtained by summing the residential and commercial emissions. The number of units of each housing type, shown on Table 25, was determined from field H30, number of units in structure, from the 2000 US Census.

The emissions by county are shown on Tables 26 and 27 for winter and non-winter months respectively. Only those portions of Kern County within the District boundaries were included. Table 28 presents the leaf blower emissions on an annual basis in tons/day.

	Fresno	Kern	Kings	Madera	Merced	San Joaquin	Stanislaus	Tulare
Total:	270,767	183,041	36,563	40,387	68,373	189,160	150,807	119,639
1 unit, detached	175,380	126,792	25,393	30,854	48,011	129,289	109,509	87,838
1 unit, attached	10,068	6,889	2,144	1,341	2,534	11,223	7,190	4,738
2 units	6,766	5,455	1,093	499	1,829	4,975	4,486	3,086
3 or 4 units	17,388	10,770	1,629	1,619	3,339	8,374	6,043	5,426
5 to 9 units	13,598	5,694	1,232	1,012	2,744	6,233	3,675	2,560
10 to 19 units	7,352	3,255	870	365	1,409	4,863	1,880	1,519
20 to 49 units	8,049	3,871	748	452	1,137	4,546	2,598	1,950
50 or more units	18,810	7,693	1,376	882	2,136	10,468	6,976	1,782
Mobile home	12,737	12,226	2,052	3,068	5,079	8,736	8,196	10,431
Boat, RV, van, etc.	619	395	26	295	155	453	254	309

Source: U.S. Census Bureau Census 2000
H30. UNITS IN STRUCTURE [11] - Universe: Housing units
Data Set: Census 2000 Summary File 3 (SF 3) - Sample Data

Table 25. Number of units by housing type.

	Fresno	Kern	Kings	Madera	Merced	S Joaquin	Stanislaus	Tulare
PM 2.5 (lb/day)	148	105	21	24	39	107	88	70
PM 10 (lb/day)	294	208	42	47	78	213	174	140
TSP (lb/day)	389	275	55	62	103	281	231	185

Table 26. Leaf blower emissions by county, non-winter months.

	Fresno	Kern	Kings	Madera	Merced	S Joaquin	Stanislaus	Tulare
PM 2.5 (lb/day)	74	52	11	12	20	54	44	35
PM 10 (lb/day)	147	104	21	23	39	106	87	70
TSP (lb/day)	195	137	28	31	51	141	115	92

Table 27. Leaf blower emissions by county, winter months.

	Fresno	Kern (SJVAPCD portion)	Kings	Madera	Merced	S.Joaquin	Stanislaus	Tulare	**Total**
PM 2.5 (tons/day)	0.07	0.05	0.01	0.01	0.02	0.05	0.04	0.03	**0.26**
PM 10 (tons/day)	0.13	0.09	0.02	0.02	0.03	0.09	0.08	0.06	**0.52**
TSP (tons/day)	0.17	0.12	0.02	0.03	0.04	0.12	0.10	0.08	**0.69**

Table 28. Annual emissions in the San Joaquin Valley from leaf blowing activities.

The results shown in Table 28 meet the project objective and are based on the application of emission factors determined by operating leaf blowers in an enclosure to estimated activity in the San Joaquin Valley. While there are many potential sources of uncertainty, like all emission inventories, these results represent a major improvement for this emission source.

7.0 REFERENCES

Botsford, C.W., Lisoski, D., Blackman, W., Kam, W. (1996) Fugitive Dust Study – Characterization of Uninventoried Sources. Final report AV-94-06-214A AeroVironment Inc. Monrovia, CA. March.

California Air Resources Board (2000) A report to the California legislature on the potential health and environmental impacts of leaf blowers. February.

Chow, J.C.; Watson, J.G.; Lowenthal, D.H.; Solomon, P.A.; Magliano, K.; Ziman, S.; and Richards, L.W. (1992) PM_{10} Source Apportionment in California's San Joaquin Valley. *Atmos. Environ.*, 26A: 3335-3354.

Fitz, D. R. and K. Bumiller (2000) Determination of PM_{10} emission rates from street sweepers. *J. Air Waste Manage. Assoc*. 50: 181-187.

Fitz, D. R. (2005) Quality Assurance Work Plan for Measurement of Particulate Matter Emission Factors and Inventories from Leaf Blowers. Unnumbered UCR report. August 9. Revision 1.

Pope, C.A., Thun, M.J. Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E., and Heath, C.W. (1995) Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults, *Am J. Respir. Crit. Care Med,* 151: 669-674.

Venkatram, A. and D. R. Fitz. (1998) Modeling of PM_{10} and $PM_{2.5}$ emissions from paved roads in California. Final report prepared for the California Air Resources Board contract 94-336. March.

Chow, J.C.; Watson, J.G.; Egami, R.T.; Frazier, C.A.; Zhiqiang, L.; Goodrich, A.; and Bird, A. (1990) Evaluation of Regenerative-air Street Sweeping on Geological Contributions to PM_{10}. *J. Air & Waste Manage. Assoc.* **40,** 1134-1142.

Lowes (2005) Leaf Blower Buying Guide. www.lowes.com/lowes/lkn?action=howTo&p=BuyGuide/leafblower.html&rn=RightNavFiles/right..

Compilation of Air Pollutant Emission Factors, AP-42, Volume 1: Stationary Point and Area Sources, Fifth Edition, U.S.E.P.A.., Research Triangle Park, NC, January 1995.

Standard Test Methods for Particle-Size Analysis of Soils, ASTM Method 422-90. American

Society for Testing and Materials. Philadelphia, PA, 1990.
Home Depot (2005) Blowers and Accessories. www.homedepot.com/prel80/HDUS/EN_US/jsearch/searchResults.jsp?com.broadvision.session.new=Yes.
Consumer Reports (2003) Power Blowers. Consumer Reports Magazine. Pg 44-46. September.

APPENDIX A: Quality Integrated Work Plan

QUALITY INTEGRATED WORK PLAN

FOR

Factors and Emission Inventory from Leaf Blowers in use in the San Joaquin Valley

Revision: 2

November 18, 2005

Prepared for:

San Joaquin Valley Unified Air Pollution Control District
1990 Gettysburg Avenue
Fresno, CA 93726

Principal Investigator:

Mr. Dennis R. Fitz
College of Engineering
Center for Environmental Research and Technology
University of California, Riverside
Riverside, CA 92507

Quality Integrated Work Plan Approval and Distribution

Title: Measurements of Particulate Matter Emission Factors and Inventories from Leaf Blowers, Revision 2, November 18, 2005

Signatures indicate that this Quality Integrated Work Plan (QIWP) is approved and will be fully implemented in performing the research project described in this document.

Dennis Fitz
Principal Investigator
CE-CERT
University of California, Riverside

Signature *Date*

David Gemmill
Quality Assurance Officer
CE-CERT
University of California at Riverside

Signature *Date*

Gary Arcemont
Air Quality Specialist
San Joaquin Unified Valley Air Pollution Control District

Signature *Date*

TABLE OF CONTENTS

TABLES

FIGURES

1.0 INTRODUCTION

1.1 Introduction

This Quality Integrated Work Plan (QIWP) presents the overall project plan, study design, organizational assumptions, and quality assurance activities in the performance of this research project to determine particulate matter emission factors for leaf blowers. This project is being performed by the University of California at Riverside - College of Engineering Center for Environmental Technology (CE-CERT), under contract with the San Joaquin Unified Valley Air Pollution Control District (District).

