Clark County (Nevada)
Paved Road Dust Emission Studies in Support of Mobile Monitoring Technologies

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EXECUTIVE SUMMARY

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1. Background

a. Need for Alternative to AP-42 Methodology

The Las Vegas Valley in Clark County, Nevada, has been classified as a serious nonattainment area for the federal fine particulate matter (PM_{10}) National Ambient Air Quality Standards (NAAQS). The June 2001 PM_{10} State Implementation Plan (SIP) specifically addressed improvement of paved road dust emission characterization because of the importance of paved road dust as a major category in the PM_{10} emission inventory.

The SIP contained a research commitment to explore the feasibility of a more comprehensive sampling system using vehicle-based mobile monitoring for development of improved paved road emissions inventories. The intention was to overcome the limitations of the AP-42 methodology, which made it impractical to represent all of the classes and subclasses of roadways. The required road surface sampling is time-consuming and potentially hazardous because of the need to block traffic lanes. In addition there are serious issues related to the number of samples needed to represent spatial and temporal variations across roadway networks. It became clear that the challenges related to the successful maintenance of conformity made it imperative that an alternative approach to measuring and estimating paved road dust emissions be developed.

Beginning in 1999, Clark County undertook a series of field studies to investigate alternative ways of estimating PM_{10} emissions in the form of surface dust entrained from paved roads. A new vehicle-mounted mobile sampling technology was tested in comparison with the traditional AP-42 method and its associated road surface sampling. In addition, the plume flux profiling method, which was the basis for development of the AP-42 emission factor equation for public paved roads, was used to calibrate the mobile monitoring technology.

Two versions of the mobile monitoring technology were tested—TRAKER and SCAMPER. Both technologies involve on-board sampling of the dust plume generated by a test vehicle. Both use continuous PM_{10} particle monitors in conjunction with GPS systems, so that dust plume concentrations can be mapped on to the road system traveled by the test vehicle. The SCAMPER samples the plume in the wake of the test vehicle. The TRAKER I and II test vehicles sample the plumes from the front wheel wells of the respective vehicles. TRAKER II has a dilution system to provide for use on unpaved roads. All three units have samplers that monitor the PM_{10} concentration in front of the vehicle so that “background” PM_{10} can be subtracted.

Early in this program, it was decided that the test vehicles would travel at the normal traffic speeds (25 to 45 mph) on the selected paved roadway network. In addition, the weights of the TRAKER and SCAMPER test vehicles were closely matched and provided a good representation of the fleet average vehicle weight in the Las Vegas Valley.

In principle, two essential mathematical calculations are involved in the mobile monitoring technology: (1) conversion of the particle monitor reading (minus background) to the net PM_{10} concentration, and (2) conversion of the net PM_{10} concentration in the test vehicle plume to the equivalent PM_{10} emission factor for the test vehicle. Note that in this study, these two steps were combined so that the average particle monitor reading was converted directly to the equivalent PM_{10} emission factor.

b. Previous Related Studies (Phases I through III)

The field study reported in this document is Phase IV of a series of studies that began in 2004. The Phase I study entailed a two-day field effort utilizing a 107-mile sampling route. The purpose of the study was to determine the feasibility of vehicle-based mobile sampling system for use in Clark County to better characterize paved-road emissions and to develop real-time emissions of PM_{10} for emissions inventory use. The sampling route was designed to include worst-case silt-impacted roads and best-case clean roads in order to evaluate the detection limits of the two systems. A total of sixteen AP-42 silt samples were also collected on the sampling route. Phase I demonstrated the feasibility of using vehicle-based mobile sampling systems as an alternative to conventional AP-42 paved-road emissions estimating methods.

The Phase II study, which was completed in early 2005, was an expansion of the Phase I study. It entailed four days of sampling with the SCAMPER and TRAKER systems on a 103-mile travel route. The route included the five classes of roadways (local, collector, minor arterial, major arterial, and freeway) and four political jurisdictions in the Las Vegas Valley. The route passed through developing areas, older established neighborhoods, and newer planned communities that were completely built-out. The developing areas included a cross section of incomplete road infrastructure (e.g. unpaved road shoulders) and deposition sources such as vacant lots and construction activities. The built-out areas had completed road infrastructure, with few vacant lots, and little construction activity. The route also included a cross section of soil classifications based on Clark County's Particulate Emission Potential (PEP) soil classification system. The sampling route included ten historical AP-42 sampling sites and eleven new sites that had not previously been sampled using AP-42 methodology.

The Phase III study utilized only the SCAMPER system and the AP-42 methodology for sensitivity and variability analysis. The study occurred over seven consecutive days in late 2005 and utilized three sampling routes. Road infrastructure, adjacent land use (e.g. vacant land, residential, etc) and sources of deposition were comprehensively mapped prior to the study. The first sampling route (industrial route) was dominated by industrial haul roads with heavy silt loadings and was used to determine the precision of the SCAMPER unit. This route included local, collector and arterial roads. The second route (transitional route) was a 7.3-mile course in a transitional development area in the Las Vegas Valley that included a mix of commercial, residential, rural residential and vacant land. The third route (developed community route) consisted of a 12.6-mile course traversing a newly developed planned community and contained local, collector and arterial roads. In addition to providing baseline measurements for fully developed roadways with minimal silt deposition sources, this route was used to evaluate the sensitivity of the SCAMPER unit.

2. Phase IV Study

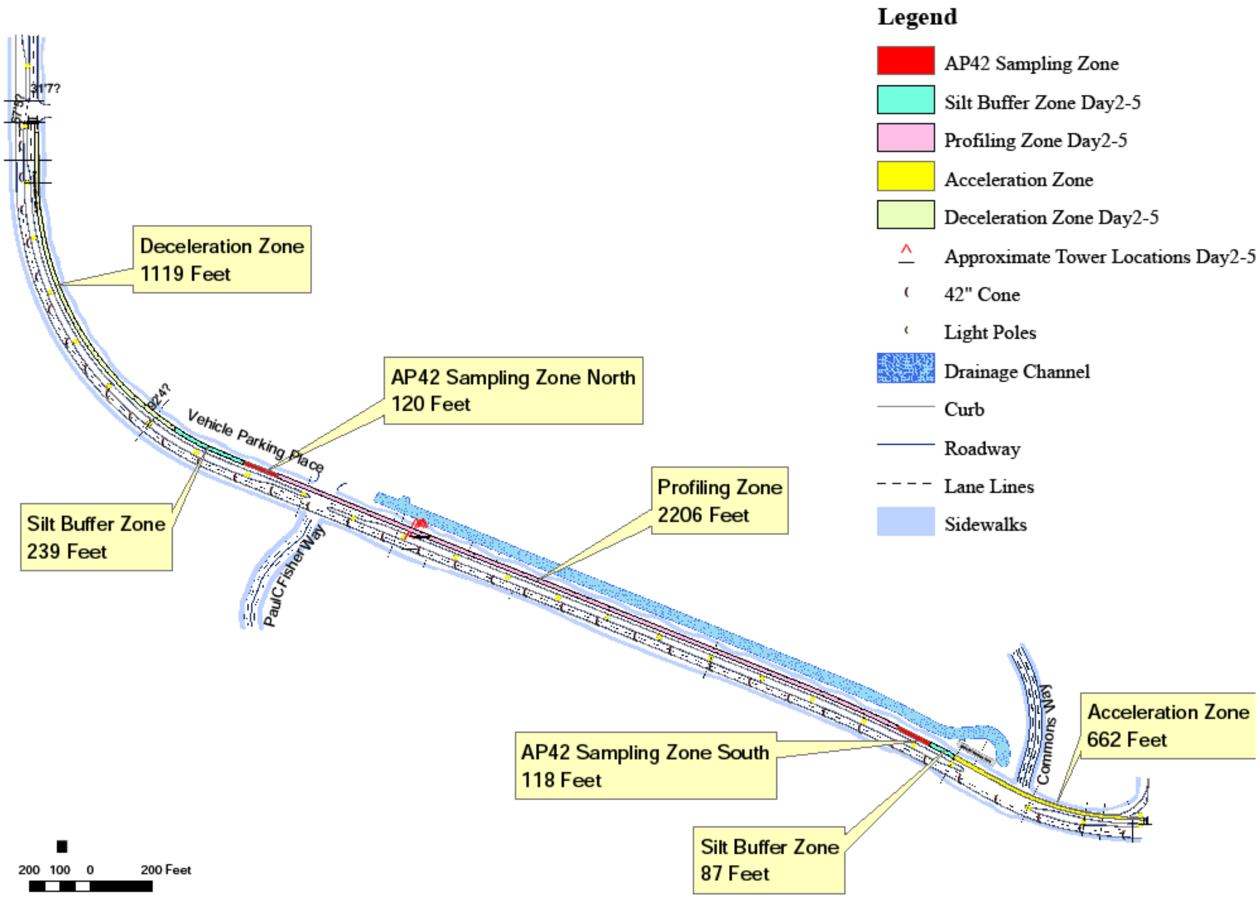
The Phase IV study was also directed to evaluating mobile monitoring technologies in comparison with the traditional AP-42 methodology, but in a controlled measurement environment that included restricted vehicle movement, controlled vehicle speeds and controlled road surface material loadings. This was accomplished by dedicating half of a divided roadway as the test course for the 5-day field study. The specific study objectives were as follows:

- Comparison of SCAMPER and TRAKER system measurements with emission measurements using a downwind flux tower.
- Determination of the relationship between roadway silt loading and SCAMPER and TRAKER measurements at several standard vehicle speeds (25, 35 and 45 mph).
- Comparison of SCAMPER and TRAKER measurements to AP-42 emission estimates.
- Characterization of road surface silt depletion rate as a function of the number of vehicle passes.
- Characterization of quantified emissions vs. quantified silt loading mass.
- Data assessment and review for recommendations on performance specifications for vehicle-mounted mobile sampling systems.

The test road consisted of two lanes of a four-lane divided highway, with a curbed median and roadsides (Veterans Memorial Boulevard) in Boulder City, Nevada. The test road segment was oriented southeast to northwest as shown in Figure 1. All of the normal road traffic was diverted to the southeast-bound lanes, allowing the two northwest-bound lanes and the stabilized median area to be utilized exclusively for the five-day study. This diversion provided for dedication of the test lanes to this project for the entire study period, so that only SCAMPER and TRAKER vehicles traveled the test lanes, except for the spreader and sweeper that applied and removed dirt from the travel course.

The test course consisted of an acceleration zone to reach the desired test vehicle speed, a silt zone (approximately 1/2 mile), followed by a deceleration zone. Except for the first two measurement sets, where test vehicles traversed the test course in both directions, a layer of silt was applied to the curbside lane (measuring on average 13’5” in width), and the test vehicles traveled over that outer lane in a northwest direction. In the course of a test series, the silt loading was measured at designated locations at both ends of the test road segment. At the end of a test set, the road was swept before the next silt layer was applied. Typically one sampling tower was located on the curbside adjacent to the test lane. It was anticipated that these controlled traffic and measurement parameters would enhance the quality of the tower flux measurements compared to previous paved road dust studies.

Figure 1-1. Layout of Test Course



Note: The silt zone, with total length 2770 feet, includes Silt Buffer Zones, AP42 Sampling Zones, and Profiling Zone.

3. Test Methods (Equipment, Operation, and Data Reduction)

Particle concentration measurements formed the basis for the mobile monitoring technologies as well as the roadside emission flux measurements. A continuously recording particle monitor (DustTrak Model 8520, TSI Inc., Shoreview MN) was the basic instrument used to log 1-sec PM_{10} readings in all cases. Because the DustTrak operates on a light-scattering principle, a collocated mass-based reference monitor was used to correct the DustTrak readings to equivalent PM_{10} mass-based concentrations, as described below.

a. Flux Tower Method

A “master” tower was erected downwind of the road (approximately 5 m from centerline of test vehicle travel path) and aligned perpendicular to road. The trailer-mounted, 9 m-high tower was instrumented with DustTraks at five heights above the ground (0.7, 2.1, 3.4, 6.4, and 9.8 m). At one of the heights (3.4 m), a DustTrak with a PM2.5 impactor inlet was collocated with the PM_{10} monitor. The master tower also included an EPA-approved reference PM_{10} monitor (TEOM Model 1400a, R&P) at a height of 2.3 m, to be used for conversion of PM_{10} measured with the tower-mounted monitors into mass-based PM_{10} concentrations. However, note that a different but comparable conversion factor from a laboratory chamber study was actually used in this study. A wind vane was mounted at the top of the tower, and cup anemometers were positioned on the tower to monitor wind speed as a function of height. All data from the PM samplers and meteorological instruments were telemetered and logged in 1-second intervals by a laptop located on the master tower.

b. AP-42 Method

As shown in Figure 1, two zones of the course, called "south" and "north," were designated for silt recovery as input to the AP-42 emission factor equation for public paved roads. The "near" end of the south AP-42 sampling zone was established 201.7 meters (662 feet) from the start of the course. This distance was selected so that the mobile monitoring vehicles could complete the acceleration portion of their pass before entering the south soil sampling zone. Both AP-42 sampling zones were approximately 36.6 meters (120 feet) long. The "far" end of the north AP-42 sampling zone was established about 500 feet from the end of the course, to allow for deceleration just before the gradual curve in the roadway.

Two different plot layouts were used during the empirical study to collect soil samples from the test course. An array of seven <u>full-size plots</u>, with 2.4 meter (8-foot) spacing between the plots was laid out at each zone of the driving course. A full size (3.3 meter long x 4.1 meter wide) plot was used to measure silt loading at the beginning and end of most of the test series. The 3.3 meter (10 foot) plot length was consistent with EPA recommendations. The 4.1 meter (13.5 foot) width was selected to recover soil from the edge of the asphalt (at the start of the concrete gutter) to the edge of the opposite edge of the test lane. For experiments evaluating the effects of vehicle passes on surface silt depletion, 0.61 meter (2 foot) wide "<u>Quickie-Strips</u>" were laid out in the zones between the full-size plots.

Canister vacuum cleaners with hard-floor inlets were used to recover applied soil from the roadway sites into pre-tared vacuum bags. Three soil recovery techniques were used during the study:

- Soil from one large heavily soiled plot would be recovered into one pre-tared vacuum bag.
- Soils from two lightly soiled large plots, sampled at the same time (before or after a particular vehicle pass) would be accumulated into one vacuum bag.
- Soil from a series of Quickie strips, sampled in sequence after a specific vehicle pass would be accumulated into one vacuum bag.

Road dust emission factors were then calculated for the silt loadings using the AP-42 emission factor equation:

$$E=k\ (sL/2)^{0.65}\ (W/3)^{1.5} - C$$

where E = particulate emission factor (having units matching the units of k)
k = base emission factor for particle size range and units of interest
sL = road surface silt loading (grams per square meter) (g/m2)

W = average weight (tons) of the vehicles traveling the road
C = emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear

A weight of 2.88 tons, based on the arithmetic average of the reported weights of the three mobile source vehicles (SCAMPER 2.5 tons, TRAKER I 3.4 tons, and TRAKER II 2.75 tons) was used to calculate the AP-42 emission factors from the silt loadings.

c. SCAMPER Technology

The SCAMPER determines PM emission rates from roads by measuring the PM_{10} concentrations in front of and in the wake of the test vehicle using DustTrak monitors. As a first approximation, the concentration difference (mg/m^3) is multiplied by the vehicle's frontal area (3.66 m^2) to obtain an emission factor in units of mg/m. The particle monitor for the vehicle wake is mounted on a small trailer with a flat bed, so that the vehicle wake was disturbed as little as possible. The inlet for the wake monitor, which is 10 ft behind the rear of the vehicle, allows sampling as isokinetically as possible over the full range of vehicle speeds. A GPS determines vehicle location and speed, and a PC collects 1-sec data from GPS and PM_{10} measuring devices.

d. TRAKER Technologies

TRAKER I is comprised of a van that is equipped with three exterior steel pipes acting as inlets for the onboard instruments. Two of the pipes are located behind the left and right front tires and are used to measure emissions from the tires. The third pipe is the inlet for background air and runs along the centerline of the van underneath the body and extends through the front bumper. The background measurement is used to correct the measurements behind the tires for fluctuating dust and exhaust emission contributions from other vehicles on the road. Separate DustTraks are connected to each of the left and right inlet lines as well as on the middle inlet line. A central computer collects all the data generated by the onboard monitors as well as GPS coordinates, and vehicle speed and acceleration with a 1-second frequency.

The TRAKER II inlet lines are configured so that on unpaved roads, where PM_{10} concentrations behind the front tires could exceed the particle monitor upper limit (150 mg/m^3), clean air can be mixed with air from the wheel well inlets in a controlled manner to achieve a desired amount of dilution. Instead of an onboard sampling plenum as in TRAKER I, a 10-cm diameter external pipe is used to channel/dilute inlet flow into a manifold with connections to particle monitors. The circular inlets used currently on TRAKER I are replaced by flattened manifolds on TRAKER II.

4. Study Design

The test conditions for the Phase IV study are summarized in Table l. Further explanation of these conditions is provided in the following paragraphs.

Table 1-1. Study Measurement Conditions

Set ID	Date	Approximate Time (local)	Activity	Vehicles used	Nominal speed (mph)	Total passes/passes per vehicle
1	9/11	11:55 - 13:15	Test: Baseline road conditions - No Sweep, No silt	All test vehicles	35	60/20
	9/11	13:35	Sweep	Street Sweeper	NA	NA
2	9/11	13:52 - 14:18	Test: After Sweeping, No silt applied	All test vehicles	35	30/10
	9/11	14:30	Silt applied to test road	Tractor/spreader	NA	NA
3	9/11	15:17 - 26:30	Test: After application of silt, 35 mph	All test vehicles	35	27/9
	9/11	17:00	Sweep	Street Sweeper	NA	NA
	9/12	9:15	Silt applied to test road	Tractor/spreader	NA	NA
4	9/12	10:15 - 11:00	Test: After application of silt, 45 mph	All test vehicles	45	30/10
	9/12	11:05	Sweep	Street Sweeper	NA	NA
	9/12	13:00	Silt applied to test road	Tractor/spreader	NA	NA
5	9/12	13:35 - 14:40	Test: After application of silt, 25 mph	All test vehicles	25	42/14
	9/12	15:00	Sweep	Street Sweeper	NA	NA
	9/13	9:00	Silt applied to test road	Tractor/spreader	NA	NA
6	9/13	9:40 - 10:25	Test: After application of silt, 45 mph	All test vehicles	45	30/10
	9/13	11:09	Sweep	Street Sweeper	NA	NA
	9/13	12:15	Silt applied to test road	Tractor/spreader	NA	NA
7	9/13	12:45 - 13:35	Test: After application of silt, 25 mph	All test vehicles	25	30/10
	9/13	14:00	Sweep	Street Sweeper	NA	NA
	9/13	14:45	Silt applied to test road	Tractor/spreader	NA	NA
8	9/13	15:20 - 16:15	Test: After application of silt, 45 mph	All test vehicles	45	36/12
	9/13	17:00	Sweep	Street Sweeper	NA	NA
	9/14	8:00	Silt applied to test road	Tractor/spreader	NA	NA
9	9/14	8:40 - 9:20	Test: Depletion of silt resulting from vehicle passes	SCAMPER Only	35	10/10
10	9/14	9:20 - 9:50	Test: Measure emissions prior to sweeping	All test vehicles	35	12/4
	9/14	10:05	Sweep	Street Sweeper	NA	NA
11	9/14	10:25 - 11:20	Test: Measure emissions after sweeping	All test vehicles	35	30/10
	9/14	11:30	Sweep	Street Sweeper	NA	NA
	9/14	12:30	Silt applied to test road	Tractor/spreader	NA	NA
12	9/14	13:10 - 14:05	Test: Speed tests	All test vehicles	25 - 45	27/9
	9/14	14:30	Sweep	Street Sweeper	NA	NA
	9/15	8:00	Silt applied to test road	Tractor/spreader	NA	NA
13	9/15	8:30 - 11:15	Test: Speed tests	All test vehicles	25 - 45	84/28
	9/15	11:30	Sweep	Street Sweeper	NA	NA

a. Passes, Runs, and Sets

Phase IV consisted of a total of 13 test sets, each encompassing different experimental conditions. Most sets consisted of approximately 30 vehicle passes, and each pass was identified separately by the type of mobile sampling technology used and the time it passed by the flux tower. A run typically consisted of three successive passes, one by each mobile sampling technology.

The first test set was performed prior to any sweeping or application of soil/silt to the roads, and is representative of the natural condition of the road. The second set was performed after the road had been cleaned by a street sweeper. Sets 3-9 consisted of applying a controlled amount of soil/silt to the road prior to the first pass. During these sets, the road was swept before each soil/silt application. There was no soil/silt application for Sets 10 and 11, but the road was still swept between the sets. Vehicle speed was held constant at 25, 35, or 45 mph for Sets 1-11. Prior to Sets 12 and 13, soil/silt was applied to the road and the speeds of the vehicles varied in cycles from 25 to 35 to 45 mph and back from 45 to 35 to 25 mph. Each speed was held for one run (one pass of each mobile technology).

During each pass within a set, emissions on the master tower were recorded along with the signal of the particular mobile technology. In most cases, silt samples were taken for AP-42 calculation at the beginning and end of each set.

b. Silt loadings

An area soil was selected for application to the test course with a measured silt fraction (14%) approximating the 65th percentile of 35 sieved road dust silt samples taken from all three roadway categories in calendar years 2005-2006. The soil was passed though a 1.18 mm sieve opening during collection to remove gravel and vegetative matter. A fertilizer drop spreader was used for soil application with a constant pull speed of 10 mph. Prior to the first application of soil, a group of preliminary measurements (sets 1 and 2) by the mobile PM_{10} sampling vehicles were used to characterize the PM_{10} emission rates of the natural road soil before and after the road was swept. The silt loading values along with other study design details are found in Table 2.

c. Quality Assurance

Quality assurance focused on flow and concentration measurement within the operating ranges of the DustTrak and reference monitors, filter and bag handling and weighing for mass-based sampling, and suitability of wind conditions for each plume passing the flux tower.

Table 1-2 Silt Loadings and Other Test Conditions

Date	Set #	Experiment Name	Start Pass_ID	End Pass_ID	Nominal Drive Speed (mph)	Applied Soil Loading (gram/m^2)	Avg. Recovered Silt Loading, (gram/m^2)
9/11/06	1	Pre-Sweep	1	60	35	N/A	0.17
9/11/06	2	Post-Sweep	63	92	35	N/A	N/A
9/11/06	3	Apply silt #1	93	139	35	6.16	0.75
9/12/06	4	Apply silt #2	140	169	45	17.17	2.48
9/12/06	5	Apply silt #3	170	211	25	16.58	3.17
9/13/06	6	Apply silt #4	212	241	45	4.99	0.88
9/13/06	7	Apply silt #5	243	272	25	4.70	0.74
9/13/06	8	Apply silt #6	273	308	45	7.63	1.14
9/14/06	9	Apply silt #7 - Depletion, SCAMPER only	309	318	35	7.78	0.80
9/14/06	10	Continuation of silt #7- Depletion, all vehicles	319	331	35	7.78	0.80
9/14/06	11	Post-sweep	334	364	35	N/A	
9/14/06	12	Apply silt #8 - strong winds	365	391	Repeat 25,35,45, 45,35,25 cycle twice	17.61	2.55
9/15/06	13	Apply silt #9 - strong winds	392	476	Repeat 25,35,45, 45,35,25 cycle 4 1/2 times	28.47	2.31

Two factors were used to determine if a specific tower flux measurement associated with an individual vehicle pass was valid. First, the one-second wind direction over the duration of the three intervals associated with a mobile monitor pass (pre-peak background, peak, and post-peak background) was examined. In cases where the average wind direction over the three intervals was within 45 degrees of the perpendicular line drawn between the tower and the road segment and the wind speed was relatively constant (i.e. holding at > 1 m/s from the same general direction), the wind direction was considered valid. If the wind direction was always less than 75 degrees from the perpendicular, the wind speed was relatively constant, and fluctuations in wind direction did not exceed 30 degrees, the wind direction was considered valid. In all other cases, wind conditions were considered to invalidate the horizontal flux measurement.

The second factor in determining the validity of a specific tower measurement was the noise level of the baseline PM_{10} concentration. During periods of high wind, non-traffic dust clouds often passed by the flux tower (especially true on the last two days of testing). These high and spurious concentrations of PM_{10} prevented subtraction of a baseline value from the plume impact concentration. In other cases, the passage of a large vehicle on the south side of Veterans Memorial Highway would sometimes result in a temporary spurious baseline reading. The entire time series of data from the flux tower was examined to flag periods when the baseline was too noisy for a measurement. Those data were considered invalid.

5. Data Analysis

a. Data Averaging

To compare PM_{10} tower flux measurements with AP-42 silt methodology and mobile system measurements, data were averaged by measurement set. For each set all tower flux measurements were averaged together regardless of the test vehicle. Thus, tower flux measurements represent average fluxes for all vehicles. This was to ensure that all methods examined would be calibrated (or compared in the case of AP-42) against the same standard and that results from future measurements can be compared using a common basis. A minimum criterion of 10 valid vehicle passes was applied to the tower flux average value.

DRI combined the following data sets (using Vehicle Pass_ID as a common variable) into a master Excel database that was used for joint data analysis:

- UNLV AP-42 emission factor data, averaged north and south for each pass,
- Tower mass emission rate data, averaged for each pass,
- SCAMPER, TRAKER I and TRAKER II mobile technologies data, averaged for each pass.

The Excel® database (containing date, time, vehicle Pass_ID, vehicle speed, silt loadings and silt loading uncertainties) and AP-42 emission factors and emission factor uncertainties were transmitted to all cooperating agencies for data analysis.

The TRAKER signal was averaged over the full test route, rather than only using values obtained near the master flux tower. It was found that there is a good correlation ($R^2 = 0.82$) between the pass-averaged TRAKER I signal and the TRAKER I signal averaged over data points that correspond to measurements within 50 m of the master tower. The SCAMPER data were collected at 1-sec intervals, and the front DustTrak value was subtracted from the rear value to yield a net value in mg/m^3. Pass averages were calculated from the net values calculated at 1-sec intervals. The background correction was generally small, and negative emission rates were not encountered.

b. Conversion of Particle-Monitor Readings to PM10 Concentrations

Several cross-comparisons were performed to determine the ratio between the DustTrak reading and the PM_{10} mass-based concentration measured by a collocated reference sampler. First, the DustTrak located at 2.1 m on the master flux tower was compared to the TEOM measurements at 2.3 m, also located on the master tower. The correlation between the DustTrak and TEOM on the master tower was quite noisy, but showed that DustTrak values would have to be multiplied by a factor of 2.8 ± 0.6 to obtain mass-equivalent PM_{10}.

Second, controlled laboratory tests were used to more accurately obtain a relationship between the DustTrak measurements and mass-based measurements. For this purpose, a well-mixed chamber was constructed, within which the same silt material that was used in the field study was injected and suspended. Measurements of the PM_{10} inside the chamber were made with the DustTrak as well as filter samples. These tests generated a DustTrak correction multiplier of 2.4, which was chosen for use in this program. The in-lab measurements resulted in a higher correlation, due to the fact that in the field the DustTrak and TEOM were only nominally collocated, whereas in the lab the two instruments sampled a well mixed volume of air.

In prior studies with the SCAMPER, the response of the rear DustTrak was compared to mass determined by a collocated filter sampler on the trailer of the vehicle. The average response factor based on a linear regression was approximately 3. Given the scatter of the data, this is in general agreement with the correction factor of 2.4 cited above.

It should be noted that in this study the factor of 2.4 was used only to correct tower sampler readings to mass-based PM_{10} concentrations.

6. Results and Conclusions

a. Calibration Factors

Calibration factors were developed for each mobile monitoring technology. Each multiplicative factor represented the ratio of the PM_{10} emission factor from the flux tower to the raw mobile monitor reading (mg/m^3). For each mobile monitoring technology, a single calibration factor was developed for each test set, using average tower flux values and average mobile monitor readings. Then regression analysis of the individual factors was used to calculate an average calibration factor for each technology. These factors are presented as coefficients in the following equations for the PM_{10} emission factor (EF):

TRAKER I	$EF = 0.54*TI$	[correlation of 0.57]
TRAKER II	$EF = 0.92*TII$	[correlation of 0.75]
SCAMPER	$EF = 20*SC$	[correlation of 0.47]

Each coefficient is used as a multiplier to convert the mobile monitor (DustTrak) reading (mg/m^3) to the equivalent PM_{10} emission factor (g/vkt).

b. Initial Emission Decay

In the context of the present study, the test data indicate that dust emissions occur under a different regime during the first 9 vehicle passes than in ensuing passes. Since for a paved road, the volume of vehicles is generally much higher than 9 per day, the first 9 passes after silt material application probably do not reflect the regime under which real-world dust emissions occur. It is more likely that the latter passes (greater than 9) more accurately reflect the slower, steadier emissions of PM_{10} road dust that occurs on paved roads.

The TRAKER I signal decay with vehicle passes matches AP-42 silt loading decay in Sets 5, 8, and 10 for cases of constant vehicle speed. However, TRAKER I measured emissions also showed, in sets 12 and 13, clear vehicle travel speed dependence that is not accounted for in the current AP-42 emission factor equation. The rising and falling TRAKER I signals in Sets 12 and 13 are a result of systematically varying vehicle speeds first rising from 25 to 35 to 45 mph, then declining from 45 to 35 to 25 mph. Silt loadings in Set 12 declined throughout the experiment, even though TRAKER I emissions increased with increasing vehicle speed. Silt loadings in Set 13 declined rapidly to a steady state value, while TRAKER I emissions fluctuated regularly with rising and falling vehicle speed. TRAKER II and SCAMPER signals showed similar behavior.

c. MM Technologies vs. AP-42 Methodology

Two conclusions can be made from the test results obtained in this study, when comparing mobile monitoring technologies with the AP-42 methodology:

- The calibrated mobile methods measured emission factors that were about 1.5 times higher than found with the AP-42 methodology when higher silt loadings were applied to the test road.
- The mobile methods tracked each other quite well under most conditions.

The first conclusion appears to reflect a different silt mobilization process, which occurred as a result of silt being distributed on top the embedded road surface aggregates and hence being more easily entrained by vehicle mechanical and aerodynamic shear. In contrast the aged silt found on most roads is more likely to be embedded between the road surface aggregates.

Throughout this field study, the implementation advantages of mobile monitoring technologies were evident. The mobile monitoring technologies were found to provide for much easier representation of spatially distributed roadway emission characteristics, while eliminating the need to divert traffic. The one limiting factor for mobile monitoring was high winds which made the monitored plume concentration difficult to differentiate from higher than normal background levels.

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1.0 INTRODUCTION

The Las Vegas Valley in Clark County, Nevada, is classified as a serious nonattainment area for federal fine particulate matter (PM_{10}) National Ambient Air Quality Standards (NAAQS). Clark County submitted a PM_{10} State Implementation Plan (SIP) for this nonattainment area in June of 2001. As part of the SIP development, Clark County contracted with a consultant to collect 24 silt samples representative of Clark County roadways for estimating PM_{10} paved road emissions. The silt measurements were significantly higher than EPA default values, and public works officials from four agencies and other stakeholders asserted that the Clark County SIP overestimated PM_{10} emissions from paved roadways. Clark County committed to conducting quarterly silt sampling through the end of 2006 as part of the now federally approved PM_{10} SIP. Sampling is ongoing and the current AP-42 data base includes sampling from the spring of 2000 through the spring of 2006. The PM_{10} SIP also contained a research commitment to explore the feasibility of vehicle-based mobile sampling systems for development of improved paved road emissions inventories.

During this timeframe, Clark County has seen substantially improved air quality for the PM_{10} pollutant, particularly from the year 2004 forward. Visually, it also appears that Las Vegas Valley roads have become cleaner, in part due to tightened controls on construction site track-out and an increased emphasis on enforcement, implemented in early 2003. However, statistical analysis performed by UNLV under contract has generally not shown statistically significant declines in paved road emission factors during this timeframe using silt sample data and AP-42 emission estimation methods. These results have reinforced Clark County's belief that the paved road emissions inventory developed using AP-42 methods for the PM_{10} SIP overestimates actual emissions. In addition, silt measurements are time consuming, expensive, and frequently require the alteration of roadway traffic patterns and increased traffic congestion while samples are being procured.

Initial work utilizing vehicle-based mobile sampling systems in Clark County occurred in 1999 as part of PM_{10} SIP development. The test results showed even higher emission rates than corresponding AP-42 calculations and were not considered realistic. In addition, the need to complete an approvable PM_{10} SIP was urgent and EPA approval of this new method was very unlikely based on work completed at that time. Phase I of the current research effort was initiated in 2004 and Phase II was completed in early 2005. Fieldwork for Phase III occurred in late 2005. Objectives for Phase IV are described below.

1.1 Study Objectives

1. Evaluate precision of all measurement methods under controlled conditions: Measurement methods include measurements from the tower sampling array, SCAMPER measurements, TRAKER measurements, and road silt measurements using AP-42 sampling methodology. Additional ancillary measurements include weights of silt material applied to test area, wind speed data, wind direction data, and relative humidity data.

2 Evaluate validity of original AP-42 emissions factor estimates: Compare measured tower emissions to AP-42 emissions calculated from silt loadings using the AP-42 equation.

3 Calibrate mobile technologies systems to the tower emissions factors: Comparison of SCAMPER and TRAKER system measurements with external sampling array measurements in a controlled measurement environment, with defined vehicle movement, controlled speeds, and controlled road material loadings.

4 Compare mobile technologies emissions factors to predicted AP-42 emissions factors: Determine relationships between roadway silt loading and measured SCAMPER and TRAKER particulate emissions under controlled conditions (standard vehicle speeds and weight). Compare SCAMPER/TRAKER measurements to AP-42 emission estimates under controlled conditions.

5 Compare mobile technologies measurements: Comparison of SCAMPER to TRAKER measurements estimates under controlled measurement conditions, including defined vehicle movement, controlled speeds, and controlled road material loadings.

6 Data assessment and review for recommendations on performance specifications: Assess data for accuracy and precision of vehicle-mounted mobile sampling systems and compare with other measurement methods. Prepare recommendations for the utilization of vehicle-mounted mobile sampling systems into AP-42.

7 Characterization of silt depletion rate: Assess by number of vehicle passes with defined vehicle speeds and weight.

1.2 Study Design Overview

The five-day study included testing two vehicle-mounted mobile sampling systems, SCAMPER and TRAKER, under controlled road conditions. One SCAMPER and two TRAKER systems were utilized in this study. Comparative external measurements included horizontal PM_{10} flux measurements with multiple samplers on a nine-meter tower and AP-42 silt sampling. Study objectives included a comparison of tower emissions measurements to SCAMPER/TRAKER measurements, a comparison of SCAMPER to TRAKER measurements, and AP-42 silt measurements/emission estimates under controlled conditions.

The sampling area consisted of two lanes of a four-lane divided highway with curbed median and curbed roadsides (see **Figure 3-1**). All road traffic was diverted to the southeast-bound lanes, allowing the two northwest-bound lanes and the stabilized median area to be utilized exclusively for the five-day study. This diversion allowed the research team to limit vehicle passes between the external tower samplers to SCAMPER and TRAKER vehicles, with the tower located either on the median between the test area and adjacent traffic or on the sidewalk on the test side of the road. It was anticipated that these controlled traffic and measurement parameters would enhance the quality of the horizontal PM_{10} flux measurements compared to previous paved road dust studies.

Controlled road silt loading conditions were created through the application of known quantities of material onto the measurement section of the test area. The applied material approximated the sand and silt/clay percentages historically sampled on paved roads in the Las Vegas Valley. The test area was of sufficient length to allow for measurement at constant speeds of up to 45 miles per hour.

2.0 BACKGROUND

2.1 EPA AP-42 Development and Limitations

The United States Environmental Protection Agency (EPA) published a document entitled Compilation of Air Pollutant Emission Factors (AP-42) beginning in 1972. Since AP-42s inception as a tool for regulators, permit writers, and environmental planners, many have used this tool to account for emissions of air pollutants from a variety of sources in the human environment. EPA periodically reviews and updates the emission factors available in AP-42 to meet the needs of state and local air pollution control programs and industry. It wasn't until the late 70's that EPA, and others started looking at emissions from paved roads. Prior to this time, much of the work with respect to roadways was focused on unpaved roads. Prior to the March 1993 research findings[1], AP-42 contained two sections concerning paved road fugitive emissions. One of the early attempts to characterize paved road dust was addressed by EPA in 1983 with the inclusion of a Section 11.2.6 Industrial Paved Roads, and was slightly modified in 1988. Section 11.2.5, Urban Paved Roads, was first drafted in 1984 using the test results from public paved roads and was included in the AP-42, 4th Edition documentation in 1985. The emission factors included in Sections 11.2.5 and 11.2.6 were never quality rated "A" through "E." The updates proposed with the March 1993 report assumed there were no distinctions between public and industrial roads or between controlled and non-controlled test. These assumptions evolved into a single emission factor equation for all paved roads.

In July 1993, the AP-42 Section 13.2.1 (Paved Roads) was published to help better characterize the paved road dust source. The quantity of dust emissions from vehicle traffic on a paved road could be estimated using the following empirical expression:

$$E=k\,(sL/2)^{0.65}\,(W/3)^{1.5} \qquad \text{Equation 1.1}$$

where E = particulate emission factor (having units matching the units of k)
k = base emission factor for particle size range and units of interest
sL = road surface silt loading (grams per square meter) (g/m2)
W = average weight (tons) of the vehicles traveling the road

This equation was slightly modified in 2004 to account for vehicle exhaust, tire and brake wear. In the most recent version the quantity of particulate emissions from re-suspension of loose material on the road surface due to vehicle travel on a dry paved road is

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[1] U.S. Environmental Protection Agency, Emission Factor Documentation for AP-42, EPA Contract No. 68-D0-0123, MRI Project No. 9712-44 dated March 8, 1993.

estimated by using the following empirical expression.

$$E=k\ (sL/2)^{0.65}\ (W/3)^{1.5} - C^{5} \qquad \text{Equation 1.2}$$

where E = particulate emission factor (having units matching the units of k)
K = base emission factor for particle size range and units of interest
sL = road surface silt loading (grams per square meter) (g/m2)
W = average weight (tons) of the vehicles traveling the road
C = emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear

The AP-42 equation variable for weight of vehicle is defined as the average weight of all vehicles traveling the road. EPA did not intend that separate weights of vehicles be used to calculate a separate emission factor for each vehicle weight class. Instead, only one emission factor is calculated to represent the "fleet" average weight of all vehicles traveling the road or road network. The particle size multiplier (k) above varies with aerodynamic size range. The emissions factors for the exhaust, brake wear and tire wear are for a 1980's vehicle fleet (C), as calculated by EPA's MOBILE6.2 model.

The AP-42 paved road emissions equation is an arithmetic equation based on 65 tests conducted in the early 1990s. The test included measurements of vehicles moving at speeds of 10 to 55 miles per hour. The equation is intended for estimating emissions from free flowing traffic and is not intended to estimate emissions for stop and go traffic. Where road specific silt loading factors are utilized, the EPA assigns a quality rating of "A" provided the silt loadings mean vehicle weight and vehicle speeds fall within the following parameters:

Silt loading:	0.02 - 400 g/m^2 [0.03 - 570 grains/square foot (ft^2)]
Mean vehicle weight:	2.0 - 42 tons
Mean vehicle speed:	6 - 88 kilometers per hour (kph) [10 –55 miles per hour (mph)]

Where the EPA recommended default silt loadings are used in place of locally measured silt loadings, the quality rating is reduced by one level (e.g. "B"). The EPA provides default values for High ADT and Low ADT roads. Each of these two ADT classes has default silt loading for normal conditions and worst-case conditions.

The assumptions, limitations, and silt loading data collection requirements needed to utilize the equation considerably diminish the accuracy of emissions inventories for paved road emissions. Urban areas, where a majority of vehicle travel occurs in most airsheds, typically do not have free flowing traffic. Vehicle speeds have been shown to exert substantial influence on road dust emission rates, but the equation lumps all speeds from 10 to 55 mph into one emissions rate. Speeds above 55 mph, which may comprise a significant component of the vehicles miles traveled in an airshed; are not accounted for at all, introducing additional error into the emissions estimates.

The determination of correct silt loading values for each class of roadway and subclass of roadway is the most serious limitation of the AP-42 methodological approach. Road silt sampling is expensive, time consuming, and dangerous. As a result, only a few silt samples can be collected in each sampling quarter. Each sampling point is therefore used to represent hundreds if not thousands of miles of roadways. This limitation prevents emission inventory developers from obtaining a statistically valid number of silt samples for the roadways represented. Moreover, because of traffic congestion and safety concerns, department of transportation officials may not allow any sampling on some roadway classes such as freeways and major arterials. As a result, the silt loading data is always suspect for any paved road dust emissions estimate.

The inherent limitation on the feasible amount of silt sampling makes it impossible to accurately estimate future emissions from projected growth in vehicle miles traveled. This arises because sufficient silt loading data is not available to develop separate emissions rates for built-out areas and developing areas. Therefore, emissions for all future increases in vehicle miles traveled must be estimated using current emissions rates. This straight-line projection for future paved road dust emissions is at variance with observed real world conditions and can doom any transportation conformity finding for an airshed experiencing substantial growth.

In summary, the limitations of the arithmetically derived AP-42 paved road dust emissions equation combined with the infeasibility of collecting sufficient silt loading data to accurately represent all classes and subclasses of roadways make all current paved road dust emissions inventories highly suspect. The increased traffic congestion and personal safety issues associated with developing better silt loading data further reduce the utility of the current road dust emission estimating methodology. Finally, the challenges related to the successful maintenance of conformity make it imperative that an alternative approach to measuring and estimating paved road dust emissions be developed.

2.2 Clark County Background with AP-42

The Las Vegas Valley in Clark County, Nevada, is classified as serious nonattainment for federal fine particulate matter (PM_{10}) National Ambient Air Quality Standards (NAAQS). Clark County submitted a PM_{10} State Implementation Plan (SIP) for this nonattainment area in June of 2001. As part of the SIP development, Clark County contracted with a consultant to collect 24 silt samples representative of Clark County roadways for estimating PM_{10} paved road emissions. The silt measurements were significantly higher than EPA default values, and public works officials from four agencies and other stakeholders asserted that the Clark County SIP overestimated PM_{10} emissions from paved roadways. Clark County committed to conducting quarterly silt sampling through the end of 2006 as part of the now federally approved PM_{10} SIP. Sampling is ongoing and the current data base includes sampling from the spring of 2000 through the spring of 2006. The PM_{10} SIP also contained a research commitment to explore the feasibility of vehicle-based mobile sampling systems for development of improved paved road emissions inventories.

During this timeframe, Clark County has seen substantially improved air quality for the PM_{10} pollutant, particularly from the year 2004 forward. Visually, it also appears that Las Vegas Valley roads have become cleaner, in part due to tightened controls on construction site track-out and an increased emphasis on enforcement, implemented in early 2003. However, statistical analysis performed by UNLV under contract has generally not shown statistically significant declines in paved road emission factors during the 1999 through 2006 timeframe using silt sample data and AP-42 emission estimation methods. These results have reinforced Clark County's belief that the paved road emissions inventory developed using AP-42 methods for the PM_{10} SIP overestimates actual emissions. In addition, silt measurements are time consuming, expensive, and frequently require the alteration of roadway traffic patterns while samples are being procured.

Initial work utilizing vehicle-based mobile sampling systems in Clark County occurred in 1999 as part of PM_{10} SIP development. The test results showed even higher emission rates than corresponding AP-42 calculations and were not considered realistic. In addition, the need to complete an approvable PM_{10} SIP was urgent and EPA approval of this new method was very unlikely based on work completed at that time. Clark County DAQEM submitted the SIP using the current AP-42 methodology, and initiated a research effort to develop better methods to characterize paved road PM_{10} emissions. Phase I of the current research effort was initiated in 2004 and Phase II was completed in early 2005. Fieldwork for Phase III occurred in late 2005 with augmentation work occurring in early 2006.

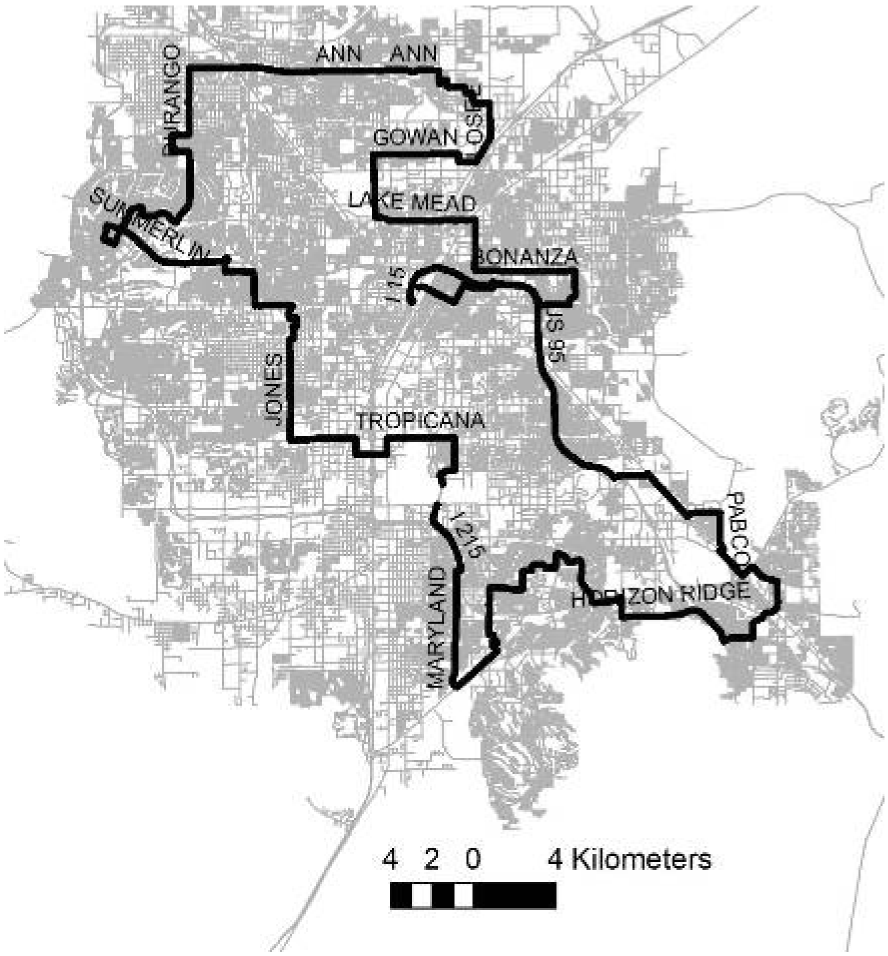
2.3 Paved Road Phase I-Phase III

The Phase I study entailed a two-day field study utilizing a 107-mile sampling route. The purpose of the study was to determine the feasibility of vehicle-based mobile sampling system for use in Clark County to better characterize paved-road emissions and to develop real-time emissions of PM_{10} for emissions inventory use. The sampling route was designed to include worst-case silt-impacted roads and best-case clean roads in order to evaluate the detection limits of the two systems. The route was further designed to include all political jurisdictions in the Las Vegas Valley. Several deviations from the original sampling route were required due to road closures resulting from road construction. An effort was made to note road infrastructure conditions and deposition sources during sampling using notepads and "wrist watch time." A total of sixteen AP-42 silt samples were also collected on the sampling route. Phase I demonstrated the feasibility of using vehicle-based mobile sampling systems as an alternative to conventional AP-42 paved-road emissions estimating methods.

The Phase II study entailed four days of sampling on a 103-mile sampling route. The Phase II sampling route was designed to include a number of parameters. The route included the five classes of roadways (local, collector, minor arterial, major arterial, and freeway) and four political jurisdictions in the Las Vegas Valley. Consideration was given to development patterns in the Las Vegas Valley and the final sampling route included developing areas, older established neighborhoods, and newer planned communities that were completely built-out. The developing areas included a cross section of incomplete road infrastructure (e.g. unpaved road shoulders) and deposition sources such as vacant lots and construction activities. The built-out areas included completed road infrastructure, with few vacant lots, and little construction activity. The final route also included a cross section of soil classifications based on Clark

County's Particulate Emission Potential (PEP) soil classification system[2]. The sampling route included ten historical AP-42 sampling sites and eleven new sites that had not previously been sampled using AP-42 methodology. Relative humidity was measured during sampling at each AP-42 site. Specific road conditions and sources were not mapped or recorded during the study. The study was delayed for two weeks due to rain. The sampling route is shown in **Figure 2-1**. Staff from Maricopa County, U.S. EPA Region 9 and U.S. EPA observed the field study. Limited notes on road infrastructure and silt deposition sources were made during development of the sampling route.

Figure 2-1. Map of Clark County 2/14/05 – 2/17/05 sampling route.



The Phase III study utilized only the SCAMPER and AP-42 emissions estimates. This study focused on development of specific emission factors for specific conditions and to assess measurement variability. A comparison of SCAMPER data to AP-42 emissions estimates was a second component of this study. To accomplish these objectives, the study occurred over seven consecutive days and utilized three sampling routes. Road infrastructure, adjacent land use (e.g.

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[2] Geotechnical and Environmental Services, Inc., *Presentation of Final Versions of Deliverables for Re-Evaluating and Updating the Particulate Emission Potential Map and Soil Classification for Dust Mitigation Best Management Practices Manual for Clark County,* dated September 26, 2003.

vacant land, residential, etc) and sources of deposition were comprehensively mapped prior to the study. In order to better evaluate site conditions during the study, a video camera was mounted externally on the driver's side of the vehicle. The video camera was linked to the SCAMPER GPS clock and camera sound was wired to a microphone located inside the vehicle to permit the operators to record comments and observations while operating the system.

The first sampling route (industrial route) was dominated by industrial haul roads with heavy silt loadings and was used to determine the precision of the SCAMPER unit. This route included local, collector and arterial roads. This route was sampled for most of day one of the study. The second route (transitional route) was a 7.3-mile track in a transitional area in the Las Vegas Valley. Development in the area is a mix of commercial, residential, rural residential and vacant land. Paved roads range from fully improved with sidewalks, curbs and gutters to unimproved with unpaved shoulders on both sides. Sources of deposition included road construction, residential construction, vacant land used for storing fill soil, and vacant land with no active use. The area also has some of the highest PEP (Particulate Emission Potential) soils in the Las Vegas Valley. The transitional sampling area route was sampled for four consecutive days, including the weekend. This allowed a comparison of weekday and weekend paved road emission rates. The third route (developed community route) consisted of a 12.6-mile track traversing a newly developed planned community and contained local, collector and arterial roads. This route contained fully developed road infrastructure that was not impacted by any observable sources of silt deposition. The route included local, collector, and arterial streets, all of which contained very light silt loadings. In addition to providing baseline measurements for fully developed roadways with minimal silt deposition sources, this route was used to evaluate the sensitivity of the SCAMPER unit. Measurements were taken on this route for two full days. Relative humidity was measured during sampling at each AP-42 site and at a nearby DAQEM monitoring site. The study was coordinated with the cities of Las Vegas and North Las Vegas to insure that none of the streets were swept within three days prior to sampling.

3.0 METHODOLOGY

3.1 Experimental Design

3.1.1 Route Selection

Based on experience with previous studies and the sampling characteristics of the SCAMPER and TRAKER systems, DAQEM developed the following criteria selection of a study site:

1. The micro scale prevailing wind direction must be roughly perpendicular to the road direction at the study site.

2. The study site cannot have trees, buildings, or other obstructions in close proximity to the roadway.

3. The study site must not have significantly elevated topography in close proximately to the roadway on either side.

4. The study site must have a four-lane road divided by a median and the traffic conditions must make it feasible to block off two of the lanes on one side of the median during the study.

5. The study site must be located where there are no significant sources of PM_{10} that may cause elevated PM_{10} concentrations at the site during the study.

6. The study site must have an uninterrupted travel distance of at least ¾ of a mile. Meteorological data from various sources was consulted to establish the road directional parameters for candidate sites. The requirements for no wind obstructions and particulate sources generally limited candidate sites to somewhat rural areas, whereas a majority of the roads in these areas did not meet the four lane and median separation criteria. Where all road and wind direction criteria were met, traffic volumes generally precluded blocking two travel lanes. After evaluating all available sites in Clark County, the Veterans Memorial Highway site in the City of Boulder City, Nevada, was the only site found that met all of the study criteria.

The study was conducted in the City of Boulder City, Nevada, on Veterans Memorial Highway, immediately west of Buchanan Boulevard. The sampling area consisted of two lanes of a four-lane divided highway with curbed median and curbed roadsides. Details are shown in the study plot plans and are also described below:

1. During the five study days, all road traffic was diverted to the southeast lanes, allowing the two northwest lanes and the stabilized curbed median area to be utilized exclusively for the five-day study. This allowed us to limit vehicle passes next to the external tower sampler to SCAMPER and TRAKER vehicles. These controlled traffic and measurement parameters enhanced the quality of the external source emissions measurements compared to previous paved road dust studies.

2. The tower sampling array was located either on the median or on the sidewalk areas and was moved to achieve optimal orientation with the prevailing winds and sampling lane. Relocation of the tower position was logged throughout the study.

As shown in **Figure 3-1**, the course ran in a northwesterly direction approximately 4551’ from the intersection of Buchanan and Veterans Memorial Hwy in the northwest-bound travel lanes. The 4551’ course was divided into sections for testing purposes. The sections are described as follows:

Entire Length of Study Area: 4551’

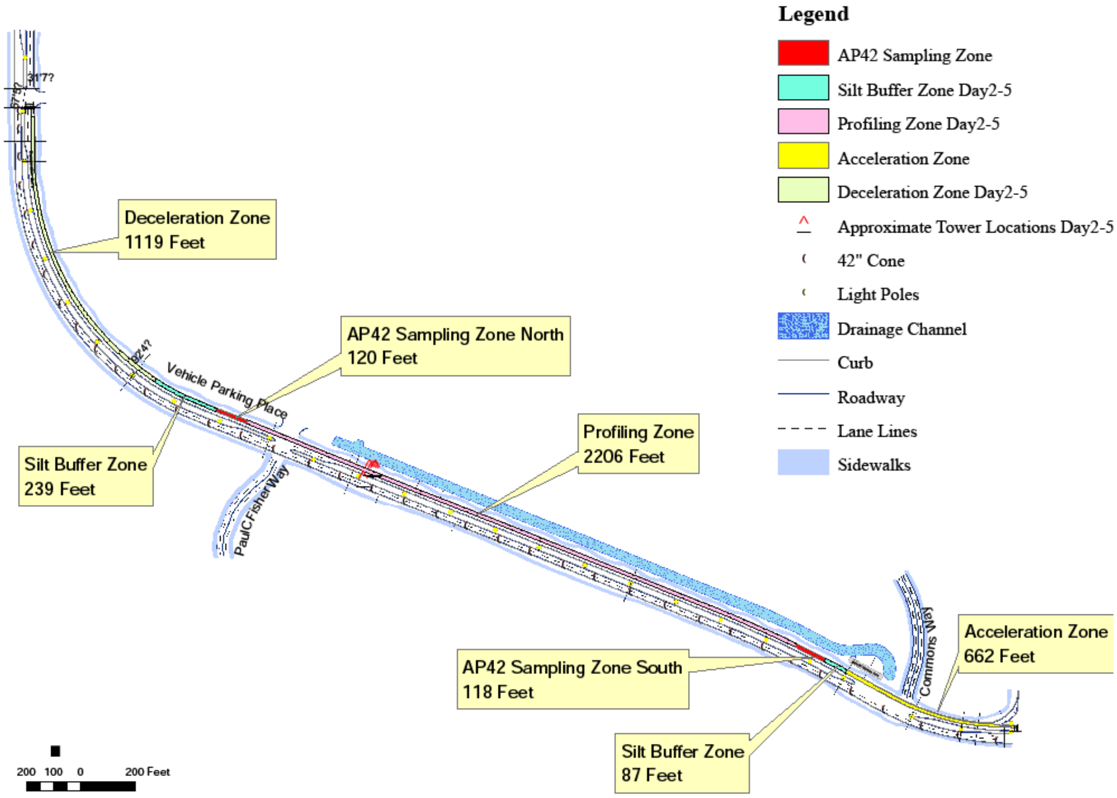
Acceleration Zone (Southern End of Course): 662’

Deceleration Zone (Northern End of Course): 1119’

Profiling Zone/Sampling Zone: 2206’

AP-42 Sampling Zones: 118'(south) located after acceleration zone and 120' (north) before deceleration zone at each end of the profiling-sampling zone, for a total of 238 feet.

Figure 3-1. Phase IV Route Map (Veterans Memorial Blvd, Boulder City)



Note: The silt zone, with total length 2770 feet, includes Silt Buffer Zones, AP42 Sampling Zones, and Profiling Zone.

3.2 Soil Selection and Application

3.2.1 Soil Sampling Site Selection

The 50th percentile silt content for collector roadways sampled in Clark County in 2005 and 2006 was used as a target value for silt content for selection of a candidate soil to be applied to the road surface for the Phase IV controlled study. Data summarizing the 50th percentile calculations are shown in **Table 3-1**. The 50th percentile silt content value for collector roads was 13%.

UNLV, in collaboration with Clark County DAQEM staff, surveyed four candidate field sites in southern metropolitan Clark County in July of 2006. Three candidate sites, in southwest Las Vegas, were not selected because either the silt content was incorrect, or because permission could not be obtained from either the US Bureau of Land Management or from private landowners for large-scale excavation.

Table 3-1. Summary of Data Used to Determine 50th Percentile Silt Loading Value for Collector Roadways

QTR-Year	UNLV Site	Site Modifier	DAQEM location name	DAQEM Roadway Classification	Plot Number	Percent Gravel	Percent Sand	Percent Silt & Clay
3rdQ-2005	24		Pabco	Collector		25.4	68.9	5.7
4thQ-2005	24		Pabco	Collector		17	76	7
1stQ-2006	23		Burkholder	Collector	4	11	77	12
3rdQ-2005	23		Burkholder	Collector		20.1	75.6	4.3
4thQ-2005	23		Burkholder	Collector		7	80	13
1stQ-2006	15		Ione	Collector	4	16	70	14
3rdQ-2005	15		Ione	Collector		13.3	75.7	11
4thQ-2005	15		Ione	Collector		5	83	12
2ndQ-2005	5		Washburn	Collector		15.6	55	29.4
3rdQ-2005	5		Washburn	Collector		2.1	7.6	90.3
2ndQ-2005	2		Marion	Collector		14.3	49.2	36.5
4thQ-2005	2		Marion	Collector		6	78	16
1stQ-2006	1		Gowan	Collector	4	8	79	13
2ndQ-2005	1		Gowan	Collector		24.9	61.8	13.3
3rdQ-2005	1		Gowan	Collector		17	78.5	4.5
geometric mean						***11.4***	***61.4***	***13.1***
10th percentile						5.4	51.5	5.0
50th percentile						14.3	75.7	13.0
90th percentile						23.0	79.6	33.7

* Gravel-sand boundary was 2.00 mm
* Sand-silt boundary was 75 microns

A 21.9 kilogram sample of soil from a site located at Sunset Park, designated UNLV Road Dust site 29 (wet sieve) or 32 (dry sieve), in Wind Erodibility Group (WEG) 2, at an elevation of 1,988 feet, latitude N36º 3.792', longitude W115º 6.748' (Garmin eTrex®, WGS 84 datum) was collected on August 4, 2006. A 675 gram sample was sieved on August 11, 2006 and was found to be predominantly sand, with a 14% silt content.

A second group of samples were collected from (60 meters) 200 feet west of the original sampling site on August 23, 2006, designated as UNLV sites 38 and 39, at latitude N36º 03.777' and longitude W115º 06.824'. Volumetric soil moistures were found to range from 0.0% to 0.5%. Results of sieve analyses for silt content were similar to the first sample, and the decision was made to use this sandy WEG 2 deposit as the source material for the Phase IV controlled study.

3.2.2 Soil Excavation and Packaging

On Wednesday, September 6, 2006, a team of Clark County DAQEM and UNLV personnel, assisted by staff from Clark County Department of Parks and Recreation, excavated soil from the Sunset Park site. The excavation location was at latitude N36º 3.782' and longitude W115º 6.770', a location in between the two original soil collection sites.

A 0.38 cubic meter (0.50 cubic yard) bucket loader was used to remove soil from the site and deposit it in a loose pile. Soil was excavated to a depth of about 0.40 meters (18 inches). Round-end hand shovels were used to excavate soil from the pile and pour it through 30.1-centimeter (12 inch) diameter 1 mm sieves placed on top of tared plastic 19-liter (5-gallon) paint buckets. Three sets of 1 mm sieves and buckets were used in parallel to speed the bulk sieving process. The sieves and buckets were vigorously rocked from side to side to agitate fine soils through the sieve opening. Loose conglomerates of soil remaining on top of the sieves were hand-crushed to pass them through the sieves. Rocks, twigs, and other debris were shaken off the sieves and placed in a spoils pile at one side of the excavation site.

Tared and total bucket weights with soil were recorded on a calibrated Sunbeam Freightmaster® 150 scale to the nearest 0.1 kilogram and were logged into a bound laboratory notebook.

After total (tare + soil) bucket weight was calculated, each bucket was covered with a tight-fitting snap-down lid and moved to the bed of a pickup truck for transport to the Phase IV study site.

Fifty (50) covered buckets of sieved soil were prepared in this manner. They were then all simultaneously transported to the storage yard of the DRI Solar facility on Adams Boulevard in Boulder City, Nevada, and stored outside for four days until September 11, 2006, when the soil samples were applied to the Phase IV road site.

3.2.3 Soil Characterization

A soil sample with a mass of about 700 grams was extracted from each of six soil buckets with a trowel during the excavation process, sealed in plastic cash bags, and transported to Ninyo and Moore, the geotechnical company contracted to perform soils analysis, on September 6, 2007 for sieve analyses. Sampled soil masses were measured with a calibrated Sunbeam model 78411 postal scale. Every tenth bucket, corresponding to Bucket numbers 1, 11, 13, 17, 28 and 39, was sampled for soil (buckets were not filled in numerical order). Soil moistures were measured with a Dynamax HH2 TDR volumetric moisture meter. Values ranged from 1.9 to 4.1 volume%.

Ninyo and Moore sieved these samples, using a sieve stack consisting of number 16 (1.18 mm), 30 (0.600 mm), 50 (0.300 mm), 100 (0.150 mm) and 200 (0.075 mm) mesh sieves, and an eight-minute shake time, to determine silt contents. This non-AP-42 sieving technique was used only for recovered field soil samples that were collected before the Phase IV AP-42 field study. Results using this method showed that the average silt fraction for the excavated soil was 14.3%.

3.2.4 Soil Application

Soil from 15 buckets (about 340 kilograms, or 750 pounds) was poured into a 12-foot wide Gandy 10T series fertilizer drop spreader at the Phase IV empirical study field site on the morning of 9/11/2006.

The Gandy spreader was then driven to the Veterans Memorial Boulevard (VMB) site.

Prior to the first application of soil a group of preliminary measurements by the mobile PM_{10} sampling vehicles were used to characterize the PM_{10} emission rates of the natural road soil on the VMB site before and after two sweeper passes. Soil was first applied from the Gandy spreader at about 1120 in the morning of 9/11/2006 after 92 vehicle passes had been completed.

During the five days of the study, the spreader pull speed was kept constant at approximately 5 meters/second (16 kilometer/hour or 10 miles per hour) over an 844.3 meter length of the course (2770 feet). The spreader was pulled by a Dodge MaxiVan on the first day while a large garden tractor was used on subsequent days. Spreader soil application was driven by geared wheel that turned an agitating feeder at a rate that is proportional to ground speed. The rate of application by the spreader is controlled by adjusting the size of the diamond-shaped openings that feed soil to the ground surface. The opening was held constant for each set. Opening size was varied for different sets to apply soil at different loadings to the test site.

Soil was applied from 27 meters (87 feet) before the start of the southern AP42 sampling zone to 72.8 meters (239 feet) after the end of the northern AP42 sampling zone.

3.3 Horizontal Flux Tower

The flux of PM downwind of the test roadway emissions was quantified using a flux measurement technique similar to that described in previous work by Gillies et al (2005). A "master" tower was erected downwind of the road (Between 4 and 6 m from centerline of test vehicle travel path) and aligned perpendicular to road (**Figure 3-2, Figure 3-3**). The trailer-mounted, 9 m-high tower was instrumented with DustTraks (Model 8520, TSI Inc., Shoreview MN) configured to measure PM_{10} at five heights above the ground surface (0.7, 2.1, 3.4, 6.4, and 9.8 m). At one of the heights (3.4 m), a DustTrak equipped with a $PM_{2.5}$ impactor inlet was collocated with the PM_{10} DustTrak. The master tower also included a TEOM (R&P, Model 1400a), which measures PM_{10} at a height of 2.3 m. The TEOM sampling inlet was nominally collocated with one of the PM_{10} inlet-equipped DustTrak monitors (at 2.1 m above ground level).

The DustTrak monitor measurement is based on light scattering of particles which is dependent on the particle size-distribution and the optical properties of the emissions. The TEOM was intended to help account for differences between optical based measurement and mass based measurements. These data were used to confirm supplemental, controlled measurements conducted in a resuspension chamber and described below. This allowed for conversion of emission factors measured with the tower-mounted DustTraks into mass-based emissions factors (see Section 4.1). A wind vane was mounted at the top of the tower and one cup anemometer was approximately collocated with each pair of DustTrak samplers. All data from the PM samplers and meteorological instruments were telemetered and logged in 1-second intervals by a laptop located on the master tower.

Figure 3-2. Photograph of Master (left) and Satellite (right, not used in present study) Towers Showing Locations of DustTrak PM_{10} Monitors. For present study, only one $PM_{2.5}$ inlet-equipped DustTrak was used on the master tower at a height of 3.4 m above ground level.

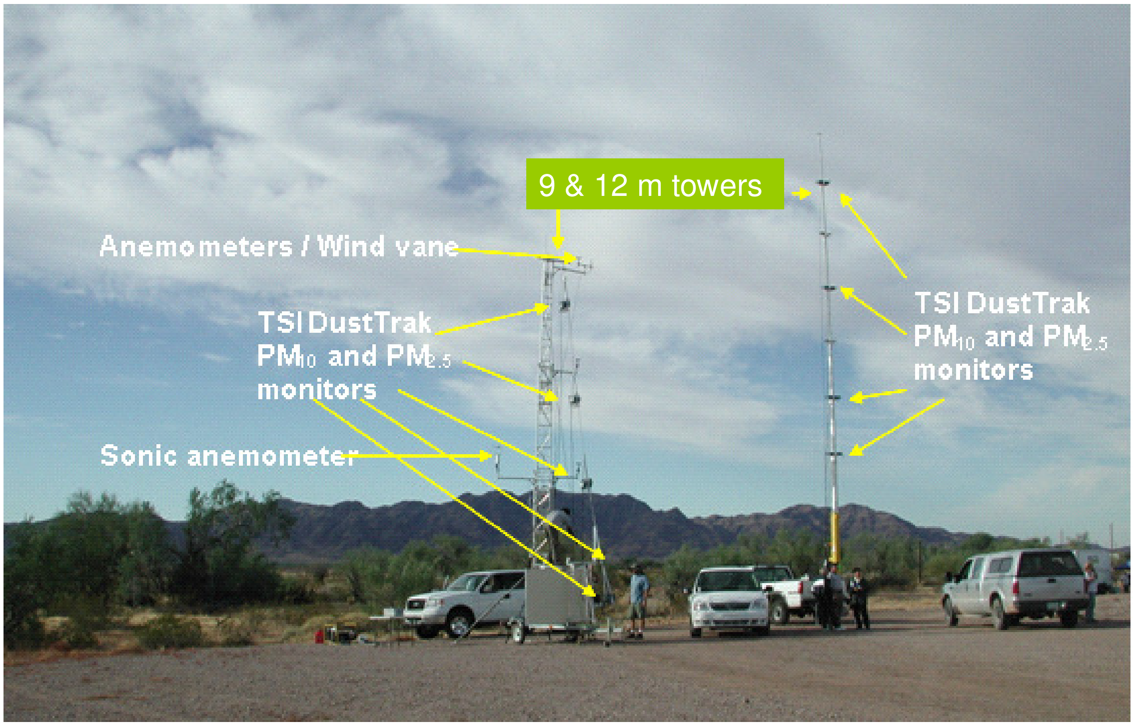
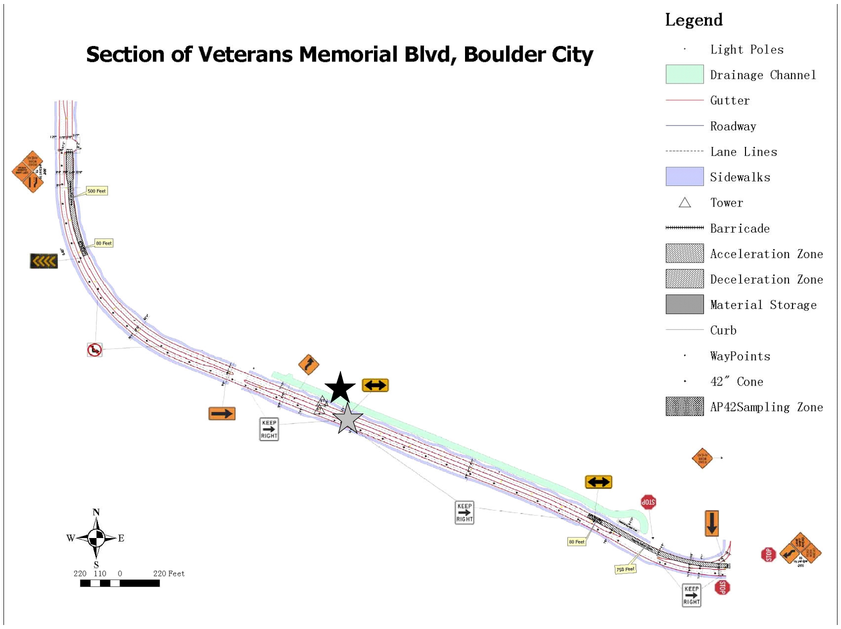
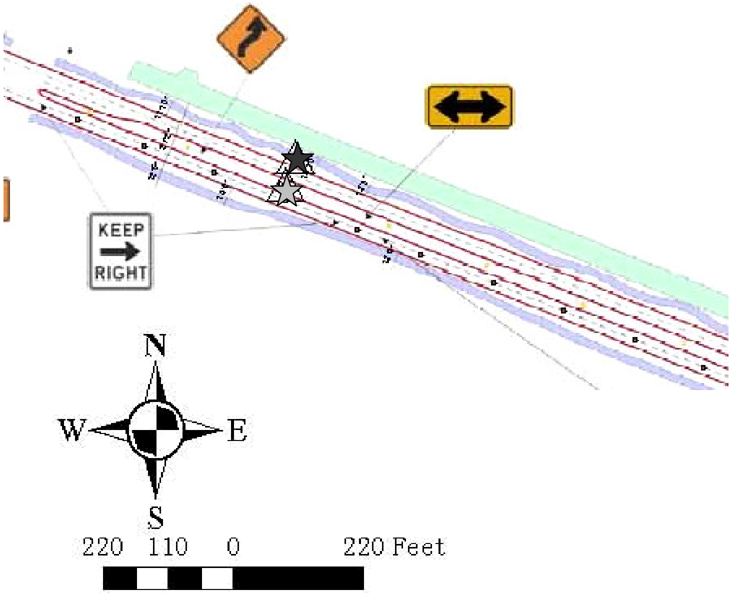


Figure 3-3. Schematic of Field Sampling Layout. The gray star shows the location of the master tower on 9/11/06 and the black star shows the location of the master tower from 9/12/06 – 9/15/06.



a. View of entire test section



b. Close-up of section where tower was located

3.4 EPA Method AP-42

3.4.1 Plot Layout

Two zones of the course, called "south" and "north" were designated for silt recovery during controlled study.

The "near" end of the south AP-42 sampling zone was established 228.3 meters (749 feet) from the start of the course, as defined by the intersection of Veterans Memorial Dr. and Adams Drive. This distance was selected so that the mobile technologies vehicles could complete the acceleration portion of their pass before entering the soil sampling zone. The south AP-42 sampling zone was 36 meters (118 feet) long. The "far" end of the north AP-42 sampling zone was 36.6 meters (120 feet) established 1358 feet (Deceleration Zone and "North" Silt Buffer Zone) from the end of the course, just before the gradual curve in the roadway. GPS coordinates of the "near" and "far" corners of the sampling zones were measured using an un-corrected Garmin E-trex Global Positioning System receiver. Distances were also measured with a measuring wheel.

Seven 3.3 meter long x 4.1 meter wide (10 foot long x 13.5 foot-wide) plots were laid out in the south and north zones for soil recovery (**Figure 3-4**). Each of the AP-42 sampling plots was separated by a 2.4 meter (eight-foot) buffer zone. The buffer zone was used to allow field personnel and equipment to access the plots without disturbing the sampled area.

Two different plot layouts were used during the empirical study to collect soil samples:

(1) A full size 3.3 meter long x 4.1 meter wide plot, with an area of 12.5 square meters was used to estimate soil and silt loading at the beginning and end of most of the mobile technologies sampling experiments. A 3.3 meter (10 foot) plot length was selected to remain consistent with recommended clean road plot length on page 7 of Appendix C.1, Procedures for Bulk Sampling of Surface Loading (US EPA 1993a) A 4.1 meter (13.5 foot) width was selected to recover soil from the edge of the asphalt (at the start of the concrete gutter) to the line dividing the eastern and western northwest-bound travel lanes on Veterans Memorial Boulevard.

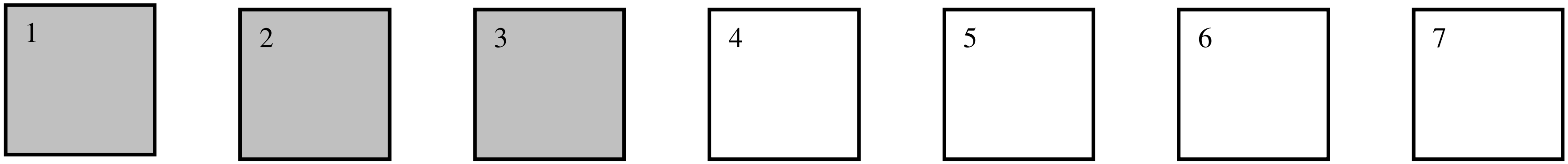
An array of seven (7) numbered full-size plots, with 2.4 meter (8-foot) spacing between the plots was laid out at each end (zone) of the driving course. Layout was established by first setting up a string rectangle consisting of colored surveyor's twine wrapped around gravel-filled cans. The 3.3 meter and 4.1 meter lengths were different colors, and were tied to form a rectangle with an uncertainty of +/- 0.05 meters. White surveyors paint was used to establish the corners of the rectangles. The surveyors' twines were pulled tight around the gravel-filled cans, and then 5.1 cm (2-inch) masking tape was applied from a roller dispenser to match the perimeter established by the colored surveyors' twine.

(2) For experiments evaluating the effects of vehicle passes on applied soil depletion, 0.61 meter (2 foot) wide "Quickie-Strips" (Etyemezian, personal communication, 2006) were laid out in the zones between the full-size plots. Quickie-strip locations were marked on the concrete gutter and on the lane dividing line with white spray painted dots spaced every 2 feet apart. Painted

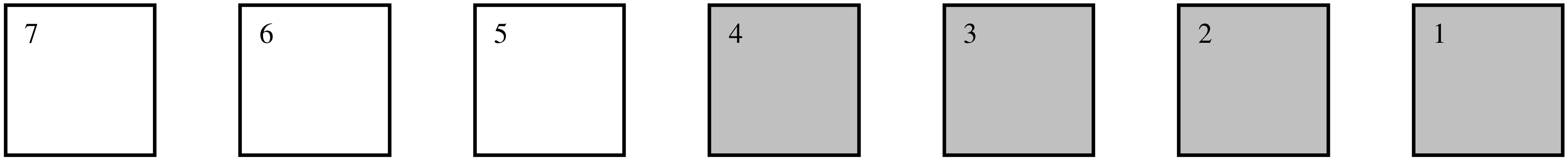
lines or masking tape were not used to indicate boundaries of the Quickie Strips. Quickie Strip samples were also collected inside unused full-size plots, when needed. Although sampled in the “buffer” zones between AP-42 plots, the Quickie-strip samples were not collected in areas where there had been foot traffic, as the seven plots and, when needed, Quickie strips in the buffer zones were sampled in a progression from the near to far ends of the course (south zone) or far to near ends of the course (north zone).

Figure 3-4. Phase IV Veterans Memorial Drive Plot Layouts

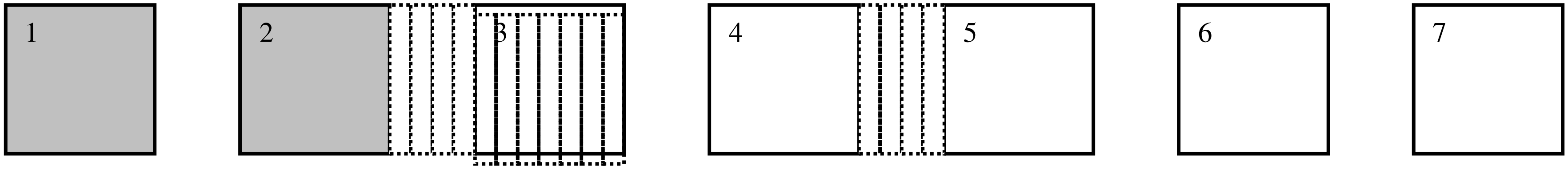
(a) Schematic south zone plot layout (not to scale). Start of course is to left of Plot 1. Plots sacrificially sampled in ascending numerical order from 1 to 7, moving from left to right. Spaces between plots are eight-foot buffer zones for personnel and equipment access. Shaded plots indicate already sampled.



(b) Schematic north zone plot layout (not to scale). End of course is to right of Plot 1. Plots sacrificially sampled in ascending numerical order from 1 to 7, moving right to left. Spaces between plots are eight-foot buffer zones for personnel and equipment access



(c) Example south zone quickie-strip plot layout (not to scale). Dotted lines show partitioning of un-used buffer zones or un-used plots into Quickie Strips for silt depletion sampling



3.4.2 Vacuum Soil Recovery Methods

One Hoover Model S3636 Wind Tunnel Plus® and two Hoover Model S3639 Wind Tunnel Plus® canister vacuum cleaners, rated at 12 amperes, were used to recover applied soil from the roadway sites. The vacuum cleaners were connected by 50-foot or 100-foot 14-gauge extension cords to portable 3750-watt 120-volt Coleman generators. In cases where two samples were required at one point in time, two vacuum cleaners were simultaneously operated in parallel at the south zone of the site, and the northern vacuum cleaner would sample two test plots in sequence.

Soil samples were recovered into pre-tared (to +/- 1 gram using the Sunbeam 78411 postal scale) Hoover Type S Allergen Canister vacuum bags, model 4010100S. To determine the tare mass of the bags, the empty Hoover bags were removed from their plastic liner bags, weighed in the laboratory to within +/- 1 gram, labeled with a bag number and a tare mass, and replaced back in their plastic bags for interim storage until used in the field.

Vacuum hose-to-bag connections were sealed with low-density, high compression white foam polyethylene weather-stripping to minimize leakage of collected sample. New secondary motor filters were installed at the start of the study. They were cleaned every morning by removing and knocking the dust off. They were replaced every two days at a point when knocking the filter could not remove visible discoloration from soil.

Hoover Hard Floor Tools were used for soil recovery. Brushes on the Hard Floor tools are known to wear out quickly on asphalt. The most rapid wear occurred on the brush closest to the wand connection, with this brush worn down from about 9 mm to about 3 mm after 1/2 day's use in the field. Floor tools were replaced when visible wear of the brush below 3 mm was observed, typically every 1/2 day.

For full-size (12.5 square meters, 135 square feet) plots, two sets of twine wrapped around gravel-filled soup cans were used to visually partition the full-size plot into thirds across the direction of travel. Each partition was vacuumed twice with a curb-to-gutter vacuum stroke. After the curb-to-gutter vacuum strokes had been completed, the twine dividers were realigned along the direction of travel. Each partition was vacuumed twice with a front-to-back vacuum stroke. A total of four vacuum strokes were passed over each portion of the vacuumed plot, consisting of two curb-to-gutter strokes and two front-to-back strokes. Four vacuuming passes had been previously shown to recover 95-98% of applied mass on asphalt surfaces (UNLV unpublished data).

For Quickie-strip plots (area 2.51 square meters or 27 square feet), the hard floor tool was passed back and forth twice over each strip (Figure 2), first on the ½ of the plot nearest the curb, starting from the curb side towards the center of the road, and then on the ½ of the plot nearest the lane divider, starting at the lane divider and vacuuming towards the curb. Quickie-strip plots, comprised of five subsections of a standard plot, were not as well-marked as standard plots, so side to side variations in the swept width of the Quickie-strips were larger than they were for the full-size plots. As a result, the absolute and relative uncertainty in the width of the Quickie-strip is larger than for the full-size plot.

Three soil recovery techniques were used during the study.

(1) One plot per bag (Individual). Soil from one large heavily soiled plot would be recovered into one pre-tared bag, the bag would be weighed, sealed with plastic film to prevent leakage, and then placed in a labeled large brown 25 cm x 35 cm (10" x 14") office envelope. The envelope would then be held closed with its brass clasp. The date and time of the collection would be noted on the bag and on the log sheets.

(2) Two large plots per bag (Cumulative). Soils from two lightly soiled large plots, sampled at the same time (before or after a particular vehicle pass) would be accumulated into one tared vacuum bag. The vacuum bag would be removed from the vacuum cleaner, weighed by one of the portable balances after the first soil recovery, and then reinstalled in the vacuum cleaner for sampling the second plot. After plot sampling was completed, the bag would be removed, sealed with film, placed in a labeled large brown office envelope and held in a sealed plastic storage container until needed for silt sampling analysis by Ninyo and Moore. The following formulae were used calculate the individual plot weights and silt loadings.

Silt mass plot 1 = (Ninyo and Moore silt fraction) x (Ninyo and Moore silt mass) x (Bag mass after plot 1 – Bag tare mass) / (Net mass for plot 1 + plot 2)

Silt mass plot 2 = (Ninyo and Moore silt fraction) x (Ninyo and Moore silt mass) x (Bag mass after plot 2 – Bag mass after plot 1) / (Net mass for plot 1 + plot 2)

(3) Multiple small plots per bag (Cumulative). Soil masses from a series of Quickie strips, sampled in sequence after a specific vehicle pass.

Filled bag masses were recorded in the field after each vacuuming using the Pelouze SP5 and Sunbeam 78411 field scales. Scales were kept shaded from direct sun and measurements were made either inside a large plastic storage box or inside a closed 12-passenger cargo van to minimize effects of wind shake.

3.4.3 Field Soil Application History

The native road dust on Veterans Memorial Boulevard was first sampled by the AP-42 recovery technique before any passes were made by the mobile technologies vehicles.

Emissions from the native road soil were then measured by the mobile technologies sampling vehicles (DRI TRAKER I, TRAKER II, and UCR SCAMPER) and the DRI tower. After a series of 60 mobile technologies sampling passes, a PM-efficient sweeper was driven twice over the site to remove native road dust. Another 30 sampling passes by the mobile technologies vehicles then took place.

Soil from the Gandy spreader was first applied after vehicle pass 92. Pass 93 was the first mobile technologies measurement using the applied soil.

A summary of the applied soil loadings, vehicle passes and speeds is shown in **Table 3-2**.

Table 3-2. Summary of Applied Silt Loadings During Phase IV Controlled Field Study—Veterans Memorial Boulevard. Boulder City, NV

Date	Set #	Nominal Drive Speed (mph)	Spreader Setting	Net wt Applied, lbs	Spreader Path Length, ft	Applied Soil Loading (gram/m^2)	Avg. Recovered Silt Loading, (gram/m^2)
9/11/06	3	35	15	45	2977	6.16	0.75
9/12/06	4	45	30	117	2775	17.17	2.48
9/12/06	5	25	30	113	2775	16.58	3.17
9/13/06	6	45	15	34	2775	4.99	0.88
9/13/06	7	25	15	32	2775	4.70	0.74
9/13/06	8	45	20	52	2775	7.63	1.14
9/14/06	9,10	35	20	53	2775	7.78	0.80
9/14/06	12	varying	30	120	2775	17.61	2.55
9/15/06	13	varying	35	194	2775	28.47	2.31

3.5 Mobile Technologies

3.5.1 SCAMPER

The SCAMPER determines PM emission rates from roads by measuring the PM concentrations in front of and behind the vehicle using real-time sensors. In this study, the concentration (mg/m^3) is found by subtracting the background concentration (front sampler) from the concentration measured by the rear sampler. As a first approximation, the concentration difference (mg/m^3) can be multiplied by the vehicle's frontal area (in this case, 3.66m^2) and by a DustTrak calibration factor to obtain an emission factor in units of mg/m. The vehicle frontal area is defined as the vehicle width at the highest part of the vehicle multiplied by the overall height at the highest part (no correction made for ground clearance). In previous SCAMPER studies, a reference sampler was collocated with the rear sampler in order to find a DustTrak calibration factor to convert from concentration-based readings to a mass-based emission factor.

This SCAMPER includes five major components:

(1) PM_{10} Sensors

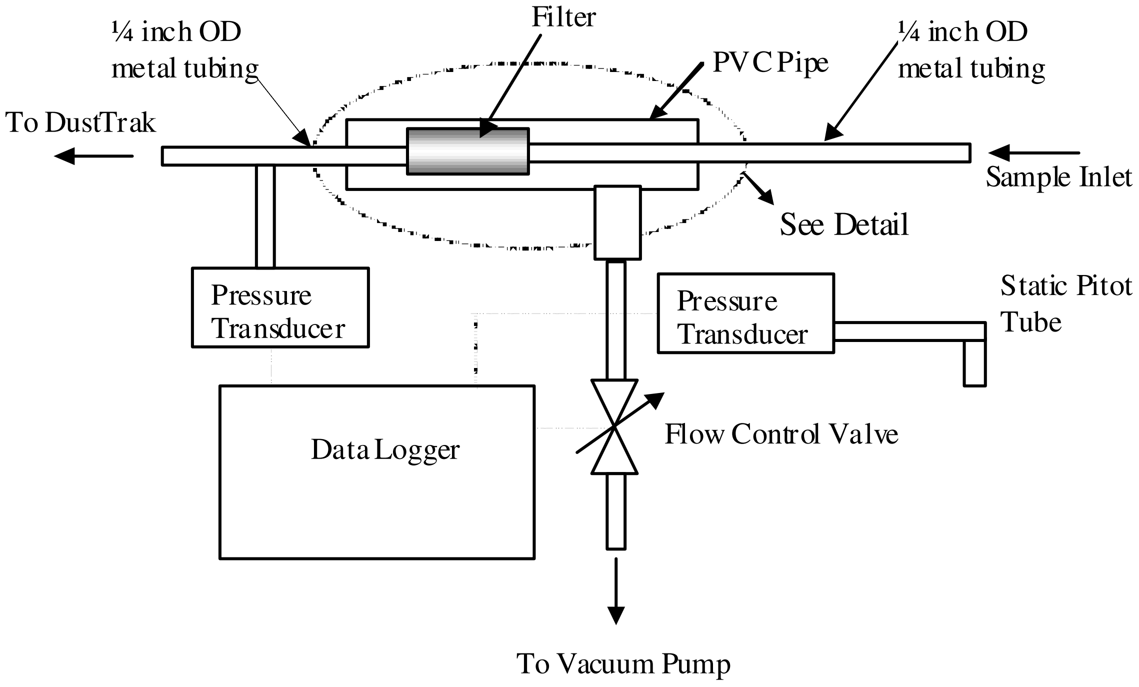
Thermo Systems Inc. (TSI Incorporated) Model 8520 DustTrak optical PM sensors with PM_{10} inlets are used. These sensors are based on the principle that the amount of light scattered by particles is related to the particle concentration. Since the efficiency of light scattering depends on particle size, the response of the sensor depends on the particle-size distribution. Particles less than approximately 0.1μm diameter are not detected. The instruments are calibrated at the factory using NIST reference material 8632 Ultrafine Test Dust, more commonly know as "Arizona Road Dust". The manufacturer recommended measurement range is from 0.001 to 100 mg/m^3, although the instrument will generate readings up to 150 mg/m^3 with less reliability. The time constants are selectable from 1-60 seconds; the 1-second time constant is used on the SCAMPER. An impactor supplied with the instrument is used as a PM_{10} size-selective inlet.

(2) Sampling Inlet

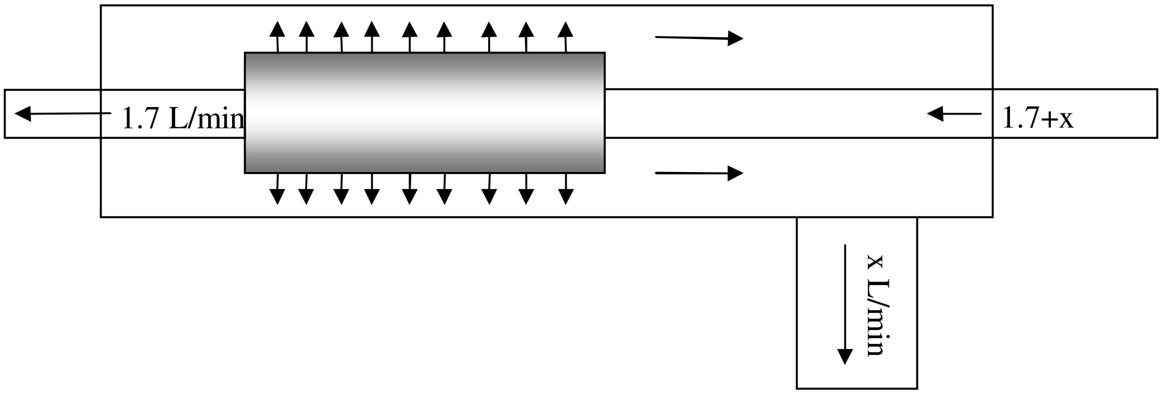
An inlet for the real-time PM sensors was used that allowed sampling as isokinetically as possible over the full range of vehicle speeds. **Figure 3-5** shows the design of the inlet. Stainless steel tubing (¼ inch OD, 3/16 inch ID) is used to connect the sample inlet to the one end of a hollow cylindrical pleated paper filter element (1.7 cm diameter, 5.0 cm long) and from the other end to the DustTrak (the sampled air is not filtered, but travels from one end of the hollow cylinder to the other). The stainless steel tubing is attached to the metal end caps of the filter element using "JB Weld". The filter element and attached tubing are contained in a 1 inch PVC pipe with a cap at each end with a PVC "T" in between. Each cap is drilled and tapped for a ¼ inch pipe fitting. A Swagelock® male connector (¼ inch pipe x ¼ inch tubing) that has been drilled through with a ¼ inch drill is screwed into each end cap. An end cap assembly is slid over each piece of stainless steel tubing and onto the PVC pipe. The Swagelock® tubing fittings are then tightened to seal the tubing within the PVC pipe assembly. The overall length of the PVC pipe section is 33 cm.

To slow the flow to the sample flow rate of the DustTrak without creating a virtual impactor, excess air is pulled through the outside of the cylindrical filter through the arm of the PVC "T" with a vacuum pump that maintains the bulk air speed at the inlet equal to the speed of the air going past the inlet. The flow rate of the vacuum pump is adjusted by the data logging PC to produce a reading of zero pressure on the gauge. When the pressure equals zero, there is no pressure drop from the probe inlet to the tubing that leads to the DustTrak. This condition creates a no-pressure-drop inlet; therefore, the sampled air stream has the same energy as the ambient air stream.

Figure 3-5. Isokinetic Inlet Schematic Diagram



Detail of Flow Splitting Section



(3) Sampling Trailer

To determine PM_{10} concentrations in the vehicle wake, a DustTrak was mounted on a small trailer. The trailer has a flat bed four feet wide and six feet long, this configuration chosen such that the vehicle wake would be disturbed as little as possible. In addition, the trailer holds the bypass flow system. The trailer has a three foot extension on the hitch to place the DustTrak in a position ten feet behind the vehicle, which was shown to be representative of the PM_{10} concentrations in the wake and yet be safe to operate on public roads (Fitz, 2001).

(4) Position Determination

A Garmin GPS Map76 global positioning system was used to determine vehicle location and speed.

(5) Data Collection

A PC was used to collect data from GPS and PM_{10} measuring devices. Data was stored as one-second averages. The PC also was used to automatically adjust the sample inlet bypass flow to maintain isokinetic particle sampling using a 10-second running average of vehicle speed based on the GPS.

Figure 3-6 shows front and rear photographs of the SCAMPER. The tow vehicle is a 2006 Ford Expedition with a custom trailer using an extended hitch.

Figure 3-6. Photographs of the Front and Rear of the SCAMPER

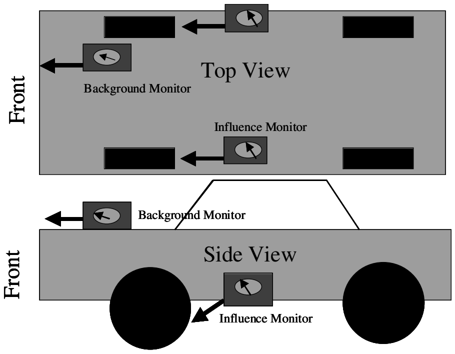
3.5.2 TRAKER I

The principle behind the TRAKER system is illustrated in **Figure 3-7**. The concentration of airborne particles is monitored through inlets that are mounted near the front tires of a vehicle. These particle sensors are influenced by the road dust generated through the tire contacting the road surface. A background measurement of particle concentrations is obtained simultaneously at a location on the vehicle farther away from the tires. The difference in the signals between the influence monitors and the background monitor is related to the amount of road dust generated:

$$T = T_T - T_b \qquad \text{Equation 3.1}$$

where T is the "raw" TRAKER signal, T_T is the particle concentration measured behind the tire (average of left and right), and T_B is the background concentration.

Figure 3-7. TRAKER Influence Monitors Measure the Concentration of Particles Behind the Tires. A background monitor is used to establish a baseline.



TRAKER I is comprised of a van that has been equipped with three exterior steel pipes acting as inlets for the onboard instruments (**Figure 3-8a**). Two of the pipes are located behind the left and right front tires and are used to measure emissions from the tires. The third pipe runs along the centerline of the van underneath the body and extends through the front bumper. This pipe is the inlet for background air. Dust and exhaust emissions from other vehicles on the road can cause fluctuations in the particle concentration above the road surface. The background measurement is used to correct the measurements behind the tires for those fluctuations.

The three exterior pipes enter the cargo compartment of the van through the underbody. Each pipe then goes into a plenum/manifold; the plenum can be used to distribute the sample air to up to five instruments (**Figure 3-8c**). For the present study, one TSI DustTrak with PM_{10} inlet was operated at each of the left and right inlet lines as well as on the middle inlet line. A central computer collected all the data generated by the onboard DTs as well as GPS coordinates, speed, and acceleration with 1-second frequency (**Figure 3-8d**).