This QIWP describes in detail the necessary activities to ensure that the data collected and reported are sufficiently complete, representative, precise, and accurate. It also provides the framework for implementing project QA and QC activities by addressing topics such as responsible individuals, data integrity, documentation, preventive maintenance, and corrective actions.

This study is being performed to develop a method and equipment to determine air borne particulate matter (PM) emission rates from leaf blower activities. Once the method has been demonstrated to be viable, emission factors for a variety of leaf blowing activities will be determined. An emission inventory for the counties within the District will be prepared using activity data and the emission factors determined in this study.

1.2 Background

Particulate matter (PM) has been implicated as being responsible for a wide variety of adverse health effects that have been shown in epidemiological studies to contribute to premature deaths (Pope et al. 1995). Many areas in the State of California consistently exceed both the State and Federal PM_{10} and $PM_{2.5}$ ambient air quality standards. To formulate effective mitigation approaches, the sources of the PM must be accurately known. Receptor modeling has shown that PM_{10} of geologic origin is often a significant contributor to the concentrations in areas that are in non-attainment (Chow et al., 1992). These geologic sources are generally fugitive in nature and come from a wide variety of activities that disturb soil or re-entrain soil that has been deposited.

Leaf blowers are an obvious source of particulate emissions. The emission rates, however, have never been quantitatively measured and there is no default emission factor in AP-42 for this source. Botsford et al. (1996) estimated an emission rate by making assumptions and applying engineering principles. These emission rate estimations have never been validated with actual measurements. Staff at the California Air Resources Board (California Air Resources Board, 2000) estimated leaf blower emission factors using the Botsford approach and the silt loadings determined by Venkatram and Fitz (1998). These silt loadings, however, were measured in gutters of paved roads, which is not a typical substrate that leaf blowers are used to clean. The ARB estimates have also not been validated by experimental measurements.

1.3 Project Objectives

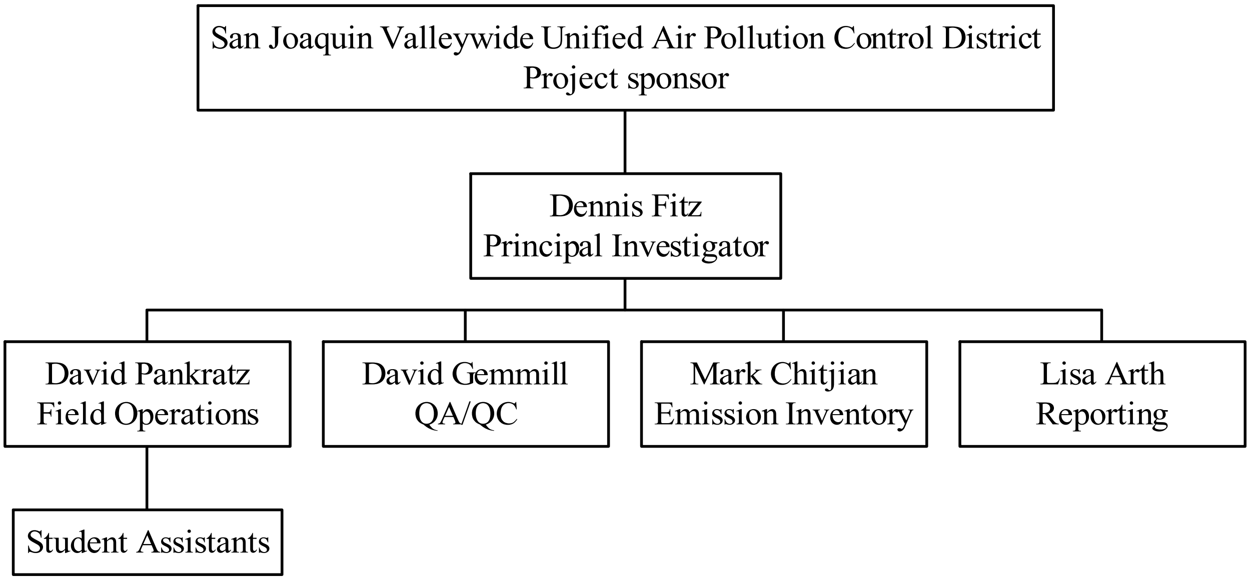
The objective of this study is to develop an emission inventory for these sources using measured emission rates. The PM emission rates from typical leaf blowers under typical actual and simulated conditions will be quantified. These emission rates will be then be used to develop emission inventories for counties in the San Joaquin Valley.

2.0 PROJECT MANAGEMENT

2.1 Project Organization

Organizational commitment is an essential element for developing and implementing a successful research project. At CE-CERT, the Principal Investigator will be kept apprised of all research program activities, from identifying the need to develop sound experimental designs to delivering data reports. Commitments to research activities, such as those described in this QIWP are made only after the activities are thoroughly reviewed and approved by the Principal Investigator. Figure 1 presents the organizational chart that shows the lines of responsibility and information flow for activities under this project. A listing of specific responsibilities of each position for this project follows.

Figure 1. Project Organization



Principal Investigator – Dennis Fitz

- Manages project technical and administrative tasks
- Directs, integrates, and schedules activities of the project team
- Provides scientific guidance on measurement methods
- Guides the overall approach for performing the experiments and verifying their results
- Project's principal point of contact with the District
- Issues monthly progress reports to the District
- Presents findings from main study to the District

Project Engineer – David Pankratz

- Designs, obtains, configures, assembles, and tests the measurement and ancillary equipment
- Verifies the viability of the system
- Performs tests to determine emission factors of leaf blowers
- Initiates corrective actions and notifies Principal Investigator and QA Officer if equipment performance exceeds established control limits
- Validates data

- Performs data analysis, interpretation and determines emission factors for leaf blowers and other equipment tested

Project Engineer – Mark Chitjian

- Develops plan to perform emission inventory for leaf blowing activities in the District.
- Using emission factors determined from this project, produces an emission inventory for the counties within the District for each season
- Prepares a report of the findings

Quality Assurance Officer – David Gemmill

- Reviews the test protocols and test matrices with particular emphasis on its quality control components
- Reviews the fabrication, assembly, and operation of the test systems
- Conducts performance audits of the assembled measurement systems
- Follows up on all unsatisfactory performance to ensure that the appropriate corrective actions are performed

Contract Manager for the District

- The District is the organization to which the results of the tests will be presented; the project objective is to deliver data of known and acceptable quality and quantity to meet the needs and requirements of the District
- Reviews the QIWP and conducts critical project reviews
- Interacts with CE-CERT Principal Investigator

2.2 Personnel Qualifications and Training

General education of all project personnel lays the foundation for successful project implementation. It is not intended to provide detailed and specific knowledge of all components of the project, but it promotes an understanding of the nature of the overall project goals, ensuring that all personnel understand the part they are to play in the project.

The measurements to be performed in this project are basically the same as those that CE-CERT routinely makes in ambient air and in smog chambers. The CE-CERT Principal Investigator has more than 30 years' experience in making measurements of gaseous and particulate air pollutants in a research environment and in managing research projects. He is the Principal Investigator of many PM studies either currently being performed or conducted in the past few years. Other staff members also have been involved with using air quality instrumentation, performing PM emission measurements and performing emission inventories.

All project personnel will be familiar with the content of this QIWP, thus obtaining a project overview, including information on all functions of the measurement systems, from experimental design, objectives, sampling, and data validation and reporting. Where applicable, project personnel will review the SOPs applicable to their responsibility. In addition, if major revisions or enhancements are made to the QIWP and/or SOPs, all affected individuals must review those revisions at that time.

2.3 Communications Plan

Each project team member is linked by e-mail correspondence, and thus kept abreast of all project developments and information. These team members include resident experts on the operations and monitoring equipment utilized for this study and/or had extensive experience developing new measurements methods, as necessary for this project. In addition, periodic project meetings and conference calls will be held. In these meetings detailed technical information will be exchanged, project status will be discussed, and project direction will be assessed.

2.4 Project Schedule

Figure 2 is a Gantt chart showing the schedule for the project. Initial measurement data will be delivered to the District by August 22, 2005. The final report for the project will be provided to the District by October 4, 2005.

Figure 2. Project Schedule.

Month	Work plan	Method Development	Riverside Testing	Fresno Testing	Inventory Development	Draft Final Report	Final Report
Jul 2005	░	▓	░		░		
Aug 2005			▓	░	░		
Sep 2005				░	░		
Oct 2005						░	░
Nov 2005							

3.0 PROJECT ASSESSMENT, DATA QUALITY OBJECTIVES, CONTROLS AND CORRECTIVE ACTION

3.1 Project Assessments

The point of contact for managerial project assessment is that of the Principal Investigators described in Section 2.1. These investigators are linked to the District contract manager. This link will provide timely reviews of the project experimental design and implementation.

The project team is committed to achieving and maintaining the highest level of quality possible throughout the performance of this program. The data generated will be both technically sound, and, where appropriate, legally defensible. The former is an obvious requirement but is not, in and of itself, sufficient to defend the data against an adversarial inquiry. The latter will address, through documentation, the level of quality achieved. The quality of the project data will be maintained not only through the development and use of data quality objectives (DQOs), which place numerical limits on the quality control indicators, but also through the use of subjective science quality objectives.

Science quality objectives are used to provide evaluations of the quality of the research project and goals of the study. Evaluations of all research activities by internal and external peer review will assure that the methodology, experimental processes, conclusions and recommendations provided by this project are scientifically sound.

Assessments of the data quality generated on this project will be made by:

- Conducting internal performance and systems audits of the critical components of the experimental setup and data processing systems. Where applicable, adherence to SOPs will be evaluated. The results of these audits will contain any suggested corrective actions, and be appended to the data interpretation reports generated in this study.

- Independent peer reviews of thesis materials, reports, and papers resulting from this project.

3.2 Data Quality Indicators

The establishment of data quality objectives (DQOs) is a systematic planning process, which is described in the EPA document, Guidance for the Data Quality Objectives Process, EPA QA/G4. Measurement performance criteria (MPC) are the set of criteria for each measurement system that are used to achieve the DQOs. These objectives vary from instrument to instrument, and will depend upon the environment in which the instrument is operated, how close the measured data are to the detection limits, the time increments employed, and other similar factors. For the instruments used on this study, DustTrak and filter PM samplers, the anemometer and pitot tube wind and air flow monitors and the tracer gas monitors, the MPC are established due to previous operation under similar conditions.

This process will be followed in the development of the experimental design described in this QIWP. The objectives associated with this study will include accuracy, precision, minimum detectible limits, completeness, representativeness, and comparability. These indicators will be measured on many of the instruments and sampling configuration experiments performed on this project. The typical criteria will be used as indicators of error or bias in a data set. However, there are a number of additional indicators such as Inference of Analysis that can be used to analyze the data, where appropriate. By the use of these indicators, the following objectives have been established for this project:

1. The error of the project data will be quantified using tools and methodologies outlined in this and related documents. This will be accomplished by conducting calibrations on selected instruments, checks of the accuracy of the flow rate measurements, peer reviews of selected components of the experimental setup, and collocation of instruments to determine precision. These data will be used to refine the provisional accuracy and precision of the project data set.

2. Data generated will be of sufficient quality to facilitate comparison with similar studies. The Project Engineers and Principal Investigator will perform the statistical evaluation of the data.

3. All project staff will strive to provide the maximum quantity of data possible for the duration of the study to allow for robust comparisons of data (data completeness). A provisional completeness objective for this study is 90% for each instrument for each sampling run. A very high level of communication will be encouraged throughout the study. Raw data comparisons will help identify instrumentation and operational problems. The accuracy and precision objectives for this main study are presented in Table 1.

Table 1. Accuracy and Precision Objectives

Measurement	Detection Limit or Resolution	Accuracy Objective	Accuracy/Precision Determination Methods	Precision Objective
PM - DustTrak	1 µg /m^3	±20%	Factory calibration/ collocation of analyzers	±20%
PM – Filter Sampler	1 µg/m^3	±20%	Balance Calibration/ collocation of analyzers	±10%
C_3H_6	0.05 ppm	±20%	Certified compressed gas cylinder	±20%

Wind Speed	0.1 m/s	±5%	Collocation with hand-held anemometer	±5%
Pitot Air Flow Sensor	0.1 m/s	±5°	Collocation with hand-held anemometer	±5°

Each indicator is discussed below, as it will be applied to this project. The results of these analyses will provide estimates of the accuracy and precision of these measurements under the conditions in which the instruments are operated.

- **Accuracy**

The accuracy of the DustTrak and C_3H_6 analyzers, plus all meteorological instruments will be determined from a performance audit conducted during the study. The audit will consist of challenging the analyzer with a test atmosphere from an independent source, or collocations of meteorological instruments with independent standards. Each report of these performance assessments will contain detailed audit procedures and results. The percent difference at each concentration will be calculated using the following equation:

$$\%\text{Dif.} = [(Y - X)/X] \times 100$$

In this equation, X is the test value and Y is the corresponding instrument response. If the test consists of a multipoint comparison, the resulting data will be used to generate a linear regression equation in the following form:

$$Y = \text{Slope}\,(X) + \text{Intercept}$$

The slope, intercept, and correlation coefficient (r) from this analysis will be used to evaluate the accuracy of the analyzers. The accuracy objectives in Table 1 are also the provisional expected control limits for calibration results. Replicate calibration tests will be assimilated and an average and standard deviation of all the %Dif values will be calculated to provide revised estimates of day-to-day accuracy for each instrument.

- **Precision**

The precision of selected instruments will be either determined from analyses from collocated data or by replicate analyses of the same span gas over time, and will be determined from calculation of the %Dif from each collocation or replicate run using the following equation:

$$\%\text{Dif.} = 2(A - B)/(A + B) \times 100$$

In this equation, A is the value from the instrument A and B is the corresponding instrument value reported from collocated instrument B. A series of replicate collocation checks will be assimilated and an average and standard deviation of the entire %Dif. values can be calculated for each measurement to provide a refinement of the precision estimates presented in Table 1. In addition, the results of these collocation tests will be plotted on dedicated control charts, enabling refinement of the control limits for each instrument for the main study. Further, this procedure will be used to establish the repeatability for selected experimental runs, as appropriate.