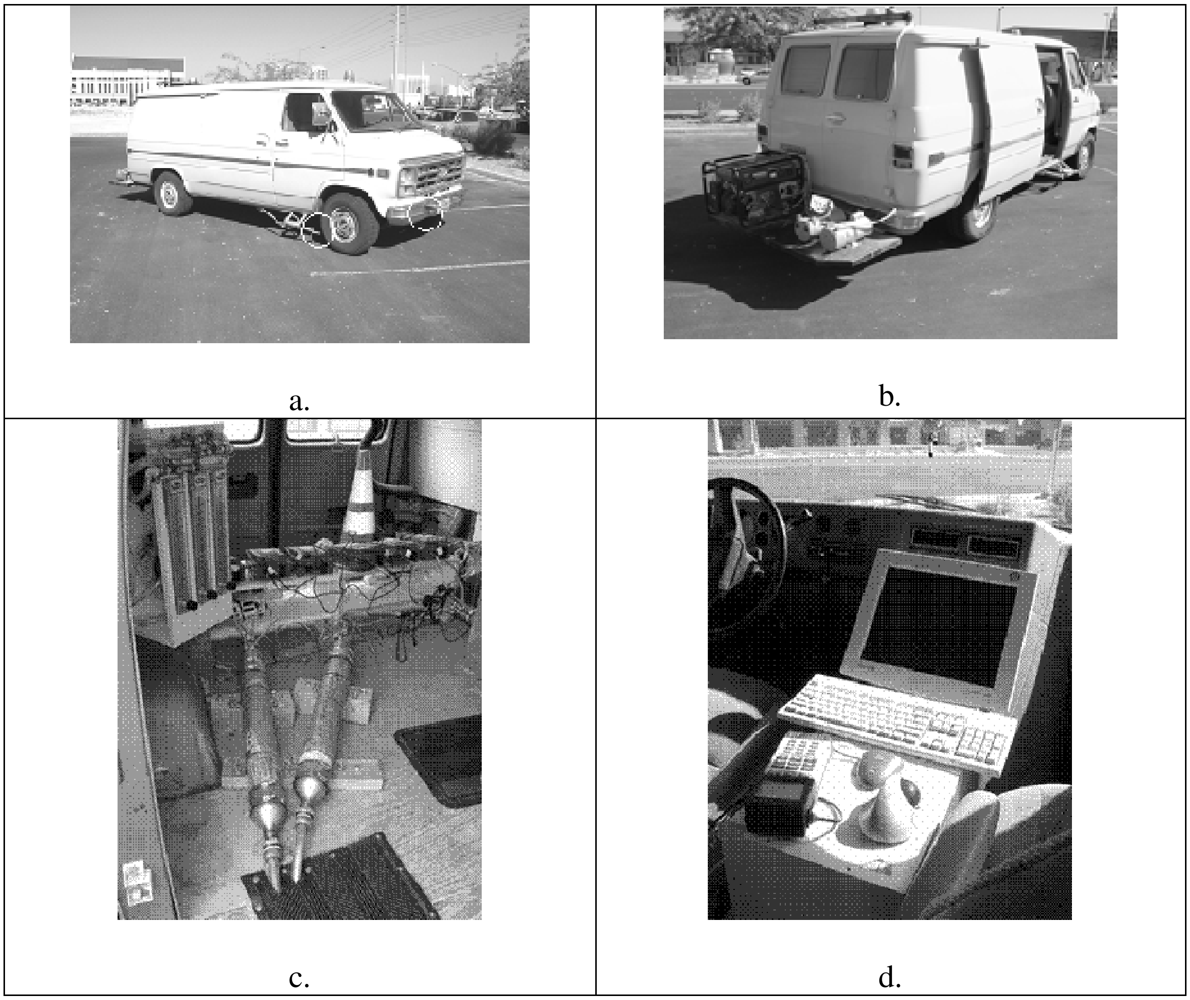
All DustTrak monitors used for the study were calibrated by the manufacturer within 12 months of their use. Prior to each day of measurement, flows on the DustTraks were checked to ensure they were within manufacturer specifications and the instruments were "zeroed" with an inline HEPA filter as specified by the manufacturer.

3.5.3 Inlet configuration

Unlike gases, particles have inertia; as a result, the sampling of particles through an inlet results in some particle losses to inlet surfaces. These losses could be due to the diffusion of particles toward inlet walls or the impaction/settling of particles upon inlet walls. Diffusion is a phenomenon that governs the motion of very small particles (less than 0.1 µm). Since road dust is composed primarily of larger particles (greater than 0.3 µm), diffusion is not an important consideration for TRAKER. Impaction and gravitational settling, however, are important processes for sampling particles with aerodynamic diameters greater than 1 µm. Gravitational settling can be minimized by reducing the amount of time a particle spends in the inlet lines (e.g., by increasing the speed of the flow). On the other hand, particle impaction can be minimized by reducing the speed of the flow turns within the inlet lines.

The inlet lines, visible in **Figure 3-8a**, are 19 mm (3/4") in diameter and 2.3 m (7.5') long for the tire lines and 3.7 m (12') long for the background line. The influence inlets on the right and left are in slightly different positions with respect to the tires. On the right, the inlet is 165 mm (6.5") above the ground, 50 mm (2") behind the tire, and 63 mm (2.5") in (toward the center of the vehicle) from the outside edge of the tire. On the left, the inlet is 165 mm (6.5") above the ground, 63 mm (2.5") behind the tire, and 63 mm (2.5") in from the outside edge of the tire. Because of the vehicle's configuration, it is not possible to avoid bends in the inlet lines. However, the bends have been kept as shallow as possible in order to minimize losses of particles to the inlet walls. Each of the inlet lines feeds into a 600 mm (20") long torpedo-shaped plenum (**Figure 3-8c**). All particle sampling instruments are connected through the plenum via short non-conductive tubes that are in turn attached to 20 mm (8") long steel tubes that extend into the body of the plenum. Flowrates through the inlets, developed with a high vacuum pump, are 75 liters per minute (lpm), corresponding to an inlet face velocity of 4 meters per s (mps) and 0.3 mps in the plenum. Rotameters connected to each of the inlet lines are used to ensure that the flows through the inlets remain within 10% of the desired value. An independent rotameter equipped with stopper is used at the inlet lines to verify the readings of the onboard rotameters. Noting that in the seven years of experience using TRAKER I, the flowrate through the inlets has never drifted by more than a few percent of the desired value over the course of a day, the operator of the TRAKER can periodically check flows by examining the readouts on the rotameters in the vehicle's rear-view mirror.

Figure 3-8. TRAKER Vehicle and Instrumentation: (a) Location of inlets (right side and background shown); (b) Generator and pumps mounted on a platform on the back of the van; (c) Two sampling plenums (bottom), a suite of DustTrak particle monitors (top right), and three rotameters used for ensuring proper flows through the two plenums; and (d) a dashboard-mounted computer screen used to view the data stream and a GPS to log the TRAKER's position every 1 second.



a. b. c. d.

3.5.4 TRAKER II

In addition to the TRAKER I test vehicle described above, DRI also employed a prototype of a modified unit (TRAKER II). There are two major design differences between TRAKER I and TRAKER II. First, TRAKER II (**Figure 3-9** and **Figure 3-10**) uses low pressure-drop blowers to pull sample air in from behind the front tires and from the background instead of the high vacuum pump utilized by TRAKER I. This substantially reduces the power requirements of TRAKER II compared to TRAKER I and allows for the modified unit to be powered by onboard DC batteries that are recharged by the vehicle's alternator. Second, the TRAKER II inlet lines are configured so that on unpaved roads, where PM_{10} concentrations behind the front tires could exceed the DustTrak instrument's upper limit (150 mg/m^3), clean air can be mixed with air from the tire inlets in a controlled manner to achieve a desired amount of dilution.

There are also other minor differences between TRAKER I and TRAKER II. For example, a) the inlets behind the front tires in TRAKER II are located farther behind the tire than in TRAKER I; b) Instead of an onboard sampling plenum as in TRAKER I, a 10 cm diameter external pipe is used to channel/dilute inlet flow and instruments can sample the air within that pipe through small manifolds located on the floor of TRAKER II; c) The circular inlets used currently on TRAKER I are replaced by flattened manifolds on TRAKER II. Aside from these differences, TRAKER II is based on the same basic principle of operation as the TRAKER I.

In the present study, the use of TRAKER II is intended to obtain preliminary data for assessing if changes in design have achieved the desired outcome or if additional changes are needed. Like TRAKER I, TRAKER II was outfitted with PM_{10} DustTraks on the left and right tire inlets as well as on the "Background" inlet, which in the case of TRAKER II resides above and slightly behind the driver-side and passenger-side doors (See **Figure 3-9**).

The electric blowers in the inlet pipes were turned on and fixed at a flowrate of 10 lpm. Within each inlet line, the flow rate is measured in 200 ms intervals by a small pitot tube attached to a pressure transducer (Dwyer Instruments, ¼" of water max). An onboard laptop computer adjusts the power to the blower motor to maintain the flow at 10 lpm with a frequency of 200 ms.

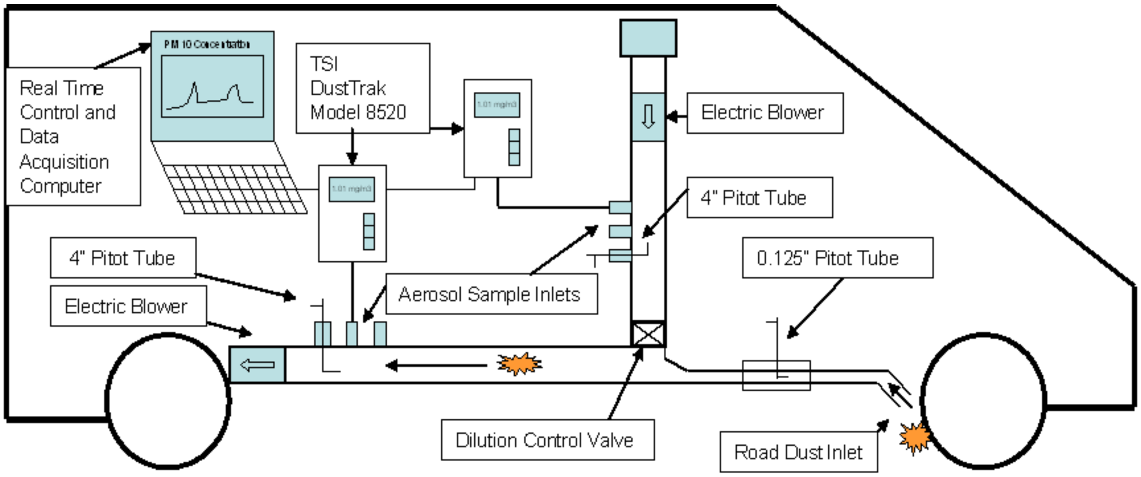
As with TRAKER I, DustTrak monitors were zero- and flow-checked at the beginning of each sampling day. In operation, the DustTrak instruments extract particle-laden air from within the pipe that runs along the underside of the vehicle through non-conductive tubing. Optionally, TRAKER II can be equipped with other instruments such as filter samplers and particle size analyzers through additional sample ports on the inlet pipe. A GPS unit in TRAKER II provides geospatial coordinates vehicle speed, acceleration, and wheel angle. These data, along with 1-second DustTrak measurements from the three inlet lines (left, right, and background) are displayed in real-time and logged by the laptop computer for subsequent analysis.

Figure 3-9. TRAKER II. Vertical inlet pipe near the passenger-side door is used to sample background air for the right side inlet.

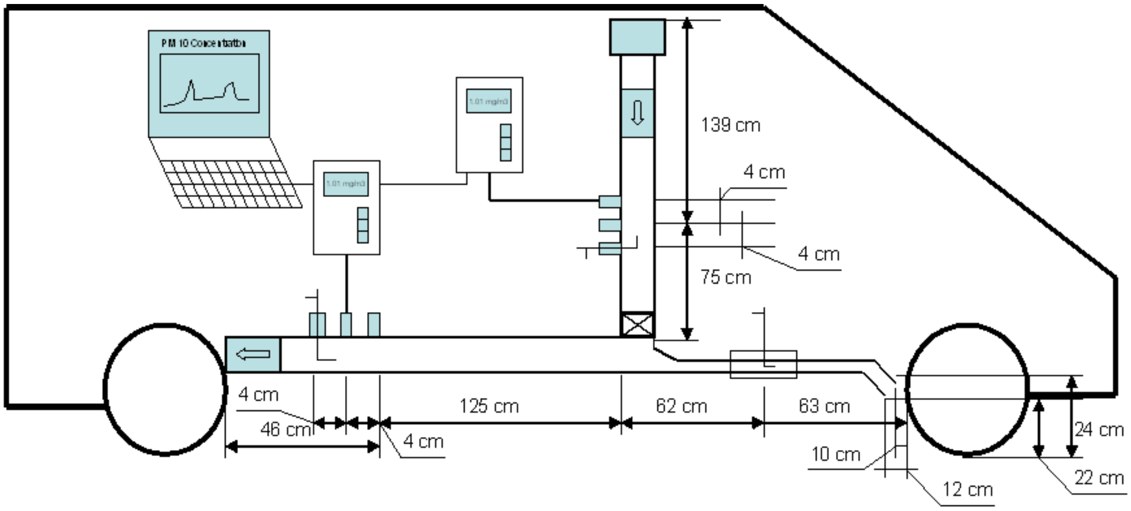
a. side view

b. inlet close-up

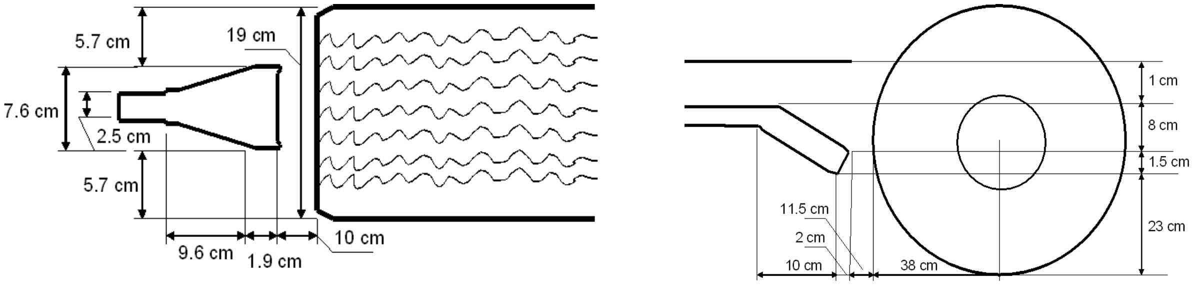
Figure 3-10. Schematics and Dimensions of TRAKER II



a. Functional TRAKER Diagram



b. Dimensions – Not drawn to scale



c. Inlet, Top View

d. Inlet, Side View

4.0 QA/QC

4.1 Horizontal Flux Tower

Horizontal fluxes of PM_{10} (units of grams PM_{10} per vehicle kilometer traveled – g/vkt) were calculated using data from the master tower. Level 0 data validation involved ensuring that instruments were operating properly and data were recorded correctly. This included cross-referencing the data recovered from computer files with dates and times of operation noted in field notebooks. Additionally, whenever new wire connections were made or modified or any part of the data acquisition was modified (change of communication ports on data acquisition system, replacement or exchange of DustTrak monitors, etc), the data files were spot-checked against the instrument visual display to ensure that readings in the data files corresponded to instrument labels.

Level I validation required visual as well as automated inspection of the data. The measured PM_{10} concentrations at multiple heights, wind speeds, and wind direction were plotted with one-second resolution. In addition, the vehicle passage times that were manually noted by field personnel and verified with GPS data onboard TRAKER I and TRAKER II were also plotted on the same graph.

Two factors were used to determine if a specific flux measurement associated with a specific vehicle pass was valid. First, the one-second wind direction over the duration of the three intervals – pre-peak background, peak, and post-peak background was examined. In cases where the average wind direction over the three intervals was within 45 degrees of the perpendicular line drawn between the tower and the road segment and the wind speed was relatively constant (i.e. holding at > 1 m/s from the same general direction), the wind direction was considered valid. In cases where the average wind direction was outside of this 90-degree window (45 degrees in each direction about the perpendicular), one-second data were examined. If the wind direction was always less than 75 degrees from the perpendicular, the wind speed was relatively constant, and fluctuations in wind direction did not exceed 30 degrees, the wind direction was considered valid. In all other cases, wind conditions were considered to invalidate the horizontal flux measurement.

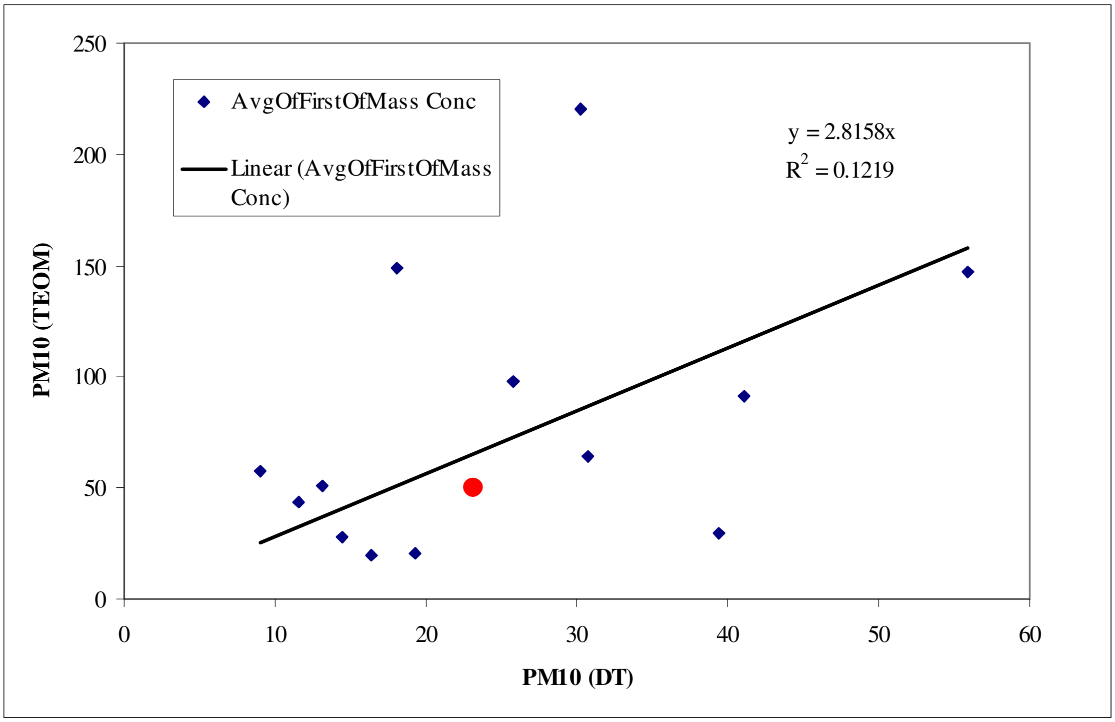
The second factor in determining the validity of a specific tower measurement was the noise level of the baseline PM_{10} concentration. During periods of high wind, wind-entrained dust clouds often passed by the flux tower (especially true on 9/14/06 and 9/15/06). These high and spurious concentrations of PM_{10} rendered the baseline from which peak values are estimated extremely noisy. In other cases, the passage of a large vehicle on the south side of Veterans Memorial Highway would sometimes result in a temporary spurious baseline reading. The entire time series of data from the flux tower was examined to flag periods when the baseline was too noisy for a measurement. Those data were considered invalid.

Note that an individual dust plume from a moving vehicle may exhibit a high degree of spatial heterogeneity, owing to the turbulent nature of air flow in the wake of a moving vehicle. Thus, an actual plume consists of clouds of dust interspersed with comparatively clean background air. This is especially true close to the road; PM_{10} concentrations become more spatially continuous and smooth as the plume advects and disperses downwind. For the present study, in certain cases, baseline noise levels and the wind direction over the expected peak period were acceptable. However, a visible peak associated with the passage of a vehicle was not always clearly discernible. In those cases, the measurement was considered valid and the PM_{10} flux was calculated and reported. Though these cases could result in near-zero or negative fluxes, which are not physically reasonable, it is important to retain these measurements to avoid biasing the data. Estimation of peak duration (whether or not peak was visible) is discussed in Section 5.1.

DustTrak Mass Correction

PM_{10} measurements with the DustTrak were compared to two types of mass-based PM_{10} measurements. First, the DustTrak located at 2.1 m on the master flux tower was compared to the TEOM measurements at the same height, also located on the master tower. Second, in-lab tests were used to more accurately obtain a relationship between the DustTrak measurements and mass-based measurements. The correlation between the DustTrak and TEOM on the master tower is quite noisy, but shows that DustTrak values would have to be multiplied by a factor of 2.8 ± 0.6 to obtain mass-equivalent PM_{10}. (See **Figure 4-1**)

Figure 4-1. Scatter Plot of DustTrak PM_{10} Average Concentrations and TEOM PM_{10} Measurements. Both measurements were collected at nearly the same height (2.1 m height) on the master flux tower. Red dot shows averages for all sets of measurements over the course of the study.



In the laboratory, we constructed a chamber in which the soil material that was used to seed the road at the Boulder City site (See section 3.2) was injected and suspended. The "resuspension chamber" was constructed from a modified medium volume sampler plenum (the DRI SGS-sampler) (Gertler et al., 1993). The dimensions of the cone shaped aluminum plenum and sampling configuration are provided in **Figure 4-2**. The resuspension technique involves the following steps. A small amount (~ 0.5 g) of the soil is placed in a 250 ml Erlenmeyer flask that is connected via Tygon tubing to the high-pressure air line in the laboratory. The valve is opened and the dust is suspended and injected into the top of the plenum by the high speed jet of air (**Figure 4-2**). At the bottom of the sampling plenum, through specially designed ports equipped with O-ring seals, dust-laden air is sampled through two Teflon filter holders (Savillex, 47 mm). This is accomplished with pumps (URG, model URG-3000-02Q) that draw 5 lpm through each of the filter holders. The chimneys of the filter holders are outfitted with in-line PM_{10} impactors (Airmetrics), similar to those used on MiniVol samplers (Airmetrics). [Note that the Airmetrics PM_{10} impactors are not regarded as primary reference instruments.] The flow rates (5 lpm) are set using calibrated rotameters. One of the Teflon filter holders houses a 47 mm Teflon filter. The other filter holder is used to channel the dust-laden air (already having passed through the PM_{10} size-selective inlet in the chimney of the filter holder) to two DustTrak samplers via conductive tubing. One DustTrak sampler is equipped with the manufacturer's PM_{10} inlet while the other is equipped with the manufacturers $PM_{2.5}$ inlet. This configuration ensures that the DustTraks "see" the same dust-laden air that goes through the Teflon filter. A zero-air filter is attached to the top of the sampling plenum to allow for through flow of clean room-air through the plenum to mix with the dust-laden air in the plenum.

Measurements with the resuspension chamber were completed within two weeks of the field study. Two DustTraks were randomly selected form the set of units that were used in the field study. Five target mass loadings were generated that spanned the ambient measured values at the test site as recorded by the DustTraks. The one-second DustTrak data measured were used to guide the target mass loadings. When the estimated target mass was reached the test was terminated. The one-second particle concentration measurements obtained with the DustTraks were used to calculate a time-integrated average, which was then compared with the average PM concentration obtained using the filter based gravimetric method for each target concentration.

The manipulation of the resuspension chamber testing was done manually. Lab personnel opened and closed all valves and started and stopped pumps manually. All timing of tests was determined by the elapsed time as recorded by the laptop computer recording the DustTrak instruments. A sampling interval was defined by the amount of time elapsed between the period when the injected dust was first recorded by the DustTraks (a quick and noticeable rapid rise above background) until the program indicated that the target mass loading had been reached. For the tests reported here, the target mass loadings were reached within 600 – 1300 seconds. All valves and pumps were closed or stopped within a few seconds after reaching the target mass. The mass concentration of PM for a sampling interval was determined by the difference between the post- and pre-weighed Teflon-filter membrane masses, the measured flow rate (5 lpm) and the elapsed time of the test (seconds). Filters were weighed on a microbalance with precision of 0.001 g.

Comparisons of DustTrak measured values and mass based PM_{10} obtained using this resuspension method are shown in **Figure 4-3**. The top panel of the Figure shows the results for the soils used in this study. For comparison, the bottom-panel shows results for a soil collected from Yuma, Arizona. The differences in the slopes indicate that this mass correction factor is specific to the type of soil being examined.

Figure 4-2. The resuspension chamber used to establish the relationship between the DustTrak-derived PM_{10} and PM_{10} derived by gravimetric analysis.

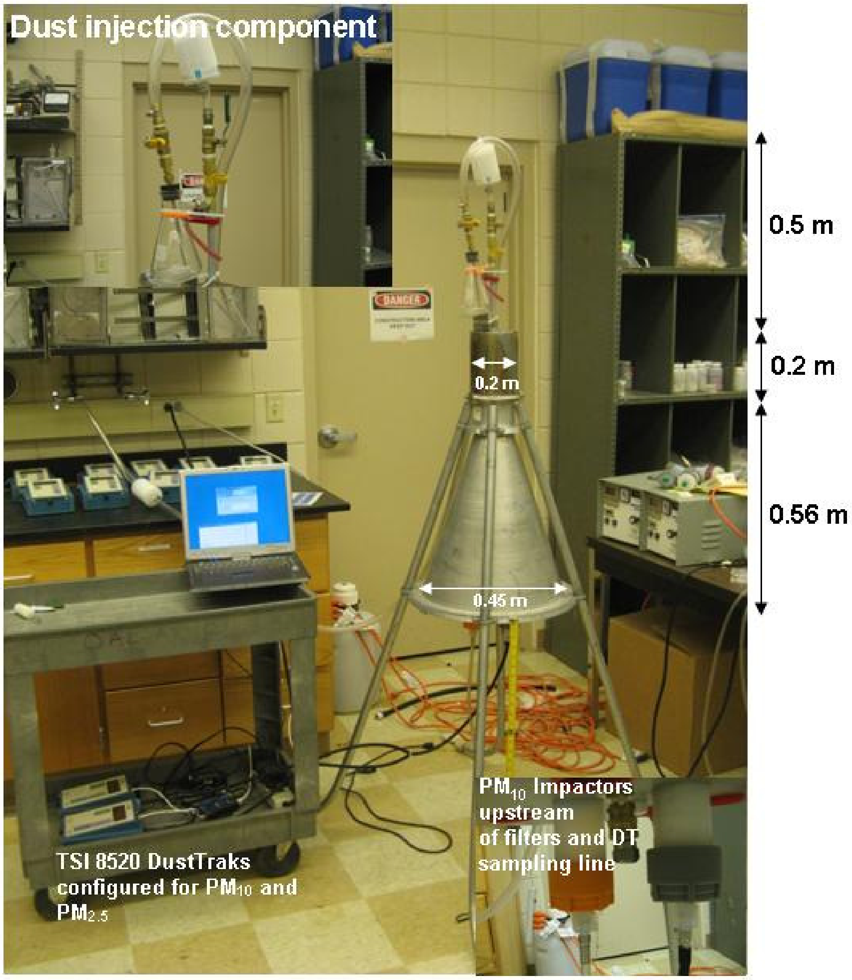
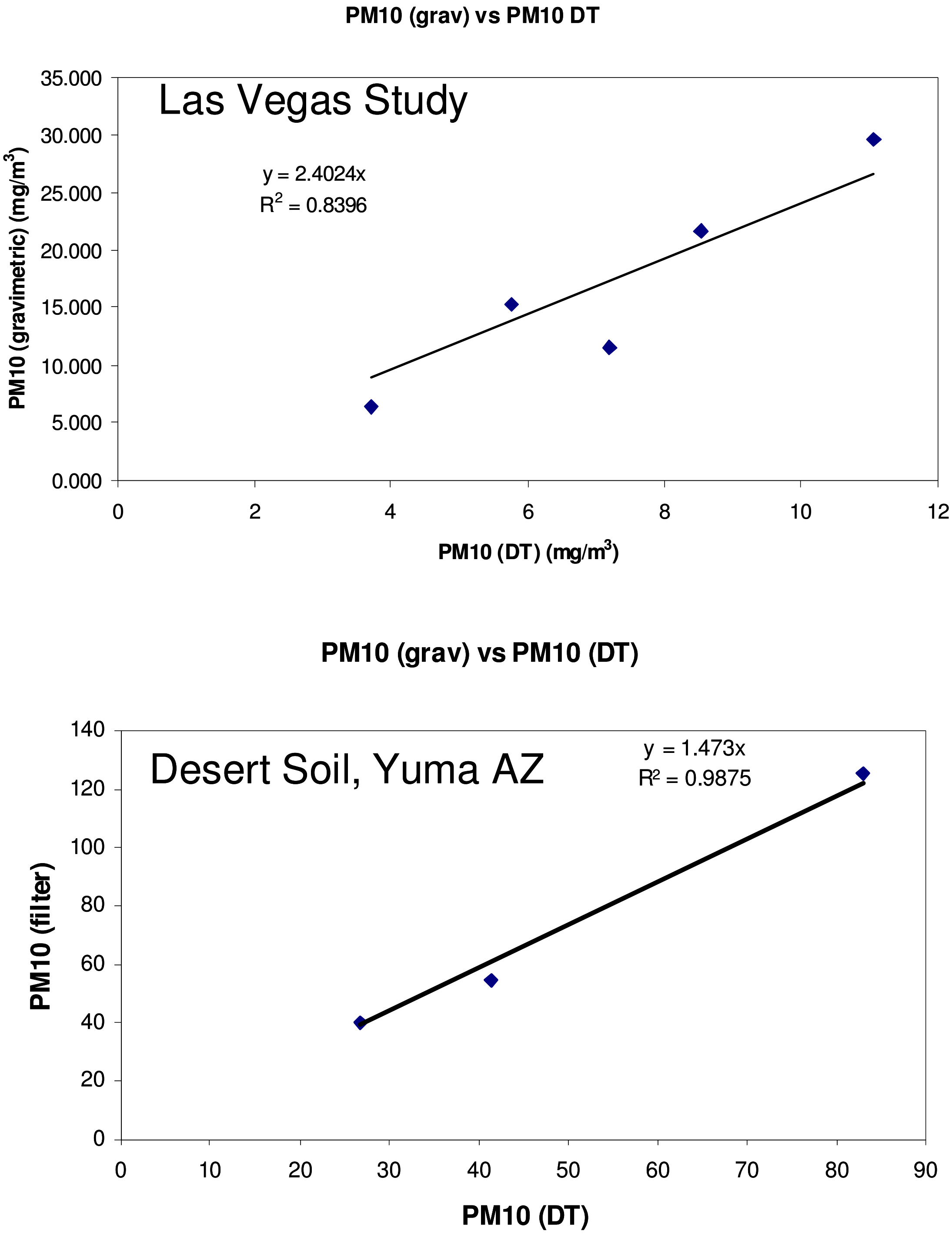


Figure 4-3. Relationships Between Gravimetrically Determined Average PM_{10} and Average PM_{10} as Measured With the DustTrak for the Boulder City Study (top panel) and a Separate Study Carried Out for a Desert Soil Collected at the Yuma Proving Ground, Yuma AZ



Results of this laboratory experiment showed that the DustTrak-measured $PM_{2.5}$ is highly correlated with the PM_{10} measurements ($PM_{2.5} = 0.501\ PM_{10}$, $R^2 = 0.955$) (**Figure 4-4**). The relationship between gravimetric mass concentration and DustTrak concentrations are also quite good. For PM_{10} filtered mass concentration versus DustTrak we observed the relationship PM_{10} (gravimetric) = 2.4 ± 0.2 × PM_{10} (DustTrak) with a correlation coefficient (R^2) of 0.84 (**Figure 4-3**). For the $PM_{2.5}$ the relationship between gravimetric and DustTrak derived mass concentrations was $PM_{2.5}$ (gravimetric) = 0.7 × $PM_{2.5}$ (DustTrak) with a correlation coefficient (R^2) of 0.891 (**Figure 4-5**).

Based on these two sets of collocated tests, one conducted in the field and the other in the lab, we chose a DustTrak correction multiplier of 2.4 corresponding to the in-lab measurements. Noting that the uncertainty in the regression between the DustTrak and the TEOM in the field encompasses this value (2.8 ± 0.6), the in-lab measurements were chosen for correcting the DustTraks because the correlation was much better than in the field. This was likely due to the fact that in the field, the DustTrak and TEOM were only nominally collocated whereas in the lab, the two instruments were sampling a well mixed controlled volume of air.

Figure 4-4. Scatter Plot of DustTrak Monitor Outfitted With $PM_{2.5}$ Inlet versus DustTrak With PM_{10} Inlet. Both instruments sampled silt material from the Phase IV tests that was resuspended in a specially designed chamber.

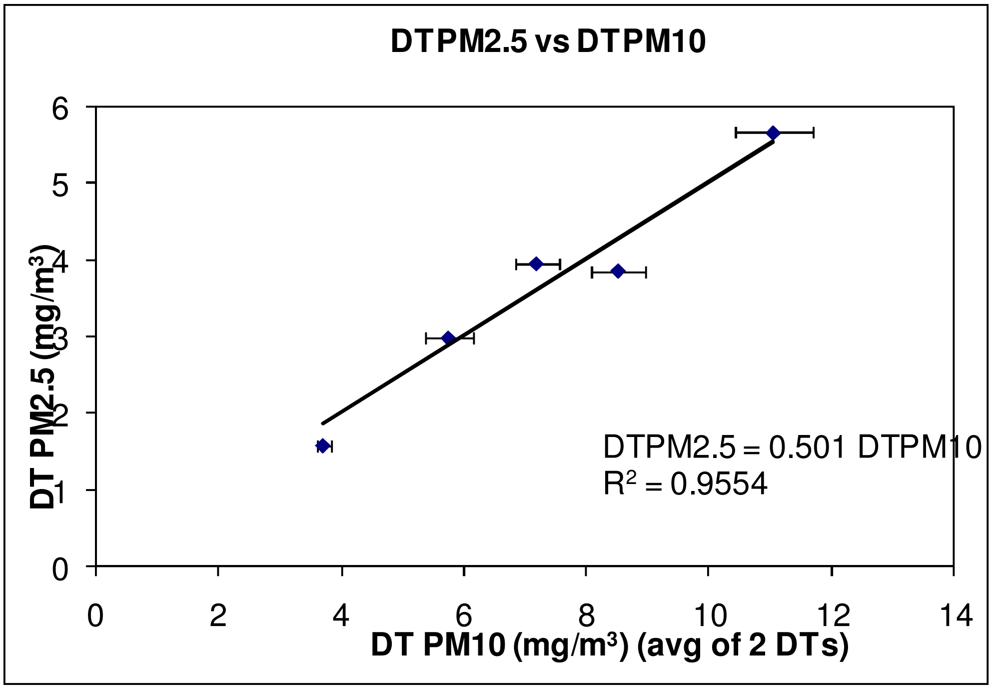
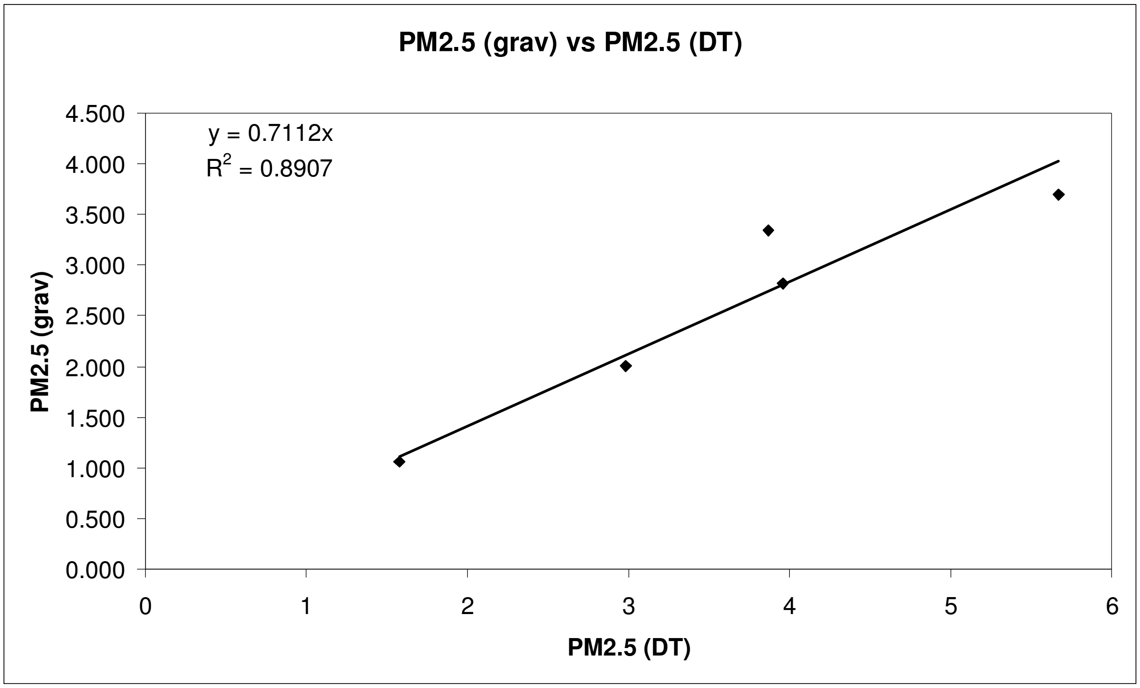


Figure 4-5. Comparison of Filter-Based $PM_{2.5}$ Mass Measurement With DustTrak Outfitted With $PM_{2.5}$ Inlet. Both instruments sampled silt material from the Phase IV tests that was resuspended in a specially designed chamber.



4.2 EPA Method AP-42

4.2.1 Field Balance Mass Calibration

Calibration of all postal measurement scales was carried out with Rite-O-Weigh® brass weights meeting ASTM Class 6 adjustment tolerances.

The Sunbeam 78411 postal scale has a readability of ±1 gram and was found to read within 1 gram of the true weight from 0 gram to 200 grams, and within 2 grams of the true weight from 200 grams to 1,000 grams.

The Pelouze SP5 Postal scale has a readability of +/1 gram was found to read within 1 gram of the true weight from 0 grams though 1,000 grams.

The Sunbeam Freightmaster® 150 scale for soil sample excavation has readability to ±0.1 kilogram. It was calibrated with the Rite-O-Weigh® brass weights over the 0.1-kilogram to 4.0-kilogram range and found to deviate less than 0.2 kilogram.

4.2.2 Road Plot Marking Uncertainty

Full size roadway plots 10 feet (3.05 meters) long by 13.5 feet (4.12) meters wide were marked with 3.05 meter and 4.12 meter string lengths were different colors, and were tied to form a rectangle with an uncertainty of +/- 0.05 meters (5 centimeters). Corners were squared so that the string was taut with standard building bricks, and then 2-inch masking tape was applied from a roller dispenser to match the perimeter established by the colored surveyors' twine. The tape perimeter was then marked with white surveyors paint and the tape was removed. White surveyor's paint spots are laid out at one foot (0.305 meter) intervals across the road way at each end of the 3.047 meter long plot to delineate the area to be vacuumed.

"Quickie strip" roadway plots 2 feet (0.610 meter) long by 13.5 feet (4.115 meters) wide were laid out between the full size plots. White surveyor's paint was used to mark the corners of the quickie strip plots. Painted lines or masking tape were not used to indicate boundaries of the quickie strips. As a result, vacuum path width for the quickie strips, guided only by the eye of the operator from the inside curb to the lane divider, tended to deviate by up to 1/6th of the 30 cm (12 inch) width of the Hard Floor tool, or about 5.0 cm or 2 inches. This deviation in path width results in a proportionately larger single sample uncertainty in the vacuumed area of the quickie-strip plots compared to the vacuumed area of the full size plots.

4.2.3 Sieve Analysis Calibration

Collected soil samples were held in sealed plastic containers for three weeks in a climate-controlled laboratory at UNLV. Ninyo and Moore's laboratory in Las Vegas, Nevada, performed sieve analyses. Sieves are manufactured to ASTM standard E-11:87 and to AASHTO M-92. Sieves are calibrated annually by a calibration laboratory following ATM Manual 32. All sieved masses are determined to ±0.1 gram on a calibrated electronic balance.

The eight-inch (20.3 cm) sieve stack recommended in AP-42, Section 13.2.1, Appendix C.2. (US EPA 1993b), consisting of sieve numbers 3/8 inch, 4 mesh, 10 mesh, 20 mesh, 40 mesh, 100 mesh, 140 mesh, and 200 mesh, plus pan, was used to sieve all recovered soil samples. A standard sieve time of 10 minutes was used, per AP-42 13.2.1 Appendix C.2. The sieves were agitated on a Tyler Ro-Tap® RX-29 mechanical Test Sieve shaker, operating at a fixed speed of 278 ± 10 revolutions per minute with 150 taps ±5 taps per minute. Silt masses were reported as the mass passing the number 200 (75 micron) sieve.

Upon review of AP-42 methods for minimum soil required sample masses (Appendix C.2, US EPA 1993b, page 7), where "100 to 300 grams may be sufficient when 90% of the sample passes a No. 8 (2.36 mm) sieve," soil masses for simultaneous parallel bags from the same sampling location and vehicle pass were combined for sieving to make total sieve masses exceeding 100 grams, if individual bag masses were less than 50 grams.

Sieving analyses by Ninyo and Moore were "blind" in that they did not know the location or expected composition of the recovered soil samples.

All sieving work was completed by the end of October 2006. Ninyo and Moore transmitted soils data back to UNLV as multi-page PDF files, with one page for each sample. Each page of the PDF file contained results for one sample, organized by UNLV site identification number.

4.3 Mobile Technologies

4.3.1 SCAMPER

The zero response and flow rate of each DustTrak was recorded at the beginning and end of each day. In prior studies the response of the rear DustTrak was compared to mass determined by collocated filter samples. The average response factor based on a linear regression was approximately 3. Given the scatter of the data, this is in general agreement with the correction factor described previously. The response of the DustTraks was therefore less than when calibrated using Arizona Road Dust. This most likely is due the PM_{10} behind the SCAMPER consisting of a greater fraction of larger particles than the Arizona Road Dust. The mass-specific light scattering response drops rapidly with increasing particle size for particles larger than 1µm diameter, thus a small change in the particle-size distribution can change the response significantly.

The data acquisition system recorded all data digitally at one-second intervals. Data was downloaded from the PC and entered into an Excel worksheet where all of the calculations were made. Quality control data such as inlet pressure and various voltages were also entered into the master worksheet in addition to GPS location, time, speed, and DustTrak values.

Data was validated to Level 0 and then Level 1 status from QC pressure and voltage data, logbook entries, and by observing time series, to determine if the results made physical sense. The data was flagged as follows in the Excel worksheet:

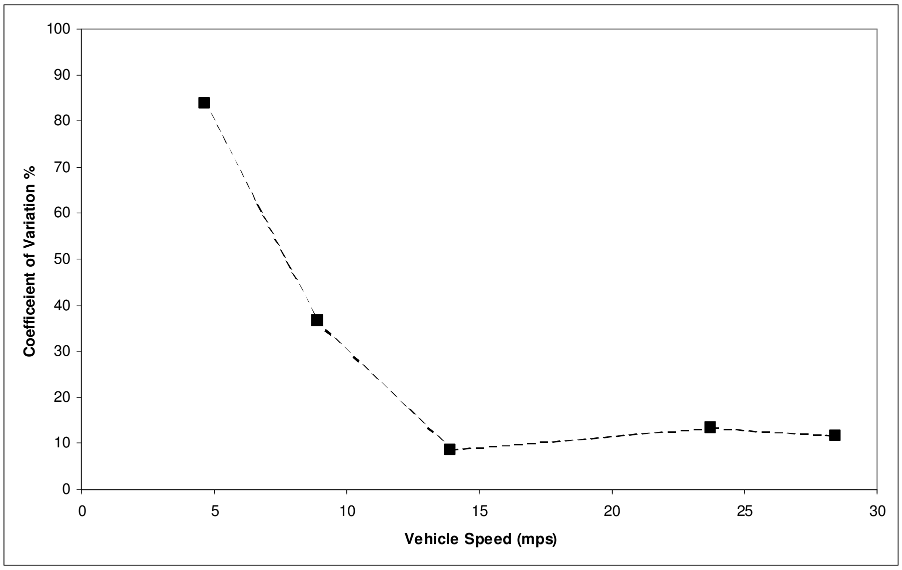
0 or blank: valid data
1: missing or erroneous
2: DustTrak on filtered air for zero check- not moving control
3: DustTrak on filtered air for zero check-moving control
J: DustTrak values not changing for 30 seconds of more

4.3.2 TRAKER I

The DustTrak instrumentation onboard the TRAKER vehicle has a resolution of 1 µg/m^3. Thus, the smallest measurable difference in concentration between the tire and the background monitor locations is 1 µg/m^3. This corresponds approximately to a single-point minimum detection limit equivalent to an emission factor of 0.0005 g/VKT (0.0008 g/VMT) for paved roads, meaning that any 1 s measurement can be resolved to within this value only. In practice, emission factors from real roads are generally higher than 0.01 g/ VKT (0.016 g/VMT). At the other end of the measurement range, DustTrak readings above 150 mg/m^3 are not reliable. This corresponds to an emission factor for PM_{10} of approximately 75 g/VKT (120 g/VMT). Again, in practice, 20 g/VKT (32 g/VMT) represents an upper limit to paved road PM_{10} emissions.

Figure 4-6 shows the TRAKER coefficient of variation calculated from the left and right PM_{10} DustTrak signals as a function of vehicle speed. The coefficient of variation is a measure of the relative precision and is equal to the standard deviation of the measurement divided by the average of the measurement. In the figure, the measurement corresponds to multiple passes on the same 1-mile stretch of road (Etyemezian et al., 2003). The figure shows that the precision of the measurement improves with increasing vehicle speed. The precision is 84% at 5 m/s, 30% at 9 m/s, and approximately 10% above 14 mps. Note that most TRAKER measurements occur at speeds greater than 9 m/s (approximately 20 mph). The poor precision at low speeds is probably due to the influence of fluctuating ambient winds on the flow regime behind the front tires. As the vehicle speed increases, such fluctuations become less important compared to the speed of the vehicle.

Figure 4-6. TRAKER coefficient of variation expressed as a percentage for left and right PM_{10} DustTrak signals as a function of speed. The data represent left and right PM_{10} DustTrak signals averaged over a 1-mile stretch of road near Boise, Idaho (Etyemezian et al., 2003). The coefficient of variation provides an estimate of the precision and is equal to the standard deviation of a measurement divided by the average.



The vehicle speed can become important in moderate to high winds. If the TRAKER is not moving fast enough, crosswinds and fluctuations in the ambient winds can lead to unsteady flow conditions between the front tire and the inlet. To avoid this possibility, a minimum speed of 5 m/s is required to consider a data point valid. Acceleration/deceleration criteria (<0.7 m/s^2) are also applied to the TRAKER measurement. During periods of high acceleration, the flow regime around the inlets may be transient; during periods of deceleration, dust from the brakes may influence the particle concentrations behind the front tire. Note that in the prior work of Etyemezian et al. (2003a, 2003b) and Kuhns et al. (2001) the criterion for acceleration was 0.5 m/s^2. Relaxation of the criterion for the present study should not affect the measurement quality significantly since the original criterion was set to be overly conservative.

In addition, the wheel angle must be less than 3 degrees with respect to the vehicle body. This is to ensure that the orientation of the inlets with respect to the front tires is not changing over the course of the measurements. The vehicle speed, acceleration, and wheel angle are calculated from the time derivatives the 1-second GPS coordinates. The criteria shown in **Table 4-1** are based on empirical observations and statistical analyses of the TRAKER measurement under a variety of driving regimes. These criteria are applied to the one-second data prior to any further aggregating or averaging. They are conservative and intended to ensure that the measurements used in this study are valid.

Table 4-1.Validity criteria applied to each 1 s TRAKER data point.

Parameter	Criterion	Threshold	Description
Speed	>	5 m/s – paved roads (~ 11 miles/hr)	Minimize disturbances due to ambient winds.
Acceleration	<	0.7 m/s^2 (~ 1.3 miles/hr/s)	Lateral shear during acceleration and transient airflow around the TRAKER inlets render TRAKER measurements during times of high acceleration unreliable.
Deceleration	<	0.7 m/s^2 (~ 1.3 miles/hr/s)	Applying the brakes releases dust particles and may result in false high road dust readings.
Wheel Angle	<	3 degrees with respect to the vehicle body	Turns cause the front wheels to form an angle with the vehicle body. This in turn changes the orientation of the TRAKER inlets with respect to the front tires. Data associated with sharp turns are not valid.

Level 0 validation was performed by examining the DustTrak and GPS time series for the entire study. The data were examined for completeness and correspondence with known sampling times. GPS data were checked by mapping coordinates from the GPS receiver on a spatially referenced GIS map. Any documented deviations in flow rate or procedure were examined to ensure that they did not affect data quality. For the entire study, all instruments were found to be logging as expected and no deviations from normal operating procedure were noted. In addition, the DustTrak zero-check on all days indicated that there was not significant instrument drift from day to day (i.e., correction required was less than 3 $\mu g/m^3$)

Level I validation included examination of the time series for each pass that was completed through the test course. We looked for sudden jumps (spikes or troughs) in the DustTrak record as well as in the GPS time series. In TRAKER I, the DustTrak samples air from a plenum with an approximate residence time of 2 seconds. Thus, spikes in PM_{10} concentration that appear for only one second are considered suspect data. No such data were found for the present study.

Level II validation included examining relationships between the signals on the left and right TRAKER inlets as well as over the course of a measurement set. The ratio of PM_{10} concentrations measured behind the tires to those measured at the background (bumper) inlet was also examined to ensure that the TRAKER signal was substantially above background.

4.3.3 TRAKER II

Noting that the use of TRAKER II as part of this study was experimental and that this updated version of TRAKER I has not been as extensively characterized, TRAKER II data were handled in a manner similar to TRAKER I. The same speed, acceleration and wheel angle criteria applied to TRAKER I (Table 4-1) were also applied to TRAKER II on a one-second basis. Level 0 validations included ensuring that all instruments were operating and logging data during the measurement period. Level I validation included examination of time series of DustTrak concentrations and GPS data. Time series of the flow rates through the left and right inlets were also examined for deviation from the fixed value of 10 lpm. It was discovered during this examination that for all of 9/11/06 and a portion of 9/12/06 the flowrate through the inlets was not being properly maintained at 10 lpm, but rather was held at 6 lpm. This problem was attributed to a glitch in the software that controls the TRAKER II data acquisition system and repaired in the field. In summary, TRAKER II passes with Pass IDs of 170 and higher were considered level I valid whereas those with Pass ID lower than 170 were considered invalid.

Level II validation was conducted as part of the data analysis for this study and the outcomes of that effort are summarized in a later section along with other study findings.

5.0 DATA HANDLING

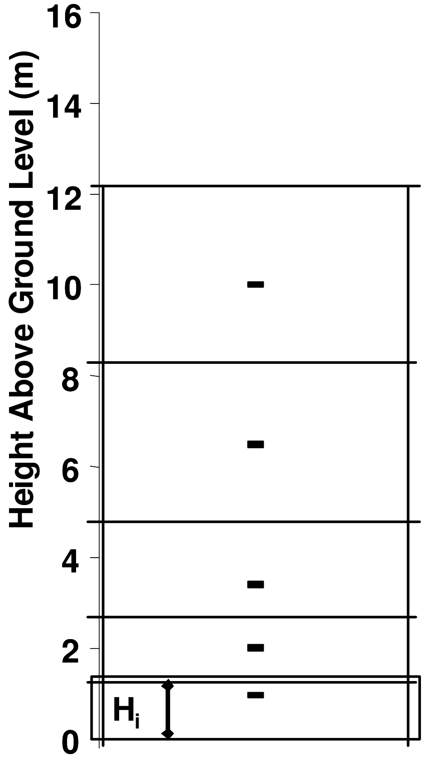
5.1 Horizontal Flux Tower

Horizontal PM_{10} fluxes were calculated from the tower data for all individual passes that met the validation criteria outlined in Section 4.1. This measurement is similar in principle to the upwind/downwind technique employed in previous work (e.g. Cowherd, 1999) with one major difference in its practical application. As the name implies, the upwind/downwind method relies on measuring the horizontal flux of PM_{10} through the upwind side of the road and the downwind side of the road separately. The flux on the upwind side is subtracted from the flux measured on the downwind side in order to determine the net contribution of horizontal PM_{10} flux from the road. The technique used in this study employs only one tower that is located on the downwind side. Since the source of PM_{10} road dust was intermittent and associated with the passage of individual vehicles through the test road, periods when there was no vehicle activity through the test road where considered to represent the background horizontal PM_{10} flux. In this sense, these periods correspond to the “upwind” measurement. Similarly, times when the tower was impacted by the passage of a test vehicle correspond to the “downwind” measurement.

As mentioned in that section, the two factors that were used to determine whether a data point was valid or not were the wind direction/speed and the background noise level, determined from periods with no influence from any of the test vehicles. The general approach for calculating the horizontal PM_{10} flux was to assume that the master tower was located in a flux plane parallel to the road and that the multiple vertical measurements of wind speed, wind direction, and DustTrak PM_{10} concentrations each represented a discrete section of the tower height. This is illustrated in **Figure 5-1** which shows instruments mounted at 0.7, 2.1, 3.4, 6.4, and 9.8 m above ground level representing the sections spanning 0 – 1.4, 1.4 – 2.75, 2.75 – 4.9, 4.9 – 8.1, and 8.1

- 12 m, respectively. Following the method of Etyemezian et al. (2004), each DustTrak was assumed to represent the concentration of PM_{10} over a distance that spanned halfway to the DustTrak location above and halfway to the DustTrak location below.

Figure 5-1. Illustration of Portions of Flux Plane Represented by DustTrak and Wind Instruments at Each Height. The dots shoe the instrument locations and the horizontal lines show the height range that the instruments represented in calculating flux.



An emission factor (*EF,* g/km) for each vehicle pass was calculated using the equation:

$$EF = \alpha \left[\sum_{i=1}^{5} \sum_{t=t_{begin}}^{t_{end}} u_{t,i} \cdot \left(C_{t,i} - C_{0,i,,t_{begin}-t_{end}} \right) \cdot H_i \cdot \cos(\theta) \right] \times 1000 \qquad \text{Equation 5.1}$$

where: i refers to the vertical section represented by the DustTrak height, t is the time (sec), t_{begin} is the peak start time, t_{end} is the peak end time, u is the wind speed (m sec^{-1}), C is the measured concentration (g m^{-3}), C_0 is the background concentration over the period t_{begin} - t_{end} (g m^{-3}), and H is the height of the section of the flux plane represented by position i, θ is the angle of the 1-sec wind direction relative to the flux plane, and α is a constant used to convert DustTrak-measured PM_{10} concentrations to mass equivalent PM_{10} and has a value of 2.4 (See Section 4.2). An example calculation is provided in an Appendix to this report.

In some cases, DustTrak concentration peaks were clearly discernible and associated with the known passage of a vehicle. In practice, this required that DustTrak concentrations departed from baseline values on multiple DTs within 15 seconds of the passage of a test vehicle in front of the master tower. In those cases where peaks were clearly associated with the test vehicle, the peak curves were divided into three intervals. The first interval corresponded to the background PM_{10} concentration prior to the peak and included the 10 – 30 second period that ends with the peak start time. The second interval was bounded by the peak start and stop times (giving the values of t_{begin} and t_{end}), which were determined visually as the instance when any of the tower-mounted DustTraks began exhibiting a peak in concentration to the instance when all of the tower-mounted DustTraks exhibited a return to baseline concentration values. The third interval corresponded to the background PM_{10} concentration after the end of the peak and included the 10- to 30-second period after the peak stop time. The first and third intervals were aggregated to estimate the baseline average PM_{10} concentrations (C_0 in Equation 1) for each DustTrak and the noise level (standard deviation) exhibited by the background signal. For cases where a peak was not clearly discernible, the peak duration was assumed to span 20 seconds that were centered on the recorded vehicle passage time.

Horizontal fluxes calculated using Equation 1 yielded an emission factor in units of gram PM_{10} per kilometer traveled for every time a test vehicle passed through the test course and wind conditions and background PM_{10} levels were considered acceptable for providing a valid measurement.

5.2 EPA Method AP-42

5.2.1 Organizing Bag Data

Soil sample bag data, consisting of a bag number, its assigned UNLV site number, date and time, tared mass, and final mass were entered into a the MS Access® database. This database was used to organize and print out bag identification data in tables were transmitted with the soil samples to Ninyo and Moore's geotechnical laboratory for soil sieve analysis.

5.2.2 Organizing AP-42 Emission Factor Data

Returned silt masses from AP-42 sieving conducted by Ninyo and Moore were manually entered into the Access® bag database.

The Access® database table was then exported to an Excel® database to facilitate calculation of AP-42 Emission Factors. The silt recovery time that most closely matched the time of a particular vehicle pass identification number, taken from the DRI Excel® vehicle Pass_ID and time database, was used to match silt recovery to a mobile technologies event. An entry was made in the AP-42 Excel® database to indicate if the silt recovery had taken place before or after the vehicle Pass_ID. Where available, separate silt mass values were entered for each corresponding Pass_ID for both the south and north zones. Silt mass data were then converted into silt loadings by dividing by the corresponding plot area in square meters. Uncertainties in individual silt loadings were computed using root-mean square (RMS) error analysis of the uncertainty in the silt mass and the uncertainty in the plot area.

AP-42 emission factors were then calculated for the silt loadings using the AP-42 emission factor equation.

$$EF = k * (SL/2)^{0.65} (W/3)^{1.5} - C, \qquad \text{Equation 5.2}$$

where: EF = the computed AP-42 PM_{10} emission factor in gram/VMT or gram/VKT

k = the coefficient for PM10, with values of
$7.3\ \text{gram}^{0.35}\text{-m}^{1.30}/(\text{VMT-ton}1.5)$ or
$4.6\ \text{gram}^{0.35}\text{-m}^{1.30}/\ (\text{VKT-ton}1.5)$

SL = silt loading in gram/m^2 calculated from field measurements,

W = a fleet average vehicle weight in U.S. short tons, and

C = the brake and tire wear correction factor, with values of:
0.2119 gram/VMT, or
0.1317 gram/VKT.

A weight of 2.88 tons, based on the arithmetic average of the reported weights of the three mobile source vehicles (SCAMPER 2.5 tons, TRAKER I 3.4 tons, and TRAKER II 2.75 tons) was used to calculate the AP-42 emission factors from the silt loadings.

Uncertainties in the individual emission factors were computed using root-mean square error analysis of the uncertainty in silt loading. Fleet vehicle weight was assumed to be known exactly, with an uncertainty of zero.

In cases where multiple silt loading measurements, in the north or south, were available for a particular Pass_ID, the average north or south silt loading measured for that pass was used to compute the AP-42 emission factor. Standard deviations of the north and south silt loadings were calculated, and for each zone, the larger value of the individual RMS silt uncertainty or the plot-to-plot silt standard deviation was used in a root mean square computation of the AP-42 emission factor uncertainty.

Averages and standard deviations of the silt loading and AP-42 Emission factors for each Pass_ID were computed from the combined north and south zone data, where available. The larger uncertainty of the RMS error calculation or the north-south standard deviation was used as the uncertainty of the AP-42 emission factor measurement.

The Excel® database containing date, time, vehicle Pass_ID, vehicle speed, silt loadings and silt loading uncertainties, and AP-42 emission factors and emission factor uncertainties was then transmitted to all cooperating agencies for data analysis.

5.2.3 Unification of Data Sets

DRI combined the following data sets using Vehicle Pass_ID as a common variable into a master Excel database that was used for joint data analysis:

(1) UNLV AP-42 emission factor data, averaged north and south for each pass,
(2) Tower mass emission rate data, averaged for each pass,

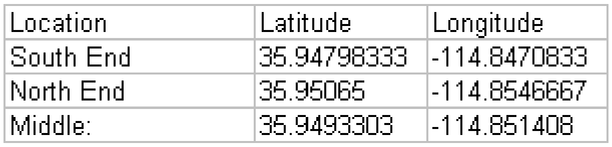
(3) SCAMPER, TRAKER I and TRAKER II mobile technologies data, averaged for each pass.

5.3 Mobile Technologies

5.3.1 SCAMPER

The data acquisition system for the SCAMPER collects GPS and digital DustTrak values once per second and stores them in a folder by hour of the day. These data were then merged into an EXCEL spreadsheet for post-processing. The one-second data from both the front and rear DustTraks were corrected for the average zero response (from the beginning and end of each set), and then the front concentration was subtracted from the rear. The result was multiplied by the frontal area of the Ford Expedition ($3.66m^2$), to yield the emission factor in mg/m. All data with a flag of 1 (missing or erroneous data) were removed from the data that were submitted. The master Excel worksheet shows all the calculations and all flags.

Data for the test track were selected from the GPS coordinates of the test track boundaries and the heading of SCAMPER. The test track was divided into southern and northern segments to facilitate comparisons with the AP-42 silt sampling conducted on those ends of the test track. The following coordinates were used for boundaries:



Location	Latitude	Longitude
South End	35.94798333	-114.8470833
North End	35.95065	-114.8546667
Middle:	35.9493303	-114.851408

The data were checked to insure that flags 2 and 3 (for QC checks conducted away from the Sampling Zone) were removed in this process. No "J" flags (concentration unchanged for 30 sec) were found in this data set. There were occasional periods when the GPS did not report data, most likely due to interferences in the sight path to a satellite. In these cases the cell was filled with the average of the position before and the position after. The same was done for speed and PM_{10} emission rate. Averages and standard deviations of this emission rate data were calculated for the southern end, northern end, and full track each test pass.

Concentration units (mg/m^3) were used in the "calibration" with the tower performed by DRI. These units were derived by dividing the emission rate originally reported for the full test track by the frontal area of the Expedition ($3.66m^2$).

5.3.2 TRAKER I

Following validation of individual one-second TRAKER I data, several steps were taken to align and aggregate the data points for data analysis. First, the GPS time stamp was retarded 3 seconds and linked to the DustTrak data using the retarded time. This was done to account for the discrete amount of time (3 seconds) that it takes for the air at the inlets of the TRAKER I to move through the inlet lines and plenum and the DustTrak sampling nozzle. That is, data logged by the DustTrak at time t_0 corresponds to the dust that was channeled to the inlet of the TRAKER (either behind a tire or through the bumper at time t_0 – 3 seconds.

Next the TRAKER signal was calculated for all valid data points using the equation:

$$T_t = \left(C_{R,t} + C_{L,t}\right)/2 - C_{B,t} \qquad \text{Equation 5.3}$$

Where T_i is the TRAKER signal in mg/m^3 at time t and C_R, C_L, and C_B are the concentrations (mg/m^3) respectively measured at the right, left, and middle (background) inlet. The quantity T in Equation 1 is the main entity that is provided by the TRAKER measurement system and is the "raw" TRAKER signal.

Next, only data that correspond to the test route were selected for analysis. This was accomplished by imposing limits on the latitudes and longitudes of the GPS coordinates as well as the direction of travel of the vehicle (See **Figure 5-2**). After extracting only data that correspond to measurements along the test route, each data point was associated with a Pass ID number common to all study participants. Depending on the speed of travel on the test route, between 28 and 57 points were associated with each Pass ID that was assigned to TRAKER I. An example of the raw vehicle Pass ID data is shown in Table 5-1. Pass durations are about 1.5 minutes at 35 mph intervals between successive vehicle passes within a given Run ID.

Table 5-1. Example of Vehicle Pass_ID Data. Pass durations are about 1.5 minutes at 35 mph intervals between successive vehicle passes within a given Run ID.

Date	Set_ID	Test_type	Run_ID	Pass_ID	Vehicle	Speed (mph)	Drive Direction	Time (Local)	Exact time?
9/11/2006	1	Pre-sweep	1	1	UC	35	N	11:56:20	Y
9/11/2006	1	Pre-sweep	1	2	TR1	35	N	11:57:32	Y
9/11/2006	1	Pre-sweep	1	3	TR2	35	N	12:02:49	Y
9/11/2006	1	Pre-sweep	1	4	UC	35	S	12:04:25	Y
9/11/2006	1	Pre-sweep	1	5	TR1	35	S	12:05:53	Y
9/11/2006	1	Pre-sweep	1	6	TR2	35	S	12:07:09	Y
9/11/2006	1	Pre-sweep	2	7	UC	35	N	12:08:49	Y
9/11/2006	1	Pre-sweep	2	8	TR1	35	N	12:10:18	Y
9/11/2006	1	Pre-sweep	2	9	TR2	35	N	12:11:42	Y
9/11/2006	1	Pre-sweep	2	10	UC	35	S	12:13:23	Y
9/11/2006	1	Pre-sweep	2	11	TR1	35	S	12:15:04	Y
9/11/2006	1	Pre-sweep	2	12	TR2	35	S	12:16:26	Y
9/11/2006	1	Pre-sweep	3	13	UC	35	N	12:18:00	Y
9/11/2006	1	Pre-sweep	3	14	TR1	35	N	12:19:27	Y
9/11/2006	1	Pre-sweep	3	15	TR2	35	N	12:20:25	Y

There are 468 total passes in the database that covers the five days of Phase IV experiments. Data in Table 5-1 are shown only for the first 15 passes of Set 1.

Experimental Set_ID numbers describe different experiments that took place during the Phase IV experiments. Each Set number describes a different experimental condition. Usually, each Set ID number describes a unique combination of applied silt loading and mobile technology vehicle speed.

A summary of the Pass_ID numbers that correspond to each Set_ID in the Phase IV study is shown in Table 5-2.

Table 5-2. Summary of Set_ID's and corresponding Pass_ID's for the Phase IV study[**]

Date	Set #	Experiment Name	Start Pass_ID	End Pass_ID	Nominal Drive Speed (mph)	Applied Soil Loading (gram/m2)	Avg. Recovered Silt Loading, (gram/m2)
9/11/06	1	Pre-Sweep	1	60	35	N/A	0.17
9/11/06	2	Post-Sweep	63	92	35	N/A	N/A
9/11/06	3	Apply silt #1	93	139	35	6.16	0.75
9/12/06	4	Apply silt #2	140	169	45	17.17	2.48
9/12/06	5	Apply silt #3	170	211	25	16.58	3.17
9/13/06	6	Apply silt #4	212	241	45	4.99	0.88
9/13/06	7	Apply silt #5	243	272	25	4.70	0.74
9/13/06	8	Apply silt #6	273	308	45	7.63	1.14
9/14/06	9	Apply silt #7 - Depletion, one vehicle	309	318	35	7.78	0.80
9/14/06	10	Apply silt #7- all vehicles	319	331	35	7.78	0.80
9/14/06	11	Post-sweep	334	364	35	N/A	
9/14/06	12	Apply silt #8 - strong winds	365	391	Repeat 25,35,45, 45,35,25 cycle twice	17.61	2.55
9/15/06	13	Apply silt #9 - strong winds	392	476	Repeat 25,35,45, 45,35,25 cycle 4 1/2 times	28.47	2.31

[**] Pass IDs 61, 62, 242, 328, 332, 333, 358, and 449 do not correspond to test vehicles used in this study.

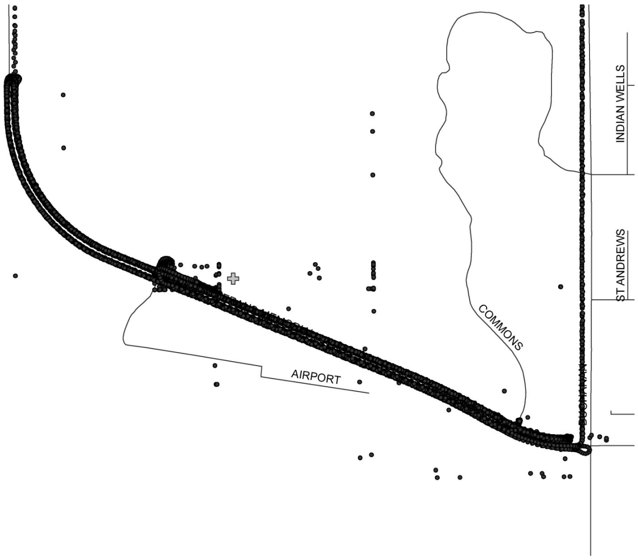
To facilitate comparison among the different measurement systems (TRAKER II, SCAMPER, Tower measurements, and silt measurements), all real-time data were aggregated by vehicle pass. For the remainder of data analysis, pass-averaged TRAKER signals are used. That is, the TRAKER signal (Equation 5.3) was averaged over all real-time data points acquired during a specific Pass ID, and the resulting average value was used to represent the TRAKER I signal for that Pass ID. Each pass corresponded to a linear distance of approximately 760 m (distance that spans northern and southern locations where AP-42 measurements were performed). The effects of this assumption/simplification were examined by comparing pass-averaged TRAKER I signals to the averages of data points that correspond only to measurements taken within 50 m of the master tower (See **Figure 5-2b**). **Figure 5-3** shows that there is a good correlation (R^2 = 0.82) between the pass-averaged TRAKER I signal and the TRAKER I signal averaged only over data points that correspond to measurements within 50 m of the master tower. Nevertheless, the relationship does exhibit substantial noise (note: in log scale) indicating that a number of factors can change over the length of the test route including the road dust loading and the portion of the lane where the driver is driving the vehicle.

Figure 5-4 shows a time series of pass-averaged TRAKER I signal over the whole length of the test road section (between the longitudes: -114.854849 and -114.847239) as well as averages in the vicinity of the DRI flux tower (between longitudes of -114.853817 and -114.852524, See also **Figure 5-2**). The "Tower-averaged" TRAKER signals tend to exhibit more pass-to-pass variability than the "pass-averaged" signals. This is to be expected since the former are averages over a smaller number of individual one-second measurements (5-12) compared to the latter which include many more data points (25 - 60). Larger numbers of data points in the average mitigate variations in driving technique and road dust distribution on the test road surface. In some cases, (e.g. Set 3 and Set 12), the "pass-averaged" TRAKER I signal is consistently higher than the tower-averaged signal, indicating that silt was probably not applied uniformly over the length of the test road. In addition, prior to application of silt (i.e. Sets 1 and 2), there are substantial differences between the TRAKER I signal over the entire test road length and the TRAKER I signal in the vicinity of the tower. This is true for both eastbound and westbound travel. This suggests that the "natural" condition of Veterans Memorial Highway around the area of the measurements consists of a high degree of spatial variability with respect to road dust emissions. However, overall, agreement between TRAKER I signal averaged over the two different lengths of road is quite good (See **Figure 5-3**).

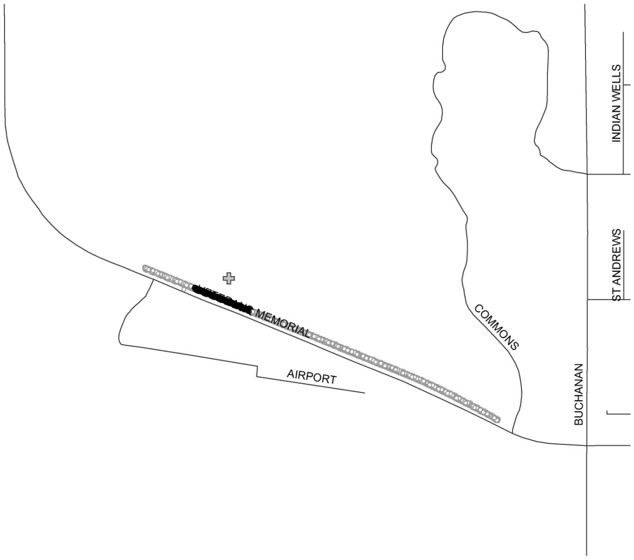
In applying Equation 5.3 to obtain the TRAKER I signal, two observations are worth noting. First, the value of C_R and C_L were substantially higher than C_B for all TRAKER I passes (**Figure 5-5**). This indicates that the "influence" measurements behind the two front tires were able to resolve a signal substantially above background (minimum of a factor of 10) for even the cleanest road conditions encountered over the duration of the study.

Second, the signals (concentrations) measured behind the right and left tires were not equal over the course of the study. While the ratio of the right to left signal fluttered about unity for many of the test passes, for some measurement sets (11 and 13), the right signal was considerably higher than the left signal and for other measurements sets (1 and 2) the opposite was true. **Figure 5-6** shows a time series of the ratio of the TRAKER I right inlet signal to the left inlet signal. The vertical lines in the Figure indicate the beginning of a new measurement set and the gray squares indicate passes along the same test route in the eastbound (instead of the primarily used westbound) direction. Note that eastbound passes were conducted in the lane adjacent to the one where westbound passes were completed. The figure shows that the ratio of right to left inlet signals can vary substantially. This variation does not appear to be caused by moderate cross-wind (< 6 m/s or < 13 mph), but rather by variations in the distribution of road dust material on the road as well as variations in where the vehicle tires are with respect to the lane (i.e. where the driver guides the vehicle with respect to previous passes and drivers of other test vehicles). Having noted these asymmetries, the actual PM_{10} emissions are a combination of the signals from both sides of the vehicle. Thus, using the average of the left and right signals as is done in Equation 1 is appropriate for estimating road dust emissions.

Figure 5-2. Schematic of GPS Data Points on Top of Street Layout. a. All TRAKER I GPS data and b. only data that correspond to the test route or data collected within 50 m of the master tower (black dots). The gray cross shows the approximate location of the master tower.



a. all TRAKER data points



b. Data filtered for validity and location on test route and/or within 50 m of master tower.

Figure 5-3. Relationship Between TRAKER I Signal Averaged Over Entire Pass (route length) and TRAKER I Signal Only Within 50 m of Master Tower

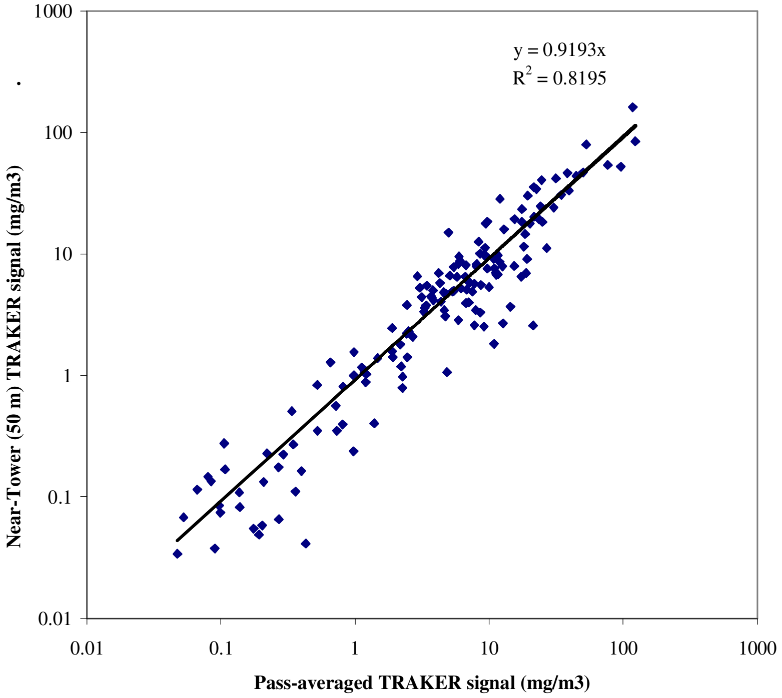


Figure 5-4. TRAKER Signal (left and right) Averaged Over Entire Pass (pass-avg.) and Averaged Over Only the Portion of Test Road in the Vicinity of Flux Tower (Tower-avg.)

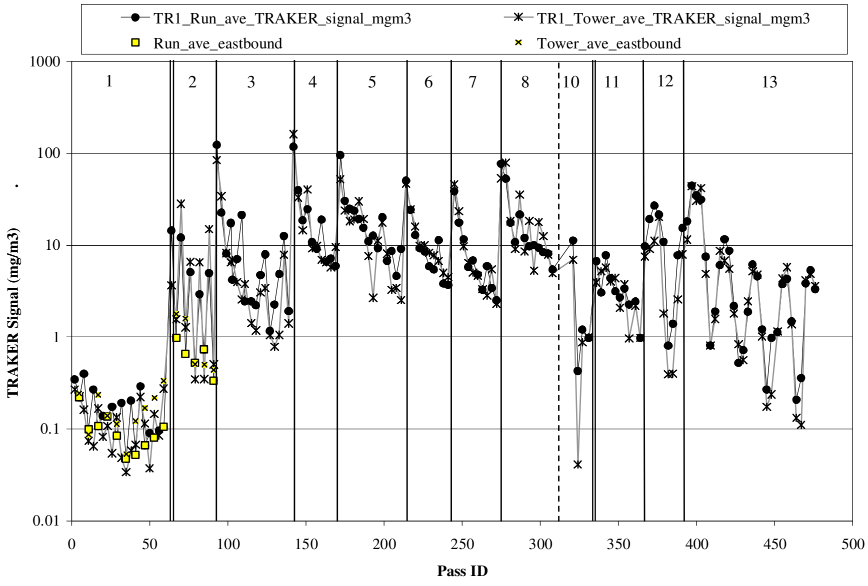


Figure 5-5. Ratio of Background (middle) Inlet PM_{10} Concentration to Average of Left and Right Tire Inlet PM_{10} Signals for TRAKER I Passes

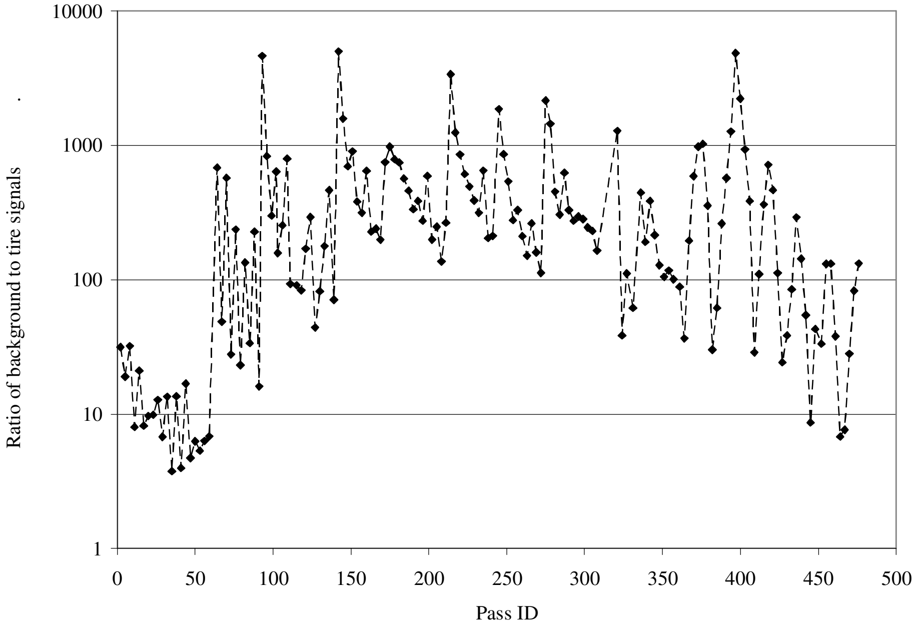
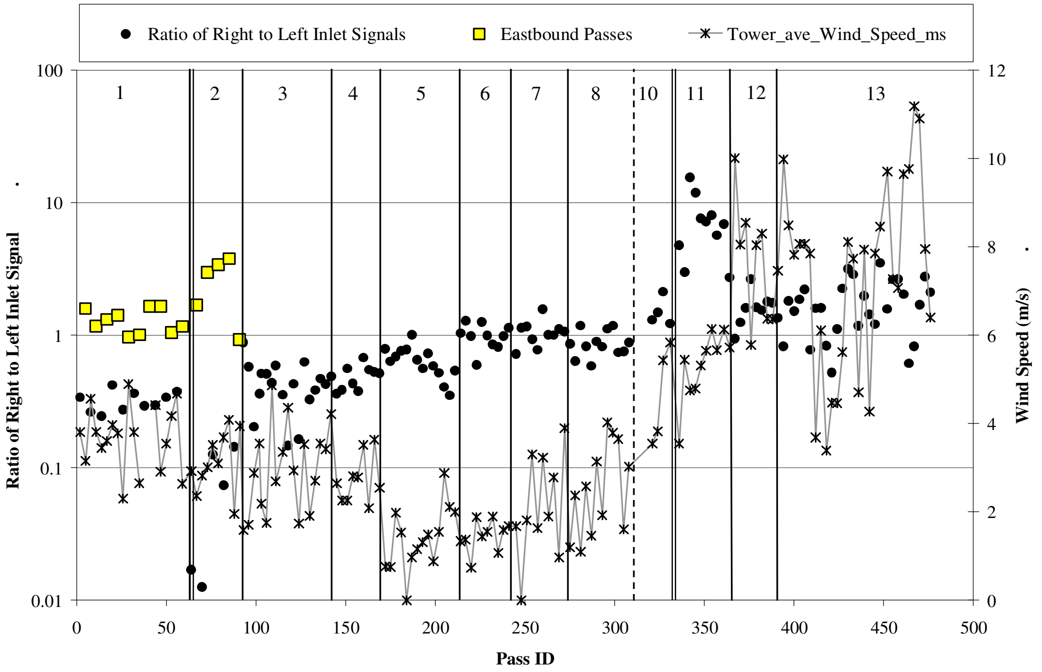


Figure 5-6. Time Series of Ratio of Pass-Averaged TRAKER I Right to Left Inlet Signal Ratios and Pass-Averaged Wind Speed (m/s). Squares denote passes where travel was in the eastbound direction. Vertical lines represent times when the road was swept and silt was applied, while double vertical lines represent times when the road was swept only. Numbers at the top correspond to different measurement sets.



Sets 4, 5, 6, 7, and 8 were analyzed further to examine the rates of decay as measured by TRAKER I. Sets 1, 2, and 3 were not associated with uniform road silt coverage. Sets 9 – 13 were associated with rather variable loadings, owing perhaps to the redistribution of road material by high winds. For each of Sets 4- 8, the first TRAKER measurement was taken to be the baseline reading and a measure of the amount of measurable road dust at the beginning of the set – i.e. immediately after silt material was laid on the road. Thus, all measurements within the same set were divided by this value to normalize the rate of decay across the different sets. **Figure 5-7** shows the normalized decay curves for Sets 4 – 8. The solid black circles and triangles in the figure represent the average normalized decay for sets completed at a 25 mph measurement speed (Sets 5 and 7) and Sets completed at a 45 mph measurement speed (Sets 4, 6, and 8), respectively. In examining the average decay curves for the 25 mph Sets (**Figure 5-8**) and the 45 mph sets (**Figure 5-9**) separately, it appears that in both cases, the decay rate can be described by two separate decay processes.

We hypothesize a conceptual mechanism for the reduction in TRAKER-measured road dust emissions over the course of a measurement set. The roadway surface is not completely smooth and there are pits and protrusions on even the smoothest asphalt surfaces. When road silt material is placed onto the road by the spreader, a portion of the material nestles into the pits and a portion settles on protrusions in the asphalt. The suspendable material that is associated with the protrusions is more exposed than the material that is nestled in the pits. We hypothesize that aerodynamic forces generated by the passage of the vehicles are able to influence the road dust associated with the protrusions and entrain a portion of that road dust. In contrast, road dust material that is nestled in the pits is protected somewhat from aerodynamic stress generated by the movement of the test vehicles through the air above the surface. Road dust material in the pitted portions can only be entrained through contact with (or more generally influence from) the tire surface. With this conceptual model, we can propose a mathematical reconstruction of the removal of road dust from the driving surfaces.

First, we assume that road dust placed on the road surface is either associated with protrusions in the road and is referred to in our model as “aerodynamically suspendable” road dust (RDA) or nested into the pits of the asphalt surface and referred to as “mechanically suspendable” road dust (RDM). These two categories sum to the total suspendable road dust (RDT):

$$RDT = RDA + RDM \qquad \text{Equation 5.4}$$

$$RDT_0 = RDA_0 + RDM_0 = 1 \qquad \text{Equation 5.5}$$

Equation 5-5 above reflects that at time 0, before any vehicles traverse the tests course, the normalized sum of RDA and RDM is unity. Second, assume that the decay curves for RDA and RDM are first-order. In words, this means that each time a test vehicle passes over the road surface; some percentage of the RDA and some percentage of the RDM are suspended. Mathematically, this is written as

$$RDA(X) = RDA_0 \cdot EXP(-a_{aero} \cdot X) \qquad \text{Equation 5.6}$$

$$RDM(X) = RDM_0 \cdot EXP(-a_{mech} \cdot X) \qquad \text{Equation 5.7}$$

where X is the number of test vehicle passes after road silt material has been applied, a_{aero} is the coefficient of decay for aerodynamically suspendable road dust, and a_{mech} is the coefficient of decay for mechanically suspendable road dust. These two decay coefficients can be thought of as the fraction of suspendable road dust (either aerodynamically or mechanically) that is removed (suspended) each time a vehicle passes over the road surface.

The data shown in **Figure 5-8** and **Figure 5-9** fit this hypothesized conceptual model quite well. The implications of this model may be quite important for road dust management practices. In the context of the present study, these data indicate that dust emissions occur under a different regime during the first 9 vehicle passes than in ensuing passes. Since for a paved road, the volume of vehicles is generally much higher than 9, the first 9 passes after silt material application probably do not reflect the regime under which real-world dust emissions occur. It is more likely that the latter passes (greater than 9) more accurately reflect the slower, steadier emissions of PM_{10} road dust that occurs on paved roads. Note that this observation does not depend on whether or not our earlier hypothesis regarding the separation of “aerodynamically suspendable” road dust (RDA) and “mechanically suspendable” road dust (MDA) is deemed physically plausible. It is clear from Figures 5-7, 5-8 and 5-9 that the rate of road dust emissions changes after the first 9 (or so) vehicle passes. This phenomenon is seen not just through the TRAKER I measurements, but from the results of all of the measurement techniques, namely AP-42 silt, SCAMPER, TRAKER II, and tower horizontal PM_{10} flux measurements (Illustrated in Chapter 6 of this report).

Figure 5-7. TRAKER I Signal Normalized to First TRAKER I Pass of the Measurement Set for Sets 4, 5, 6, 7, and 8. The black circles and triangle represent averages for speeds of 25 mph (circles) and 45 mph (triangles)

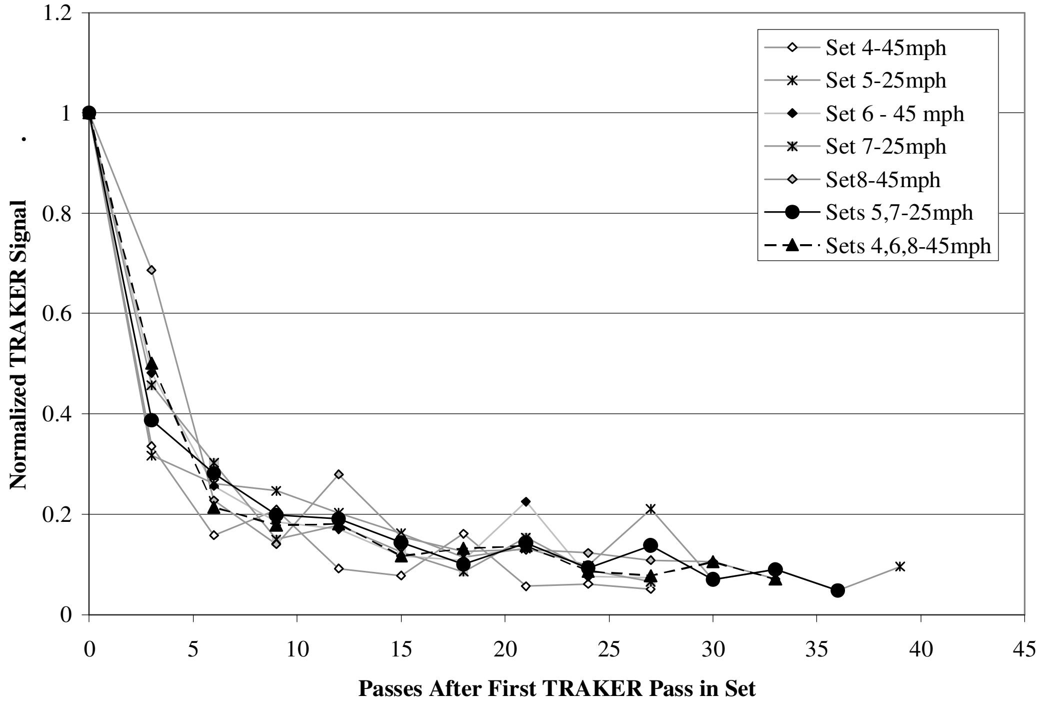


Figure 5-8. Normalized TRAKER I Decay Curve for Sets 5 and 7 (25 mph measurement) and Hypothesized Aerodynamically Suspendable, Mechanically Suspendable, and Total Suspendable (aerodynamic plus mechanical) Road Dust Decay Curves

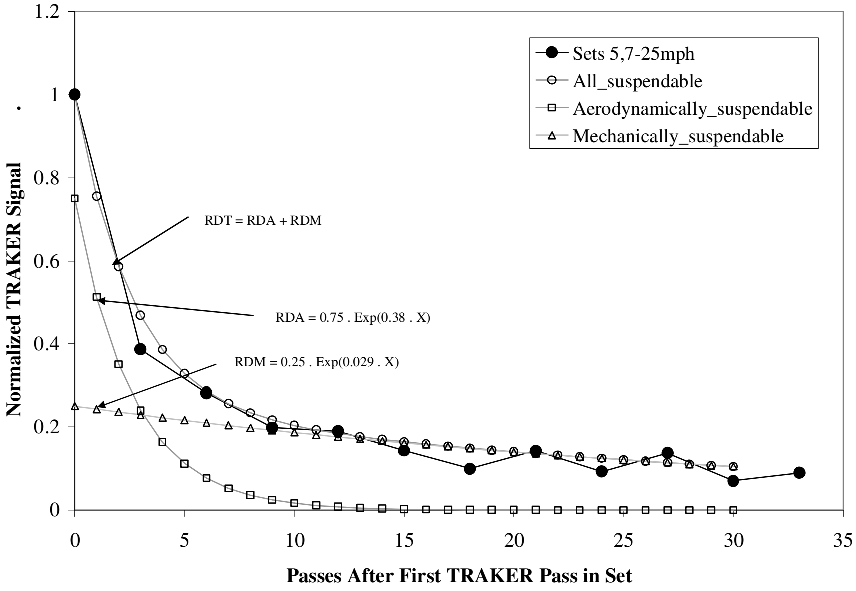
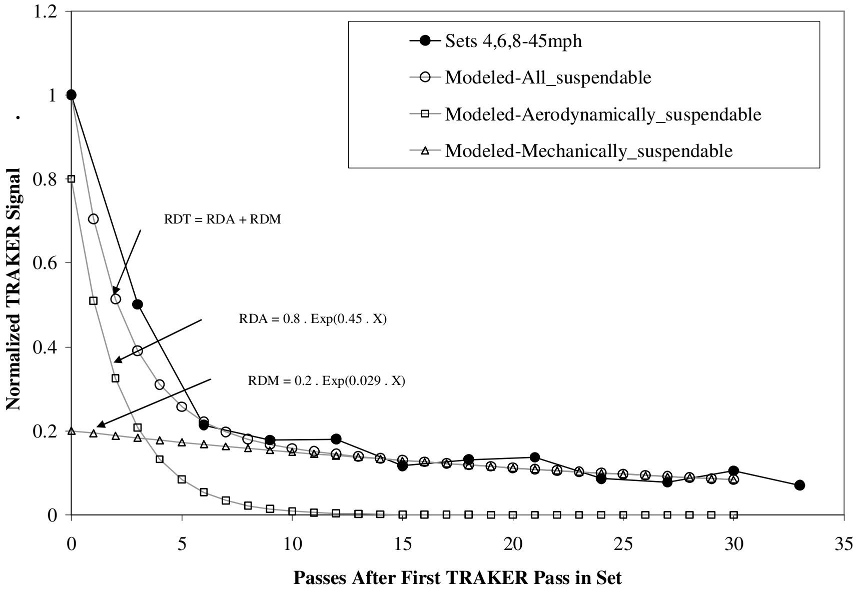


Figure 5-9. Normalized TRAKER I Decay Curve for Sets 4, 6, and 8 (45 mph measurement) and Hypothesized Aerodynamically Suspendable, Mechanically Suspendable, and Total Suspendable (aerodynamic plus mechanical) Road Dust Decay Curves



In prior work, it was observed that the TRAKER I signal was dependent on the speed of travel on the road that was being measured. Those speed response relationships summarized in prior work were obtained by traversing the same section of road several times at varying travel speeds (15 – 60 mph). The underlying assumption behind those tests was that the test road was essentially unaffected by the passage of the TRAKER I and provided a constant "loading" of road dust, allowing us to isolate the effect of traversal speed on the TRAKER I signal (i.e. road "dirtiness" was constant throughout speed tests). In several of the prior studies, it was found that the TRAKER I signal for a given, time-invariant test road, was approximately proportional to the speed of traversal raised to the third power (cubed).

It is instructive to extract a similar speed response relationship from the present study for comparison. However, there are some complicating factors. First, the only full set of speed tests were completed on the last day of the field study during Set 13. Second, owing to the high winds on that day, the ratio of right to left inlet signals was quite variable (See **Figure 5-6**). Third, owing to the nature of the field study, the road dust loadings were constantly changing over the course of the Set 13 measurements. In order to extract speed response information comparable to the speed tests reported in earlier work, it was necessary to account for these three non-idealities. Set 13 TRAKER I passes were separated into 4 complete cycles, with each cycle consisting of 2-25 mph, 2-35 mph, and 2 – 45 mph passes (See **Figure 5-10**). Using only the TRAKER I signal from the right side of the vehicle (the side sheltered from direct southerly crosswinds which were prevalent during Set 13), the TRAKER I signal from the two 25 mph measurements within each cycle were averaged and assumed to reflect the average condition of the roadway over the cycle. The two 35 mph measurements within each cycle were averaged together as were the two 45 mph measurements. To account for cycle-to-cycle changes in road conditions, these averages were normalized to the 25 mph average for each cycle. The results of this normalization for each of the four cycles appear in **Figure 5-11** as do the normalized data averaged over all four cycles. A least-squares power-fit to the 4-cycle average suggests that the TRAKER I signal for Set 13 data approximately obeys a cubic (regression exponent = 3.1) relationship with speed, though we note that there are some differences from cycle to cycle.