- **Minimum Detection Limits**

The minimum detection limits (MDLs) are defined as a statistically determined value above which the reported concentration can be differentiated, at a specific probability, from a zero concentration. For gas analyzers, MDLs will be determined by repeatedly challenging the analyzer with zero air, followed by span and multiple calibrations. Generally, the MDL for measurements on this program is determined as three times the standard deviation of the instrument response when subjected to zero air. The MDL for each analyzer has been well characterized; this information is located in the appropriate analyzer manual. This information is verified through statistical evaluation of data from zero air checks, using the following:

$$MDL = t(n-1,1-a = 0.99) * s$$

In this equation, s is the standard deviation of the replicate zero analyses; t is the Student's t value appropriate to a 99% confidence level and a standard deviation estimate with n-1 degrees of freedom.

The MDLs calculated for each measurement will include all sampling and conditioning procedures and therefore will represent a detection limit that can be applied to the reported concentrations. Provisional detection limits for the instruments to be used in this study are presented in Table 1.

- **Completeness**

Completeness is determined from the collected data generated during the study using the following equation:

$$Completeness = (D_x - D_c)/D_c * 100$$

Where D_x is the number of samples for which valid results are reported and D_c is the number of samples that are scheduled to be collected. The provisional completeness objective for this study is 90% for each instrument for each sampling run.

- **Representativeness**

Representativeness generally expresses how closely a measurement reflects the characteristics of the surrounding environment. This will be verified by review of the sample probe placements effect the measured values. Representativeness will also be determined by the variabilities in emissions related to soil types.

- **Comparability**

Comparability refers to how confidently one data set can be compared with another. It is the objective of this study that the generated data will be of sufficient quality to facilitate comparison with similar studies. This will require adherence to the data quality objectives of each criterion listed above.

3.3 Routine Controls and Procedures

Control over the handling and operation of the project instrumentation will be maintained throughout this project. This section presents the types of controls that will be incorporated into the project process. Where applicable, instrument manuals and SOPs will be utilized.

- **Documentation Procedures**

All relevant instrument calibrations, experimental procedures and observations will be recorded in dedicated project logbooks. Data sheets will be maintained for any collected samples and instrument QC checks.

- **Calibrations and QC Checks**

The calibration procedures for this project include criteria that include daily calibration frequencies for many of the instruments. The accuracy objectives presented in Table 1 are also the provisional calibration control limits for this study. When instrument performance is outside these limits, actions will be taken to re-calibrate or repair the instrument. The description, operation, and maintenance of calibration standards are included as part of calibration procedures. In addition, an ongoing records management system will be maintained so that the calibration status of all instruments is readily available and easily retrievable in the future.

- **Determination of Instrument Readiness and Precision**

During the periods between test runs on a given day, the air monitoring instrumentation will continue to operate so that the ambient concentrations will be measured. Analysis of these data will help establish the operational readiness of the instrumentation by comparison with the expected ambient concentrations. In addition, in the case of multiple analyzers for the same species, collocated monitoring under ambient conditions will enable determination of measurement precision. Linear regression analysis of the ambient data collected from pairs of analyzers will be performed before test runs. Minimum standards will be established for correlation coefficients for each type of analyzer, within established concentration ranges to determine if they are operating correctly. Test runs will be aborted if critical analyzers are found to not be operating correctly.

4.0 MEASUREMENT EQUIPMENT AND METHODS

4.1 Real-Time PM Monitors – DustTraks

Real-time total suspended particulate matter (TSP), PM_{10} and $PM_{2.5}$ measurements will be performed using Thermo Systems Inc. Model 8520 DustTrak Aerosol Monitors. Impactors are used to perform the size cuts and the PM concentrations are then determined by measuring the intensity of the 90^{o} scattering of light from a laser diode. The instruments are calibrated at the factory with Arizona road dust (NIST SRM 8632), but the real-time data will be compared with the mass determinations from the filter collections. The instrument sample flow rate is 1.7 L/min. The time constant is adjustable from 1 to 60 seconds, and will be used in the one-second position.

4.2 Time-Integrated PM Measurements using Filter Samplers

Filter samples will be collected using custom sampling systems designed by UCR for the collection of total suspended particulate matter TSP, PM_{10} and $PM_{2.5}$ samples. A single rotary vane pump will provide the vacuum to draw air through six filter media, two with each size cut. The sampler has six flow meters with metering valves for controlling and monitoring the flow rate through each sample media.

The samples will be collected on 47 mm Gelman Teflo filters with a 2.0 µm pore size. A Cahn Model 34 microbalance at the CE-CERT laboratory will be used to determine the weight of the filters to within 1 µg before and after sampling. All filters will be equilibrated at $23^{o}C$ and 40% RH for at least 24 hours prior to weighing.

4.3 Wind and Air Flow Rate Measurements

- **Wind Speed and Wind Direction**

Prevailing winds for testing performed at CE-CERT will be determined using a wind system located at a height of 5 meters at CE-CERT. A Climatronics F460 wind speed and wind direction monitoring system will be connected to a Campbell 10X data logger. This system will measure and process winds into hourly averages. The system has an accuracy of +\-5 degrees for wind direction and +/-5% wind speed accuracy for winds greater than 5 m/s.

- **Propeller Anemometer Measurements of Air Flow Through Test Chamber**

For testing performed with the test chamber ends open (tunnel mode), the mean air flow rate through the tunnel will be measured and continuously recorded using a Model 27106 Gill propeller anemometer. The wind sensor will be placed in the test chamber and oriented to measure air flow through the chamber. It will output wind speed (i.e. air flow rate) data to a data logger recording the data once per second.

4.4 Propylene Tracer Gas Measurements

For testing performed with the test chamber ends open (tunnel mode), the air flow rate through the test chamber measured by the propeller anemometer will be checked using a tracer gas. Pure Propylene will be metered into the tunnel approximately 1-2 meters in from the upwind end using a mass flow controller. Measurements for this tracer gas will be performed using a RAE Systems ppbRAE hydrocarbon analyzer located 1-2 meters in from the tunnel outlet. The instrument determines the concentration of hydrocarbons using a 10.3 electron volt photoionization detector (PID). The instrument has a lower detection limit for C_3H_6 of approximately 50 ppb.

4.5 Data Acquisition System

Data from the following instruments will be collected using a laptop PC with LabVIEW software and appropriate A/D cards and RS-232 multiplexers. The logging and averaging periods for each channel will be set to one second.

- TSI DustTrak PM samplers
- Filter samplers (on/off condition)
- Gill Propeller Anemometer

Data from the Climatronics WS/WD system will be collected using a Campbell 10X data logger.

At the conclusion of each set of tests, all data will be transferred to a networked PC for storage and backup.

4.6 Leaf Blowers

There are several categories of leaf blowers. For this project, we will procure one of each of the following: gasoline powered hand held, gasoline powered backpack and electric powered with blower and vacuum capability. We will procure these from a home supply store. We will select the ones that are most popular and most likely of the style to be in use in the San Joaquin Valley.

We have tentatively selected the following three leaf blowers as they have been identified as the most popular from a major supply store (Home Depot, 2005):

- Black & Decker Model BV 4000 Hand Held Electric Blower/Vacuum
- Echo Model PB 403 Gas Backpack Blower
- Homelite Model 30 cc Vac Attack II Gas Hand Held Blower

4.7 Rakes and Brooms

A rake and push broom will be procured for examining alternate methods to leaf blowers for this study. We will procure one new broom and rake from a major home supply store. We will attempt to select the ones that are most popular and most likely to be used in place of leaf blowers.

4.8 Test Chamber

For testing leaf blowers we will build a test chamber. The chamber will be 2m wide, 2m high and 20m long. It will be constructed using 1” PVC pipe and aluminum modular pipe and rail fitting. The chamber will be enclosed using polyethylene sheeting. Figure 3 is a sketch of the chamber. Two different configurations of the system are being considered. The first is the “tunnel mode” with the system to be open at the two ends and for air to flow through with the prevailing winds. The second is for the “chamber mode” with the system to be fully enclosed. Testing and determination of which configuration will be used for the emission factor determinations are discussed in the next section.

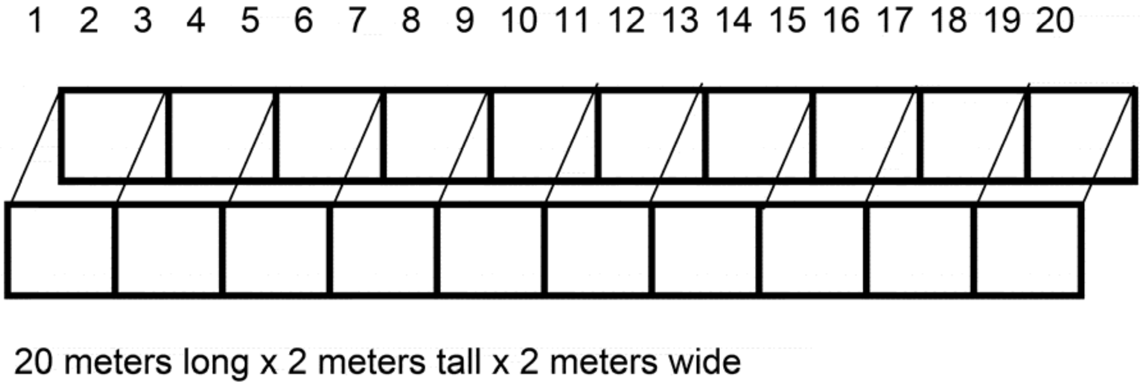


Figure 3. Test Chamber.

4.9 Safety Instruments

- **Confined Space Gas Detector**

A three gas monitor (lower explosive limit, oxygen and carbon monoxide) will be placed in the test chamber to alert test crews of potentially dangerous levels of the latter two gases due to the leaf blower operation. An appropriate instrument will either be borrowed from the UCR Environmental Health and Safety Group or rented.

- **High Concentration Particulate Matter Sensor**

The output of one of the DustTraks measuring TSP inside the test chamber will be monitored or configured to set off an alarm if PM levels approach levels that are unsafe for project staff to be in without respiratory protection gear.

4.10 Soil Silt Content

CE-CERT has soil from three agricultural facilities located in three different areas of the San Joaquin Valley as well as soil from UCR’s agricultural facility in Moreno Valley from a previous study. We plan on using these soils in the present study. We had aliquots of all of these soils analyzed for silt content using the following two methods.

- **AP-42 Soil Analysis Method**

The current protocol used by most agencies to estimate the amount dust entrained from agricultural tilling and from dirt roads is presented in AP-42 (EPA, 1995). Appendix C.2 of AP-42 describes a dry sieve protocol to determine the percentage of mass that passes through a No. 200 sieve (75µm) and to define this fraction the “silt content.” Aliquots of soils from UC agricultural facilities in Shafter, Kearney, 5-Points and Moreno Valley and artificial soils were analyzed by this method.

- **Multisize Fraction Laboratory Analysis of Soils**

Aliquots of the above four soils all soils and artificial soils were analyzed by methods to provide more comprehensive particle size information (in particular for the ~75 micron and smaller size diameters) than is provided by the Method AP-42 protocol.

ASTM Method D422 (ASTM, 1990) was used to determine the sand, silt and clay content in the under 75 µm size range. This is a wet sieve method that uses sedimentation of the soil (or a sieved fraction of the soil) to determine diameter of the soil particles.

4.11 Fertilizer Spreader

A fertilizer spreader will be used to spread our surrogate soil consisting of soil and grass clippings or leaves along ground inside the test chamber. A key selection criterion for the fertilizer spreader will be to find one with a spreading method that minimizes segregating the material based on size or mass as they are deposited.

4.12 Triple Beam Balance

A model 710-00 Ohaus triple beam balance will be used to weigh soil and vegetative matter used in the tests. The balance has a resolution of 0.1 grams.

5.0 MEASUREMENT PROGRAM

The purpose of the measurements is to obtain emission factors for leaf blowers, rakes and brooms when used for cleaning over various surfaces. The first three sections below present the initial tests necessary to obtain a viable system for performing measurements to determine these emission factors.

5.1 Design and Evaluation of Test Chamber

Designing, constructing and testing a system for determining PM generation from leaf blower operation is the first task in the measurement program. The initial plan for the test chamber is shown in Figure 3 and the tunnel and chamber configurations are discussed in Section 4.7. A test chamber configuration has several advantages over the tunnel. A major advantage of the chamber is there is no need to determine the air flow rate through the test apparatus. However, characterizing PM concentration differences throughout the tunnel becomes important as it is a closed system and it is the calculations will be based on accurately knowing the total amount of mass in the air in the test chamber. We will initially pursue the program using the chamber method for the following reasons:

- We believe that we will be able to accurately quantify the entire amount of mass in the chamber
- The chamber method eliminates the need to quantify the air flow rate through the measurement system
- The chamber method does not need winds to be present or blowing at any particular speed or in any particular direction

Should the chamber method be found not to be viable, then we will pursue testing and evaluation of the open end tent method. The remainder of this section will discuss testing using the chamber method.

5.1.1 Viability of Structure

Material will be laid out as shown in Figure 4. A leaf blower will be used to sweep the material into a collection area at the end of the structure. Observations will be made for the following:

- Losses along the length of the structure due to using round pipe at the bottom
- Losses under the length of the structure due to non flat surface – integrity between ground and pipe running along ground not maintained
- Too copious of dust plume created; unsafe work environment
- Too high of exhaust buildup in chamber – unsafe work environment

- Ability/inability to sweep dirt due to shape/dimensions of test chamber

Any problems found will be addressed as necessary.

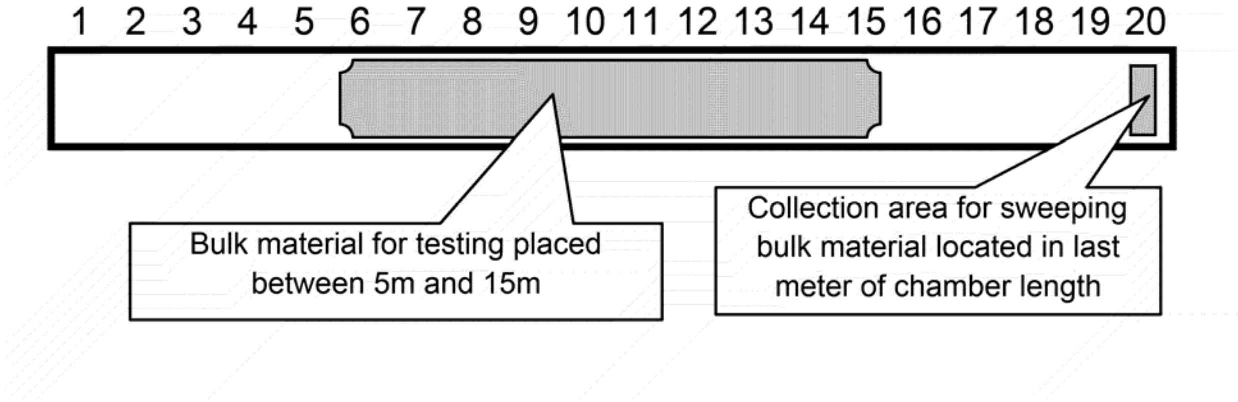


Figure 4. Top View of Test Chamber Showing Test Material and Collection Area.