Figure 5-10. Division of Set 13 Into Four Cycles, With Each Cycle Comprised of Six Passes for TRAKER I

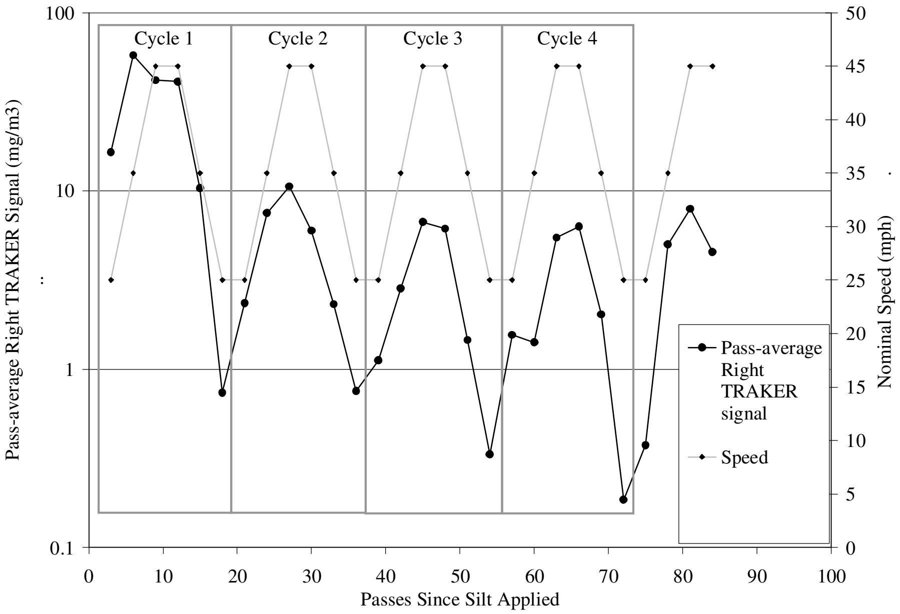
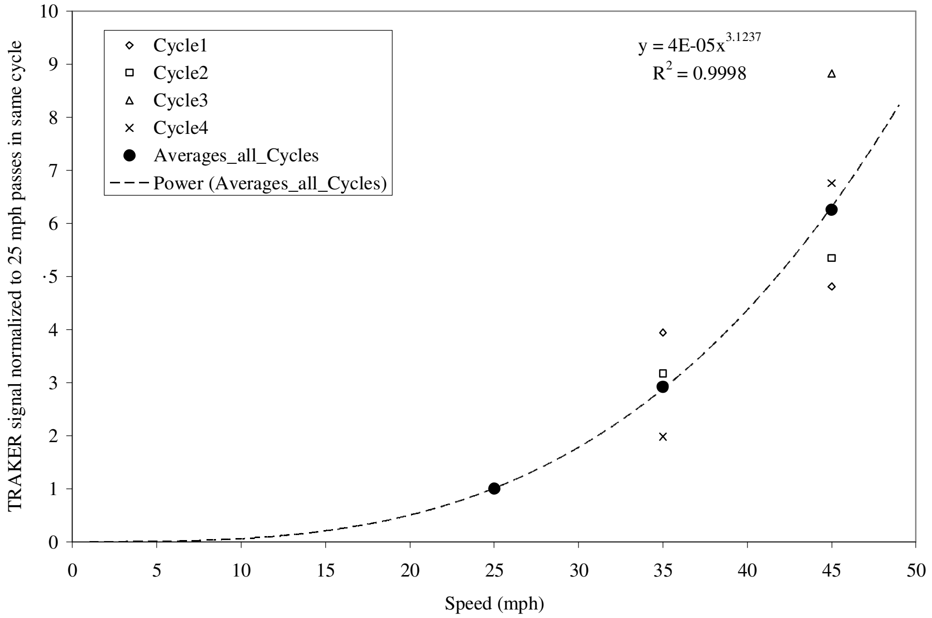


Figure 5-11. Speed Response of TRAKER I Signal. Figure shows the TRAKER I signal at each speed normalized to the average signal at 25 mph in the same cycle. Data are shown for 4 consecutive cycles as well as the average value for all cycles.



5.3.3 TRAKER II

Data alignment and aggregation for TRAKER II were conducted almost identically as for TRAKER I. Starting with all valid 1-second data, the GPS time was retarded by 3 seconds and then re-associated with DustTrak data. The TRAKER II 1-second signal was calculated with equation 1 for each valid data point. Only data associated with measurements on the test route were considered for further analysis and each of those data points was linked with a Pass ID. Pass-average values were calculated from the 1-second data points for further data analysis.

As with TRAKER I, some differences were evident between the TRAKER II signal averaged over an entire pass and the signal averaged only over data points corresponding to measurements within 50 m of the master tower (**Figure 5-12**). Also, the concentrations measured in the left and right tire inlets were always substantially higher than those measured in the background (**Figure 5-13**).

Examination of the ratio of the right to left inlet signals indicated that overall, the signal from the left side was higher than the signal from the right side (**Figure 5-14**). Unlike the near-unity values for Sets 4 to 8 exhibited by the TRAKER I data (**Figure 5-6**), TRAKER II data suggest that for almost all passes, the signal from the left side was higher than from the right (less than unity ratio). Moreover, the ratio is much more variable for TRAKER II. There are several possible reasons for this. First, the cargo bay in TRAKER II was heavily loaded on the left side with tools and equipment with an approximate mass of 300 kg. This may have resulted with a higher signal on the left. Second, the inlets for TRAKER II are further behind the tire than TRAKER I, resulting perhaps in a generally noisier signal. Third, the signal values from TRAKER II were consistently lower than TRAKER I, also perhaps contributing to greater noise in the ratio for right to left inlet signals. Fourth, TRAKER II was operated by a different driver than TRAKER I and it is possible that small differences in the paths that the vehicle tires followed could have caused higher signals on the left side of TRAKER II compared to the right side. The difference between the left and right signals in TRAKER II deserves further attention in future work. However, for the present study, we note again that the road dust emissions from the TRAKER II will be a combination of the emissions from the left and right sides of the vehicle and that it is appropriate to apply Equation 1 to obtain a representative TRAKER II signal for the whole vehicle.

Finally, **Figure 5-15** shows the speed response of the TRAKER II signal (same as **Figure 5-11** for TRAKER I). The relationship between speed and TRAKER II signal is close to the cubic relationship (exponent of speed term is 3.3 according to regression) exhibited by TRAKER I.

Figure 5-12. Relationship Between TRAKER II Signal Averaged Over Entire Pass (route length) and TRAKER II Signal Only Within 50 m of Master Tower

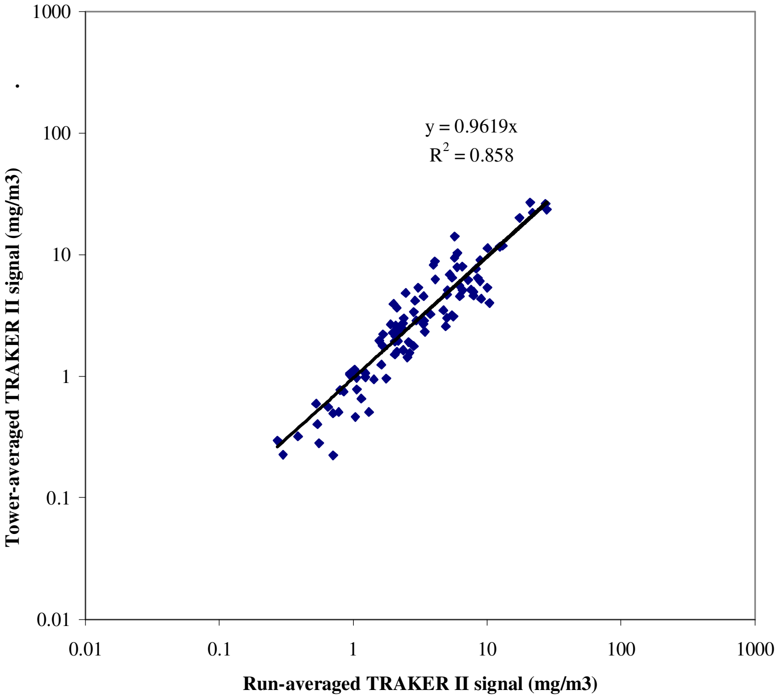


Figure 5-13. TRAKER II Ratio of Average of Left and Right Tire Inlet PM_{10} Concentrations to Background (middle) Inlet PM_{10} Concentration

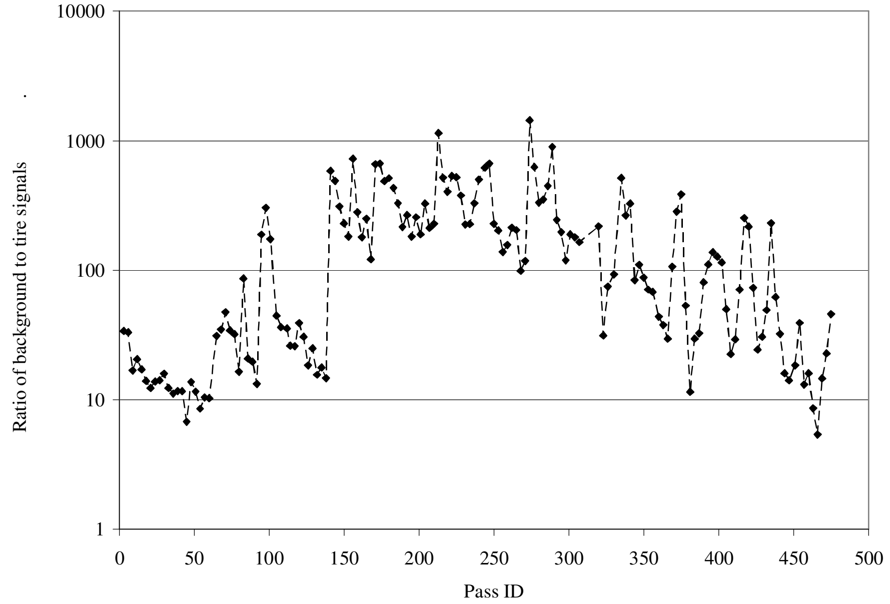


Figure 5-14. TRAKER II Time Series of Ratio of Pass-Averaged Right to Left Inlet Signal Ratios and Pass-Averaged Wind Speed (m/s). Vertical lines represent times when the road was swept and silt was applied, while double vertical lines represent times when the road was swept only. Numbers at the top correspond to different measurement sets.

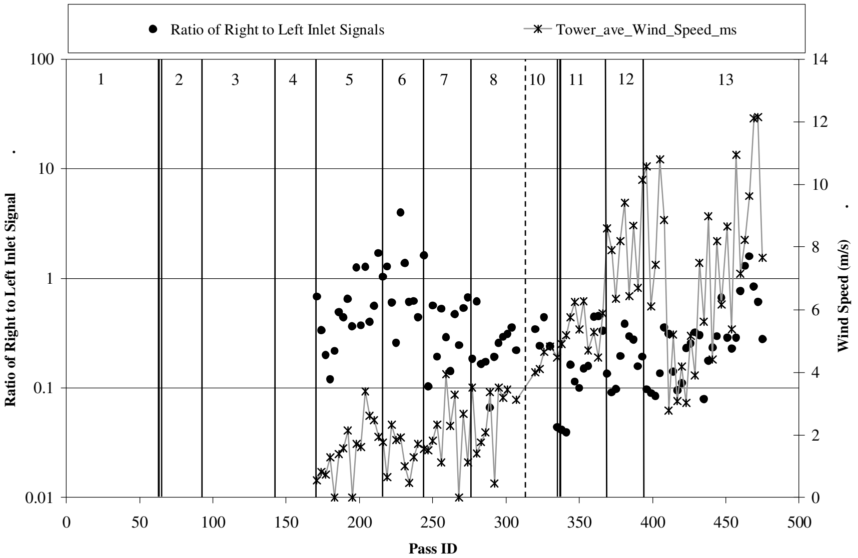
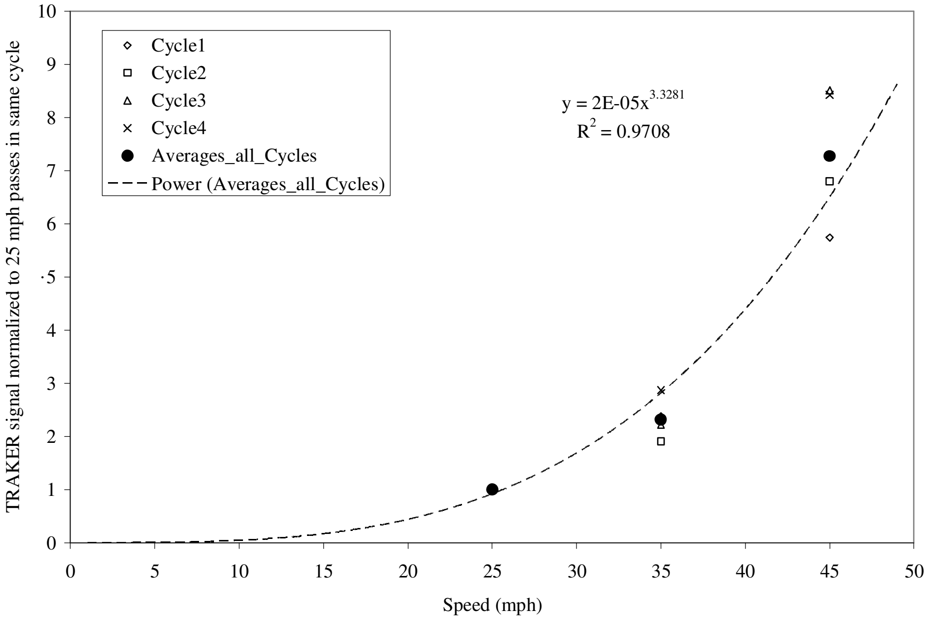


Figure 5-15. Speed Response of TRAKER II Signal. Figure Shows the TRAKER II Signal at Each Speed Normalized to the Average Signal at 25 mph in the Same Cycle. Data are shown for four consecutive cycles as well as the average value for all cycles.



6.0 RESULTS

The test types, times, vehicles involved, and number of vehicle passes are summarized in **Table 6-1**. The total numbers of traversals through the test course for each test vehicle were: TRAKER I – 154, TRAKER II – 152, SCAMPER – 162. The distribution of nominal speeds at which measurements were conducted was approximately: 25 mph – 24%, 35 mph – 47%, and 45 mph – 29%. Except for the first two sets of measurements, where test vehicles traversed the test course in both directions, vehicles traversed the course from the eastern end of Veterans Memorial Highway by the Command Center (CC) towards the west/northwest.

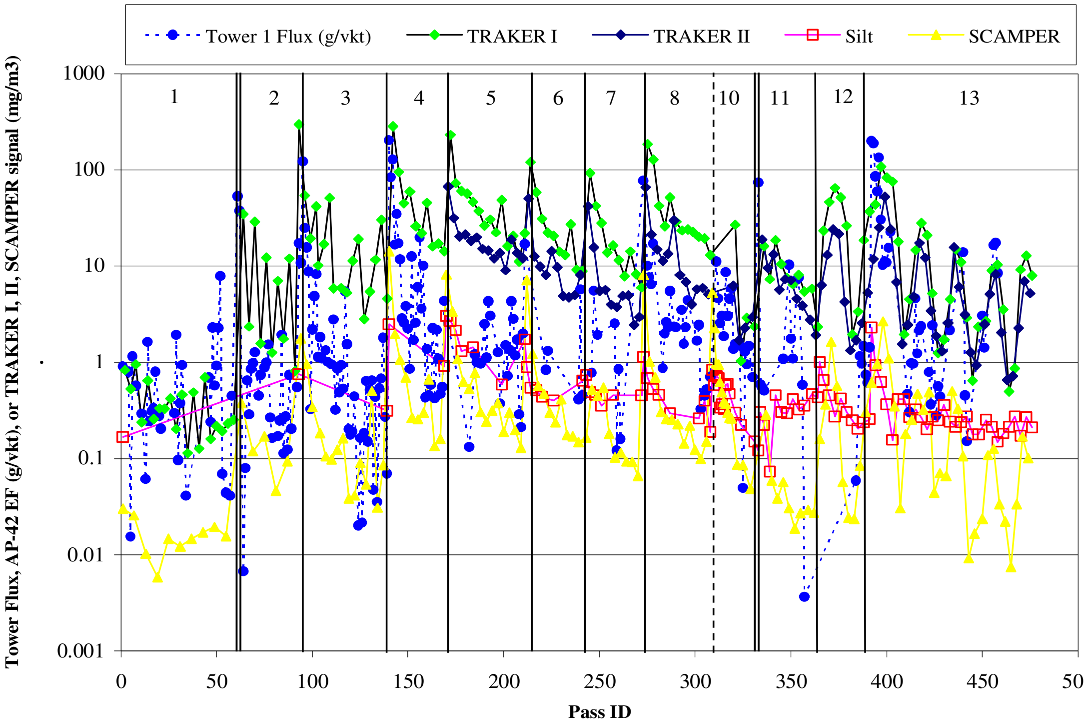
Results from AP-42 silt measurements and the three mobile systems used in this study (TRAKER I, TRAKER II, and SCAMPER) are discussed in individual sections below. In addition to providing data summaries, those sections assimilate the different methods for road dust emission estimation with horizontal PM_{10} tower flux data. In the case of AP-42 silt sampling, this provides a basis for comparing the AP-42 methodology to emission factors measured on-site. In the cases of the mobile systems, the horizontal flux measurements which represent an independent measure of PM_{10} emission factors are used to calibrate the three systems used as part of this study.

One important finding deserves discussion here since it applies to all the mobile systems as well as the AP-42 silt sampling. It was noted when examining the time series of the tower flux, TRAKER I, TRAKER II, SCAMPER, and even the AP-42 silt measurements that the application of silt material to the test road section led to an initial surge in PM_{10} emissions. This can be seen in **Figure 6-1** where the pass-averaged time series for all of these data sets are plotted. Starting with measurement Set 3 - the first instance when silt was applied to the test road - the first several passes in the set exhibit comparatively very high road dust emissions or mobile system raw signals. Subsequently, emissions begin to stabilize at a lower though not necessarily constant value. Measurement Sets 12 and 13 deviate somewhat from this pattern because during those sets, the travel speeds of the test vehicles were varied over the course of the Sets. We alert the reader at this time that for comparing the signals from the mobile systems to those measured on the horizontal flux tower, the first 9 vehicle passes will not be considered for sets where road silt material was applied to the surface. The justification for this was provided in an earlier section (Section 5.3.2).

Table 6-1. Summary of Tests During Field Study (9/11/06 – 9/15/06)

Set ID	Date	Approximate Time (local)	Activity	Vehicles used	Nominal speed (mph)	Total passes/passes per vehicle
1	9/11	11:55 - 13:15	Test: Baseline road conditions - No Sweep, No silt	All test vehicles	35	60/20
	9/11	13:35	Sweep	Street Sweeper	NA	NA
2	9/11	13:52 - 14:18	Test: After Sweeping, No silt applied	All test vehicles	35	30/10
	9/11	14:30	Silt applied to test road	Tractor/spreader	NA	NA
3	9/11	15:17 - 26:30	Test: After application of silt, 35 mph	All test vehicles	35	27/9
	9/11	17:00	Sweep	Street Sweeper	NA	NA
	9/12	9:15	Silt applied to test road	Tractor/spreader	NA	NA
4	9/12	10:15 - 11:00	Test: After application of silt, 45 mph	All test vehicles	45	30/10
	9/12	11:05	Sweep	Street Sweeper	NA	NA
	9/12	13:00	Silt applied to test road	Tractor/spreader	NA	NA
5	9/12	13:35 - 14:40	Test: After application of silt, 25 mph	All test vehicles	25	42/14
	9/12	15:00	Sweep	Street Sweeper	NA	NA
	9/13	9:00	Silt applied to test road	Tractor/spreader	NA	NA
6	9/13	9:40 - 10:25	Test: After application of silt, 45 mph	All test vehicles	45	30/10
	9/13	11:09	Sweep	Street Sweeper	NA	NA
	9/13	12:15	Silt applied to test road	Tractor/spreader	NA	NA
7	9/13	12:45 - 13:35	Test: After application of silt, 25 mph	All test vehicles	25	30/10
	9/13	14:00	Sweep	Street Sweeper	NA	NA
	9/13	14:45	Silt applied to test road	Tractor/spreader	NA	NA
8	9/13	15:20 - 16:15	Test: After application of silt, 45 mph	All test vehicles	45	36/12
	9/13	17:00	Sweep	Street Sweeper	NA	NA
	9/14	8:00	Silt applied to test road	Tractor/spreader	NA	NA
9	9/14	8:40 - 9:20	Test: Depletion of silt resulting from vehicle passes	SCAMPER Only	35	10/10
10	9/14	9:20 - 9:50	Test: Measure emissions prior to sweeping	All test vehicles	35	12/4
	9/14	10:05	Sweep	Street Sweeper	NA	NA
11	9/14	10:25 - 11:20	Test: Measure emissions after sweeping	All test vehicles	35	30/10
	9/14	11:30	Sweep	Street Sweeper	NA	NA
	9/14	12:30	Silt applied to test road	Tractor/spreader	NA	NA
12	9/14	13:10 - 14:05	Test: Speed tests	All test vehicles	25 - 45	27/9
	9/14	14:30	Sweep	Street Sweeper	NA	NA
	9/15	8:00	Silt applied to test road	Tractor/spreader	NA	NA
13	9/15	8:30 - 11:15	Test: Speed tests	All test vehicles	25 - 45	84/28
	9/15	11:30	Sweep	Street Sweeper	NA	NA

Figure 6-1. Time Series of Pass-Averaged Horizontal Tower PM_{10} flux (g/vkt), Silt-estimated AP-42 Emission Factor (g/vkt), TRAKER I, TRAKER II, and SCAMPER raw signals (mg/m^3). Vertical lines represent times when the road was swept and silt was applied, while double vertical lines represent times when the road was swept only. Numbers at the top correspond to different measurement sets.

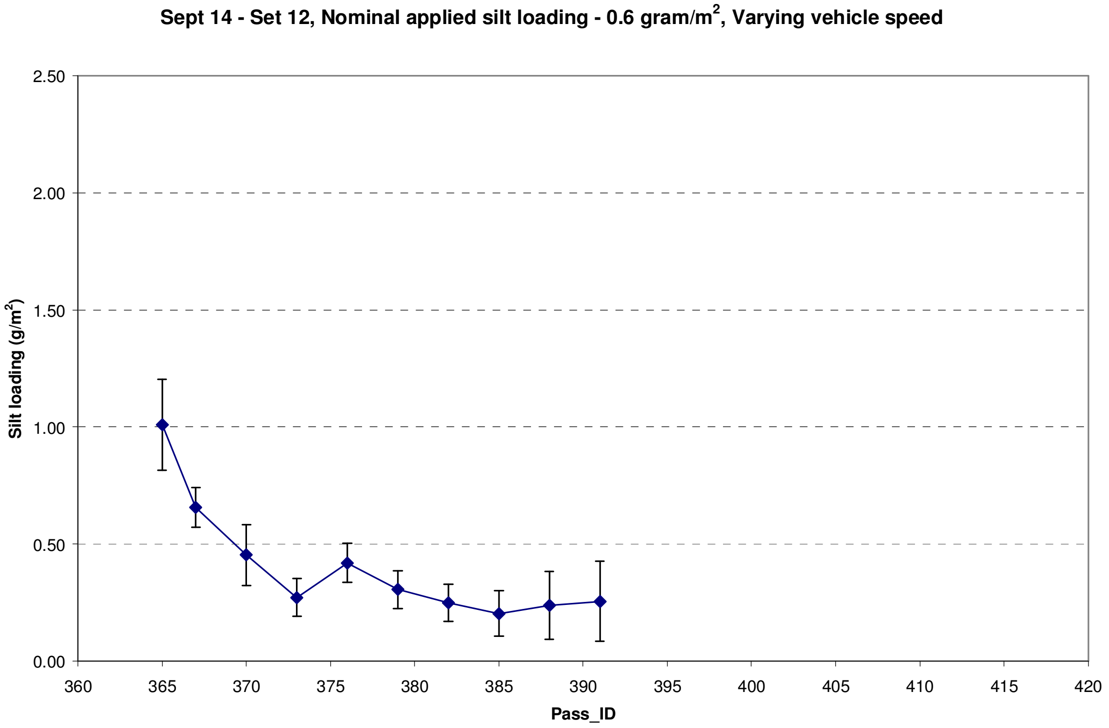


6.1 Short-Term Emission Factor Decay and Silt Loading Depletion

6.1.1 Silt Loading Depletion

Figure 6-2 shows a typical pattern of silt loading depletion for Set 12, at a low initial applied silt loading of 0.6 g/m^2 depleted at cyclically varying vehicle travel speeds of 25, 35, and 45 mph. Silt loading undergoes a rapid decay to about for the first nine passes, and then stabilizes at a low constant value that is about one-third of the initial value.

Figure 6-2. Silt Depletion With Increasing Vehicle Passes



This pattern was observed in five of the nine data sets for which sufficient silt loading information is available. Results are summarized in **Table 6-2.**

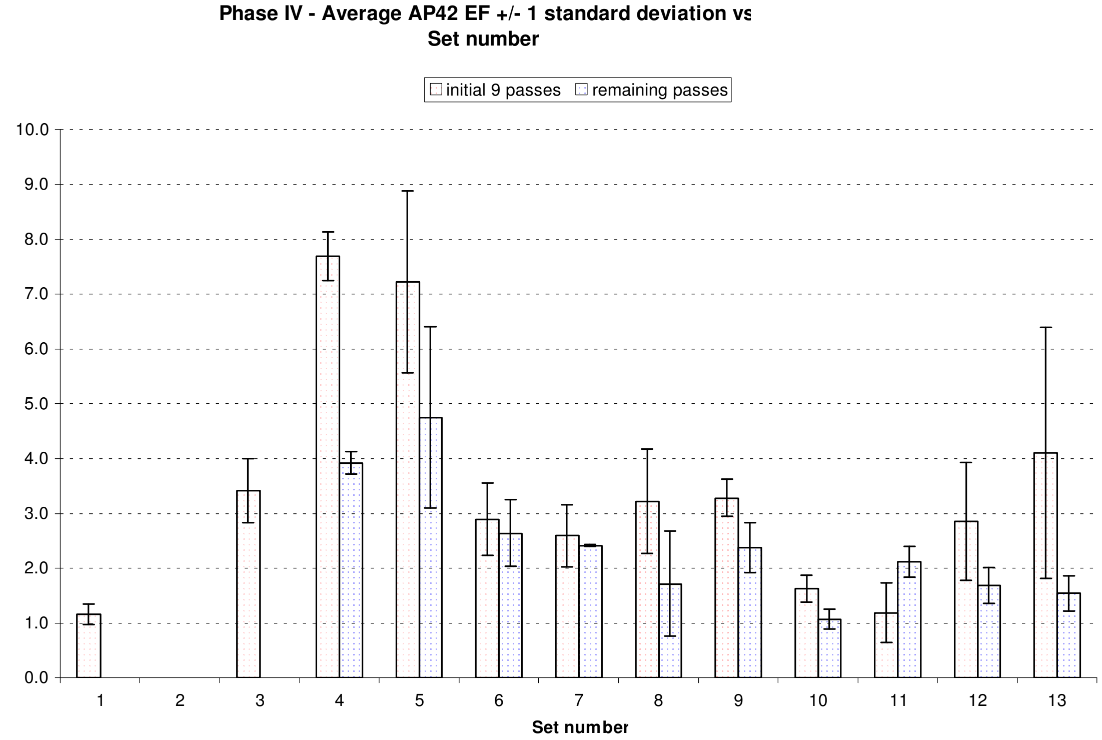
Table 6-2. Summary of Observed Silt Decay With Increasing Number of Vehicle Passes

Set	Initial Loading (gram/m2)	Vehicle Speed (mph)	Decay First Nine Passes?	Ratio Last Pass Avg./ first 9 Pass Averages	Comments
4	2.5	45	N/A		decay observed, but only 2 data points
5	2.3	25	Yes	0.55	
6	0.6	45	No	0.87	
7	0.5	25	Yes	0.89	first 6 passes
8	0.7	45	Yes	0.41	
9	0.7	35	Yes	0.63	
10	0.3	35	Yes	0.57	9 passes total
11	0.2	35	No	2.11	
12	0.6	varying	Yes	0.47	Strong cross winds at end of experiment
13	1.1	varying	Yes	0.23	Strong cross winds throughout experiment

A comparison of AP-42 Emission factors computed separately for the first nine passes and for the remaining vehicle passes (**Figure 6-3**) shows that AP-42 emission factor values for the first nine passes, were (with the exception of Run 11) higher than values for the remaining passes.

The rapid decay in silt loading over the first few passes lends support to the DRI/UCR hypothesis that two separate mechanisms, aerodynamic (first nine passes) and mechanical (subsequent passes) may be responsible for suspending PM_{10} from paved road surfaces.

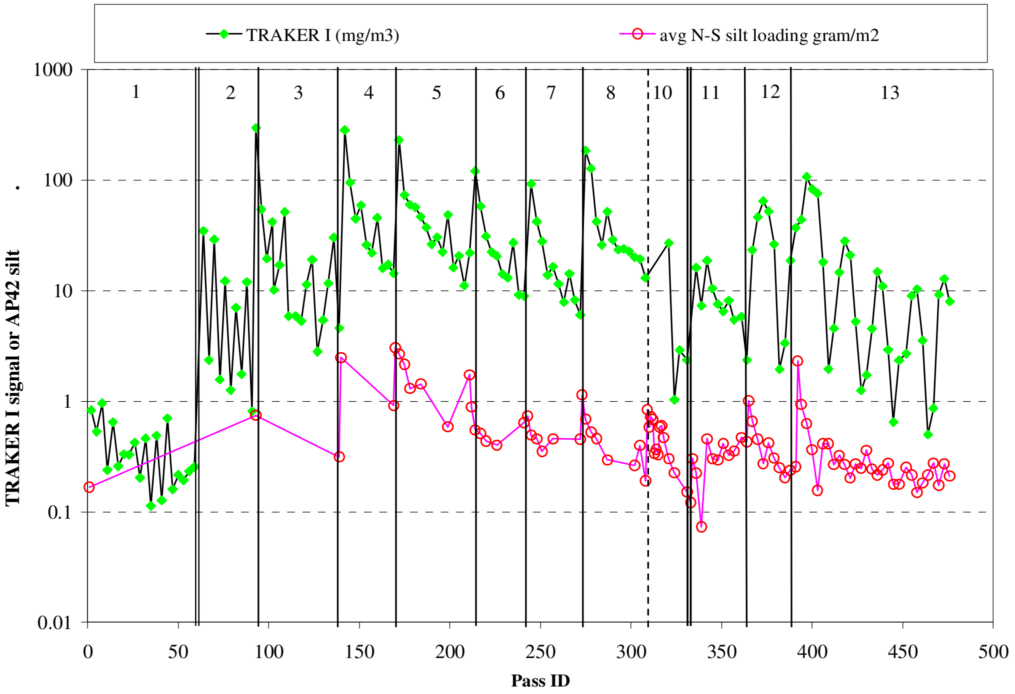
Figure 6-3. Comparison of Averaged AP-42 Emission Factors, in gram/VMT, Computed From Silt Loadings for First Nine Passes, Compared to AP-42 Emission Factors for Remaining Passes



*Error bars are ± one standard deviation.

Signals from the mobile technologies systems also showed high initial decay within several experimental sets. **Figure 6-4** compares TRAKER I signal to AP-42 silt over all observed experimental runs.

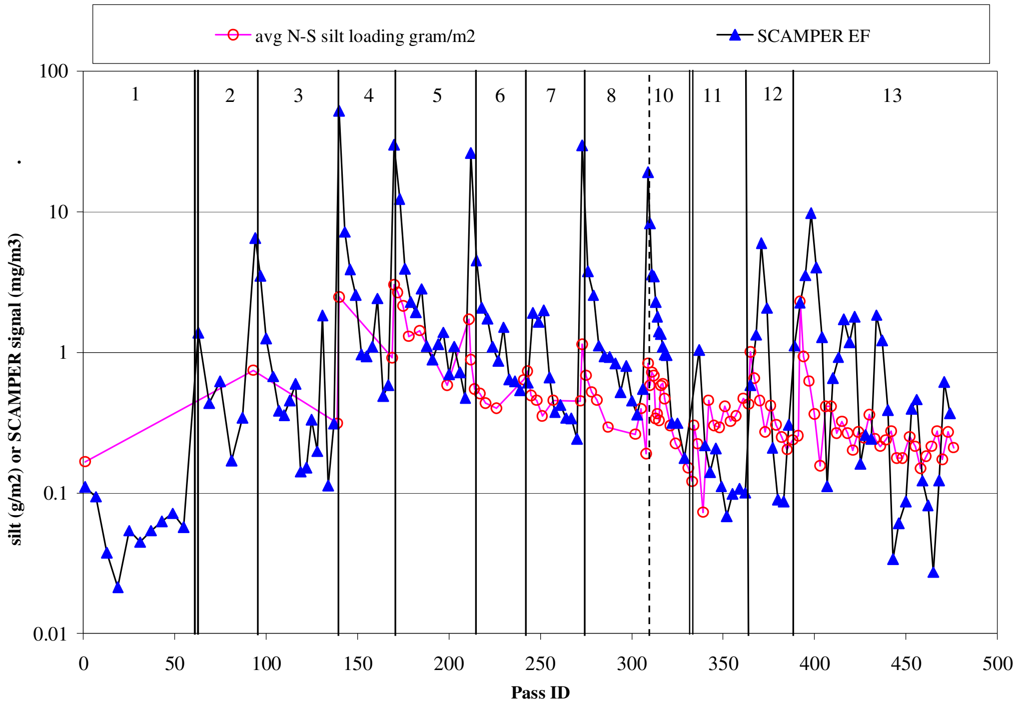
Figure 6-4. Comparison of TRAKER I Signal and Average North-South Silt Loading for All Vehicle Passes



The TRAKER I signal decay with vehicle passes matches AP-42 silt loading decay in Sets 5, 8, and 10 for cases of constant vehicle speed. However, TRAKER I measured emissions also showed, in sets 12 and 13, clear vehicle travel speed dependence that are not accounted for in the current AP-42 emission factor equation. The rising and falling TRAKER I signals in Sets 12 and 13 are a result of systematically varying vehicle speeds first rising from 25 to 35 to 45 mph, then declining from 45 to 35 to 25 mph. Silt loadings in Set 12 declined throughout the experiment, even though TRAKER I emissions increased with increasing vehicle speed. Silt loadings in Set 13 declined rapidly to a steady state value, while TRAKER I emissions fluctuated regularly with rising and falling vehicle speed.

TRAKER II and SCAMPER signals showed similar behavior. The SCAMPER signal is plotted alongside silt loading in **Figure 6-5**.

Figure 6-5. Comparison of SCAMPER Signal and Average North-South Silt Loading for All Vehicle Passes

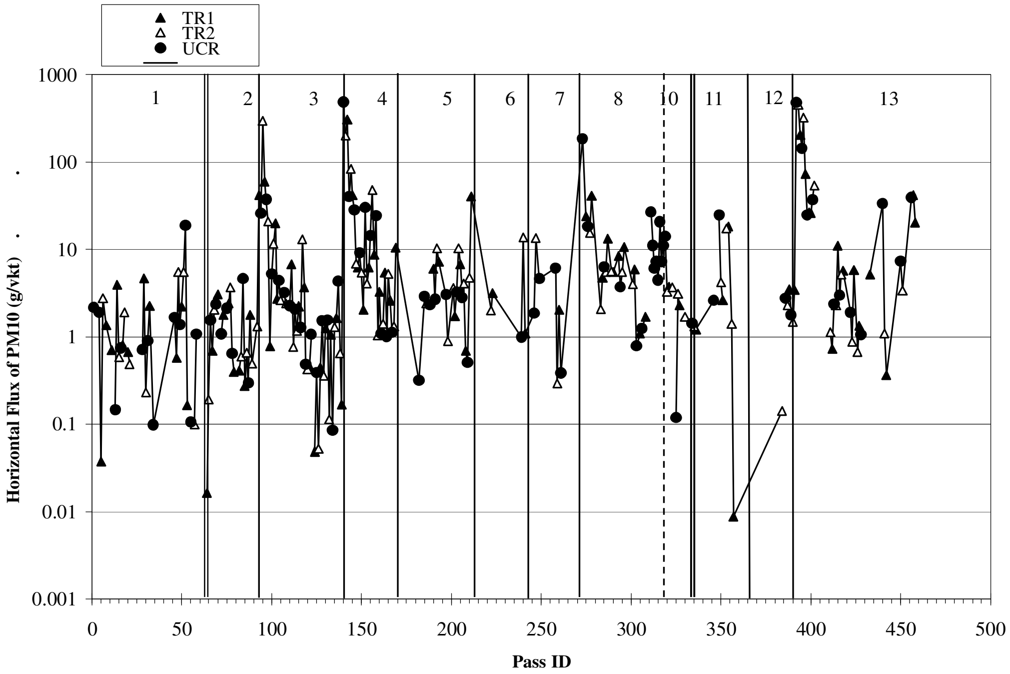


The SCAMPER signal tracks decay in AP-42 silt loading with vehicle speed in Sets 5, 8, and 10 for cases of constant speed. However, just as in the case for TRAKER I, SCAMPER measured emissions showed, in sets 12 and 13, clear vehicle travel speed dependence that are not accounted for in the current AP-42 emission factor equation.

6.2 Comparison of Horizontal Flux Tower Emission Factors to EPA Method AP-42

Plumes from point and line sources are often modeled as exhibiting smooth, Gaussian concentration distributions. This type of representation has been adequate over long spatial and time scales, where a dispersive force from random turbulent eddies are allowed to proceed for long periods and average out. In practice, individual, non-steady plumes such as from a point puff or a moving line source are quite erratic and the instantaneous spatial distribution of concentration does not at all resemble a Gaussian profile. Furthermore, owing to the random nature of plume dispersion, the flux measured at a point in space is likely to vary considerably from one event (e.g. passage of a vehicle) to the next. This can be seen in **Figure 6-6** where individual tower flux measurements associated with the passage of the test vehicles are plotted. The figure (Note log y-axis scale) shows that individual flux measurements exhibit substantial pass-to-pass variability.

Figure 6-6. Time Series of Horizontal PM_{10} Fluxes Measured With Tower Measurement System for Different Test Vehicles



The inherent variability of tower flux measurements requires that data be aggregated (averaged) over several replicate measurements in order to filter out some of the measurement noise. In the case of the present study, this poses a slight challenge because the road dust loading on the test road was not constant over the course of the field study and indeed was changing over the course of a single set of measurements. This can be seen quite clearly in (See **Figure 6-2**) where, as the number of vehicle passes within a measurement set increases, the signals from the three mobile systems decrease, indicating decay in road dust loading over time. (Please refer to **Figure 5-8** and **Figure 5-9** in Section 5.3.2) The observed decay pattern suggests that there are two modes for this decay. During the first several vehicle passes after silt is applied to the surface, road dust loading appears to diminish quickly. Earlier, we termed this “aerodynamically suspendable” road dust. After 9 or so vehicle passes, the road dust loading decreases much more slowly as the “mechanically suspendable” material is all that remains on the test road surface. As discussed earlier, for the purpose of reporting emissions from the different test vehicles used in this study, we consider only the horizontal PM_{10} fluxes for times when the number of vehicles passing over the road after silt application was greater than 9 (Note that this does not affect Sets 1 and 2 when silt was not applied to the surface). This serves to both mitigate the large range of emissions factors that were measured (if first 9 passes are included) as well as separate the “mechanically suspendable” road dust from the “aerodynamically suspendable” road dust – the former being more likely to prevail on well traveled roads.

The average horizontal fluxes (emissions) by measurement set, and test vehicle are reported in **Table 6-3**. With some set-to-set variation in the emissions magnitude, in general all three vehicles exhibit approximately the same emissions within the standard error of the measurement set. If averaged over all valid horizontal flux measurements, mechanically suspended PM_{10} dust fluxes are 4.1 ± 0.7, 5.0 ± 1.2, and 5.0 ± 2.0 g/vkt for TRAKER I, TRAKER II, and UCR SCAMPER, respectively – not statistically significant differences.

Table 6-3. Summary of Measured PM_{10} Horizontal Fluxes. Data shown are averages for all passes following the ninth pass after silt application. Standard errors shown are based on the standard deviation divided by the square root of the number of measurements included in the average.

Set	TRI Valid Flux Count	TRI Flux ave (g/vkt)	TRI Std err (g/vkt)	TRII Valid Flux Count	TRII Flux ave (g/vkt)	TRII Std err (g/vkt)	UCR Valid Flux Count	UCR Flux ave (g/vkt)	UCR Std err (g/vkt)	All Valid Flux Count	All Flux ave (g/vkt)	All Std err (g/vkt)
1	7	1.32	0.62	4	1.66	1.28	7	0.59	0.36	18	1.11	0.38
2	5	1.53	0.58	5	0.94	0.70	5	0.72	0.65	15	1.06	0.36
3	13	3.04	1.50	12	1.91	1.05	12	1.89	0.42	37	2.30	0.63
4	7	5.53	1.19	7	9.44	6.39	7	11.64	4.51	21	8.87	2.57
5	6	10.53	6.13	8	4.51	1.40	8	2.23	0.41	22	5.32	1.80
6	2	2.13	1.04	2	7.90	5.88	1	0.99	NA	5	4.21	2.42
7	1	2.05	NA	1	0.29	NA	2	3.24	2.86	4	2.21	1.36
8	8	6.40	1.48	5	4.57	0.69	4	3.02	1.27	17	5.07	0.82
9	NA	NA	NA	NA	NA	NA	1	11.04	NA	1	11.04	NA
10	4	1.18	1.11	4	2.94	0.43	4	3.32	3.60	12	2.48	1.18
11	5	3.70	3.78	5	4.53	3.32	4	6.46	6.24	14	4.79	2.33
12	3	0.40	3.08	3	1.31	0.63	2	2.28	0.50	8	1.21	1.07
13	9	5.47	2.25	10	11.03	6.26	9	13.88	5.77	28	10.16	2.96

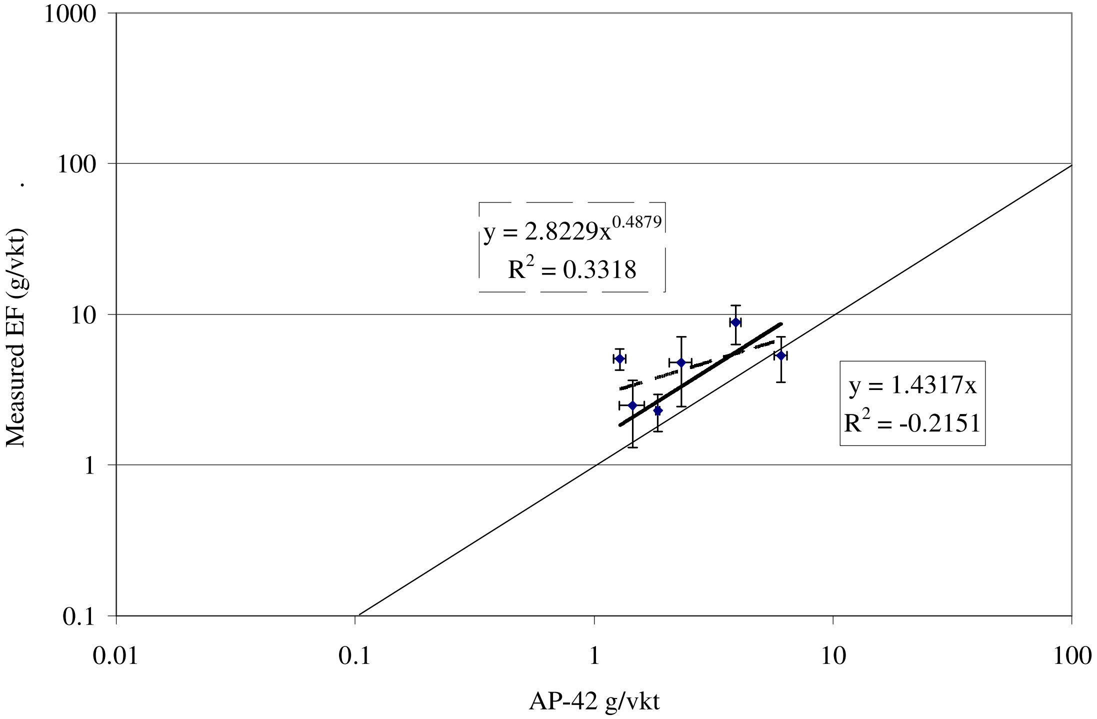
"NA" indicates that either there were no valid flux measurements during the indicated period or silt was not applied to test road prior to measurements.

Silt measurements were conducted at various points in time over the course of measurement sets and within measurement sets (Please refer to **Table 6-1**). Full silt sampling (as opposed to "quickie strips") was primarily conducted at the beginning and end of measurement sets. The silt sample procured at the beginning of measurement sets where silt was applied to the road contain significant fractions of "aerodynamically suspendable" road dust. This can be seen in **Figure 6-1** in Section 6.0 where it is clear that at the beginning of those measurement sets, the rate of decay of silt loading is high compared to later periods (i.e. after the first 9 vehicle passes). Silt samples procured at the end of those measurement sets represent, in principle, the lowest emission factors of the measurement set. Referring again to **Figures 5-8** and **5-9** in Section 5.3.2, the rate of decay of "mechanically suspendable" road dust is much lower than that of "aerodynamically suspendable" road dust. If for the purposes of the present effort, we accept the decay rates shown for mechanically suspendable" road dust (**Figures 5-8** and **5-9** in Section 5.3.2), namely an exponential decay of -0.029 X, where X is the number of passes since silt application, then the difference in mechanically suspendable road dust between X=10 and X=25 is about a factor of two. Considering that PM_{10} emission fluxes from consecutive passes can vary by an order of magnitude or more (**Figure 6-6**), the error introduced by assuming that the silt sample procured at the end of the measurement set represents all passes where "mechanically suspendable" road dust was dominant (i.e. from > 9 passes after silt until set completion) is acceptably small.

To compare PM_{10} tower flux measurements with AP-42 silt methodology and mobile system measurements, data were averaged by measurement set. For each set all tower flux measurements were averaged together regardless of the test vehicle. Thus, tower flux measurements represent average fluxes for all vehicles. This was to ensure that all methods examined would be calibrated (or compared in the case of AP-42) against the same standard and results from future measurements can be compared using a common basis. In examining **Table 6-3** (three rightmost columns), it is clear that the number of valid flux measurements varied from set to set. A minimum criterion of 10 valid vehicle passes was applied to the tower flux average value. This invalidated sets 6, 7, 9, and 12. In addition, data from set 13 were considered invalid because wind speeds were very high during that period and neither the mobile systems nor the tower flux measurement system measurements are trustworthy at high winds. The remaining valid sets for comparison were 1, 2, 3, 4, 5, 8, 10, and 11. These measurement sets were used to compare AP-42 silt-based emission factors estimated from the AP-42 emission factor equation (See Section 5.2.2 for full equation) to PM_{10} emission factors measured with the horizontal flux tower. Silt measurements at the end of a set were available for Sets 3 – 13. Thus, the measurement sets that remained for comparison between the AP-42 methodology and the tower data were 3, 4, 5, 8, 10, and 11.

Comparison of AP-42 silt based emission factors and set-averaged PM_{10} emission factors are shown in **Figure 6-7**. The solid line in the Figure represents a least-square linear fit to the data with a zero intercept while the dashed line represents a power law fit. The power law fit appears to accommodate the data better than the linear fit ($R^2 = 0.33$ compared to -0.22). In general, AP-42 estimated emission factors appear to be substantially lower than measured tower-based PM_{10} emission factors for all measurements sets by about 40%.

Figure 6-7. Tower-Based PM_{10} Emission Factors versus AP-42 Silt-Based Emission Factors. Solid squares represent emission factors that are averages of all valid tower measurements for sets 3, 4, 5, 8, 10, and 11. AP-42 data shown are averages of the north and south sample measurements procured at the end of the measurement sets. The solid line in the Figure represents a least-square linear fit to the data with a zero intercept while the dashed line represents a power law fit. A one-to-one line is included in the Figure for comparison. X and Y error bars represent standard errors which are based on the standard deviation of individual measurements within the measurement Set divided by the square root of the number of measurements included in the average.



We hypothesize in Section 7.2 that an altered distribution of freshly applied road silt on a low roughness experimental road surface increased mobile PM_{10} emission factors compared to AP-42 PM_{10} emission factors.

(1) On the Phase IV road surface, soil was freshly-applied and had not yet been swept by repeated vehicle passes into the “pits” between asphalt-embedded aggregate “protrusions,” as would occur on normally traveled road surfaces. As a result, for the same silt loading, a greater proportion of the freshly applied silt would be located on the “protrusions” of the road surface, and would be less sheltered from conditions of applied mechanical or aerodynamic shear than is the case for a well-traveled road where road silt has been generated by natural processes.

(2) The road surface used in this experiment was recently paved, is very smooth, and is in better condition than the normally traveled road surfaces studied in earlier phases of this project. The road surface “pits” were therefore shallower and the silt that is deposited in the valleys would be less sheltered than would normally be the case on a well-traveled road with silt generated by natural processes.

The combined effects of 1) and 2) are to make the freshly-applied PM_{10} on the experimental road more “exposed” to suspension during conditions of mechanical vehicular shear and moderate vehicular aerodynamic than the amount of more “sheltered” PM_{10} mobilized into the air from a normally traveled, rougher typical road surface.

Compared to the moderate shears developed by vehicles, vacuum cleaners apply much higher shears during AP-42 silt recovery (Bettancourt Rodriguez, 2006). Silt recoveries of greater than 99% were observed after four vacuum cleaner head passes (Rodrigues, 2006) on both smooth and rough road surfaces. As a result, both silt recoveries and calculated AP-42 PM_{10} emissions factors would not be as sensitive to silt distribution or road surface condition as mobile technologies emission factors.

When simultaneously measuring AP-42 emissions factors and mobile technologies emission factors that are sensitive to roughness and silt spatial distribution on a smooth road with freshly applied silt, we hypothesize that, compared to what would be observed on a well-traveled road, mobile technologies PM_{10} emissions factors would increase relative to AP-42 emissions factors.

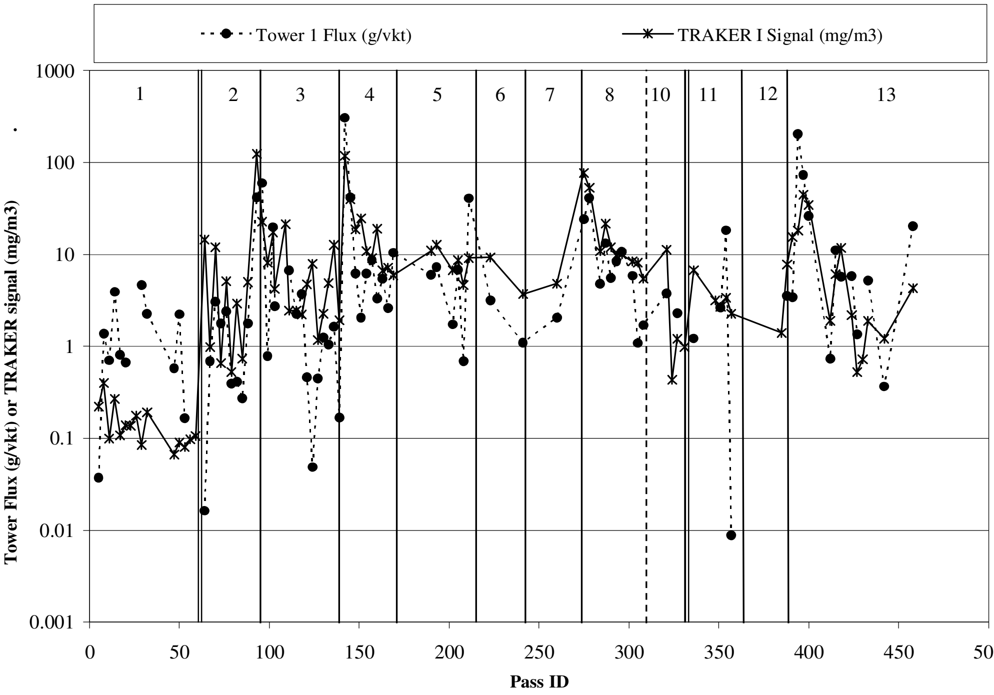
Recommendations of experiments that could be performed to test this hypothesis are proposed in Section 8.2

6.3 Comparison of Horizontal Flux Tower Emission Factors to Mobile Technologies Emission Factors

6.3.1 TRAKER I

Figure 6-8 shows the pass-averaged PM_{10} emission factor measured by the tower system and the pass-averaged TRAKER signal for cases where both data sets were valid. Overall, the flux measurement and the TRAKER signal track reasonably well, though on a point-to-point basis, the relationship between the two measurements is somewhat noisy. To compare PM_{10} tower flux measurements with AP-42 silt methodology and mobile system measurements, data were averaged by measurement set. For each set valid. tower flux measurements for all passes excluding the first 9 following silt application were averaged together regardless of the test vehicle. A minimum criterion of 10 valid vehicle passes was applied to the tower flux average value. This invalidated sets 6, 7, 9, and 12. In addition, data from set 13 were considered invalid because wind speeds were very high during that period. The remaining valid sets for comparison of TRAKER signal to PM_{10} flux were 1, 2, 3, 4, 5, 8, 10, and 11.

Figure 6-8. Time Series of Measured Horizontal PM_{10} Flux on the DRI Tower System and the Pass-Averaged TRAKER I Signal for Passes When the Horizontal Flux Measurement was Valid



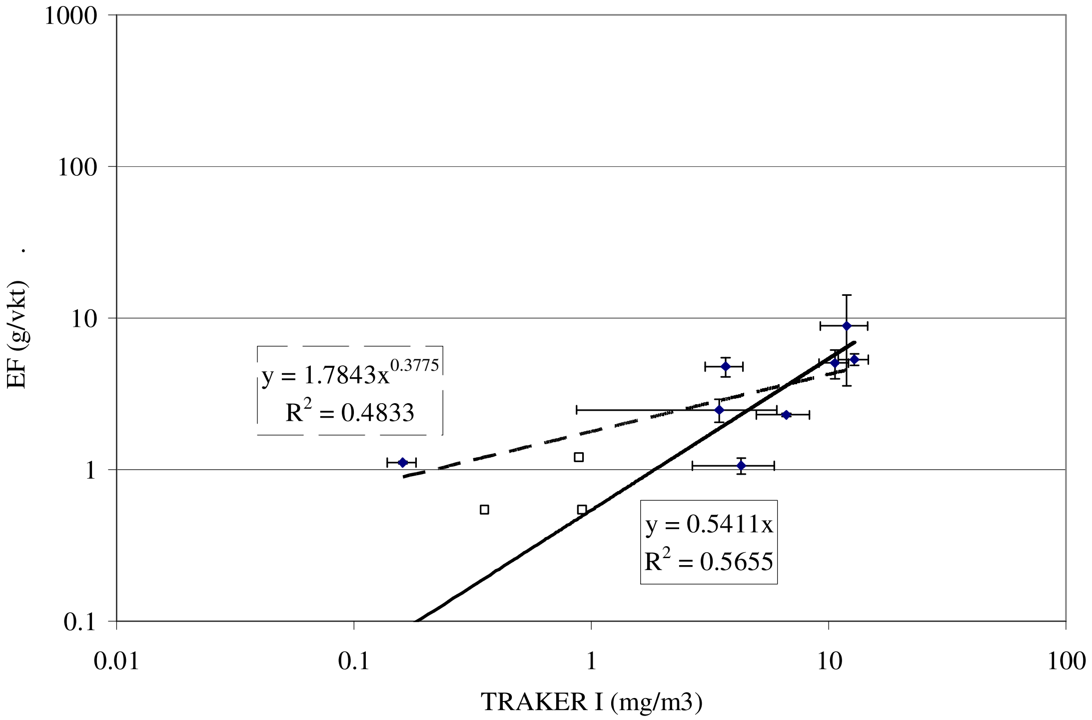
Comparison of set-averaged TRAKER I data and set-averaged PM_{10} emission factors are shown in **Figure 6-9**. The solid line in the Figure represents a least-square linear fit to the data with a zero intercept while the dashed line represents a power law fit. The power law fit appears to accommodate the leftmost data point better than the linear fit, though we note that the linear fit provides a better R^2 value (0.57 compared to 0.48). However, it is unknown whether the leftmost data point is an outlier. The white squares also shown in the figure were collected on a road near Lake Tahoe, California as part of an earlier study (Kuhns et al., 2004). Whereas these earlier data are not fully comparable owing to a slightly different field setup, they tend to indicate that the linear fit (or a near-linear fit) to the data from the present study is more reasonable than the power law fit which exhibits an exponent of 0.38. Of course, without a mechanistic understanding of the road dust emission process, there is no a priori reason to anticipate a specific form for the equation that best represents a calibration of TRAKER I. In the absence of further information, we assume for simplicity that the TRAKER I signal is related to PM_{10} emission factors through the simple linear relationship:

$$EF_{10} = 0.54 \times T \qquad \text{Equation 6.1}$$

where: EF_{10} = the PM_{10} mass emission factor from the tower data for all the vehicles used as test vehicles in the present study, and

T = the TRAKER signal defined simply as the background corrected average of the concentrations measured behind the left and right tires (Equation 5.3).

Figure 6-9. PM_{10} Emission Factors versus TRAKER I Average Signal. Solid squares are data from the present study and represent emission factors that are averages of all valid tower measurements for sets 1, 2, 3, 4, 5, 8, 10, and 11. TRAKER I data shown are averages of TRAKER I passes during the respective set. Averages include only passes after the ninth pass following silt application for sets when silt was applied to the test road. The solid line in the Figure represents a least-square linear fit to the data from the present study with a zero intercept while the dashed line represents a power law fit. The white squares are data collected during an earlier study near Lake Tahoe, California. X and Y error bars represent standard errors which are based on the standard deviation of individual measurements within the measurement Set divided by the square root of the number of measurements included in the average.



6.3.2 TRAKER II

Figure 6-10 shows the PM_{10} horizontal fluxes and the TRAKER II signal averaged by pass when both measurements were valid. As with the TRAKER I data, the two measurements tend to follow each other, though not consistently owing to the noise that is inherent to both measurements, especially the tower fluxes. As with the TRAKER I data, to obtain a correspondence between tower measured PM_{10} emission factors and the TRAKER II signal, we compared set-averaged tower data to set averaged TRAKER II signal. Only Sets with at least 10 valid tower measurements corresponding to "mechanically suspendable" road dust (i.e. more than 9 passes after silt application) were considered (1, 2, 3, 4, 5, 8, 10, and 11). Although the TRAKER II data for pass IDs lower than 170 were considered of suspect validity because of a malfunction in the inlet flow control, they have been included in the comparison shown in **Figure 6-11**. If not included, only a few points for comparison would be available. Thus, the relationship between the TRAKER II signal and the PM_{10} emission factors should be considered preliminary.

Unlike TRAKER I, the power law fit for TRAKER II provides a substantially higher R^2 value than the simple linear fit (0.90 compared to 0.75). It would be interesting as additional research becomes available to re-examine the relationship between the TRAKER II signal and tower measured emission factors. For the purposes of comparison with TRAKER I and SCAMPER (below), we propose to use the same simple linear form that was presented for TRAKER I in Equation 1 above, namely,

$$EF_{10} = 0.92 \times T_{II} \qquad \text{Equation 6.2}$$

where T_{II} is the TRAKER II signal.

Figure 6-10. Time Series of Measured horizontal PM_{10} flux on the DRI Tower System and the Pass-Averaged TRAKER II Signal for Passes When the Horizontal Flux Measurement was Valid

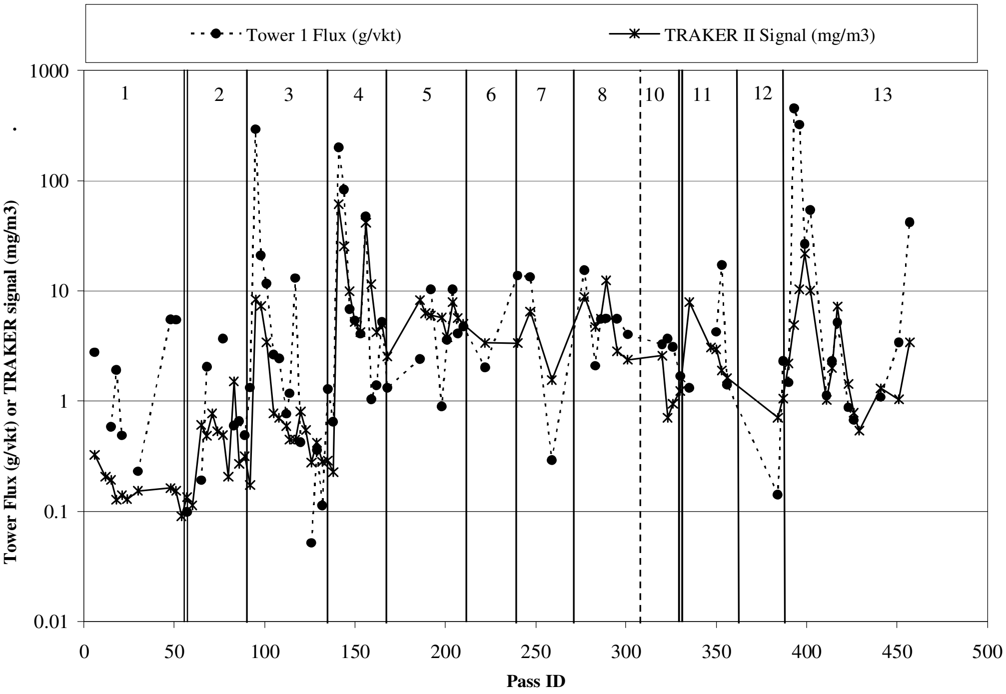
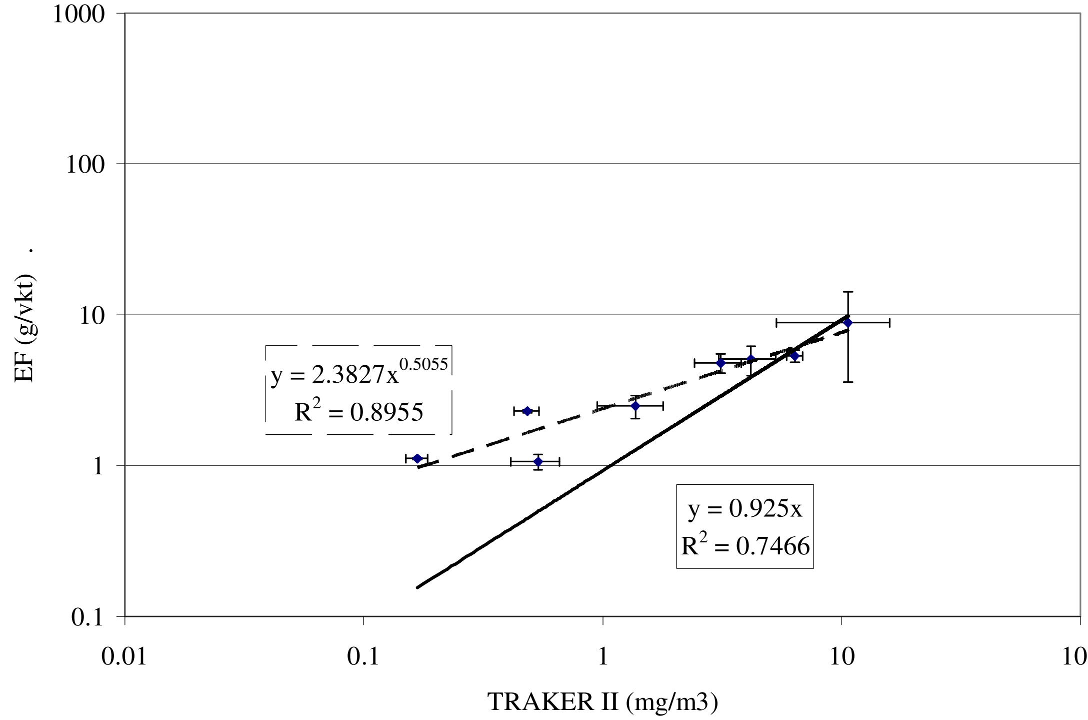


Figure 6-11. PM_{10} Emission Factors versus TRAKER II Average Signal. Solid squares represent emission factors that are averages of all valid tower measurements for sets 1, 2, 3, 4, 5, 8, 10, and 11. TRAKER II data shown are averages of TRAKER II passes during the respective set. Averages include only passes after the ninth pass following silt application for sets when silt was applied to the test road. The solid line in the Figure represents a least-square linear fit to the data with a zero intercept while the dashed line represents a power law fit. X and Y error bars represent standard errors which are based on the standard deviation of individual measurements within the measurement Set divided by the square root of the number of measurements included in the average.



6.3.3 SCAMPER

Figure 6-12 shows the time series of pass-averaged net (rear – front DustTrak signal) SCAMPER signal and PM_{10} horizontal flux measurements when both types of measurements were valid. As with TRAKERs I and II, the UCR SCAMPER follows the general trend of emission factors captured by the tower system. For comparing the SCAMPER signal to PM_{10} emission factors measured by the tower, only Sets with at least 10 valid tower measurements corresponding to "mechanically suspendable" road dust (i.e. more than 9 passes after silt application) were considered (1, 2, 3, 4, 5, 8, 10, and 11). Set averaged PM_{10} emission factors are plotted against set-averaged SCAMPER signal in **Figure 6-13**. As with TRAKER I and TRAKER II, we show both a linear fit and a power law fit in the Figure. Similar to TRAKER I, there was no benefit in terms of R^2 values in a power law fit (0.40) over a linear fit (0.47). Assuming a linear relationship between PM_{10} emission factors and the SCMAPER signal, the following empirical equation can be used to relate the two quantities:

$$EF_{10} = 20 \times SC \qquad \text{Equation 6.3}$$

where *SC* is the SCAMPER signal.

In the SCAMPER the net signal is multiplied by the frontal area of the tow vehicle (maximum height * maximum width), 3.66 and the DustTrak "calibration factor". The later is determined from PM_{10} filter sampling collocated with the rear-mounted DustTrak. Due to a leak in the PM_{10} sampler during this study, we did not determine a calibration factor. In previous studies conducted in Clark County NV and in Maricopa County AZ the average factor has been measured as 3.4 with an estimated uncertainty of 1. Therefore the emission factor based on this method is given by:

$$EF_{10} = 12 \text{ x } SC \qquad \text{Equation 6.4}$$

This is within a factor of two of the value determined by the tower measurements and given the scatter in both data sets, they are in reasonable agreement.

It is interesting to note the multipliers for the different mobile systems that are needed to obtain the same emission factors (**Table 6-4**), especially in the context of the distance of the mobile measurement from the road dust source. The inlets of TRAKER I are located closest to the vehicle's front tires. In TRAKER II, the distance between the inlet and the vehicle front tires is almost twice that of TRAKER I. For SCAMPER, the distance between the "influence" DustTrak mounted on the trailer behind the vehicle and the vehicle tires is more than an order of magnitude that of TRAKERs I and II. These simple observations suggest that the differences in the signals from these three mobile systems are closely related to the distances between where the "influence" measurement is taken compared to the locations of the tires.

Table 6-4. Summary of Equivalence Multipliers Between Mobile Measurement Systems and PM_{10} Emission Factors Assuming that the Raw Signal for the Mobile Systems is Linearly Related to Measured Emission Factors

System	Raw Signal (mg/m^3) Multiplier to get PM_{10} Emission Factor (g/vkt or g/vmt)
TRAKER I	0.54 (0.86)
TRAKER II	0.92 (1.5)
SCAMPER	20 (32)

Figure 6-12. Time Series of Measured Horizontal PM_{10} Flux on the DRI Tower System and the Pass-Averaged SCAMPER Signal for Passes When the Horizontal Flux Measurement was Valid

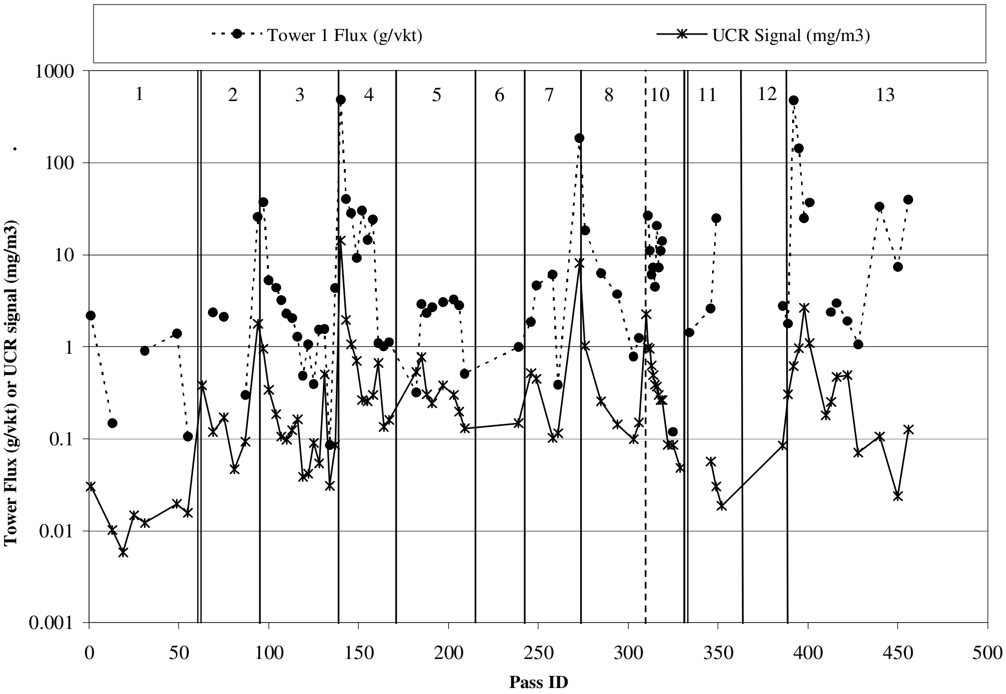
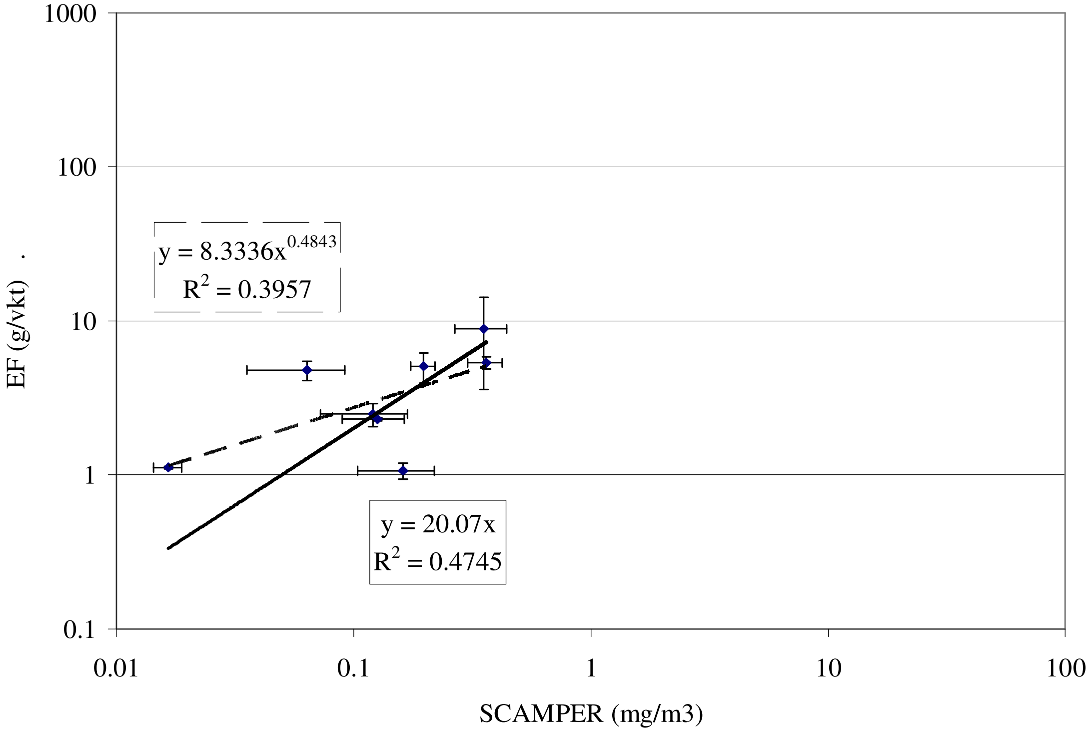


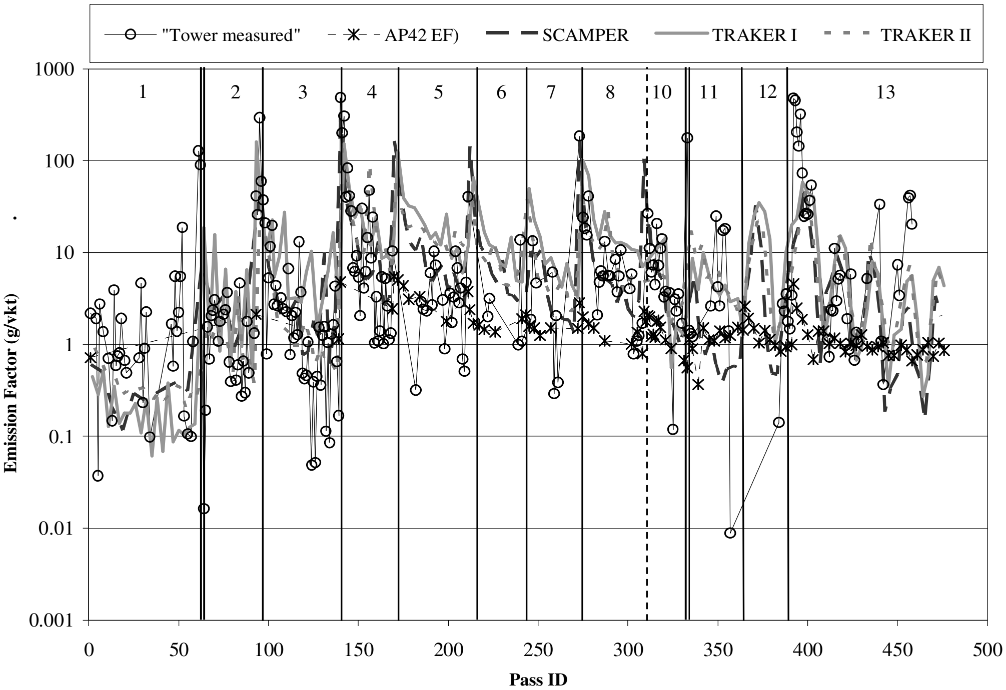
Figure 6-13. PM_{10} Emission Factors versus SCAMPER Average Signal. Solid squares represent emission factors that are averages of valid tower measurements for sets 1, 2, 3, 4, 5, 8, 10, and 11. SCAMPER data shown are averages of SCAMPER passes during the respective set. Averages include only passes after the ninth pass following silt application for sets when silt was applied to the test road. The solid line in the Figure represents a least-square linear fit to the data with a zero intercept while the dashed line represents a power law fit. X and Y error bars represent standard errors which are based on the standard deviation of individual measurements within the measurement Set divided by the square root of the number of measurements included in the average.



6.4 Comparison of Calibrated Mobile Technologies Emission Factors to EPA Method AP-42 Emission Factors to measured PM_{10} Horizontal Flux Tower Values

Figure 6-14 shows a time series comparison of pass-averaged emission factors using the five different methods. The Figure shows direct PM_{10} horizontal flux measurements with the tower system, emission factors estimated from silt measurements and use of AP-42 equations, and calibrated emission factors from the three mobile systems, TRAKER I, TRAKER II, and SCMAPER. The mobile system emission factors are calculated by multiplying the respective pass-averaged signals (in mg/m^3) by the appropriate calibration factors discussed in Section 6.3 (Equations 1 – 3). The Figure illustrates how well the mobile systems track one another and to a lesser extent, the horizontal flux tower measurements. It also shows that the silt-based AP-42 method tends to underestimate the measured emission factors and does not respond to changes in emission factors that appear to be related to vehicle speed (see for example the speed test cycles in Set 13 measurements).

Figure 6-14. Emission Factors (g/vkt) For All Valid Passes. Tower data are direct measurements, AP-42 data are based on silt measurements and use of AP-42 equations, SCAMPER, TRAKER I, and TRAKER II data are based on the regression between those mobile systems and measured PM_{10} tower fluxes (using Equations 1-3 in Section 6.).



The current approved AP-42 PM_{10} emission factor equation does not include speed as a factor in estimating PM_{10} emissions. The equation assumes an equilibrium silt loading, SL, that is determined by rates of removal by mechanical and aerodynamic shear that are opposed by rates of creation and deposition from road, brake and tire wear, and atmospheric and hydrologic transport and vehicle track-out. Equilibrium silt loadings are known to be lower on roadways with higher average daily traffic (ADT), and higher ADT's are usually accompanied by higher average speeds.

In this experiment, freshly applied silt on the road surface was not in equilibrium, and was progressively depleted by successive vehicular passes. Rapid depletion was observed in both the first 9 passes of the mobile technologies data and in the "quickie strip" AP-42 silt sampling.
Additionally, effects of varying vehicular speed can be clearly observed in sets 12 and 13 (from Pass_ID 360 onwards) in **Figure 6-14**, where mobile technologies vehicle speeds were increase from 25 mph to 45 mph and then decreased back to 25 mph over several cycles. Al three mobile technologies emissions factors consistently increased with increasing vehicle speed, and decreased with decreasing speed.
It is illustrative to examine the estimates of emission factors from the different mobile systems, tower measurements, and AP-42 silt based method on a set-averaged basis. As was done previously, during sets when silt was applied to the road surface, we include in the set average only data from passes after the ninth pass following silt application. **Figure 6-15** shows the estimated emission factors using the calibrated mobile systems (SCAMPER, TRAKER I,

TRAKER II) and AP-42 equations that utilize on-site silt measurements. Overall, 1) mobile methods measured higher emission factors when higher silt loadings were applied, and 2) the mobile methods track each other quite well. The silt-based AP-42 emission factor method captures some of the variability exhibited by the mobile systems, but agreement of AP-42 with mobile systems is not as good as agreement among mobile systems. The same information is shown as scatter plots of TRAKER I, II, and silt based EF versus SCAMPER EF in **Figure 6-16** and TRAKER II, SCAMPER, and silt-based EF in **Figure 6-17**.

Figure 6-15. Comparison of Set-Averaged Emission Factors (g/vkt). Figure shows averages over sets with valid data for mobile systems calibrated against PM_{10} tower flux measurements as described in Equations 1-3 of Section 6.2 and silt-based emission factors using AP-42 equations. Averages include only passes after the ninth pass following silt application for sets when silt was applied to the test road. AP-42 emission factors are calculates using measured silt loadings at the end of a measurement set.

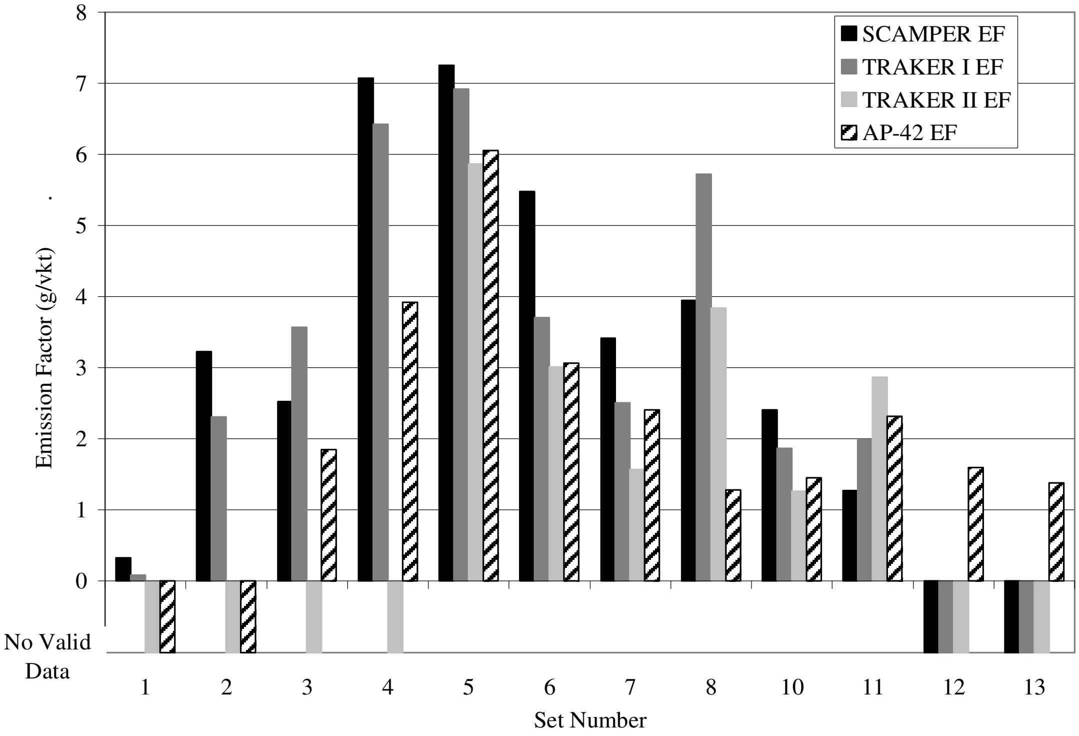


Figure 6-16. Set Averaged TRAKER I EF, TRAKER II EF, and AP-42 Silt-Based EF Plotted Against SCAMPER EF

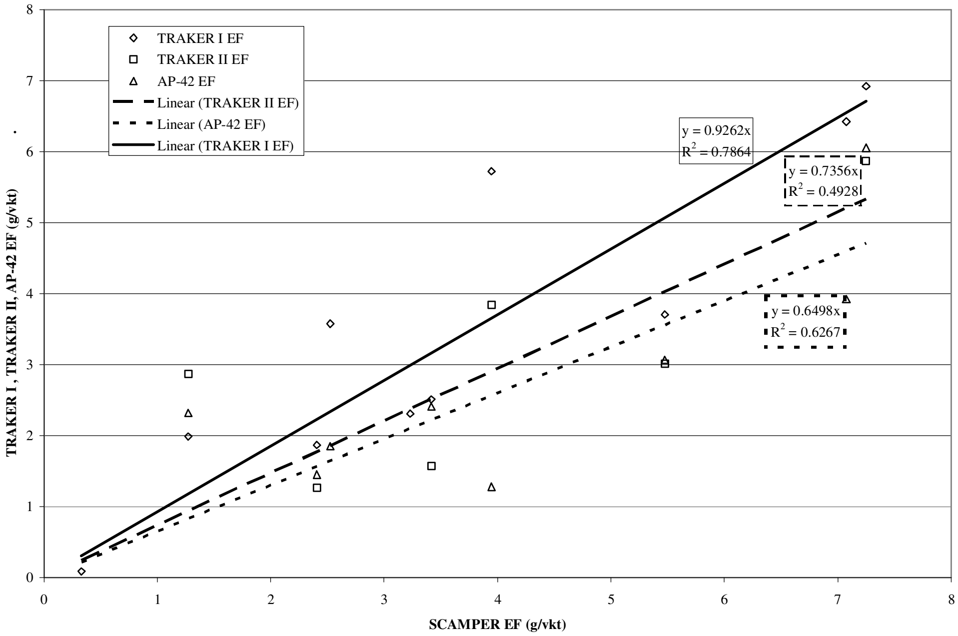
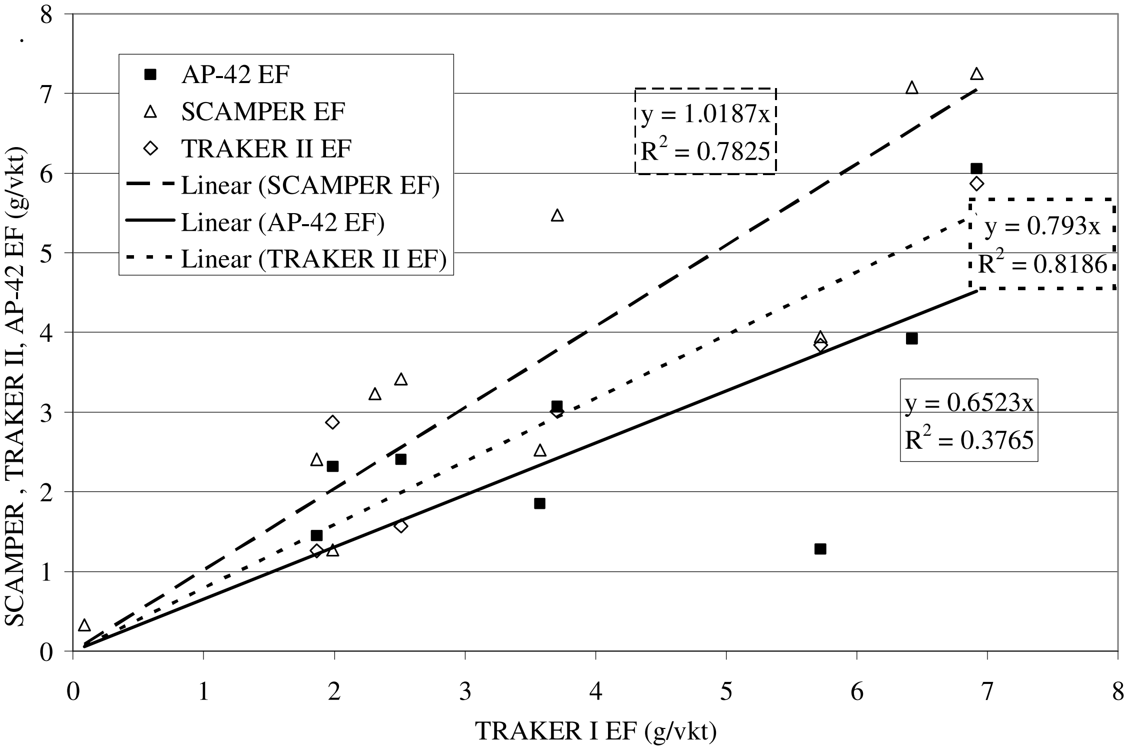


Figure 6-17. Set Averaged TRAKER II EF, SCAMPER EF, and AP-42 Silt-Based EF Plotted Against TRAKER I EF



6.5 Comparisons of SCAMPER "First Principles" EF With TRAKER and AP-42

By first principles, the emission factor can be calculated by multiplying the average net PM_{10} concentration in the plume by the area of the plume swept out by the vehicle. Although detailed plume concentration data are not available from this study, the location of the SCAMPER's rear DustTrak has been shown to be representative of the average concentration within the plume, and the plume height and width have been shown to be approximately the frontal area of the vehicle (Fitz, 2001). Thus, multiplying the frontal area by the net PM concentration gives an approximate emission rate. The rear DustTrak's central position tend to give values of PM concentrations that are higher than the average, while the plume dimensions have been shown to be somewhat greater than the frontal area. These two factors tend to cancel one another in the multiplication process.

Based on the tower calibration, the net SCAMPER PM_{10} concentration is multiplied by a factor of 20 to convert mg/m^3 to g/vmt. Using the first principle approximation, the net SCAMPER concentration is multiplied by 3.66 m^2, the frontal area of the Ford Expedition and multiplied by the factor of 2.4 described in Section 4.1 to account for the discrepancy between DustTrak and filter-based data.

As shown in Figure 6-16, the regression of "calibrated" SCAMPER emission factors with the AP-42 emission factors yielded a slope of 0.65 with an R^2 of 0.63. Using the "first principle" SCAMPER emission factor, the SCAMPER EF shown in the figure should be divided by 20 and then multiplied by 3.66 and 2.4; a factor 0.44 should therefore be applied. The correlation coefficient, R^2, would remain essentially the same. Multiplying the SCAMPER values by 0.44 would increase the slope of the regression with the AP-42 emission factor to 1.48 (0.65/0.44). This approach, without using a calibration, therefore gives results within a factor of two compared to the tower calibration approach. Given the potential errors in the tower technique and AP-42 measurements, the results for both approaches are therefore approximately equivalent when comparing with the AP-42 emission factors.

7.0 DISCUSSION

7.1 Real World Precision and Reproducibility

7.1.1 UCR Paved Road Phases II & III for DAQEM

In the DAQEM's Phase II evaluation of mobile emissions from paved roads the SCAMPER system was used to characterize PM_{10} emission rates on a single 120 mile long test route in Las Vegas, NV. Tests were conducted February 14-17, 2005, with one traverse of the route per day. Emission rates for speeds less than 10 mph were excluded, as we would not expect a well-developed plume behind the SCAMPER vehicle. The results showed that PM_{10} emission rates were generally near zero except when occasional "hot spots" were encountered, which is consistent with previous measurements. The daily average PM_{10} emission rates for the routes were 0.086, 0.105, 0.040 and 0.012 g/VKT (0.14, 0.17, 0.064, and 0.019 g/VMT) for February 14th, 15th, 16th, and 17th, respectively. Due to likely enforcement activities after the second measurement day, the precision of the measurement approach could not be quantified. The two initial days suggest that the precision is approximately 10%. The emission rates for the first two days were approximately a factor of two lower than those measured in the summer of 2004 during phase I. The test route, however, was different than the summers and there are likely to also be seasonal differences that affect emission rates.

In the DAQEM's Phase III evaluation of mobile emissions from paved roads the SCAMPER system was used to characterize PM_{10} emission rates from road loops in the Las Vegas area. One of the primary objectives of this study was to determine measurement uncertainty. This was done by making consecutive measurements over a loop of roads. One loop was short with high emission potential roads in an industrial area so that a large number of traverses could be made. Two longer loops were chosen to be more representative of emission potential of roads in the area. High PM_{10} emission rates were expected from one of the longer loops, while low rates were expected from the other. The measurements were also used to compare the SCAMPER results with AP-42 silt sampling, and evaluate diurnal variations of the emission factors.

The results showed that PM_{10} emission rates met the loop expectations and were generally low except when "hot spots" were encountered, which is consistent with previous measurements. We concluded that the measurement uncertainty, based on the coefficient of variation for each loop, was approximately 25%. The PM_{10} emission rates did not change significantly during the course of the day, but on the high emission longer loop the rates dropped by a factor of two over the weekend. The comparison with AP-42 silt sampling showed good correlation ($R^2 = 0.86$) with the SCAMPER segment results, which were three times lower. The SCAMPER data however were not calibrated to actual mass measurement. The calibration factor, based on a limited (8) number of filter samples was approximately 2, which compares well with the value of 2.4 reported here. Applying this factor, the SCAMPER and AP-42 silt PM_{10} emission rates were equivalent well within experimental uncertainty. Since SCAMPER directly measures PM emission rates, it is likely to be a more direct and accurate measure of PM emissions from roads.

7.1.2 DRI Studies—Clark County Phase II, Lake Tahoe and Idaho

The study reported here is the latest in a series of TRAKER studies that started in 1999 when a passenger vehicle was outfitted with sample tubes behind the front tire. That earlier study in Las Vegas, Nevada, reported by Kuhns et al. (2001), was the "proof of concept" for the TRAKER idea. Since then a number of research efforts have been completed using the TRAKER in the Treasure Valley in Idaho (Etyemezian et al., 2003a, 2003b; Kuhns et al, 2003), near El Paso, Texas (Kuhns et al., 2005; Gillies et al., 2005), in the vicinity of Lake Tahoe on both the California and Nevada sides (Gertler et al., 2006), and again in Las Vegas, Nevada (Etyemezian et al., 2006).

The study near El Paso, Texas, involved the use of a horizontal PM_{10} flux tower to directly measure the PM_{10} emissions from an unpaved road and correlate those measurements with the TRAKER signal. Three important findings came out of that study. First, it was found that the PM_{10} emission factor for a vehicle traveling on an unpaved road was directly proportional to the speed of the vehicle as well as its weight (Etyemezian et al., 2003a; Gillies et al., 2005). This was tested for speeds ranging from 5 to 45 mph and vehicle sizes ranging from a small passenger vehicle (Dodge Neon) to a 22-wheeled tractor-trailer. Second, it was found that for the same paved road, the TRAKER signal increased with speed. Specifically, the TRAKER signal was proportional to a constant multiplied by the TRAKER travel speed raised to the third power. Third, it was found that for unpaved roads, the PM_{10} emission factor scaled with the cube root of the raw TRAKER signal. In summary, it was found that the TRAKER signal could be related to PM_{10} road dust emissions from unpaved roads using the Equation:

$$EF = kT^{1/3} \qquad \text{Equation 7.1}$$

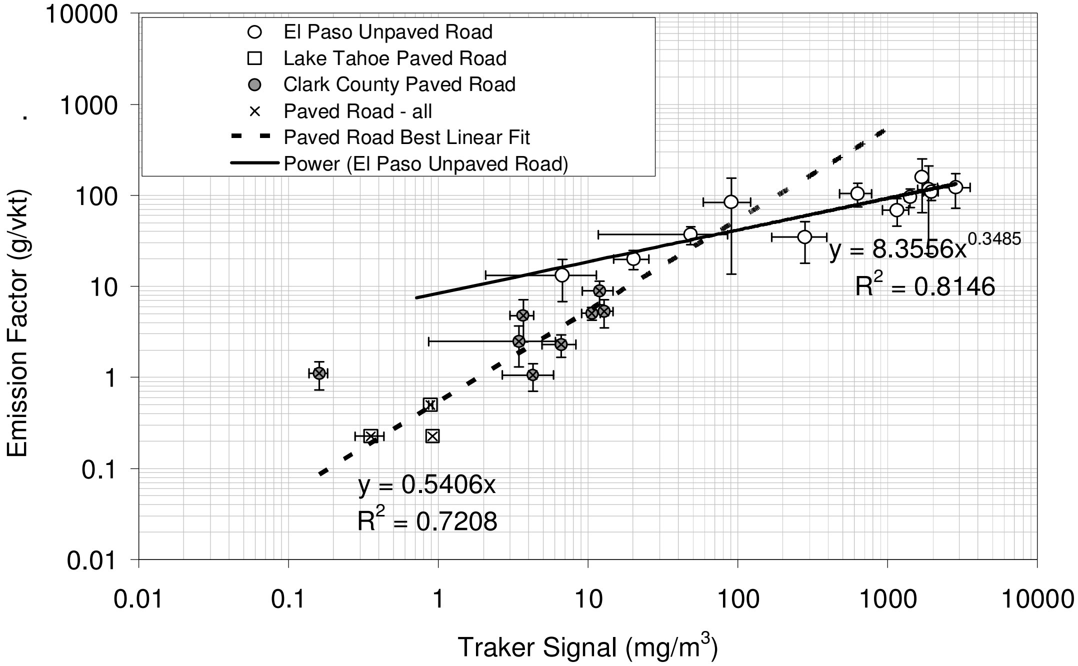
where *EF* is the emission factor (g/vkt), k is the constant that relates emissions to the TRAKER signal and is approximately 0.33 (σ_g=1.5), and *T* is the TRAKER signal as defined in Equation 5.3 in Section 5.3.2. This provided the fit shown in **Figure 7-1** for the solid circles.

For the Treasure Valley Road Dust Study, Etyemezian et al., (2003b) used TRAKER I data collected over 150 miles of roads near Boise, Idaho over two seasons to assemble a PM_{10} paved and unpaved road dust emission inventory. At the time of that study, the TRAKER I had not been calibrated against an independent measure (such as horizontal flux towers) on a paved road. Therefore, those authors extrapolated the unpaved road calibration to obtain preliminary estimates of emissions from Treasure Valley Roads. It was clear from the relative magnitude of road dust emissions in the emissions inventory that the unpaved road calibration was providing unreasonably high values for PM_{10} emission factors. This was reinforced during the Lake Tahoe Study (Gertler et al., 2006), when TRAKER I was operated on a paved road segment that was also outfitted with a horizontal tower flux emission measurement system. This resulted in three data points (shown as open squares in **Figure 7-1**) that were clearly not in line with the unpaved road calibration used in the Treasure Valley Study.

It is worth noting that up until the present study, emission factors reported for TRAKER I measurements were based on calibration of the TRAKER I primarily on unpaved roads. In the absence of a paved road calibration, those earlier calibrations from an unpaved road were extrapolated to measurements on paved roads. The present study provides a direct paved road calibration for the TRAKER I (and TRAKER II).

In the present research effort, TRAKER I – along with SCAMPER and TRAKER II – was extensively operated on a paved road in conjunction with horizontal tower flux measurements. The results of this study, shown in **Figure 7-1** as gray circles, along with the Lake Tahoe measurements (open squares), indicate that the relationship between the TRAKER signal and PM_{10} emission factors on paved roads is quite different from unpaved roads. This shows that earlier emissions estimates obtained with the TRAKER I (using unpaved road calibration extrapolated to paved roads) were substantially higher than emissions that would have results from using a paved road calibration (See **Figure 7-1**).