5.1.2 Determination of Amount of Material to be used

The amount of material to be used will be varied to determine the lower limit and range that can be used to provide responses on the DustTraks that significantly above their detection limit, allowing emission calculations with minimum uncertainty from the DustTraks. The material will be soil from at least one of the UC research areas in the San Joaquin Valley. We will also evaluate soil from the Fresno area if supplied by the District. We will determine the silt content of this soil. All material used will be weighed before it is laid out.

5.1.3 Dust Plume Characterization

Material will be laid out as shown in Figure 4. All DustTraks will have their impactors removed so that they are all measuring TSP. They will be placed at a height of 1m at the following distances in: 2m, 5m, 10m, 15m, 17m, and 20m. The DustTraks will be hooked up to the data logger and one-second data will be recorded. A leaf blower will be used to blow the material into a collection area at the end of the chamber. The DustTrak data will be reviewed to determine plume characteristics across the chamber. The test will be repeated several times. The test will also be repeated with PM_{10} and $PM_{2.5}$ inlets on the DustTraks.

Three DustTraks will be placed 10m in at heights of 0.5m, 1.0m and 1.5m and three DustTraks will be placed in at 15m at the same three heights. The above tests will be repeated with TSP, PM_{10} and $PM_{2.5}$ inlets to obtain vertical profile data.

The findings from these tests will be used to determine the minimum number and placement of PM samplers in order to perform subsequent tests. Although the findings from these tests may determine otherwise, we will presume that six DustTraks, two for each particle size cut, are sufficient for the study. We will also presume that placing the samplers at a height of 1.5 meters height and at distances of 10m and 15m in is appropriate. Filter samples will be collocated with these six DustTraks for collection of samples on filter media on a daily basis.

5.1.4 Mass Balance

A series of tests will be performed to determine if it is possible to account for all of the material that is swept in the test chamber. The following steps will be performed several times:

- Weigh out material
- Spread out on ground in chamber as shown in Figure 4
- Use leaf blower to sweep into collection area at end of chamber
- Vacuum material from collection area and weigh
- Collect concentration data inside chamber using DustTraks
- Calculate total suspended mass using concentration data, volume of test chamber and plume profile characteristics
- Determine how well start mass is accounted for

Several of these tests may be performed, varying the amount of material deployed from zero to larger numbers and possibly using other materials, such as $CaCO_3$ with a known nominal diameter, as necessary in order to understand any mass imbalances.

5.2 Real-Time PM Sampler Collocated Testing

The DustTraks will be collocated and operated for several hours measuring ambient air or chamber air after some dust has been generated, as appropriate, to check that their responses are the same, within the instrument's stated accuracy and the accuracy goals of this project. The collocated tests will be performed for TSP, PM_{10} and $PM_{2.5}$ operation. Instruments not performing as necessary will be repaired or excluded from the project.

5.3 Artificial and Natural Soil Selection, Preparation and Evaluation

- **Crustal versus Vegetative Mass Ratio of Test Material**

A range of the mass of soil to be used for this study will be determined as described in Section 5.1.2. We will vacuum measured areas at selected locations around UCR where leaf blowers are routinely used just prior to routine leaf blowing activities. The vacuumed material will be separated via sieves into crustal components and vegetative components (leaf, grass, etc). The separated components will be weighed to determine the relative masses of the two components. The average or median, as appropriate, of the ratio of the two masses of the two components will be used for preparation of subsequent soil samples standards.

- **Preparation of Surrogate Material**

Using the crustal/vegetative ratio determined above, surrogate soils will be prepared using the soils from the four UC facilities and that supplied by the District. Separate samples with grass and leaf material will be made for each of the soil samples. The material will be spread out as shown in Figure 4 and a leaf blower will be used to sweep the material into a collection area at the end. The collected material will be weighed. Comparisons of the airborne PM levels and the mass of the material collected will be made between the four UC facility soils to identify any differences. The range of differences will be noted. If there are significant differences, additional tests on additional soils present in the District will be performed to obtain better emission data that is related to soil type and independent of blower type. For the emissions testing to determine emissions related to different types of blowers, brooms and rakes, the soil from only a single UC facility from the San Joaquin Valley will be used as it is desired to have just a single variable, type of sweeper, for those emission determinations. However, the testing will include different vegetative material mixed into the single soil and also include sweeping over surfaces with the indigenous dirt and vegetative matter.

5.4 Emission Factor Measurements at UCR

The bulk of the testing will be conducted in Riverside using the surrogate debris mixtures consisting of vegetative matter and soil from a UC facility in the San Joaquin Valley or supplied by the District, as discussed in the previous section. Table 2 shows the test matrix. Each test will be repeated three times, the $PM_{2.5}$, PM_{10}, and TSP emission rates being determined each time.

Table 2. Matrix of Tests.
(each test run represented by an "x")

Equipment Used	Concrete Driveway	Concrete Sidewalk	Asphalt Parking Lot	Lawn	Shrubs, Flower Beds
Leaf Blower #1	xxx	xxx	xxx	xxx	xxx
Leaf Blower #2	xxx	xxx	xxx	xxx	xxx
Leaf Blower #3	xxx	xxx	xxx	xxx	xxx
Broom Sweeping	xxx	xxx	xxx	xxx	xxx
Vacuuming, bag full	xxx	xxx	xxx	xxx	xxx
Vacuuming, Bag Empty	xxx	xxx	xxx	xxx	xxx
Raking	xxx	xxx	xxx	xxx	xxx

5.5 Emission Factor Measurements in Fresno

A location will be selected in Fresno area for performing additional emission. We have tentatively selected the University of California Kearney Agricultural Field Station in Parlier. The test chamber will be setup at the location, along with all PM measurement and data recording instrumentation. A matrix of tests similar to those shown in Table 2 will be performed. In order to verify that there are no systematic differences in the equipment due to the location change, at least three runs will be performed with a single leaf blower over a single surface using the same surrogate material as used for the testing at UCR. All subsequent testing will be performed using soil and vegetative matter material from the Fresno site under actual conditions (after a mowing or trimming activity). The results will be compared with those of similar tests in Riverside and the extent of bias due to location will be estimated using a non-parametric statistical test.

5.6 Quality Assurance Audit

An audit of the particulate matter samplers will be performed. The audit will consist of determining if the filter sampler flow rates are within the within the project accuracy goals.

6.0 DATA PROCESSING AND ANALYSIS

6.1. Data Handling

The Project Team will maintain a dedicated record, which will clearly identify each instrument with its associated data input channel number. In addition, all periods of data collection, including the specific sampling mode and any known problems with any of the instruments, will be logged at a sufficient level of detail in order to preclude misdirection of data.

Data collected on the laptop PC will be transferred to a desktop PC for storage and backup on a daily basis. In addition, the data management software enables downloading of the raw data directly into Excel spreadsheets, within which the data will be validated, analyzed, and archived.

Power failures, instrument or computer failures, operator intervention for maintenance and calibration, deviation of the instrument calibration results outside the acceptable limits, deviations of the QC checks outside the acceptable ranges, problems with the sample runs, or other problems are all factors can potentially compromise data validity. The Project Team will identify those periods during which specific data may be considered unreliable by the use of data flags. When and if any of these factors occur it will be recorded in the project logbook and communicated directly to those performing the data validation and analysis. The data will be inspected graphically and all discrepancies and inconsistencies will be resolved by discussion within the project team and/or by reference to the raw data and the project logbook.

6.2 Data Validation

Data validation will follow guidelines described by the U.S. Environmental Protection Agency (U.S. EPA, 1978, 1980). All data will be screened for outliers that are not within the physically reasonable (normal) ranges. Next, the following steps will be taken:

1. Data will be flagged when deviations from measurement assumptions have occurred.
2. Computer file entries will be checked for proper date and time.
3. Measurement data resulting from instrument malfunctions will be invalidated.
4. Data will be corrected for calibrations or interference biases.

Meteorological and DustTrak data will be reviewed as time series plots and using computer based outlier screening routines. Rapidly changing, anomalous or otherwise suspect data will be examined with respect to other data. Computer based outlier programs will be used to screen the data from the six DustTraks for anomalies (e.g. $PM_{2.5} > PM_{10}$, etc).

Data will not be invalidated unless there is an identifiable problem or the measurement result is physically impossible.

Data values below detection limits will be entered to the database as the detection limit and flagged as a non-detect. For most of the measurements with fewer than 20% non-detectable values, the data analysis value will be set to one half the detection limit. For measurements and chemical species with a higher proportion of non-detectable values, the effect on the analysis of alternative treatments of these low concentrations will be evaluated. Approaches will include setting the values to zero, the computed detection limit, and one half the detection limit. It is not anticipated that sufficient samples will be collected that will require imputation techniques for substituting these low values.

The data reporting forms will contain a column for flagging and indicating the data validity. All problematic and missing data points will be highlighted in the form through the insertion of an appropriate coded flag. Invalidated data will not be placed in the reporting form in order to avoid their possible inadvertent use. These flags will include the following:

- Valid value
- Valid but comprised wholly or partially of below-MDL data
- Valid but interpolated (value is above the highest calibration point)
- Valid despite failing a statistical outlier test
- Valid but qualified because of possible contamination or interference
- Valid but qualified due to non-standard sampling conditions
- Missing value because no data are available
- Missing value because the data were invalidated by the operator

The data will be checked for internal consistency, consistency with operator logbooks, and consistency with calibration zero and span checks, and instrument precision checks. Internal consistency requires that data fall within normal operating ranges and do not exhibit excessive and rapid variations that are inconsistent with expected variations. Consistency with operator logbooks requires that all data acquired during calibrations, maintenance, and outage periods be flagged appropriately. Consistency with calibration zero and span checks requires checking verified data against all calibration data to assure that reported data provides the most accurate possible measure of each parameter. All verified data that have been subjected to these tests will be designated as validated data.

6.3 Data Analysis

The filter sampler data will be used to develop correction factors between the mass concentrations reported by the DustTraks and the concentrations determined by those determined from the filter data. These correction factors will be used to adjust the data measured by the DustTraks for the airborne particulate matter used in this project.

Emission factors will be calculated for the sweeping activities. We will be able to calculate both emissions in terms of airborne mass (TSP, PM_{10} and $PM_{2.5}$) per unit area swept and airborne mass per unit mass swept for all soil types and mixtures for all leaf blowers, brooms and rakes tested. These findings will be tabulated. Comparisons of the emission factors will be made to better understand variables effecting emissions as well as to perform a level 2 validation of the data. Final validated emission factors will be presented in manner that will be compatible with the emission inventory needs.

7.0 EMISSION INVENTORY

Data on the area typically cleaned and the time spent at each task will be gathered from interviews with operators and observation of operators at work. Several residences, single family and multiple unit, and commercial location will be visited to estimate areas requiring cleaning From this data the area cleaned and the time spent per task will be determined for each unit of typical residence and commercial location

For each season, s, the following calculation will determine a seasonal emission factor for each location type, l. For each type of unit, single-family residence, multiple family residence and commercial unit, the typical area cleaned for each task will be multiplied by the emission factor for that task, t. This calculation will be repeated for each blower model type, m. For each task, t, the emissions will be summed over all model types, m. The resulting emissions for each task will be summed over all tasks to produce an overall emission factor for each location type. This calculation will be repeated for each season.

$$A_{lts} \text{ x } EF_{tm} = EF_{ltsm}$$

$$\sum EF_{ltsm} = EF_{lts}$$

$$\sum EF_{lts} = EF_{ls}$$

The amount of units of each type of residence will be determined from field H30, number of units in structure, from the 2000 US Census. The number of commercial locations will be determined as a ratio of the number of residences. This calculation will be repeated for each county (including the District portion of Kern county).

The activity data produced for each county will be compared to other researchers estimates (Botsford 1996, ARB 2000). Adjustments to the activity data will be made where indicated.

Finally, seasonal emissions will be determined for each county (including the District portion of Kern county) by multiplying the number of units of each location type, by the emission factor for that location type, for that season, to arrive at the emissions for that county for that season.

$$U_{lc} \times EF_{ls} = E_{lsc}$$

$$\sum E_{lsc} = E_{sc}$$

8.0 REPORTING

Monthly progress reports will be issued to District that will review the work conducted and describe any problems encountered. This Quality Integrated Work Plan will be submitted for review and acceptance by the District prior to initiating measurements.

A draft final report will be written and submitted to the District. A complete database of the activity and resulting emissions inventory, along with documenting assumptions and uncertainties, will be provided with this report.

A final report will be prepared. The final report will incorporate the comments provided by the District in reviewing the draft final report.

9.0 REFERENCES

Botsford, C.W., Lisoski, D., Blackman, W., Kam, W. (1996) Fugitive Dust Study – Characterization of Uninventoried Sources. Final report AV-94-06-214A AeroVironment Inc. Monrovia, CA. March.

California Air Resources Board (2000) A report to the California legislature on the potential health and environmental impacts of leaf blowers. February.

Chow, J.C.; Watson, J.G.; Lowenthal, D.H.; Solomon, P.A.; Magliano, K.; Ziman, S.; and Richards, L.W. (1992) PM_{10} Source Apportionment in California's San Joaquin Valley. *Atmos. Environ.*, 26A: 3335-3354.

Fitz, D. R. and K. Bumiller (2000) Determination of PM_{10} emission rates from street sweepers. *J. Air Waste Manage. Assoc*. 50: 181-187.

Pope, C.A., Thun, M.J. Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E., and Heath, C.W. (1995) Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults, *Am J. Respir. Crit. Care Med,* 151: 669-674.

Venkatram, A. and D. R. Fitz. (1998) Modeling of PM_{10} and $PM_{2.5}$ emissions from paved roads in California. Final report prepared for the California Air Resources Board contract 94-336. March.