Figure 7-1. TRAKER I Calibrations. Open circles show data collected from unpaved road calibration near El Paso, Texas (Etyemezian et al., 2003a). Open squares show later data collected on a paved road near Lake Tahoe in California (Gertler et al., 2006). Closed circles are data collected on paved road from the present study. Dashed line is best linear fit to data from current study and Lake Tahoe study.



As part of an earlier phase (Phase II) of the Clark County research effort, the TRAKER I was used to measure road dust emission potential over a road circuit (~ 100 miles) on four consecutive days in February, 2005. Researchers from UNLV were also collecting silt samples for AP-42 based emissions estimation from points along the road circuit over the same period. Two important findings resulted from the Phase II study that is relevant to the present effort. First, Etyemezian et al. (2006), reported that over the 645 separate road segments that constituted the road circuit, the precision of the TRAKER I measurement system was better than 20% for 62% of the road segments and the precision was better than 50% for 96% of the road segments.

Second, the data collected as part of Phase II were re-processed using the relationship between the TRAKER signal and paved roads that has resulted from the present study (namely, Equation 1 in Section 6.3). Where data were available from both the TRAKER I measurement and silt samples collected from UNLV, the emission factors measured by TRAKER I were compared to the emission factors estimated from silt measurements and application of the AP-42 equations. Emission factors using these two methods are shown side by side in **Figure 7-2**. For the majority of the streets where both measurements were completed, the TRAKER I emission factors using the paved road calibration obtained from the present study are substantially lower than the silt based emission factors calculated using the AP-42 equations. Two exceptions are Sapphire Light and Hardin, both of which were heavily loaded with soil. Combined with the information provided in **Figure 6-15** in Section 6.4, these data point to a preliminary trend. It appears that for heavily loaded roads, mobile measurement systems such as TRAKER I provide higher emission factor estimates than silt-based methods. This seems to be true for most of the Phase IV measurements (with mobile system emission factors in the range of 2 – 7 g /vkt) as well as the Sapphire Light and Hardin roads measured in Phase II of the Clark County Study (with mobile emission factors around 10 g/vkt). In contrast, for lightly loaded roads (Emission factors less than 1 g/vkt); the mobile systems appear to provide a lower estimate of emission factors than silt based methods.

Figure 7-3 shows the same information in scatter plot format. The regression between AP-42 silt based emission factor estimates and TRAKER I emission factor estimates exhibits a poor correlation (R^2 ~ 0). This is in contrast to the regression of silt-based methods against TRAKER I from the Phase IV study, where the relationship is not one to one, but does exhibit at least a weak correlation ($R^2 = 0.37$, See **Figure 6-17**, Section 6.4). There are two possible reasons for this difference between the Phase IV study and the real-World conditions of the Phase II study. In the Phase IV study, the same parent road material was used for silt application for all tests and silt was applied to the entire roadway test section more or less homogeneously. In contrast, in the real World, the road material that can result in road dust may be of quite variable composition (in terms of size distribution at least). Furthermore, there are likely to be rather large differences in road dirt loading over several kilometers of the same street. These differences cannot be captured by what is essentially a single point silt sample.

Figure 7-2. Emission Factors (g/vkt) From Phase II Clark County Study. Data are shown for streets where both TRAKER I and silt-based measurements were conducted. TRAKER I emission factors were calculated using the paved road calibration resulting from the present study (See Equation 1 Section 6.2).

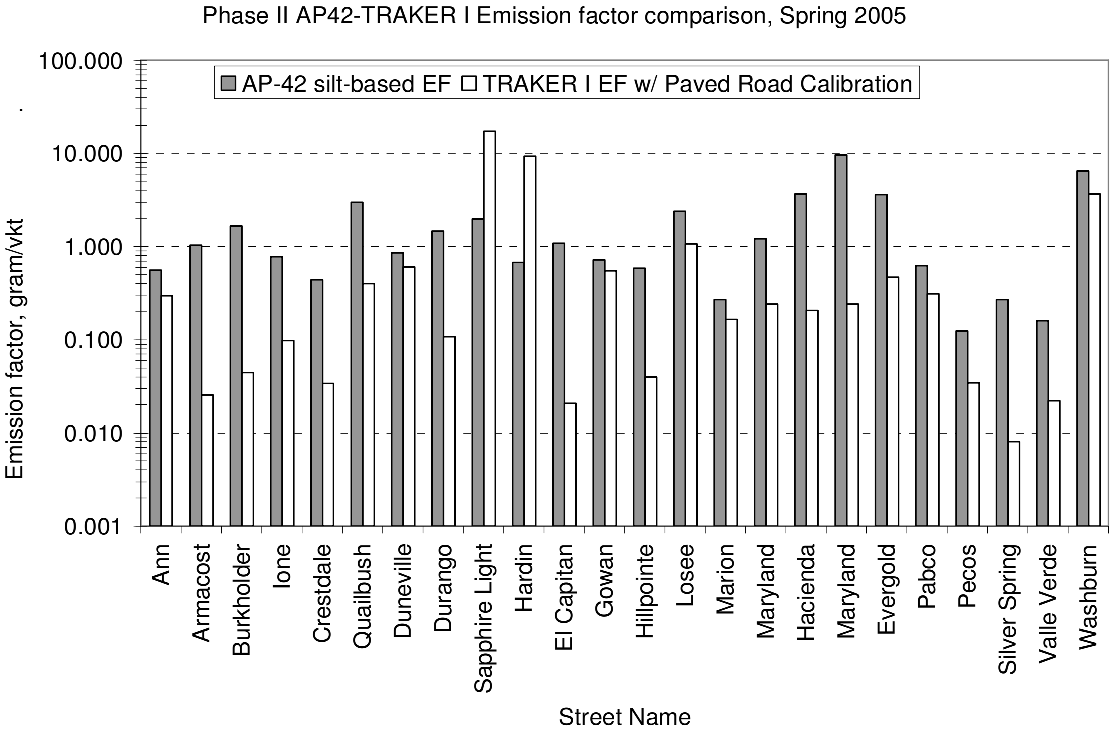
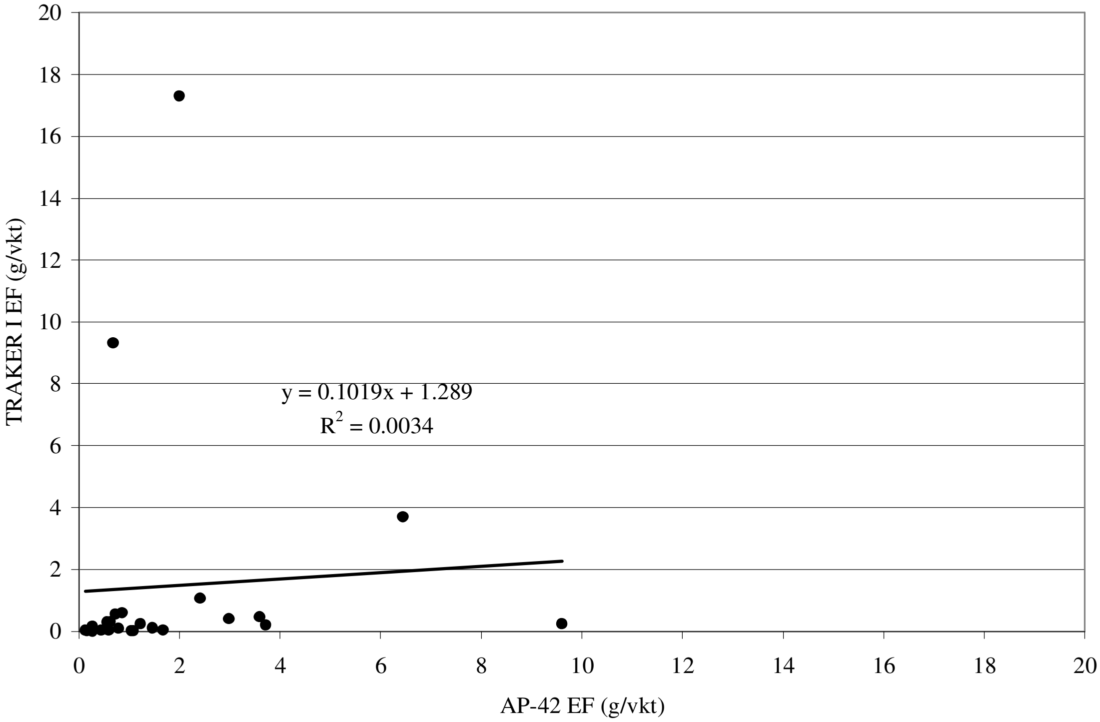


Figure 7-3. Scatter Plot of TRAKER I EF (g/vkt) versus AP-42 Silt-Based EF (g/vkt)



7.2 Applying Phase IV Results in Real World Conditions- Explanation of Higher EF's in Phase IV

We propose a working hypothesis about the cause of the shift in the relationship between AP-42 emission factors and mobile technologies emission factors, which we call the "differential silt mobilization hypothesis", or DSMH, for short. We will attempt to use DSMH to explain why, in Phase II, AP-42 EF's were higher than mobile EF's compared Phase IV, where AP-42 EF's were lower than mobile EF's. We believe that these observations are caused by both different availabilities of silt for resuspension in Phase II and Phase IV, and by the higher amount of shear applied to mobilize silt in the AP-42 method compared to mobile technologies methods.

(a) The Phase IV experiment was conducted on a road surface in excellent condition with very low physical roughness. In comparison, the roadways sampled during Phase II exhibited a variety of roughness, but are thought to have generally higher physical roughness, and have more highly worn pavements than the Phase IV site.

(b) Silt deposited from natural processes on well-traveled road surfaces tends to be swept into the pits of the road surface, between the protrusions caused by aggregate embedded in the asphalt binder.

(c) Measurements by Rodriguez-Bettancourt (2006) showed that aerodynamic shear applied by a conventional vacuum cleaner head during AP-42 silt recovery is likely to be one to three orders of magnitude higher than the shear applied by vehicles.

The combined result of (a), (b), and (c) makes it more difficult to mobilize silt into the air when it is embedded in the pits of a normally-traveled, medium-rough road surface during conditions of moderate shear applied by vehicle tires and aerodynamic wakes compared to the greater degree of mobilization resulting from conditions of higher shear applied by a vacuum cleaner head during AP-42 sampling. As a result, on natural, rougher road surfaces, a higher mobilization of the silt fraction by a vacuum cleaner would lead to a higher AP-42 emission factor, for the same amount of silt loading, than the emission factors observed by mobile technologies vehicles.

In contrast, during the Phase IV experiment, freshly applied road silt was more evenly distributed between the smaller "protrusions" and "pits" on a smoother, well-sealed road surface, and was therefore easier to mobilize in conditions of moderate applied vehicle shear than a similar loading on a normally traveled paved road. As a result, observed mobile EF's would be higher, for the same silt loading, on the Phase IV experimental road surface, than they were on the normally traveled paved roads that were measured in Phase II. AP-42 vacuumed EF's would be similar, since four vacuum passes have been shown to recover greater than 99% of applied road silt on both smooth and rough road surfaces, and the vacuum exerts a very high level of aerodynamic shear. The result is that mobile technologies EF's are hypothesized to have increased relative to AP-42 EF's on the Phase IV surface compared to the Phase II surface.

This hypothesis would also explain why, in conditions of heavy soil loading, such as Hardin and Sapphire Light in Phase II, as well as for the Veterans Memorial Boulevard loadings in Phase IV, mobile technologies emissions factors were higher than for AP-42, because, under these conditions, there is a large amount of silt on top of the protrusions that can be easily suspended

7.3 Advantages of Mobile Technologies

Real-time vehicle mounted mobile sampling systems provide a number of very significant improvements over the current AP-42 paved road dust emissions estimating equation. The mobile sampling systems are not subject to many of the assumptions and limitations applicable to the AP-42 equation, including the requirement for free flowing traffic, speed ranges between 10 and 55 mph, the need to block lanes of traffic for silt sampling, the ability to sample on all road functional classes, and the ability to collect a large number of measurements over a short time period.

Mobile sampling systems can effectively sample on congested urban streets where traffic is not free flowing, whereas the AP-42 emissions equation is predicated on free flowing traffic. Applying AP-42 emissions estimating methodology to roadways with heavily congestion results in unknown but potentially significant errors. The GPS linked data collection system utilized in the mobile sampling systems allow the operator to easily exclude data points collected below a specified *de minimus* threshold speed, typically set at 10 mph.

Mobile sampling systems are speed independent and can accurately measure emissions at all non-*de minimus* (>10 mph) speed ranges, including speeds above 55 mph. By comparison, the AP-42 emissions equation is not validated for vehicle speeds above 55 mph.

Mobile sampling systems provide a safer method of measuring paved road dust emissions. The mobile sampling systems can operate without the need for lane closures and the associated public safety risk and increased traffic congestion.

Mobile sampling systems can accumulate paved road emissions data much faster and more economically than the AP-42 emissions equation methodology. The mobile sampling systems provide a means of sampling significant percentages of the entire road network in an airshed or nonattainment area. The abundance of data developed with the mobile sampling systems approach allows for the development of specific emission factors for many criteria known to affect the paved road dust emission rate. These include, in addition to road functional classification, road infrastructure development and land use type and development. Impacts of specific silt deposition sources may also be evaluated. These detailed breakdowns will allow SIP developers to prepare more complete and representative emissions inventories for the paved road dust source category. The benefits of more robust emission factor information would be even more profound for air regulatory agencies and MPOs developing future emissions projections for this source category. The mobile sampling systems ability to provide much larger data sets will allow SIP planners and MPOs to develop far more detailed and realistic projected emissions estimates for future year paved road dust emissions.

7.4 Paved Road Dust Emission Inventory Development

The AP-42, Section 13.2.1 Paved Roads – Background Documentation, sets forth test results for selected functional classes of roadways. This documentation does not address utilization of emissions factors or development of emissions inventories. State and local transportation agency nomenclature for functional road classification may very slightly from place to place, but a typical breakout of functional road classifications is as follows:

- Freeway
- Major Arterial
- Minor Arterial
- Collector
- Local

In addition, certain other classes such as freeway on-ramps and off-ramps, industrial roads, and alleys may also be included in an MPO's functional road classification and transportation model.

Most agencies vested with state implementation plan development responsibilities use the AP-42 default silt loading values provided in the AP-42 document in lieu of acquiring current local silt measurements. This significantly degrades the quality and confidence levels of the AP-42 derived paved road dust emissions estimates. For those entities that make local silt loading measurements when developing emission factors for paved road dust emissions, the measurements are typically confined to minor arterial, collector, and local roads. Public works agencies typically will not issue encroachment permits for sampling on heavily congested major arterial roads. Less heavily congested major arterial roads are sometimes sampled, but these results in biased emissions estimates as the samples are not representative of the most heavily traveled major arterial roads. State departments of transportation seldom allow silt sampling on congested urban freeways due to severe traffic disruptions and related safety hazards of traffic flow disruption. Emission inventory developers must therefore rely on silt loading data for freeways which may be decades old and may have originated from freeways located in another state.

Once silt sampling and analysis is complete, the AP-42 paved road equation is used to establish a vehicle miles traveled (VMT) based emission rate for each functional road class. This VMT emission rate for each functional road class is then applied to the regional road network to determine the total emissions from that functional road class. This step is repeated for each functional road class represented in the road network. The sum of emissions from all functional road classes provides the total road network emissions. VMT values for each functional road class are obtained from the transportation model utilized by the MPO.

The VMT by functional road class approach would also be utilized with emissions data developed using near real time vehicle mounted mobile sampling systems. The primary difference between the mobile sampling system and AP-42 approach would be the number of data points used and the percentage of that road network that could be represented by sampling. Where cost and time constraints inherent in the AP-42 method limit sampling to a few hundred feet of the road network, the mobile systems allow sampling of many miles of the road network. It is also feasible to make multiple repeat measurements of road segments to allow assessment of week day and weekend emission rates using the mobile sampling systems.

The largest constraints on road network emissions characterization with mobile sampling systems are the transportation models. Given the ability to sample many miles of roads using a mobile system, it is feasible to develop emission factors for subclasses for each functional road class. One sub classification might reflect the presence or absence of paved shoulders, curbs and gutters. Clark County research has shown that, other factors remaining the same, emission rates are higher on roads without paved shoulders, curbs and gutters. Another sub classification that may affect a road's emission rate are adjacent or nearby land uses. Industrial land uses typically contain more sources of road silt deposition than commercial or residential land uses. Another matrix that might be applied to each functional road class is some quantification of construction activity occurring in the vicinity of each road segment.

Transportation models are typically not currently set up to break out these sub classifications of functional road class. As a result, the potential refinement of the functional road class emission factors may not provide additional benefits with the current transportation models. The DAQEM is currently exploring the feasibility of using functional sub classification emission factors with the Regional Transportation Commission of Southern Nevada (RTC). Development of a more comprehensive library of emission factors could potentially provide significant improvements to present and future year emission inventories.

The DAQEM will continue to work with the RTC (the MPO for Clark County) to determine the appropriate sub class emission factors that can be used in conjunction with the TransCAD transportation model to develop the most refined paved road dust emission inventory. It may be necessary to pre-process data inputs for the model in order to utilize certain sub class emission factors. For example, the current road network data set may not include complete information on existing curb and gutter infrastructure. Curb and gutter location information can be developed using Geo Span digital street imagery and then coded into the model input data. Model VMT outputs will then allow use of the correct sub class emission factor.

Once an optimal set of sub class emission factors are identified, a sampling plan will be developed for determining the emission factor for each road sub classification using a real time vehicle mounted mobile sampling system. This sampling plan will provide the basis of the emission inventory improvement plan for the paved road dust source category and will be submitted to EPA Region 9 for review and concurrence.

Upon receipt of concurrence from EPA Region 9, DAQEM will complete a formal scope of work for field measurements, data processing and analysis, and report preparation. The department will then acquire the services of a qualified consultant utilizing standard county business practices.

Following completion of field measurements and acceptance of the study report and data, the DAQEM will work with the RTC to develop a new "clean sheet" emissions inventory for paved road dust emissions. Incorporation of this inventory into the PM_{10} Maintenance Plan will allow Clark County to develop improved future year PM_{10} projections and transportation conformity budgets.

8.0 CONCLUSIONS

8.1 Conclusions

In this study, controlled measurements of PM_{10} road dust emissions were completed on a test road in Boulder City, Nevada. Well-characterized parent soil was spread onto the test road surface at the beginning of most measurement sets. Silt samples were procured at the beginning and end of each measurement set as well as during the measurement set in some cases. Simultaneously, three mobile road dust measurement systems were used to traverse the test road: SCAMPER, TRAKER I, and TRAKER II. These mobile systems were used both to measure the potential for road dust emissions and to serve as road dust sources. Horizontal flux of PM_{10} was measured using an instrumented tower system to obtain an independent measure of the PM_{10} emission factors from travel on the test road section. The tower measurements were considered as the standard for comparing the other four measurement methods (three mobile methods and silt method).

It was clear from examining the data from both the horizontal flux tower and the mobile systems that after the application of soil to the test road, the first nine or so vehicle passes resulted in PM_{10} emissions that were

(a) much higher than subsequent passes and

(b) apparently caused by a different mechanism than subsequent passes.

In comparisons of mobile and silt systems to horizontal tower measurements, the first nine vehicle passes were omitted as they likely represented a very short-lived mechanism for road dust emissions that would not be prevalent on a well traveled real road.

Averages of PM_{10} emission factors measured with the tower system were calculated on a measurement set basis along with comparable averages for mobile systems. A simple linear fit appeared to be adequate for describing the relationship between the mobile systems' raw signal and the emission factors measured by the tower system. The raw signals for all three mobile units were calculated as the PM_{10} concentration at a location that is influenced by the road dust generated by the vehicle minus the background PM_{10} concentration. All three mobile systems correlated reasonably well with the tower measurements (with R^2 values ranging from 0.47 to 0.75). To obtain PM_{10} emission factors, it was found that the TRAKER I, TRAKER II, and SCAMPER raw signals required multiplication by 0.54, 0.92, and 20, respectively.

Silt measurements were used to calculate emission factors following the equations provided in AP-42. Those emission factors were then compared to the tower data as well as to emission factors obtained with the calibrated mobile systems. The mobile systems agreed well with one another – not surprising since they were all calibrated against the same tower data – and showed reasonable correlation with silt-based emission factors.

In general, silt based measurements resulted in slightly lower emission factors than those measured by the tower and mobile systems. In contrast, when the same tower based calibration was applied to TRAKER I data acquired on a wide range of Clark County roads as part of an earlier phase of this research effort, and compared to AP-42 emissions factors derived from silt measurements obtained from those same roads over the same sampling period, the TRAKER I measurements generally provided much lower emission factors than emission factors calculated from the silt measurements.

As described in Section 7.2, we believe that this shift in the relationship between mobile technologies EF's and AP-42 EF's is caused by differential silt mobilization, which occurred as result of a greater proportion of the applied silt loading being distributed on a the tops of the embedded road surface aggregates, and hence being more easily entrained by vehicle mechanical and aerodynamic shear from the Phase IV experimental road surface, compared to the less easily entrained silt more likely to be embedded between the road surface aggregates on the Phase II road surfaces.

8.2 Recommendations

Vehicle mounted mobile sampling systems avoid many limitations of the current AP-42 method for estimating road dust emissions. These limitations led Clark County to conduct the Phase I through IV field measurement studies to validate the effectiveness of the mobile sampling systems. These studies augmented six-years of extensive AP-42 silt sampling and analysis for emissions inventory development. As a result of this effort, the DAQEM concluded that real-time based vehicle mounted mobile sampling systems provide superior and a more flexible approach for developing SIP emissions inventories. These systems provide similar advantages for inventorying emissions from stabilized unpaved haul roads and other public and private unpaved roads. In addition to SIP emissions inventory development, these systems provide a preeminent method for measuring road dust emissions at stationary sources for permitting purposes.

DAQEM has discussed approval of real-time based vehicle mounted mobile sampling systems for SIP emissions inventory development with EPA Region 9 and EPA OAQPS. Both offices have indicated the need for a peer review process prior to a regional or OAQPS approval. DAQEM is seeking regional (Region 9) approval to utilize vehicle mounted mobile sampling systems to develop the paved road dust emission inventory for the County's PM_{10} Maintenance Plan. As part of Clark County's evaluation of the real-time based vehicle mounted mobile sampling systems, DAQEM informally contacted a number of state and local air regulatory agencies, many of which have expressed support for this alternative method of emission inventory development. This alternative method was also discussed with Metropolitan Planning Organizations (MPOs), all of whom were interested.

Following the presentation of Clark County's conference paper at the 16th Annual International Emissions Inventory Conference, Clark County worked with project contractors to further refine the study findings and develop a formal research report. A number of air regulatory agency, MPO staff, and research scientists have agreed to participate in the peer review. Following completion of the peer review process, Clark County will request EPA Region 9 approval of real-time vehicle-mounted mobile sampling systems as a locally approved method for use in the Clark County's PM_{10} Maintenance Plan.

Clark County's mandates do not require EPA OAQPS approval of the real-time based vehicle mounted mobile sampling system as an approved (alternative) AP-42 method, Clark County may indirectly benefit from improved characterization of the paved road dust sources by other regulatory agencies if this were to occur. Clark County DAQEM will provide technical assistance as requested, to other state and federal agencies such as BLM and DOD, MPOs and organizations such as WRAP, NACAA, WESTAR, who may wish to pursue AP-42 federal reference method approval through OAQPS.

9.0 REFERENCES

U.S. Environmental Protection Agency, Emission Factor Documentation for AP-42, EPA Contract No. 68-D0-0123, MRI Project No. 9712-44 dated March 8, 1993.

Geotechnical and Environmental Services, Inc., *Presentation of Final Versions of Deliverables for Re-Evaluating and Updating the Particulate Emission Potential Map and Soil Classification for Dust Mitigation Best Management Practices Manual for Clark County*, dated September 26, 2003.

Etyemezian V., H. Kuhns, J. Gillies, M. Green, M. Pitchford, and J. Watson (2003). Vehicle based road dust emissions measurements (I): Methods and Calibration. Atmospheric Environment 37: 4559-4571.

Etyemezian V., H. Kuhns, J. Gillies, J. Chow, K. Hendrickson, M. McGown and M. Pitchford (2003b). Vehicle based road dust emissions measurements (III): Effect of speed, traffic volume, location, and season on PM_{10} road dust emissions. Atmospheric Environment 37*:* 4583-4593.

Etyemezian, V., H. Kuhns, and G. Nikolich (2006). Precision and repeatability of the TRAKER vehicle-based paved road dust emission measurement. Atmospheric Environment 40: 2953-2958.

Gertler A, H. Kuhns, M. Abu-Allaban, C. Damm, J. Gillies, V. Etyemezian, R. Clayton, D. Profitt (2006). A Case Study of the Impact of Winter Road Sand/Salt and Street Sweeping on Road Dust Re-entrainment. Atmospheric Environment 40 (31): 5976-5985.

Gillies, J.A.; V. Etyemezian, H. Kuhns, D. Nikolic, and D.A. Gillette (2005). Effect of vehicle characteristics on unpaved road dust emissions; Atmospheric Environment 39, 2341–2347.

Kuhns, H., Etyemezian, V., Landwehr, D., MacDougall, C., Pitchford, M., and M. Green. (2001). Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER): A New Approach to Infer Silt Loading on Roadways. Atmospheric Environment 35: 2815-2825.

Kuhns H., V. Etyemezian, M. Green, Karin Hendrickson, Michael McGown, and Kevin Barton, Marc Pitchford (2003) Vehicle-based road dust emissions measurement (II): Effect of precipitation, winter time road sanding, and street sweepers on PM_{10} fugitive dust emissions from paved and unpaved roads. Atmospheric Environment 35: 4572-4583

Kuhns, H., M.-C. O. Chang, J.C. Chow, V. Etyemezian, L.-W. A. Chen, N. Nussbaum, S.K.K. Nathagoundenpalayam, D. Trimble, S. Kohl, M. MacLaren, M. Abu-Allaban, J. Gillies, A. Gertler, C. Damm, C. Denney, C. Gallery, and J. Skotnik (2004). DRI Lake Tahoe Source Characterization Study: Final Report. Prepared for California Air Resources Board, 1001 I Street, Sacramento, CA 95812, Oct. 2004.

Kuhns, H., V. Etyemezian, J. Gillies, D. DuBois, S. Ahonen, and D. Nikolic (2005). Spatial Variability of Unpaved Road Dust PM_{10} Emission Factors near El Paso, Texas. Journal of the Air and Waste Management Association.55*:* 3-12.

Etyemezian, V., H. Kuhns, J. Gillies, M. Green, M. Pitchford and J. Watson (2003). "Vehicle-based road dust emission measurement: I - methods and calibration." *Atmospheric Environment* 37(32): 4559-4571.

Kuhns, H., V. Etyemezian, D. Landwehr, C. MacDougall, M. Pitchford and M. Green (2001). "Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER): a new approach to infer silt loading on roadways." *Atmospheric Environment* 35(16): 2815-2825.

Countess, R. (2001). Methodology for Estimating Fugitive Windblown and Mechanically Resuspended Road Dust Emissions Applicable for Regional Scale Air Quality Modeling. Prepared for the Western Governors Association by Countess Environmental, Westlake Village, CA, April, 2001

Cowherd, C. (1984). Paved Road Particulate Emissions: Source Category Report. Report No. EPA-600/7-84-077. Prepared by U.S. Environmental Protection Agency, Research Triangle Park, NC, USA.

Cowherd, C. (1999). Profiling Data for Open Fugitive Dust Sources. Prepared for U.S. Environmental Protection Agency, Emission Factors and Inventory Group, Office of Air Quality Planning and Standards, Research Triangle Park, NC, by Midwest Research Institute, Kansas City, MO.

Cowherd, C., and T. Pace (2002). Potential role of vegetative ground cover in the removal of airborne fugitive dust. Presented at the Annual meeting of the Air and Waste Management Association, Baltimore, MD, June 2002.

Etyemezian V., Kuhns, H., Chow, J., Gillies, J., Green, S. Kohl, and M. Pitchford (2001). The Treasure Valley Road Dust Study: Final Report. Prepared for the Idaho Department of Environmental Quality, Boise, Idaho by the Desert Research Institute, Las Vegas, NV. February, 2002.

Etyemezian V., Kuhns, H., Chow, J., Gillies, J., Green, M., Hendrickson, K., McGown, M., and M. Pithford (2003a). Vehicle Based Road Dust Emissions Measurement (I): Methods and Calibration. Manuscript submitted as companion paper to Atmospheric Environment.

Etyemezian, V., Gillies, J., Kuhns, H., Nikolic, D., Watson, J., Veranth, J., Laban, R., Seshadri, G., and D. Gillette (2003b). Report prepared for the WESTAR Council, Lake Oswego, OR, USA by DRI, Las Vegas, NV, USA, January 2003.

Etyemezian, V., H. Kuhns, G. Nikolich, and K. Graham (2004). The Las Vegas Road Dust Emissions Technology Assessment: Final Report. Prepared by the Desert Research Institute, Las Vegas NV for the Clark County Department of Air Quality and Environmental Management, Las Vegas, NV, July, 2005.

Gillette, D. (2002). The Long-distance "Transportable Fraction" of the Vertical Flux of wind-transported dust. *Proceedings of ICAR5/GCTE-SEN Joint Conference*, Jeffrey A. Lee and Ted M. Zobeck editors, Lubbock, Texas, USA Publication 02-2 p. 34.

Gillies, J.A.; Watson, J.G.; Rogers, C.F.; Dubois, D.; Chow, J.C.; Langston, R.; and Sweet, J. (1999). Long Term Efficiencies of Dust Suppressants to Reduce PM_{10} Emissions from Unpaved Roads. *JAWMA,* 49:3-16.

Kuhns, H., Etyemezian, V., Landwehr, D., MacDougall, C., Pitchford, M., Green, M. (2001). Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER): A New Approach to Infer Silt Loading on Roadways. Atmospheric Environment Vol 35: 2815-2825.

Kuhns, H., Etyemezian, V., Gillies, J., Green, M., Hendrickson, K., McGown, M., and M. Pitchford (2003). Vehicle Based Road Dust Emissions Measurement (II): Effect of Precipitation, Wintertime Road Sanding, and Street Sweepers on PM_{10} Fugitive Dust Emissions from Paved and Unpaved Roads. Manuscript submitted as companion paper to Atmospheric Environment.

Moosmuller, H., Gillies, J.A., Rogers, C.F., Dubois, D.W., Chow, J.C., Watson, J.G., and R. Langston (1998). Particulate Emission Rates for Unpaved Shoulders along a Paved Road. J. Air & Waste Manage. Assoc., Vol 48: 398-407.

Raupach, M.R., and F.L. Leys (1999). The Efficacy of Vegetation in Limiting Spray Drift and Dust Movement. Report Prepared for the Department of Land and Water Conservation, Gunnedah, Australia by CSIRO, Canberra, Australia.

Sehmel, G.A. (1973). Particle Resuspension from an Asphalt Road Caused by Car and Truck Traffic. Atmospheric Environment, Vol 7: 291-309.

U.S. EPA (1995). Compilation of Air Pollutant Emission Factors. Report No. AP-42. Prepared by the U.S. Environmental Protection Agency, Research Triangle Park, NC, USA.

U.S.EPA (1998). National air pollutant emission trends, procedures document, 1900-1996. Report No. EPA-454/R-98-008. Prepared by U.S. Environmental Protection Agency, Research Triangle Park, NC, USA.

U.S.EPA (1999). Compilation of air pollutant emission factors - Vol. I, Stationary point and area sources. Report No. AP-42, 5th ed. Prepared by U.S. Environmental Protection Agency, Research Triangle Park, NC, USA.

U.S.EPA (2002). User's Guide to MOBILE6.0 Mobile Source Emission Factor Model. Report No. EPA-420/R-02-001. Prepared by U.S. Environmental Protection Agency, USA.

Venkatram, A. (2000). A Critique of Empirical Emission Factor Models: A Case Study of the AP-42 Model for Estimating PM_{10} Emissions from Paved Roads. Atmospheric Environment, Vol 34: 1-11.

Venkatram, A. (2001). Response to Comments by Nicholson. A Critique of Empirical Emission Factor Models: A Case Study of the AP-42 Model for Estimating PM_{10} Emissions from Paved Roads. Atmospheric Environment Vol 35: 187.

Watson, J.G., and J. Chow (2000). Reconciling Urban Fugitive Dust Emission Inventory and Ambient Source Contribution Estimates: Summary of Current Knowledge and Needed Research. DRI Document No. 6110.4F. Prepared for the U.S. Environmental Protection Agency, by Desert Research Institute, Reno, NV. May, 2000.

Watson, J.G., Chow, J.C., Pace, T.G. (2000). Fugitive dust emissions. Air Pollution Engineering Manual, Davis, W.T., Ed. Van Nostrand Reinhold, New York, NY, pp. 117-134.

Watson, J.G., and J. Chow (2000). Reconciling Urban Fugitive Dust Emissions Inventory and Ambient Source Contribution Estimates: Summary of Current Knowledge and Needed Research. DRI Document No. 6110.4F. Prepared for the U.S. Environmental Protection Agency, by Desert Research Institute, Reno, NV. May, 2000.

Countess, R. (2001). Methodology for Estimating Fugitive Windblown and Mechanically Resuspended Road Dust Emissions Applicable for Regional Scale Air Quality Modeling.

Prepared for the Western Governors Association by Countess Environmental, Westlake Village, CA, April, 2001.

Veranth, J. M., G. Seshadri and E. Pardyjak (2003). Vehicle-generated fugitive dust transport: Analytic models and field study. Atmos Env 37(16): 2295-2303.

Raupach, M.R., N. Woods, G. Dorr, J.F. Leys, and H.A. Cleugh (2001). The Entrapment of Particles by Windbreaks. Atmos. Env. 35: 3373-3383.

Lamb, R.G., and D.R. Duran (1977). Eddy Diffusivities Derived from a Numerical Model of the Convective Boundary Layer. Nuovo Cimento, 1c: 1-17.

Shir, C.C. (1973). A preliminary Numerical Study of Atmospheric Turbulent Flows in the Idealized Planetary Boundary Layer. J. Atmos Sci., 30: 1327-1339.

Venkatram, A. (1993). The Parametrization of the Vertical Dispersion of A Scalar in the Atmospheric Boundary Layer. Atmos Env., 27A: 1963-1966.

U.S. EPA, (1995). User's Guide for the Industrial Source Complex (ISC3) Dispersion Models Volume II: Description of Model Algorithms. US Environmental Protection Agency, Office of Air Quality Planning and Standards: Emissions, Monitoring, and Analysis Division, RTP, NC.

Seinfeld, J.H., and S.N. Pandis (1997). Atmospheric Chemistry and Physics: From Air Pollution to Climate Change. Wiley Interscience. New York, USA.

Willeke, K., and M. Xu (1992). Impaction and rebound of particles from surfaces. J. Aerosol Sci. 23, Supplement: S15-S18.

Gillies, J.A., J.G. Watson, C.F. Rogers, D. Dubois, J.C. Chow, R. Langston, and J. Sweet. (1999). Long term efficiencies of dust suppressants to reduce PM_{10} emissions from unpaved roads. J. Air Waste Manage. Assoc. 49:3-16.

Cowherd, C. (1999). Profiling data for open fugitive dust sources. Prepared for U.S. Environmental Protection Agency, Emissions Factor and Inventory Group, Office of Air Quality Planning and Standards, RTP, NC, by Midwest Research Institute, Kansas City, MO.

Niu, J., B.M.K. Lu, and T.C.W. Tung (2002). Instrumentation Issue in Indoor Air Quality Measurements: The Case with Respirable Suspended Particulates. Indoor Built Environment 11: 162-170.

Moosmüller, H., W.P. Arnott, C.F. Rogers, J.L. Bowen, J.A. Gillies, W.R. Pierson, J.F. Collins, T.D. Durbin, and J.M. Norbeck (2001). Time resolved characterization of diesel particulate emissions. 1. Instruments for particle mass measurement. Environ. Sci. Technol. 35: 781-787.

Chung, A., D.P.Y. Chang, M.J. Kleeman, K.D. Perry, T.A. Cahill, D. Dutcher, E.M. McDougall, and K. Stroud (2001). Comparison of real-time instruments used to monitor airborne particulate matter. J. Air & Waste Manage. Assoc. 51: 109 – 120.

Etyemezian, V., J. Gillies, H. Kuhns, D. Nikolic, J. Watson, J. Veranth, R. Labban, G. Seshadri, and D. Gillette (2003). Field Testing and Evaluation of Dust Deposition and Removal Mechanisms: Final Report. Report Prepared for WESTAR Council, Lake Oswego, OR, by DRI, Las Vegas, NV. January 2003.

Etyemezian, V.,D. Gillette, J. Gillies, H. Kuhns, D. Nikolic, J. Veranth, and J. Watson (2003). PM_{10} Emissions Factors for Unpaved Roads: Correction for Near-Field Deposition. PM AAAR

2003: Atmospheric Sciences, Exposure, Health and Welfare Effects, Policy. Poster. American Association for Aerosol Research, Pittsburgh, PA, March 31 – April 4, 2003.

Rodrigues, Geisa Bettancourt, 2006. Improved Techniques for estimation of PM_{10} emissions. Master's thesis, University of Nevada, Las Vegas, NV. 171 pp.

US EPA 2006. AP42 Emissions Factors. Miscellaneous Sources, Section 13.2.1. Paved Roads. US Environmental Protection Agency, Research Triangle Park, NC, November, 2006. 15 pp.

US EPA 1993a. AP42 Emissions Factors. Miscellaneous Sources, Section 13.2.1. Paved Roads. Appendix C.1. Procedures for Sampling Surface/Bulk Dust Loading. US Environmental Protection Agency, Research Triangle Park, NC, November, 2006 13 pp.

US EPA 1993b. AP42 Emissions Factors. Miscellaneous Sources, Section 13.2.1. Paved Roads. Appendix C.2. Procedures for Laboratory Analysis of Surface/Bulk Dust Loading Samples. US Environmental Protection Agency, Research Triangle Park, NC, November, 2006 9 pp.

Fitz, Dennis R (2001). Final Report, Measurements of PM_{10} and PM2.5 Emission Factors from Paved Roads in California, Prepared for the California Air Resources Board Monitoring and Laboratory Division, Contract No. 98-723.

Venkatram, Akula and Fitz, Dennis R (1998). Phase 1 Final Report, Measurement and Modeling of PM_{10} and PM2.5 Emissions from Paved Roads in California. Prepared for the California Air Resources Board Monitoring and Laboratory Division, Contract No. 94-336.

Gertler, A.W., Coulombe, W.G., Watson, J.G., Bowen, J.L. and Marsh, S., 1993. Comparison of PM_{10} concentrations in high- and medium-volume samplers in a desert environment. Environmental Monitoring and Assessment, 24: 13-25.

Etyemezian, V., H. Kuhns, J. Gillies, S. Uppapalli, G. Nikolich, and D. Zhu (2008). Clark County Alternative Technologies for Paved Road Dust Emissions Measurement: DRI Draft Final Report. Report Prepared for Clark County Department of Air Quality and Environmental Management 500 S. Grand Central Pky. P.O. Box 551741 Las Vegas, NV 89155-1741.

Fitz, D.R. (2001) Measurements on PM_{10} and $PM_{2.5}$ Emission Factors from Paved Roads in California. Final Report to the California Air Resources Board under Contract No 98-723, June 2001.

10.0 GLOSSARY

Term	Explanation
Set	Measurements were organized into sets, runs, and passes. A measurement set consisted of a series of tests conducted with the mobile sampling systems under a specific set of conditions. The conditions specified include whether or not and how much silt material is applied to the road surface, the speed of travel of the mobile sampling systems through the test course, and the purpose of the measurements (e.g. uncover the rate of road dust material depletion over time).
Run	Measurements were organized into sets, runs, and passes. Within each measurement set, the three mobile sampling systems would go through the test course in turn. A run refers to three consecutive measurements through the test course with one measurement associated with each the TRAKER I, TRAKER II, and SCAMPER.
Pass	Measurements were organized into sets, runs, and passes. A pass refers to the completion of a single test vehicle through the test course. The Pass ID is an integer index used to uniquely identify the vehicle that passed through the test course, the measurement set, and the time of the pass (the time that the vehicle passes the tower measurement system).
TRAKER I	Testing Re-Entrained Aerosol Kinetic Emissions from Roads I. This is a vehicle based, mobile sampling platform developed at DRI that measures the amount of dust suspended behind the vehicle's front tires.
TRAKER II	Fundamentally similar to TRAKER I with some modifications of the inlet configurations behind the front tires and some software improvements.
Silt application	Refers to the intentional spreading of soil material on the test road surface in order to simulate different degrees of road "dirtiness". The material applied is not exclusively composed of silt, but rather represents soils in Southern Nevada.
Aerodynamically suspendable	Refers to emissions of road dust through aerodynamic entrainment. This usually occurred during the first 9 times that a vehicle passed through the test course following silt application. Measurements associated with aerodynamic entrainment (first 9 passes) were not included in the calibration procedures where tower-based PM_{10} emission factors were compared to data from the mobile sampling systems.
Mechanically suspendable	Refers to emissions of road dust through mechanical entrainment. Immediately after silt application, the dominant emission process was aerodynamic entrainment. After 9 vehicle passes, emissions occur under a long-lived mechanical regime.
Tower-based measurements	Measurements of the horizontal flux of PM_{10} road dust using a vertical tower. By measuring wind speed, wind direction, and PM_{10} concentrations at several different heights above the ground, it is possible to numerically integrate the mass of PM_{10} crossing a vertical plane that is parallel to the test road.
PM_{10} horizontal flux	Tower-based measurements provide PM_{10} horizontal flux. By measuring wind speed, wind direction, and PM_{10} concentrations at several different heights above the ground, it is possible to numerically integrate the mass of PM_{10} crossing a vertical plane that is parallel to the test road. Since the emitted particles are moving with the wind, this is referred to as the horizontal flux. For the purposes of this study, "PM_{10} horizontal flux" and "tower-based PM_{10} emission factor" are synonymous.
PM_{10} emission factor	For the purposes of this study, "PM_{10} horizontal flux" and "tower-based PM_{10} emission factor" are synonymous.
TRAKER signal	Refers to the background-corrected PM_{10} concentrations measured behind the front tires of the TRAKER vehicle. The TRAKER signal is calculated by

Term	Explanation
	obtaining the average of the PM_{10} concentrations measured through the inlets located behind the left and right front tires and then subtracting the background PM_{10} concentration from this value. The background PM_{10} concentration is measured at the front bumper of TRAKER I and through a chimney located near the roof of TRAKER II.
Set average	Applies to mobile systems as well as tower-based measurements. When averaging over a set, data from individual passes that comprise the measurement set are averaged. For tower-based measurements, set averages consist of all valid PM_{10} horizontal flux measurements obtained within the measurement set regardless of the test vehicle. For some sets, where silt was intentionally applied to the road surface, the set average does not include data associated with the first 9 passes after silt application (See "aerodynamically entrainable"). For mobile system measurements, set averages consisted of all valid passes of the specific sampling vehicle (i.e. TRAKER I set averages are based only on TRAKER I passes). As with the tower data, for some measurement sets, the first 9 passes after silt application were excluded from the average.
Pass average	Average of data associated with the passage of a specific test vehicle through the test course. For tower-based measurements, the pass-average is obtained from the horizontal PM_{10} flux measured at a single location along the test course. For mobile measurement systems, the pass average encompasses all the 1-second data collected over the duration of the pass (i.e. from the time the test vehicle crosses the beginning of the test course till the vehicle crosses the end marker of the test course).

11.0 ACKNOWLEDGMENTS

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Clark County (Nevada)

Paved Road Dust Emission Studies in Support of Mobile Monitoring Technologies

Appendices A–E

Appendix A

TABULATED SUMMARY DATASHEET

(Set and Pass ID, AP42 EF, SCAMPER EF, TRACKER I EF and TRACKER II EF)

SEPTEMBER 2006

December 22, 2008

Set 1 Date: 9/11/2006 Test Type: Pre-Sweep Vehicle Speed: 35 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
1	1	N	0	UCR	11:56:20	0.03	0.60	2.17	0.73
2	1	N	0	TR1	11:57:32	0.36	0.19	IB	ND
3	1	N	0	TR2	12:02:49	0.42	0.38	IB	ND
4	1	S	0	UCR	12:04:25	ND	ND	1.92	ND
5	1	S	0	TR1	12:05:53	0.23	0.13	0.04	ND
6	1	S	0	TR2	12:07:09	0.33	0.30	2.77	ND
7	2	N	0	UCR	12:08:49	0.03	0.51	IB	ND
8	2	N	0	TR1	12:10:18	0.41	0.22	1.37	ND
9	2	N	0	TR2	12:11:42	0.24	0.22	IB	ND
10	2	S	0	UCR	12:13:23	ND	ND	IB	ND
11	2	S	0	TR1	12:15:04	0.11	0.06	0.70	ND
12	2	S	0	TR2	12:16:26	0.21	0.19	-0.03	ND
13	3	N	0	UCR	12:18:00	0.01	0.21	0.15	ND
14	3	N	0	TR1	12:19:27	0.28	0.15	3.91	ND
15	3	N	0	TR2	12:20:25	0.19	0.18	0.59	ND
16	3	S	0	UCR	12:21:52	ND	ND	0.75	ND
17	3	S	0	TR1	12:23:22	0.12	0.07	0.81	ND
18	3	S	0	TR2	12:24:13	0.13	0.12	1.91	ND
19	4	N	0	UCR	12:25:38	0.01	0.12	-0.03	ND
20	4	N	0	TR1	12:27:12	0.15	0.08	0.67	ND
21	4	N	0	TR2	12:27:56	0.14	0.13	0.49	ND
22	4	S	0	UCR	12:29:06	ND	ND	-0.08	ND
23	4	S	0	TR1	12:30:36	0.15	0.08	-0.03	ND
24	4	S	0	TR2	12:31:15	0.13	0.12	-0.47	ND
25	5	N	0	UCR	12:32:41	0.01	0.29	-0.57	ND
26	5	N	0	TR1	12:34:11	0.19	0.10	-0.86	ND
27	5	N	0	TR2	12:34:53	0.15	0.13	IB	ND
28	5	S	0	UCR	12:36:05	ND	ND	0.71	ND
29	5	S	0	TR1	12:37:34	0.10	0.05	4.65	ND
30	5	S	0	TR2	12:38:20	0.15	0.14	0.23	ND
31	6	N	0	UCR	12:39:45	0.01	0.24	0.90	ND
32	6	N	0	TR1	12:41:17	0.21	0.11	2.25	ND
33	6	N	0	TR2	12:41:59	0.13	0.12	IB	ND
34	6	S	0	UCR	12:43:11	ND	ND	0.10	ND
35	6	S	0	TR1	12:44:34	0.06	0.03	IB	ND
36	6	S	0	TR2	12:45:18	0.11	0.11	IB	ND
37	7	N	0	UCR	12:46:51	0.01	0.29	IB	ND
38	7	N	0	TR1	12:47:17	0.22	0.12	IB	ND
39	7	N	0	TR2	12:48:00	0.14	0.13	IB	ND

40	7	S	0	UCR	12:49:07	ND	ND	IB	ND
41	7	S	0	TR1	12:49:42	0.07	0.04	IB	ND
42	7	S	0	TR2	12:50:17	0.11	0.10	IB	ND
43	8	N	0	UCR	13:02:02	0.02	0.34	IB	ND
44	8	N	0	TR1	13:02:22	0.31	0.17	IB	ND
45	8	N	0	TR2	13:03:04	0.13	0.12	IB	ND
46	8	S	0	UCR	13:04:25	ND	ND	1.67	ND
47	8	S	0	TR1	13:04:47	0.08	0.05	0.58	ND
48	8	S	0	TR2	13:05:36	0.16	0.15	5.51	ND
49	9	N	0	UCR	13:07:18	0.02	0.39	1.38	ND
50	9	N	0	TR1	13:07:38	0.11	0.06	2.23	ND
51	9	N	0	TR2	13:08:26	0.15	0.14	5.48	ND
52	9	S	0	UCR	13:09:29	ND	ND	18.87	ND
53	9	S	0	TR1	13:09:56	0.10	0.05	0.17	ND
54	9	S	0	TR2	13:10:35	0.09	0.08	-0.37	ND
55	10	N	0	UCR	13:12:14	0.02	0.31	0.11	ND
56	10	N	0	TR1	13:12:44	0.11	0.06	-0.29	ND
57	10	N	0	TR2	13:13:30	0.13	0.12	0.10	ND
58	10	S	0	UCR	13:14:30	ND	ND	1.07	ND
59	10	S	0	TR1	13:14:58	0.12	0.07	-0.18	ND
60	10	S	0	TR2	13:15:39	0.11	0.10	-0.27	ND

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 2 Date: 9/11/2006 Test Type: Post-Sweep Vehicle Speed: 35 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
63	1	N	0	UCR	13:53:00	0.38	7.57	-0.36	ND
64	1	N	0	TR1	13:52:05	14.51	7.83	0.02	ND
65	1	N	0	TR2	13:54:00	0.61	0.56	0.19	ND
66	1	S	0	UCR	13:55:18	ND	ND	1.56	ND
67	1	S	0	TR1	13:55:49	1.01	0.54	0.69	ND
68	1	S	0	TR2	13:56:26	0.48	0.44	2.05	ND
69	2	N	0	UCR	13:57:53	0.12	2.37	2.35	ND
70	2	N	0	TR1	13:58:23	12.08	6.52	3.05	ND
71	2	N	0	TR2	13:59:06	0.77	0.71	-0.28	ND
72	2	S	0	UCR	14:00:16	ND	ND	1.08	ND
73	2	S	0	TR1	14:00:49	0.68	0.37	1.78	ND
74	2	S	0	TR2	14:01:27	0.53	0.49	-0.39	ND
75	3	N	0	UCR	14:02:57	0.17	3.41	2.13	ND
76	3	N	0	TR1	14:03:27	5.12	2.76	2.39	ND
77	3	N	0	TR2	14:04:37	0.50	0.46	3.69	ND
78	3	S	0	UCR	14:05:46	ND	ND	0.64	ND
79	3	S	0	TR1	14:06:16	0.55	0.30	0.39	ND
80	3	S	0	TR2	14:06:56	0.21	0.19	-0.13	ND
81	4	N	0	UCR	14:08:39	0.05	0.93	-0.82	ND
82	4	N	0	TR1	14:09:09	2.94	1.59	0.41	ND
83	4	N	0	TR2	14:09:46	1.51	1.39	0.60	ND
84	4	S	0	UCR	14:10:58	ND	ND	4.64	ND
85	4	S	0	TR1	14:11:26	0.76	0.41	0.27	ND
86	4	S	0	TR2	14:12:04	0.27	0.25	0.66	ND
87	5	N	0	UCR	14:13:30	0.09	1.87	0.30	ND
88	5	N	0	TR1	14:14:03	5.01	2.70	1.77	ND
89	5	N	0	TR2	14:14:55	0.32	0.29	0.49	ND
90	5	S	0	UCR	14:16:06	ND	ND	IB	ND
91	5	S	0	TR1	14:16:38	0.36	0.19	IB	ND
92	5	S	0	TR2	14:17:17	0.17	0.16	1.33	ND

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 3 Date: 9/11/2006 Test Type: Silt Depletion Vehicle Speed: 35 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
93	1	N	1	TR1	15:17:49	123.41	66.64	41.55	2.15
94	1	N	2	UCR	15:20:00	1.78	35.55	25.92	ND
95	1	N	3	TR2	15:19:07	8.40	7.73	293.74	ND
96	2	N	4	TR1	15:22:55	22.66	12.24	59.61	ND
97	2	N	5	UCR	15:23:38	0.96	19.12	37.48	ND
98	2	N	6	TR2	15:24:19	7.30	6.72	21.04	ND
99	3	N	7	TR1	15:27:18	8.12	4.39	0.79	ND
100	3	N	8	UCR	15:27:52	0.34	6.86	5.26	ND
101	3	N	9	TR2	15:28:37	3.43	3.16	11.70	ND
102	3	N	10	TR1	15:31:05	17.39	9.39	19.83	ND
103	4	N	11	TR1	15:34:44	4.24	2.29	2.72	ND
104	4	N	12	UCR	15:35:16	0.18	3.68	4.40	ND
105	4	N	13	TR2	15:35:51	0.77	0.71	2.65	ND
106	5	N	14	TR1	15:37:48	7.11	3.84	IB	ND
107	5	N	15	UCR	15:38:29	0.11	2.10	3.21	ND
108	5	N	16	TR2	15:39:15	0.71	0.65	2.44	ND
109	6	N	17	TR1	15:41:33	21.37	11.54	-0.67	ND
110	6	N	18	UCR	15:46:25	0.10	1.96	2.27	ND
111	6	N	19	TR1	15:47:00	2.47	1.33	6.71	ND
112	6	N	20	TR2	15:47:43	0.60	0.55	0.77	ND
113	7	N	21	UCR	15:50:50	0.12	2.48	2.05	ND
114	7	N	22	TR2	15:51:40	0.45	0.41	1.18	ND
115	8	N	23	TR1	15:52:08	2.49	1.34	2.24	ND
116	8	N	24	UCR	15:54:10	0.16	3.25	1.28	ND
117	8	N	25	TR2	15:54:54	0.45	0.41	13.09	ND
118	9	N	26	TR1	15:55:26	2.24	1.21	3.70	ND
119	9	N	27	UCR	15:58:14	0.04	0.77	0.48	ND
120	9	N	28	TR2	15:58:54	0.80	0.74	0.42	ND
121	10	N	29	TR1	15:59:26	4.76	2.57	0.46	ND
122	10	N	30	UCR	16:06:50	0.04	0.83	1.07	ND
123	10	N	31	TR2	16:07:39	0.54	0.50	-0.14	ND
124	11	N	32	TR1	16:08:00	7.98	4.31	0.05	ND
125	11	N	33	UCR	16:11:07	0.09	1.81	0.39	ND
126	11	N	34	TR2	16:11:34	0.28	0.26	0.05	ND
127	12	N	35	TR1	16:12:00	1.20	0.65	0.45	ND
128	12	N	36	UCR	16:15:01	0.05	1.08	1.54	ND
129	12	N	37	TR2	16:15:30	0.42	0.39	0.36	ND
130	13	N	38	TR1	16:15:56	2.29	1.24	1.25	ND
131	13	N	39	UCR	16:19:00	0.50	10.03	1.56	ND

132	13	N	40	TR2	16:19:35	0.28	0.26	0.11	ND
133	14	N	41	TR1	16:19:58	4.88	2.64	1.05	ND
134	14	N	42	UCR	16:23:15	0.03	0.62	0.09	ND
135	14	N	43	TR2	16:23:51	0.29	0.27	1.29	ND
136	15	N	44	TR1	16:24:10	12.65	6.83	1.63	ND
137	15	N	45	UCR	16:27:48	0.09	1.71	4.33	ND
138	15	N	46	TR2	16:28:29	0.23	0.21	0.65	ND
139	15	N	47	TR1	16:28:55	1.94	1.05	0.17	1.17

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 4 Date: 9/12/2006 Test Type: Silt Depletion Vehicle Speed: 45 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
140	1	N	1	UCR	10:15:21	14.30	285.98	486.90	4.84
141	1	N	2	TR2	10:19:37	61.61	56.68	200.75	ND
142	1	N	3	TR1	10:20:11	117.72	63.57	306.61	ND
143	2	N	4	UCR	10:23:55	1.97	39.31	40.32	ND
144	2	N	5	TR2	10:24:24	25.39	23.36	83.17	ND
145	2	N	6	TR1	10:24:53	39.51	21.34	41.45	ND
146	3	N	7	UCR	10:27:47	1.06	21.26	28.32	ND
147	3	N	8	TR2	10:28:22	9.93	9.14	6.84	ND
148	3	N	9	TR1	10:28:49	18.64	10.07	6.23	ND
149	4	N	10	UCR	10:31:42	0.70	14.01	9.22	ND
150	4	N	11	TR2	10:32:18	5.21	4.79	5.41	ND
151	4	N	12	TR1	10:32:44	24.66	13.31	2.05	ND
152	5	N	13	UCR	10:36:01	0.26	5.28	30.18	ND
153	5	N	14	TR2	10:36:32	4.25	3.91	4.08	ND
154	5	N	15	TR1	10:37:00	10.79	5.83	6.23	ND
155	6	N	16	UCR	10:40:00	0.26	5.12	14.51	ND
156	6	N	17	TR2	10:40:39	41.75	38.41	47.56	ND
157	6	N	18	TR1	10:41:05	9.18	4.96	8.69	ND
158	7	N	19	UCR	10:43:56	0.30	6.00	24.31	ND
159	7	N	20	TR2	10:44:32	11.51	10.59	1.04	ND
160	7	N	21	TR1	10:44:57	18.97	10.25	3.30	ND
161	8	N	22	UCR	10:47:46	0.66	13.24	1.09	ND
162	8	N	23	TR2	10:48:21	4.22	3.88	1.40	ND
163	8	N	24	TR1	10:48:44	6.68	3.61	5.44	ND
164	9	N	25	UCR	10:51:51	0.13	2.69	1.01	ND
165	9	N	26	TR2	10:52:27	4.99	4.59	5.23	ND
166	9	N	27	TR1	10:53:05	7.19	3.89	2.61	ND
167	10	N	28	UCR	10:56:08	0.16	3.20	1.12	ND
168	10	N	29	TR2	10:56:43	2.53	2.33	1.32	ND
169	10	N	30	TR1	10:57:07	5.98	3.23	10.41	2.47

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 5 Date: 9/12/2006 Test Type: Silt Depletion Vehicle Speed: 25 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
170	1	N	1	UCR	13:29:19	8.19	163.76	IB	5.55
171	1	N	2	TR2	13:29:57	27.92	25.69	IB	ND
172	1	N	3	TR1	13:30:16	96.03	51.85	IB	5.09
173	2	N	4	UCR	13:34:08	3.38	67.55	IWD	ND
174	2	N	5	TR2	13:35:07	13.09	12.04	IWD	ND
175	2	N	6	TR1	13:35:45	30.43	16.43	IWD	4.40
176	3	N	7	UCR	13:39:37	1.08	21.59	IWD	ND
177	3	N	8	TR2	13:40:29	8.50	7.82	IWD	ND
178	3	N	9	TR1	13:41:02	25.07	13.54	IWD	3.14
179	4	N	10	UCR	13:44:52	0.63	12.52	IWD	ND
180	4	N	11	TR2	13:45:53	8.85	8.15	IWD	ND
181	4	N	12	TR1	13:46:29	23.72	12.81	IWD	ND
182	5	N	13	UCR	13:50:00	0.53	10.59	0.32	ND
183	5	N	14	TR2	13:51:01	7.56	6.96	IWD	ND
184	5	N	15	TR1	13:51:31	19.47	10.51	IWD	3.35
185	6	N	16	UCR	13:55:19	0.77	15.49	2.90	ND
186	6	N	17	TR2	13:56:23	8.30	7.63	2.41	ND
187	6	N	18	TR1	13:56:50	15.56	8.40	IWD	ND
188	7	N	19	UCR	14:00:50	0.30	6.06	2.32	ND
189	7	N	20	TR2	14:01:32	6.28	5.78	-0.33	ND
190	7	N	21	TR1	14:02:14	11.00	5.94	6.02	ND
191	8	N	22	UCR	14:05:57	0.24	4.86	2.69	ND
192	8	N	23	TR2	14:07:04	6.03	5.55	10.33	ND
193	8	N	24	TR1	14:07:48	12.72	6.87	7.27	ND
194	9	N	25	UCR	14:11:30	0.31	6.26	IWD	ND
195	9	N	26	TR2	14:12:18	5.00	4.60	IWD	ND
196	9	N	27	TR1	14:12:57	9.36	5.06	IWD	ND
197	10	N	28	UCR	14:16:48	0.38	7.58	3.05	ND
198	10	N	29	TR2	14:17:40	5.72	5.26	0.89	ND
199	10	N	30	TR1	14:18:16	20.20	10.91	IWD	1.82
200	11	N	31	UCR	14:20:00	0.19	3.81	IWD	ND
201	11	N	32	TR2	14:22:38	3.78	3.48	3.61	ND
202	11	N	33	TR1	14:23:13	6.77	3.66	1.73	ND
203	12	N	34	UCR	14:26:44	0.30	6.02	3.25	ND
204	12	N	35	TR2	14:27:46	7.90	7.26	10.31	ND
205	12	N	36	TR1	14:28:23	8.66	4.67	6.79	ND
206	13	N	37	UCR	14:31:48	0.20	3.95	2.82	ND
207	13	N	38	TR2	14:32:39	5.72	5.26	4.11	ND
208	13	N	39	TR1	14:33:19	4.67	2.52	0.69	ND

209	14	N	40	UCR	14:36:38	0.13	2.58	0.51	ND
210	14	N	41	TR2	14:37:38	5.02	4.62	4.76	ND
211	14	N	42	TR1	14:38:21	9.20	4.97	40.67	3.81

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 6 Date: 9/13/2006 Test Type: Silt Depletion Vehicle Speed: 45 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
212	1	N	1	UCR	9:40:55	7.17	143.45	IWD	2.42
213	1	N	2	TR2	9:41:38	21.02	19.34	IWD	ND
214	1	N	3	TR1	9:42:22	50.34	27.18	IWD	1.73
215	2	N	4	UCR	9:45:32	1.23	24.67	IWD	ND
216	2	N	5	TR2	9:46:24	5.27	4.85	IWD	ND
217	2	N	6	TR1	9:47:03	24.26	13.10	IWD	1.65
218	3	N	7	UCR	9:49:48	0.57	11.40	IWD	ND
219	3	N	8	TR2	9:50:33	4.11	3.78	IWD	ND
220	3	N	9	TR1	9:51:15	12.91	6.97	IWD	1.48
221	4	N	10	UCR	9:53:57	0.47	9.48	IWD	ND
222	4	N	11	TR2	9:54:41	3.38	3.11	2.01	ND
223	4	N	12	TR1	9:55:22	9.31	5.03	3.17	ND
224	5	N	13	UCR	9:58:07	0.30	5.99	IWD	ND
225	5	N	14	TR2	9:58:55	5.96	5.48	IWD	ND
226	5	N	15	TR1	9:59:35	8.58	4.63	IWD	1.39
227	6	N	16	UCR	10:02:29	0.24	4.75	IWD	ND
228	6	N	17	TR2	10:03:11	4.08	3.75	IWD	ND
229	6	N	18	TR1	10:03:55	5.92	3.20	IWD	ND
230	7	N	19	UCR	10:06:46	0.41	8.24	IWD	ND
231	7	N	20	TR2	10:07:30	2.04	1.88	IWD	ND
232	7	N	21	TR1	10:08:16	5.46	2.95	IWD	ND
233	8	N	22	UCR	10:11:03	0.18	3.52	IWD	ND
234	8	N	23	TR2	10:11:38	1.98	1.82	IWD	ND
235	8	N	24	TR1	10:12:23	11.33	6.12	IWD	ND
236	9	N	25	UCR	10:15:16	0.17	3.40	IWD	ND
237	9	N	26	TR2	10:16:00	2.08	1.92	IWD	ND
238	9	N	27	TR1	10:16:46	3.84	2.07	IWD	ND
239	10	N	28	UCR	10:19:33	0.15	2.95	0.99	ND
240	10	N	29	TR2	10:20:20	3.36	3.09	13.78	ND
241	10	N	30	TR1	10:21:04	3.73	2.01	1.09	1.93

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 7 Date: 9/13/2006 Test Type: Silt Depletion Vehicle Speed: 25 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
243	1	N	1	UCR	12:46:39	0.17	3.32	IWD	2.13
244	1	N	2	TR2	12:47:28	17.47	16.07	IWD	ND
245	1	N	3	TR1	12:48:12	38.49	20.78	IWD	1.61
246	2	N	4	UCR	12:52:17	0.52	10.41	1.86	ND
247	2	N	5	TR2	12:53:05	6.52	6.00	13.39	ND
248	2	N	6	TR1	12:53:39	17.61	9.51	IWD	1.53
249	3	N	7	UCR	12:57:19	0.45	8.97	4.63	ND
250	3	N	8	TR2	12:58:15	2.31	2.13	IWD	ND
251	3	N	9	TR1	12:58:49	11.66	6.30	IWD	1.27
252	4	N	10	UCR	13:02:22	0.54	10.89	IWD	ND
253	4	N	11	TR2	13:03:13	2.35	2.17	IWD	ND
254	4	N	12	TR1	13:03:41	5.79	3.13	IWD	ND
255	5	N	13	UCR	13:07:15	0.18	3.63	IWD	ND
256	5	N	14	TR2	13:08:05	1.65	1.52	IWD	ND
257	5	N	15	TR1	13:08:40	6.86	3.71	IWD	1.53
258	6	N	16	UCR	13:12:19	0.10	2.05	6.10	ND
259	6	N	17	TR2	13:13:07	1.56	1.44	0.29	ND
260	6	N	18	TR1	13:13:43	4.83	2.61	2.05	ND
261	7	N	19	UCR	13:17:18	0.12	2.31	0.39	ND
262	7	N	20	TR2	13:18:14	2.05	1.89	IWD	ND
263	7	N	21	TR1	13:18:41	3.29	1.78	IWD	ND
264	8	N	22	UCR	13:22:18	0.09	1.86	IWD	ND
265	8	N	23	TR2	13:22:58	2.06	1.90	IWD	ND
266	8	N	24	TR1	13:23:41	5.94	3.21	IWD	ND
267	9	N	25	UCR	13:27:27	0.09	1.86	IWD	ND
268	9	N	26	TR2	13:28:07	1.02	0.94	IWD	ND
269	9	N	27	TR1	13:28:46	3.45	1.86	IWD	ND
270	10	N	28	UCR	13:32:26	0.07	1.32	IWD	ND
271	10	N	29	TR2	13:33:11	1.24	1.14	IWD	ND
272	10	N	30	TR1	13:33:46	2.53	1.37	IWD	1.52

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 8 Date: 9/13/2006 Test Type: Silt Depletion Vehicle Speed: 45 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
273	1	N	1	UCR	15:21:39	8.14	162.82	185.29	2.87
274	1	N	2	TR2	15:23:22	27.38	25.19	IWD	ND
275	1	N	3	TR1	15:24:49	77.12	41.65	24.13	2.03
276	2	N	4	UCR	15:28:18	1.03	20.60	18.34	ND
277	2	N	5	TR2	15:29:12	8.86	8.15	15.41	ND
278	2	N	6	TR1	15:29:52	52.99	28.62	41.13	1.68
279	3	N	7	UCR	15:32:43	0.70	13.92	IWD	ND
280	3	N	8	TR2	15:33:31	6.19	5.69	IWD	ND
281	3	N	9	TR1	15:34:07	17.59	9.50	IWD	1.53
282	4	N	10	UCR	15:37:02	0.30	6.09	IWD	ND
283	4	N	11	TR2	15:37:44	4.73	4.35	2.09	ND
284	4	N	12	TR1	15:38:27	10.83	5.85	4.77	ND
285	5	N	13	UCR	15:41:11	0.26	5.13	6.31	ND
286	5	N	14	TR2	15:41:57	5.59	5.14	5.55	ND
287	5	N	15	TR1	15:42:39	21.58	11.65	13.25	1.11
288	6	N	16	UCR	15:45:38	0.25	5.07	IWD	ND
289	6	N	17	TR2	15:46:22	12.42	11.43	5.63	ND
290	6	N	18	TR1	15:47:05	12.02	6.49	5.54	ND
291	7	N	19	UCR	15:50:07	0.23	4.55	IWD	ND
292	7	N	20	TR2	15:50:51	3.35	3.08	IWD	ND
293	7	N	21	TR1	15:51:33	9.78	5.28	8.40	ND
294	8	N	22	UCR	15:54:24	0.14	2.85	3.72	ND
295	8	N	23	TR2	15:55:12	2.84	2.62	5.57	ND
296	8	N	24	TR1	15:55:56	10.02	5.41	10.62	ND
297	9	N	25	UCR	15:58:45	0.22	4.38	IWD	ND
298	9	N	26	TR2	15:59:30	1.67	1.54	IWD	ND
299	9	N	27	TR1	16:00:07	9.48	5.12	IWD	ND
300	10	N	28	UCR	16:03:11	0.12	2.47	IWD	ND
301	10	N	29	TR2	16:03:57	2.39	2.20	4.02	ND
302	10	N	30	TR1	16:04:36	8.41	4.54	5.86	1.02
303	11	N	31	UCR	16:07:28	0.10	1.98	0.78	ND
304	11	N	32	TR2	16:08:14	2.47	2.27	IB	ND

305	11	N	33	TR1	16:08:54	8.11	4.38	1.09	1.38
306	12	N	34	UCR	16:11:37	0.15	3.01	1.25	ND
307	12	N	35	TR2	16:12:22	2.12	1.95	IWD	ND
308	12	N	36	TR1	16:13:06	5.47	2.96	1.70	0.81

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 9 Date: 9/14/2006 Test Type: Silt Depletion Vehicle Speed: 35 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
309	1	N	1	UCR	8:42:00	5.24	104.78	IB	2.33
310	2	N	2	UCR	8:46:00	2.27	45.38	-0.67	1.81
311	3	N	3	UCR	8:50:48	0.98	19.57	26.69	2.10
312	4	N	4	UCR	8:54:54	0.95	18.93	11.13	2.03
313	5	N	5	UCR	8:57:54	0.62	12.47	6.09	1.23
314	6	N	6	UCR	9:00:58	0.49	9.81	7.30	1.30
315	7	N	7	UCR	9:04:12	0.39	7.72	4.47	1.21
316	8	N	8	UCR	9:07:37	0.37	7.39	20.75	1.81
317	9	N	9	UCR	9:10:50	0.30	6.00	7.26	1.85
318	10	N	10	UCR	9:15:18	0.26	5.30	11.04	1.56

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 10 Date: 9/14/2006 Test Type: Silt Depletion Vehicle Speed: 35 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
319	11	N	11	UCR	9:23:29	0.26	5.24	14.13	ND
320	11	N	12	TR2	9:24:03	2.59	2.38	3.29	ND
321	11	N	13	TR1	9:24:27	11.22	6.06	3.75	1.13
322	12	N	14	UCR	9:27:41	0.09	1.72	-0.35	ND
323	12	N	15	TR2	9:28:22	0.71	0.65	3.68	ND
324	12	N	16	TR1	9:28:49	0.44	0.24	-0.76	0.91
325	13	N	17	UCR	9:43:05	0.09	1.71	0.12	ND
326	13	N	18	TR2	9:43:33	0.95	0.87	3.10	ND
327	13	N	19	TR1	9:44:02	1.21	0.66	2.29	ND
329	14	N	20	UCR	9:48:53	0.05	0.97	-0.60	ND
330	14	N	21	TR2	9:49:26	1.24	1.14	1.69	ND
331	14	N	22	TR1	9:49:50	1.00	0.54	-0.59	0.68

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 11 Date: 9/14/2006 Test Type: Post-Sweep Vehicle Speed: 35 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
334	1	N	0	UCR	10:28:13	0.00	0.00	1.43	1.14
335	1	N	0	TR2	10:28:53	7.90	7.27	1.31	ND
336	1	N	0	TR1	10:29:16	6.73	3.63	1.22	0.91
337	2	N	0	UCR	10:35:33	0.29	5.71	IWD	ND
338	2	N	0	TR2	10:36:13	3.97	3.65	IWD	ND
339	2	N	0	TR1	10:36:37	3.06	1.65	IWD	0.37
340	3	N	0	UCR	10:40:10	0.06	1.19	IB	ND
341	3	N	0	TR2	10:40:40	5.48	5.04	IB	ND
342	3	N	0	TR1	10:41:07	7.78	4.20	IB	1.53
343	4	N	0	UCR	10:44:23	0.04	0.77	IB	ND
344	4	N	0	TR2	10:44:54	2.36	2.17	IB	ND
345	4	N	0	TR1	10:45:18	4.39	2.37	IB	1.13
346	5	N	0	UCR	10:48:40	0.06	1.14	2.61	ND
347	5	N	0	TR2	10:49:20	3.05	2.81	-1.57	ND
348	5	N	0	TR1	10:49:45	3.17	1.71	-3.60	1.11
349	6	N	0	UCR	10:52:56	0.03	0.61	24.83	ND
350	6	N	0	TR2	10:53:27	2.96	2.72	4.25	ND
351	6	N	0	TR1	10:53:53	2.72	1.47	2.62	1.42
352	7	N	0	UCR	10:57:54	0.02	0.37	-3.01	ND
353	7	N	0	TR2	10:58:29	1.90	1.75	17.28	ND
354	7	N	0	TR1	10:58:54	3.42	1.85	18.24	1.19
355	8	N	0	UCR	11:03:32	0.03	0.54	IB	ND
356	8	N	0	TR2	11:04:05	1.62	1.49	1.40	ND
357	8	N	0	TR1	11:04:35	2.29	1.24	0.01	1.27
359	9	N	0	UCR	11:11:01	0.03	0.59	IB	ND
360	9	N	0	TR2	11:11:33	1.15	1.06	IB	ND
361	9	N	0	TR1	11:11:56	2.46	1.33	IB	1.56
362	10	N	0	UCR	11:16:48	0.03	0.55	IB	ND
363	10	N	0	TR2	11:17:20	0.80	0.73	IB	ND
364	10	N	0	TR1	11:17:46	1.01	0.54	IB	1.46

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 12 Date: 9/14/2006 Test Type: Silt Depletion Vehicle Speed: varying: 25, 35, 45 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
365	1	N	1	UCR	13:12:49	0.16	3.19	IB	2.64
366	1	N	2	TR2	13:13:30	2.64	2.43	IB	ND
367	1	N	3	TR1	13:15:29	9.78	5.28	IB	1.97
368	2	N	4	UCR	13:21:17	0.36	7.27	IB	ND
369	2	N	5	TR2	13:21:50	5.47	5.03	IB	ND
370	2	N	6	TR1	13:22:15	19.27	10.40	IB	1.52
371	3	N	7	UCR	13:26:30	1.63	32.68	IB	ND
372	3	N	8	TR2	13:27:01	10.03	9.23	IB	ND
373	3	N	9	TR1	13:27:30	26.94	14.55	IB	1.05
374	4	N	10	UCR	13:32:07	0.57	11.31	IB	ND
375	4	N	11	TR2	13:32:38	9.04	8.31	IB	ND
376	4	N	12	TR1	13:33:06	21.67	11.70	IB	1.44
377	5	N	13	UCR	13:37:26	0.06	1.14	IB	ND
378	5	N	14	TR2	13:37:56	1.77	1.63	IB	ND
379	5	N	15	TR1	13:38:22	10.95	5.91	IB	1.15
380	6	N	16	UCR	13:42:03	0.02	0.49	IB	ND
381	6	N	17	TR2	13:42:39	0.56	0.51	IB	ND
382	6	N	18	TR1	13:43:05	0.84	0.45	IB	0.99
383	7	N	19	UCR	13:52:37	0.02	0.48	IB	ND
384	7	N	20	TR2	13:53:13	0.71	0.65	0.14	ND
385	7	N	21	TR1	13:53:38	1.42	0.77	-5.75	0.85
386	8	N	22	UCR	13:58:02	0.08	1.68	2.78	ND
387	8	N	23	TR2	13:58:38	1.06	0.98	2.31	ND
388	8	N	24	TR1	13:59:02	7.80	4.21	3.54	0.95
389	9	N	25	UCR	14:02:27	0.30	6.09	1.78	ND
390	9	N	26	TR2	14:02:56	2.20	2.03	1.48	ND
391	9	N	27	TR1	14:03:28	15.46	8.35	3.42	1.01

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Set 13 Date: 9/14/2006 Test Type: Silt Depletion Vehicle Speed: varying: 25, 35, 45 mph

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
392	1	N	1	UCR	8:31:01	0.62	12.30	479.50	4.62
393	1	N	2	TR2	8:31:58	4.92	4.52	453.58	ND
394	1	N	3	TR1	8:32:26	18.21	9.83	205.03	2.51
395	2	N	4	UCR	8:36:01	0.97	19.30	143.54	ND
396	2	N	5	TR2	8:36:32	10.41	9.58	322.49	ND
397	2	N	6	TR1	8:37:02	44.63	24.10	73.25	1.90
398	3	N	7	UCR	8:40:20	2.67	53.46	24.83	ND
399	3	N	8	TR2	8:40:52	21.87	20.12	26.67	ND
400	3	N	9	TR1	8:41:26	34.68	18.73	26.14	1.30
401	4	N	10	UCR	8:46:02	1.10	21.97	37.03	ND
402	4	N	11	TR2	8:46:34	10.08	9.28	54.27	ND
403	4	N	12	TR1	8:47:03	31.50	17.01	IB	0.69
404	5	N	13	UCR	8:50:40	0.35	6.99	IB	ND
405	5	N	14	TR2	8:51:14	2.83	2.60	IB	ND
406	5	N	15	TR1	8:51:48	7.53	4.07	IB	1.42
407	6	N	16	UCR	8:55:55	0.03	0.61	IB	ND
408	6	N	17	TR2	8:56:40	0.65	0.60	IB	ND
409	6	N	18	TR1	8:57:08	0.85	0.46	IB	1.42
410	7	N	19	UCR	9:07:09	0.18	3.59	-0.80	ND
411	7	N	20	TR2	9:07:49	1.02	0.94	1.13	ND
412	7	N	21	TR1	9:08:20	1.91	1.03	0.73	1.04
413	8	N	22	UCR	9:12:07	0.25	5.04	2.38	ND
414	8	N	23	TR2	9:12:42	2.00	1.84	2.31	ND
415	8	N	24	TR1	9:13:12	6.11	3.30	11.10	1.19
416	9	N	25	UCR	9:16:57	0.47	9.40	2.98	ND
417	9	N	26	TR2	9:17:28	7.22	6.64	5.18	ND
418	9	N	27	TR1	9:17:57	11.70	6.32	5.69	1.04
419	10	N	28	UCR	9:22:58	0.32	6.46	IB	ND
420	10	N	29	TR2	9:23:33	5.06	4.65	IB	ND
421	10	N	30	TR1	9:23:58	8.73	4.72	IB	0.84
422	11	N	31	UCR	9:27:28	0.49	9.83	1.90	ND
423	11	N	32	TR2	9:27:56	1.43	1.31	0.88	ND
424	11	N	33	TR1	9:28:26	2.20	1.19	5.82	1.05
425	12	N	34	UCR	9:32:41	0.04	0.88	IB	ND
426	12	N	35	TR2	9:33:20	0.78	0.72	0.67	ND
427	12	N	36	TR1	9:33:45	0.55	0.29	1.35	0.98
428	13	N	37	UCR	9:38:22	0.07	1.41	1.06	ND
429	13	N	38	TR2	9:39:03	0.54	0.50	-0.48	ND
430	13	N	39	TR1	9:39:26	0.74	0.40	-1.34	1.29

431	14	N	40	UCR	9:44:42	0.07	1.32	IB	ND
432	14	N	41	TR2	9:45:00	1.07	0.98	IB	ND
433	14	N	42	TR1	9:45:44	1.91	1.03	5.19	0.97
434	15	N	43	UCR	9:49:30	0.50	10.06	IB	ND
435	15	N	44	TR2	9:50:03	6.57	6.05	IB	ND
436	15	N	45	TR1	9:50:32	6.21	3.35	IB	0.88
437	16	N	46	UCR	9:54:30	0.33	6.63	IB	ND
438	16	N	47	TR2	9:55:10	2.54	2.33	IB	ND
439	16	N	48	TR1	9:55:39	4.62	2.50	IB	0.96
440	17	N	49	UCR	9:59:00	0.11	2.12	33.56	ND
441	17	N	50	TR2	9:59:33	1.31	1.21	1.09	ND
442	17	N	51	TR1	10:00:02	1.24	0.67	0.37	1.06
443	18	N	52	UCR	10:04:14	0.01	0.18	IB	ND
444	18	N	53	TR2	10:04:49	0.53	0.49	IB	ND
445	18	N	54	TR1	10:05:15	0.30	0.16	IB	0.76
446	19	N	55	UCR	10:10:43	0.02	0.33	IB	ND
447	19	N	56	TR2	10:11:20	0.39	0.36	IB	ND
448	19	N	57	TR1	10:11:45	1.00	0.54	IB	0.76
450	20	N	58	UCR	10:16:39	0.02	0.48	7.35	ND
451	20	N	59	TR2	10:17:13	1.04	0.96	3.41	ND
452	20	N	60	TR1	10:17:44	1.16	0.63	IB	0.99
453	21	N	61	UCR	10:23:10	0.11	2.17	IB	ND
454	21	N	62	TR2	10:23:43	2.12	1.95	IB	ND
455	21	N	63	TR1	10:24:21	3.78	2.04	IB	0.88
456	22	N	64	UCR	10:30:38	0.13	2.52	39.49	ND
457	22	N	65	TR2	10:31:11	3.43	3.16	41.88	ND
458	22	N	66	TR1	10:31:36	4.34	2.35	20.30	0.67
459	23	N	67	UCR	10:38:07	0.03	0.67	IB	ND
460	23	N	68	TR2	10:38:44	0.85	0.78	IB	ND
461	23	N	69	TR1	10:39:08	1.52	0.82	IB	0.78
462	24	N	70	UCR	10:43:59	0.02	0.45	IB	ND
463	24	N	71	TR2	10:44:39	0.27	0.25	IB	ND
464	24	N	72	TR1	10:45:03	0.24	0.13	IB	0.88
465	25	N	73	UCR	10:51:08	0.01	0.15	IB	ND
466	25	N	74	TR2	10:51:55	0.30	0.28	IB	ND
467	25	N	75	TR1	10:52:13	0.41	0.22	IB	1.06
468	26	N	76	UCR	10:57:31	0.03	0.67	IB	ND
469	26	N	77	TR2	10:58:06	0.95	0.87	IB	ND
470	26	N	78	TR1	10:58:32	3.99	2.15	IB	0.75
471	27	N	79	UCR	11:01:40	0.17	3.38	IB	ND
472	27	N	80	TR2	11:02:14	2.90	2.67	IB	ND
473	27	N	81	TR1	11:02:43	5.41	2.92	IB	1.05
474	28	N	82	UCR	11:09:14	0.10	2.02	IB	ND
475	28	N	83	TR2	11:09:44	2.17	2.00	IB	ND
476	28	N	84	TR1	11:10:05	3.35	1.81	IB	0.87

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

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+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++ IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++*ND = No silt data corresponding exactly to specified pass ID

Clark County (Nevada)

Paved Road Dust Emission Studies in Support of Mobile Monitoring Technologies

Appendices A–E

Appendix B

PAVED ROAD MOBILE SAMPLING SYSTEM STUDIES - PHASE IV EMPIRICAL PAVED ROAD DUST EMISSIONS STUDY DESIGN & WORKPLAN

SEPTEMBER 2006

December 22, 2008

PAVED ROAD MOBILE SAMPLING SYSTEM STUDIES
PHASE IV EMPIRICAL PAVED ROAD DUST EMISSIONS STUDY

Study Overview:

This study entails testing two mobile sampling systems, System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways (SCAMPER) and Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER), under controlled road conditions. One SCAMPER and two TRAKER systems are utilized in this study. Comparative external measurements include upwind and downwind source measurements with multiple samplers on twelve-meter towers and AP-42 silt sampling.

Project Background:

Since the fourth quarter of 2001, the Department of Air Quality and Environmental Management (DAQEM) has been conducting silt sampling on paved roads located in the Las Vegas Valley in order to fulfill commitments contained in the June 2001 PM_{10} State Implementation Plan (PM_{10} SIP). This sampling program has continued through the year 2006. Silt samples from Las Vegas Valley paved roads were previously collected in 1999 as part of the PM_{10}SIP development process.

During the SIP development process, the validity of the AP-42 equation for estimating paved roads was questioned. It has been noted that AP-42 is a statistically-derived equation that only reflects the sampled roads under the conditions tested and cannot predict emissions on a mechanistic basis. The use of twenty-four silt samples to characterize the entire Las Vegas Valley road network was particularly criticized as neither statistically significant nor representative of the entire road network. Clark County noted that the AP-42 approach was the only EPA-approved method for estimating paved road emissions and that the collection of a much larger number of silt samples was not economically feasible. These issues not withstanding, Clark County committed to continue improving the paved road emissions inventory.

From 2002 through 2004, PM_{10}concentrations in the Las Vegas Valley have significantly decreased. However, over the last four years, a statistically significant decline in paved road silt loadings, and therefore, the estimated emission rate per Vehicle Miles Traveled (VMT), has not occurred. Moreover, the total VMT in the Las Vegas Valley has increased at a faster rate than projected in the PM_{10} SIP. These trends lead Clark County to conclude that the AP-42 paved road emission factor may not accurately reflect the PM_{10} emission rates for Clark County paved roads, and that these emissions may be overestimated in the Clark County PM_{10} SIP.

Clark County has therefore embarked on a set of studies to develop improved emission factors for Clark County roadways. Clark County contracted with two research institutes to evaluate alternative technologies to measure emissions from paved roads. The respective technologies utilize vehicle-mounted samplers to directly measure PM_{10} emissions from paved roads.

In total, three phases have been completed thus far. Phases II and I were conducted to evaluate the respective technologies and collect baseline data on paved road emissions from roads in the Las Vegas Valley. The Phase III study focused on the collection of additional data for specific road conditions and coordinated AP-42 sampling. Based on these field studies and results, Clark County has funded the Phase IV Empirical Paved Road Dust Emissions Study to validate the accuracy of vehicle-mounted paved road mobile sampling systems and develop a more comprehensive data set from which the relationships between road silt loadings and vehicle emissions can be characterized.

Empirical Paved Road Dust Emissions Study:

Study Overview

The five-day study includes testing two vehicle-mounted mobile sampling systems, SCAMPER and TRAKER, under controlled road conditions. One SCAMPER and two TRAKER systems are utilized in this study. Comparative external measurements will include upwind and downwind measurements with multiple samplers on twelve-meter towers and AP-42 silt sampling. Study objectives include a comparison of upwind/downwind source emissions measurements to SCAMPER/TRAKER measurements, a comparison of SCAMPER to TRAKER measurements, and AP-42 silt measurements/emission estimates under controlled conditions.

The sampling area consists of two lanes of a four-lane divided highway with curbed median and curbed roadsides (see Figure 1). All road traffic will be diverted to the southeast-bound lanes, allowing the two northwest-bound lanes and the stabilized median area to be utilized exclusively for the five-day study. This will allow us to limit vehicle passes between the external tower samplers to SCAMPER and TRAKER vehicles, with one sampling tower located on the median between the test area and adjacent traffic. It is anticipated that these controlled traffic and measurement parameters will enhance the quality of the upwind/downwind source emissions measurements compared to previous paved road dust studies.

Controlled road silt loading conditions will be created through the application of known quantities of material onto the measurement section of the test area. The applied material will approximate the sand and silt/clay percentages historically sampled on paved roads in the Las Vegas Valley. The test area is of sufficient length to allow for measurement speeds of up to 45 miles per hour.

Study Objectives

1. Comparison of SCAMPER and TRAKER system measurements with upwind and downwind sampling towers in a controlled measurement environment, with restricted vehicle movement, controlled speeds, and controlled road material loadings.

2. Determine relationship between roadway silt loading and measured SCAMPER and TRAKER particulate emissions at several standard vehicle speeds (25, 35 and 45 mph). Characterization of silt depletion rate by vehicle passes under controlled conditions (vehicle speed and weight).

3. Comparison of SCAMPER to TRAKER measurements and a comparison of SCAMPER/TRAKER measurements to AP-42 emissions estimates under controlled measurement conditions.

4. Characterization of silt depletion rate by number of vehicle passes under controlled conditions of vehicle speed and weight.

5. Comparison of tower-estimated emissions to alternative technologies emissions Characterization of quantified emissions vs. quantified silt loading mass.

6. Limited characterization of non-entrained road silt movement.

7. Data assessment and review for recommendations on performance specifications for vehicle-mounted mobile sampling systems.

Study Components

Study Area: The study will occur in the City of Boulder City, Nevada, on Veterans Memorial Highway, immediately west of Buchanan Boulevard. The sampling area consists of two lanes of a four-lane divided highway with curbed median and curbed roadsides. Details are shown in the study plot plans and set forth below:

1. During the five study days, all road traffic will be diverted to the southeast lanes, allowing the two northwest lanes and the stabilized median area to be utilized exclusively for the five-day study.

2. Tower sampling arrays will be located on the median and sidewalk areas and may be moved forward or backward relative to each other to achieve optimal orientation with the prevailing winds and sampling lane. Relocation of tower locations will be logged throughout the study.

Study Area Layout and Vehicle Movement: As shown in Figure 1 Plot Plan, the study will take place on the north side of Veterans Memorial Hwy, utilizing both northwest-bound lanes from the median to the curb. The course will run in a northwesterly direction approximately 4598’ from the intersection of Buchanan and Veterans Memorial Hwy in the northwest-bound travel lanes. The 4598’ course has been broken up into sections for testing purposes and are described as follows:

Entire Length of Study Area: 4598’

Acceleration Zone (Southern End of Course): 750’

Deceleration Zone (Northern End of Course): 500’

Constant Speed Zone/Sampling Zone: 3188’

AP-42 Sampling Zones: 80 feet each, located after acceleration zone and before deceleration zone at each end of the constant speed-sampling zone, for a total of 160 feet.

The soil material in the study will be applied to the constant Speed Zone and the AP-42 sampling zones. Soil will be collected from a deposit of windblown and fine alluvial sand, corresponding to wind erodibility group 2, in Sunset Park. This soil was selected because the measured silt fraction (14%) is approximately in the 65th percentile of 35 sieved road dust silt samples taken from all three roadway categories in calendar years 2005-2006 (more than 35 samples were taken, but data from the 35 samples were readily available in electronic format). The soil will be passed though a 1.18 mm sieve opening during collection to remove gravel and vegetative matter. The soil will then be mixed with trace amounts of fluorescent dye in a 9 cubic- foot concrete mixer.

After the road surface is cleaned with a PM_{10} efficient sweeper, the soil material will be applied in a twelve-foot swath using an agricultural spreader measuring twelve feet in width. Application rates will be chosen to reflect low, medium, and high silt loadings that have been found from AP-42 road dust studies. The right-hand (curb side) lane of the northbound travel lanes will be used for the soil application, because it is the widest of both lanes (measuring on average 13’5” in width). The left northbound lane will be the travel lane for the sampling vehicles to return to the beginning of the course (Buchanan and Veterans Memorial intersection).

There will be a staging area for all personnel and stationary equipment located at the southern end of the course along the shoulder on the north side, just north of Commons (depicted in Figure 1).

Study Instrumentation: Study instrumentation will include continuous type particulate samplers; filter particulate samplers, and meteorological instrumentation. Instruments utilized on SCAMPER/TRAKER systems and the sampling towers are described below.

The SCAMPER and TRAKER sampling systems both employ TSI Model 8520 DustTrak® instruments for continuous emissions measurements. These instruments measure light scattering and require calibration to match the size distribution of the particulate matter sampled. The SCAMPER and TRAKER systems use a standard TSI calibration. Each system will also utilize a filter sampler to provide a method for assessing the fluorescent tracer material.

The twelve-meter towers will contain continuous Tapered Element Oscillating Microbalance (TEOM) samplers, minivol filter samplers, TSI DustTrak® continuous instruments measuring PM_{10} and $PM_{2.5}$, wind speed and wind direction instruments and relative humidity instruments.

Study Measurements:

1. Baseline pre-sweep measurements with SCAMPER, TRAKER (Upwind/Downwind Flux Towers in place), and AP-42 on the first day only.
    a. AP-42 sampling to occur for road segments (six sampling spots at the beginning and at the end of course) prior to any vehicle travel on the study surfaces for AP-42 baseline establishment
    b. SCAMPER and TRAKER will make ten sample runs at 35 mph on the course in conjunction with the upwind/downwind flux tower measurements prior to any sweeping of the sampling course.

2. Baseline post-sweep measurements with SCAMPER, TRAKER (Upwind/Downwind Flux Towers in place), and AP-42 on the first day only.
    a. AP-42 sampling to occur for road segments (six sampling spots at the beginning and at the end of course) after street sweeper cleans the roadway surfaces for AP-42 baseline establishment
    b. SCAMPER and TRAKER will make ten sample runs at 35 mph on the course in conjunction with the upwind/downwind flux tower measurements after street sweeping of the sampling course.

3. Quantified material loading measurements with SCAMPER, TRAKER (Upwind/Downwind Flux Towers in place), and AP-42
    a. SCAMPER and TRAKER will make sample runs at a set of planned speeds (25, 35 and 35 mph) for each planned loading on the course after each application of quantitative loadings on the roadway surfaces in conjunction with the upwind/downwind flux tower measurements A proposed speed and loading matrix is shown below in Table 1.
    b. Table 1a: Range of silt loadings (gram/m2) observed from AP-42 Clark county database. AP-42 Silt loadings vary by a factor of about 100 for the three sampled roadway categories.

Silt loading	Minor arterials	Collector roads	Local roads
16th percentile	0.14	0.10	0.13
50th percentile	0.40	0.83	1.48
84th percentile	1.90	3.52	13.54

c. Table 1b: Range of soil loadings (gram/m2) assuming 14% silt content

Soil loading	Minor arterials	Collector roads	Local roads
16th percentile	1.00	0.71	0.93
50th percentile	2.86	5.93	10.6
84th percentile	13.6	25.1	96.7

d. Table 1c. Range of soil loadings (lb/1,000 ft2) assuming 14% silt content

Proposed	Minor arterials	Collector roads	Local roads
16th percentile	0.20	0.15	0.19
50th percentile	0.58	1.21	2.16
84th percentile	2.78	5.14	19.8

e. Table 2 Proposed matrix of planned silt loadings and speeds. A set of candidate silt loadings, using a logarithmic series, increasing from 16th percentile for collector roads to 84th percentile for local roads, is shown for discussion. Per DRI and UCR suggested modifications, do 14 runs by each vehicle at each loading, six at constant speed and 4 “ramp” tests. Goal is to make sure that loadings and speeds characteristic of each roadway type are sampled.

Day number	Low silt loading (gram/m2) at 25, 35, 45	Medium silt loading gram/m2) at 25, 35, 45	High silt loading (gram/m2) at 25, 35, 45
1	0.10	0.58	3.32
2	0.14	0.82	4.72
3	0.20	1.16	6.69
4	0.29	1.65	9.50
5	0.41	2.34	13.5

f. Time required to conduct each study activity, including material deposition, AP-42 sampling, and mobile sampling system sampling runs will influence the final daily sampling schedule. Additional factors such as wind speeds and direction and the decay rate of deposited material will also influence the final daily study schedule. Table 3 shows the tentative schedule vehicle speeds and loadings. Study participants will meet at end of each day to discuss interim findings and consider revisions to draft sampling schedule. Note Table 3 values are subject to modification as necessary to address actual field conditions.

Table 3 SCAMPER and TRAKER vehicle measurement speeds and sampling area material loadings for study days Monday through Friday.

Day	Speed strategy	Silt loading strategy
Monday	Constant speed, 35 and 45, and 25, if time	Start with low silt loading, 0.10 gram/m2,then try 0.82 gram/m2 adjust as needed. If the loadings degrade rapidly apply different load, but stay with same value if load degrades slowly. Sample silts via AP-42 at beginning, at 50% depletion, and at end
Tuesday	Constant speed, 35, 45, 25	Go with moderate low loading, 0.41 gram/m2, ,then try 3.32 gram/m2 adjust as needed. If the loadings degrade rapidly apply different load, but stay with same value if load degrades slowly. Sample silts via AP-42 at beginning, at 50% depletion, and at end
Wednesday	Ramp up and down speed strategy	Go with moderate loading, 1.65 gram/m2, 9.50 gram2, adjust as needed. If the loadings degrade rapidly apply different load, but stay with same value if load degrades slowly. Sample silts via AP-42 at beginning, at 50% depletion, and at end
Thursday	Ramp up and down speed strategy	Go with moderate high loading, 6.69 gram/m2 and try 13.5 gram/m2 Sample silts via AP-42 at beginning, at 50% depletion, and at end
Friday	Ramp up and down speed strategy	Go with low silt loadings 0.14 gram/m2 and 0.58 gram/m2 Sample silts via AP-42 at beginning, at 50% depletion, and at end

g. Table 3: Proposed matrix of planned SOIL loadings and speeds, assuming 14% silt content in final composited sample (this will be verified by laboratory analysis before Sept 11, 2006). - Final soil loadings will depend on silt content analysis of collected bulk sample. Goal is to make sure that loadings and speeds characteristic of each roadway type are sampled.

h. A particular quantified material loading may be repeated so that SCAMPER and TRAKER may make repeated sampling runs at a different fixed vehicle speed. Fixed speeds of 25, 35 and 45 mph have been suggested for the study, corresponding, respectively to speed limits for local, collector and minor arterial roads

i. The daily test schedule for project is set forth in Table 4. Note Table 3 values are subject to modification as necessary to address actual field conditions.

Table 4. Daily project schedule

Day	Activity
1 Monday, Sept 11	a) Set up barricades b) Set up of AP-42 sampling plots (2 hours). c) Pre-sweeping measurements. AP-42 sampling of extant dust. Measurement of baseline emissions, and testing of all equipment. d) Sweeping of road surface e) Post-sweeping measurements. AP-42 sampling of residual dust, after Measurement of baseline emissions post-sweeping. f) Evaluation of sweeper effectiveness from reduction of soil loading and reduction of observed particulate concentrations g) Mixing of dye and soil h) Initial application of dyed-soil to road, suggest testing at low threshold (just in case the stuff is hard to remove from the road. Photographic documentation of all steps in process i) Initial drive-overs at (what initial? Suggest low) velocity to evaluate ability of instruments to detect plume j) Continue drive-overs and sacrificial AP-42 sampling to evaluate depletion rate of road dust reservoir. k) Evaluation of initial runs to adjust either loading or speed. l) Possible reapplication of dyed soil and more runs if time and weather allow m) More AP-42 and mobile sampling as time allows n) Clean up applied dust with sweeper o) Remove barricades

2 – Tuesday, Sept 12	a) Set up barricades b) Sweep road surface c) Apply intended loading for day – suggest high loading, high speed. Loading and speed could be varied if time allows. d) Initial AP-42 sacrificial sampling e) Initial drive-overs f) Intermediate AP-42 sampling g) Continued drive overs and AP-42 sampling, with reapplication as needed h) Final AP-42 sampling for that loading i) Possible reapplication of dyed soil and more runs if time and weather allow j) More AP-42 and mobile sampling as time allows k) Sweep road surface l) Remove barricades
3 – Wednesday Sept 13	Press day – may need to do demonstration runs and interviews for local media a) Set up barricades b) Sweep road surface c) Apply intended loading for day – suggest medium loading, medium speed. (collector roads) d) Initial AP-42 sacrificial sampling e) Initial drive-overs f) Intermediate AP-42 sampling g) Continued drive overs and AP-42 sampling, with reapplication as needed. Loading and speed could be varied if time allows h) Final AP-42 sampling for that loading i) Possible reapplication of dyed soil and more runs if time and weather allow j) More AP-42 and mobile sampling as time allows k) Sweep road surface l) Remove barricades
4 – Thursday, Sept 14	a) Set up barricades b) Sweep road surface c) Apply intended loading for day – suggest high loading, low speed (local roads) d) Initial AP-42 sacrificial sampling e) Initial drive-overs f) Intermediate AP-42 sampling g) Continued drive overs and AP-42 sampling, with reapplication as needed. Loading and speed could be varied if time allows h) Final AP-42 sampling for that loading

	i) Possible reapplication of dyed soil and more runs if time and weather allow j) More AP-42 and mobile sampling as time allows k) Sweep road surface l) Remove barricades
5 – Friday, Sept 15	a) Set up barricades b) Sweep road surface c) Apply intended loading for day – suggest low loading, high speed (minor arterial roads) d) Initial AP-42 sacrificial sampling e) Initial drive-overs f) Intermediate AP-42 sampling g) Continued drive overs and AP-42 sampling, with reapplication as needed. Loading and speed could be varied if time allows h) Final AP-42 sampling for that loading i) Possible reapplication of dyed soil and more runs if time and weather allow j) More AP-42 and mobile sampling as time allows k) Sweep road surface l) Remove barricades m) Wrap up and discuss next steps at local watering location. n) Pack up and go home

- j. AP-42 sampling to occur for road segments (six sampling spots at the beginning and at the end of course) after deployment of quantitative loadings on the roadway surfaces for AP-42 silt measurements. AP-42 sampling will be performed for all loading quantitative measurement levels
- k. On the first day, soil/silt sampling may need to occur at increased sampling frequencies to determine the rate of depletion of the applied reservoir. Estimated time to sacrificially sample one plot is about 10-15 minutes. Plots at each end of course could be sampled simultaneously
- l. Silt sampling could be conducted on a fixed schedule (i.e. after every 2 runs) or it could be conducted in consultation with observed average particulate concentrations for each run measured by SCAMPER and TRAKER. If individual averages are not available, then quick visual estimates of depletion, perhaps matched to residuals remaining using a quick "clear tape stick test" will be used to determine the need to resample the applied soil. Total mass measurements from AP-42 sampling could be rapidly made available to participants to assist in decision-making about when to reapply loading or to clean it up. (UNLV will train its crews to sample 1 10'x13' plot in 10-15 minutes, with crews at each end working simultaneously).

4. Post-study assessment of road surface roughness for both tire track and non-tire track surfaces (UNLV - assessment method TBD)
    - a. Candidate: Sand-spill Test
    - b. Candidate: Stylus-roughness Test

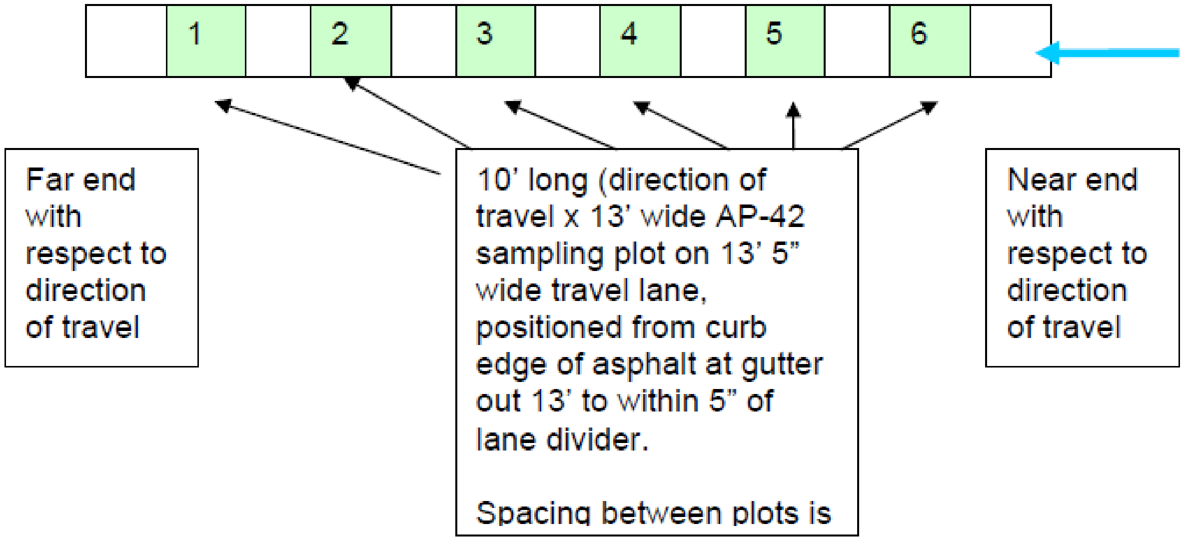
Appendix I. **Addendum proposed by Dave James on AP-42 silt sampling**

REVISED DRAFT UNLV AP-42 silt sampling plan for Phase IV paved road study. DRAFT
Please address comments to Dave James, 702-895-1067, drdavej@unlv.nevada.edu

A. AP-42 site layout planning:

The proposed AP-42 sampling layout is shown in Figure 1.

Figure 1: Pre-vacuuming layout of AP-42 sampling zone. There will be two sampling zones, one at each end of the driving course. Blue arrow shows vehicle drive direction



Tire Revolution Considerations:
For a 29” high truck tire (measured on 3/4-ton 2006 Chevy Silverado pickup truck using LT245-75R16 tires with 7” tread width), the circumference of the tire, for one revolution is 3.14 x 29 = 91.1 inches per revolution / 12 inches/foot = 7.59 feet per revolution. For a 10-foot long AP-42 sampling zone, this will correspond to 10/7.59 = 1.32 revolutions of the tire. If 100 feet are available at each end of the drive route for AP-42 sampling (20 feet more than originally requested), then this will correspond to 13.2 revolutions of the truck wheels.

Plot spacing considerations
If six 10-foot long plots are painted within each 100 foot zone, there will be 100 – 6x10 = 40 feet of un-used space, with 5 gaps between the sampling zones and a gap at each end, for a total of 7 gaps, leaving 50/7 = 7.1 feet of gap for operator access.

B. AP-42 site sampling sequence

To minimize impact of vacuumed AP-42 sampling plots on remaining plots or on the constant speed sampling zone, the AP-42 plots will be sampled sacrificially beginning from the “far” end of each zone (“far” means the end that the test vehicle would reach last) and then moving toward the near end with each subsequent sampling.

Please see Figures 2 and 3 for a proposed sequence of removal of AP-42 samples.

Figure 2a: Yellow shading indicates first AP-42 sacrificial sampling, at far end of course and far end of direction of travel

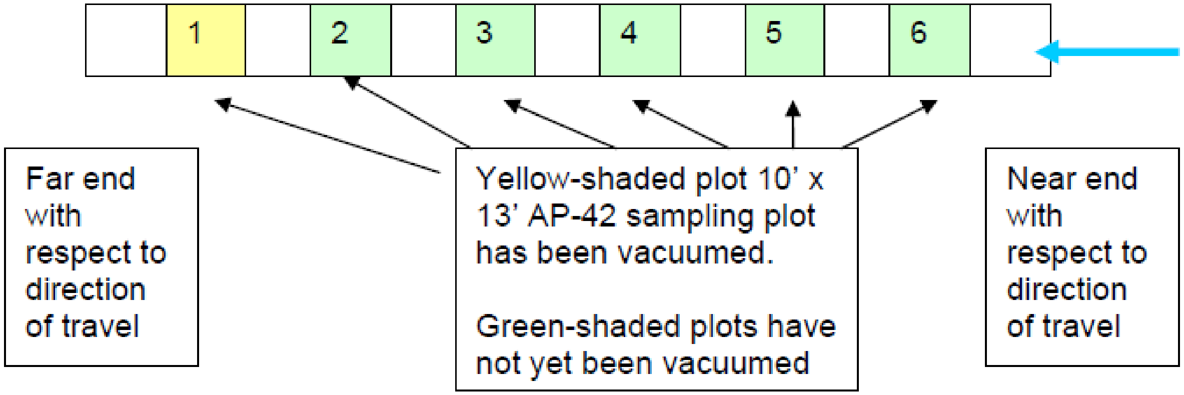


Figure 2b: Yellow shading indicates first AP-42 sacrificial sampling, at near end of course and near end of direction of travel

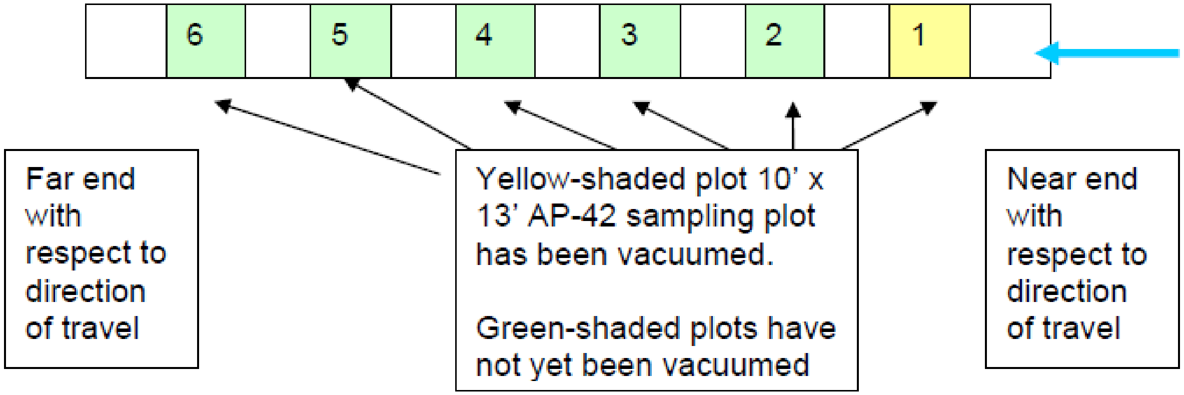


Figure 3a: Yellow shading indicates three AP-42 sacrificial samplings, at far end of course and far end of direction of travel

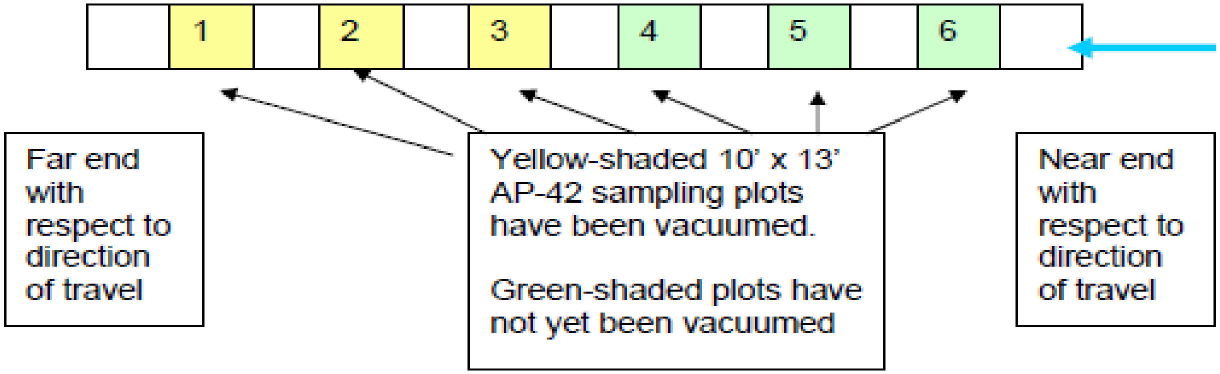


Figure 3b: Yellow shading indicates first AP-42 sacrificial sampling, at near end of course and near end of direction of travel

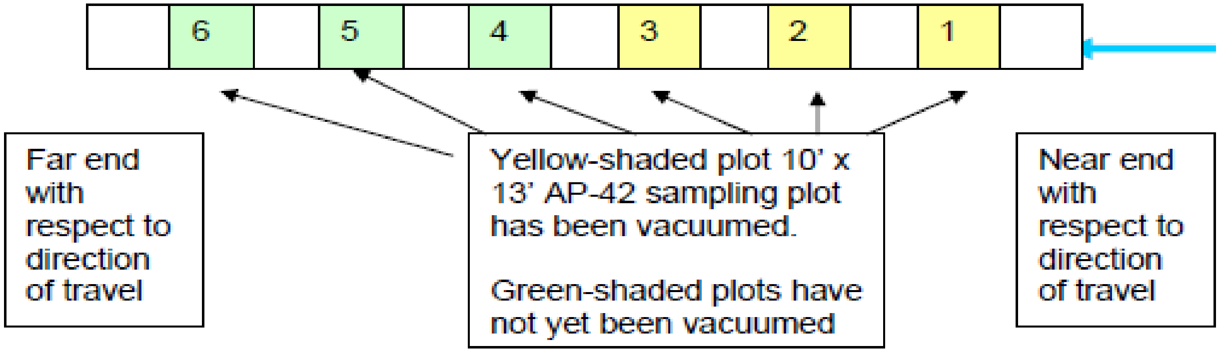


Table 1: Proposed AP-42 sampling order

Plot number	Sampling order
1	Simultaneously sample plot 1 <u>at each end of course</u> immediately after lay-down of material, before any vehicles drive over. Estimated time to sample, 10-15 minutes
2	Simultaneously sample plot 2 at each end of course after “2” initial vehicle drive over runs. “X” could be an arbitrary number (say X = 2) or could be determined by detectable change in average concentrations measured by TRAKER/SCAMPER or by stationary towers, if it is feasible to report rapidly with confidence (if not feasible, prefer to go with fixed number for X)
3	Simultaneously Sample at each end of course after X=4 runs
4	Simultaneously Sample at each end of course after X = 6 runs
5	Simultaneously Sample at each end of course after X = 8 runs
6	Simultaneously Sample at each end of course after X=10 runs or the end of the day.

C. Proposed availability of road dust loading data

With a laboratory scale on-site, it will be possible to report changes in total mass loading over time as vehicles drive over. This data may be of value in estimating rate of total mass depletion, and could be used to adjust total road soil loadings up or down on subsequent sampling days.

Silt loading data may take 1 day to several days, depending on priority requested by Clark County DAQEM. Soil samples would have to be driven back to Henderson from Boulder City for analysis.

Clark County (Nevada)
Paved Road Dust Emission Studies in Support of Mobile Monitoring Technologies

Appendices A–E

Appendix C

1. UNIVERSITY OF RIVERSIDE, COLLEGE OF ENGINEERING, CENTER FOR ENVIRONMENTAL RESEARCH AND TECHNOLOGY (CE-CERT) MEASUREMENTS OF PM10 EMISSION FACTORS FROM PAVED ROADS IN CLARK COUNTY, NV

"ROADWAY DUST SAMPLING EVALUATION - PHASE II"

DRAFT FINAL REPORT

MAY 2005

2. UNIVERSITY OF NEVADA SYSTEM OF HIGHER EDUCATION - DESERT RESEARCH INSTITUTE (DRI)

"THE LAS VEGAS ROAD DUST EMISSIONS TECHNOLOGY ASSESSMENT –PHASE II"

FINAL REPORT

JULY 15, 2005

December 22, 2008

Appendix C

1. UNIVERSITY OF RIVERSIDE, COLLEGE OF ENGINEERING, CENTER FOR ENVIRONMENTAL RESEARCH AND TECHNOLOGY (CE-CERT)

MEASUREMENTS OF PM_{10} EMISSION FACTORS FROM PAVED ROADS IN CLARK COUNTY, NV

“ROADWAY DUST SAMPLING EVALUATION - PHASE II”

DRAFT FINAL REPORT

MAY 2005

MEASUREMENTS OF PM_{10} EMISSION FACTORS FROM PAVED ROADS IN CLARK COUNTY, NV

DRAFT FINAL REPORT

for

ROADWAY DUST SAMPLING EVALUATION
PHASE –II

Submitted to:
Clark County Department of Air Quality Management
500 S. Grand Central Parkway, 1st Floor
Las Vegas, NV 89155

By

Center for Environmental Research and Technology

May, 2005

by Principal Investigator:

Dennis R. Fitz

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ABSTRACT

The SCAMPER system for measuring PM_{10} emission rates from paved roads was used to characterize emission on a test route in Las Vegas, NV. Tests were conducted February 14-17, 2005. The test route was approximately 120 miles long and tests were conducted either following of leading the TRAKER measurement system operated by the University of Nevada Desert Research Institute. One test run was conducted per day. The results showed that PM_{10} emission rates were generally near zero except when occasional "hot spots" were encountered, which is consistent with previous measurements. The daily average PM_{10} emission rates varied from 0.012 to 0.105 mg/m. The emission rates for the last two days were considerably lower than the first two, which is likely the result of enforcement action.

The emission rates for the first two days were approximately a factor of two lower than those measured in the summer of 2004. The test route, however, was different than the summer's and and there are likely to also be seasonal differences that affect emission rates. A factor of two is generally good agreement for measurements of emission rates that are often strongly influence by sporadic exceedances. We concluded that the SCAMPER system is useful for both identifying "hot spots" and generally characterizing PM^{10} emission rates from paved roads.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

Kurt Bumiller's work in upgrading the sampling system, conducting the field measurements, and in preparing the data set is gratefully appreciated. I also like to thank my colleagues at the Desert Research Institute, Vic Etyemezian, George Nikolich, and Hampton Kuhns for their cooperation and in providing a secure storage are for our test vehicle.

1.0 PROJECT DESCRIPTION AND OBJECTIVES

1.1 Background

The expression contained into the EPA document AP-42 for predicting emission rates and has been widely used all over the country to estimate the fraction of PM_{10} originating from roads:

$$E = k(sL/2)^{0.65}\ (W/3)^{1.5} g/VKT$$

where:

E = PM emission factor in the units shown
k = A constant dependent on the aerodynamic size range of PM (1.8 for $PM_{2.5}$; 4.6 for PM_{10})
sL = Road surface silt loading of material smaller than 75μm in g/m_2
W = mean vehicle weight in tons
VKT = vehicle kilometer traveled

Equation (1) was derived by measuring the total flux across roadways using a PM_{10} monitoring array and based solely on surface silt loading. We recently conducted a study to measure and model the PM_{10} emissions from paved roads in southern California (Fitz, 2001, Fitz and Bufalino, 2002). In this approach the PM_{10} concentrations were measured directly on moving vehicles in order to improve the measurement sensitivity for estimating the emission factors for vehicle on paved roads. Optical sensors were used to measure PM_{10} concentrations with a time resolution of approximately two seconds. Sensors were mounted in the front and behind the vehicle in the well-mixed wake. A special inlet probe was designed to allow isokinetic sampling under all speed conditions. The emission factor was based on the concentration difference between front and back of the test vehicle and the frontal area. The emissions factors for a wide variety of roads in southern California ranged from 64 to 124 mg/km. These are consistent with but generally lower than measurements using upwind-downwind techniques and those estimated by AP-42. This technique is useful for quickly surveying large areas and for investigating hot spots on roadways caused by greater than normal deposition of PM_{10} forming debris.

1.2 Objective

The primary objective of this project was to measure PM emission rates from roadways in the Las Vegas area of Nevada. A secondary objective was to compare these values with the measurements made at the same time by researchers at the Desert Research Institute (DRI) of the University of Nevada using a similar but different approach (Etyemezian et al. 2003).

1.3 Approach

We determined vehicle PM emission factors by measuring the PM concentrations in front of and behind the vehicle using real-time sensors. This approach included into five components:

1) Sampling Inlet

An inlet for the real-time PM sensors was used that allowed sampling as isokinetically as possible over the full range of vehicle speeds. This involves a bypass flow system that is adjusted to vehicle speed with a PC using GPS speed data.

2) PM_{10} Sensors

DustTrak optical PM sensors with PM_{10} inlets are used.

3) Sampling Trailer

From our studies to determine concentrations in the vehicle wake the sampling position behind the vehicle was optimized. This position required using a trailer to mount the sampling inlet. The trailer was designed to disturb the vehicle wake as little as possible. In addition, the trailer holds the bypass flow system.

4) Position Determination

A Garmin GPS Map76 global positioning system was used to determine vehicle location and speed.

5) Data Collection

A PC was used to collect data from GPS and PM_{10} measuring devices. Data was stored as one-second averages. The PC also was used to automatically adjust the sample inlet bypass flow to maintain isokinetic particle sampling using a 10-second running average of vehicle speed based on the GPS. For backup, data was also collected from the DustTraks using their internal data collection system. These data were two-second averages, the shortest interval allowed by the DustTrak software.

2.0 FIELD MEASUREMENTS

These measurements were made in a similar manner as those in Phase I, but a revised route was used and test were conducted on four, rather than two test days. Appendix A shows a map of the test route used.

3.0 DATA QUALITY

- Data Capture

The data capture form the DustTrak analyzers was nearly 100% except for several instances when the rear Dust Trak quit operating. This happened five times on the 14th and required physically restarting the instrument. Both DustTraks were then mounted on foam rubber to minimize physical shock. Apparently bumpy roadways were more of a problem in this study compared to Phase I or southern California testing. Only one other failure occurred, on the 15th. On the 16th we attempted to swap the DustTraks to evaluate potential bias. During the initial portion of the test the DustTrak in the back showed greater noise in this location, and the instruments were swapped back to their initial locations at 09:28. Data until this time were invalidated.

- DustTrak Drift

The zero of the DustTrak was determined before, after, and at least once during the test runs. Table 3-1 summarizes this data. The drift during the course of the each test day was less than a few thousandths of a mg/m^3, near the 0.001 mg/m^3 detection limit of the instrument. The data for each test run was corrected for zero offset using the mean zero response for that day.

Table 3.1 Summary of zero check data

Date February	Time	PM10 Front mg/m3	PM Rear mg/m3
14	10:33	-0.012	-0.016
14	15:32	-0.013	-0.016
14	18:18	-0.014	-0.009
15	9:00	-0.016	-0.012
15	11:05	-0.016	-0.009
15	12:31	-0.015	-0.008
16	10:07	-0.011	-0.015
16	12:30	-0.009	-0.015
16	15:20	-0.008	-0.014
17	8:35	-0.017	-0.016
17	12:35	-0.006	-0.014
17	14:54	-0.007	-0.014

4.0 DATA SUMMARY

4.1 DATA VALIDATION

The data acquisition system recorded all data accurately. The only problem that resulted in the invalidation of data was the GPS data from the start of the test on February 15th until 14:02 in the afternoon. During this period position and speed data were found to be unreliable. We therefore obtained the location information and PM_{10} measurements from DRI. By matching our PM10 data with DRI's we were able to assign a position to our PM10 data. For consistency, all of the location data for this entire day were from the DRI GPS. It should be noted that the location assigned from DR data is not as an exact match as when we collected our own GPS data on other days. At times the locations will be somewhat ahead or behind our data depending on the relative difference in time between the two test vehicles as the travel the test route.

We found that the output of the rear DustTrak occasionally spiked, either positive or negative, most likely due to physical shock. These spikes always showed up on two consecutive seconds. These were unlikely to be associated with an actual PM_{10} concentration as concentrations rarely change to that degree in less than one second. This two-second characteristic of this noise spike is also expected from the internal averaging and output characteristics of the DustTrak. On the time constant we selected (which is the shortest available) the DustTrak output is a two-second running average that is updated every second. A large spike in a one-second period will therefore show up as two smaller spike for two consecutive seconds. To filter this noise we tabulated the data as 5-second running medians. Two-second spikes therefore would be removed from the data set. At the same time we calculated the running medians we also corrected for the zero response for each analyzer. These data manipulations are shown in the full data set that was submitted.

4.2 DATA SUMMARY

The net PM_{10} concentration is determined by subtracting the concentration from the front DustTrak from that of the rear. Since the DustTrak data is noisy at the shortest time constant, we plotted the data as a 10-second running average of the 5-second running medians. We have found that this period of a running average produces higher quality data although the time resolution is not as great. This is an inherent limitation of the DustTrak instrument when using the shortest time constant. This is the averaging period that we used in Phase I. We then multiplied the net PM_{10} concentration by 3.66m^2, the frontal area of the test vehicle, to obtain the PM_{10} emission rate in units of mg/m.

Measuring PM_{10} emission rates in real time assumes that there is a plume in a wake behind the vehicle. Data below a certain speed may not be valid. DRI chose 10mph as this speed and for consistency we sorted the emission rate data by speed and deleted those values less than 10 mph. The data was first saved as “values” in the EXCEL spreadsheet to preserve the original median calculations as the vehicle goes above and below 10 mph. These data manipulations are shown in the submitted data set.

The following subsections describe each day of data collected. This is accomplished with a time series plot and a location plot. The time series plots give good overviews of the data, especially for comparison with other test days. Since the speed varies from day to day, the location data, however, is approximate. The location plots are useful to pinpoint hot spots, but it is difficult to compare data with other days. The combination of the two presentations therefore gives a comprehensive view of the data.

4.2.1 FEBRUARY 14, 2005

Figure 4-1 shows the PM_{10} emission rate calculated as a running ten-second average for periods when the running average speed was greater than 10 mph. The emission rate is typically less than 0.1 mg/m except when “hot spots” are encountered. These are often observed as trackout onto the roadway. As shown in the figure, the PM_{10} emission rates can increase by two orders of magnitude when passing over these hot spots. Figure 4-2 shows a map of the test rout with the PM_{10} emission rates shown as circles, with the size of the circle

Figure 4-1 Time series plot of PM_{10} Emissions during the test conducted on February 14, 2005.

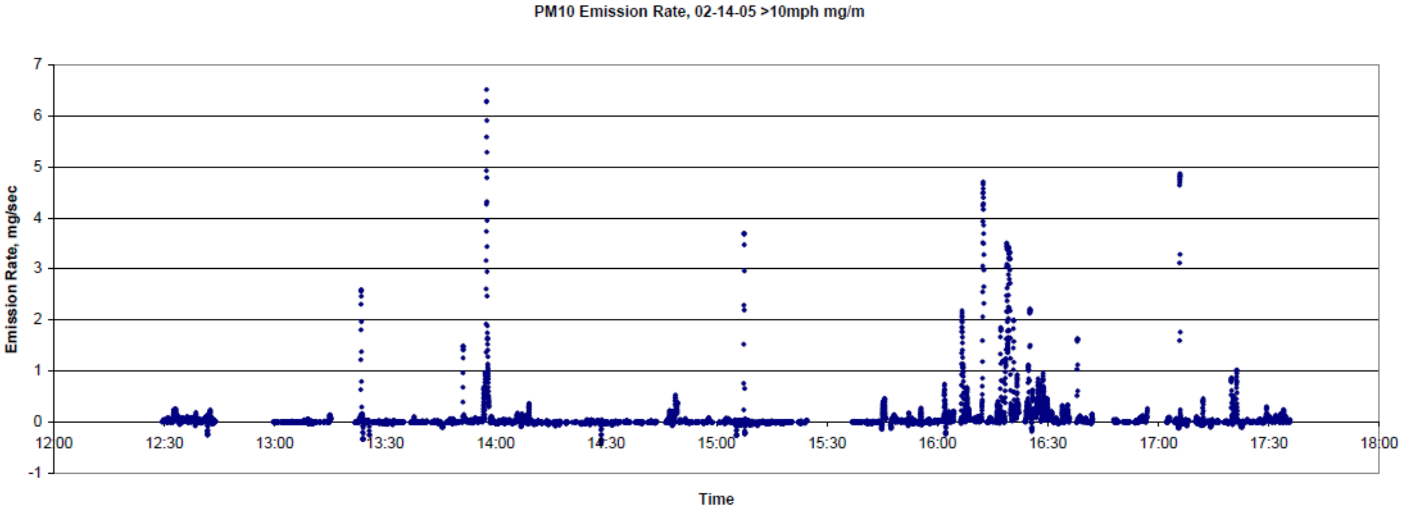
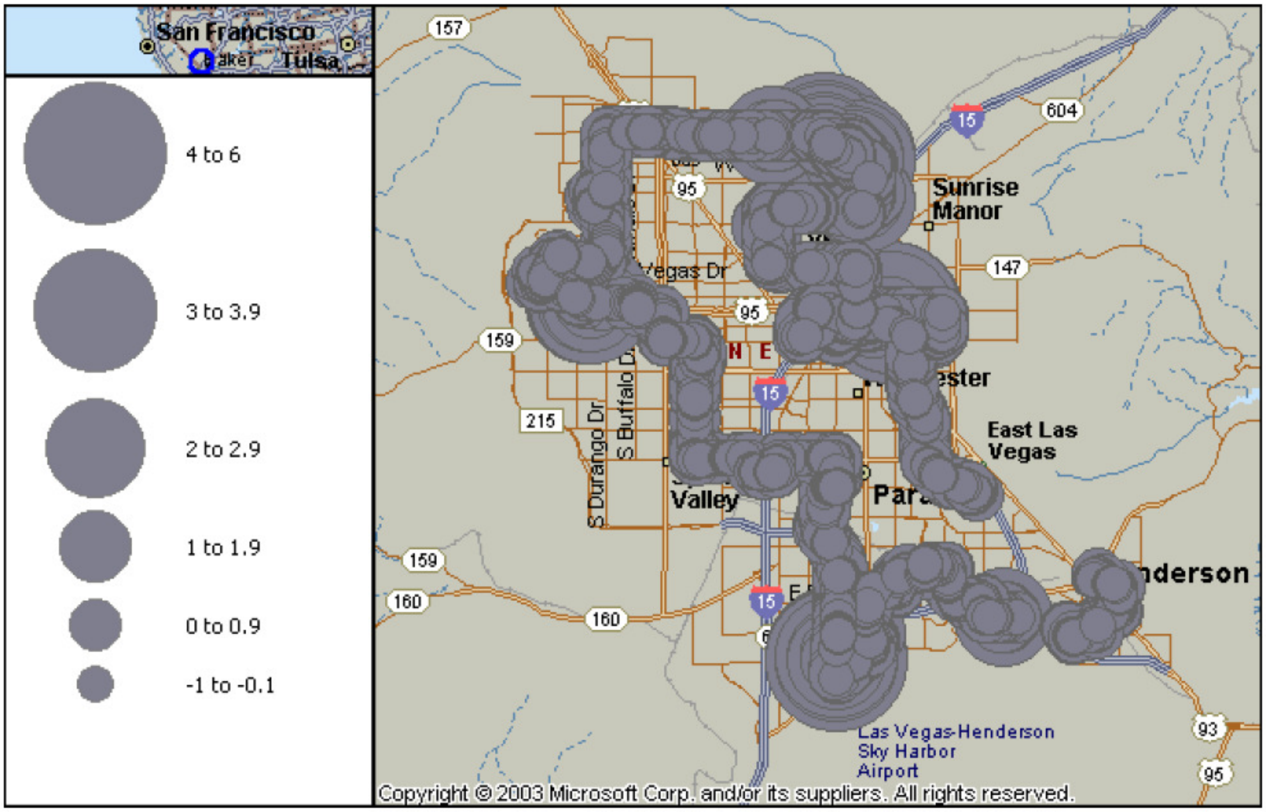


Figure 4-2. PM_{10} emission rates along the test route on February 14, 2005



representing a range of emission rates. The hot spots on the north and south ends of the route are clearly visible and add geographic information to the time series in Figure 4-1. Much greater resolution, down to individual circles is possible to further evaluate hot spots.

4.2.2 FEBRUARY 15, 2005

Figure 4-3 shows the PM10 emission rate calculated as a running ten-second average for periods when the running average speed was greater than 10 mph. The hot spots on the northwest side of the route are significantly diminished. Figure 4-4 shows the emission rates along the route and indicates that the hot spots are on the northeast side of the route.

4.2.3 FEBRUARY 16, 2005

Figure 4-5 shows the PM_{10} emission rate calculated as a running ten-second average for periods when the running average speed was greater than 10 mph. The number of hot spots is much reduced from the previous two days. An unusually large negative value was observed at 14:05 hours. Such values could occur as a result of conditions that expose the front, but not the rear, of the vehicle to high concentrations of PM_{10}. We have previously observed this phenomenon while waiting at a light in which a crosswind blew fugitive dust (generated by a vehicle on a roadway or wind blowing on loose soil) into the front of the vehicle. An examination of the 1-second data showed that high front PM_{10} concentrations were observed while the vehicle was slowing down to nearly a stop (not shown in Figure 4-5 since speeds less than 10 mph were excluded) and that the PM_{10} concentrations returned to normal three seconds after the vehicle started accelerating to speeds above 10mph (this is shown as a longer period in Figure 4-5 since it is a 10-second running average). These negative data points therefore probably should be deleted at a higher level of data validation. We included them as an example of when emission rates can be negative under unusual circumstances.

Figure 4-6 shows the emission rates along the route and indicates that the only significant hot spot is on the northeast side of the route.

Figure 4-3 Time series plot of PM_{10} emissions during the test conducted on February 15, 2005.

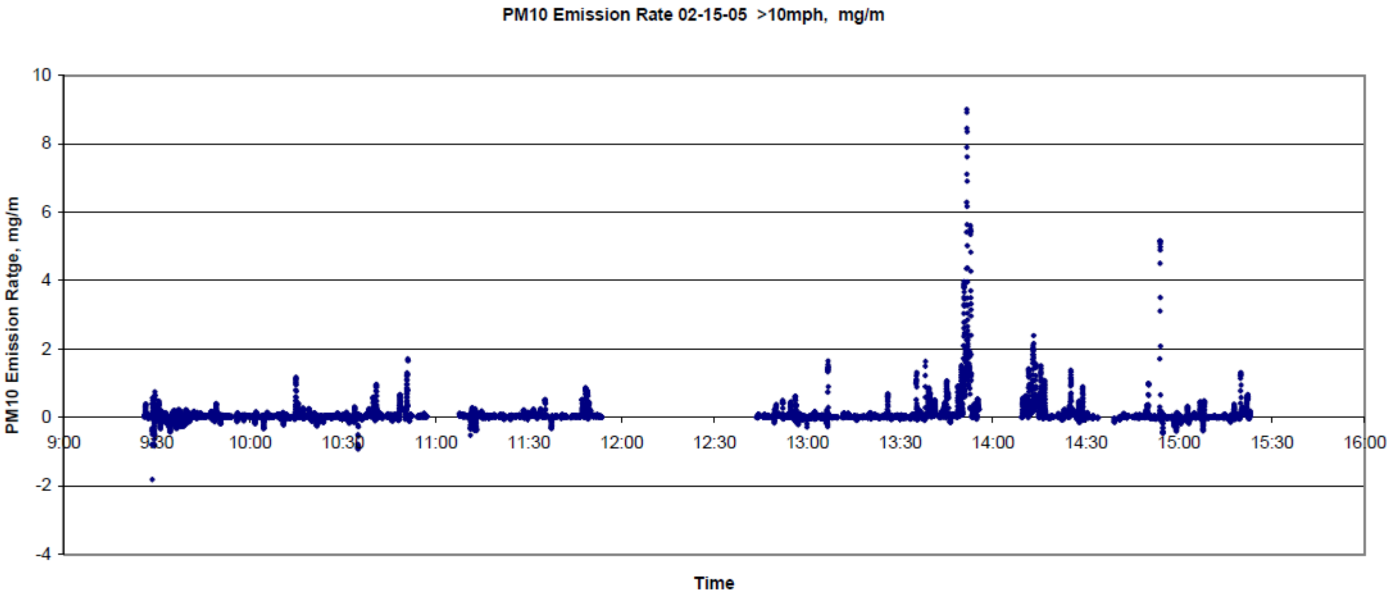


Figure 4-4. PM_{10} emission rates along the test route on February 15, 2005

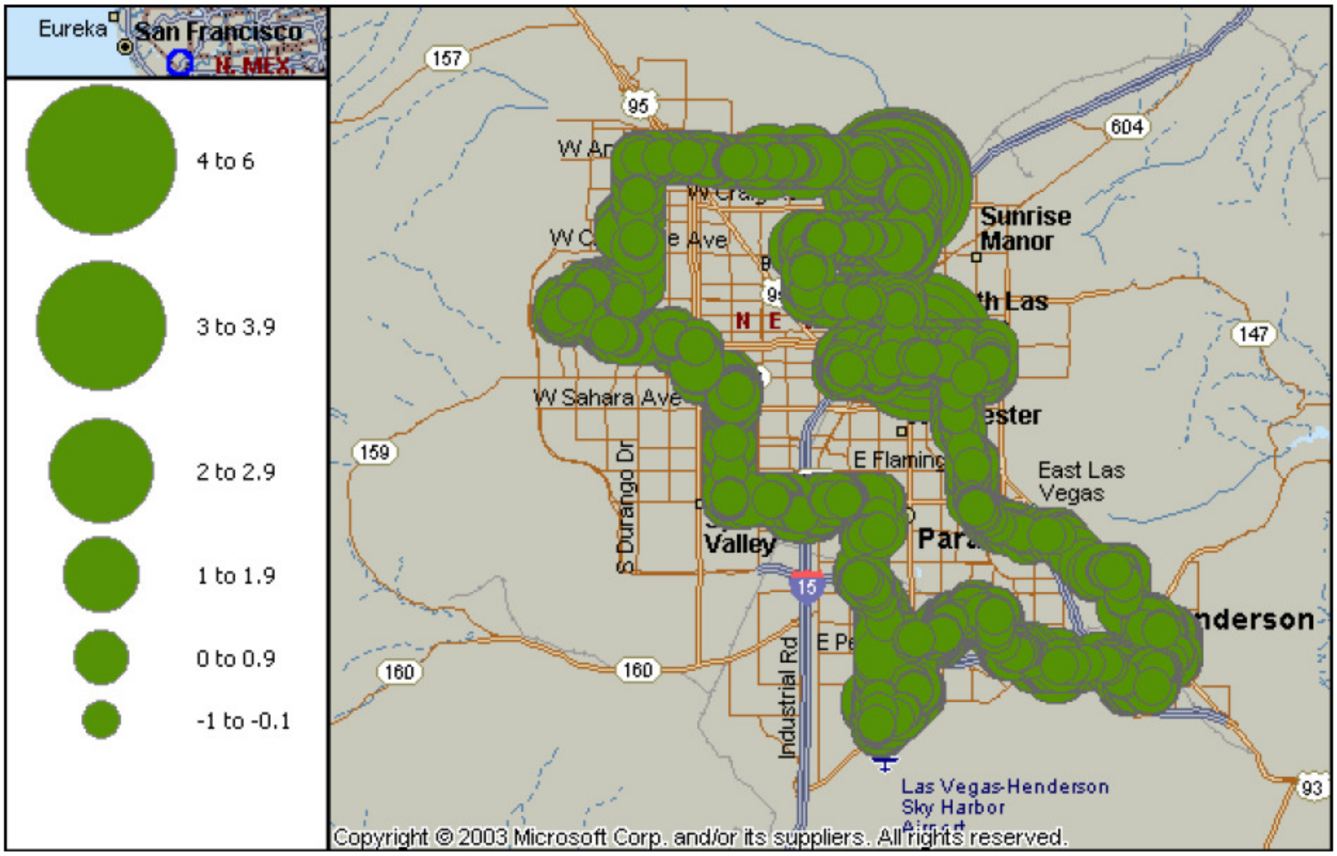


Figure 4-5 Time series plot of PM_{10} emissions during the test conducted on February 16, 2005.

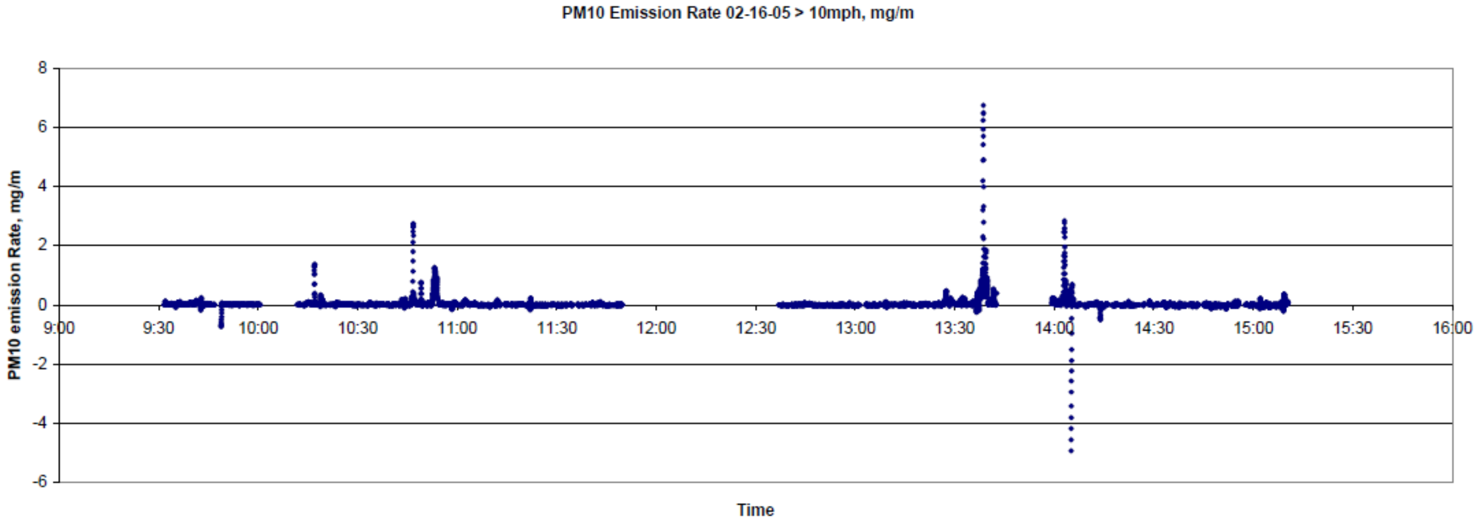
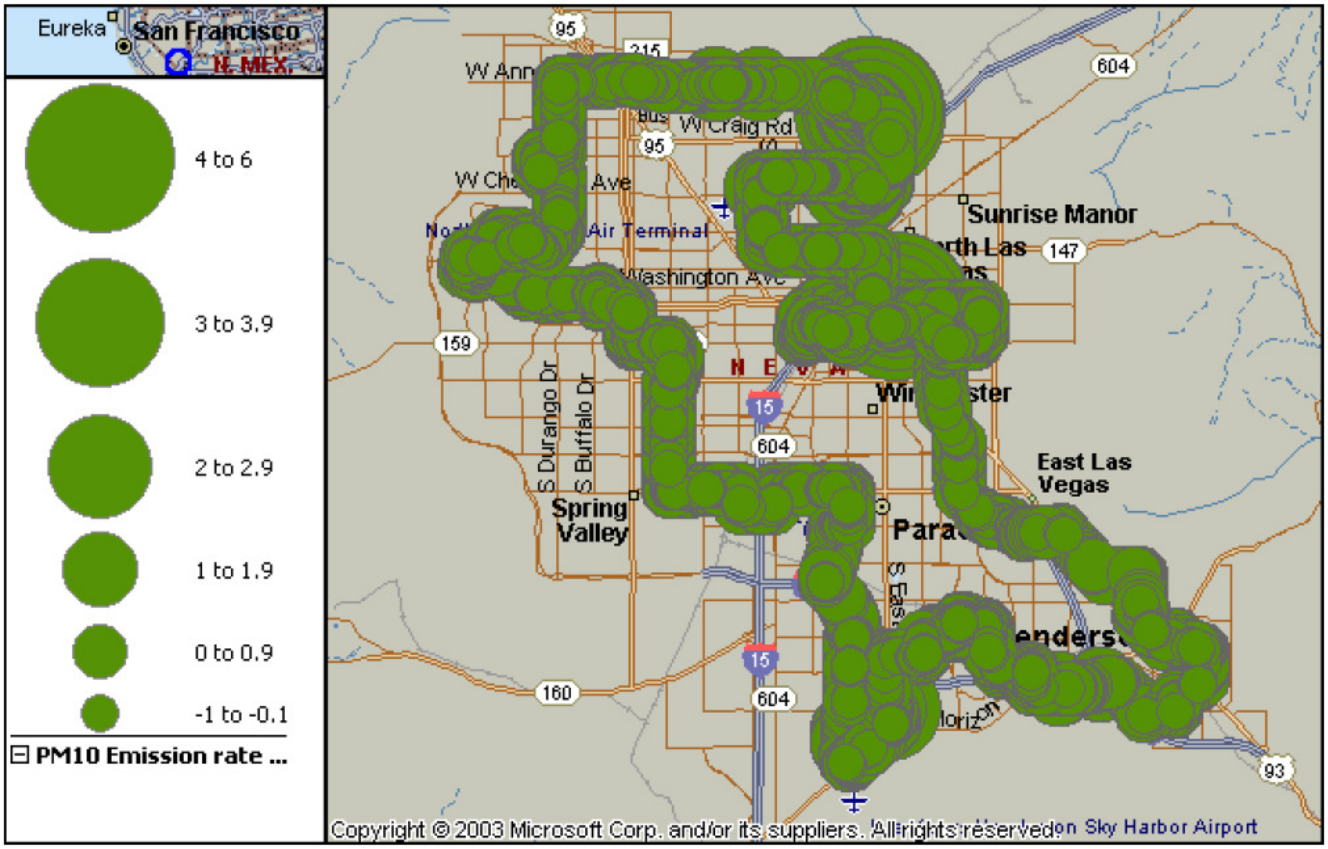


Figure 4-6. PM_{10} emission rates along the test route on February 16, 2005



4.2.4 FEBRUARY 17, 2005

Figure 4-7 shows the PM_{10} emission rate calculated as a running ten-second average for periods when the running average speed was greater than 10 mph. This day, like the previous, showed fewer hot spots than the first two days of sampling. Note that there were several periods where the PM_{10} emission rates were negative. An examination of the 1-second data showed that the negative emission rates at 09:17 hours were immediately followed by high positive rates. This indicates that the vehicle may have past through an existing dust cloud.

Figure 4-8 shows the emission rates along the route and indicates that the hot spot on the southwest corner of the route had again intensified.

Figure 4-7 Time series plot of PM_{10} emissions during the test conducted on February 17, 2005.

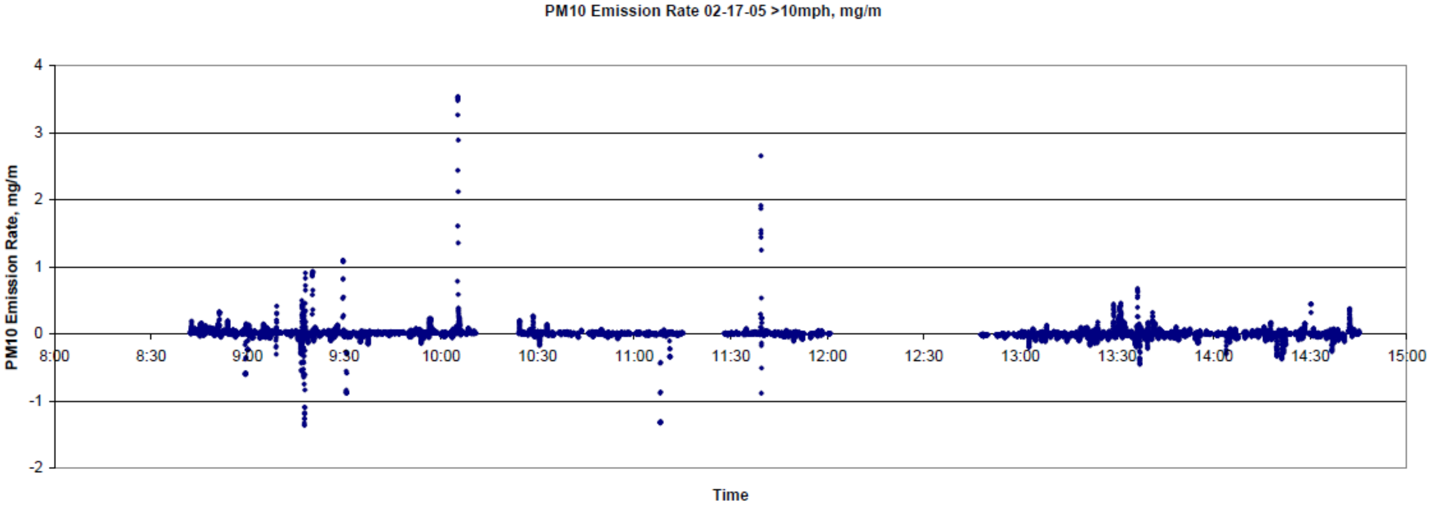
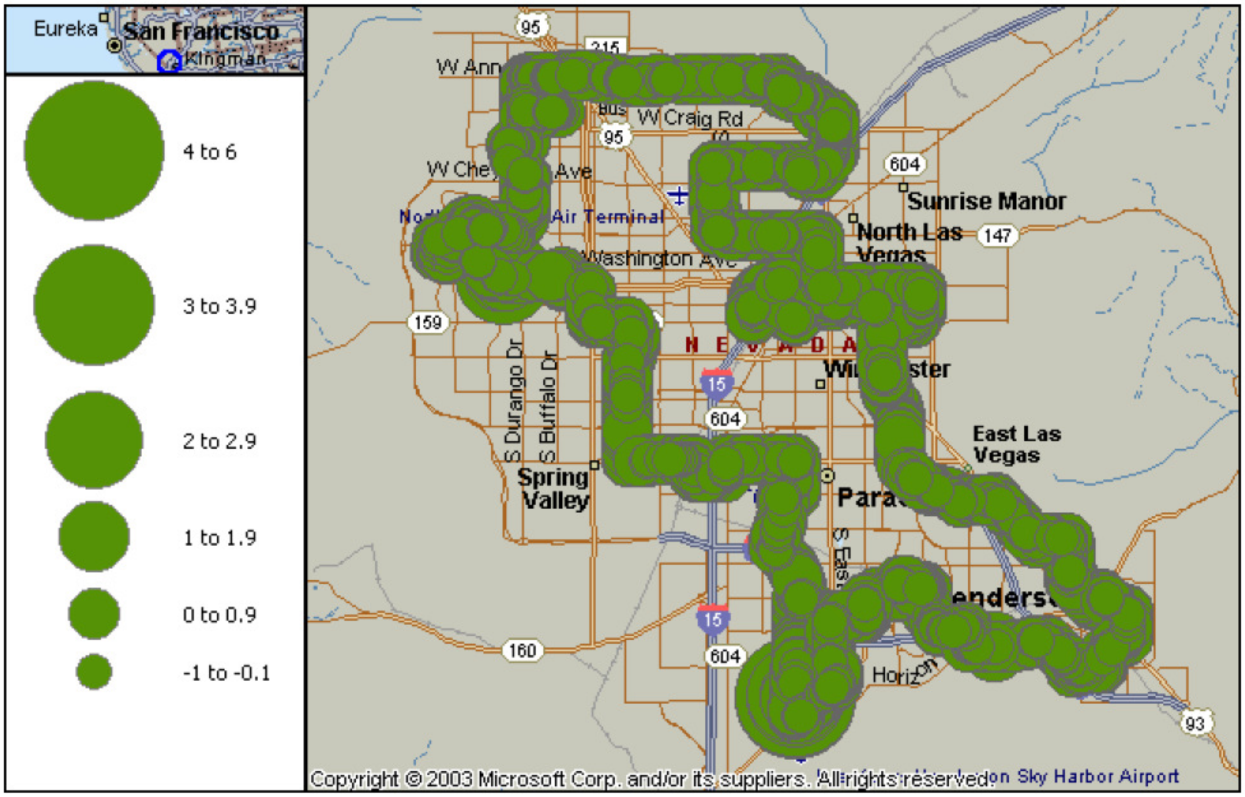


Figure 4-8. PM_{10} emission rates along the test route on February 17, 2005



5.0 SUMMARY AND CONCLUSIONS

The data summarized in the previous section show that PM_{10} emission rates were generally near zero except when occasional “hot spots” were encountered. This is consistent with all of the previous data we have collected. Significantly higher emissions were observed during the first two days of testing compared to the second two. This conclusion was also supported by observations during the test run. This difference was likely due to Clark County DAQEM observation staff notifying the Enforcement Division.

Table 5-1 summarizes the data as overall average emission rates for each test run, for all data and for speed greater than 10mph. Note that the latter are somewhat greater than the former since low speed data often shows near zero emission rate. The table also shows the average emission rates measured during the summer of 2004. These values are somewhat higher as might be expected in this season, but the route was also somewhat different. It is significant that the 2005 values were similar to those measured in 2004, especially on the first two days of testing. This shows that the measurement method is capable of giving consistent results.

The results show that SCAMPER measurement system is useful for both quantitatively identifying PM_{10} “hot spots” and determining the overall emission rate from roadways. This route successfully created several anomalies that could be explained from an analysis of the 1-second data. A video camera would be a useful addition to the SCAMPER system in order that situations where large changes in PM_{10} emission rates occur could be visually reviewed.

Table 5-1 Summary of average emission rate data

Date	Average PM10 Emission Rate (>10mph), mg/m	Average PM10 Emission Rate (all), mg/m
2/14/2005	0.086	0.060
2/15/2005	0.105	0.087
2/16/2005	0.040	0.027
2/17/2005	0.012	0.010
6/30/2004		0.167
6/30/2004		0.130

Although it is beyond the scope of this project to compare the results with those obtained from DRI, we would like to point out several precautions if this is done. First, it is that both data sets have many periods where GPS data is not available due to lack of satellite signals. A further complication is that the DRI time series has skips in time when the GPS data are missing, while our time series is contiguous. To align the time, it would be necessary to add rows to the DRI data so that we could compare time series directly. Another complication is that DRI deletes data for speeds less than 10 mph. We have done this in one worksheet of our final data, but the locations will be somewhat different.

Probably the most useful comparison, due to the variability of “hot spots”, would be an average emission rate during selected segments of travel where all data are available.

6.0 REFERENCES

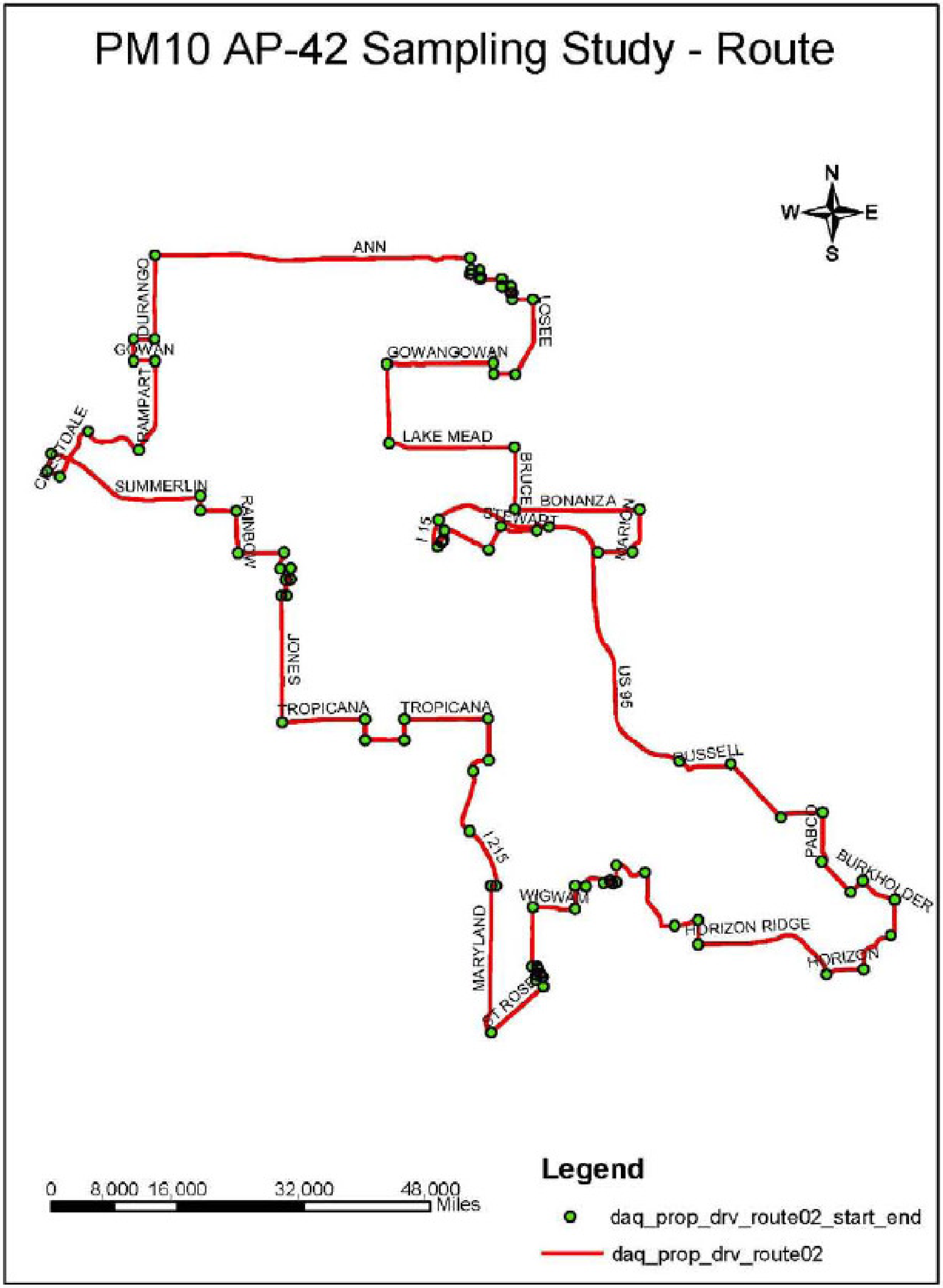
Fitz, D.R. Measurements of PM_{10} and $PM_{2.5}$ emission factors from paved roads in California. Final Report to the California Air Resources Board under Contract 98-723, June 2001.

Fitz, D.R.and C. Bufalino. 2002. Measurement of PM_{10} emission factors from paved roads using on-board particle sensors. Air and Waste Management Association Symposium on Air Quality Measurement Methods and Technology – 2002. San Francisco, CA November 13-15.

Etyemezian, V., Kuhns, H., Gilles, J. Green, M., Ptchford, M., and Watson, J. (2003) Vehicle-based road dust emission measurement: I-methods and calibration. *Atmos. Environ.* **37,** 4559-4571.

APPENDIX A

Test Route


PM10 AP-42 Sampling Study - Route
N
W
E
S
ANN
DURANGO
GOWAN
RAMPART
LOSEE
GOWANGOWAN
CLIFFDALE
LAKE MEAD
SUMMERLIN
BRUCE
BONANZA
RAINBOW
STEWART
I 15
MARION
JONES
US 95
TROPICANA
TROPICANA
RUSSELL
PABCO
I 215
BURKHOLDER
WIGWAM
HORIZON RIDGE
HORIZON
MARYLAND
ST ROSE
0
8,000
16,000
32,000
48,000
Miles
Legend
● daq_prop_drv_route02_start_end
daq_prop_drv_route02

Appendix C

2. UNIVERSITY OF NEVADA, SYSTEM OF HIGHER EDUCATION - DESERT RESEARCH INSTITUTE (DRI)

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FINAL REPORT
JULY 15, 2005

The Las Vegas Road Dust Emissions Technology Assessment Phase II Final Report:

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1. Executive Summary

As part of a study sponsored by the Clark County, Nevada, Department of Air Quality and Environmental Management (DAQEM), the Desert Research Institute was contracted to demonstrate a relatively novel method for measurement of PM10 road dust emissions in the Las Vegas Valley. The intent of the study was to assess the state of vehicle-based technologies for measurement of road dust emissions as a possible alternative to inferring emissions from silt measurements. In addition to the DRI-developed TRAKER (Testing Re-entrained Aerosol Kinetic Emissions from Roads), the DAQM contracted the University of California in Riverside (UCR) to demonstrate a technology that is similar in concept, but that differs in measurement configuration. The first phase of this study was completed in June and July, 2004. This report summarizes the results of the second phase of the study performed in Clark County in February, 2005.

A set of roads with a combined length of 170 km was pre-selected for the purpose of PM10 road dust emission measurement. The “loop” formed by these roads covered a variety of street types including freeway, arterial, collector, and local roads from several geographic locations within the Las Vegas Valley. The loop was traversed by the TRAKER and UCR measurement systems on 4 consecutive days (2/14/05 – 2/17/05). The DAQEM, through a third party, procured silt samples at locations that were coincident with the selected loop in order to compare the silt loading method against the vehicle-based methods tested as part of this study.

TRAKER measurements were processed and data points that did not meet a set of criteria that were imposed on the speed, acceleration, and wheel angle of the vehicle were invalidated. While individual, 1-second data points were provided to DAQEM, for the purposes of data analysis, it was more instructive to average TRAKER measurements over links in the Clark County Traffic Demand Model. Overall, analysis showed that PM10 emission factors were generally higher for low speed roads such as residential streets than high speed roads such as freeways.

The DRI TRAKER and CE_CERT SCAMPER results were compared on a road segment and daily average basis. When emission factors for individual road segments were averaged over all 4 days, regression of TRAKER vs SCAMPER emission factors showed a positive correlation (R2 = 0.45 with intercept, R2 = 0.30 with intercept forced to zero). On average, the ratio of SCAMPER PM10 emission factors to TRAKER factors was 0.25. However, this ratio was quite variable, when considered on a day-to-day basis. Scatter plots of road segment-averaged emission factors for a given day vs the average for all four days showed that of the two measurement platforms, the TRAKER has considerably higher signal to noise ratios on the spatial scale of a road segment. It was hypothesized that this may be due to the greater range of PM10 road dust concentrations measured by the TRAKER behind the front tires compared to those measured by the SCAMPER in the wake of the test vehicle.

2. Introduction

Dust emissions originating from motor vehicle travel on paved and unpaved roads constitute a significant fraction of the PM10 (particulate airborne matter with aerodynamic diameter less than 10 microns) in many areas of the western United States (e.g. Watson and Chow, 2000). For the purposes of estimating emission inventories of PM10 road dust, the AP-42 (USEPA, 1999) guidance document suggests the possibility of using silt content and silt loading measurements to estimate emissions from unpaved and paved roads, respectively. Silt measurements are time consuming and frequently require the alteration of roadway traffic patterns while samples are being procured. The Clark County, Nevada Department of Air Quality and Environmental Management (DAQEM) has sought to investigate alternative methods for estimating paved and unpaved road dust PM10 emissions. As part of this study, DAQEM contracted the Desert Research Institute (DRI) and the University of California in Riverside (UCR) to demonstrate two similar but separate technologies for vehicle-based, real-time road dust emission measurement methods. The first phase of the study was completed in the summer of 2004 (Etyemezian et al., 2004). This report summarizes the methods and results during the second phase of the study, completed in February of 2005. The methods and results obtained with the DRI technology are discussed and a comparison of DRI and UCR measurement methods is provided. A separate report (Fitz, 2005) summarizes the complete results using the UCR system.

Following background information in Section 3, Experimental Methods are summarized in Section 4. The results obtained by TRAKER and comparison with data obtained by the SCAMPER are discussed in Section 5.

2.1. Statement of Objectives

The objective of this study was to measure PM10 paved road dust emissions over a series of contiguous roads in the Las Vegas Valley that constitute a closed loop. The purpose of this work was to provide DAQEM with hands-on experience with the nature of the measurement method (TRAKER) and to collect data that would be directly comparable to measurements made by a similar system developed by the University of California, Riverside.

3. Background

Inhalable dust emissions from paved and unpaved roads are frequently estimated by measuring airborne concentrations of PM10 upwind and downwind of a road (Cowherd et al., 1984; Gillies et al., 1999). Combined with measurements of wind speed and direction, the differences between the downwind and upwind concentrations can be used to estimate the horizontal flux of PM10 dust across the plane that is parallel to the road and perpendicular to the ground. The horizontal flux can in turn be translated into an emission factor. The emission factor is an estimate of the amount of PM emissions that result from incremental levels of a certain activity and, in the case of road dust, is expressed as the mass of particles in a given size range emitted as a result of a unit of vehicle travel (e.g., grams per vehicle kilometers traveled or g/vkt).

The upwind/downwind technique is not practicable for measurement of emission factors on the scale of an entire airshed because of the costs involved. A more common practice is to measure a surrogate for emission factors. In the AP-42 guidance document (USEPA, 1999), the USEPA suggests the procurement of loose debris from roads by vacuuming and subsequently analyzing the vacuumed material for silt content. Silt, in this case, is defined operationally as the portion of material that passes through a 200 mesh sieve, corresponding roughly to particles having geometric diameters less than 75 microns. For paved roads, the loading of silt on a per unit area basis (g/m2) is used to infer emission factors:

$$EF_{10} = c\,(sL)^{0.65}(W)^{1.5} \tag{1}$$

where *c* is the paved road dust emission factor multiplier for PM_{10} (0.56 g/vkt), *sL* is the silt loading of the surface material (g/m^2), and *W* is the mean vehicle weight (Mg).

alternative to silt measurements. The TRAKER (Testing Re-entrained Aerosol Kinetic Emissions from Roads) is a cargo van that measures road dust emission potential by utilizing three inlets, two that are behind each of the front tires and one that extends through the front bumper in front of the vehicle. As the TRAKER is driven on a road, air that is laden with particles suspended behind the front tires and background air sampled ahead of the front bumper are channeled to nephelometer-style instruments (TSI, DustTrak model 5820) located inside the vehicle. The instruments record PM_{10} concentrations in one-second intervals. An onboard GPS logs the location of each one-second measurement as well as other parameters such as the speed, acceleration, and heading of the TRAKER. The background-corrected concentration behind the tire varies with speed so that:

$$T = T_T - T_B = as_T^h \tag{2}$$

where *T* is the background-corrected TRAKER signal (mg/m^3), T_T is the PM_{10} concentration measured behind the tire (mg/m^3), T_B is the PM10 concentration measured ahead of the front bumper (mg/m^3), s_T is the speed of the TRAKER (m/s), and *a* and *b* are fitted constants. Both T_T and T_B represent concentrations (measured with DustTraks) that are corrected for particle losses within the TRAKER inlet lines. Based on tests conducted in the Treasure Valley and at the Ft. Bliss military installation near El Paso, TX, Etyemezian et al. (2003a) report that for paved roads the value of b is approximately equal to 3. The value of *a* is specific to the road measured and can be calculated from the speed of the TRAKER at the time of the measurement and knowledge of T_T and T_B.

Using the TRAKER van as a test vehicle on an unpaved road and simultaneously measuring the horizontal flux of PM_{10} with upwind/downwind towers, Etyemezian et al. (2003a) found that the PM_{10} horizontal flux was proportional to the speed of travel. This result was reinforced by a similar relationship for other vehicles examined during the same field campaign and also in the work of Sehmel et al. (1973). In summary, the equations that relate the TRAKER signal to emissions are:

$$T = as_T^3 \tag{3}$$

$$EF_T = lT^{1/3} \tag{4}$$

$$\theta_T = EF_T / s_T \tag{5}$$

where EF is the emission factor (g/vkt), θ is the emission potential ([g/vkt]/[m/s]), and k is the constant that relates emissions to the TRAKER signal and is approximately 0.33 (σ_g=1.5). The subscript T indicates that the parameter is specific to the TRAKER vehicle (i.e., a 1979 Chevy van). Using Equation (5) to define the emission potential, θ_T, and rearranging Equations (3) and (4) gives:

$$\theta_T = k \bullet a^{1/3} \tag{6}$$

Thus, the emission potential is dependent only on the parameter a, which is related directly to the "dirtiness" of the road – in terms of its potential to emit PM10 dust when a vehicle passes.

A number of authors (Watson and Chow, 2000; Watson et al., 2000; Venkatram, 2000; Countess, 2001) have pointed out that horizontal fluxes measured with the upwind/downwind technique may overestimate the mass of PM_{10} that is actually available for transport over long distances. That is, some of the PM, especially the fraction associated with coarse particles, may deposit within one kilometer or so of the source by particle impaction or settling. It follows, that methods based on the upwind/downwind technique, such as silt measurement and TRAKER, are subject to the same concerns.

4. Methods

The field study was designed to assess the abilities of the TRAKER and the UCR measurement systems to measure road dust emissions over a wide range of paved road types in Clark County Nevada. A prescribed route was followed by both the DRI and UCR teams on four consecutive days (2/14/05 – 2/17/05).

4.1. Time and location of measurements

The route prescribed for the road dust measurement is detailed in Appendix A and a map of the route can be seen in Figure 1. The total length of the route was 104 miles (~170 km). The loop shown in Figure 1 was generally traversed in a clockwise fashion, starting at the Clark County building near the intersection of Charleston and I-15, traversing southeast on the 95 freeway, continuing through Henderson to the I-215 followed by the I-15 freeways, exiting westbound on Tropicana, traversing through the northwest sections of the Valley and finally returning eastbound towards North Las Vegas prior to returning to the Clark County offices.

The TRAKER and SCAMPER followed one another closely with the two vehicles alternating the lead position. Therefore, measurements completed with TRAKER during this study are directly comparable to those obtained with the UCR SCAMPER system.

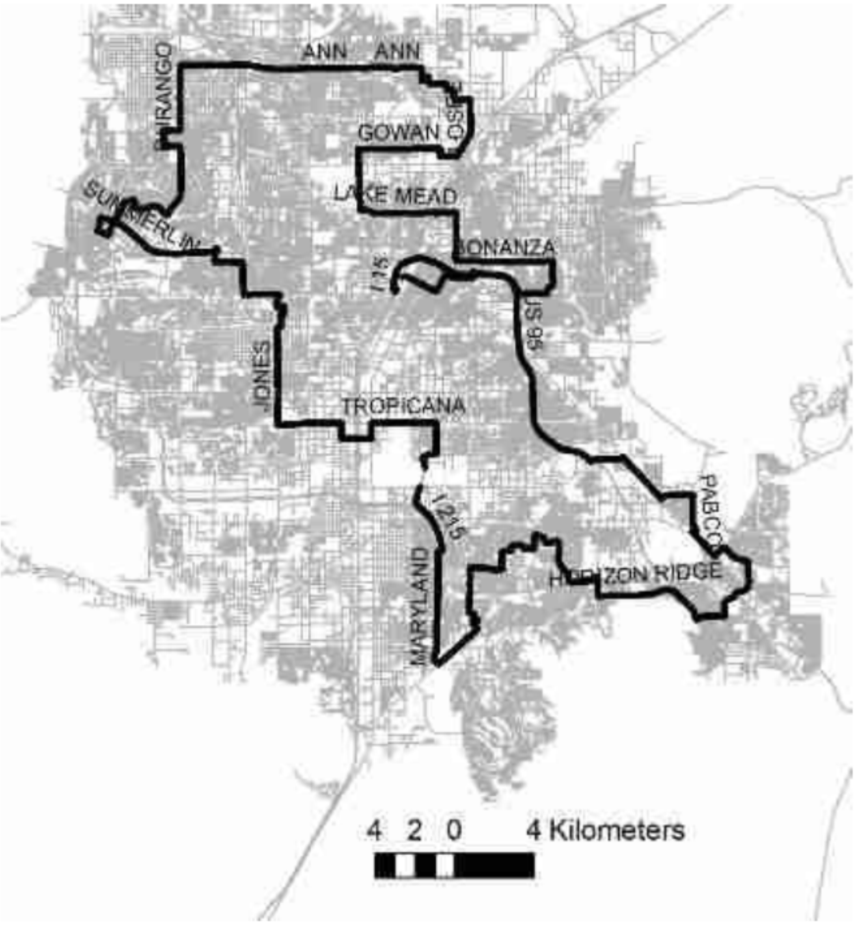


Figure 1. Map of Clark County road dust measurement loop for 2/14/05 – 2/17/05 sampling period

4.2. TRAKER Measurements

The TRAKER system was first used in Las Vegas to survey road dust on over 100 miles of paved roads (Kuhns et al., 1999). The principle behind the TRAKER is illustrated in Figure 2. The concentration of airborne particles is monitored through inlets that are mounted near the front tires of a vehicle. These particle sensors are influenced by the road dust generated from the spinning of a tire. A background measurement of particle concentrations is obtained simultaneously at a location on the vehicle farther away from the tires. The difference in the signals between the influence monitors and the background monitor is related to the amount of road dust generated:

$$T = T_T - T_b$$

where T is the raw TRAKER signal, T_T is the particle concentration measured behind the tire, and T_B is the background concentration.

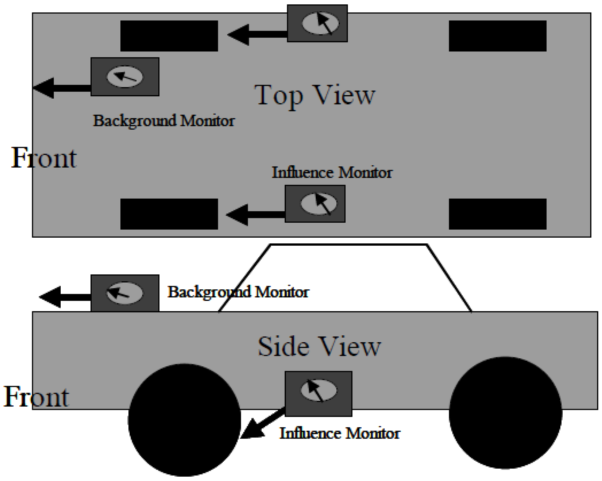


Figure 2. TRAKER influence monitors measure the concentration of particles behind the tires. A background monitor is used to establish a baseline.

The TRAKER is composed of a van that has been equipped with three exterior steel pipes acting as inlets for the onboard instruments (Figure 3a). Two of the pipes are located behind the left and right front tires and are used to measure emissions from the tires. The third pipe runs along the centerline of the van underneath the body and extends through the front bumper. This pipe is the inlet for background air. Dust and exhaust emissions from other vehicles on the road can cause fluctuations in the particle concentration above the road surface. The background measurement is used to correct the measurements behind the tires for those fluctuations.

The three exterior pipes enter the cargo compartment of the van through the underbody. Each pipe then goes into a plenum/manifold; the plenum can be used to distribute the sample air to up to five instruments (Figure 3c). For the present study, two TSI DustTraks with 10 µm inlets were operated in parallel at each of the left and right inlet lines. A single DustTrak with a PM10 inlet was operated on the middle inlet line. A central computer collected all the data generated by the onboard instruments (Figure 3d). Data from TRAKER measurements were imported into a Microsoft Access database for subsequent data processing and analysis.

4.2.1. Inlets

Unlike gases, particles have inertia; as a result, the sampling of particles through an inlet results in some particle losses to inlet surfaces. These losses could be due to the diffusion of particles toward inlet walls or the impaction/settling of particles upon inlet walls. Diffusion is a phenomenon that governs the motion of very small particles (less than 0.1 µm). Since road dust is composed primarily of larger particles (greater than 0.3 µm), diffusion is not an important consideration for TRAKER. Impaction and gravitational settling, however, are important processes for sampling particles with aerodynamic diameters greater than 1 µm. Gravitational settling can be minimized by reducing the amount of time a particle spends in the inlet lines (e.g., by increasing the speed of the flow). On the other hand, particle impaction can be minimized by reducing the speed of the flow turns within the inlet lines.

The inlet lines, visible in Figure 3a, are 19 mm (3/4”) in diameter and 2.3 m (7.5’) long for the tire lines and 3.7 m (12’) long for the background line. The influence inlets on the right and left are in slightly different positions with respect to the tires. On the right, the inlet is 165 mm (6.5”) above the ground, 50 mm (2”) behind the tire, and 63 mm (2.5”) in (toward the center of the vehicle) from the outside edge of the tire. On the left, the inlet is 165 mm (6.5”) above the ground, 63 mm (2.5”) behind the tire, and 63 mm (2.5”) in from the outside edge of the tire. Because of the vehicle’s configuration, it is not possible to avoid bends in the inlet lines. However, the bends have been kept as shallow as possible in order to minimize losses of particles to the inlet walls. Each of the inlet lines feeds into a 600 mm (20”) long torpedo-shaped plenum (Figure 2-11c). All particle sampling instruments are connected through the plenum via short Tygon tubes that are in turn attached to 200 mm (8”) long steel tubes that extend into the body of the plenum. Flowrates through the inlets are 75 liters per minute (lpm), corresponding to an inlet face velocity of 4 meters per s (mps) and 0.3 mps in the plena.

4.2.2. Instruments Used Onboard TRAKER

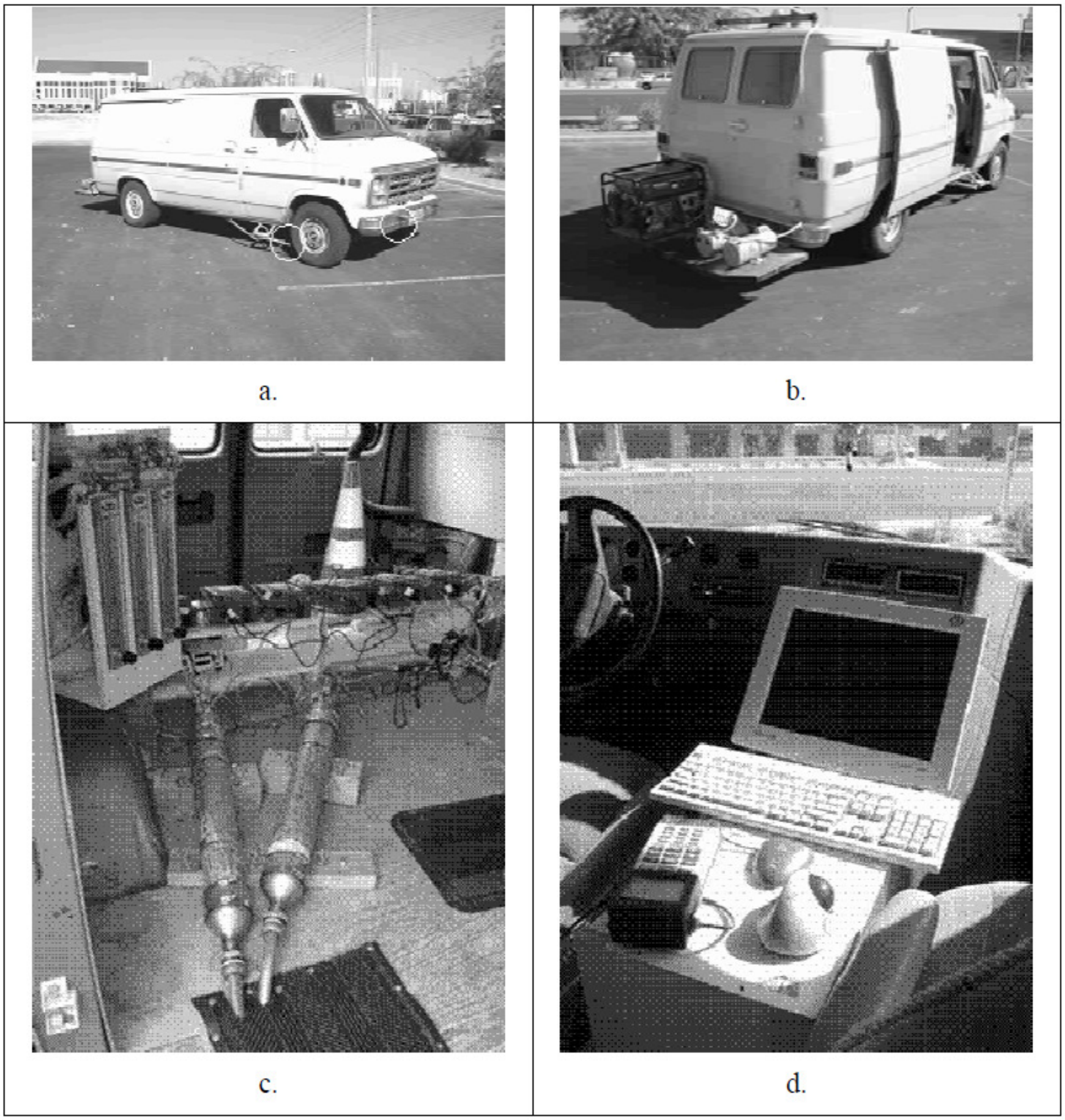
4.2.2.1. TSI DustTraks

The DustTrak is a rugged portable instrument that uses particle light scattering to infer PM concentrations. The DustTrak was chosen because it operates over a wide range of particle concentrations spanning 0.001 mg/m3 to 100 mg/m3 and provides the fast-response measurements (1 Hz) needed to detect individual road dust plumes. The flowrate at the instrument inlet is 1.7 lpm and for the data presented here, the instrument has been equipped with a nominal PM10 inlet provided by the manufacturer. The instrument is calibrated by the manufacturer using the respirable fraction of an Arizona Road Dust standard (ISO 12103-1, A1) to relate light scattering intensity at 90° with respect to the incident laser light to aerosol mass concentrations in mg/m3. The ISO 12103-1, A1 standard consists of primarily silica particles (>70%) that are provided with some particle size specifications. By volume, the standard consists of 1-3% particles with diameters less than 1 µm, 36-44 % less than 4 µm, 83-88% less than 7 µm, and 97-100% less than 10 µm.

Niu et al. (2002) found that in comparing data from four DustTraks collocated in an indoor environment, the inter-instrument variability was a reasonable 3%. Several authors have also reported that DustTrak measurements correlate well with filter-based measurements of diesel exhaust (moosmuller et al., 2001), ambient urban particulate matter (Chung et al., 2001), and indoor airborne particles (Niu et al., 2002), though in all cases, investigators noted that the DustTrak deviated from filter-based measurements by a factor that depends on the nature of the aerosol measured. One shortcoming of using a nephelometer style instrument is that light scattering response to changes in mass concentration can depend strongly on particle composition as well as particle size. Based on manufacturer specifications, for the DustTrak, the greatest change in light scattering per unit mass for silica aerosols occurs for particles with a diameter of around 0.4 µm. The instrument is less sensitive to changes in mass concentration of smaller or larger particles. For 10 µm particles, light scattering sensitivity to changes in mass concentration is approximately a factor of 50 less than 0.4 µm particles. This suggests that two different values measured by the DustTrak may not necessarily translate into proportional differences in actual PM10 mass concentration, especially if the two measurements represent airborne particles that are either substantially different in composition or in particle size distribution.

4.2.2.2. Ashtech Promark GPS

The TRAKER uses an onboard GPS (Ashtech, Promark) to relate road dust emission measurements to a specific position on the road network. The accuracy of the GPS signal varies between 3 m and 15 m depending on the access. All data obtained from the mobile GPS used in this study were logged to a central TRAKER computer every 1 s.


a. b. c. d.

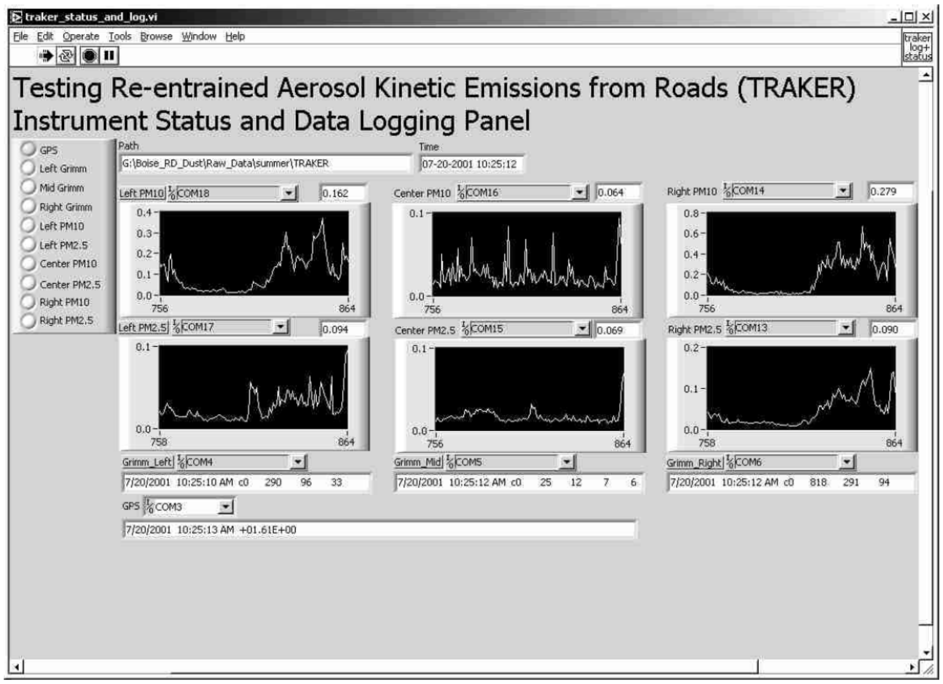
); b) Generator and pumps mounted on a platform on the back of the van; c) Two sampling plenums (bottom), a suite of DustTrak particle monitors (top right), and three rotameters used for ensuring proper flows through plena; and d) a dashboard-mounted computer screen used to view the data stream and a GPS to log the TRAKER's position every 1 s.

4.2.3. Data Acquisition and Measurement Documentation

The TRAKER may utilize up to 10 instruments (six DustTraks, three PSAs, and one GPS), with each generating data at a rate of up to 60 readings per minute. A central onboard computer is used to capture the data in real time. Data from individual instruments are transferred via RS-232 serial interfaces to a multiplexing unit that is in turn connected to the computer. Specialized software has been written to capture the data, use the computer clock to provide a common time stamp, write to a database in real time, and provide the operator(s) with feedback regarding the status of instruments. An example of the TRAKER display panel is shown in Figure 4.

4.2.4. Data Quality

The DustTrak instrumentation onboard the TRAKER vehicle has a resolution of 1 µg/m^3. Thus, the smallest measurable difference in concentration between the tire and the background monitors is 1 µg/m^3. This corresponds approximately to a single-point minimum detection limit equivalent to an emission factor of 0.9 g/VKT for unpaved roads (or 0.04 g/VKT for paved roads), meaning that any 1 s measurement can be resolved to within this value only. Substantially smaller emission factors can be measured with the TRAKER if multiple data points are used to calculate an average. At the other end of the measurement range, DustTrak readings above 150 mg/m^3 are not reliable. This corresponds to an emission factor for PM$_{10}$ of approximately 50 g/VKT.



Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER)
Instrument Status and Data Logging Panel

Path: G:\Boise_RD_Dust\Raw_Data\summer\TRAKER
Time: 07-20-2001 10:25:12

Left PM10: COM18 0.162
Center PM10: COM16 0.064
Right PM10: COM14 0.279
Left PM2.5: COM17 0.094
Center PM2.5: COM15 0.069
Right PM2.5: COM13 0.090

Grimm_Left: COM4
7/20/2001 10:25:10 AM c0 290 96 33
Grimm_Mid: COM5
7/20/2001 10:25:12 AM c0 25 12 7 6
Grimm_Right: COM6
7/20/2001 10:25:12 AM c0 818 291 94
GPS: COM3
7/20/2001 10:25:13 AM +01.61E+00

Figure 4. TRAKER Control Panel. Real-time figures show the magnitude of the response of DustTraks. The 10 lights atthe top left of the screen serve as indicators of the health of onboard instruments (green = OK; red = not functioning).

Figure 5 shows the TRAKER coefficient of variation calculated from the left and right PM$_{10}$ DustTrak signals as a function of vehicle speed. The coefficient of variation is a measure of the relative precision and is equal to the standard deviation of the measurement divided by the average of the measurement. In the figure, the measurement corresponds to multiple passes on the same 1-mile stretch of road (Etyemezian et al., 2003). The figure shows that the precision of the measurement improves with increasing vehicle speed. The precision is 84% at 5 m/s, 30% at 9 m/s, and approximately 10% above 14 mps. Note that most TRAKER measurements occur at speeds greater than 9 m/s (approximately 20 mph). The poor precision at low speeds is probably due to the influence of fluctuating ambient winds on the flow regime behind the front tires. As the vehicle speed increases, such fluctuations become less important compared to the speed of the vehicle.

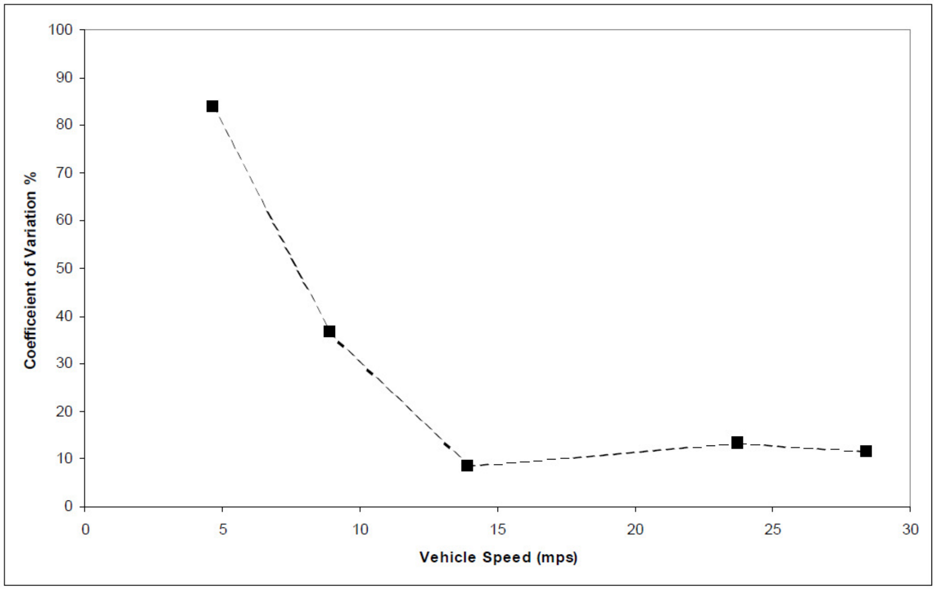


Figure 1. TRAKER coefficient of variation expressed as a percentage for left and right PM_{10} DustTrak signals as a function of speed. The data represent left and right PM_{10} DustTrak signals averaged over a 1- mile stretch of road near Boise, Idaho (Etyemezian et al., 2003). The coefficient of variation provides an estimate of the precision and is equal to the standard deviation of a measurement divided by the average.

The vehicle speed can become important in moderate to high winds. If the TRAKER is not moving fast enough, crosswinds and fluctuations in the ambient winds can lead to unsteady flow conditions between the front tire and the inlet. To avoid this possibility, a minimum speed of 5 m/s is required to consider a data point valid. Acceleration/deceleration criteria (<0.7 m/s2) are also applied to the TRAKER measurement. During periods of high acceleration, the flow regime around the inlets may be transient; during periods of deceleration, dust from the brakes may influence the particle concentrations behind the front tire. Note that in the prior work of Etyemezian et al. (2003a, 2003b) and Kuhns et al. (2001) the criterion for acceleration was 0.5 m/s^2. Due to the start and stop nature of the loop selected for the present study, that criterion had to be relaxed slightly in order to avoid losing much of the data collected. This relaxation of the criterion should not affect the measurement significantly since the original criterion was set to be overly conservative.

In addition, the wheel angle must be less than 3 degrees with respect to the vehicle body. This is to ensure that the orientation of the inlets with respect to the front tires is not changing over the course of the measurements. The criteria shown in Table 1 are based on empirical observations and statistical analyses of the TRAKER measurement under a variety of driving regimes. They are conservative and intended to ensure that the measurements used in this study are valid.

Table 1. Validity criteria applied to each 1 s TRAKER data point.

Parameter	Criterion	Threshold	Description
Speed	>	5 m/s – paved roads (~11 miles/hr)	Minimize disturbances due to ambient winds.
Acceleration	<	0.7 m/s^2 (~1.3 miles/hr/s)	Lateral shear during acceleration and transient airflow around the TRAKER inlets render TRAKER measurements during times of high acceleration unreliable.
Deceleration	<	0.7 m/s2 (~1.3 miles/hr/s)	Applying the brakes releases dust particles and may result in false high road dust readings.
Wheel Angle	<	3 degrees with respect to the vehicle body	Turns cause the front wheels to form an angle with the vehicle body. This in turn changes the orientation of the TRAKER inlets with respect to the front tires. Data associated with sharp turns are not valid.