Chow, J.C.; Watson, J.G.; Egami, R.T.; Frazier, C.A.; Zhiqiang, L.; Goodrich, A.; and Bird, A. (1990) Evaluation of Regenerative-air Street Sweeping on Geological Contributions to

PM_{10}. *J. Air & Waste Manage. Assoc.* **40,** 1134-1142.

Lowes (2005) Leaf Blower Buying Guide. www.lowes.com/lowes/lkn?action=howTo&p=BuyGuide/leafblower.html&rn=RightNavFiles/right..

Compilation of Air Pollutant Emission Factors, AP-42, Volume 1: Stationary Point and Area Sources, Fifth Edition, U.S.E.P.A.., Research Triangle Park, NC, January 1995.

Standard Test Methods for Particle-Size Analysis of Soils, ASTM Method 422-90. American Society for Testing and Materials. Philadelphia, PA, 1990.

Home Depot (2005) Blowers and Accessories. www.homedepot.com/prel80/HDUS/EN_US/jsearch/searchResults.jsp?com.broadvision.session.new=Yes.

Consumer Reports (2003) Power Blowers. Consumer Reports Magazine. Pg 44-46. September.

.

APPENDIX B: Audit of Filter Sampling Measurement System

QUALITY ASSURANCE AUDIT REPORT

Revision 0

Measurements of Particulate Matter Emission Factors and Inventories from Leaf Blowers

Field Measurements Performed by:

**College of Engineering
Center for Environmental Research and Technology
University of California at Riverside
Riverside, CA 92507**

Audit Dates: September 8 and 27, 2005

Audit Performed by:

**David Gemmill
Quality Assurance Officer
College of Engineering
Center for Environmental Research and Technology
University of California at Riverside
Riverside, CA 92507**

CONTENTS

TABLES

1.0 Introduction

This report presents the results of a performance audit of an air particulate measurement system used on a project entitled, "Measurements of Particulate Matter Emission Factors and Inventories from Leaf Blowers." The measurement system was designed to measure and determine particulate matter emission factors for leaf blowers. This project is being performed by the University of California at Riverside - College of Engineering Center for Environmental Technology (CE-CERT), under contract with the San Joaquin Valley Air Pollution Control District (District).

Mr. David Gemmill, the Quality Assurance Officer for the UCR College of Engineering-Center for Environmental Research and Technology (CE-CERT), performed flow rate audits on the filter-based particulate samplers used on this project on September 8 and 27, 2005. Present for the audits was Mr. David Pankratz of CE-CERT, whose cooperation and assistance are gratefully acknowledged.

2.0 Description of Measurement System

The measurement system was installed and operated as described in the *Quality Integrated Work Plan (QIWP) for Measurements of Particulate Matter Emission Factors and Inventories from Leaf Blowers, Revision 1*, August 9, 2005. This QIWP presents detailed background information, project objectives, project management structure, measurement methods, study design, test chamber description, test instrumentation (leaf blower types), data acquisition and validation methods, and quality assurance objectives.

The field operation generally consisted of operating the leaf blowers for a known time inside a test chamber containing soils and similar materials of very accurately known content. An array of particulate samplers was operated concurrently inside the chamber to characterize the resulting airborne particulate matter.

The filter-based particulate samplers were configured in two separate systems, each containing a TSP sampler, a PM_{10} sampler and a $PM_{2.5}$ sampler. These systems were designed and fabricated by CE-CERT. Each sampler system contains rotary vane pumps to provide the vacuum to draw air through the six filter media, and each system has four rotameters with metering valves for controlling and monitoring the flow rate through each sample media (the $PM_{2.5}$ sampling system utilized two rotameters and valves). The target flow rate for the TSP and PM_{10} samplers is 16.7 actual liters per minute (ALM) and the target flow rate for the PM2.5 samplers is 110 ALM.

3.0 Particulate Sampler Audit Procedures, Equipment and Standards

The particulate samplers are audited using the procedures described in the *Quality Assurance Handbook for Air Pollution Measurement Systems (EPA-600-R-94/038b),* Sections 2.10.7, and 2.12.10.2. The audit consists of tests of the accuracy of each sampler's flow rate. Further, the sampler is inspected for proper operation, leaks, cleanliness, and structural integrity. All gaskets and fittings are inspected, and the sample filter holders are inspected for integrity.

The audit standard for the TSP and PM_{10} samplers is a Bios Model DC-1 HC flow meter, S/N 810. Its certification information is presented in each audit report. The Bios is an authoritative volume which meets all applicable NIST specifications. The audit standard for the $PM_{2.5}$ samplers is an American Co. certified dry gas meter, S/N 8426722.

The sampler's inlet is removed and an adapter fitting is attached to the downtube to which the audit standard is connected. The following are then recorded:

1. The flow rate as read by the sampler rotameter and converted to ALM by means of the latest calibration.

2. The flow rate as read by the audit standard and converted to ALM.

The sampler flow rates are compared to the corresponding audit flow rates in percent difference, using the following equation:

$$\%\text{Dif.} = [(S-A)/A] \times 100$$

In this equation, S is the indicated sampler flow rate in ALM, and A is the measured audit flow rate in ALM. The satisfactory range for these audit results is a percent difference of ±10% or less.

4.0 Audit Results

The audit results are presented in Table 1. The system for the $PM_{2.5}$ sampler consisted of two pumps metered by two rotameters, plumbed together at the point where the filter media was attached. This configuration was necessary to achieve the 110 ALM flow rate required for this sampler. As shown in the table, the $PM_{2.5}$ system was audited a second time because the target flow rates were not set correctly during the first audit. The audit results indicate that all audit results are within the ±10% satisfactory category.

Table 1. Particulate Sampler Audit Results

Sampler: 6-Meter Rack		Date: 09/08/05		Begin: 1416 End: 1520
Unusual Conditions: None				
Species	**Audit, ALM(1)(2)**	**Rotameter**	**Sampler, ALM(1)**	**%Dif.(3)**
TSP	18.4	40	19.0	3.3
PM_{10}	16.9	40	16.0	-5.3
$PM_{2.5}$	88	100, 100	83	-5.7

Sampler: 2-Meter Rack		Date: 09/08/05		Begin: 1416 End: 1520
Unusual Conditions: None				
Species	**Audit, ALM(1)(2)**	**Rotameter**	**Sampler, ALM(1)**	**%Dif.(3)**
TSP	17.1	40	16.0	-6.4
PM_{10}	19.2	40	21.0	9.4
$PM_{2.5}$	91	100, 100	88	-3.3

Sampler: 2-Meter Rack		Date: 09/27/05		Begin: 0930 End: 1005
Unusual Conditions: None				
Species	**Audit, ALM(1)(2)**	**Rotameter**	**Sampler, ALM(1)**	**%Dif.(3)**
$PM_{2.5}$	114	100, 160	112	-1.8

Sampler: 6-Meter Rack		Date: 09/27/05		Begin: 0930 End: 1005
Unusual Conditions: None				
Species	**Audit, ALM(1)(2)**	**Rotameter**	**Sampler, ALM(1)**	**%Dif.(3)**
$PM_{2.5}$	111	130, 130	105	-5.4

(1) Flow rates are presented in actual liters per minute (ALM)
(2) Audit standard for TSP and PM_{10}: Bios Model DC-1 HC, Serial No. H 810
(2)Audit standard for $PM_{2.5}$: American Co. dry gas meter, S/N 8426722
(3) Satisfactory criterion for difference between audit flow rate and sampler flow rate = ±10.0%