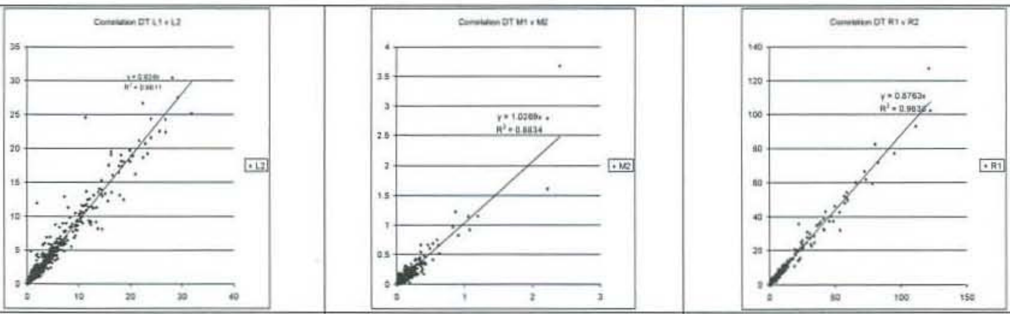
4.2.5. Data QA/QC and Reduction

4.2.5.1. DustTrak zero, flow check, and drift

Prior to the beginning of each sampling day, DustTrak monitors were zeroed with a HEPA filter and the flowrates through the instruments were adjusted to the manufacturer specification (1.7 liters/minute). The zero setting on the instrument is known to drift over the course of a sampling day, usually as a result of changes in ambient temperature that affect the response of the light scattering measurement. To account for this possibility, a HEPA filter was attached to the DustTrak inlets at the end of the sampling day and the reading from the instrument was recorded, providing an approximate estimate of the zero drift experience by each unit over the course of the day. In all cases, the zero drift never exceeded 4 µg/m3, which is considered negligible compared to the magnitudes of dust concentration measured during sampling (See Figure 6).

4.2.5.2. DustTrak Instrument inter-comparison

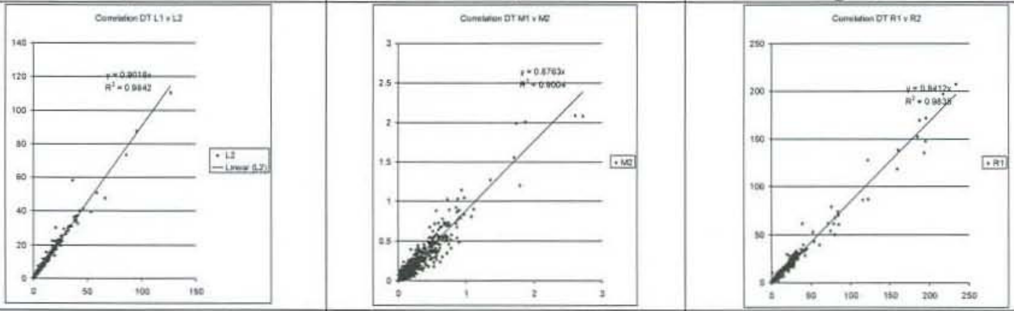
Because the DustTrak is a nephelometer based instrument that uses an internal calibration to infer PM_{10} mass concentrations, the instrument requires recalibration by the manufacturer once every six months or so. All of the six DustTraks used in this study were previously unused and had been calibrated within the prior six months. Two collocated DustTraks were operated in each TRAKER inlet. Figure 6 shows the relationship between the collocated DustTraks at each inlet during each of the four sampling days. In general, excellent linearity was observed between the collocated instruments. In addition, on the first days of the study, 2/14/05, all participants collocated their DustTraks for an ambient measurement test at Sam Boyd Stadium. The PM_{10} concentrations measured by the DRI DustTraks are shown in Figure 7, where the vertical bars represent the standard error of the measurement. The six DustTraks show good agreement with one another within the uncertainty of the measurement.



a. Left, 2/14/05

b. Middle, 2/14/05

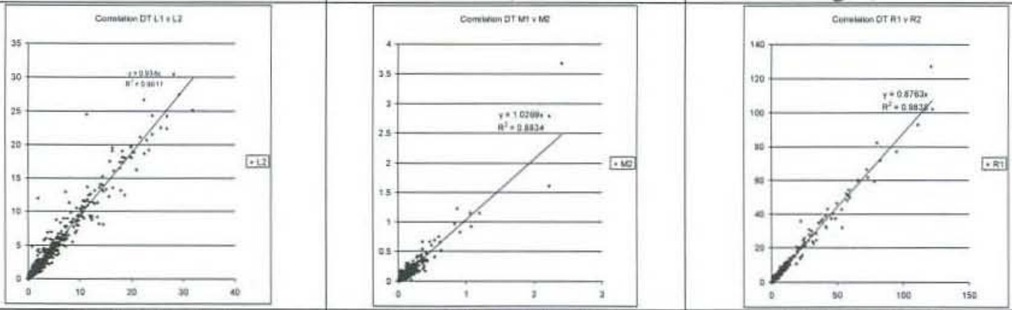
c. Right, 2/14/05



d. Left, 2/15/05

e. Middle, 2/15/05

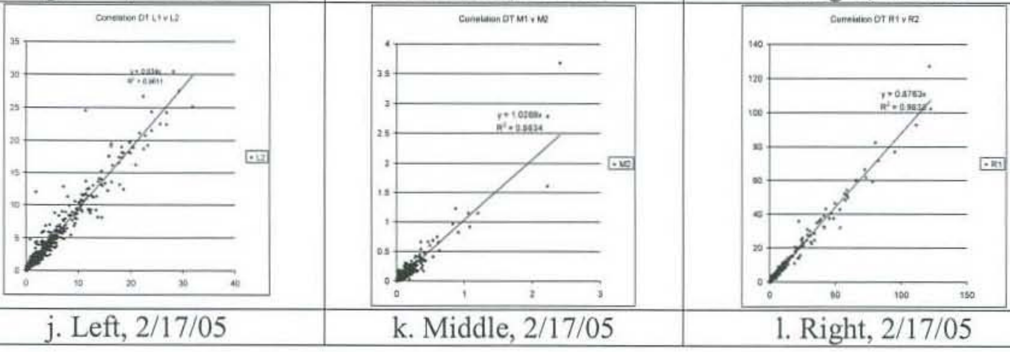
f. Right, 2/15/05



g. Left, 2/16/05

h. Middle, 2/16/05

i. Right, 2/16/05



j. Left, 2/17/05

k. Middle, 2/17/05

l. Right, 2/17/05

Figure I. Comparison of Collocated PM10 DustTrak Measurements on the left (a, d, g, and j), middle (b, e, h, and k) and right (c, f, i, l) inlets for each of the four sampling days from *2/14/05* to *2/17/05.* Units are in mg/m^3. Data obtained during measurements are several orders of magnitude higher than the zero drift experienced by the DustTrak instruments (< 4 μg/m^3) over the course of a sampling day.

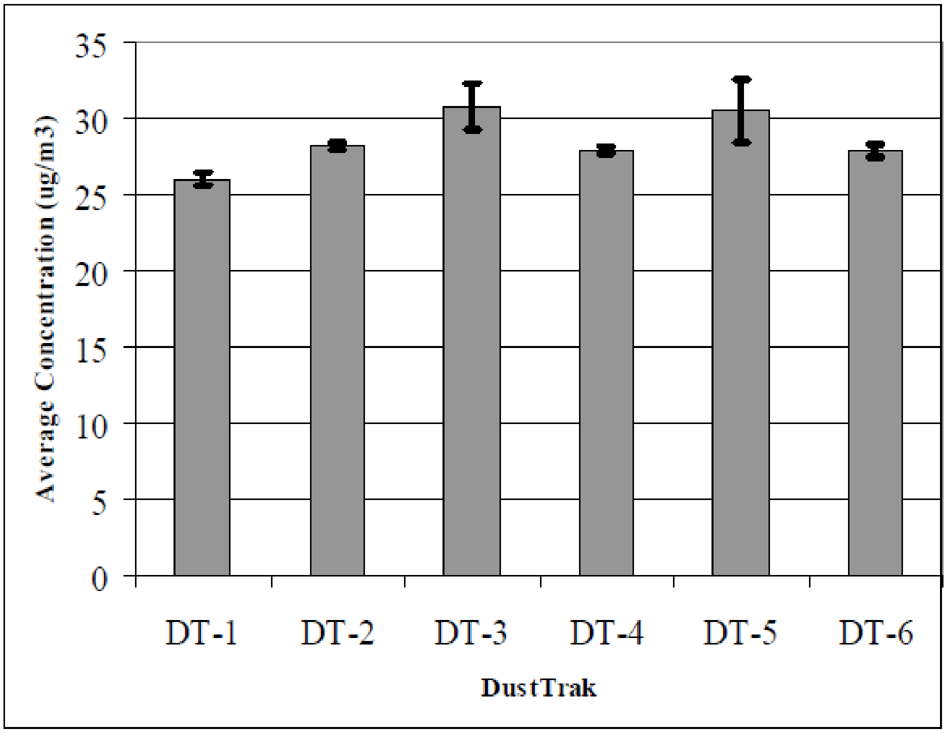


Figure 1. Results of collocation of the siz DRI DustTraks at Sam Boyd Stadium on 2/14/2005. Vertical bars represent standard errors over the 1,138 individual measurement points.

Comparison of TRAKER with Flux Towers

On 03/31/03, the TRAKER was operated in conjunction with a horizontal flux tower near Lake Tahoe. The TRAKER signal was compared with the flux of particles measured downwind of a road. The flux of particles past the tower was calculated only when the winds were blowing within 45 degrees of perpendicular of the road. Between 12:10 and 16:40, this criterion eliminated 10,300 of the 16,141 1 s measurements on the tower. The resultant winds for the period were from the southwest (222 degrees) at 1.6 m/s.

Over the same interval, the TRAKER vehicle made 45 (23 southbound and 22 northbound) passes in front of the instrumented tower. The average and standard deviation of the TRAKER vehicle speed over the 150 m before and after the tower was 20.1 m/s ± 0.1 m/s. For comparison, the average speed of all vehicles as measured by the road tube counter collocated with the flux tower was 21.1 m/s ± 0.3 m/s. The average and standard deviation of the TRAKER signal over the 45 passes was 0.748 mg/m^3 ± 0.415 mg/m^3.

The flux of PM_{10} normal to the road was calculated when winds were within the 45 degree criterion. The flux was then multiplied by the total number of seconds between 12:10 and 16:40 and divided by the number of valid measurements (i.e. 16,141/5841). This scaling factor was used to estimate the total flux over the time interval from the subset of valid flux measurements when the winds were within 45 degrees of perpendicular to the road. The total flux in units of mg/m over the period was divided by the total number of vehicles (1683) passing the tower to calculate an average fleet average PM_{10} emission factor of 0.305 g/vkt.

Prior to these measurements, the TRAKER vehicle had not been compared with directly measured paved road particulate matter (PM) emissions. Figure 8 below shows the average measured TRAKER signal versus the fleet average emission factors from 03/31/03. The points on the upper right of the figure were calculated from unpaved road experiments (Etyemezian et al., 2003; Kuhns et al., 2004). The paved road emission factor is lower than the unpaved road trend line by approximately a factor of 25.

The reason for this discrepancy is unknown. Hypotheses include:

- The traffic counter identified the fleet passing the flux tower as 98% light duty and 2% heavy duty vehicles. Recent field studies indicated that unpaved road dust emission factors increase linearly with both vehicle weight and vehicle speed (Gillies et al., 2004). Typical light duty vehicles have a mass of ~1.5 Mg (1 Mg = 1 metric ton) and heavy duty trucks have a mass of ~9 Mg. Based on these assumptions, the average mass of a vehicle passing the flux tower was ~1.6 Mg per vehicle, whereas TRAKER has a mass of ~3.1 Mg. If the relationship between emission factors (in g PM/vkt) and vehicle mass exists for paved roads as well as unpaved roads, then the fleet average emission factors should be lower than the TRAKER emission factor by a factor of 2 (i.e. 1.6 Mg/3.1 Mg). This would bring the LT emission factors more in line with the unpaved road measurements.
- Material suspended from unpaved roads may be entrained by the wake of the vehicle. If this is not occurring on paved roads, the flux of particles downwind of the roadway may be less.

The Lake Tahoe emission factor is the only comparison of the TRAKER signal with a paved road emission factor. In this study, TRAKER exclusively surveyed paved roads. Based only on the one calibration point collected at Sand Harbor, the revised equation relating the fleet average emission factors with the TRAKER signal is:

$$EF\left(\frac{g}{vkt}\right) = 0.33\left(T\left(\frac{mg}{m^3}\right)\right)^{0.33}$$

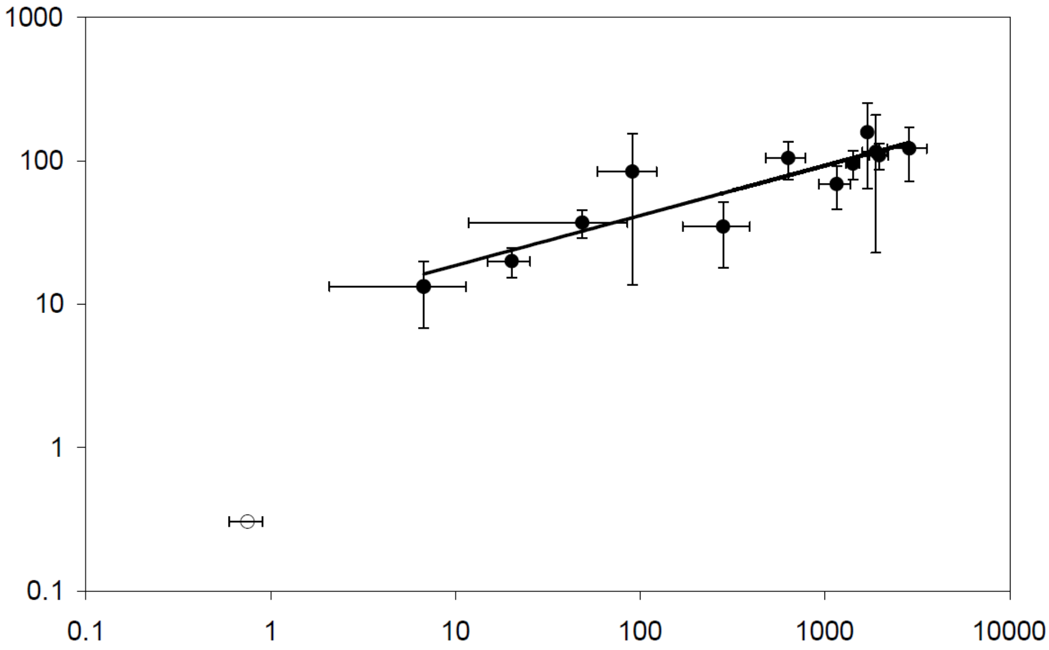


Figure 8. Regression of measured PM emission factors with TRAKER measurements. The line through points was drawn by holding the exponent of the regression equation at 1/3.

5. Results

Results from Phase II of the Road Dust Measurement Technology Assessment Study are given below. A description of the database provided to Clark County is given in 5.1. A summary of the results from the TRAKER measurements follows in 5.2. A comparison of measurement values and characteristics between the DRI TRAKER and the UCR SCAMPER is provided in Section 5.3

5.1. Presentation of Database Results

The TRAKER measurements from Phase II of the Clark County Road Dust Measurement Technology Assessment Study are provided in a separate Access database file. The Table "Exported_Valid_PHASE_II_TRAKER_Data" contains validated TRAKER data that have passed the criteria in Table 1. Applying the criteria from Table 1 results in 35,479 valid 1-second measurements over the two day period. Each valid TRAKER data point was associated with a road segment from a GIS street coverage of Clark County (Indicated by the "FID_1" field). This was done to allow for summary of emission characteristics by road segment and in order to facilitate comparison between TRAKER and SCAMPER in section 5.3. The TRAKER data table provided to Clark County as a deliverable of this study contains the following fields

DateTime
This field represents the time that the measurement was collected accurate to within one second of the time on the TRAKER on-board computer.

Format: Standard Microsoft Date/Time field # m/dd/yyyy hh:mm:ss #

Day
This field represents the date of the measurement and may be useful for separating data from the 6/30/04 and 7/1/04 sampling days.

Format: Standard Microsoft Date field # m/dd/yyyy #

Lat_dd
The latitude in decimal degrees N of the location of the measurement.

Format: Standard floating point

Lon_dd
The longitude in decimal degrees E ("-" means West) of the location of the measurement.

Format: Standard floating point

Height_m
Elevation at the location of measurement in meters above sea level.

Format: Standard floating point

PDOP
Point Dilution of Precision, a number indicating the accuracy of the GPS receiver coordinates at the time of the measurement. Values less than 2.00 are ideal, but values up to 9 are still usable.

Format: Standard floating point

Speed_ms
The speed of the TRAKER in meters per second at the time of the measurement

Format: Standard floating point

Acceleration_ms2
The scalar acceleration of the TRAKER at the time of the measurement.

Format: Standard floating point

Wheelangle_decdeg
The wheel angle of the TRAKER tire with respect to the vehicle body in decimal degrees.

Format: Standard floating point

EP

The emission potential corresponding to the TRAKER measurement. This is a measure of the inherent “dirtiness” of the road and is based on the TRAKER signal and the speed of travel at the time of the measurement. The units of emission potential are grams of PM10 emitted per vehicle kilometer traveled per meter per second of speed [g/vkt/(m/s)].

Format: Standard floating point

EF

The emission factor in grams of PM10 per vehicle kilometer traveled corresponding to the TRAKER measurement. The Emission Factor is equal to the Emission Potential multiplied by the vehicle speed. For the Las Vegas study, the speed of the TRAKER at the time of the measurement is used as a surrogate for the vehicle speeds on a given roadway. The units of emission factor are grams of PM10 emitted per vehicle kilometer traveled (g/vkt).

Format: Standard floating point

FID_1

An integer that uniquely identifies the road segment in the GIS street coverage that is associated with the measurement point.

Format: Long Integer

Datetime	Day	Lat_dd	Don_dd	Height_m	PDOP	Speed_ms	Accel_ms2	Wheelangle_decdeg	EP	EF	FID_1
2/14/2005 12:35:45	2/14/2005	36.16189529	-115.1564268	589.8	2.53	5.41	0.41	0.024	0.0698	0.3773	34687
2/14/2005 12:35:46	2/14/2005	36.161923	-115.1564849	589.9	2.53	5.83	0.44	0.188	0.0705	0.4114	34687
2/14/2005 12:35:47	2/14/2005	36.16195141	-115.156543	689.8	2.53	6.07	0.04	0.171	0.0707	0.4294	34687
2/14/2005 12:36:05	2/14/2005	36.16250636	-115.1563882	588.6	4.3	5.44	-0.02	0.074	0.0923	0.5024	34687
2/14/2005 12:36:06	2/14/2005	36.16254424	-115.1563499	588.7	4.3	5.43	0.00	0.331	0.0911	0.4953	34687
2/14/2005 12:36:07	2/14/2005	36.16258325	-115.1563115	588.6	4.3	5.49	0.10	0.240	0.0887	0.4863	34687
2/14/2005 12:36:10	2/14/2005	36.16266372	-115.1562322	588.4	4.29	5.71	0.10	0.046	0.0882	0.5037	34687
2/14/2005 12:36:11	2/14/2005	36.16274652	-115.1561507	588.2	4.29	5.88	0.09	0.209	0.0803	0.4716	34687
2/14/2005 12:36:12	2/14/2005	36.16278745	-115.156108	588.3	4.29	5.93	0.02	0.329	0.0748	0.4439	34687
2/14/2005 12:36:34	2/14/2005	36.16320916	-115.1560955	588.7	2.54	6.27	0.64	1.074	0.0914	0.5732	34687
2/14/2005 12:36:35	2/14/2005	36.16323706	-115.156165	588.8	2.54	6.78	0.36	0.412	0.1000	0.6773	34687
2/14/2005 12:36:36	2/14/2005	36.16326485	-115.1562336	589.0	2.54	6.92	-0.07	0.043	0.0933	0.6460	34687
2/14/2005 12:36:38	2/14/2005	36.16329107	-115.156298	588.9	2.54	6.68	-0.42	0.030	0.0822	0.5488	34687

Figure 9. Example data table for “Exported_Valid_PHASE_II_TRAKER_Data “

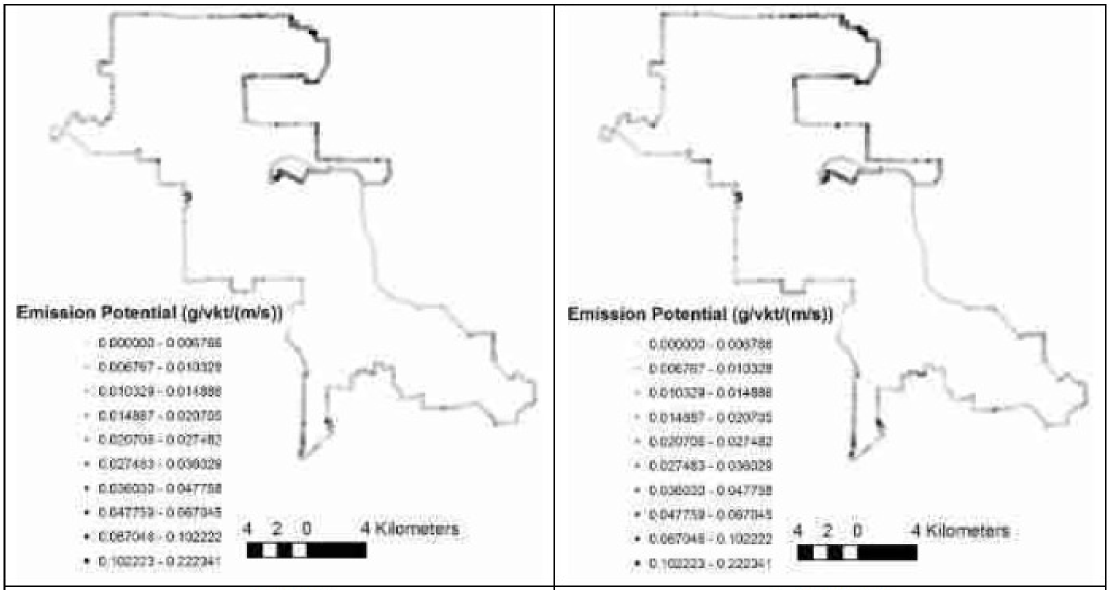
5.2. Summary of TRAKER Results

Figure 10 shows all valid TRAKER measurements of emission potentials obtained during Phase II of the Clark County study. Recall that the emission potential, θ, is a measure of the dirtiness of the road in [g PM_{10} /vkt/(m/s)]. To obtain the emission factor (g PM_{10} /vkt), the emission potential must be multiplied by the vehicle speed. Individual, one-second emission potentials and emission factors measured with the TRAKER exhibit an inherent variability for several reasons. First, the road surface is not homogeneous in the cross lane direction. Therefore, depending on where the vehicle tires are within a specific lane, emission potentials (and emission factors) may vary significantly. This is especially true for smaller, less frequently traveled roads where debris may accumulate near the curbs and gutters. A tire close to the curb would then result in greater dust emissions than a tire traveling close to the middle of the pavement, an area that is generally cleaner. Second, especially on long routes, it is usually difficult to remain in the same lane of traffic during multiple sampling periods and there may exist some variability in road dust emission potential because of differences of travel lane. The ability to capture such variability is an important advantage that vehicle-based road dust emission measurements have over silt loading techniques where the area vacuumed may not be representative of the area over which tires travel. By employing “natural driving” practice, vehicle-based technologies more accurately capture the actual PM_{10} road dust emissions that result from “real-world” driving.

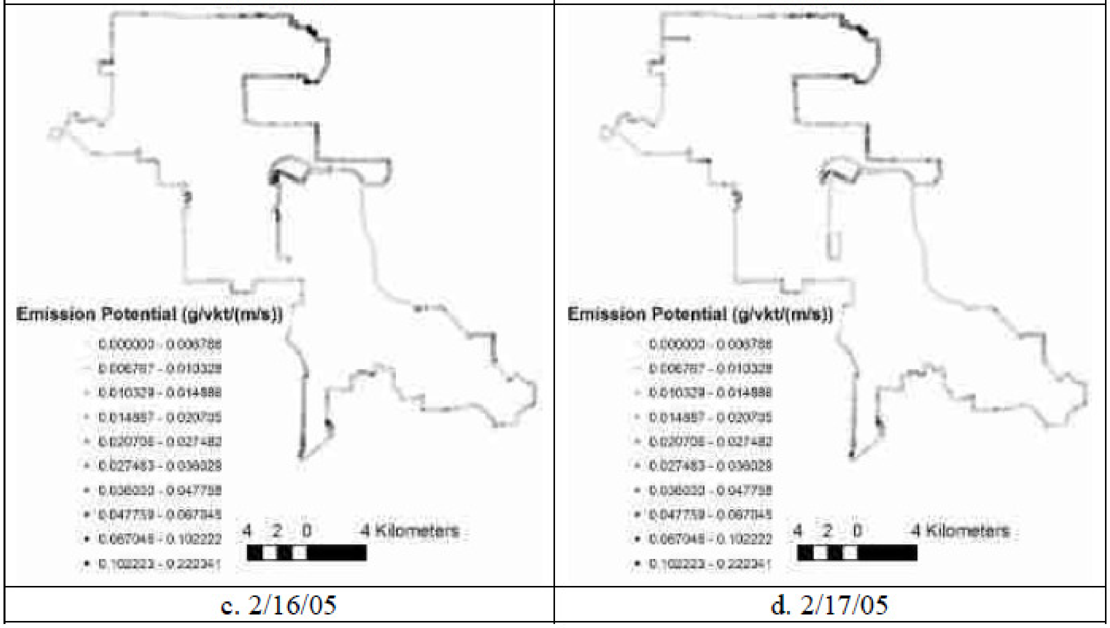
Nevertheless, such variability makes it difficult to compare one second measurements that are obtained on two separate days at the same location. Simply, there is too much noise in the data to allow for day to day, point to point comparison. One way to circumvent this difficulty is to average measurements over longer periods, or equivalently, over a comparatively long segment of road. Therefore, it is instructive to examine the spatial variability of the TRAKER measurement over predefined sections of the Las Vegas loop. The sections are provided by the 2003 traffic demand model (TDM) that is available from the Clark County Regional Transportation Commission web site. Clark County maintains a model of its roadway network, where individual sections of road are represented by “links” between nodes in the model. By averaging measurements obtained by the TRAKER over the corresponding links in the traffic demand model, it is possible to filter out much of the noise that is associated with individual point measurements.

In order to associate the TRAKER data with the Clark County TDM, each TRAKER data point was associated with a link in the TDM. Link-level values of emission potentials and emission factors were obtained by averaging those quantities for each data point associated with the specific link. In order to ensure that averages were statistically meaningful, a minimum of five data points was required per link. Links that had fewer than five data points associated with them were not considered.

Figure 11 shows the results of emission factors averaged over individual road segments visually (a.) and using a histogram (b.). The majority of road segments (~90%) have associated emission factors that fall between 0.1 and 0.3 g/vkt. The highest emission factors are exhibited by roads that fall in the northeast and southernmost portions of the test loop. These coincided with areas that were undergoing road and home construction.

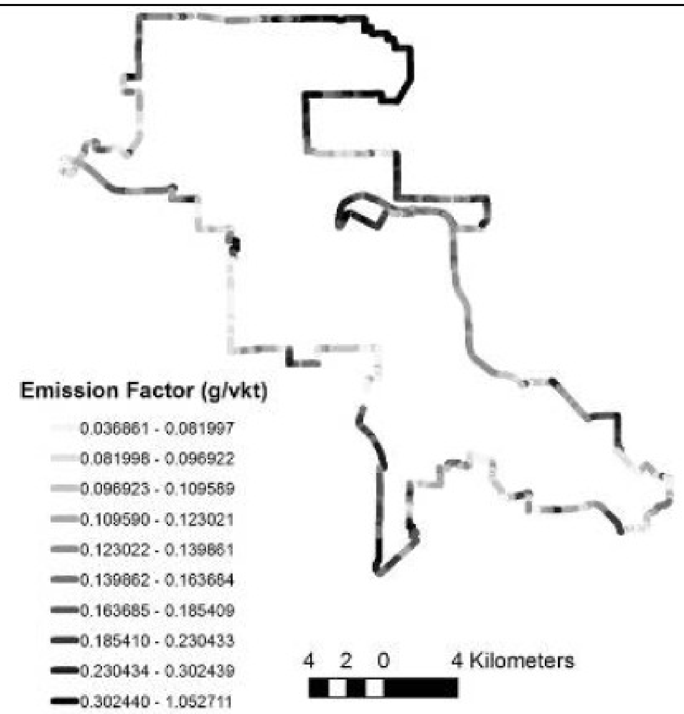


a. 2/14/05 b. 2/15/05

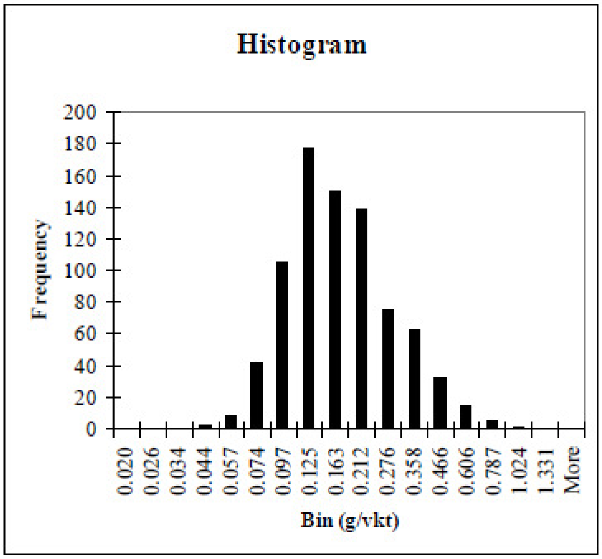


c. 2/16/05 d. 2/17/05

Figure 10. All valid TRAKER emission potential [g PM$_{10}$/vkt/(m/s)] measurements



a. Map of Emission Factors averaged over road segments as measured by TRAKER



b. Histogram of emission factors (g/vkt) averaged over all days for 820 individual road segments

Figure 2. Distribution of TRAKER measured emission factors over test loop summarized by road segment

Along with the prescribed driving route, Clark County DAQEM provided descriptive fields associated with each section of road traveled. Those fields were intended to delineate the road class (arterial, collector, freeway, local), presence/absence of construction, presence/absence of vacant lands, curbing/shouldering, and the number of travel lanes per direction. Using these descriptive fields, it was possible to segregate road characteristics and calculate emission factors for a specific set of conditions. Table 2 provides a summary of the effects of various road attributes on the emission factor. Note that for the construction and vacant land categories, the averages may be misleading because these attributes are not associated with a quantity. For example, it is expected that a larger number of construction sites along a segment would have a greater influence on emission factors. The data provided by Clark County DAQEM does not specify the extent of construction or the prevalence of vacant land along a specific segment. Thus, these data are presented here for completeness, but the authors do not recommend their use for any planning or calculation purpose.

Table 2. Effect of Road Segment Attributes on Emission factors based on 820 road segments

Class	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
Arterial	0.153	0.093	469	0.004
Collector	0.199	0.121	203	0.008
Freeway	0.166	0.054	107	0.005
Local	0.327	0.241	41	0.038
Lanes/direc	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
1	0.287	0.179	141	0.015
2	0.153	0.079	374	0.004
3	0.143	0.076	257	0.005
4	0.154	0.028	6	0.012
5	0.241	0.047	8	0.016
Constr	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
No	0.169	0.113	648	0.004
Yes	0.197	0.122	172	0.009
Vac lands	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
No	0.154	0.103	563	0.004
Yes	0.220	0.129	257	0.008
Curbs/shoulders	Average Emission Factor (g/vkt)	Standard Deviation (g/vkt)	# of Road Segments	Standard Error (g/vkt)
No/No	0.572		1	
No/Yes	0.208	0.139	115	0.013
Yes/No	0.158	0.109	533	0.005
Yes/Yes	0.204	0.105	171	0.008

The data in Table 2 are consistent with the prior work of Etyemezian et al (2003) in that heavily traveled roads such as freeways and arterials tend to exhibit lower PM_{10} emission factors than roads with lower traffic volumes such as collectors and local roads. The table also suggests that the presence of curbs and shoulders reduces PM10 emission factors. The lowest emission factors were found for roads that were curbed, but not shouldered. We note however that this may be a consequence of a correlation between such roads and traffic volume. Of the 533 road segments that have curbs, but no shoulders, 375 are arterials, which tend to exhibit lower emission factors than other road types.

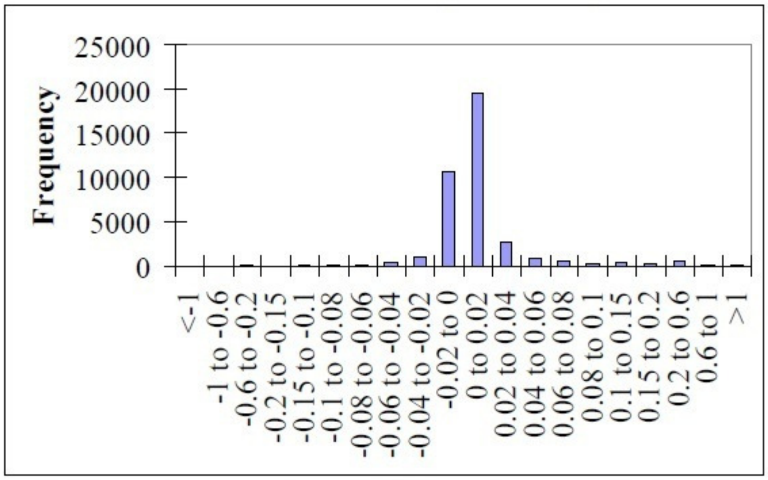
5.3. Comparison between DRI TRAKER and UCR SCAMPER Measurements and Characteristics

The major difference between the TRAKER and SCAMPER systems is that the SCAMPER measures the amount of road dust entrained by the test vehicle in the wake of the vehicle while the TRAKER measures the road dust entrained behind the front tires. Thus, the SCAMPER uses first principles and some simplifying assumptions to estimate road dust emission factors while the TRAKER requires that the signal measured behind the tire be calibrated against a known standard such as the upwind/downwind tower flux method.

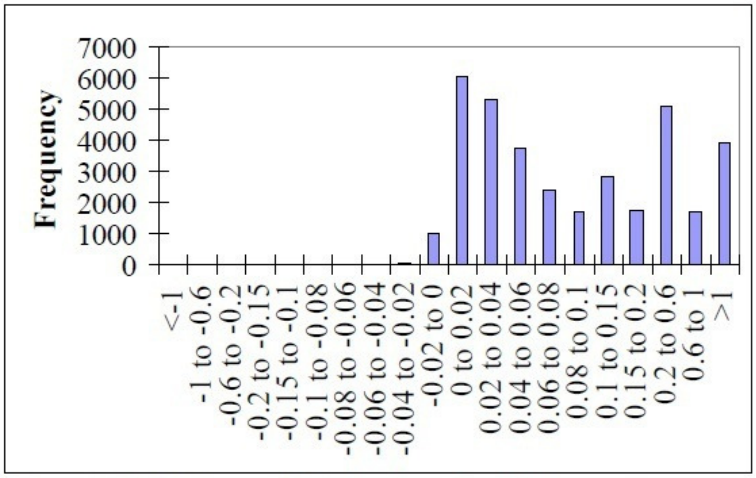
Another consequence of the difference in geometry is that the quantities of dust measured behind the front tire are much greater than those measured in the wake of the vehicle, where the plume from the tires has been diluted somewhat by ambient air. This can be seen quite clearly by considering the magnitudes of the TRAKER signal (defined simply as the difference in PM_{10} concentration measured at the tire inlets and the background inlet) and the magnitude of the SCAMPER signal (defined as the difference between the PM_{10} concentration measured in the wake of the test vehicle and the background inlet). Histograms of the TRAKER and SCAMPER signals for all valid data points (subjected to the criteria in Table 1) are shown in Figure 12. SCAMPER signals are one to two orders of magnitude lower than raw TRAKER signals. In addition, owing perhaps to the dilution of road dust with ambient air, many of the raw SCAMPER measurements are negative (~33%). Comparatively fewer data points from the TRAKER are negative (3%) and they are generally small in magnitude compared to the positive values. The existence of few negative points for the TRAKER measurement is important since the application of the calibration equation does not permit the inclusion of negative numbers. We note that Figure 12 shows that the omission of negative numbers from the TRAKER measurements presents a negligible bias in the TRAKER dataset.

In order to compare results between the CE-CERT SCAMPER and the DRI TRAKER, CE-CERT data obtained from the Project FTP site were analyzed in the same manner as the TRAKER data. Specifically, the criteria in Table 1 were applied to the SCAMPER data. Each SCAMPER data point was associated with a road segment so that TRAKER and SCAMPER emission factors could be compared on a road segment and sample date basis. As with the TRAKER data, when a specific road segment was associated with fewer than 5 data points, that road segment was not considered in the analysis.

A side-by-side comparison of segment averaged emission factors using the TRAKER and SCAMPER is shown in Figure 13. Qualitatively, the two measurement methods give similar spatial distributions for road dust emission factors. In general, portions of the loop where SCAMPER measures high emission factors correspond to portions where TRAKER measures high emission factors. There are however some important differences between the two methods. Figure 14 shows a scatter plot of road segment-averaged emission factors using the two different measurement platforms for 697 non-overlapping road segments. The scatter plot shows that the two measurement methods are correlated (R^2 = 0.46 and 0.30 for a linear fit with and without an intercept, respectively). The SCAMPER however gives slightly lower emission factors. When segregated by day, the ratio of SCAMPER to TRAKER emission factors is quite variable ranging from 0.05 on 2/17/05 to 0.45 on 2/15/05 (See Table 3).



a. Histogram of Raw CE_CERT signal defined as the difference in concentration between the PM_{10} monitor in the wake of the vehicle and the monitor measuring ambient air



b. Histogram of Raw TRAKER signal defined as the difference in concentration between the PM_{10} monitors behind the front tires and the monitor measuring ambient air

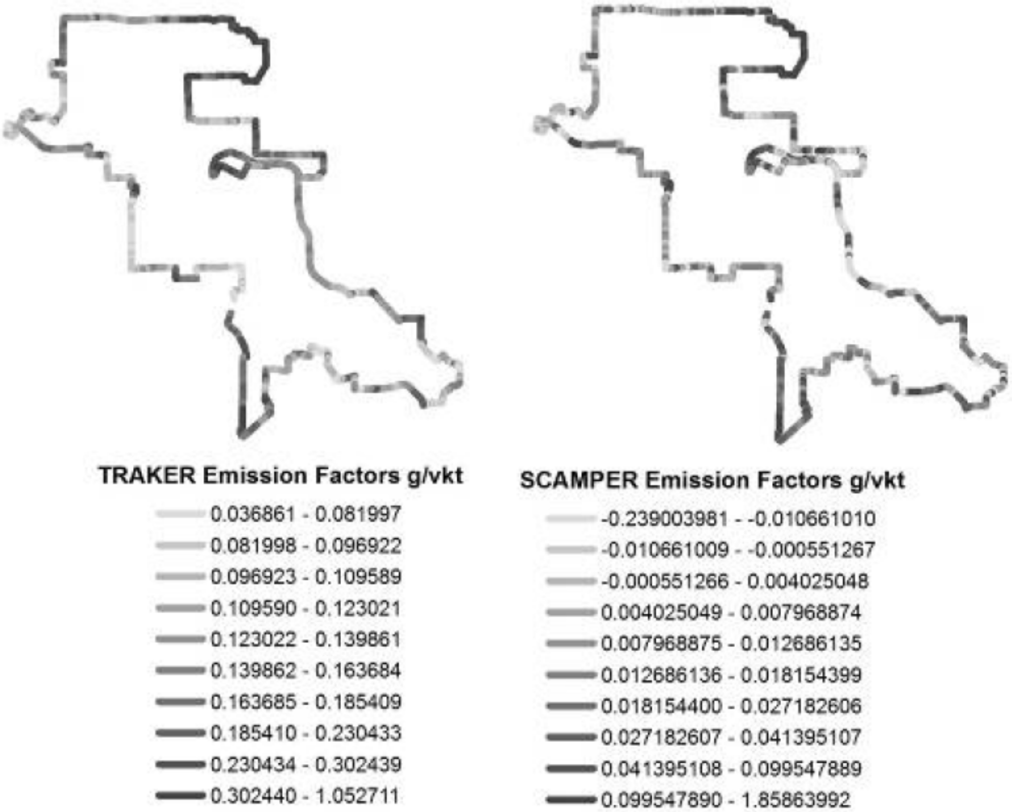


Figure 1. Side by side comparison of road segment-averaged emission factors using the TRAKER and SCAMPER methods. Data from Phase II of the study have been averaged over all 4 days of sampling.

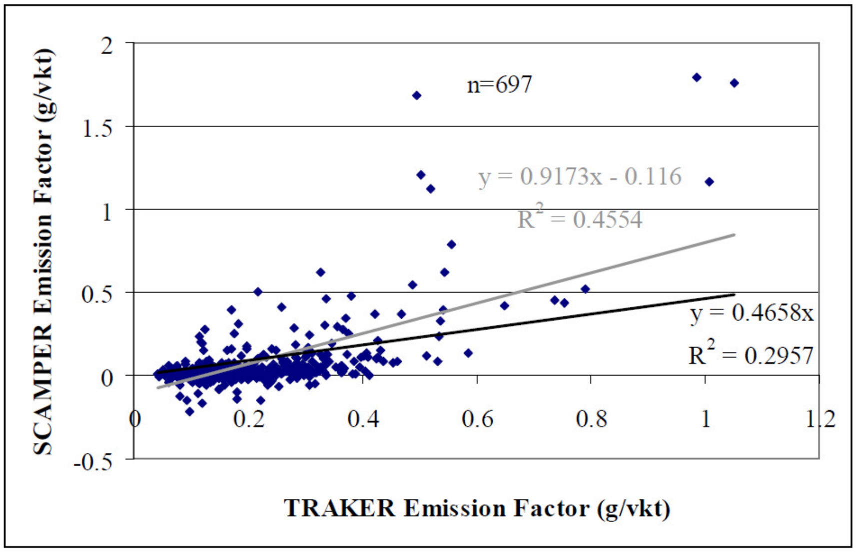
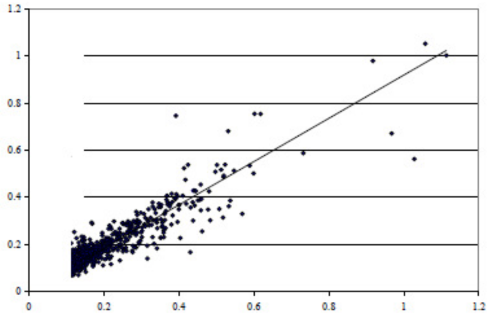


Figure 2. Scatter plot of TRAKER and SCAMPER segment-averaged emission factors for all days. The Gray trend line is a linear best fit to the data, while the black line represents a best fit when the intercept is forced to be zero.

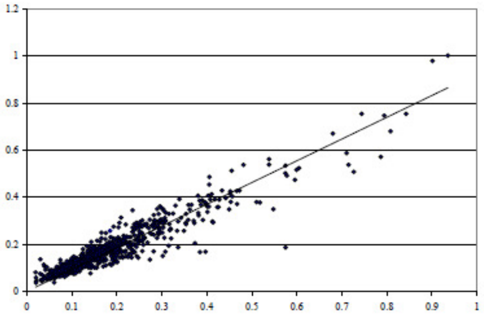
Table 3. Emission factors for TRAKER and SCAMPER averaged over all road segments by sample day and associated ratios of emission factors using the two methods

Day_	TRAKER Emission Factor Avergaed over all sements(g/vkt)	SCAMPER Emission Factor Average over all segments(g/vkt)	Ratio SCAMPER EF/ TRAKER EF
2/14/2005	0.185	0.062	0.34
2/15/2005	0.180	0.081	0.45
2/16/2005	0.176	0.029	0.17
2/17/2005	0.168	0.008	0.05
All Days Average	0.177	0.045	0.25
Standard deviation	0.007	0.033	0.18

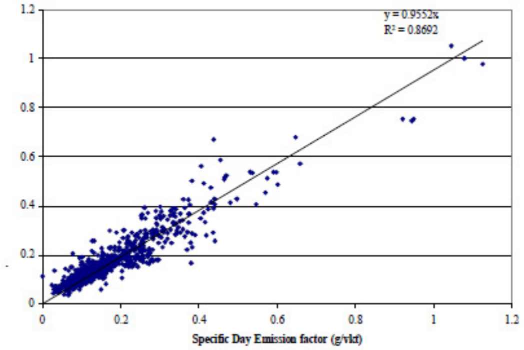
Table 3 also shows that the standard deviation of the TRAKER measurement among the 4 sampling days (4.1% of average) is comparatively lower than that of the SCAMPER (72% of average). This may be a consequence of the differences between the two measurement configurations. Owing perhaps to the larger signal range behind the front tires than in the wake of the vehicle, the TRAKER measurement has a higher degree of precision on the spatial scale of a road segment than the SCAMPER (See Figure 15 and Figure 16).



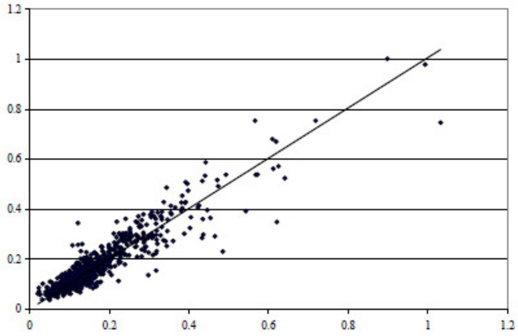
a. 2/14/05



b. 2/15/05

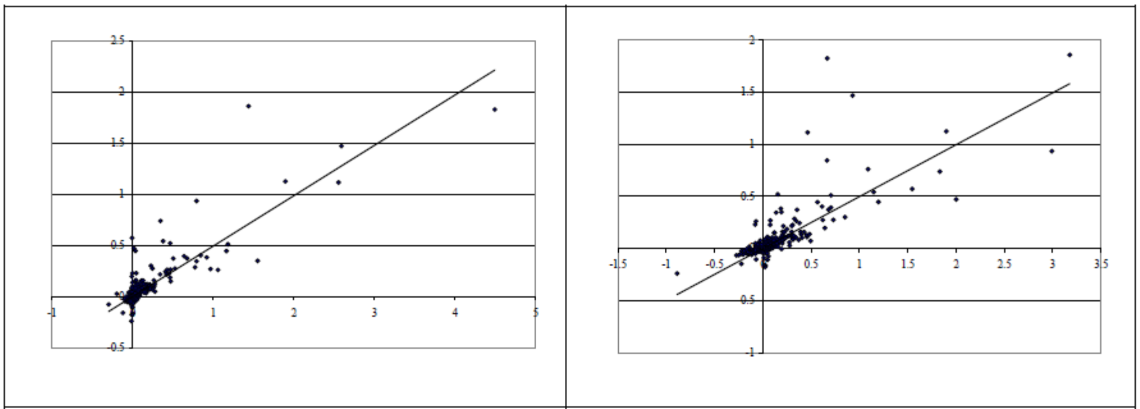


c. 2/16/05



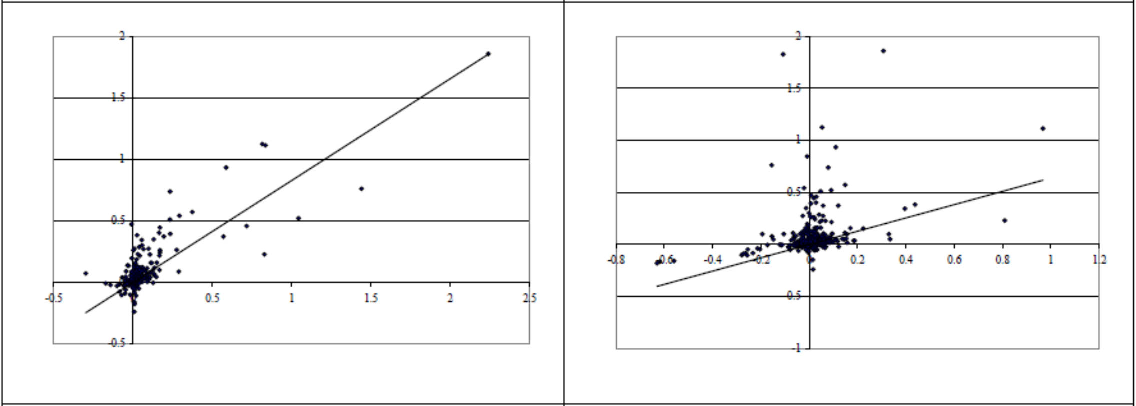
d. 2/17/05

Figure 15. Scatter plots of road segment average emission factors vs 4-day average emission factors for the TRAKER



a. 2/14/05

b. 2/15/05



c. 2/16/05

d. 2/17/05

Figure 16 Scatter plots of road segment averaged emission factors vs 4-day average emission factors for the SCAMPER

6. References

Etyemezian, V., H. Kuhns, J. Gillies, M. Green, M. Pitchford and J. Watson (2003) "Vehicle-based road dust emission measurement: I - methods and calibration." *Atmospheric Environment* 37(32): 4559-4571.

Kuhns, H., V. Etyemezian, D. Landwehr, C. MacDougall, M. Pitchford and M. Green (2001). "Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER): a new approach to infer silt loading on roadways." *Atmospheric Environment* 35(16): 2815-2825.

Countess, R. (2001). Methodology for Estimating Fugitive Windblown and Mechanically Resuspended Road Dust Emissions Applicable for Regional Scale Air Quality Modeling.

Prepared for the Western Governors Association by Countess Environmental, Westlake Village, CA, April, 2001

Cowherd, C. (1984). Paved Road Particulate Emissions: Source Category Report. Report No. EPA-600/7-84-077. Prepared by U.S. Environmental Protection Agency, Research Triangle Park, NC, USA.

Cowherd, C. (1999). Profiling Data for Open Fugitive Dust Sources. Prepared for U.S. Environmental Protection Agency, Emission Factors and Inventory Group, Office of Air Quality Planning and Standards, Research Triangle Park, NC, by Midwest Research Institute, Kansas City, MO.

Cowherd, C., and T. Pace (2002). Potential role of vegetative ground cover in the removal of airborne fugitive dust. Presented at the Annual meeting of the Air and Waste Management Association, Baltimore, MD, June 2002.

Etyemezian V., Kuhns, H., Chow, J., Gillies, J., Green, S. Kohl, and M. Pitchford (2001). The Treasure Valley Road Dust Study: Final Report. Prepared for the Idaho Department of Environmental Quality, Boise, Idaho by the Desert Research Institute, Las Vegas, NV. February, 2002.

Etyemezian V., Kuhns, H., Chow, J., Gillies, J., Green, M., Hendrickson, K., McGown, M., and M. Pithford (2003a). Vehicle Based Road Dust Emissions Measurement (I): Methods and Calibration. Manuscript submitted as companion paper to Atmospheric Environment.

Etyemezian, V., Gillies, J., Kuhns, H., Nikolic, D., Watson, J., Veranth, J., Laban, R., Seshadri, G., and D. Gillette (2003b). Report prepared for the WESTAR Council, Lake Oswego, OR, USA by DRI, Las Vegas, NV, USA, January, 2003.

Etyemezian, V., H. Kuhns, G. Nikolich, and K. Graham (2004). The Las Vegas Road Dust Emissions Technology Assessment: Final Report. Prepared by the Desert Research Institute, Las Vegas NV for the Clark County Department of Air Quality and Environmental Management, Las Vegas, NV, July, 2005.

Gillette, D. (2002). The Long-distance “Transportable Fraction” of the Vertical Flux of wind-transported dust. *Proceedings of ICAR5/GCTE-SEN Joint Conference*, Jeffrey A. Lee and Ted M. Zobeck editors, Lubbock, Texas, USA Publication 02-2 p. 34.

Gillies, J.A.; Watson, J.G.; Rogers, C.F.; Dubois, D.; Chow, J.C.; Langston, R.; and Sweet, J. (1999). Long Term Efficiencies of Dust Suppressants to Reduce PM_{10} Emissions from Unpaved Roads. *JAWMA*, 49:3-16.

Kuhns, H., Etyemezian, V., Landwehr, D., MacDougall, C., Pitchford, M., Green, M. (2001). Testing Re-entrained Aerosol Kinetic Emissions from Roads (TRAKER): A New Approach to Infer Silt Loading on Roadways. Atmospheric Environment Vol 35: 2815-2825.

Kuhns , H., Etyemezian, V., Gillies, J., Green, M., Hendrickson, K., McGown, M., and M. Pitchford (2003). Vehicle Based Road Dust Emisssions Measurement (II): Effect of Precipitation, Wintertime Road Sanding, and Street Sweepers on PM10 Fugitive Dust Emissions from Paved and Unpaved Roads. Manuscript submitted as companion paper to Atmospheric Environment.

Moosmuller, H., Gillies, J.A., Rogers, C.F., Dubois, D.W., Chow, J.C., Watson, J.G., and R. Langston (1998). Particulate Emission Rates for Unpaved Shoulders along a Paved Road. J. Air & Waste Manage. Assoc., Vol 48: 398-407.

Raupach, M.R., and F.L. Leys (1999). The Efficacy of Vegetation in Limiting Spray Drift and Dust Movement. Report Prepared for the Department of Land and Water Conservation, Gunnedah, Australia by CSIRO, Canberra, Australia.

Sehmel, G.A. (1973). Particle Resuspension from an Asphalt Road Caused by Car and Truck Traffic. Atmospheric Environment, Vol 7: 291-309.

U.S. EPA (1995). Compilation of Air Pollutant Emission Factors. Report No. AP-42. Prepared by the U.S. Environmental Protection Agency, Research Triangle Park, NC, USA.

U.S.EPA (1998). National air pollutant emission trends, procedures document, 1900-1996. Report No. EPA-454/R-98-008. Prepared by U.S. Environmental Protection Agency, Research Triangle Park, NC, USA.

U.S.EPA (1999). Compilation of air pollutant emission factors - Vol. I, Stationary point and area sources. Report No. AP-42, 5th ed. Prepared by U.S. Environmental Protection Agency, Research Triangle Park, NC, USA.

U.S.EPA (2002). User’s Guide to MOBILE6.0 Mobile Source Emission Factor Model. Report No. EPA-420/R-02-001. Prepared by U.S. Environmental Protection Agency, USA.

Venkatram, A. (2000). A Critique of Empirical Emission Factor Models: A Case Study of the AP-42 Model for Estimating PM10 Emissions from Paved Roads. Atmospheric Environment, Vol 34: 1-11.

Venkatram, A. (2001). Response to Comments by Nicholson. A Critique of Empirical Emission Factor Models: A Case Study of the AP-42 Model For Estimating PM10 Emissions from Paved Roads. Atmospheric Environment Vol 35: 187.

Watson, J.G., and J. Chow (2000). Reconciling Urban Fugitive Dust Emission Inventory and Ambient Source Contribution Estimates: Summary of Current Knowledge and Needed Research. DRI Document No. 6110.4F. Prepared for the U.S. Environmental Protection Agency, by Desert Research Institute, Reno, NV. May, 2000.

Watson, J.G., Chow, J.C., Pace, T.G. (2000). Fugitive dust emissions. Air Pollution Engineering Manual, Davis, W.T., Ed. Van Nostrand Reinhold, New York, NY, pp. 117-134.

Watson, J.G., and J. Chow (2000). Reconciling Urban Fugitive Dust Emissions Inventory and Ambient Source Contribution Estimates: Summary of Current Knowledge and Needed Research. DRI Document No. 6110.4F. Prepared for the U.S. Environmental Protection Agency, by Desert Research Institute, Reno, NV. May, 2000.

Countess, R. (2001). Methodology for Estimating Fugitive Windblown and Mechanically Resuspended Road Dust Emissions Applicable for Regional Scale Air Quality Modeling. Prepared for the Western Governors Association by Countess Environmental, Westlake Village, CA, April, 2001.

Veranth, J. M., G. Seshadri and E. Pardyjak (2003). Vehicle-generated fugitive dust transport: Analytic models and field study. Atmos Env 37(16): 2295-2303.

Raupach, M.R., N. Woods, G. Dorr, J.F. Leys, and H.A. Cleugh (2001). The entrapment of particles by windbreaks. Atmos. Env. 35: 3373-3383.

Lamb, R.G., and D.R. Duran (1977). Eddy Diffusivities Derived from a Numerical Model of the Convective Boundary Layer. Nuovo Cimento, 1c: 1-17.

Shir, C.C. (1973). A preliminary Numerical Study of Atmospheric Turbulent Flows in the Idealized Planetary Boundary Layer. J. Atmos Sci., 30: 1327-1339.

Venkatram, A. (1993). The Parametrization of the Vertical Dispersion of A Scalar in the Atmospheric Boundary Layer. Atmos Env., 27A: 1963-1966.

U.S. EPA, (1995). User’s Guide for the Industrial Source Complex (ISC3) Dispersion Models Vollume II: Description of Model Algorithms. US Environmental Protection Agency, Office of Air Quality Planning and Standards: Emissions, Monitoring, and Analysis Division, RTP, NC.

Seinfeld, J.H., and S.N. Pandis (1997). Atmospheric Chemistry and Physics: From Air Pollution to Climate Change. Wiley Interscience. New York, USA.

Willeke, K., and M. Xu (1992). Impaction and rebound of particles from surfaces. J. Aerosol Sci. 23, Supplement: S15-S18.

Gillies, J.A., J.G. Watson, C.F. Rogers, D. Dubois, J.C. Chow, R. Langston, and J. Sweet. (1999). Long term efficiencies of dust suppressants to reduce PM10 emissions from unpaved roads. J. Air Waste Manage. Assoc. 49:3-16.

Cowherd, C. (1999). Profiling data for open fugitive dust sources. Prepared for U.S. Environemntal Protection Agency, Emissions Factor and Inventory Group, Office of Air Quality Planning and Standards, RTP, NC, by Midwest Research Institute, Kansas City, MO.

Niu, J., B.M.K. Lu, and T.C.W. Tung (2002). Instrumentation Issue in Indoor Air Quality Measurements: The Case with Respirable Suspended Particulates. Indoor Built Environment 11: 162-170.

Moosmüller, H., W.P. Arnott, C.F. Rogers, J.L. Bowen, J.A. Gillies, W.R. Pierson, J.F. Collins, T.D. Durbin, and J.M. Norbeck (2001). Time resolved characterization of diesel particulate emissions. 1. Instruments for particle mass measurement. Environ. Sci. Technol. 35: 781-787.

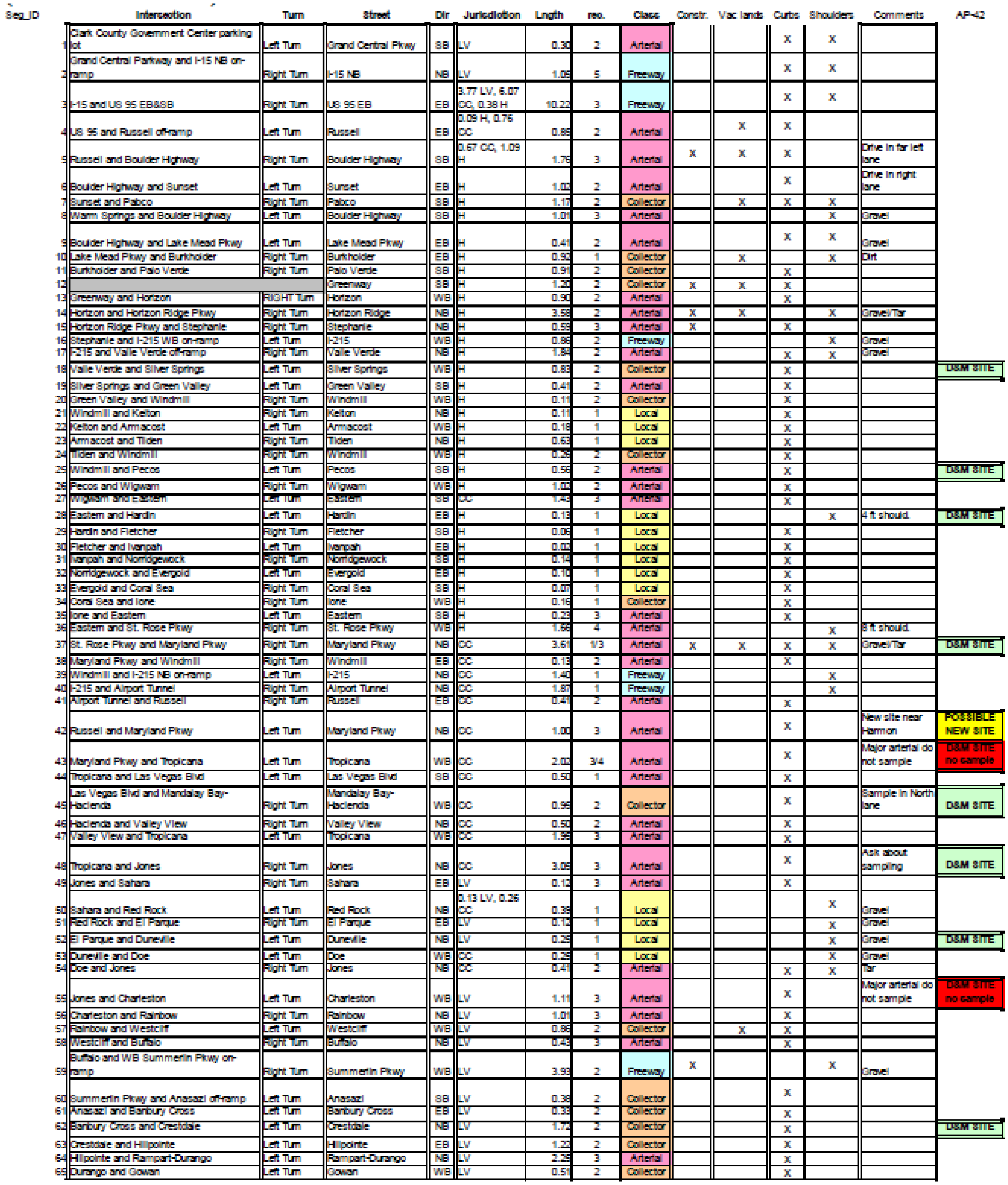
Chung, A., D.P.Y. Chang, M.J. Kleeman, K.D. Perry, T.A. Cahill, D. Dutcher, E.M. McDougall, and K. Stroud (2001). Comparison of real-time instruments used to monitor airborne particulate matter. J. Air & Waste Manage. Assoc. 51: 109 – 120.

Etyemezian, V., J. Gillies, H. Kuhns, D. Nikolic, J. Watson, J. Veranth, R. Labban, G. Seshadri, and D. Gillette (2003). Field Testing and Evaluation of Dust Deposition and Removal Mechanisms: Final Report. Report Prepared for WESTAR Council, Lake Oswego, OR, by DRI, Las Vegas, NV. January, 2003.

Etyemezian, V.,D. Gillette, J. Gillies, H. Kuhns, D. Nikolic, J. Veranth, and J. Watson (2003). PM10 Emissions Factors for Unpaved Roads: Correction for Near-Field Deposition. PM AAAR 2003: Atmospheric Sciences, Exposure, Health and Welfare Effects, Policy. Poster. American Association for Aerosol Research, Pittsburgh, PA, March 31- April 4, 2003.

Appendix A. Driving Directions for Clark County Road Dust Study Phase II

Driving Instructions Alternative Technologies for Paved Road Silt Sampling (2/14/05 – 2/17/05)



Seg_ID	Intersection	Turn	Street	Dir	Jurisdiction	Lngth	reo.	Class	Constr.	Vac lands	Curbs	Shoulders	Comments	AP-42
1	Clark County Government Center parking lot	Left Turn	Grand Central Pkwy	SB	LV	0.30	2	Arterial			X	X		
2	Grand Central Parkway and I-15 NB on-ramp	Right Turn	I-15 NB	NB	LV	1.05	5	Freeway			X	X		
3	I-15 and US 95 EB&SB	Right Turn	US 95 EB	EB	3.77 LV, 6.07 CC, 0.38 H	10.22	3	Freeway			X	X		
4	US 95 and Russell off-ramp	Left Turn	Russell	EB	0.09 H, 0.76 CC	0.85	2	Arterial		X	X			
5	Russell and Boulder Highway	Right Turn	Boulder Highway	SB	0.67 CC, 1.09 H	1.76	3	Arterial	X	X	X		Drive in far left lane	
6	Boulder Highway and Sunset	Left Turn	Sunset	EB	H	1.02	2	Arterial			X		Drive in right lane	
7	Sunset and Pabco	Right Turn	Pabco	SB	H	1.17	2	Collector		X	X	X		
8	Warm Springs and Boulder Highway	Left Turn	Boulder Highway	SB	H	1.01	3	Arterial				X	Gravel	
9	Boulder Highway and Lake Mead Pkwy	Left Turn	Lake Mead Pkwy	EB	H	0.41	2	Arterial			X	X	Gravel	
10	Lake Mead Pkwy and Burkholder	Right Turn	Burkholder	EB	H	0.92	1	Collector		X		X	Dirt	
11	Burkholder and Palo Verde	Right Turn	Palo Verde	SB	H	0.91	2	Collector			X			
12			Greenway	SB	H	1.20	2	Collector	X	X	X			
13	Greenway and Horizon	RIGHT Turn	Horizon	WB	H	0.90	2	Arterial			X			
14	Horizon and Horizon Ridge Pkwy	Right Turn	Horizon Ridge	NB	H	3.58	2	Arterial	X	X		X	Gravel/Tar	
15	Horizon Ridge Pkwy and Stephanie	Right Turn	Stephanie	NB	H	0.59	3	Arterial	X		X			
16	Stephanie and I-215 WB on-ramp	Left Turn	I-215	WB	H	0.86	2	Freeway				X	Gravel	
17	I-215 and Valle Verde off-ramp	Right Turn	Valle Verde	NB	H	1.84	2	Arterial			X	X	Gravel	
18	Valle Verde and Silver Springs	Left Turn	Silver Springs	WB	H	0.83	2	Collector			X			D&M SITE
19	Silver Springs and Green Valley	Left Turn	Green Valley	SB	H	0.41	2	Arterial			X			
20	Green Valley and Windmill	Right Turn	Windmill	WB	H	0.11	2	Collector			X			
21	Windmill and Kelton	Right Turn	Kelton	NB	H	0.11	1	Local			X			
22	Kelton and Armacost	Left Turn	Armacost	WB	H	0.18	1	Local			X			
23	Armacost and Tilden	Right Turn	Tilden	NB	H	0.63	1	Local			X			
24	Tilden and Windmill	Right Turn	Windmill	WB	H	0.29	2	Collector			X			
25	Windmill and Pecos	Left Turn	Pecos	SB	H	0.56	2	Arterial			X			D&M SITE
26	Pecos and Wigwam	Right Turn	Wigwam	WB	H	1.02	2	Arterial			X			
27	Wigwam and Eastern	Left Turn	Eastern	SB	CC	1.43	3	Arterial			X			
28	Eastern and Hardin	Left Turn	Hardin	EB	H	0.13	1	Local				X	4 ft should.	D&M SITE
29	Hardin and Fletcher	Right Turn	Fletcher	SB	H	0.06	1	Local			X			
30	Fletcher and Ivanpah	Left Turn	Ivanpah	EB	H	0.02	1	Local			X			
31	Ivanpah and Norridgewock	Right Turn	Norridgewock	SB	H	0.14	1	Local			X			
32	Norridgewock and Evergold	Left Turn	Evergold	EB	H	0.10	1	Local			X			
33	Evergold and Coral Sea	Right Turn	Coral Sea	SB	H	0.07	1	Local			X			
34	Coral Sea and Ione	Right Turn	Ione	WB	H	0.16	1	Collector			X			
35	Ione and Eastern	Left Turn	Eastern	SB	H	0.23	3	Arterial			X			
36	Eastern and St. Rose Pkwy	Right Turn	St. Rose Pkwy	WB	H	1.66	4	Arterial				X	8 ft should.	
37	St. Rose Pkwy and Maryland Pkwy	Right Turn	Maryland Pkwy	NB	CC	3.61	1/3	Arterial	X	X	X	X	Gravel/Tar	D&M SITE
38	Maryland Pkwy and Windmill	Right Turn	Windmill	EB	CC	0.13	2	Arterial			X			
39	Windmill and I-215 NB on-ramp	Left Turn	I-215	NB	CC	1.40	1	Freeway				X		
40	I-215 and Airport Tunnel	Right Turn	Airport Tunnel	NB	CC	1.87	1	Freeway				X		
41	Airport Tunnel and Russell	Right Turn	Russell	EB	CC	0.41	2	Arterial			X			
42	Russell and Maryland Pkwy	Left Turn	Maryland Pkwy	NB	CC	1.00	3	Arterial			X		New site near Harmon	POSSIBLE NEW SITE
43	Maryland Pkwy and Tropicana	Left Turn	Tropicana	WB	CC	2.02	3/4	Arterial			X		Major arterial do not sample	D&M SITE no sample
44	Tropicana and Las Vegas Blvd	Left Turn	Las Vegas Blvd	SB	CC	0.50	1	Arterial			X			
45	Las Vegas Blvd and Mandalay Bay-Hacienda	Right Turn	Mandalay Bay-Hacienda	WB	CC	0.99	2	Collector			X		Sample in North lane	D&M SITE
46	Hacienda and Valley View	Right Turn	Valley View	NB	CC	0.50	2	Arterial			X			
47	Valley View and Tropicana	Left Turn	Tropicana	WB	CC	1.99	3	Arterial			X			
48	Tropicana and Jones	Right Turn	Jones	NB	CC	3.05	3	Arterial			X		Ask about sampling	D&M SITE
49	Jones and Sahara	Right Turn	Sahara	EB	LV	0.12	3	Arterial			X			
50	Sahara and Red Rock	Left Turn	Red Rock	NB	0.13 LV, 0.26 CC	0.39	1	Local				X	Gravel	
51	Red Rock and El Parque	Right Turn	El Parque	EB	LV	0.12	1	Local				X	Gravel	
52	El Parque and Duneville	Left Turn	Duneville	NB	LV	0.29	1	Local				X	Gravel	D&M SITE
53	Duneville and Doe	Left Turn	Doe	WB	CC	0.29	1	Local				X	Gravel	
54	Doe and Jones	Right Turn	Jones	NB	CC	0.41	2	Arterial			X	X	Tar	
55	Jones and Charleston	Left Turn	Charleston	WB	LV	1.11	3	Arterial			X		Major arterial do not sample	D&M SITE no sample
56	Charleston and Rainbow	Right Turn	Rainbow	NB	LV	1.01	3	Arterial			X			
57	Rainbow and Westcliff	Left Turn	Westcliff	WB	LV	0.86	2	Collector		X	X			
58	Westcliff and Buffalo	Right Turn	Buffalo	NB	LV	0.43	3	Arterial			X			
59	Buffalo and WB Summerlin Pkwy on-ramp	Right Turn	Summerlin Pkwy	WB	LV	3.93	2	Freeway	X			X	Gravel	
60	Summerlin Pkwy and Anasazi off-ramp	Left Turn	Anasazi	SB	LV	0.38	2	Collector			X			
61	Anasazi and Banbury Cross	Left Turn	Banbury Cross	EB	LV	0.33	2	Collector			X			
62	Banbury Cross and Crestdale	Left Turn	Crestdale	NB	LV	1.72	2	Collector			X			D&M SITE
63	Crestdale and Hillpointe	Left Turn	Hillpointe	EB	LV	1.22	2	Collector			X			
64	Hillpointe and Rampart-Durango	Left Turn	Rampart-Durango	NB	LV	2.29	3	Arterial			X			
65	Durango and Gowan	Left Turn	Gowan	WB	LV	0.51	2	Collector			X			

Clark County (Nevada) Paved Road Dust Emission Studies in Support of Mobile Monitoring Technologies

Appendices A–E

Appendix D
MEASUREMENTS OF PM_{10} EMISSION FACTORS FROM PAVED ROADS IN CLARK COUNTY, NV

PHASE III QUANTIFYING PAVED ROAD DUST EMISSION MEASUREMENTS - *Expanded Research Using Alternative Technologies*
REVISED FINAL REPORT
June 22, 2007

December 22, 2008

MEASUREMENTS OF PM_{10} EMISSION FACTORS FROM PAVED ROADS IN CLARK COUNTY, NV

PHASE III
QUANTIFYING PAVED ROAD DUST EMISSION MEASUREMENTS

Expanded Research Using Alternative Technologies

REVISED FINAL REPORT

Submitted to:
Clark County Department of Air Quality Management
500 S. Grand Central Parkway, 1st Floor
Las Vegas, NV 89155

By

Center for Environmental Research and Technology

June 22, 2007

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ABSTRACT

The SCAMPER system for measuring PM_{10} emission rates from paved roads was used in order to characterize PM_{10} emission rates from road loops in the Las Vegas area. One loop was short with high emission potential roads in an industrial area so that a large number of traverses could be made. Two longer loops were chosen to be more representative of emission potential of roads in the area. High PM_{10} emission rates were expected from one of the longer loops (Washburn), while low rates were expected from the other (Summerlin). The measurements were used to determine the precision of the SCAMPER measurements, compare the SCAMPER results with AP-42 silt sampling, and evaluate diurnal variations of the emission factors. The results showed that PM_{10} emission rates met the loop expectations and were generally low except when “hot spots” were encountered, which is consistent with previous measurements. We concluded that the SCAMPER system is useful for both identifying “hot spots” and generally characterizing PM_{10} emission rates from paved roads with a precision of approximately 25%. The PM_{10} emission rates did not change significantly during the course of the day, but on the high emission longer loop the rates dropped by a factor of two over the weekend. The comparison with AP-42 silt sampling showed good correlation ($R^2 = 0.86$) with the SCAMPER segment results, which were about three times lower. Since SCAMPER directly measures PM emission rates, it is likely to be a more direct and accurate measure of PM emissions from roads.

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ACKNOWLEDGEMENTS

Kurt Bumiller's work in upgrading the sampling system, conducting the field measurements, and in preparing the data set is gratefully appreciated.

1.0 PROJECT DESCRIPTION AND OBJECTIVES

1.1 Background

The expression contained into the EPA document AP-42 for predicting emission rates and has been widely used all over the country to estimate the fraction of PM_{10} originating from paved roads:

$$E = k(sL/2)^{0.65} (W/3)^{1.5} \text{ g/VKT} - C \qquad (1)$$

where:

E = PM emission factor in the units shown
k = A constant dependent on the aerodynamic size range of PM (1.8 for $PM_{2.5}$; 4.6 for PM_{10})
sL = Road surface silt loading of material smaller than 75µm in g/m^2
W = mean vehicle weight in tons
C = emission factor for 1980's vehicle fleet exhaust, brake wear, and tire wear
VKT = vehicle kilometer traveled

Equation (1) was derived by measuring the total flux across roadways using a PM_{10} monitoring array and based solely on surface silt loading as the independent variable. We developed an alternative technique using a vehicle equipped real-time PM sensors to measure concentrations in front of the vehicle and in its rear wake (Fitz, 2001, Fitz and Bufalino, 2002; Fitz et al. 2005a,b). In this approach the PM_{10} concentrations are measured directly on moving vehicles in order to improve the measurement sensitivity for estimating the emission factors for vehicle on paved roads. Optical sensors are used to measure PM_{10} concentrations with a time resolution of approximately two seconds. Sensors were mounted in the front and behind the vehicle in the well-mixed wake. A special inlet probe was designed to allow isokinetic sampling under all speed conditions. The emission factors are based on the concentration difference between front and back of the test vehicle and the frontal area. The test system has been designated as SCAMPER (System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways)

This SCAMPER technique is useful for quickly surveying large areas and for investigating hot spots on roadways caused by greater than normal deposition of PM_{10} forming debris. While there is an AP-42 equation for paved roads that has silt content as the independent variable, the SCAMPER approach directly measures emissions and does not depend on independent variables.

1.2 Objectives

The primary objectives of this project were to determine the precision of SCAMPER measurements of the PM_{10} emission rates from roadways in the Las Vegas area of Nevada and compare the measurements with those determined from silt sampling. Secondary objectives were to isolate sources and to determine the diurnal variation of PM_{10} emission rates. Of particular importance was the difference in emission rates between weekdays and weekends when construction activities were diminished. The extensive data emission data set will be also be useful in classifying PM_{10} emission rates by road type.

1.3 Approach

We determined vehicle PM emission factors by measuring the PM concentrations in front of and behind the vehicle using real-time sensors. This approach included into six components:

1) Sampling Inlet

An inlet for the real-time PM sensors was used that allowed sampling as isokinetically as possible over the full range of vehicle speeds. This involves a bypass flow system that is adjusted to vehicle speed with a PC using GPS speed data.

2) PM_{10} Sensors

DustTrak optical PM sensors with PM_{10} inlets are used.

3) Sampling Trailer

From our studies to determine concentrations in the vehicle wake the sampling position behind the vehicle was optimized. This position required using a trailer to mount the sampling inlet. The trailer was designed to disturb the vehicle wake as little as possible. In addition, the trailer holds the bypass flow system.

4) Position Determination

A Garmin GPS Map76 global positioning system was used to determine vehicle location and speed.

5) Data Collection

A PC was used to collect data from GPS and PM_{10} measuring devices. Data was stored as one-second averages. The PC also was used to automatically adjust the sample inlet bypass flow to maintain isokinetic particle sampling using a 10-second running average of vehicle speed based on the GPS.

6) Video Documentation

A Canon Optura 50 DBCAM video camera was mounted on the Suburban’s windshield to record the condition of the roadway, potential dust plumes, and the location of other vehicles. The video will be useful for analyzing "hot spots" to determine the reason for high emission rates.

Figure 1-1 shows front and rear photographs of the SCAMPER. The tow vehicle is a 1995 Chevrolet Suburban with a custom trailer with an extended hitch.

Figure 1-1. Photographs of the front and rear of the SCAMPER.

2.0 FIELD MEASUREMENTS

PM_{10} Emission testing was conducted with the SCAMPER over three test routes in the Las Vegas area. The first one, loop A (Gowan), was a short loop (2.8 miles, requiring approximately five minutes to drive) of a roadway heavily impacted with trackout and soil hauling trucks. This loop, shown in Figure 2.1, was expected to have values well above the detection limit most of the time in order that the precision could be determined. The Figure also shows the approximate speeds as a function of location for a typical test run. This loop was a worst-case scenario for precision as the deposits and traffic on the road were highly variable and significant dust was generated by vehicles in front. SCAMPER testing was conducted on November 2, 2005. Silt sampling was conducted at the location shown in the Figure. Traffic counts were also made at the locations shown and included separate counts of heavy-duty vehicles.

The second test loop, loop B (Washburn), shown in Figure 2-2, was chosen to have significant impacts from construction activities. The loop was 7.3 miles long and required 20-25 minutes to transverse. The loop contained arterial, collector, and local and classes of roadways. The Figure also shows locations where silt sampling and traffic counts were conducted.

The third test loop, loop C (Summerlin), shown in Figure 2-3, was chosen to be typical of fully developed areas in which trackout is light or non-noticeable. This loop was 12.6 miles long and required 25-30 minutes to complete. The loop contained arterial, collector, and local classes of roadways. Silt sampling and traffic counts were conducted at the locations shown in the Figure.

All sampling was conducted at speeds consistent with the flow of traffic and with safety considerations for towing a trailer. Local agencies were responsible to ensure that no street sweeping was conducted during or at least three days before the tests were conducted.

Figure 2-1. Map of test loop A (Gowan) with typical vehicle speeds.

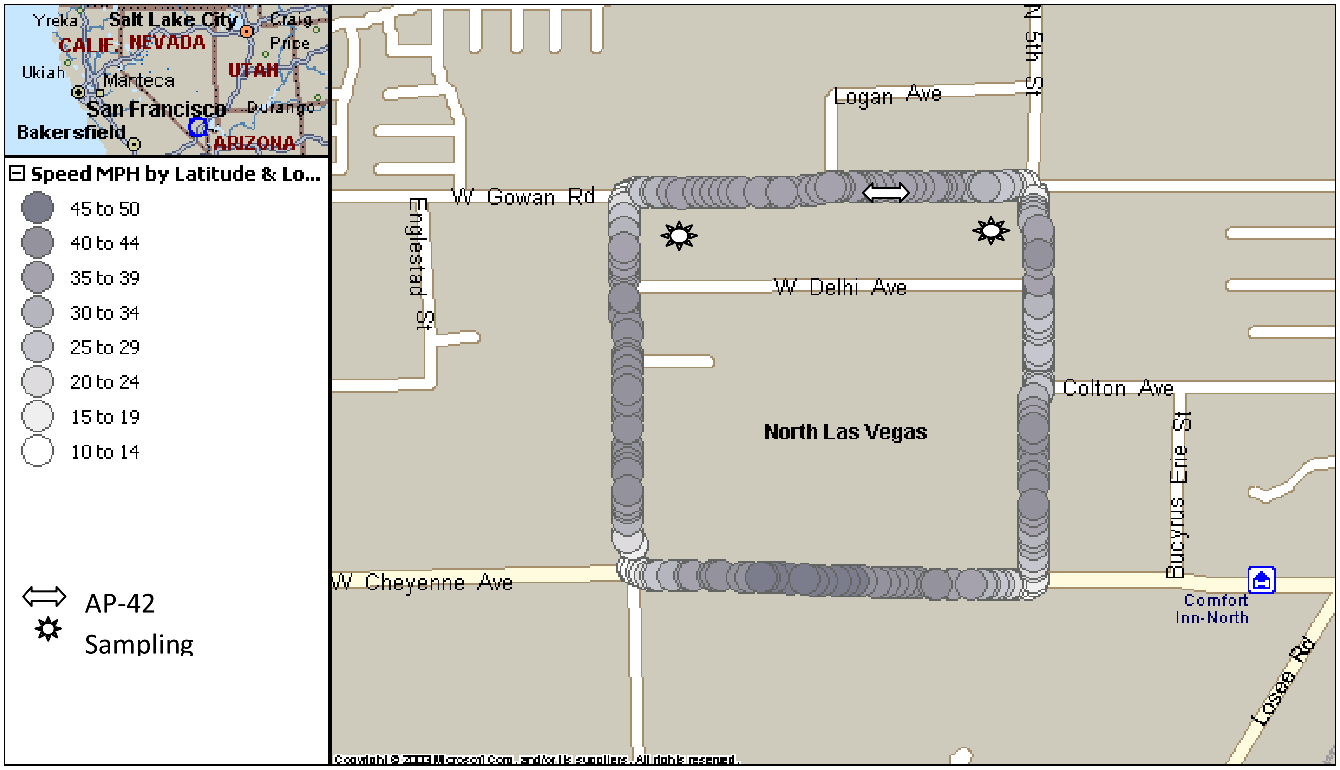


Figure 2-2. Map of test loop B (Washburn) with typical vehicle speeds.

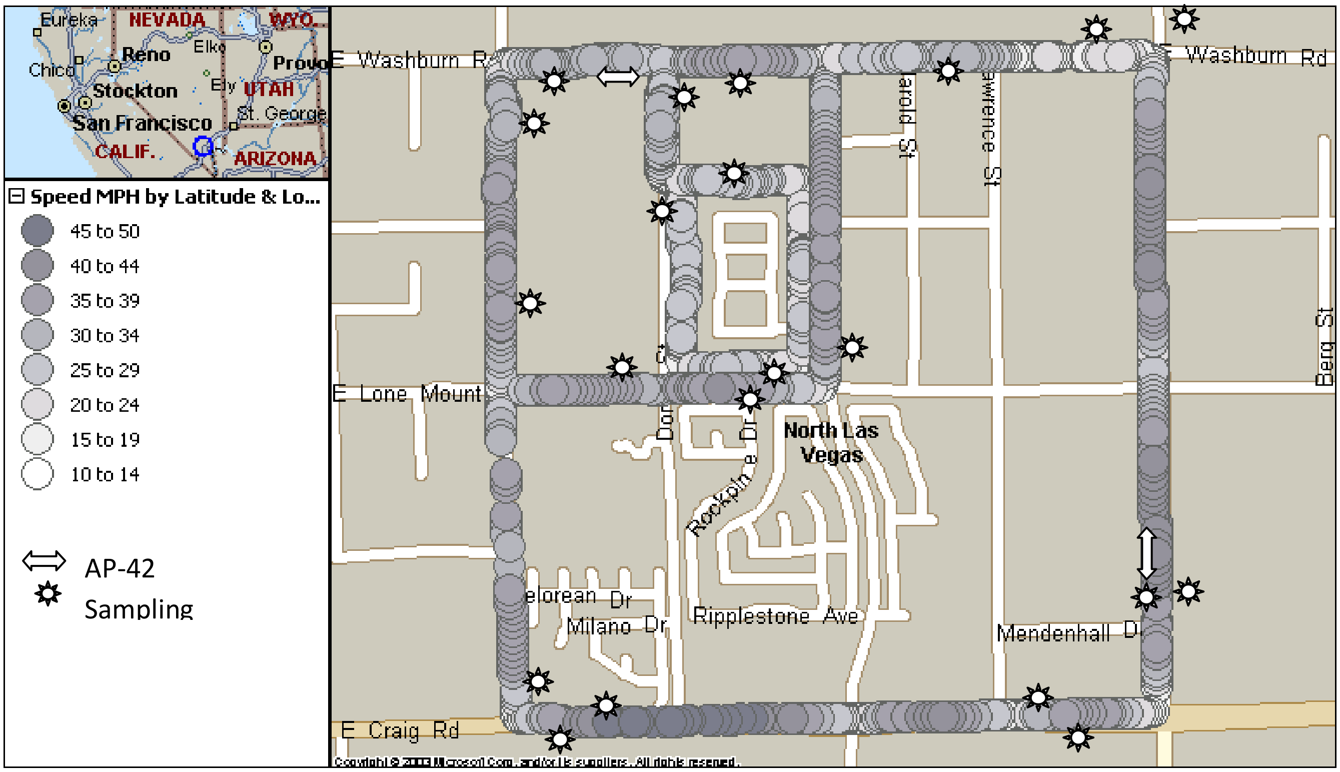
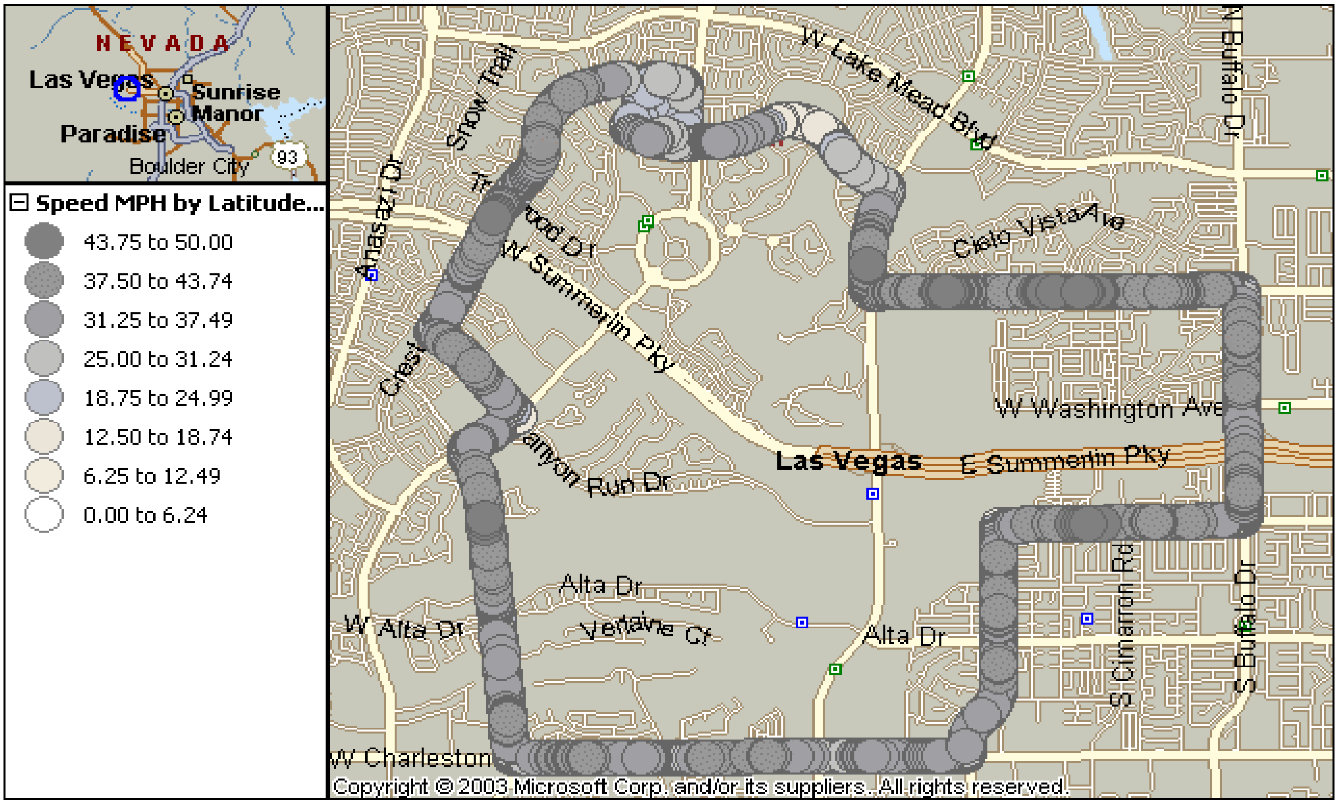


Figure 2-3. Map of test loop C (Summerlin) with typical vehicle speeds.



3.0 DATA QUALITY

- Data Capture

The data capture from the DustTrak analyzers was approximately 90%, due to instances when the front or rear DustTrak quit operating. We are not sure of the cause of these failures, but it is likely that the shock mounting was insufficient.

- DustTrak Drift

The zero of the DustTrak was determined before, after, and during test runs (each day one loop was conducted with filters installed on the dustTraks). The drift during the course of the each test day was less than a few thousandths of a mg/m^3, near the 0.001 mg/m^3 detection limit of the instrument. The instrument is temperature sensitive and therefore the zero drift may be different for moving and stationary modes. The data for each test run was corrected for zero offset using the mean zero response for that day.

4.0 DATA SUMMARY

4.1 DATA VALIDATION

The data acquisition system recorded all data accurately. Data were downloaded from the PC and entered into an EXCEL worksheet where all of the calculations were made. Quality control data such as inlet pressure and various voltages were also entered into the master worksheet in addition to GPS location, time and speed and DustTrak values.

Data were validated from logbook entries and by observing time series to determine if the results made physical sense. The data were flagged as follows in the EXCEL worksheet:
0 or blank: valid data
1: missing or erroneous
2: DustTrak on filtered air for zero check- not moving control
3: DustTrak on filtered air for zero check-moving control
J: DustTrak values not changing for 30seconds of more

There were occasional periods when the GPS did not report data, most likely due to interferences in the sight path to a satellite. In these cases the cell was filled with the average of the position before and the position after. The same was done for speed and PM10. We found that the output of the rear DustTrak occasionally spiked, either positive or negative, most likely due to physical shock. These spikes always showed up on two consecutive seconds. These were unlikely to be associated with an actual PM$_{10}$ concentration as concentrations rarely change to that degree in less than one second. This two-second characteristic of this noise spike is also expected from the internal averaging and output characteristics of the DustTrak. On the time constant we selected (which is the shortest available) the DustTrak output is a two-second running average that is updated every second.

A large spike in a one-second period will therefore show up as two smaller spikes for two consecutive seconds. To filter this noise we tabulated the data as 5-second running medians. Two-second anomalous spikes therefore would be removed from the data set. At the same time we calculated the running medians we also corrected for the zero response for each analyzer.

All obviously bad data were removed from the data that will be submitted. The master EXCEL worksheet shows all the calculations and all the flags. The DustTrak values were zero corrected and 5-second medians and running averages were calculated. This averaging period was used because the DustTrak data is noisy at the shortest time constant. We have found that this period of a running average produces higher quality data although the time resolution is not as great. This is an inherent limitation of the DustTrak instrument when using the shortest time. This is the averaging period that we used in Phase I and II. The differences between the front and rear DustTraks were calculated and the results were multiplied by the frontal area of the Suburban, 3.66m^2 to yield the emission factor in mg/m. A summary worksheet was prepared that includes only time, location, speed, and PM$_{10}$ emission rate. All flagged data were removed as were data when the vehicle speed was less than 10mph since measuring PM$_{10}$ emission rates in real time using this technique assumes that there is a plume in a wake behind the vehicle. This worksheet was used for all subsequent data analyses.

4.2 DATA ANALYSIS METHODS

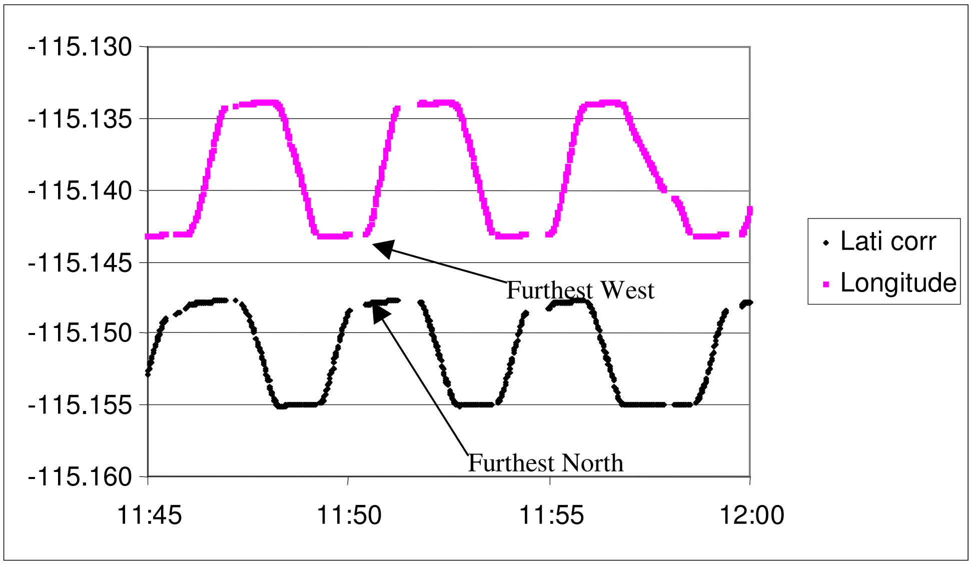
In order to calculate the precision for each loop it was necessary to determine the start and end location of each loop. This was done by plotting the longitude and latitude on a single plot so that these locations (and therefore other data) could be distinguished in the spread sheet row (which have a resolution of one second). To make a useful plot it was necessary to subtract a constant number from each latitude. Figure 4-1 shows a plot of this for several repetitions of loop A. Since loop A is essentially a “box” the pattern of latitude and longitude variation takes the shape of a flat-topped sawtooth as shown in the figure. The arrows point out the furthest north and the furthest west of the loop, the northwest corner. This location and the time associated with it was used as the starting/end point for calculating the average speed or emission factor for each loop.

The following subsections describe each day of data collected. This is accomplished with a time series plot and a summary of the average PM$_{10}$ emission rates values for each loop. The time series plots give good overviews of the data. Since the speed varies from loop to loop, the location data, however, is approximate on the time axis.

4.3 Video Data Storage and Graphical Display

Digital videos were of all test loop runs were recorded on tape and transferred to a hard drive. The time code was synchronized with data logging system and both the time code and PM_{10} emission factored were added to the video display through post-processing. Since there are over 32 hours of video, it would be impractical to archive the data on DVDs. We will therefore copy several test runs from loops A, B, and C on a DVD for demonstration purposes and submit the full set of videos on a hard drive for archiving.

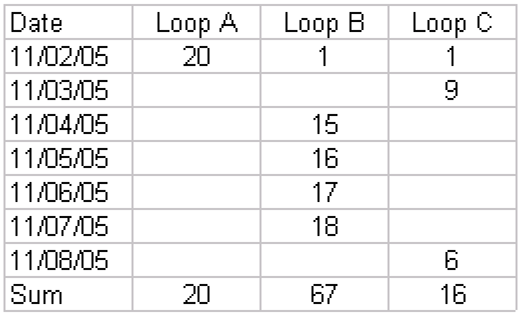
Figure 4-1. Sample plot of latitude and longitude on the same scale to choose start/stop points.



4.4 SUMMARY DESCRIPTION OF TEST LOOP RESULTS

A total of 103 test loops were completed over the seven test days. Table 4-1 shows the breakdown of the tests conducted.

Table 4-1. Summary of SCAMPER PM_{10} test loops conducted November 2-8, 2005.



Date	Loop A	Loop B	Loop C
11/02/05	20	1	1
11/03/05			9
11/04/05		15	
11/05/05		16	
11/06/05		17	
11/07/05		18	
11/08/05			6
Sum	20	67	16

4.4.1 Relationship of the DustTrak PM_{10} to Mass PM_{10} Measurements

A total of eight PM_{10} filter samples were collected collocated with the rear DustTrak. These 47mm Gelman Teflo filters were equilibrated to 70ºF and 45% RH prior to weighing. The average DustTrak PM_{10} was calculated for the intervals in which the filters were collected. Figure 4-2 shows a plot of these measurements. There is considerable scatter with a R^2 of 0.59. The point with the highest filter mass concentration seems to fall low on the plot. If this point is removed the R^2 value increases to 0.83 and the slope is 1.25 as shown in Figure 4-3. In both cases the intercept is higher than the near zero expected. Given the amount of variability, this comparison should be used to qualitatively show that the measurements are equivalent.

Additional comparisons between Filter and DustTrak PM_{10} measurements were conducted as a part of the Phase IV study. These comparisons also showed considerable amounts of scatter for both field and laboratory comparisons. Based on the more consistent laboratory comparison, a factor of 2.4 was used to convert DustTrak PM_{10} concentrations to mass-based PM_{10} concentrations. A more extensive field comparison using the SCAMPER in Phoenix, AZ gave a correction factor of 3.4. While this indicates a similar trend, this factor is not recommended for use in Clark County.

In the following tables we also show emission rates corrected by a factor of 2.4. This was not done for the time series plots since the objective of these plots is to show the emission rate variability.

Figure 4-2. Plot of PM_{10} filter mass concentration vs average DustTrak concentration.

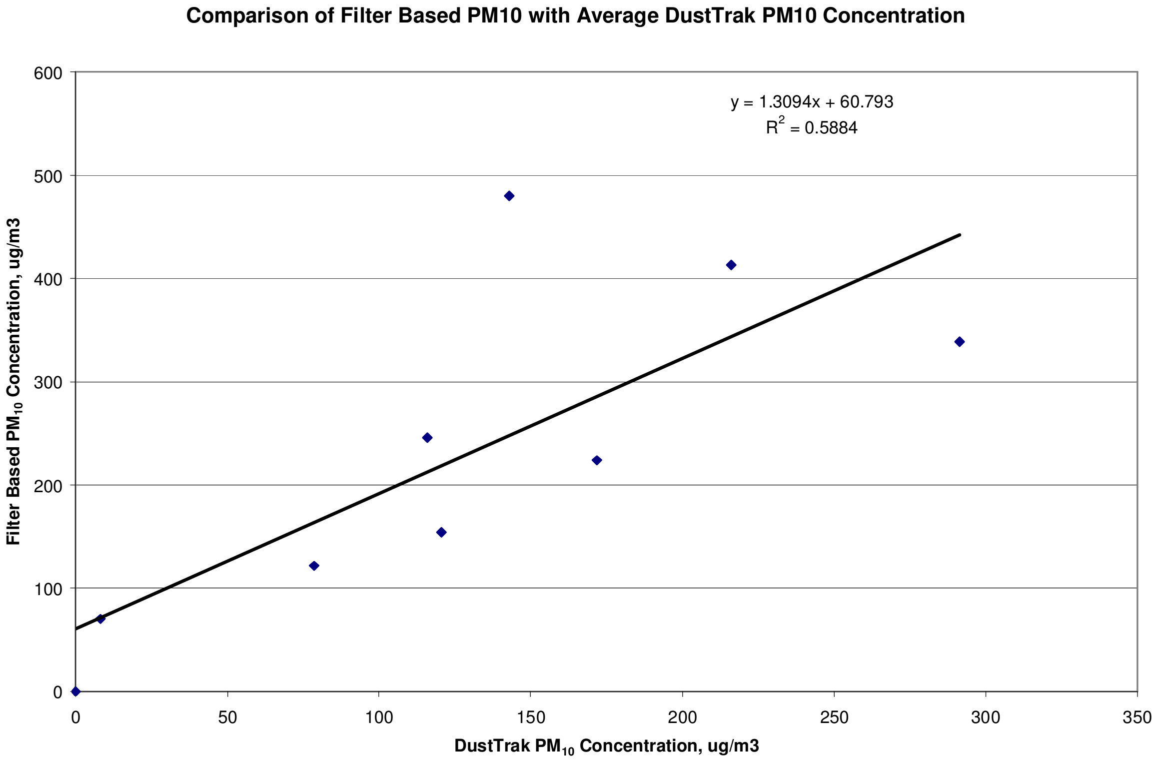
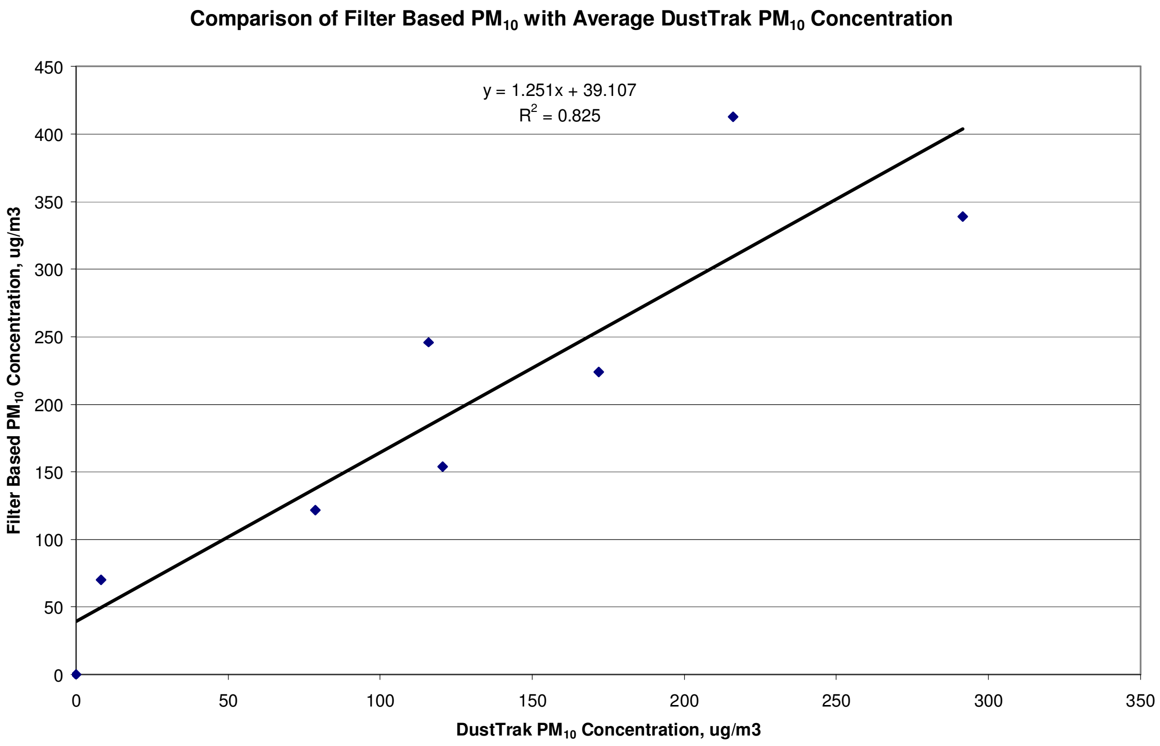


Figure 4-3. Figure 4-2. Plot of PM_{10} filter mass concentration vs average DustTrak concentration with highest filter concentration removed.



4.4.2 Test Loop A (Gowan)

Figure 4-4 shows a time series of the test runs conducted on 11/02/04. The data consists of a series of peaks, presumably due to the inconsistent deposit of silt on the roads. The pattern is fairly consistent except for one high dust episode that was encountered at 11:10 am. Table 4-2 summarizes the average values for each loop performed. The average speed was very consistent at 33 mph. The mean PM_{10} emission rate was 0.52 mg/m with a standard deviation of 0.19 mg/m. The overall relative variability (measurement and environmental) was therefore 37%. Given the variation of traffic and dust production observed, a measurement with this amount of variability was considered very good.

The PM_{10} emission rate was also calculated for specific segments where silt sampling was conducted. The segment was defined as the block in which the sampled area was located. If the sampled area was near the end of a block, the next block was included. For test loop A the entire section of Gowan road was defined the segment. The mean PM_{10} emission rate for all traverses was 0.94 mg/m with a standard deviation of 0.46 mg/m^3.

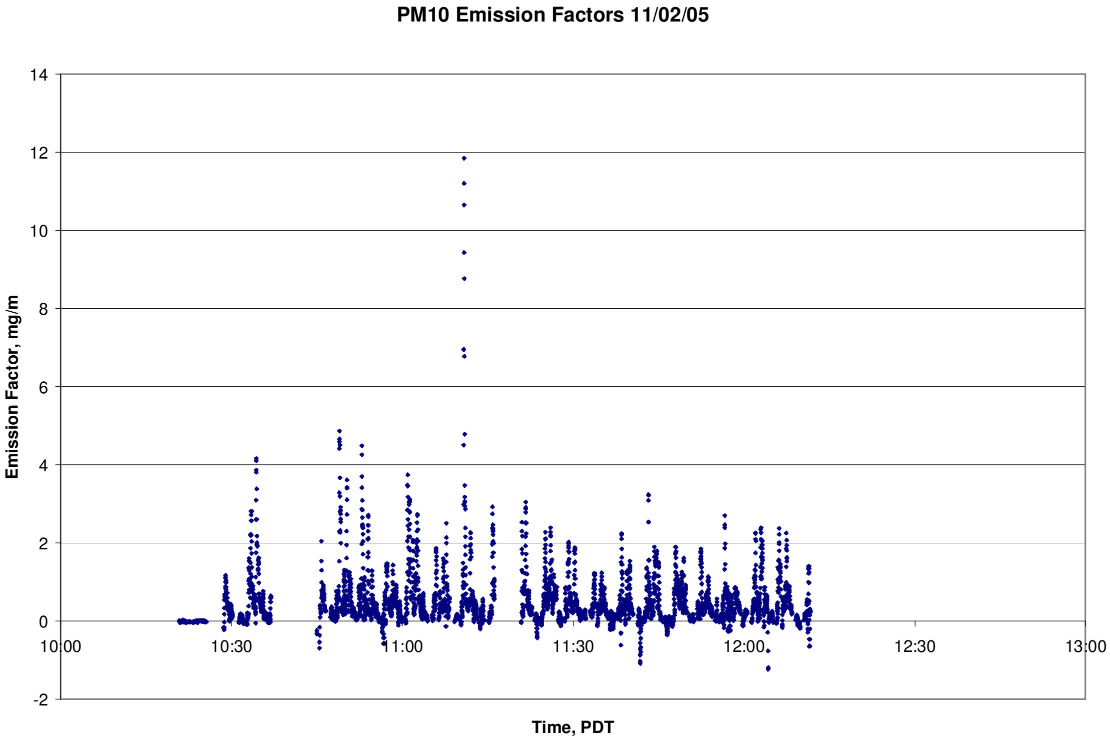
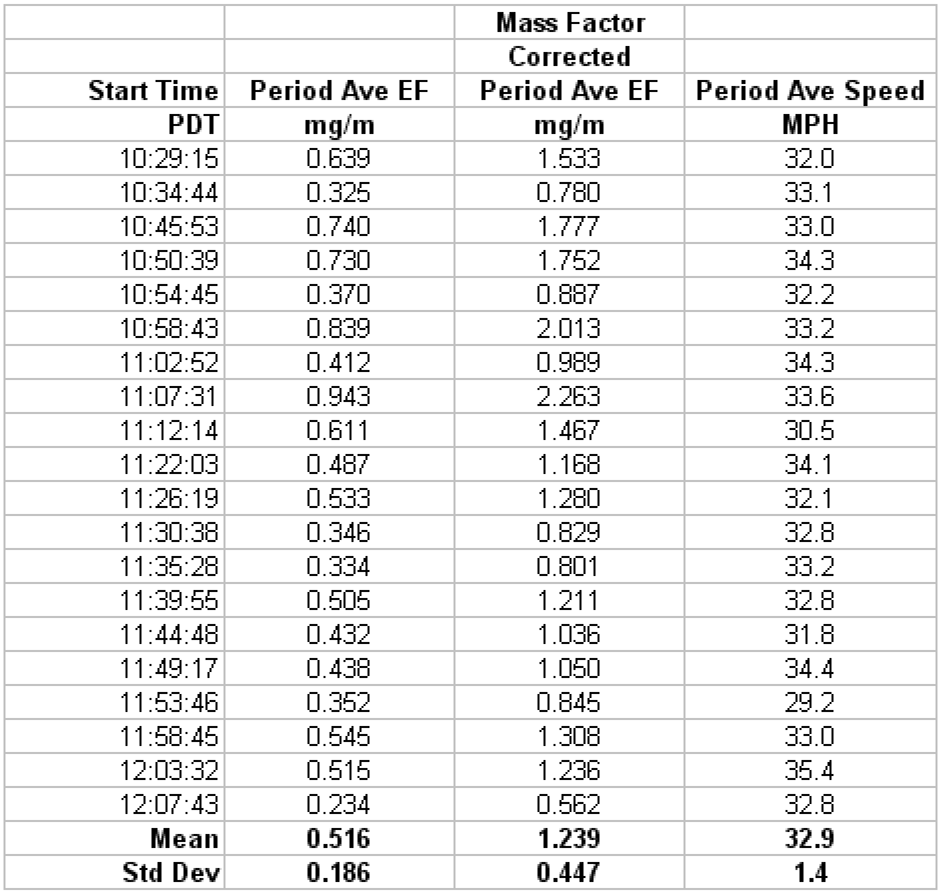


Figure 4-4. Test runs conducted on loop A (Gowan) on 11/02/05.

Table 4-2. Summary of test loop A (Gowan) runs.



		Mass Factor	
		Corrected	
Start Time	**Period Ave EF**	**Period Ave EF**	**Period Ave Speed**
PDT	**mg/m**	**mg/m**	**MPH**
10:29:15	0.639	1.533	32.0
10:34:44	0.325	0.780	33.1
10:45:53	0.740	1.777	33.0
10:50:39	0.730	1.752	34.3
10:54:45	0.370	0.887	32.2
10:58:43	0.839	2.013	33.2
11:02:52	0.412	0.989	34.3
11:07:31	0.943	2.263	33.6
11:12:14	0.611	1.467	30.5
11:22:03	0.487	1.168	34.1
11:26:19	0.533	1.280	32.1
11:30:38	0.346	0.829	32.8
11:35:28	0.334	0.801	33.2
11:39:55	0.505	1.211	32.8
11:44:48	0.432	1.036	31.8
11:49:17	0.438	1.050	34.4
11:53:46	0.352	0.845	29.2
11:58:45	0.545	1.308	33.0
12:03:32	0.515	1.236	35.4
12:07:43	0.234	0.562	32.8
Mean	**0.516**	**1.239**	**32.9**
Std Dev	**0.186**	**0.447**	**1.4**

4.4.3 Test Loop B (Washburn)

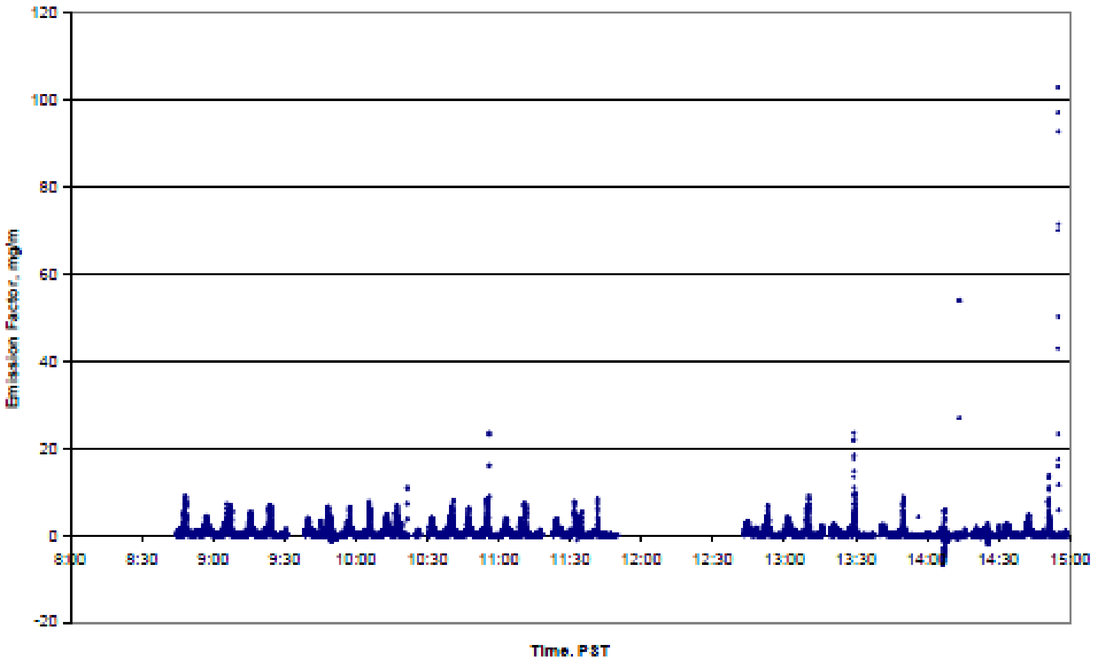
Figure 4-5 shows a time series of the test runs conducted on November 4th and 5th 2005, while Figure 4-6 shows the time series for November 6th and 7th. These data also show a series of peaks. The patterns are consistent except for several high dust episodes that were encountered. Table 4-3 summarizes the average values for each loop performed and verifies the consistency with a daily mean PM_{10} emission rate of ranging from 0.35 to 1.07 mg/m. The daily overall relative variability ranged from 23-30%. As in the loop A testing, this was considered to be better than expected precision given the multiple and changing sources. Both of the weekend days were significantly lower, by almost a factor of two. The jump in emission rate from Sunday to Monday was particularly striking. The average speed was consistent at 29 mph for all four days.

The mean PM_{10} emission rates were calculated for each of the three segments for which silt sampling was conducted. The following overall average (all days) emission rate results were obtained:

Emerald Stone and Sapphire Light: average: 2.20 mg/m; standard deviation: 1.18 mg/m
Lone Mountain and Losee: average: 0.43 mg/m; standard deviation: 0.68 mg/m
Goldfield and Washburn: average: 0.78 mg/m; standard deviation: 1.27 mg/m

As expected, the variability for a single segment is higher than that of the entire route.

Figure 4-5. Time series of emission factors measured on loop B (Washburn) on 11-04-05 and 11-05-05.


PM10 Emission Factors on Loop B 11-04-05

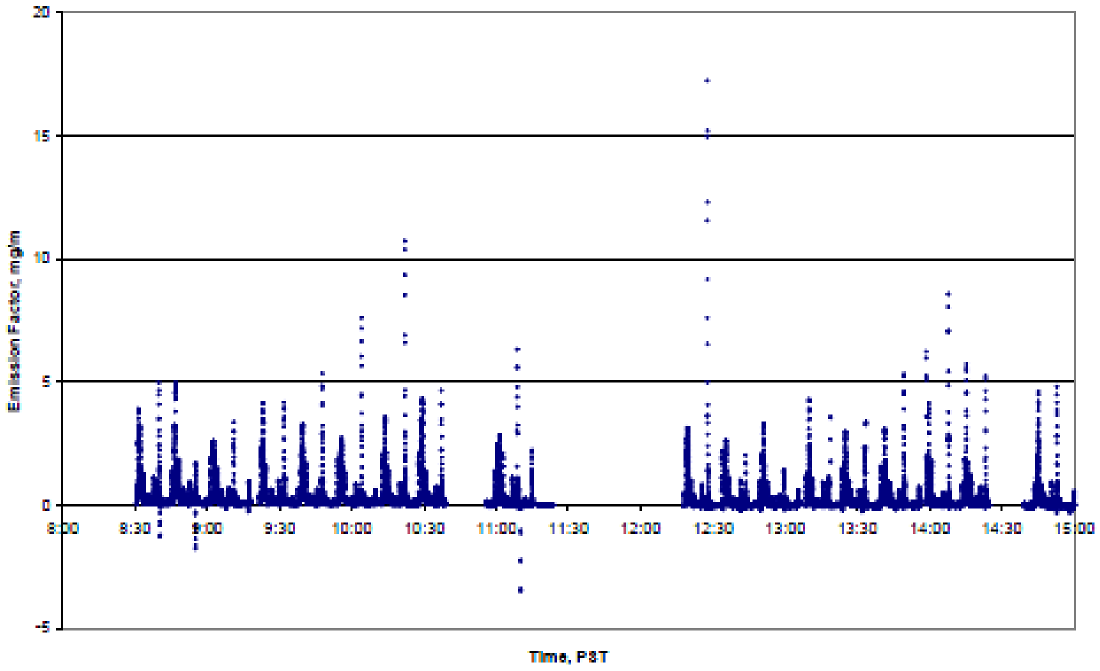
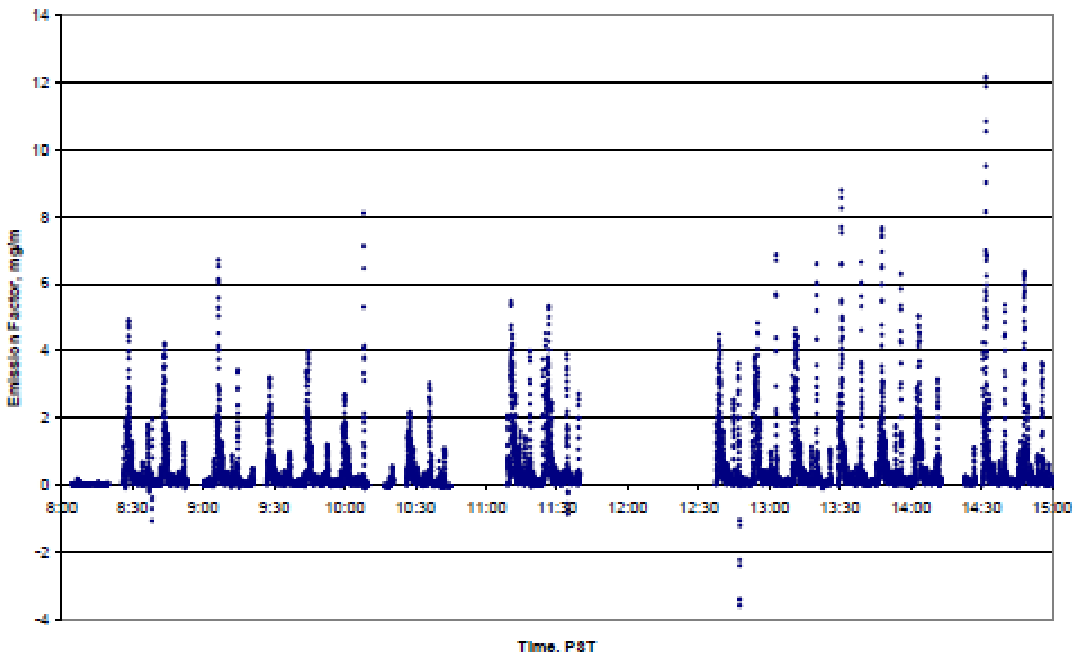

PM10 Emission Factor on Loop B on 11-05-05

Figure 4-6. PM$_{10}$ emission factor for loop B (Washburn) on 11-06-05 and 11-07-05.

PM10 Emission Factors on Loop B on 11-0605



PM10 Emission Factors on Loop B on 11-07-05

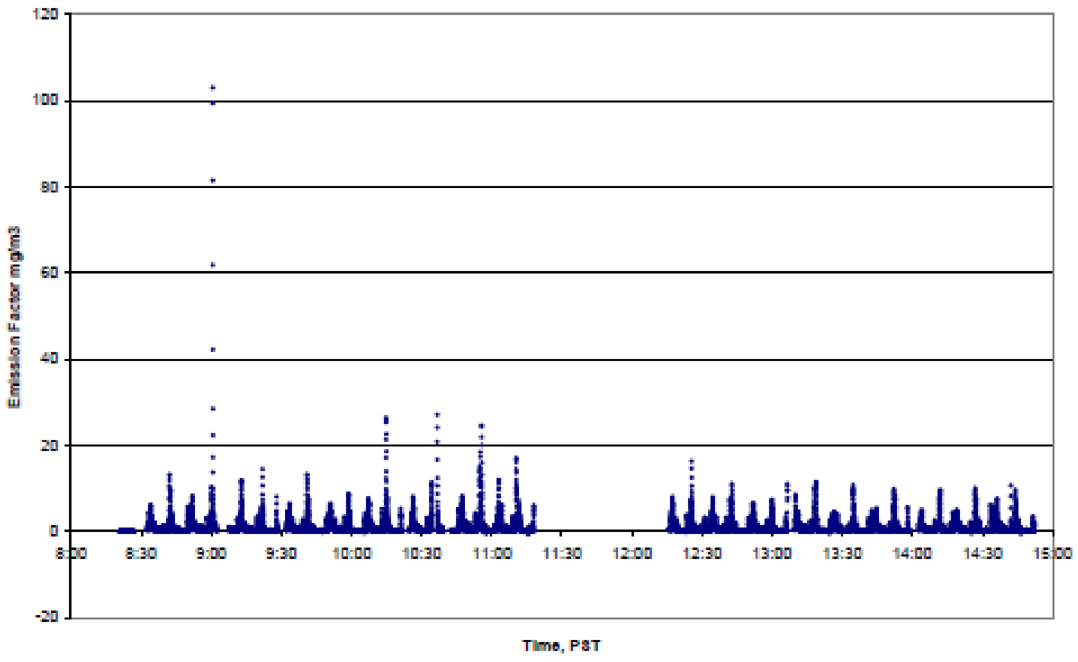


Table 4-3. Summary of test runs on loop B (Washburn)

Date	Period Start Time	Period Ave EF	Mass Factor Corrected Period Ave EF	Period Ave Speed
	PDT	mg/m	mg/m	MPH
11/02/05	13:31:09	0.601	1.444	27.1
11/02/06	13:48:13	0.826	1.983	28.1
11/02/05	**Mean**	**0.714**	**1.713**	**0.7**
11/02/06	**Std Dev**	**0.159**	**0.382**	**0.2**
11/04/06	8:56:01	0.758	1.819	27.2
11/04/06	9:14:33	0.813	1.951	28.4
11/04/06	9:38:56	0.658	1.578	28.3
11/04/06	9:56:01	0.702	1.685	29.5
11/04/06	10:11:50	0.982	2.356	28.3
11/04/06	10:30:44	0.860	2.064	29.8
11/04/06	10:46:14	0.911	2.186	29.3
11/04/06	11:01:55	0.708	1.700	29.5
11/04/06	11:23:08	0.641	1.539	29.0
11/04/06	12:43:22	0.634	1.521	28.8
11/04/06	13:00:09	0.695	1.669	29.5
11/04/06	13:19:30	0.810	1.945	29.0
11/04/06	13:40:31	0.507	1.217	28.6
11/04/06	13:56:40	0.368	0.884	29.5
11/04/06	14:13:59	0.145	0.349	28.7
11/04/06	**Mean**	**0.680**	**1.631**	**28.9**
11/04/06	**Std Dev**	**0.213**	**0.511**	**0.7**
11/05/05	8:30:42	0.50	1.188	30.5
11/05/05	8:45:37	0.435	1.045	29.9
11/05/05	9:01:35	0.364	0.874	28.9
11/05/05	9:21:53	0.421	1.010	29.6
11/05/05	9:38:25	0.403	0.967	29.9
11/05/05	9:54:31	0.410	0.984	29.3
11/05/05	10:12:47	0.473	1.136	29.9
11/05/05	10:59:48	0.373	0.896	30.9
11/05/05	12:18:15	0.387	0.928	29.2
11/05/05	12:34:03	0.213	0.511	29.7
11/05/05	12:49:48	0.213	0.511	29.0
11/05/05	13:08:29	0.276	0.663	29.7
11/05/05	13:23:43	0.273	0.655	29.6
11/05/05	13:40:02	0.320	0.767	29.7
11/05/05	13:58:35	0.332	0.796	30.1
11/05/05	14:43:52	0.270	0.648	30.5
11/05/05	**Mean**	**0.354**	**0.849**	**29.8**
11/05/05	**Std Dev**	**0.087**	**0.209**	**0.5**
11/06/05	8:27:07	0.371	0.890	29.4
11/06/05	8:42:24	0.317	0.760	28.9
11/06/05	9:05:09	0.355	0.852	29.1
11/06/05	9:27:03	0.276	0.662	28.6
11/06/05	9:43:17	0.306	0.734	29.5
11/06/05	10:26:20	0.210	0.504	29.1
11/06/05	11:09:48	0.617	1.482	31.0
11/06/05	11:24:30	0.586	1.406	30.4
11/06/05	12:37:37	0.535	1.285	19.8
11/06/05	12:53:18	0.501	1.201	28.8
11/06/05	13:10:11	0.478	1.146	28.3
11/06/05	13:29:20	0.528	1.268	28.2
11/06/05	13:46:00	0.502	1.206	28.9
11/06/05	14:30:31	0.598	1.436	28.7
11/06/05	14:46:10	0.487	1.168	29.9
11/06/05	15:01:51	0.505	1.212	28.4
11/06/05	**Mean**	**0.448**	**1.076**	**28.6**
11/06/05	**Std Dev**	**0.125**	**0.300**	**2.5**
11/07/05	8:32:56	0.990	2.377	27.9
11/07/05	8:50:32	1.783	4.278	29.3
11/07/05	9:11:50	1.086	2.607	28.6
11/07/05	9:32:17	0.960	2.304	28.2
11/07/05	9:49:55	0.876	2.103	28.1
11/07/05	10:06:17	1.327	3.186	30.6
11/07/05	10:24:49	1.124	2.699	29.5
11/07/05	10:46:26	1.386	3.326	29.3
11/07/05	11:01:58	1.278	3.067	30.0
11/07/05	12:16:13	0.985	2.365	29.8
11/07/05	12:33:33	0.944	2.265	29.7
11/07/05	12:50:24	0.952	2.286	29.6
11/07/05	13:09:49	1.107	2.657	30.3
11/07/05	13:25:28	0.907	2.178	29.1
11/07/05	13:43:17	0.868	2.083	29.4
11/07/05	14:02:55	0.852	2.044	29.7
11/07/05	14:18:03	0.963	2.312	28.5
11/07/05	14:34:59	0.831	1.994	29.2
	Mean	**1.068**	**2.563**	**29.3**
	Std Dev	**0.242**	**0.582**	**0.8**

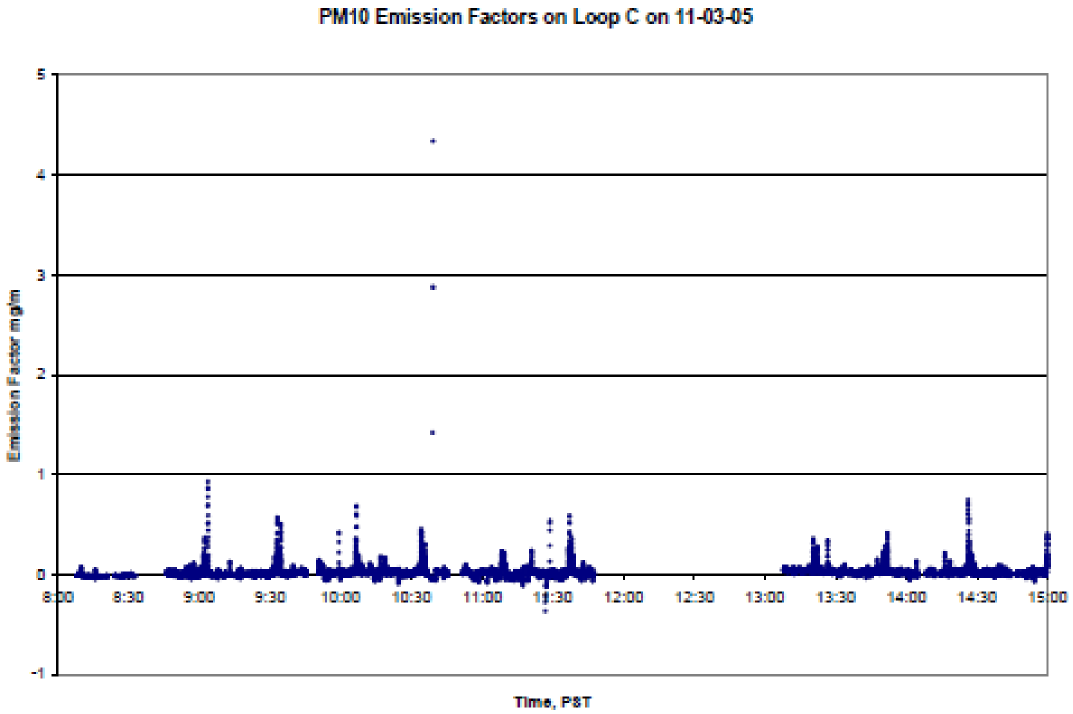
4.4.4 Test Loop C (Summerlin)

Figure 4-7 shows time series plots of the emission rates for loop C on November 3rd and 8th, 2005. On November 8th, problems were encountered with erratically high measurements from the DustTrak in the front of the vehicle. While we removed the values that were obviously bad, there was still a period of time between 10:30 and 11:00 when high values of the front DustTrak caused the calculation of negative PM_{10} emission rates. Table 4 shows the average PM_{10} emission rate for each of the loop C test runs. On November 3rd, when the DustTraks were operating properly, the average PM_{10} emission rate was 0.027 mg/m, about a factor of twenty less than the other loops that were chosen for high potential PM_{10} emission rates. Despite these much lower rates, the relative variability was 30%, consistent with values obtained from the other loops. Although the PM_{10} emission rates on November 8th were erratic, the mean rate was 0.034, consistent with data collected on the 2nd and 3rd of November, but the relative variability was 100%. All the mean loop speeds were consistently 31 mph.

The mean PM_{10} emission rates were calculated for each of the three segments for which silt sampling was conducted. The following average (all days) PM_{10} emission rates were obtained:
Crestdale and Hillpointe: mean = 0.04 mg/m; standard deviation = 0.07 mg/m
Banbury Cross and Crestdale: mean = 0.02 mg/m; standard deviation = 0.02 mg/m
Aspen Glow and Warm Walnut: mean = 0.17 mg/m; standard deviation = 0.0.10 mg/m

The standard deviation of the measurements was elevated due in part to the erratic response of the front DustTrak on November 8th, which produced some negative values, although negative values were also obtained on November 3rd. It is likely that some of these negative values were a result of measurements very near the detection limit of the instruments and the noise in the emission factor may be due to slight zero drift, which cannot be completely eliminated. An emission factor of 0.02 represents a net concentration difference of only 0.005 mg/m^3, which is well within expected daily drift. The conclusion is that comparison of emission rates with silt sampling on "clean" portions of roads will generally be near the SCAMPER detection limit and therefore will produce data with low confidence limits.

Figure 4-7. Time series of PM_{10} emission factors on loop C (Summerlin) on 11-03-05 and 11-08-05.



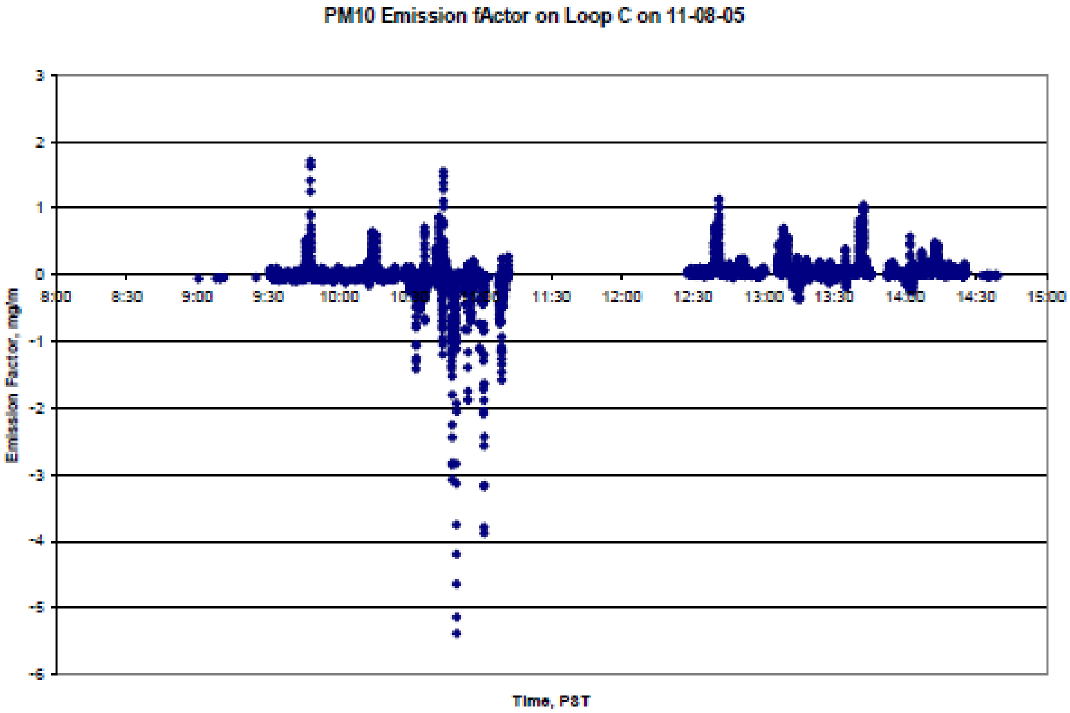


Table 4-4. Summary of test runs on loop C (Summerlin).

			Mass Factor	
			Corrected	
Date	Period Start Time	Period Ave EF	Period Ave EF	Period Ave Speed
	PDT	mg/m	mg/m	MPH
11/02/05	14:56:00	0.015	0.035	30.5
11/03/05	8:46:11	0.019	0.046	31.0
11/03/05	9:13:35	0.022	0.054	30.8
11/03/05	9:45:34	0.030	0.072	31.6
11/03/05	10:17:47	0.039	0.093	32.6
11/03/05	10:45:25	0.021	0.051	31.2
11/03/05	11:19:48	0.039	0.093	31.0
11/03/05	13:33:18	0.032	0.078	29.4
11/03/05	14:04:49	0.032	0.078	30.8
11/03/05	14:40:26	0.022	0.052	30.2
	Mean	**0.029**	**0.068**	**31.0**
	Std Dev	**0.008**	**0.018**	**0.9**
11/08/05	9:30:58	0.011	0.027	30.3
11/08/05	9:58:32	0.009	0.021	31.8
11/08/05	10:27:33	-0.006	-0.014	31.2
11/08/05	12:50:27	0.061	0.146	30.5
11/08/05	13:22:40	0.077	0.184	29.8
11/08/05	13:54:02	0.054	0.129	30.5
11/08/05	**Mean**	**0.034**	**0.082**	**30.7**
11/08/05	**Std Dev**	**0.034**	**0.081**	**0.7**

4.4.5 Meteorological Considerations

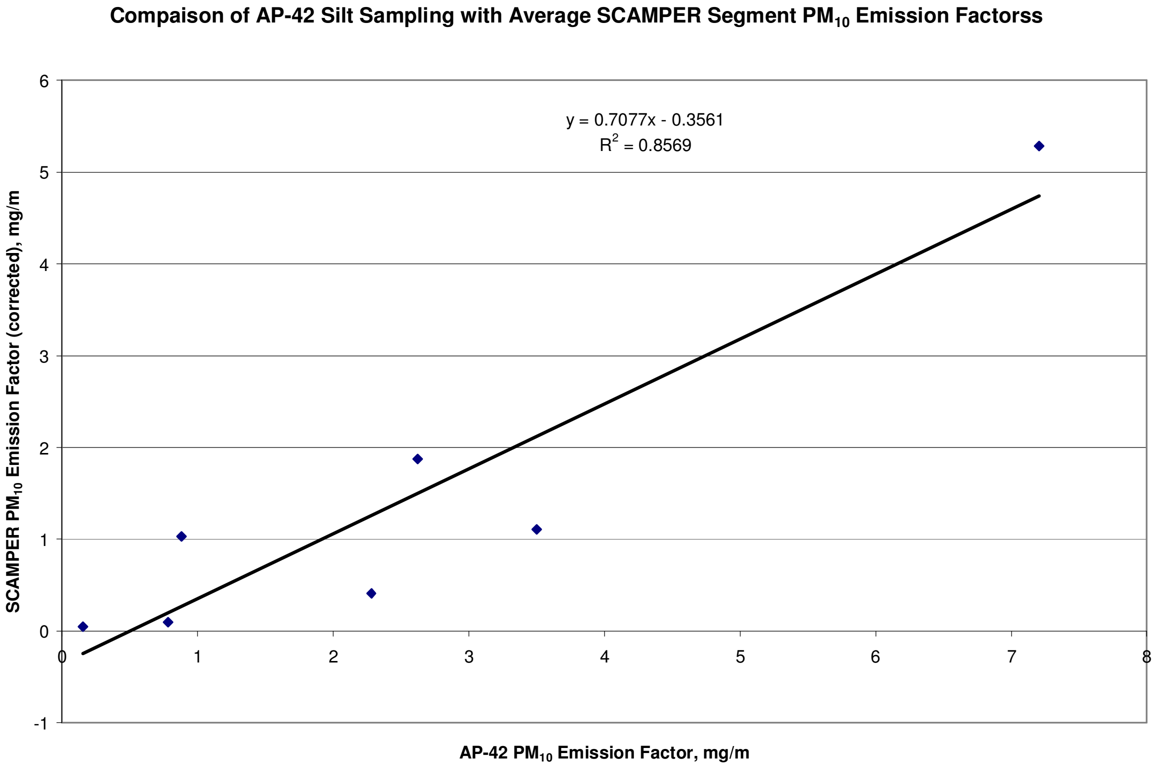
Meteological conditions can affect both the SCAMPER measurement and the PM_{10} emission rates of roads. For SCAMPER, side winds greater than approximately 15mph may move the PM_{10} plume from the measurement location in back. Strong winds may also increase the amount of PM_{10} in the background measured in front of the SCAMPER, thus adding to the uncertainty of the measurement. Relative humidity (without rain) may have an effect on PM_{10} emission rates but this effect has not been quantified. As long as the relative humidity is typical for the season in which the measurements were made, then the emission rates will be valid for the season.

SCAMPER PM_{10} emission rate measurements were made during normal business hours from November 2-8, 2005 inclusive. T&B Systems conducted an assessment of the meteorological conditions for the past five years and a more focused review of the September-October 2005 time period. This assessment is included as Appendix A. During this study the temperatures ranged from normal of 15°C to as much as 5°C above normal. Relative humidities ranged from 20% to the normal of 36%. The test days were therefore somewhat warmer and drier than normal. The daily wind speeds ranged from 2-6 mph compared to the normal of 4mph. Although the wind speeds were somewhat lower than normal, there were significant gusts, up to 15mph on November 2nd. Although these wind gusts may have had a small effect on SCAMPER measurements, they were relatively short in duration and, based on DAQEM data, had only a slight effect on PM_{10} concentrations. While there was a major precipitation event on October 17 and 18, 2005, no further precipitation was recorded through the end of the study period. This precipitation event should have no effect on the PM_{10} emission rates two weeks later.

4.5 COMPARISON OF SCAMPER AND AP-42 SILT SAMPLING EMISSION RATES

Figure 4-8 is a plot of the emission factors calculated from AP-42 silt sampling compared with that of the average value (corrected for the mass correction factor) obtained from the SCAMPER for the seven segments of roads where the silt sampling was conducted. All days were included for the SCAMPER data. The R^2 value from the least squares regression is 0.85 and the slope is 0.71, indicating that the SCAMPER emission rates are nearly equal to those derived from silt sampling. The correlation, however, is driven by the single high emission location (Emerald Stone and Sapphire Light). The primary conclusion is that SCAMPER and AP-42 emission rates are generally correlated. This result has been consistently observed from previous phases of this study and reported upwind-downwind emission rate determinations from paved roads (Ashbaugh et. al, 1996, Claiborn et al., 1995, Harding and Lawson, 1996, Kantamaneni et al., 1996, and Venkatram and Fitz, 1998). Correlations are not necessarily expected to be high since silt loading is merely a surrogate for the direct PM emission measurement.

Figure 4-8. Comparison of PM_{10} emission rates determined by AP-42 silt sampling and the average segment values obtained with the SCAMPER.



4-6 SPECIAL SEGMENT ANALYSES

A list of segments was supplied by DAQEM personnel that were typical of roads with unpaved shoulders, near construction activities, and next to vacant land. Table 4-5 shows these segments along with the coordinates of the endpoints that were obtained from a Google Earth interactive map. For the vacant land comparison intersection endpoints were not supplied so we chose the endpoints from a Google Earth aerial photographs. All of these segments were from loop B.

Table 4-6 shows the mean PM_{10} emission rate averaged over all of the test runs along with the standard deviation. The PM_{10} emissions on Losse were a factor of two higher on the segment with unpaved shoulders. Craig was over a factor three higher than Lone Mountain between Bruce and Donna. For the collectors the PM_{10} emission rates on Washburn with curbs and gutters was between that of segments of Washburn and Bruce that had only partial shoulder improvement. Except for 5th St, all of the construction segments were higher than typical improved roads without construction activities. The two roads with vacant land along side were only somewhat higher than 5th St.

Table 4-5. Road segments typical of roads with unpaved shoulders or near contraction activities or vacant land.

Segment Description	Intersection 1	Intersection 2	Latitude 1	Latitude 2	Longitude 1	Longitude 2
Unpaved shoulders						
Arterial: Losee	Washburn	Lone Mountain	36.254267	36.247053	-115.116938	-115.117080
Curbed Comparison Arterial: Losee	Lone Mountain	Craig	36.246774	36.239811	-115.116561	-115.117049
Arterial: Craig	Losee	5th St.	36.239912	36.23962	-115.116811	-115.134213
Arterial Assessment: Craig	Bruce	Donna	36.239869	36.23965	-115.125515	-115.129825
Arterial Assessment: Lone Mountain	Bruce	Donna	36.247064	36.246845	-115.125946	-115.130191
Collector: Washburn	Donna	Bruce	36.254364	36.254105	-115.125907	-115.130205
Collector: Washburn	Lawrence	Bruce	36.25433	36.254184	-115.12137	-115.12574
Collector: Bruce	Washburn	Lone Mountain	36.254063	36.247114	-115.125761	-115.125944
Construction Activities						
Arterial: Losee	Washburn	Lone Mountain	36.254267	36.247053	-115.116938	-115.117080
Collector: Washburn	Lawrence	Losee	36.254319	36.254201	-115.116971	-115.121302
Collector: Washburn	5th St.	Donna	36.254334	36.254096	-115.130289	-115.134673
Collector: 5th Street	Washburn	La Madre	36.254163	36.250555	-115.134579	-115.134878
Local: Donna	Washburn	Emerald Stone	36.25414	36.25153	-115.13025	-115.13044
Local: Emerald Stone	Sappire Light	Drifting Pebble	36.2517	36.251444	-115.126623	-115.129667
Local: Graphite Ash	Sappire Light	Drifting Pebble	36.247553	36.247401	-115.126581	-115.129506
Vacant Lands						
Arterial: Nevada Power Equipment on Losee	Lone Mountain	Parking Lot	36.246830	36.254364	-115.116561	-115.117049
Arterial: Losee north of Mendenhall	Parking Lot	Mendenhall	36.254178	36.241858	-115.116561	-115.117049

Table 4-6. PM$_{10}$ emission rates of segments typical of roads with unpaved shoulders or near contraction activities or vacant land.

UNPAVED SHOULDERS	PM10 EF mg/m Ave	PM10 EF mg/m Std Dev
Arterial		
Losee: Washburn to Lone Mountain - Two-lane road, gravel shoulders	1.85	0.85
Losee: Lone Mountain to Craig - Both road directions are paved, full curb and gutter	0.79	1.03
Craig: Losee to 5th Street - Full curb and gutter	0.12	0.14
Craig: Bruce to Donna - Full curb and gutter, vacant land on travel side	0.40	3.45
Lone Mountain: Bruce to Donna - Full curb and gutter	0.12	0.02
Collector		
Washburn: Donna to Bruce - Fully improved curb and gutter	0.43	0.26
Washburn: Lawrence to Bruce - No curb and gutter on travel side. Full improvements on opposite side	0.62	0.47
Bruce: Washburn to Lone Mountain - Curb and gutter on travel side. No curb and gutter, though stabilized on opposite side	0.32	0.15

CONSTRUCTION ACTIVITIES	PM10 EF mg/m Ave	PM10 EF mg/m Std Dev
Arterial		
Losee: Washburn to Lone Mountain - Roadway is a two lane road with gravel shoulders, limited construction	1.85	0.85
Collector		
Washburn: Lawrence to Losee - Narrow road, unpaved sholders	2.06	1.77
Washburn: 5th Street to Donna - no curb and gutter on travel side, opposite side has full improvements and limited landscaping	0.70	0.35
5th Street: La Madre to Washburn - New road construction with curb and gutter, travel side has partial construction activity	0.10	0.09
Local		
Emerald Stone: Drifting Pebble to Sapphire Light - Fully Improved. Track-out/on from construction activities.	1.87	0.81
Granite Ash: Sapphire Light to Drifting Pebble-- Fully improved. Limited track-out/on from construction activities.	0.87	0.21

VACANT LANDS	PM10 EF mg/m Ave	PM10 EF mg/m Std Dev
Arterial		
Nevada Power Equipment: Losee - Unpaved	0.29	0.32
Industrial Lots North of Mendenhall: Losee - Paved industrial lots	0.29	0.19

5.0 SUMMARY AND CONCLUSIONS

The overall relative variability of PM_{10} emission measurements using the SCAMPER was consistently 25-30%. Since these values include environmental uncertainty, the precision of the SCAMPER measurement method is most likely considerably less than this. The data summarized in the previous section show that PM_{10} emission rates were generally near the detection limit except when occasional “hot spots” were encountered, which show up as spikes and peaks. This is consistent with all of the previous SCAMPER data we have collected.

The test loops chosen for high PM_{10} emission potential gave rates about a factor of twenty higher than the loop chosen for minimal PM_{10} potential. No significant change of PM_{10} emission rates was observed during the course of the day. The emissions on the high potential test route dropped by a factor of two on weekend days.

The comparison of averaged SCAMPER segment data with AP-42 silt sampling at seven test sites resulted in an R^2 of 0.86 with the SCAMPER results lower by about a factor of three.

The results show that SCAMPER measurement system is useful for both quantitatively identifying PM_{10} “hot spots” and determining the overall emission rate from roadways with a known and acceptable precision. Since SCAMPER is a more direct measure of PM emission rates, we suggest that it is a more accurate measurement of rates than silt sampling.

6.0 REFERENCES

Ashbaugh, L.; Chang, D.; Flocchini, R.G.; Carvacho, O.F.; James, T.A.; and Matsumara, R.T. Traffic Generated PM_{10} "Hot Spots"; Air Quality Group, Crocker Nuclear Laboratory, University of California, Davis, August 1996.

Claiborn, C.; Mitra, A.; Adams, G.; Bamesberger, L.; Allwine, G.; Kantamaneni, R.; Lamb, B.; Westberg, H. Evaluation of PM_{10} Emission Rates from Paved and Unpaved Roads Using Tracer Techniques; *Atmos. Environ.* **1995**, *29*, 1075-1089.

Fitz, D.R. Measurements of PM_{10} and $PM_{2.5}$ emission factors from paved roads in California. Final Report to the California Air Resources Board under Contract 98-723, June 2001.

Fitz, D.R.and C. Bufalino. 2002. Measurement of PM_{10} emission factors from paved roads using on-board particle sensors. Air and Waste Management Association Symposium on Air Quality Measurement Methods and Technology – 2002. San Francisco, CA November 13-15.

Fitz, D.R., Bumiller, K., Etymezian, V., Kuhns, H., and Nikolich, G. 2005a Measurement of PM_{10} Emission Rates from Roadways in Las Vegas, Nevada using a SCAMPER Mobile Platform with Real-Time Sensors. Presented at the U.S. Environmental Protection Agency's 13th Annual Emission Inventory Conference: Transforming Emission Inventories, Meeting Future Challenges Today. Las Vegas, NV April 12-14.

Fitz, D.R., Bumiller, K., Etymezian, V., Kuhns, H., and Nikolich, G. 2005b Measurement of PM_{10} Emission Rates from Roadways in Las Vegas, Nevada Using a Mobile Platform and Real-Time Sensors and Comparison with the TRAKER. Presented at the 98th Annual Air and Waste Management Association Meeting. Minneapolis-St. Paul, MN, June 21-24.

Harding Lawson Associates, Final Report for the 1993-1994 ADEQ Paved Road Emissions Research Study; Maricopa Association of Governments, 1996.

Kantamaneni, R.; Adams, G.; Bamesberger, L.; Allwine, E.; Westberg, H.; Lamb, B.; Claiborn, C. The Measurement of Roadway PM_{10} Emission Rates Using Atmospheric Tracer Ratio Techniques; *Atmos. Environ.* **1996**, *24*, 4209-4223.

Venkatram, A., and Fitz, D. Measurement and Modeling of PM_{10} and $PM_{2.5}$ Emissions from Paved Roads in California. Final Report; California Air Resources Board Contract 94-336, 1998.

APPENDIX A

Las Vegas Meteorological Assessment for the Years 2001 Through 2005

M E M O R A N D U M

To:	Rodney Langston
From:	Robert A. Baxter, CCM David Yoho
Subject:	Las Vegas meteorological assessment for years 2001 through 2005
Date:	July 28, 2006
Cc:	

A five-year meteorological assessment, which includes the years from 2001 through 2005 was conducted to identify seasonal climatological averages (running 30- year "normal") and variations (departure from "normal") leading up to and during the Phase III Scamper project, which occurred in Fall of 2005. Monthly data were analyzed over a seasonal (three-month period) for each year and includes the months of September, October and November. The four years prior to the SCAMPER project from 2001 through 2004 were analyzed to characterize the climatological conditions and trends leading up to the study and to provide a basis for comparison to what was observed during the SCAMPER effort in 2005. A more detailed analysis was conducted for the period in 2005 that was originally anticipated for the SCAMPER study from October 19 through October 25 and for the period when the actual measurements were made, which was from November 2 through November 8. For these periods, daily averages and departures from averages were calculated to determine if anomalous conditions were present during the SCAMPER study period. PM_{10} concentrations during the study period were also evaluated to identify periods of abnormally high or low concentrations, which may have been attributed to unseasonable meteorological conditions. For each of the analysis tasks, archived monthly and daily meteorological data from the National Weather Service (NWS) office at McCarran International Airport were used and include ambient temperature, relative humidity, wind speed and gust, and precipitation. The Department of Air Quality and Environmental Management (DAQEM) in Clark County provided the PM_{10} data for evaluation.

Table 1 through **Table 4** present data, which include monthly normal (September, October and November), seasonal normal (three month average including September through November) and observed variations for years 2001 through 2005 and include ambient temperature, relative humidity and wind speed. Precipitation is expressed as percent of normal for the indicated period. **Figure 1**

through **Figure 8** present plots of the monthly and seasonal normals and observed variations for years 2001 through 2005. Precipitation data are presented as a percent of normal for the indicated period. **Figure 9** through **Figure 20** present plots of the daily meteorological observations compared to both daily or monthly normals for the period during the SCAMPER project and include the months of September, October and November of 2005. Daily normal data were not available for relative humidity, wind speed and precipitation. For these variables, with the exception of precipitation, monthly normal data were used for the comparison to the observed daily values. Precipitation is presented as the total observed for the indicated period. **Figure 21** through **Figure 24** present plots of the observed 24-hour average PM_{10} concentrations from all DAQM sites for October and November 2005. PM_{10} plots are also presented during the anticipated SCAMPER study period from October 19 through October 25 and during the actual study period, which occurred from November 2 through November 8.

The following is a description of the meteorlogical conditions observed between the years 2001 through 2005 and include measured monthly and seasonal data, which were compared to the calculated 30-year monthly normal values.

As seen in **Table 1**, seasonal temperatures were near normal with some years reporting averages above and below the seasonal normal. Fall 2001 experienced the greatest temperature departure with 2.2°C above the seasonal average of 20.2°C. **Table 2** presents the seasonal relative humidity with all years reporting values slightly higher than the indicated seasonal normal. **Table 3** presents the observed wind speeds, which were near or slightly lower than the indicated seasonal normal. As seen in **Table 4**, seasonal precipitation was below normal during 2001 and 2002 and above normal for years 2003, 2004 and 2005. Fall 2004 had the highest recorded precipitation with 2.48 inches being recorded, which is 288% above the seasonal normal of 0.86 inches.

The following is a description of the meteorological conditions observed at the time of the SCAMPER project in 2005 and includes the months of September, October and November. Additionally, a description of the observed PM_{10} concentrations that were recorded in October and November 2005 are presented to document any anomalous trends that may have been observed during the SCAMPER project.

The temperature departures in **Figure 9**, **10** and **11** can be characterized as near normal with departures of approximately ±5°C over the three month period. The temperatures in November **(Figure 11)** were slightly above normal for most of the period with a monthly departure of 2.4°C. The relative humidity departures presented in **Figure 12**, **13** and **14** were near normal for the indicated period. There were short periods of higher relative humidity in September and October with increased monsoonal moisture and associated precipitation. October 17, 2005 had an hourly relative humidity reading of 74%, which was associated with a precipitation event. Observed wind speeds presented in **Figure 15**, **16** and **17** can be characterized as normal to slightly below normal. Some periods had higher wind gusts with subsequent blowing dust. The highest gusts occurred on October 8 with a measured gust of 20.3 m/s with a documented observation of blowing dust at McCarran International Airport. There was no recorded precipitation for the months of September and November (**Figure 18** and **20**). October **(Figure 19)** experienced a relatively large precipitation event with 1.45 inches of rain measured at McCarran International Airport, which is over 600% of the monthly normal of 0.24 inches.

As can be seen in **Figure 21** through **Figure 24**, 24-hour average PM_{10} concentrations were generally normal across the DAQEM network during the months of October and November 2005. An exception to this occurred on October 18 when PM_{10} concentrations throughout the network were all below 12 $\mu g/m^3$, which was a result from heavy rainfall that fell throughout the Las Vegas area. As a result of the above normal rainfall, the original SCAMPER study period from October 19 through October 25 was postponed until November. PM_{10} concentrations during the study in November appear to be relatively normal with no obvious periods of anomalous concentrations.

Table 1. Monthly and seasonal temperature data for 2001 through 2005.

Month/Year	**Monthly Normal (°C)**	**Average Temperature (°C)**	**Departure (°C)**
Sep 2001	27.4	29.5	2.1
Sep 2002	27.4	28.2	0.8
Sep 2003	27.4	29.1	1.7
Sep 2004	27.4	27.6	0.2
Sep 2005	27.4	27.8	0.4
Oct 2001	20.4	22.3	1.9
Oct 2002	20.4	19.7	-0.7
Oct 2003	20.4	24.1	3.7
Oct 2004	20.4	20.1	-0.3
Oct 2005	20.4	21.3	0.9
Nov 2001	12.8	14.8	2.0
Nov 2002	12.8	13.7	0.9
Nov 2003	12.8	11.4	-1.3
Nov 2004	12.8	12.1	-0.7
Nov 2005	12.8	15.2	2.4
Season/Year	**Seasonal Normal (°C)**	**Average Temperature (°C)**	**Departure (°C)**
Fall 2001	20.2	22.2	2.2
Fall 2002	20.2	20.5	0.1
Fall 2003	20.2	21.6	-1.3
Fall 2004	20.2	19.9	0.3
Fall 2005	20.2	21.4	-1.3

Table 2. Monthly and seasonal relative humidity data for 2001 through 2005.

Month/Year	Monthly Normal (%)	Average Relative Humidity (%)	Departure (%)
Sep 2001	25	20	-5
Sep 2002	25	22	-3
Sep 2003	25	24	-1
Sep 2004	25	21	-4
Sep 2005	25	15	-10
Oct 2001	29	24	-5
Oct 2002	29	34	5
Oct 2003	29	24	-5
Oct 2004	29	28	-1
Oct 2005	29	27	-2
Nov 2001	36	38	2
Nov 2002	36	31	-5
Nov 2003	36	41	5
Nov 2004	36	45	9
Nov 2005	36	29	-7
Season/Year	**Seasonal Normal (%)**	**Average Relative Humidity (%)**	**Departure (%)**
Fall 2001	22	27	5
Fall 2002	21	29	8
Fall 2003	22	30	8
Fall 2004	20	31	11
Fall 2005	21	24	3

Table 3. Monthly and seasonal wind speed data for 2001 through 2005.

Month/Year	Monthly Normal (m/s)	Average Wind Speed (m/s)	Departure (m/s)
Sep 2001	4.0	3.5	-0.5
Sep 2002	4.0	3.3	-0.7
Sep 2003	4.0	3.1	-0.9
Sep 2004	4.0	3.3	-0.7
Sep 2005	4.0	3.5	-0.5
Oct 2001	3.6	2.7	-0.9
Oct 2002	3.6	2.4	-1.2
Oct 2003	3.6	2.7	-0.9
Oct 2004	3.6	3.1	-0.5
Oct 2005	3.6	3.1	-0.5
Nov 2001	3.4	3.1	-0.3
Nov 2002	3.4	2.7	-0.7
Nov 2003	3.4	2.3	-1.1
Nov 2004	3.4	2.9	-0.5
Nov 2005	3.4	2.3	-1.1
Season/Year	**Seasonal Normal (m/s)**	**Average Wind Speed (m/s)**	**Departure (m/s)**
Fall 2001	3.7	3.1	-0.6
Fall 2002	3.7	2.8	-0.9
Fall 2003	3.7	2.7	-1.0
Fall 2004	3.7	3.1	-0.6
Fall 2005	3.7	3.0	-0.7

Table 4. Monthly and seasonal precipitation data for 2001 through 2005.

Month/Year	Monthly Normal (inches)	Total Precipitation (inches)	% of Normal
Sep 2001	0.28	0.00	0
Sep 2002	0.31	0.31	100
Sep 2003	0.31	0.52	168
Sep 2004	0.31	0.18	58
Sep 2005	0.31	0.00	0
Oct 2001	0.21	0.00	0
Oct 2002	0.24	0.32	133
Oct 2003	0.24	0.00	0
Oct 2004	0.24	0.59	246
Oct 2005	0.24	1.45	604
Nov 2001	0.43	0.09	21
Nov 2002	0.31	0.12	39
Nov 2003	0.31	0.61	197
Nov 2004	0.31	1.71	552
Nov 2005	0.31	0.00	0
Season/Year	Seasonal Normal (inches)	Total Precipitation (inches)	% of Normal
Fall 2001	0.92	0.09	10
Fall 2002	0.86	0.75	87
Fall 2003	0.86	1.13	131
Fall 2004	0.86	2.48	288
Fall 2005	0.86	1.45	169

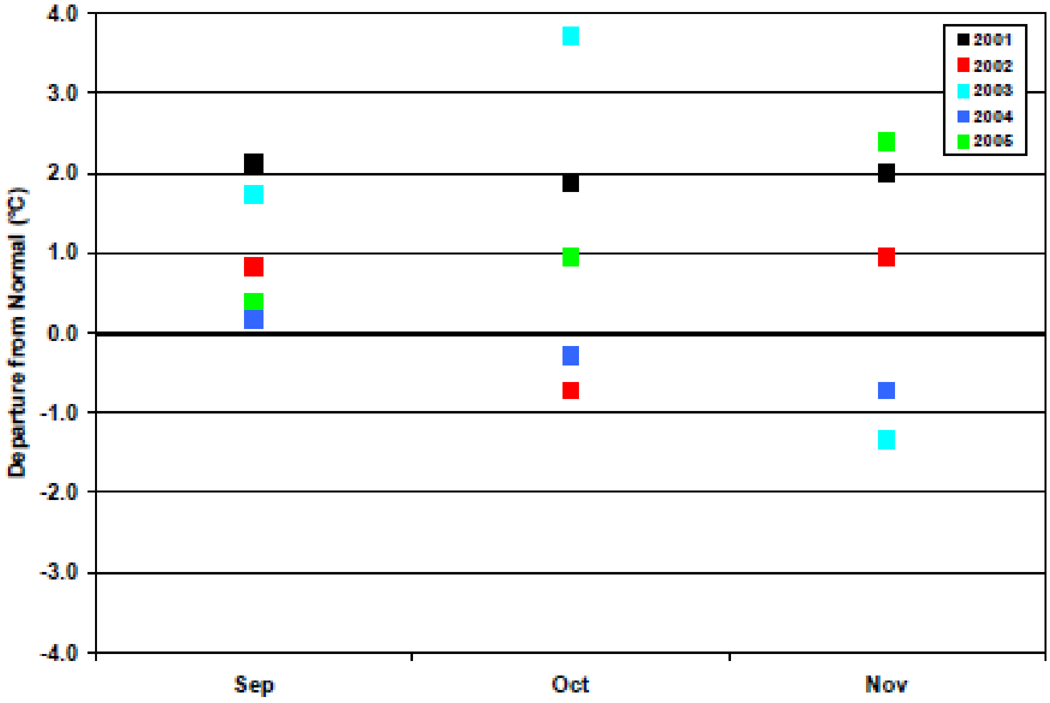


Figure 1. Monthly temperature departures for years 2001 through 2005.

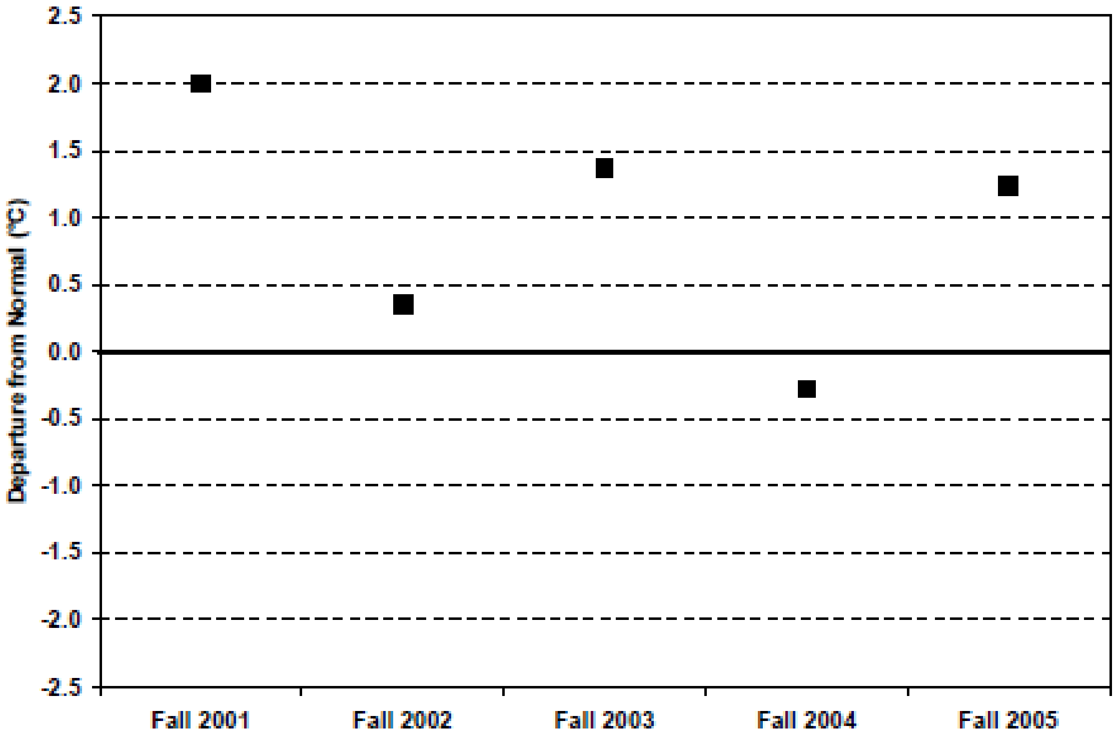


Figure 2. Seasonal temperature departures for years 2001 through 2005.

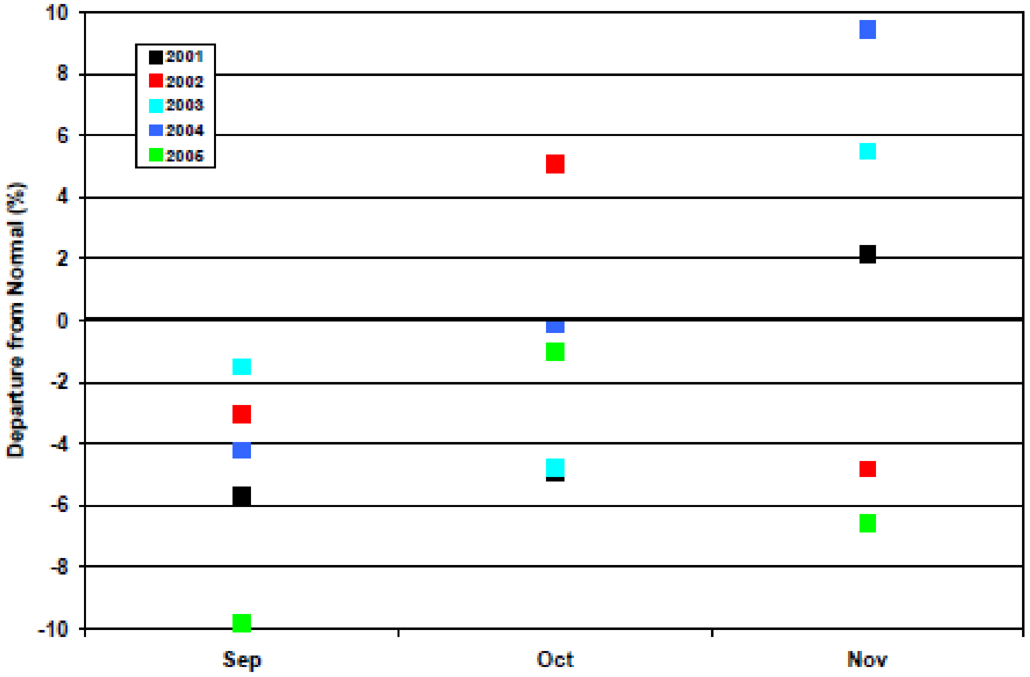


Figure 3. Monthly relative humidity departures for years 2001 through 2005.

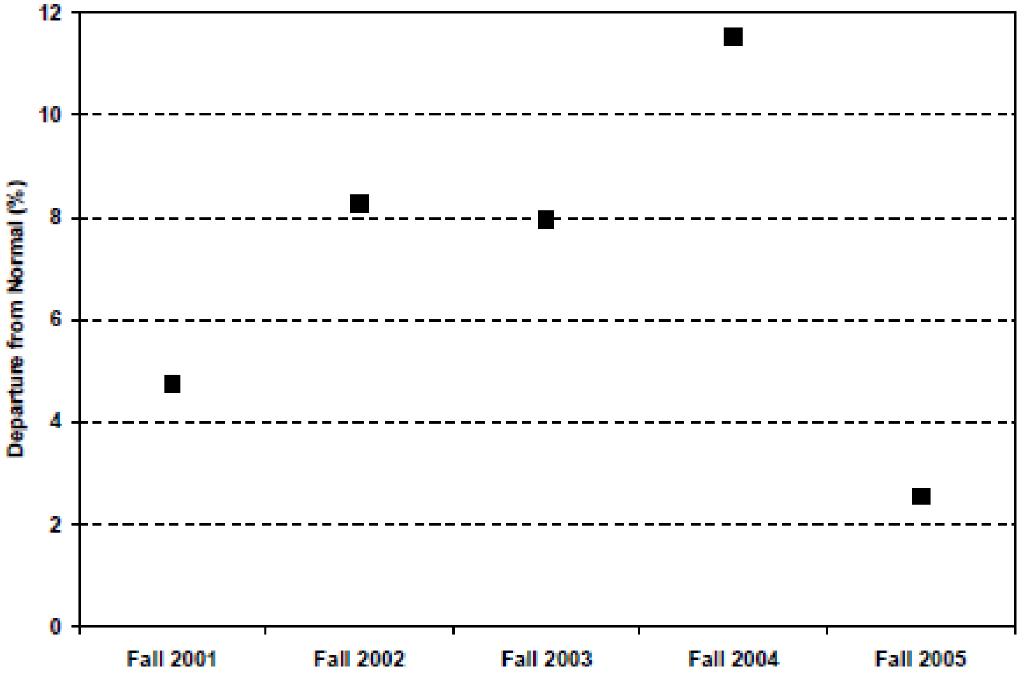


Figure 4. Seasonal relative humidity departures for years 2001 through 2005.

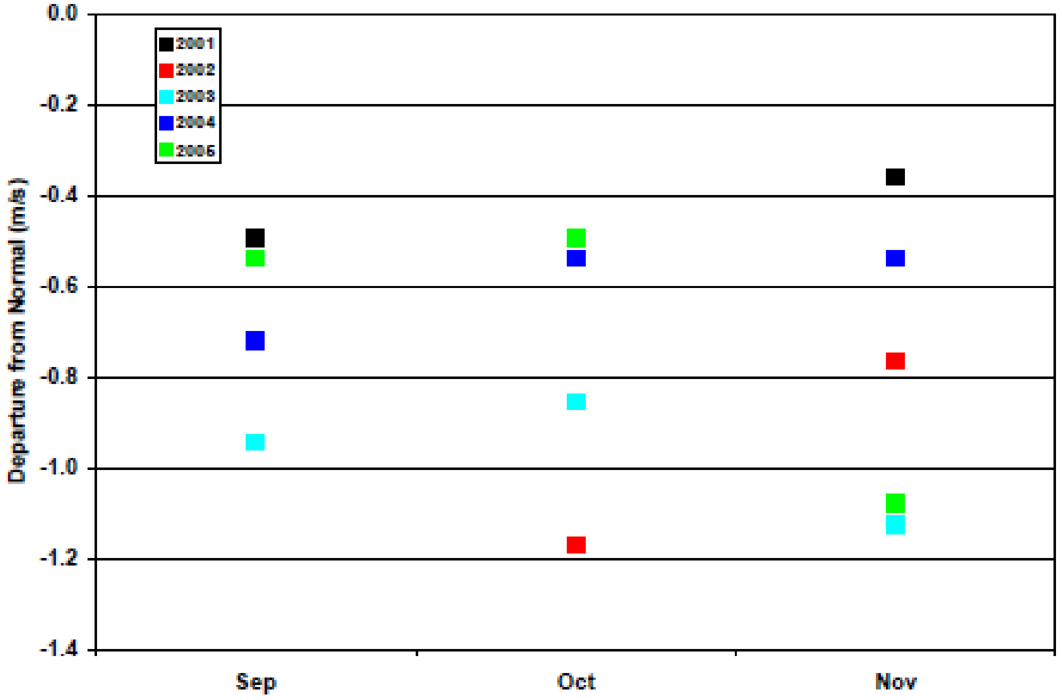


Figure 5. Monthly wind speed departures for years 2001 through 2005.

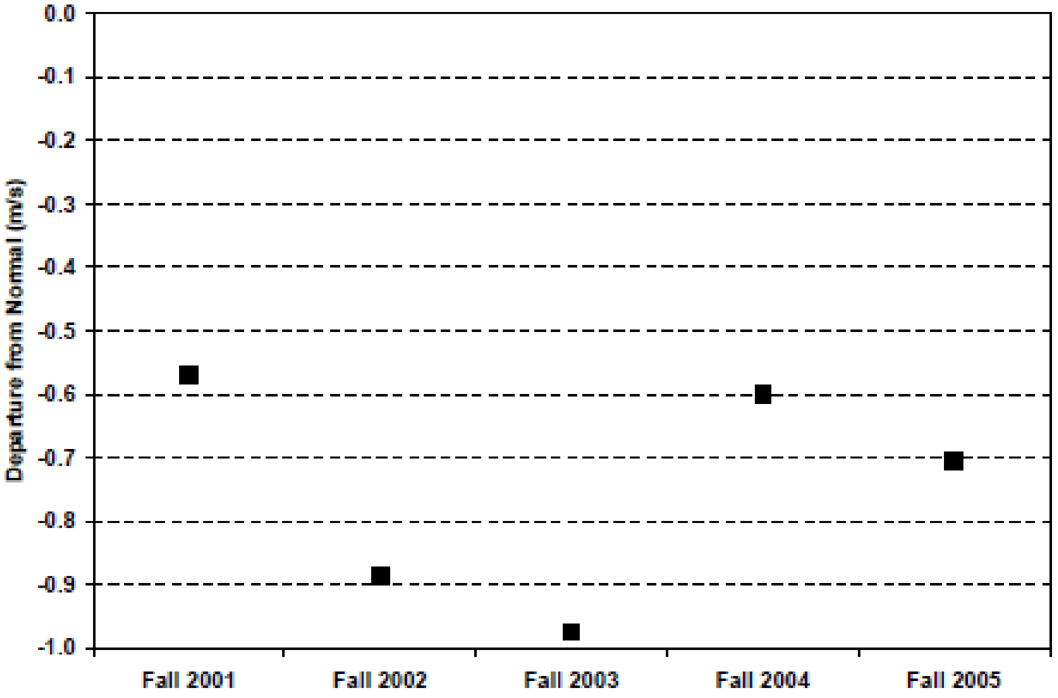


Figure 6. Seasonal wind speed departures for years 2001 through 2005.

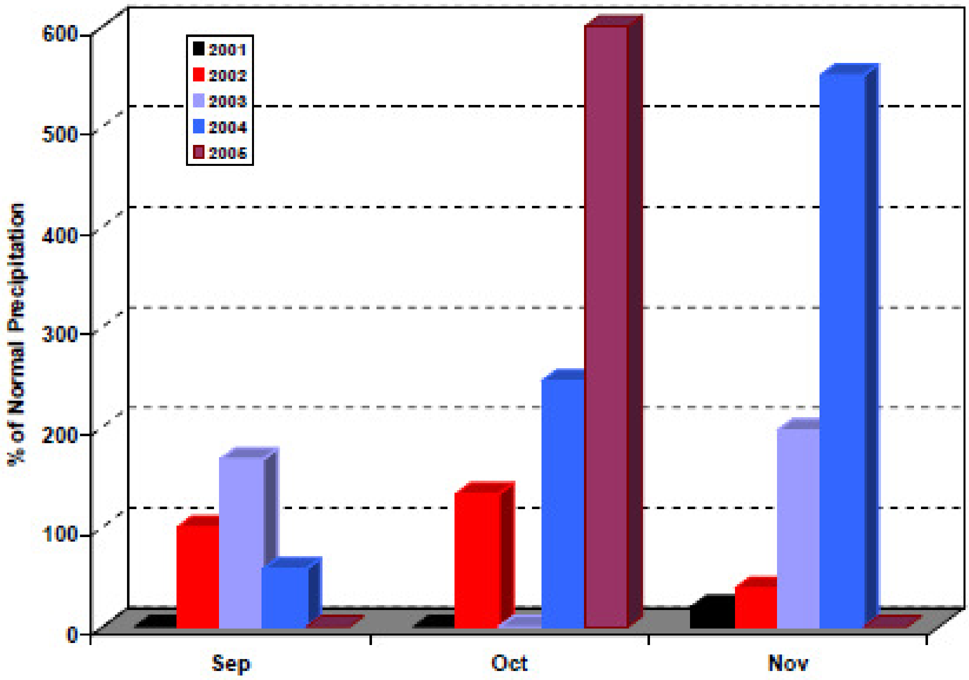


Figure 7. Monthly precipitation (percent of normal) for years 2001 through 2005.

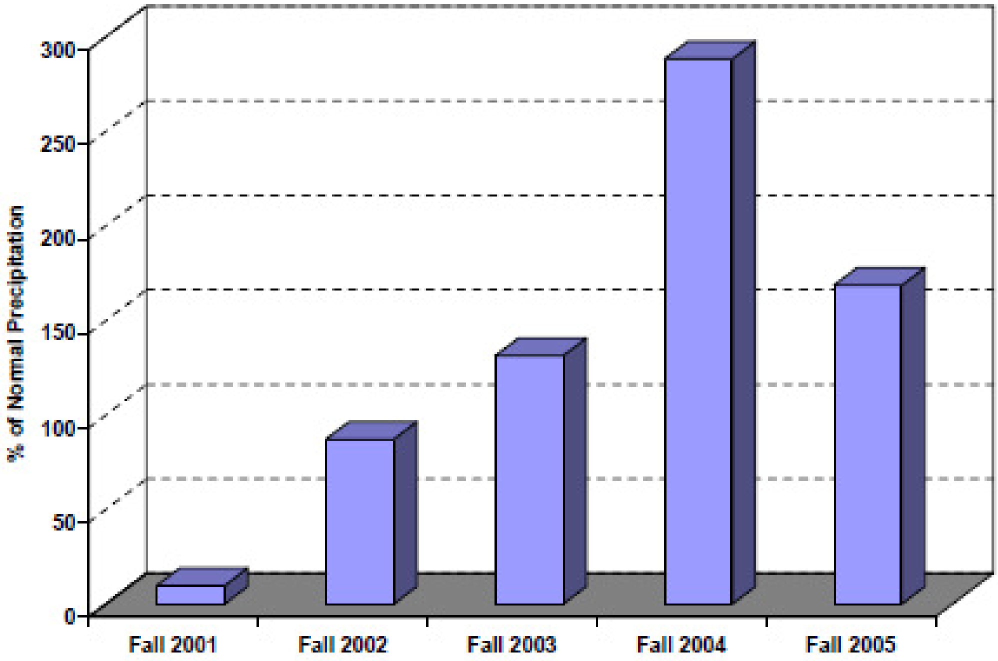


Figure 8. Seasonal precipitation (percent of normal) for years 2001 through 2005.

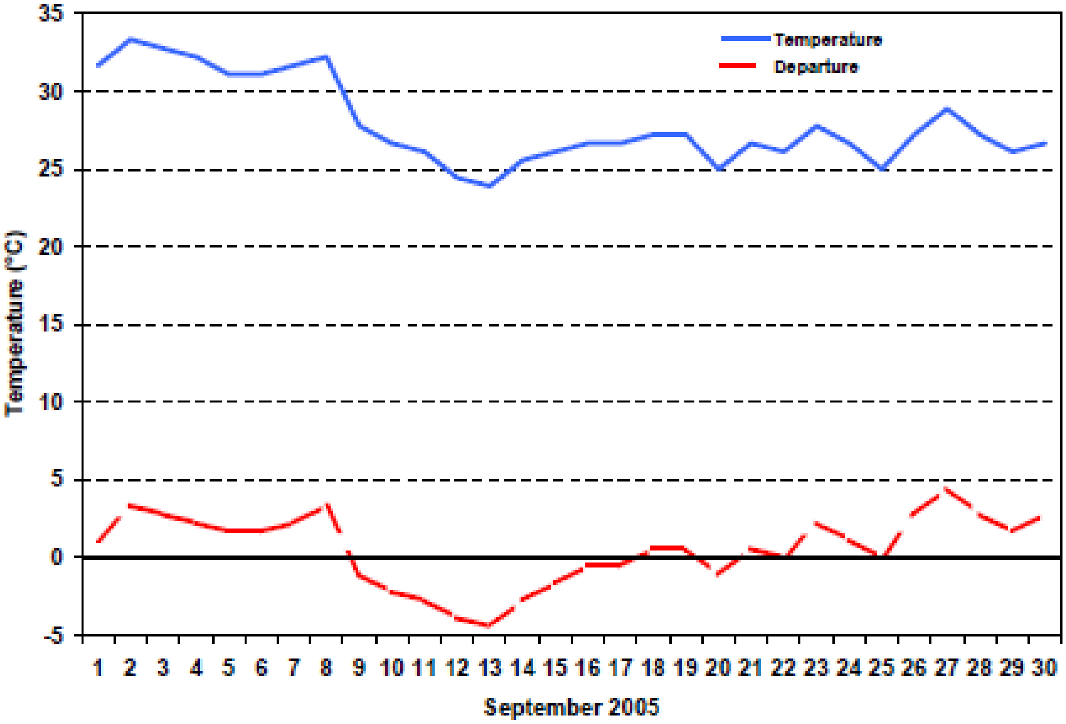


Figure 9. Daily temperature observations and departures for September 2005.

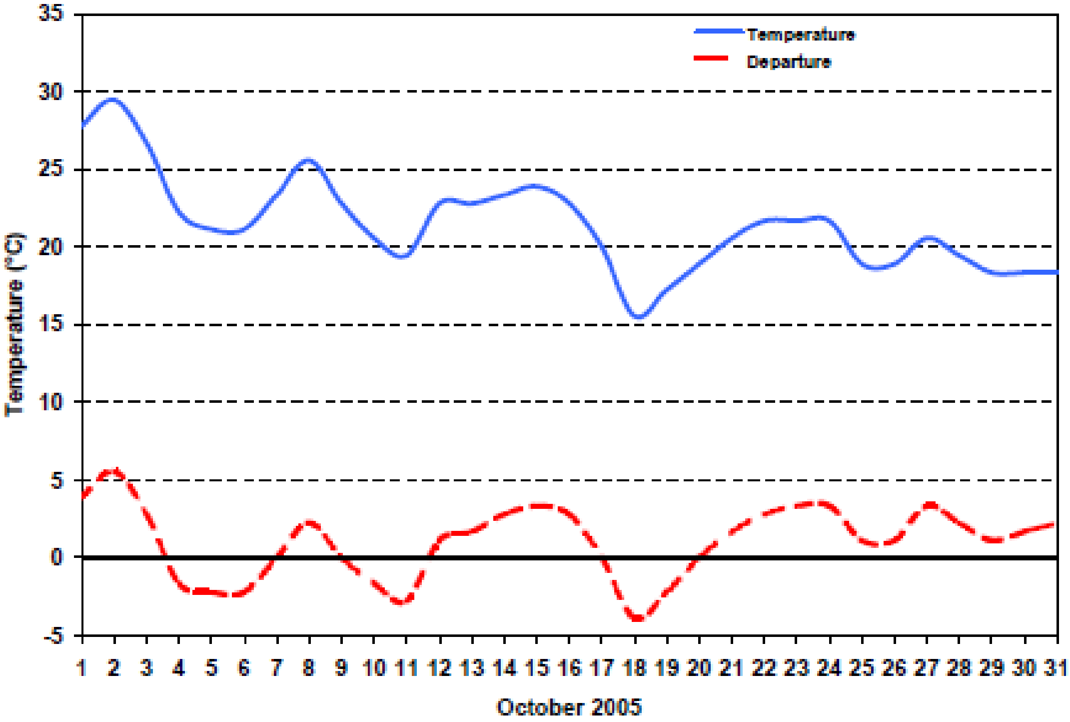


Figure 10. Daily temperature observations and departures for October 2005.

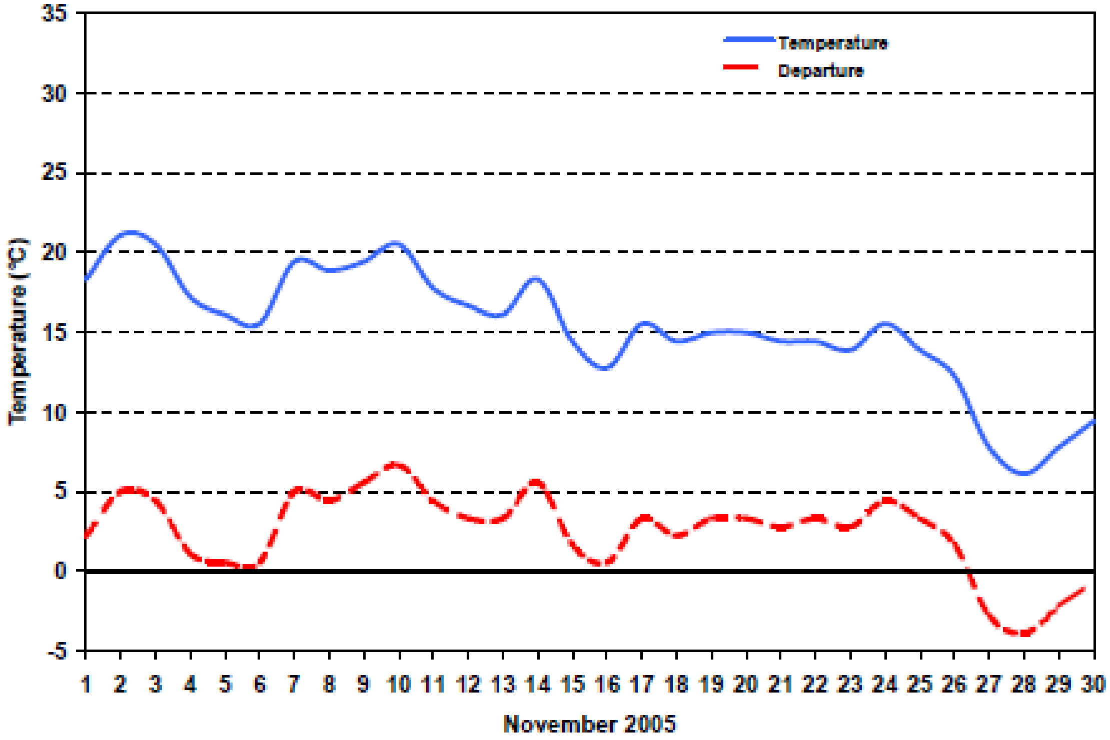


Figure 11. Daily temperature observations and departures for November 2005.

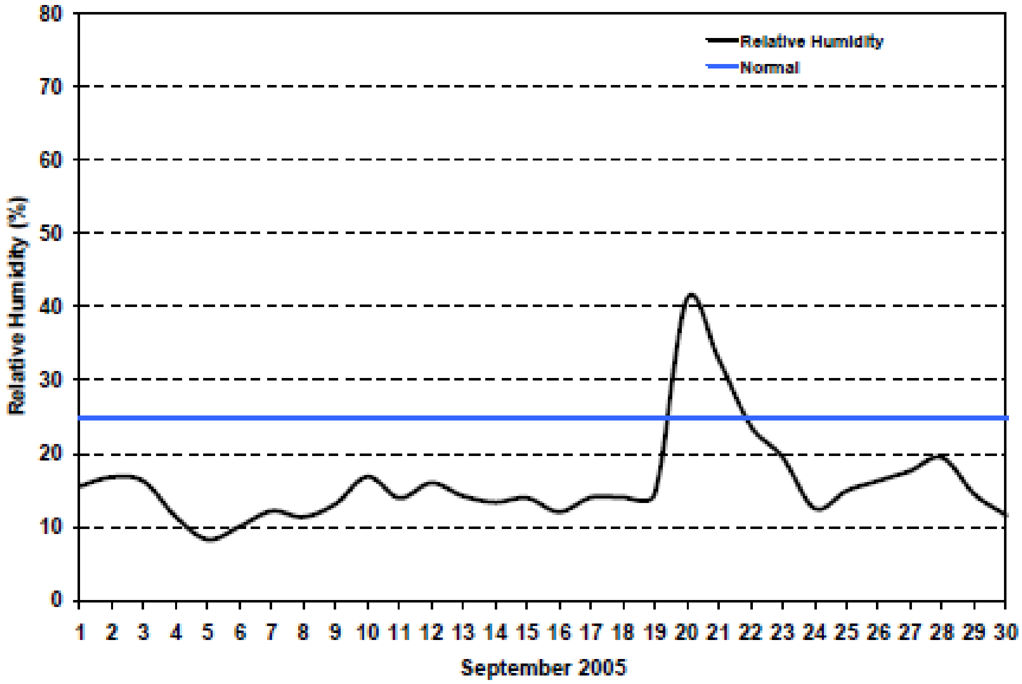


Figure 12. Daily relative humidity observations compared to the monthly average for September 2005.

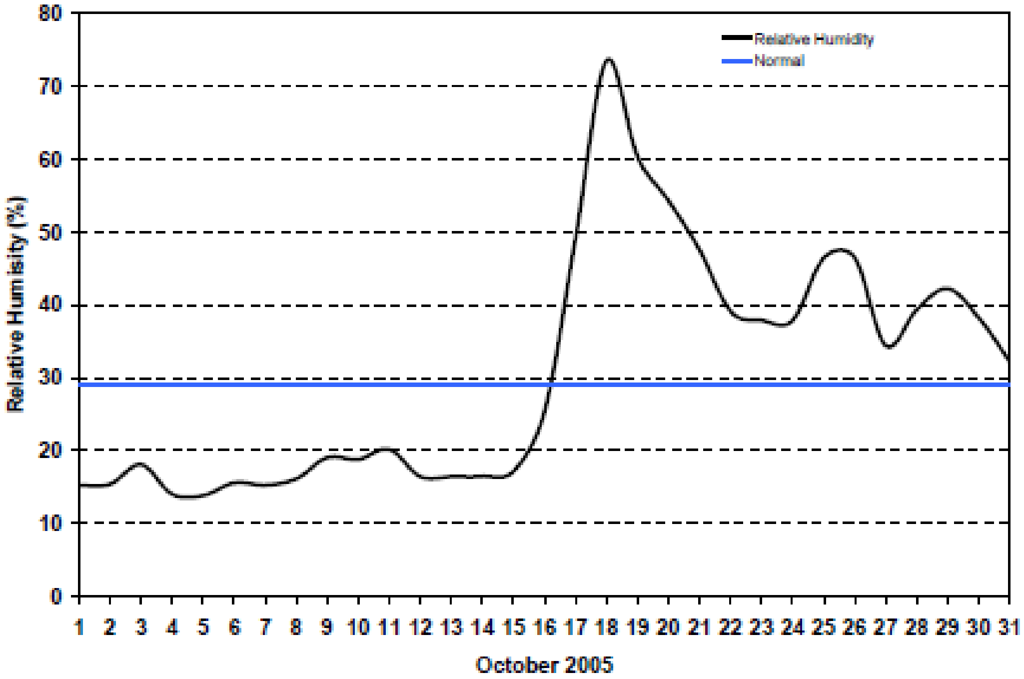


Figure 13. Daily relative humidity observations compared to the monthly average for October 2005.

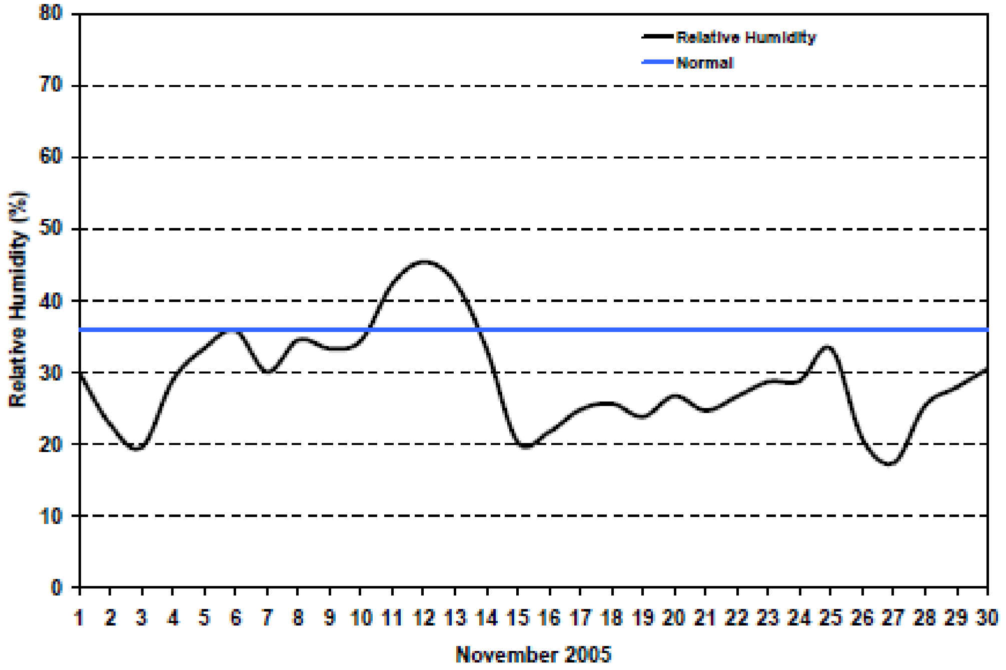


Figure 14. Daily relative humidity observations compared to the monthly average for November 2005.

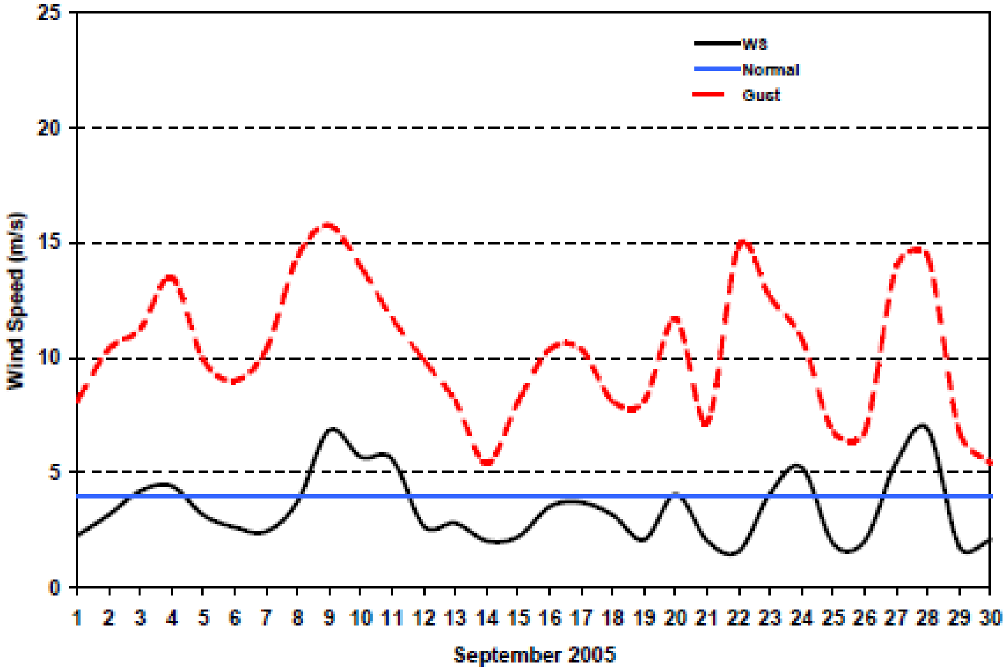


Figure 15. Daily wind speed observations compared to the monthly average for September 2005.

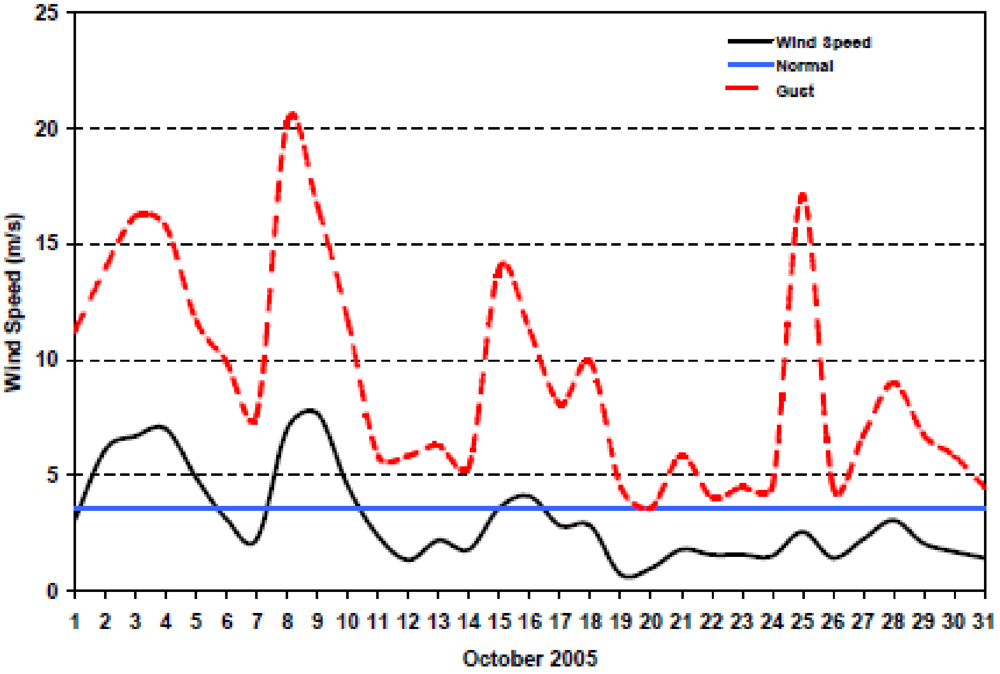


Figure 16. Daily relative humidity observations compared to the monthly average for October 2005.

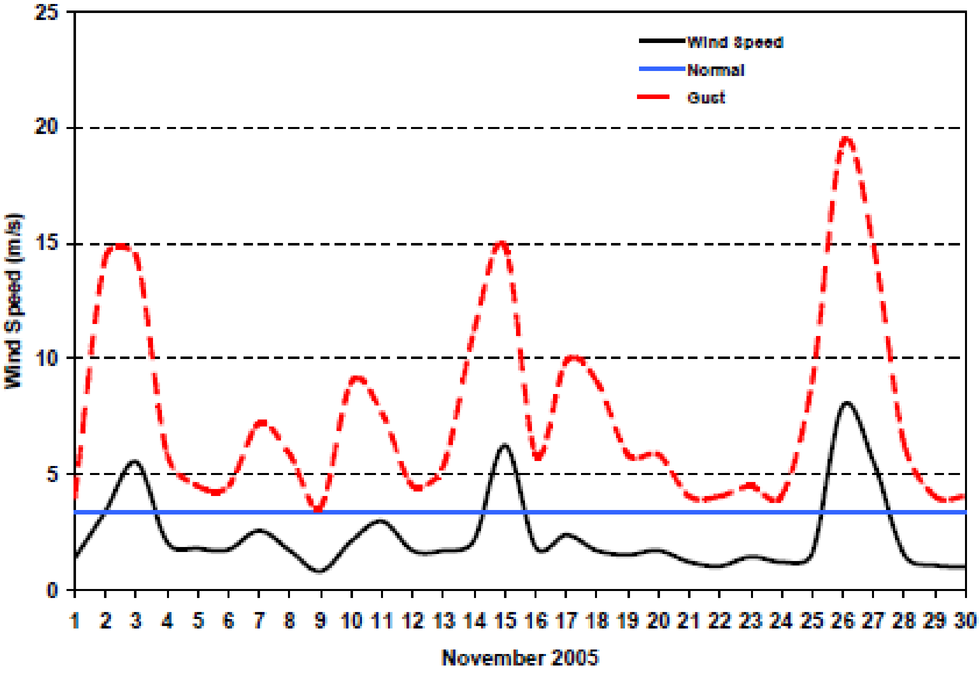


Figure 17. Daily wind speed observations compared to the monthly averag for November 2005.

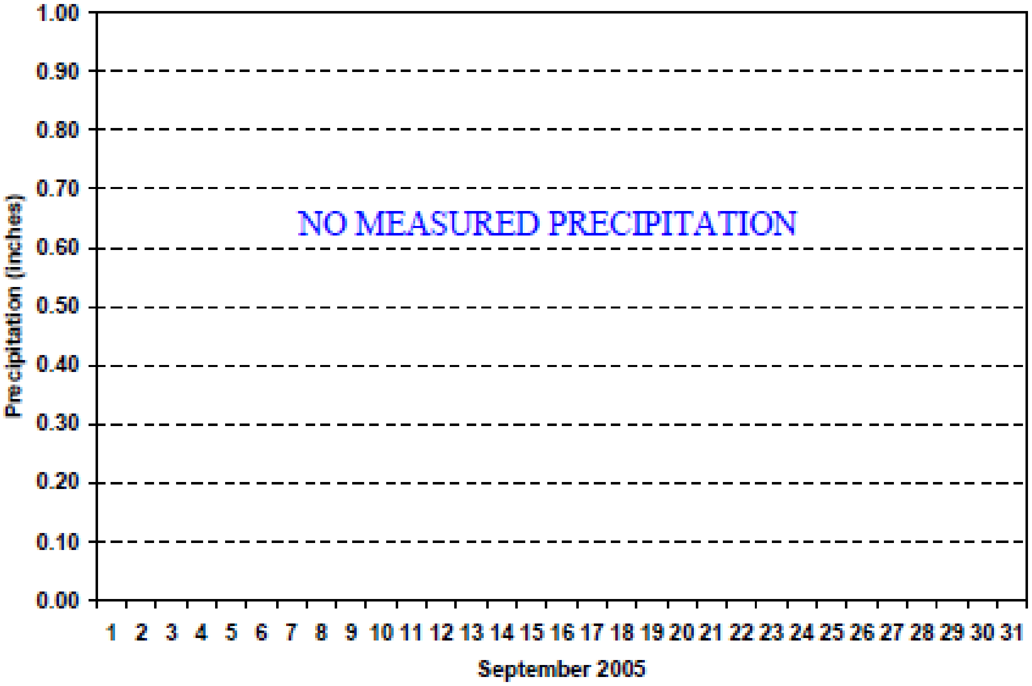


Figure 18. Daily precipitation observations for September 2005.

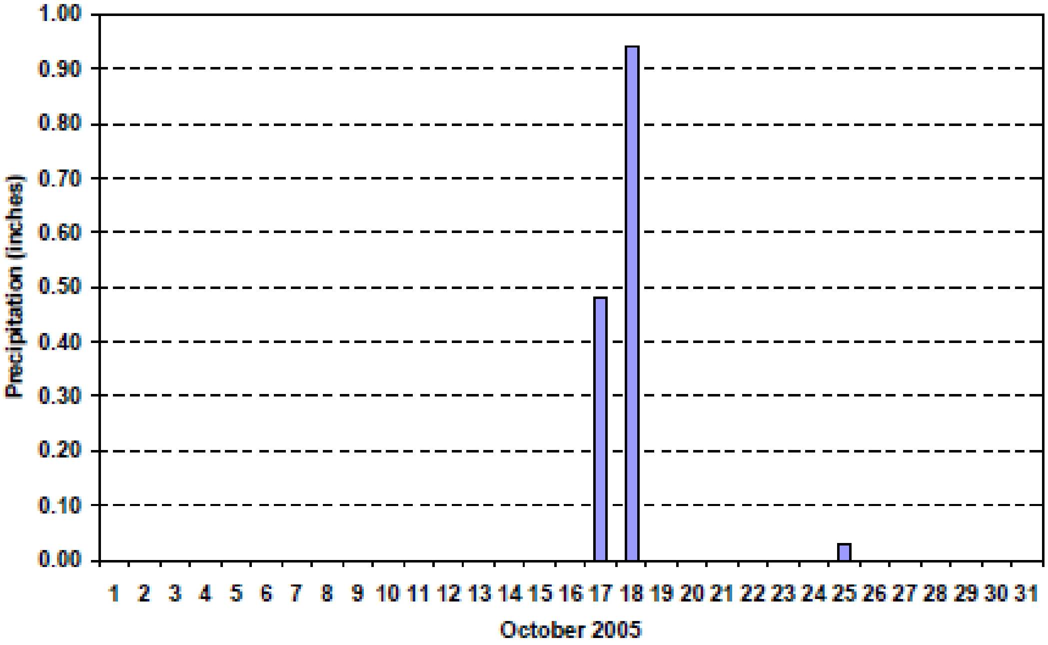


Figure 19. Daily precipitation observations for October 2005.

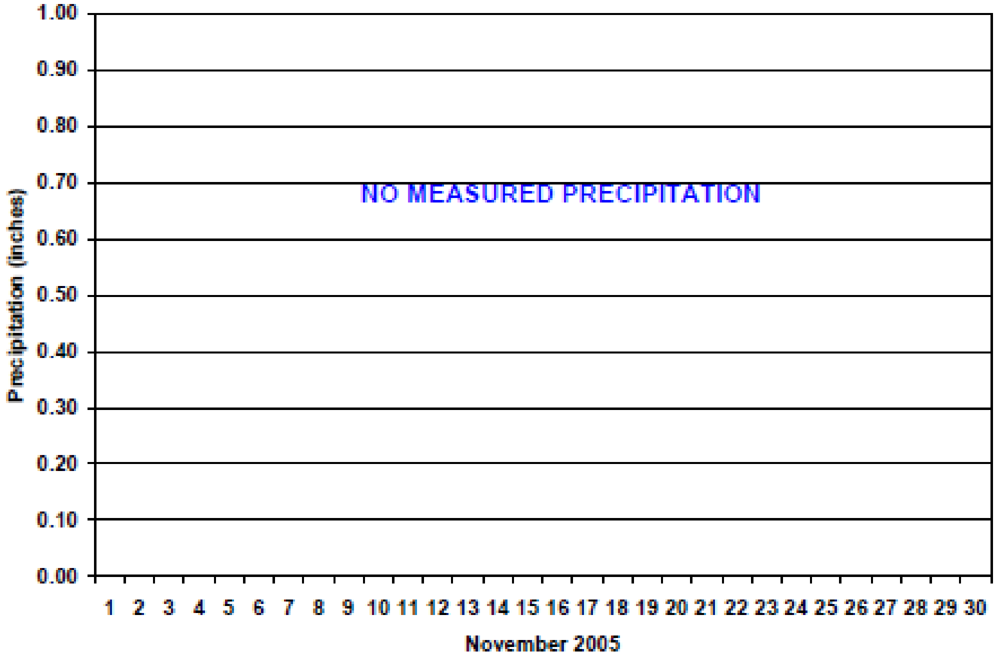


Figure 20. Daily precipitation observations for November 2005.

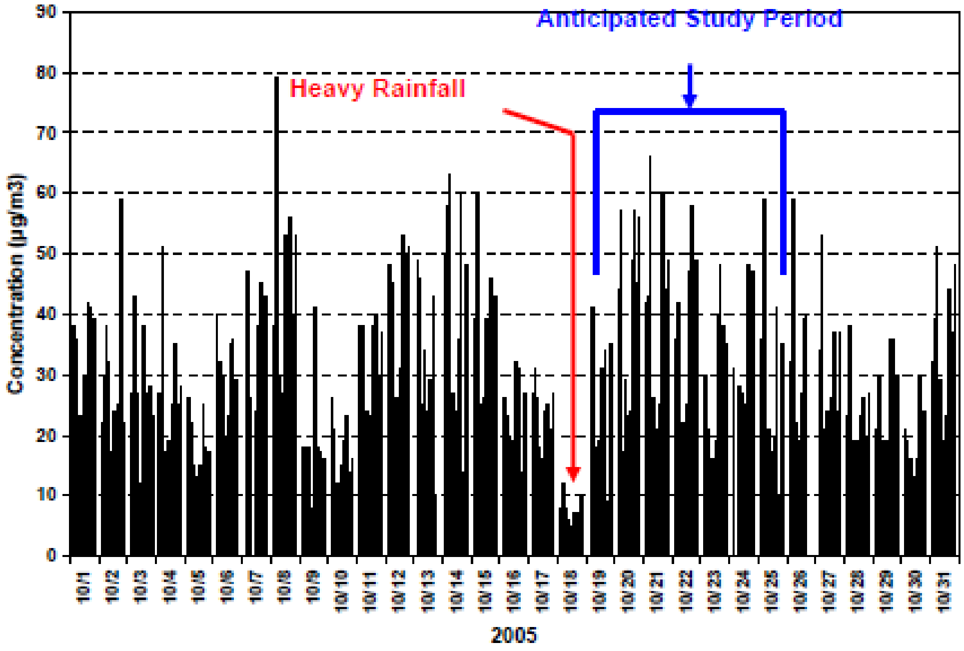


Figure 21. 24-hour average PM_{10} concentrations for all DAQEM sites October 2005.

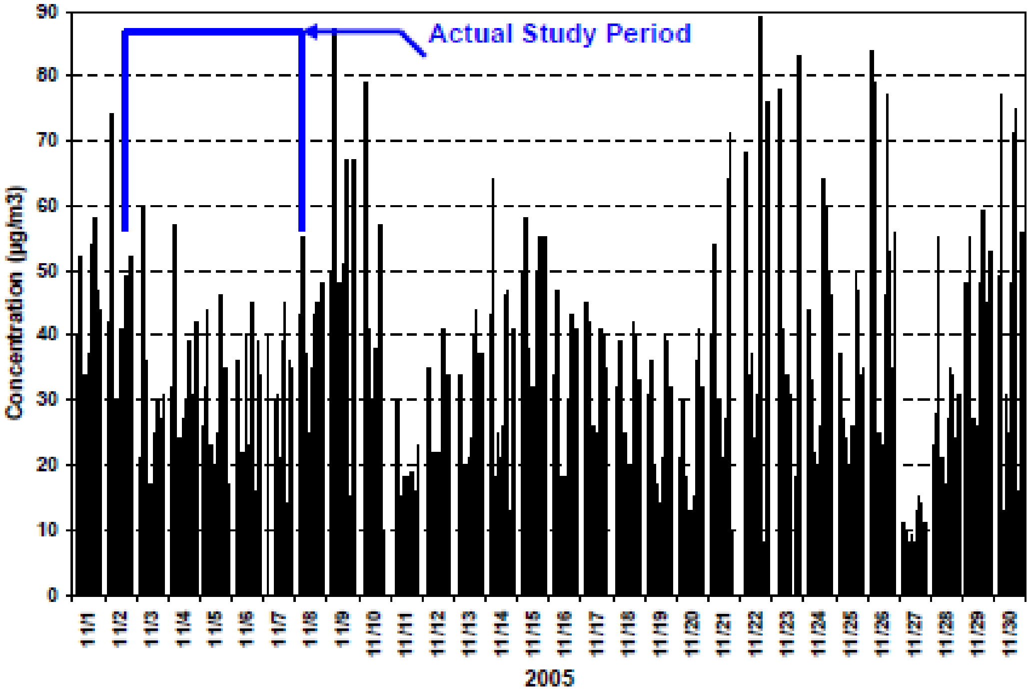


Figure 22. 24-hour average PM_{10} concentrations for all DAQEM sites November 2005.

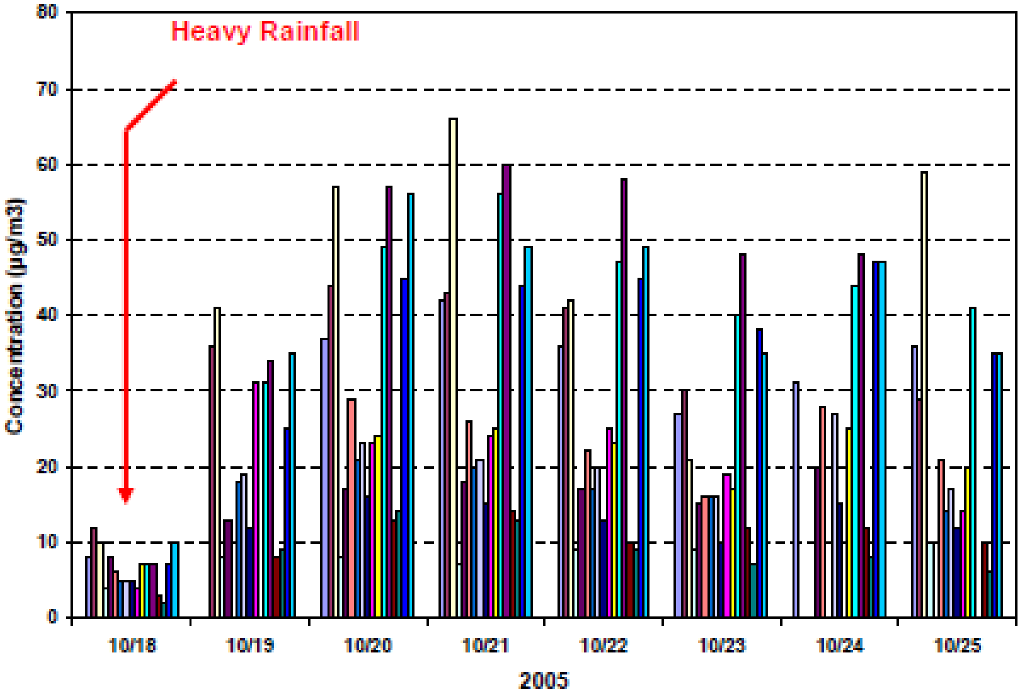


Figure 23. 24-hour average PM_{10} concentrations for all DAQEM sites October 18 - 25 2005 (anticipated study period 10/19 – 10/25).

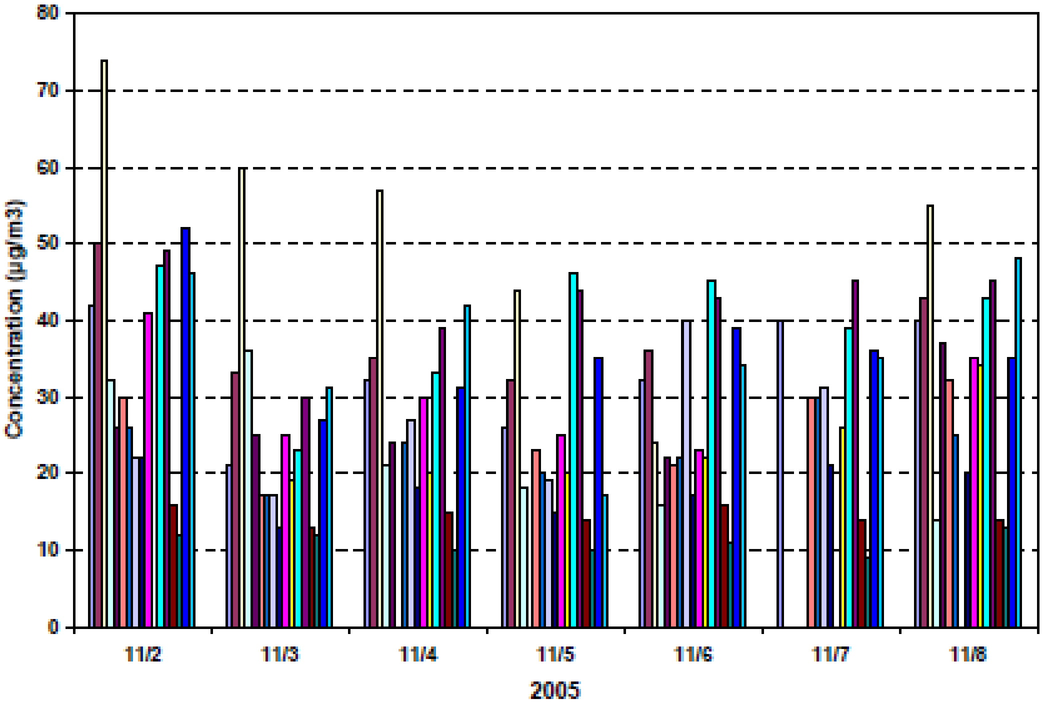


Figure 24. 24-hour average PM_{10} concentrations for all DAQEM sites November 2 - 8 2005.

Clark County (Nevada)
Paved Road Dust Emission Studies in Support of Mobile Monitoring Technologies

Appendices A–E

APPENDIX E
NON-PARAMERIC TREND ANALYSIS OF HISTORICAL AP 42 PAVED ROAD DUST MONITORING DATA 2000-2005
DECEMBER 2007

December 22, 2008

Horizontal PM$_{10}$ Fluxes (Roadside Tower)

Horizontal dust fluxes are calculated from the 1-sec resolution tower data by first examining the time series of DustTrak signals measured at the different levels on the tower. Figure 1 shows a time sample time series of these data. In a labor intensive process, integration points are determined by visually inspecting the DustTrak signal peaks associated with each vehicle pass. The vehicle pass times as recorded in the field (shown in dots at the top of the figure) are overlaid with the concentration data. Background periods exist before and after the peak period. An analyst manually inspects each peak and records the start and stop times for each background and peak integration period. In some cases, a peak is not visible in the graphical time series. For these situations, the analyst marks a flag that the peak is not visible and sets integration points of ~10 seconds for the pre- and post-peak background periods with a ~10 second peak period.

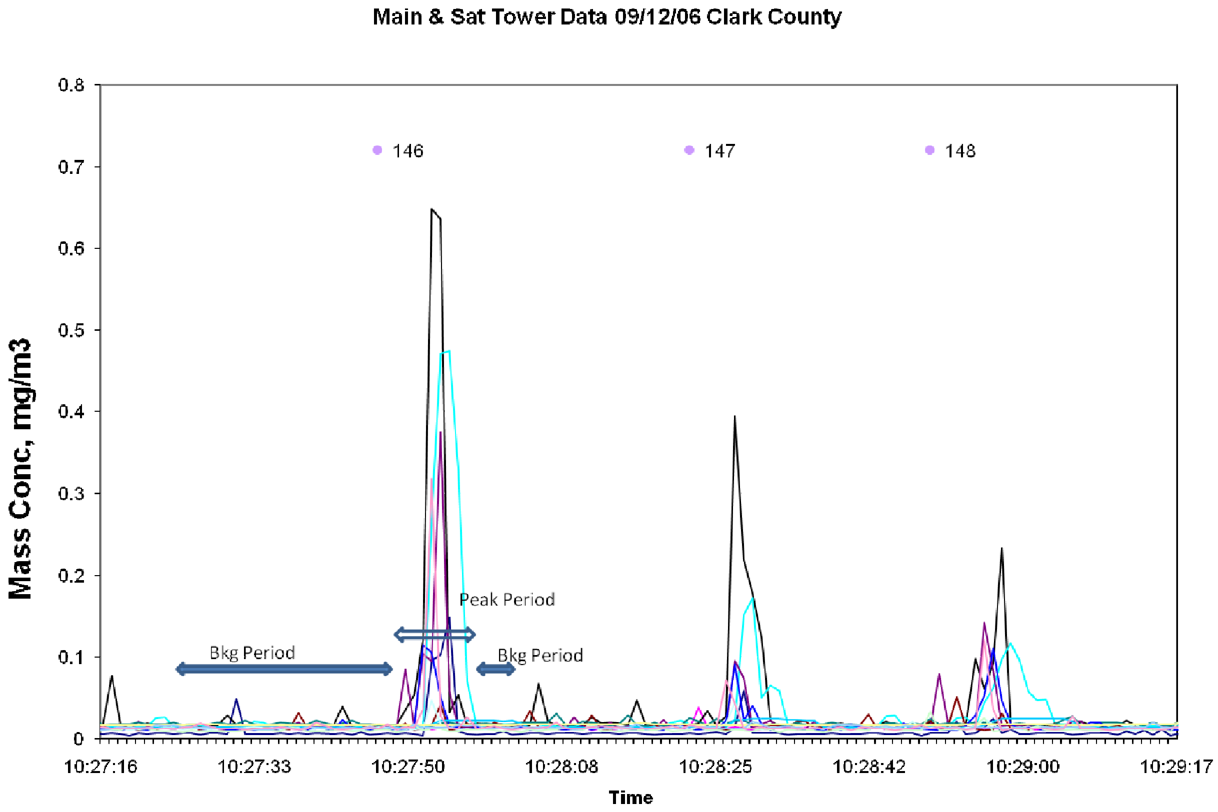


Figure 2. Time Series of Flux Tower DustTrak Concentrations.

Points at the top of the figure indicate the time of vehicle passing the tower observed in the field. The multicolor lines are the DustTrak concentrations on both the master and satellite towers. The shaded arrows represent the integration periods to determine the background concentration. The open arrow represents the integration period associated with the vehicle's dust plume.

Prior to calculating horizontal fluxes, the average from each DustTrak concentration for the background periods is calculated and subtracted from corresponding DustTrak concentrations during the peak periods.

The horizontal PM_{10} flux (*EF,* g/km) for each vehicle pass was calculated using the equation:

$$EF = \sum_{i=1}^{5} EF_i = \alpha \left[\sum_{i=1}^{5} \sum_{t=t_{begin}}^{t_{end}} u_{t,i} \cdot \left(C_{t,i} - C_{0,i,,t_{begin}-t_{end}} \right) \cdot H_i \cdot \cos(\theta) \right] \times 1000 \qquad \text{Equation 5.1}$$

where: *i* refers to the vertical section represented by the DustTrak height, *t* is the time (sec), t_{begin} is the peak start time, t_{end} is the peak end time, u is the wind speed (m sec^{-1}), *C* is the measured concentration (g m^{-3}), C_0 is the background concentration over the period t_{begin} - t_{end} (g m^{-3}), and *H* is the height of the section of the flux plane represented by position *i*, θ is the angle of the 1-sec wind direction relative to the flux plane, and α is a constant used to convert DustTrak-measured PM_{10} concentrations to mass equivalent PM_{10} and has a value of 2.4

For example, for the case of vehicle pass 146, the flux calculation from the DustTraks, wind vanes, and anemometers are shown in Table 1. The upper table refers to the pass number, background and peak integration points, peak duration (Δt), and wind direction. The lower table indicates the tower position of each measurement (on Tower 1; downwind of the road), the height interval represented by each DustTrak (ΔH_i), the average wind speed ($u_{i,ave}$) at each height, the average DustTrak PM_{10} concentration calculated during the background and peak periods, the standard deviation of the background concentrations at each height ($\sigma_{C_{bkg}}$), the average background subtracted peak concentration ($\overline{C_i} = \overline{C_{i,peakperiod}} - \overline{C_{i,backgroundperiods}}$). In practice, the emission factor values at each height are calculated from the equation:

$$EF_i = \alpha H_i\,(cm) \cos(\theta)\, u_{i,ave} (m/s)\, \overline{C_i} \left(mg/m^3 \right) \Delta t$$

The standard deviation of the emission factor is propagated from the standard deviation of the background concentration by substituting $\sigma_{C_{bkg}}$ for $\overline{C_i}$ in the above equation. The actual uncertainty of the calculated emission factor is based on the standard error which is equal to the standard deviation divided by the square-root of the number of measurements during the peak (7 in the case of the example below). The standard deviation is a measure of how much the background signal fluctuates while the standard error is the measure of how close the calculated emission factor is to the real value. The first line underneath the lower table indicates the sum of each EF_i. The final calculation multiplies the DustTrak calculated EF by 2.4 (α) to convert this into a PM_{10} mass EF.

Table 1 Example emission factor calculation.

Pass ID	146
Vehicle Pass Time	20060912 10:27:47
Bkg Start	10:27:19
Peak Start	10:27:49
Peak End	10:27:56
Bkg End	10:27:59
Peak Duration(s)	7
Bankground Duration(s)	35
WD w.r.t. perpendicular to road (deg)	22.3

Tower Position	Delta Z (cm)	Wind Speed (m/s)	Avg Bkg conc (mg/m3)	Bkg Conc Stdev (mg/m3)	Avg Peak Conc (mg/m3)	Peak Conc above Bkg (mg/m3)	EF at each height (g/vkt)	Unc Propogated from Bkg Conc Stdev (g/vkt)
73 cm	139	2.3	0.017	0.005	0.199	0.182	3.7	0.1
205 cm	133.5	2.8	0.018	0.010	0.200	0.183	4.4	0.2
340 cm	217.5	3.1	0.014	0.002	0.095	0.081	3.5	0.1
640 cm	320	3.4	0.013	0.004	0.017	0.0003	0.2	0.3
980 cm	300	3.6	0.018	0.002	0.017	-0.001	-0.1	0.1

Sum of EF at each Height in DustTrak Concentrations (g/vkt)	**11.8**	**0.8**
Sum of EF at each Height in Mass conc (i.e. DustTrak conc * 2.4) (g/vkt)	**28.4**	**1.9**

Set-Averaged Horizontal PM_{10} Fluxes

To calibrate the individual mobile systems to the tower flux measurements, tower flux measurements from individual passes within a set were averaged over the set. These set averages were then compared to the average signals from individual mobile systems. This section provides an example of how these data were averaged and how the uncertainties were calculated.

As explained in section 6.2 of the report, during the first 9 passes after the application of fresh road silt material, emissions appeared to be a result of a different mechanism than for ensuing vehicle passes. It was hypothesized that during the first 9 passes, PM_{10} dust emissions are a result of “aerodynamic” entrainment while during ensuing passes, emissions were associated with “mechanical” entrainment. Since the duration of aerodynamic entrainment appears to be quite short, it was noted that the mechanism of entrainment on “real” roads is likely to be mechanical. Thus, when comparing tower measured emissions to mobile measurement signals, only vehicle passes after the ninth pass following silt loading application should be considered (See section 6.2).

For the example case of Set 4, the average PM_{10} emission flux is calculated by taking the average of measured emissions from all valid passes (regardless of sampling vehicle) within the measurement set excluding the first 9 passes (highlighted in gray in the Table below). Thus the average is based on the 21 (n) bottom-most numbers in the column entitled (Tower EF (g/vkt)) since there are 30 measurements altogether, but the first 9 are not included in the average.

The Set 4 PM_{10} tower-measured emissions average = 8.87 g/vkt

The associated standard deviation is: 11.76 g/vkt

The value used to represent the uncertainty of the measurement is the standard error which is equal to the standard deviation divided by the square root of the number of measurements.

The standard error is equal to (11.76 g/vkt)/$(21)^{1/2}$ = 2.57 g/vkt.

While the standard deviation provides a measure of how much variability there is among a number of data points, the standard error provides an estimate of how much uncertainty there is associated with the calculated average, given the variability exhibited by the data set.

The pass averaged signals and standard errors are calculated similarly for the mobile systems. The outcomes of these calculations for TRAKER I over the measurement set are shown below.

Number of valid TRAKER I measurements during Set 4 excluding first 9 passes after silt application = 7 (n)
Average of valid TRAKER I measurements excluding first 9 passes after silt application: 11.9 mg/m^3
Standard deviation of valid TRAKER I measurements excluding first 9 passes after silt application: 7.14 mg/m^3
Standard error: = 11.9 mg/m^3 / $7^{1/2}$ = 2.7 mg/m^3.

Set 4 Date: 9/12/2006 Test Type: Silt Depletion Vehicle Speed: 45 mph Directions: N

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
140	1	N	1	UCR	10:15:21	14.30	285.98	486.90	4.84
141	1	N	2	TR2	10:19:37	61.61	56.68	200.75	ND
142	1	N	3	TR1	10:20:11	117.72	63.57	306.61	ND
143	2	N	4	UCR	10:23:55	1.97	39.31	40.32	ND
144	2	N	5	TR2	10:24:24	25.39	23.36	83.17	ND
145	2	N	6	TR1	10:24:53	39.51	21.34	41.45	ND
146	3	N	7	UCR	10:27:47	1.06	21.26	28.32	ND
147	3	N	8	TR2	10:28:22	9.93	9.14	6.84	ND
148	3	N	9	TR1	10:28:49	18.64	10.07	6.23	ND
149	4	N	10	UCR	10:31:42	0.70	14.01	9.22	ND
150	4	N	11	TR2	10:32:18	5.21	4.79	5.41	ND
151	4	N	12	TR1	10:32:44	24.66	13.31	2.05	ND
152	5	N	13	UCR	10:36:01	0.26	5.28	30.18	ND
153	5	N	14	TR2	10:36:32	4.25	3.91	4.08	ND
154	5	N	15	TR1	10:37:00	10.79	5.83	6.23	ND

Pass ID	Run ID	Dir (N/S)	Passes since Silt Applied*	Sampling Vehicle	Time Vehicle Passed Tower (hr:min:sec)	Mobile Sampler Net Concentration (mg/m3) *+	Mobile Sampler Emission Factor (EF)*+* (g/vkt)	Tower EF (g/vkt) *+*+	AP-42 EF Estimate (g/vkt) *+*+*
155	6	N	16	UCR	10:40:00	0.26	5.12	14.51	ND
156	6	N	17	TR2	10:40:39	41.75	38.41	47.56	ND
157	6	N	18	TR1	10:41:05	9.18	4.96	8.69	ND
158	7	N	19	UCR	10:43:56	0.30	6.00	24.31	ND
159	7	N	20	TR2	10:44:32	11.51	10.59	1.04	ND
160	7	N	21	TR1	10:44:57	18.97	10.25	3.30	ND
161	8	N	22	UCR	10:47:46	0.66	13.24	1.09	ND
162	8	N	23	TR2	10:48:21	4.22	3.88	1.40	ND
163	8	N	24	TR1	10:48:44	6.68	3.61	5.44	ND
164	9	N	25	UCR	10:51:51	0.13	2.69	1.01	ND
165	9	N	26	TR2	10:52:27	4.99	4.59	5.23	ND
166	9	N	27	TR1	10:53:05	7.19	3.89	2.61	ND
167	10	N	28	UCR	10:56:08	0.16	3.20	1.12	ND
168	10	N	29	TR2	10:56:43	2.53	2.33	1.32	ND
169	10	N	30	TR1	10:57:07	5.98	3.23	10.41	2.47

* Indicates the number of vehicles that have traversed the course since silt application for depletion studies. Gray boxes correspond to the first 9 passes after application of silt, when aerodynamic entrainment is dominant emission process.

*+ SCAMPER Net Conc. = Rear Sampler – Background Sampler, TRAKER I and II Net Conc. = Average of right and left inlet samplers – background bumper sampler. ND Indicates that no data are available for this measurement

+ Mobile Sampler EF equals Net Concentration * calibration factor (0.54, 0.92, or 20 for TRAKER I, TRAKER II, or SCAMPER, respectively). ND Indicates that no data are available for this measurement

++* IB = Invalid measurement due to excessive noise on background signal. IWD = Invalid measurement due to inappropriate wind conditions

++* ND = No silt data corresponding exactly to specified pass ID

Technical Support Document for Mobile Monitoring Technologies

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January 9, 2009

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Technical Support Document for Mobile Monitoring Technologies

In recent years, there has been increasing dissatisfaction with the traditional AP-42 methodology for estimating re-entrained dust emissions from paved road networks for emissions inventory purposes. The AP-42 equation requires on-site characterization of road surface parameters related to dustiness characteristics. Road surface sampling is time-consuming and potentially hazardous because of the need to block traffic lanes. In addition there are serious issues related to the large number of samples required to represent spatial and temporal variations across roadway networks.

The Clark County Department of Air Quality and Environmental Management has undertaken a series of field studies to investigate alternative ways of estimating PM_{10} emissions in the form of surface dust entrained from paved and unpaved roads. A new series of vehicle-mounted monitoring technologies has emerged that provides for much easier representation of spatially distributed roadway emission characteristics, while eliminating the need to divert traffic.

A peer review process has been conducted to determine whether the mobile monitoring method (as represented in the current technologies) is a suitable alternative to the traditional AP-42 method for developing road dust emission factors. Seven peer reviewers evaluated the series of Clark County test reports and used their expertise to judge the value of mobile monitoring technologies in relation to the traditional approach for determining paved road dust emission factors.

Objective

The primary objectives of this technical support document are to demonstrate that: (a) mobile monitoring technologies are equivalent or even superior to the traditional AP-42 methodology for paved road dust emission characterization and (b) the mobile monitoring method should be accepted as an alternative standard method for roadway emission characterization.

The items addressed in this document include the following:

- Road dust entrainment dynamics
- Current test methods and their limitations
    - Road surface characterization coupled with AP-42 emission factor equations
    - Roadside plume (exposure) profiling, which was used as the reference method to develop the AP-42 emission factor equations

- Demonstrated mobile monitoring technologies
    - Desert Research Institute (DRI) version
    - CE-CERT version
- Discussion of the test method evaluation process

Dynamics of Road Dust Entrainment

Dust emissions occur whenever vehicles travel over a paved or unpaved surface such as a road or parking lot. Dust emissions consist primarily of entrained surface material from the roadway, although brake and tire wear particles are additional components. On unpaved roads, the entrained dust dominates over the other sources including vehicle exhaust. The remainder of this discussion, however, will focus on paved roads.

In general terms, entrained dust from paved surfaces originates from, and results in the lift-off of the loose material present on the surface (i.e., the surface loading expressed in terms of mass per area). In turn, the surface loading is continuously replenished by other sources. In industrial areas, surface loading is replenished by spillage of material and track-out from unpaved roads and staging areas. Other contributors to paved road surface loading include granular abrasives for snow and ice control, mud/dirt carryout from construction activities in the area, and deposition from wind and/or water erosion of surrounding unstabilized soils or other aggregate materials.

In the absence of continuous addition of fresh material (through localized track-out or application of antiskid material), the paved road surface loading at a particular location should reach an equilibrium value, such that the amount of material entrained matches the amount replenished. For roads with freely flowing traffic at higher speeds, the equilibrium surface loading is lower than for local roads with lower traffic speeds. In other words, there is an inter-correlation between equilibrium surface loading and average vehicle speed on a given paved road segment.

Whenever the surface dust loading on a paved road is suddenly increased above the equilibrium value, the emission rate also increases sharply. An example would be after spillage of material onto the road surface. Visible dust emissions are often observed when these situations occur. It may take hours to days for the increased loading to return to the equilibrium condition. Similarly, the loading on a paved road may be suddenly decreased by street sweeping, and there is a sharp decrease in emission rate followed by a gradual return to equilibrium.

Emission Factor Test Method Summaries

The **traditional AP-42 method** uses emission factor equations with correction parameters that relate to road conditions, as published in USEPA's "Compilation of Air Pollutant Emission Factors" (AP-42). These emission factor equations were developed from roadside plume profiling of paved roadways in the various standard roadway categories: local, collector, arterial, and freeway. Road surface dust samples were also collected at each profiling test site by edge-to-edge vacuuming of travel lanes. In addition, traffic counts and vehicle categorization data were obtained.

The road surface samples were dry sieved to determine the silt (fines) content, to be used as a surrogate for the fine particle dust emission potential of the roadway. Silt, which is defined as particles that pass a 200-mesh screen, is the finest particle size segment that can be separated reliably by conventional dry sieving.

The emission factor equations were developed through step-wise regression analysis of the test data. In this process, correction parameters were identified in order of importance, so that emission factors could be adjusted to specific road and traffic conditions. The regression analyses of test data showed that paved road dust emissions depend on the following road and traffic conditions:

- Road surface silt loading
    - Strong inter-correlation with vehicle speed

- Vehicle weight (fleet average for mixed traffic)
    - Inter-correlation with vehicle speed

In the AP-42 emission factor equations for paved roadways, the primary correction parameters are the silt loading (mass per pavement area) and the fleet average vehicle weight. Vehicle speed does not appear, because of its inter-correlation with the other two parameters. If vehicle speed were to be used as a correction parameter, there would be no way of accounting for the strong effects of non-equilibrium silt loading conditions which are unrelated to vehicle speed. A good example is track-out from construction sites onto public paved roads, which can produce large increases in road dust emissions.

Default values of the silt loading correction parameter for paved roads have been developed for the four identified road categories. The loadings are inversely related to the average daily traffic (ADT) range as represented by the category. For example, local roads have the lowest traffic but the highest loadings. Most inventories are dominated by arterial and collector categories because of relatively large combinations of traffic and loadings.

In most efforts to inventory emissions from paved roadway systems, default silt loading values are used in place of actual measurements of silt loading, because of the costs and technical difficulties of silt loading surveys. Road vacuuming to measure actual silt loadings is time consuming, labor intensive, and hazardous. These measurements require road lane blockage and manual vacuuming of full-width lane sections at multiple locations across a road network to assure representativeness. There are obvious safety issues in doing this work, especially on busy roads.

Use of default silt loadings in place of a local survey of silt loading values reduces the accuracy of the traditional AP-42 method. Clark County has documented that the rating of the traditional AP-42 method decreases from “A” to “C” when default silt loadings are used.

Mobile monitoring is a new alternative emission characterization method for determining road dust emission factors on either paved or unpaved roads. It utilizes a test vehicle that generates and monitors its own dust plume concentration (mass basis) at a fixed sampling probe location. The basic premise is that emission intensity of any given portion of roadway is proportional to the intensity of the dust concentration that is monitored.

Typically the dust plume concentration is measured at 1-sec intervals, which correspond to approximately 50 ft of travel at a speed of 35 mph. By traveling over the entire road network in a test vehicle with 1-sec dust plume concentrations and GPS readings, a map of relative emission intensity is generated.

Interferences with mobile monitoring can occur as a result of strong ambient winds or along congested roads with a high background dust levels. Ideally the ambient wind speed should be no more than half of the speed of the test vehicle, so that the plume configuration around the test vehicle is relatively stable. In any case, mobile monitoring should not be conducted when ambient wind speeds exceed 15 mph. The interference of background concentrations in the roadway air environment is removed by subtracting the monitored concentration in front of the test vehicle.

A calibration factor is needed for each mobile monitoring configuration (test vehicle and sampling system), to convert the relative dust emission intensity to an equivalent emission factor. The type and operating characteristics of the continuous monitor for fine particle concentration (normally PM-10) must be specified. In most reported applications of mobile monitoring, a portable laser photometer (light-scattering device) has been used. It is typically the case that portable continuous particle concentration monitors do not comply with Federal Reference Method (FRM) standards for the specified particle size range (e.g., PM-10). Therefore, a controlled study in a well-mixed chamber must be performed to develop a conversion factor that can be used to adjust the monitor reading to the true particle concentration for the applicable particle size range.

Calibration of a mobile monitoring configuration is accomplished by establishing a relationship between the mobile monitor concentration and the equivalent emission rate. Roadside plume flux profiling (traditionally referred to as exposure profiling) is the recognized standard method for calibrating mobile monitoring systems. Three or more test sites (or independent sets of test conditions) should be used for the calibration program, so that a range of road and traffic conditions are represented. At each test site, the paved road should be blocked to normal traffic so that only test vehicle passes are occurring during the calibration procedure.

The test roads should have moderate to heavy silt loadings so that a significant concentration increments above ambient background are measured at all plume impact heights on the roadside profiling tower. Ambient wind speeds in the 5 to 10 mph range are ideal because they tend to result in stable wind direction without excessive dilution of the dust plumes.

In the calibration tests, multiple test vehicle passes should be accumulated in the calibration factors in order to average for differences in single-pass plume variations that occur because of momentary wind variations. If continuous monitors are used on the roadside profiling tower to provide more measurement sensitivity, it is important that the relationship between the continuous monitor reading and the true concentration is determined. This is best accomplished using a well-mixed environmental chamber where representative test dust is entrained and exposed to the continuous monitor and to FRM samplers for the particle size range of interest.

The calibration factor changes with the location of the sampling probe on the outside of the test vehicle. This reflects differences in intensity of the dust plume generated by the test vehicle. For example, the dust plume intensity in the wheel well of a test vehicle is greater than the intensity in the mixed plume behind the vehicle. It is important that the test vehicle body design and weight be specified (vehicle manufacturer, year and model) along with the precise location of the sampling probe(s).

Two separate sets of calibration factors have been reported by DRI and CE-CERT. In the DRI mobile monitoring technology, separate probes are located in the front wheel wells of the test vehicle, while in the CE-CERT technology, a single probe is located on a trailer towed behind the test vehicle. In both cases, a background probe is located on the front of the test vehicle.

Because the mobile monitor response has been shown to vary directly with the speed of the test vehicle, it is important to perform the calibration tests at documented test vehicle speeds. The calibration factor can incorporate a range of test vehicle speeds that are representative of the paved roadway system in the locality of interest. For example, the calibration factors developed for the DRI and CE-CERT mobile monitors represent a normal speed range for paved roads (25 to 45 mph), excluding periods of traffic congestion. It should be noted that 10 mph is regarded as the threshold vehicle speed below which traffic-entrained dust emissions are negligible.

To the extent possible, the speed of the calibrated mobile monitoring test vehicle should be restricted to the value or range of values for which the calibration was developed. However, mobile monitoring data may be collected outside of the calibrated speed range but with somewhat less reliability unless supplementary data on speed applicability of a calibration can be used to demonstrate that the full reliability applies. For example, in the case of the mobile monitoring technologies demonstrated in the Clark County study, the monitors were calibrated over a speed range of 25 mph to 45 mph, but monitoring over a speed range of 10 mph (the effective dust entrainment threshold) to 60 mph will still provide useful data.

Because the paved road dust emissions are also dependent on the fleet average vehicle weight, it is important that the weight of the test vehicle correspond closely to the fleet average vehicle weight for the application locality. For example, in the Clark County study, the average weight of the test vehicles (2.8 tons) closely matched the fleet average weight for traffic on paved roads (2.3 tons) in the Las Vegas area study location, so no weight correction factor was needed. It should be noted that 2.3 ton fleet average weight is fairly representative of most localities, except for roads such as rural interstate highways heavily traveled by tractor trailers.

Any calibration factor developed for a specific test vehicle/sampling configuration should remain valid in different regions of the country, unless (a) the road dust characteristics are markedly different, or (b) the fleet average weight for traffic on paved roads in the study location is different. In either case, a new calibration factor must be developed, unless prior studies have generated test data that can be used to make reliable adjustments to the original calibration factor.

A well-mixed dust entrainment chamber can be used to determine whether entrained dust from a new roadway study area is comparable to entrained dust from the locality where the mobile monitor calibration was performed. The chamber should be equipped with approved reference particulate samplers along with the continuous monitor used in the specific mobile monitoring system. When equal amounts of test dust from the original source and the new source are suspended, similar reference concentrations should be obtained and the ratio between the integrated particle monitor reading and the reference method sampler should be consistent.

Emission Factor Test Method Comparisons

A comparison of method implementation factors (including those that apply to roadside plume flux profiling) is given in Table 1 below. This includes both paved road and unpaved road applications.

Mobile monitoring provides for efficient roadway system representation without dealing with difficult issues of selecting fixed point sampling sites. Although mobile monitoring method does require calibration against the roadside profiling reference method, there is no need to repeat the calibration if the mobile monitoring configuration (test vehicle, on-board monitoring system and probe location) remains intact. Exceptions would occur (a) if the road dust characteristics in the study area are significantly different from those where the calibration factor was determined, or (b) if the fleet average vehicle weight in the study area is significantly different from the weight of the test vehicle.

Table 1. Test Method Time and Space Parameters

Test Method	**Sampling Time at One Location**		**Measurement Variability--Time**		**Measurement Variability --Space**	
	Paved Roads	Unpaved Roads	Paved Roads	Unpaved Roads	Paved Roads	Unpaved Roads
Roadside plume profiling	Up to 4 hrs for set-up plus 4 hrs for sampling	Up to 4 hrs for set-up plus 1 hr for sampling	Integrated over sampling period		NA—Sampling location fixed	
AP-42 surface sampling	3 hrs including setup	1 hr including set-up	Integrated over sampling period		NA—Sampling location fixed	
Mobile monitoring*	1 hr per 35 mi transit	1 hr per 35 mi transit	Integrated over sampling period		Provides full spatial resolution in map form	

*Assuming that the calibration factor has already been developed.

A more detailed list of test method implementation requirements is given in Table 2. Roadside plume profiling with a sampling tower, which is regarded as a reference method, has the most stringent implementation requirements: (a) moderate winds that have a strong component at right angles to the road orientation, (b) an open area for unobstructed air transport on the upwind side of the road, and (c) no more than two lanes of traffic upwind of the sampling tower. Note that environmental specialists can be readily trained to perform any of these specified methods with approximately the same level of training program intensity.

Table 2. Test Method Implementation Requirements

Implementation Requirements	**Emission Factor Test Method**		
	Roadside Profiling	**AP-42 Road Surface Sampling**	**Mobile Monitoring**
Daylight	Yes	Yes	No
Wind speed	3 to 15 mph	0 to 10 mph	0 to 15 mph
Wind direction	Within 45 deg of normal to road	Unrestricted	Unrestricted
Road width	No more than 2 lanes upwind of sampling tower	Unrestricted	Unrestricted
Roadside condition	No wind blockage upwind and only minor blockage downwind	Unrestricted	Unrestricted
Test sites	Multiple	Multiple	NA
Traffic count	Required	Not required	Not required
Traffic mix	Required	Not required	Not required
Calibration requirement	No	No	Yes
Safety	Roadside protection	Lane blockage and arrow board*	Low risk if traveling at traffic speed

*Often not feasible for congested roads

The sources of uncertainty in the test methods are listed in Table 3, which gives a first-tier screening analysis of comparative uncertainty. The estimated levels of uncertainty range from 0 to 3. Level 3 represents the greatest relative uncertainty. The level 0 denotes that the factor is not of primary importance to the method. This approximate uncertainty analysis indicates that all three methods have roughly equivalent uncertainty. It should be noted that a more rigorous uncertainty analysis is presented in the section below on the assessment of peer review comments.

Table 3. Sources and Estimated Levels of Method Uncertainty

	Level of Uncertainty by Test Method (0 to 3)		
Factor	**Roadside Profiling**	**Vacuuming + AP-42***	**Mobile Monitoring**
Plume concentrations	1	NA	1
Winds	1	0	1
Site Representativeness	3	3	0
Calibration Factor	NA	NA	2
Conversion Equation	NA	2	NA

*Unpaved road surface materials are sampled by hand sweeping.

Development of Emission Inventories

Emission estimates for entrained road dust within an inventory area are found by multiplying emission factors in lb/VMT (or g/vkt) for each roadway category by VMT values for that category. In turn, the VMT values for a given averaging period (daily, weekly or annually) are obtained by multiplication of traffic counts on representative road segments within a roadway category by the lengths of the segments. The full emission inventory for a defined study locality is complete when all active road segments that pass a significance test have been represented in the calculations. It is assumed that traffic-entrained dust emissions are negligible when traffic speeds are below 10 mph, requiring that this adjustment be made to the emission inventory by subtracting VMT components associated with traffic congestion.

Method Evaluation by Peer Review

To determine whether mobile monitoring has been demonstrated to be equivalent or even superior to the conventional AP-42 method for determining paved road dust emission factors, a peer review process has been implemented.

Name	Affiliation
Arthur, Cathy	Maricopa AG
Fransioli, Paul	J3AQM
Goss, Tracy Laybourn, Mike	South Coast AQMD
Inouye, Daniel	Washoe Co. Health Dist.
Ono, Duane	Great Basin UAPCD
Pienta, Walter	NY DEC
Withycombe, Earl	CARB

The most important aspect of this peer review was the evaluation of mobile monitoring technologies in terms of the requirements for method standardization. In considering whether mobile monitoring has the potential for approval as a standard method, the peer reviewers were asked to consider its characteristics in three specific areas:

- Physical description
- Performance specifications
- Measurement comparisons

EPA uses the following specific criteria when evaluating a new method, so the peer reviewers were asked these questions:

- Is there a need for the intended scope and application of the method?
- Will the submitted method generate data consistent with the intended scope and application of the method?
- Have appropriate quality control procedures been developed for this method?
- Is the method described in sufficient detail for an independent investigator to implement it?
- Has this method been shown to be equivalent to a standard reference method?
- How is this method superior/inferior to the established reference method?

The peer reviewers were asked to consider the following specific factors in evaluating mobile monitoring in comparison with the traditional AP-42 method:

- Scope of application (required labor, training, equipment, materials)
- Mitigation of safety hazards
- Weather restrictions on testing (winds, temperature)
- Site restrictions on testing
- Measurement system availability in terms of off-the-shelf components
- Interferences (background concentrations in relation to plume concentrations)
- Measurement repeatability
- Data analysis requirements
- Quality control requirements

The ultimate objective of the review was to determine whether mobile monitoring technologies are suitable as an alternative to the standard AP-42 method for determining PM_{10} emission factors for paved roads.

In each assessment, the reviewer was asked to evaluate the following aspects of the specified mobile monitoring technologies in relation to the standard AP-42 method (road surface sampling plus emission factor equation application):

- Equivalency in determining road dust PM_{10} emission factors at specific locations within a roadway system
- Capability to represent distributed roadway types and traffic conditions that dominate emissions within an air quality control area
- Ease of use/safety considerations
- Executability with commercial off-the-shelf components

An ftp site at Midwest Research Institute was set up to provide the peer reviewers access to the study documents. The following documents were accessible through the ftp site.

- Main Report (Phase IV of the Clark County Test Series)
    - Executive Summary
    - Main body of Report
    - Glossary
- Appendix A: Data Tables
- Appendix B: Study Design
- Appendix C: Phase II Report
- Appendix D: Phase III Report
- Appendix E: Example Calculations

The form to be completed for the method evaluation by peer reviewers is included as Attachment A. Dr. Chatten Cowherd of Midwest Research Institute administered the peer review process as an independent investigator with experience in this field.

Assessment of Peer Review Comments

The results of the peer review process in terms of the completed method evaluation forms are presented in Appendix B. The reviewers generally agreed that the mobile monitoring method is superior to the traditional AP-42 method. However, there were some concerns about (a) clearly specifying the method implementation procedures and (b) evaluating method uncertainties.

Several of the review comments called for greater specification of method requirements going forward, indicating how the mobile monitoring method can be implemented in a study area where the method had not previously been used. In anticipation of these concerns, plans had already been made to prepare a separate document on Mobile Monitoring Method Specifications as a final step in the desired standardization process.

The method specifications document will address the following items mentioned in the peer reviews:

- Provide a protocol summarizing how the method should be implemented in an area that has not been previously tested against tower flux measurements.
- Address the applicability limits of the calibration factor assigned to each specific test vehicle configuration regarding future use.
- Provide criteria for deciding the need to adjust calibration factors to local road dust particle size characteristics that may differ significantly from those found in the locations where the original calibrations were performed.
- Specify the acceptable test vehicle speed range in relation to value or range of values for which the calibration was developed.
- Discuss roadway traffic speed as a function of roadway class, which is commonly used to differentiate road dust emission factors.
- Define a specific upper limit to wind speed under which mobile monitoring can be implemented.
- Address the general availability of commercial PM samplers that meet the necessary requirements.
- Provide a general description of the data acquisition software that is needed to implement the method.
- Provide general descriptions of the qualifications of persons who might develop new configurations for mobile monitoring.
- Include recommended QA procedures in a final test method description.
- Provide a more rigorous data validation procedure for calibrating and implementing the mobile monitoring method.
- Describe step-by-step method implementation and expected outcomes in comparison with traditional methods, including uncertainty analysis.
- Identify the weather and traffic conditions under which mobile monitoring should not be performed.
- Address the potential variations of fleet average vehicle weight across roadway classifications.
- Explain the relationship between the mobile monitoring method and the traditional AP-42 silt-based method for calculating road dust emission factors, recognizing that both methods are tied to plume flux profiling as a reference standard.

The other major area of concern was the uncertainty of the mobile monitoring method, in comparison the traditional AP-42 method.

The Clark County field tests of mobile monitoring focused around two mobile monitoring systems. The two systems used in evaluating the method were the TRAKER (Testing Re-entrained Aerosol Kinetic Emissions from Roads) system developed by Desert

Research Institute and the SCAMPER (System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways) developed by University of California-Riverside.

The primary source of uncertainty in the mobile monitoring method is the calibration factor for the specific test vehicle/sampling system configuration. In the case of the TRAKER and SCAMPER units, the linear relationships between mobile monitor concentrations and the roadside emission factors had R^2 values in the range of 0.5 to 0.75, where R is the correlation coefficient and.R^2 is a measure of the portion of the variance that is explained by the relationship.

In order to compare the uncertainties in the traditional AP-42 method and the mobile monitoring method as implemented in the Las Vegas Valley, the scatter of the test points about the predictive relationship was evaluated. Figure 1 gives the cumulative frequency distribution of the ratios of predicted to observed (P/O) emission factors from the 86-point field test data set used in developing the AP-42 emission factor equation for paved roads. For example, the figure shows that for 60 % of field tests, predicted emission factors lie within a factor of 3 of the observed (measured) values.

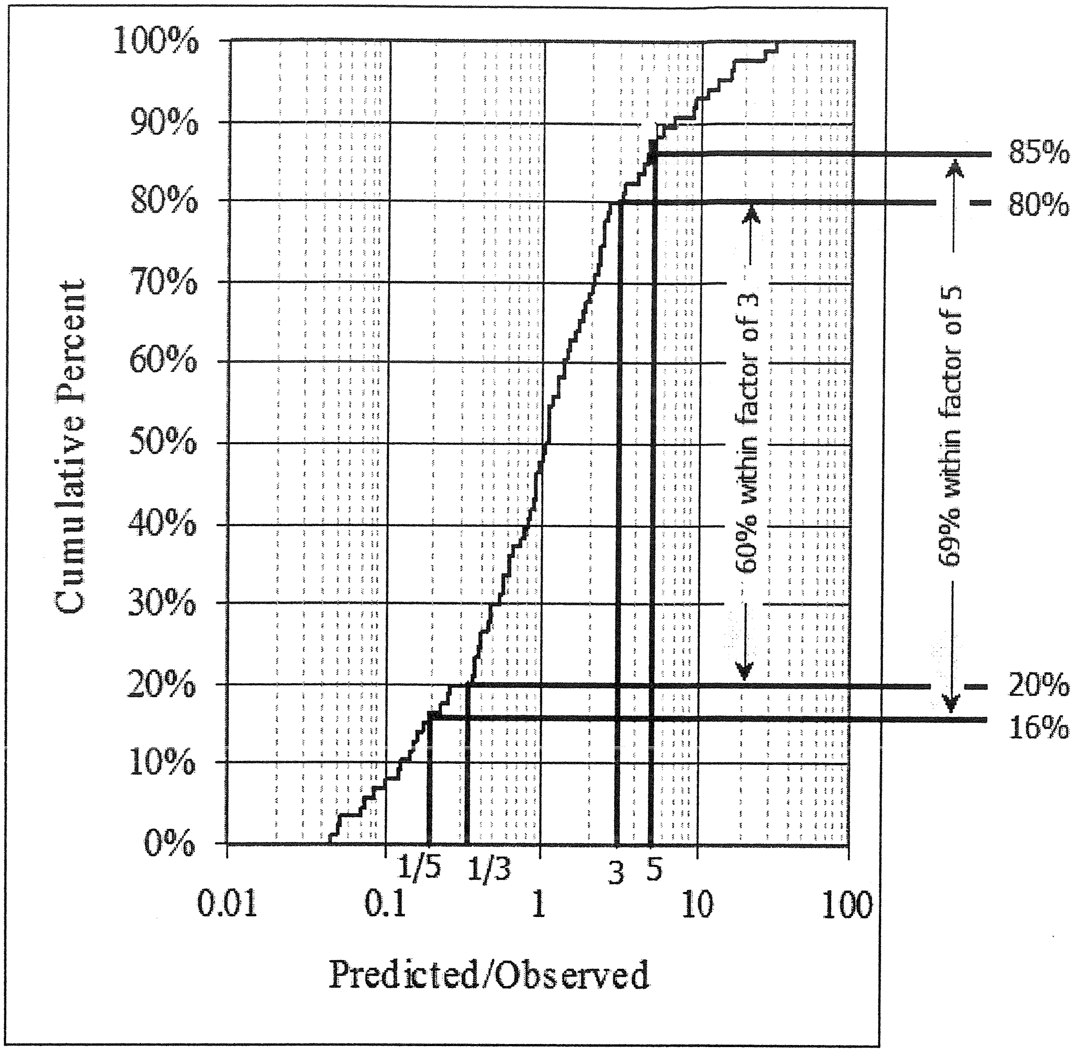

Figure 1. Cumulative Frequency Distribution of P/O Ratios for AP-42 Equation

By comparison, a similar data presentation for the TRAKER and SCAMPER calibration test results is provided in Figure 2, where each test series is represented by a single data point. As indicated in the figure, the TRAKER and SCAMPER data are merged for this comparison, giving a total of 16 data points.

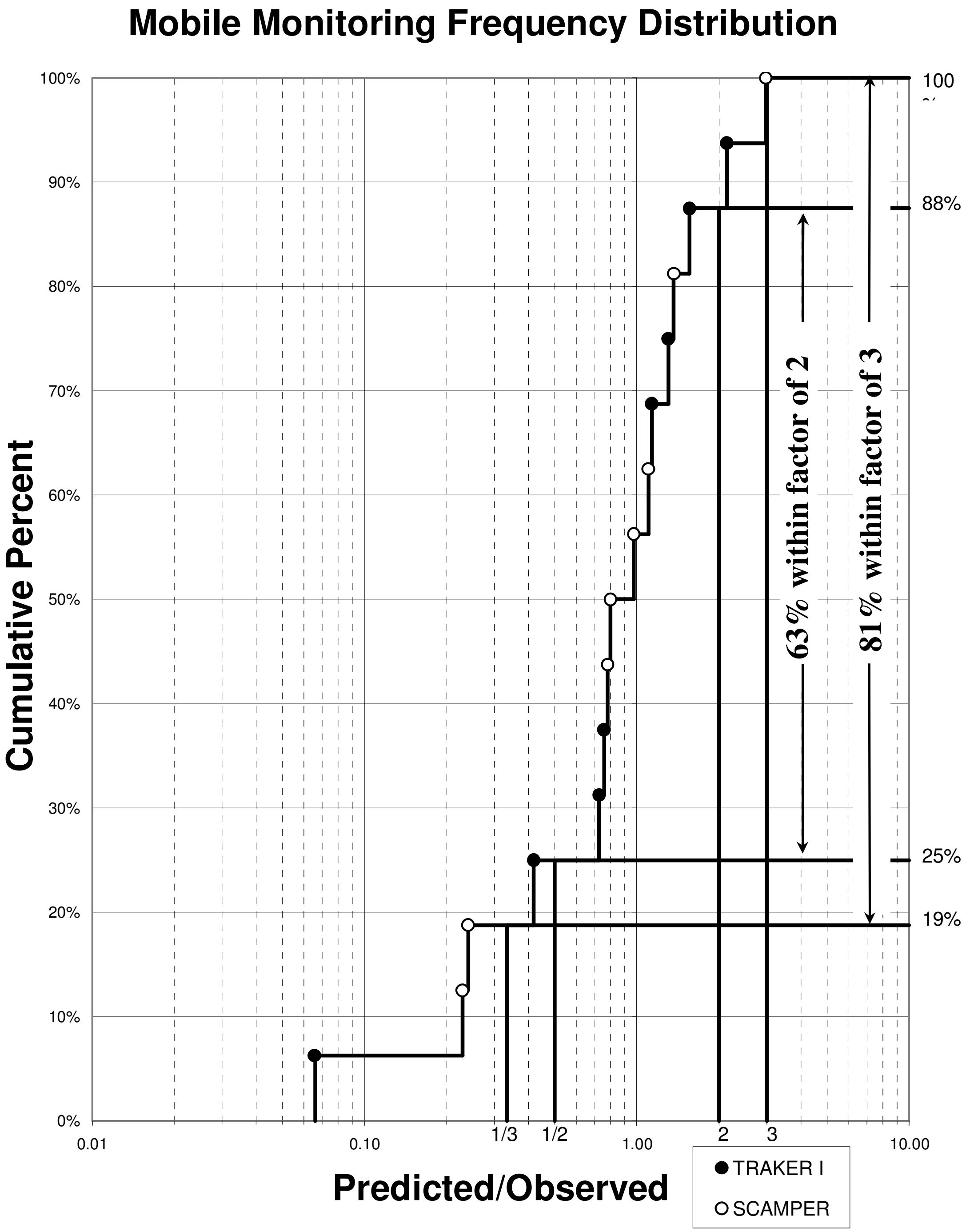

Figure 2. Cumulative Frequency Distribution of P/O Ratios for MM Tests

The tabulated results for typical uncertainty measures (such as a factor of 2) are given in Table 4. Note that in every case a higher percentage of mobile monitoring test results fall within the specified factor as compared to the AP-42 test data. This indicates a lower level of uncertainty for mobile monitoring as compared to the traditional AP-42 method, even when individual site-specific silt loading values are used in predicting the measured emission factors. If default silt loading values are used in predicting road dust emission factors with the AP-42 emission factor equation, a higher level of uncertainty would be expected. Nonetheless, the AP-42 emission factor is very effective in reducing the uncertainty that would be generated by the use of simple averages of test data to predict individual data points.

Table 4. Percentages of Observed Data Within Given Factor of Predictions

Factor of:	**AP-42 Equation**	**Mobile Monitoring Calibration**
2	38%	63%
3	60%	81%
5	69%	94%

This analysis clearly indicates that linear equations used to generate the calibration factors for the TRAKER and SCAMPER systems on average have lower uncertainty than the AP-42 emission factor equation for paved roads. This is not surprising when it is realized that the AP-42 equation was developed from test data collected under a much broader range of conditions at many locations across the country.

Even if it were to be assumed that the uncertainty levels of the two methods compared in Table 4 are similar, there is a second significant source of uncertainty in the traditional AP-42 method that has no uncertainty counterpart in the mobile monitoring method. Whereas the AP-42 method requires a priori judgments as to where to collect silt loading samples, the mobile monitoring method provides for rapid characterization of a large segment of a roadway system. Even if only an uncalibrated mobile monitor were available in a particular study area, it could be used as an effective tool to locate silt loading collection points in implementing the traditional AP-42 method.

In summary, it is believed that preparation of the Mobile Monitoring Method Specifications document along with the comparative analysis of method uncertainties (as shown above) will satisfy any concerns raised by the peer reviewers. In addition this information can be used to fully qualify mobile monitoring as a suitable, and even superior, alternative to the standard AP-42 method for determining PM_{10} emission factors for paved roads.

Bibliography

1. Countess Environmental, 2006. *WRAP Fugitive Dust Handbook.* WGA Contract No. 30204-111.

2. USEPA, 2006. Compilation of Air Pollutant Emission Factors, Volume I: Stationary and Area Sources, Research Triangle Park, NC.

3. Guidance for Mobile 6.2: http://www.epa.gov/EPA-AIR/2004/May/Day-19/a11340.htm

4. Teng, H., Kwigizile, V., Moses, K., James, D., Etyemezian, V., 2008. *Investigation of the AP-42 Sampling Method.* Journal of the Air & Waste Management Association, Vol. 58, 6/2008.

5. Assessment and Standards Division; Office of Transportation and Air Quality; U.S. EPA, 2005. *EPA's National Mobile Inventory Model (NMIM), A Consolidated Emissions Modeling System for MOBILE6 and NONROAD*. EPA420-R-05-024.

6. Langston, R., Merle, R. Jr., Etyemezian, V., Kuhns, H., Gillies, J., Dongzi, Z., Fitz, D., Bumiller, K., James, D., Teng, H., 2008. *Clark County (Nevada) Paved Road Dust Emission Studies in Support of Mobile Monitoring Technologies.* Final Report. December 2008.

7. Nevada Department of Transportation. "Total AVMTs by County and Functional Class," 2006.
   http://www.nevadadot.com/reports_pubs/miles_of_travel/pdfs/2006/2006_page3_6.pdf

8. California Air Resources Board Emission Inventory Methodology:
   http://www.arb.ca.gov/ei/ei.htm

9. Teng, H., Kwigizile, V., James, D., Merle, R., 2007. *Identifying Influencing Factors on Paved Roads Silt Loading*. Journal of the Air & Waste Management Association, Vol. 57, 7/2007. 778-784.

10. Cowherd, C. Jr., 2008. *Mobile Versus Fixed Point Monitoring of Dust Emissions from Paved Road Networks.* Presented at the Annual Meeting of the Air and Waste Management Association, Portland OR.

11. Fitz, Dennis R (2005). Draft Final Report, Measurements of PM10 Emission Factors from Paved Roads in Clark County, NV, Prepared for Clark County Department of Air Quality Management's Roadway Dust Sampling Evaluation Phase II.

12. C. Cowherd, Jr., *et al., Improved Activity Levels for National Emission Inventories of Fugitive Dust from Paved and Unpaved Roads,* Presented at the 11th International Emission Inventory Conference, Atlanta, Georgia, April 2002

Attachment A: Method Evaluation Form

Evaluation of Mobile Monitoring Technologies in Comparison with the Traditional AP-42 Methodology for Paved Road Emission Inventories

Submitted by ______________________________ Date____________
Qualifications attached (initial): _______________

Please address the following questions in performing your evaluation of the mobile monitoring method. Add as much space as necessary in presenting your response to each question.

1. Identify your impression of the intended scope and application of the proposed mobile monitoring method. (What is the method supposed to accomplish?)

2. Is there a regulatory need for the intended scope and application of the method?

3. Will the submitted method generate data consistent with the intended scope and application of the method?

4. Is the method described in sufficient detail for an independent investigator to implement it?

5. Can the method be implemented with commercially available off-the-shelf components?

6. Have appropriate quality control procedures been developed for this method?

7. Has this method been shown to be equivalent to a standard reference method? If so, what are the limits of applicability of the calibration factors that have been developed for the mobile monitoring method?

8. How is this method superior/inferior to the traditional AP-42 emission factor test method? What are the limits of applicability of the mobile monitoring method?

9. Other comments:

Attachment B: Comment/Response Log for Peer Review of Clark County's Road Dust Emission Studies in Support of Mobile Monitoring Technologies

Comments from Peer Reviewers received via email from:
[DO] Duane Ono (7-23-08), [CA] Cathy D. Arthur (7-27-08), [DI] Daniel Inouye (8-14-08), [EW] Earl Withycombe (8-22-08),
[PF] Paul Fransioli (8-15-08), [GL] Tracy Goss & Mike Laybourn (9-3-08), [WP] Walter J. Pienta (10-22-08)

Comment	Response
Question 1. Identify your impression of the intended scope and application of the proposed mobile monitoring method. (What is the method supposed to accomplish?)	
DO- I found that the 3 mobile monitoring methods evaluated in the report were all capable of serving as an alternative method to the current AP-42 silt loading technique for estimating PM emission factors for paved and unpaved roadways. It appears that mobile monitoring methods can provide more accurate estimates of vehicle emission factors, especially if the readings are calibrated to local road dust conditions. The mobile monitoring methods also provide valuable information that can't be easily obtained using the AP-42 method. They can measure relative changes in spatial and temporal emission factors. This is quite useful for developing area-wide emission inventories on many roadways with different surface condition and traffic patterns, and for evaluating changes over a period time, such as seasonal differences, or the changes in emission rates after a deposition event or even after clean-up, such as street sweeping.	No response required.
CA- The Phase I-IV evaluations conducted by Clark County were designed to demonstrate that mobile monitoring techniques produce paved road PM emission factors that are at least as accurate as the AP-42 equation based on vacuumed silt loading samples. Clark County would like to apply emission factors based on the mobile monitoring techniques in their PM-10 Maintenance Plan. In addition, the new PM emission factors would be used in preparing transportation conformity analyses and periodic emission inventories required by EPA.	No response required.
PF- Safely and economically acquire relevant paved road PM_{10} emission factors over a range of vehicle activity levels in Clark County to use in SIP process.	No response required.
DI- My impression of the purpose of the proposed method is to investigate alternatives to the AP-42 method of estimating paved road PM10 emissions.	No response required.

EW- The proposed mobile monitoring method is intended to provide paved road emission factors over many more road links than is presently feasible using either plume profiling or road silt sweeping methods. The mobile method can be used on any paved road, under most weather conditions, with greater safety than is afforded by the road sweeping method, and with less equipment and set up required of the plume profiling method. An alternative scope and application of the mobile monitoring method is the measurement of road silt levels for use with the existing AP-42 emission factor equation.	No response required.
GL- The scope and application of the proposed mobile monitoring method are laudable as concerns over the accuracy of current paved road dust emission estimation methodologies have been growing in recent years.	No response required.
WP- The primary objective of this study appears to be to make some comparisons of mobile sampling technology to conventional “street vacuuming” to determine silt loads. Ironically, these would be input to the existing parametric model (a.k.a. the existing AP-42 silt loading method) as a never changing quantity, when, in fact, the experiments show significant change (removal) with as few as 9 vehicle passes. Rather than yielding some steady state value by arbitrarily throwing-away the “front end” of an exponential decay, this series of controlled experiments should be used to shed some light on the dynamics of silt loads, and how they must be modeled to make them time (from hourly timescales out to seasonal ones) and traffic dependent. This will, in turn, raise more fundamental questions about “what’s an emission?”, and “what’s an inventory?” That in turn raises the question of what parts of the total procedures used in these experiments are the “method”. A secondary objective is to make some intercomparisons of three mobile sampling techniques, in the same silt loading context. For Clark County’s limited regulatory purpose of seeking approval for a new means of collecting silt loads, this series of experiments does, indeed, meet it’s objectives in very comprehensive ways. It should be noted that I continue to believe that the scope and application of the current set of experiments (as contrasted with the mobile “methods”) should be to provide the data necessary to begin building a better model (suggestions provided as part of this review). Given more time, I would want to better understand this work in the context of building that better model. There is a lot of good information in this series of experiments that appears to be getting thrown away as irrelevant to Clark County’s limited objective of developing an approvable, alternate means of collecting silt loading estimates.	It should be clarified that mobile monitoring is completely independent of the “existing AP-42 silt loading method.” Developing data sets for input to, or refinement of, the AP-42 equation, was not the intent of this study. Unlike the AP-42 method, mobile monitoring offers the mapping of road dustiness conditions by allowing miles of roadway to be characterized within an hour. In this way, it becomes feasible to evaluate spatial variability across roadway systems as well as the effects of sudden changes in road dust emission potential as the result of short-term events such as the application of anti-skid abrasives during wintertime conditions in the Mountain West or the Northeast. It should be noted that the peer reviewer was contacted for additional discussion of his comments. The reviewer agreed that the new Technical Support Document for mobile monitoring would likely address much of his broader concern about emission factor modeling of paved road dust.
Question 2. Is there a regulatory need for the intended scope and application of the method?	

DO- Mobile monitoring methods can be used to develop roadway emission inventories for PM SIPs, for evaluating control strategies, e.g. street sweeping, adding curbs and shoulders, or using sand for winter-time anti-skid control. Accurate emission estimates are also useful for tracking the impacts of road dust emissions for transportation conformity analysis.	No response required.
CA- Clark County needs to obtain EPA Region IX approval to use an alternate method to AP-42 in developing PM emission inventories. OAQPS will have to approve the method if it is to be formally adopted by EPA as an alternative to the current silt loading based equation in AP-42.	No response required.
PF- Yes; the emission factors are to be used to model the impacts of vehicle-entrained PM$_{10}$ for use in SIP-related documentation. The issue is whether the emission factors are generated by traditional AP-42 silt measurements and vehicle travel, or by mobile measurements.	No response required
DI- Yes. Paved road emissions are typically a significant portion of PM10 emission inventories. Relying on default AP-42 factors, especially silt loading, may inaccurately estimate these emissions and alter the air quality planning process. State Implementation Plans are developed based on these emission inventories.	No response required.
EW- Paved road emissions, in many urban areas, constitute the largest categorical source of PM$_{10}$ emissions. This is due, in spite of relatively low emission factors per unit of activity, to the sheer magnitude of overall motor vehicle use in urban areas. If an urban area happens to be nonattainment for the PM$_{10}$ ambient air quality standard, reduction of paved road emissions is usually a priority in the development of attainment strategies and plans. Currently, eight areas in the nation are designated as serious PM$_{10}$ nonattainment and thirty nine areas are designed as moderate nonattainment. Within these areas, air quality planning would benefit from any improvement in the tools used to assess emissions from paved road travel.	No response required.
GL- Yes. An improved methodology to estimate paved road dust emissions will greatly enhance the inventory and modeling efforts that serve as key components in attainment demonstrations required by many planning documents (e.g., SIPs, maintenance plans, etc.) for both PM10 and PM2.5.	No response required.
WP- I am not familiar with the extent of PM$_{10}$ problems west of the Mississippi, and more specifically in arid, desert locales, and how a road dust model plays a part in strategy development, so I am not able to	The reviewer attached a document prepared in April 2008 as part of the NYS Implementation Plan for PM2.5,

comment on the regulatory need in SIP development processes. From my perspective, we would use road dust estimates for transportation conformity and to review other large scale projects for legally required, state environmental review purposes. We do not have any PM$_{10}$ nonattainment areas problems in New York State, but we do use PM$_{10}$ estimates as threshold values for certain further analyses that may lead to requirements for mitigation. Because large errors in road dust emissions might lead to "mitigating a problem that does not really exist", I believe that the existing method should not be used in the conformity process (nor in our own state reviews). To support such a position, we, like others, use the large disconnect in comparing PM$_{2.5}$ monitoring results to an inventory amount that represents up to 10 times that portion of our total inventory. That is, we estimate 3%-6% crustal material in the total mass of a filter, whereas 3%-65% of the inventory is road dust, depending on the extremes of an order-of-magnitude estimate[1]. I recognize that this raises further questions about the relationship between emissions, inventories, dispersion models, and what ends up on a filter, but that discussion needs to occur, especially if EPA continues to insist on the use of those estimates. Furthermore, what weight of evidence is necessary to have EPA acknowledge that things need to be fixed? To highlight our dissatisfaction with the current procedure, the Department drafted a PM$_{2.5}$ state implementation plan (SIP) that declares road dust to be indeterminate at this time (the appropriate section of that DRAFT SIP is attached). The Department, therefore, can expect to be cast in the same role as Clark County, as EPA demands that we suggest an alternative to the existing AP-42 (silt loading) method. It is somewhat ironic, but mostly annoyingly illogical, that they can make such a demand without an admission that their approach must somehow be flawed. We have provided some pieces of the alternative we will propose to EPA in these comments. The remainder, we hope, will evolve into what we have begun to refer to as the NYS PPM (parsimonious particulate model). It will not be so parsimonious as the existing two parameter model, because, if one looks at Figure 13.2.1-1 of the AP-42 procedure, we are dealing with a complicated process here. We believe that the NYS PPM would borrow liberally from the "Swedish Road Dust Model" (a phrase of my making)[2]. It may even be compatible with and feed into the (equally Scandinavian) Ordinary Street Pollution Model (OSPM)[3].	Attainment Demonstration for the NY Metropolitan Area. It states that the traditional EPA method is flawed to the extent that NYS has declared the road dust emission estimation indeterminate. This conclusion is based on the "disconnect" between modeled and monitored PM2.5 levels, as noted in his comment. EPA has begun to recognize that it is infeasible to develop modeling algorithms that account for near-source dust plume losses (to a distance of about 200 m from the source) because of the complexity of the phenomena involved. The approach of a "source adjustment" to the calculated emissions to account for near-source plume loss is much more feasible. Conservatism would be built into the adjustment in relation to the magnitude of plume losses that have been measured. The adjustment would be based on the type of groundcover bordering the source, as recommended by Tom Pace of EPA. As noted above, the reviewer is awaiting review of the TSD with the expectation that it will address many of his basic concerns.

[1] An example of a set of order-of-magnitude estimates is given in Pienta, W.J. (2004), NYS PM$_{2.5}$ Road Dust Estimates for CY 2002, internal report; subsequently submitted to the USEPA docket, Oct. 2004. Available from the author at wjpienta@gw.dec.state.ny.us

[2] The model is discussed by Olmstedt, G., Bringfelt, B., & Johannson, C. (2005), "*A model for vehicle-induced non-tailpipe emissions of particles along Swedish roads*", **Atmospheric Environment** 39 (2005) 6088–6097. I discuss it further at the end of the evaluation.

[3] The OSPM is a street canyon model developed by the Danish Ministry of Environment and Energy and their National Environmental Research Institute. It is referenced in a report by Berkowicz, R., Hertel, O., Larsen, S.E., Sorenson, N.N., & Nielsen, M. (1997), *Modeling Traffic Pollution in Streets*. (available as a PDF document from me or at http://www2.dmu.dk/1_viden/2_Miljoe-tilstand/3_luft/4_spredningsmodeller/5_OSPM/5_description/ModellingTrafficPollution_report.pdf). An evaluation of the OSPM by Kukkonen, J., et. al. (2003) using Finnish data appears at **Atmospheric Environment** 37 (2003) 1101-1112, and one by Berkowicz, R., (2008) using Danish data appears at **Environmental Modelling & Software** 23 (2008) 296-303.

Question 3. Will the submitted method generate data consistent with the intended scope and application of the method?

DO- The 3 mobile monitoring methods can provide good information for PM emission inventories and for control strategy analysis, especially in those areas where the mobile methods have already been	The commenter's recommendation will be followed in developing detailed specifications for the mobile

tested against tower flux measurements. However, it would be good to provide a brief protocol summarizing how each method should be implemented in an area that has not been previously tested against tower flux measurements.	monitoring method.
CA- The mobile monitoring methods generate paved road emissions rates (in grams/VMT) that can be used by Clark County to develop PM emission inventories.	No response required.
PF- Yes, the mobile monitoring methods could be used to generate the intended emission factors.	No response required.
DI- Yes. The results will provide an alternative method for paved road PM10 emission estimates.	No response required.
GL- The California Air Resources Board (CARB) methodology for estimating paved road dust emissions involves entering a series of inputs (i.e., silt loading) and the end result is an emission factor based in terms of grams per vehicle mile travelled (g/vmt) for different types of roads. It is unclear if the mobile monitoring methodology would result in similar emission factors for different types of roads or if a "composite" emission factor would be developed for an entire region or subregion.	The mobile monitoring method will result in a set of emission factors that are applicable to the geographic location where the monitoring is performed. The emission factors can easily be subdivided by road category and even by additional factors such as land use, presence of curbs, and so on, depending on the extent of data analysis performed. If desired, a composite emission factor for the area of interest can also be developed
WP- Given some common understanding of what is to be included as an emission, and whether dispersion models can adequately explain or reliably provide some correction to the propagation of said emissions as part of an overall inventory that is consistent with what's on the ambient monitoring filters, the methods hold some promise for developing values for certain parameters necessary to adjust local conditions in some new improved road dust model.	No response required.

EW- The mobile monitoring methods will generate data needed to improve paved road emission inventories, but may not directly generate emission factors without additional research or analysis of existing data. The reported results of this and predecessor studies indicate that: 1. The precision demonstrated by individual mobile monitors on the same road links run several times per day demonstrate the utility of these systems to measure relative values of road silt over large geographic domains and frequent time intervals; 2. The correspondence between different mobile monitors on the same road links with respect to variability demonstrates the repeatability of systems using the same fundamental design to also measure relative values of road silt over geographic domains and frequent time intervals; 3. The R^2 values of less than 0.5 between mobile monitor and flux tower measurements suggests that additional analysis or research is needed to determine the bases for variability between these two sets of measurements; 4. Similar R^2 values of less than 0.5 between mobile monitor-derived emission factors and AP-42 swept silt-derived emission factors suggest that additional analysis or research is needed to determine the bases for variability and, if needed, the reconstruction of the AP-42 emission factor equation to reflect the significance of vehicle speed; and 5. The findings of this study and previous work by DRI and UCR indicate that paved road travel PM_{10} emissions may vary with the cube of the vehicle speed, a parameter that does not appear in the AP-42 equation as developed from flux tower measurements.	No response required to items 1 and 2. Concerning items 3 and 4, uncertainty analysis shows that the mobile monitoring method is more reliable than the traditional AP-42 method, provided that the calibration of the mobile monitoring system is performed over a vehicle speed range that is sufficiently representative of paved road conditions. This will be demonstrated in the new TSD for mobile monitoring. In response to item 5, it should be pointed out that field tests have shown that silt loading and vehicle speed are inter-correlated, so that in stepwise regression analysis, only one can be used as a correction parameter in the predictive emission factor equation. If speed is used rather than silt loading, there can be no accounting of the road silt additions that are unrelated to vehicle speed, such as mud/dirt carry-out from construction sites or the application of anti-skid abrasives during wintertime ice/snow events. This will be clarified in the Technical Support Document (TSD) for the mobile monitoring method.

Question 4. Is the method described in sufficient detail for an independent investigator to implement it?	
DO- The test procedures discussed in the report were explained in great detail, but the application of these methods to other areas should be explained. 1) Will the same calibration factor be used or will additional tower studies be needed? 2) Will additional chamber study comparisons be suitable to calibrate the PM10 and PM2.5 DustTraks to the local road dust particle size distribution? 3) At what speed will the mobile monitoring vehicle travel? 4) Will roadway traffic speed be incorporated into the emission factor? 5) What are the wind speed restrictions for testing? Note: The 0-15 mph wind speed restriction was only in the peer review guidance.	In the TSD for the mobile monitoring method, the following items will be specified: 1) Each specific test vehicle configuration will have a given calibration factor for future use.. 2) Criteria will be set for the need to adjust calibration factors to local road dust particle size characteristics that may differ significantly from those found in the locations where the original calibrations were performed. 3) To the extent possible, the test vehicle speed will be restricted to the value or range of values for which the calibration was developed. However, mobile monitoring data may be collected outside of the calibrated speed range but with somewhat less reliability unless supplementary data on speed applicability of a given monitoring system can be used to demonstrate that the full reliability applies. For example, in the case of the mobile monitoring technologies demonstrated in the Clark County study, the monitors were calibrated over a speed range of 25 mph to 45 mph, but monitoring over a speed range of 10 mph (the effective dust entrainment threshold) to 60 mph will still provide useful data. This will be discussed further in the TSD for mobile monitoring. 4) Roadway traffic speed is indicative of roadway class, which is commonly used to differentiate road dust emission factors. Moreover, mobile sampling systems make it feasible to develop separate emission factors for peak and non-peak traffic conditions by road class. 5) The recommended upper limit to the allowable ambient wind speed for mobile monitoring is 15 mph, as will be stated in the TSD.

CA- The method is described in sufficient detail for an independent investigator to replicate the evaluations done in Clark County, assuming the investigator has access to equivalent mobile technologies and other equipment (e.g., vacuums, horizontal flux tower).	No response required.
PF- Yes; there is no shortage of detail in the presentation.	No response required.
DI- Overall, I think the methodology is sufficiently described in Section 3 and Appendix B and should be repeatable by another team of investigators. The most difficult portion of the method to replicate may be calibration of the mobile monitoring methods to the flux tower. Locating an ideal roadway segment will be challenging. It should meet specific width and orientation criteria. Another factor is meteorological conditions on the day of testing. Wind speed and direction are important factors, but an uncontrollable variable.	The site requirements for use of plume flux profiling to calibrate a mobile monitoring configuration will be clearly stated in the TSD.
EW- The mobile monitoring methods developed by DRI and UCR are described in sufficient detail for an independent investigator to implement them. Additional information beyond that provided in this study is needed, however, to describe how TRAKER I or TRAKER II inlet concentrations are converted to vehicular emission factors.	The discussion in Section 6.3 of the test report describes how TRAKER inlet concentrations are converted to emission factors. The general procedure for this conversion will also be addressed in the TSD in such a manner that it is applicable to all qualified mobile monitoring configurations.
GL- With guidance material and appropriate training, the methodology should be repeatable by an independent investigator.	No response required.
WP-Yes, provided that the investigator has access to the “current embodiment” of the method’s equipment; or when the investigator has the time, money, and people to “invent” an alternative mobile data gathering scheme.	Ultimately, the specifications of the mobile monitoring method will be defined such that a range of test vehicle/sampling configurations is possible, extending beyond those tested in the Clark County comparison study. Obviously, each mobile monitoring configuration must comply with the necessary requirements. This will be made clear in the TSD.

Question 5. Can the method be implemented with commercially available off-the-shelf components?	
DO- Sufficient information has been provided in the report so that these mobile methods could be duplicated by people with a technical background. A rudimentary system of DustTraks calibrated to Arizona Road dust and placed on a vehicle or trailer could likely provide better emission factors than one could obtain with the AP-42 method. This would use the TRAKER or SCAMPER calibration factors from this study. Better estimates could be obtained by calibrating the DustTraks to local road dust in a re-suspension chamber, and/or setting up a roadside PM monitor tower to calibrate the system to airborne dust.	The primary source of uncertainty in the mobile monitoring method is the calibration factor for the specific configuration. In the TSD, it will be made clear that the calibration factors already developed for tested configurations (e.g. TRAKER and SCAMPER) generate emission factors with significantly lower uncertainty than obtained using the traditional AP-42 method with either default or site-specific silt loading measurements. Further reductions of uncertainty may be obtainable when calibration factors are checked against road dust characteristics of the geographic area of interest.
CA- I do not know if all components of the mobile technologies are commercially available and off-the-shelf, but I suspect some may be of custom design, since both technologies were developed by research institutes. The good news is that there are two sources for these technologies and more may surface, if the method is widely adopted.	Statements will be added to the TSD regarding general availability of commercial PM samplers that meet the necessary requirements.
PF- Yes, when installed and operated correctly as part of a full sampling system.	No response required.
DI- Yes. With the exception of the equipment used to modify the test vehicles, all of the components used in the studies are commercially available off-the-shelf. Each test vehicle will likely require unique modifications.	No response required.
EW- Yes, each method described can be implemented with commercially available off-the shelf hardware components. The data acquisition software developed by each of the DRI and UCR teams, however, appears to be custom designed and may be proprietary.	A general description of the data acquisition software will be included in the TSD.
GL- All of the equipment appears to be readily available, however, there appears to be a need to have either significant field experience or extensive training to configure, calibrate and operate the equipment.	General descriptions of the qualifications of persons who might develop new configurations for mobile monitoring will be provided in the TSD.
WP-It would appear so. However, given that vehicle aerodynamics may play a confounding role, its surrogates (in terms of geometric parameters of differing vehicles, trailers, intakes, and frontal areas), may be important considerations. At least they cannot be dismissed until intercomparisons with the current versions of the equipment show them to be unimportant, minor explanatory variables.	Each new test vehicle/sampler configuration will require an independent calibration.

Question 6. Have appropriate quality control procedures been developed for this method?	
DO- Good quality assurance appears to have been carried out for the study. It would be good to include recommended QA procedures in a final test method description.	This recommended will be followed. In addition to the TSD, a Method Standardization document will also be prepared, spelling out the QA procedures for mobile monitoring technologies.
CA- The quality control procedures for Phase IV appear to be exemplary.	No response required.
PF- The data validation precautions seem reasonable, though a more rigorous would be needed for a standardized method. The material on the laboratory-derived relations for the DustTraks in Section 4 seems out of place for a QA/QC section.	Possible restructuring and clarification of quality control procedures will be reviewed with the developers of the tested mobile monitoring configurations.
DI- I could not locate it in the study, but I'm assuming that a QA plan was prepared for the TEOM	Because the TEOM is a federal reference method, no special QA actions need to be addressed.
EW- From the descriptions provided in the study, it appears that appropriate quality control procedures have been developed for each monitoring system. It would be useful, however, for these procedures to be extracted from the report and succinctly assembled in a stand-alone document to assure completeness.	Section 4 of the test report addresses QA/QC procedures. The TSD and the Method Standardization document will prescribe that a stand-alone QA/QC document be prepared prior to executing the mobile monitoring method in a particular locality.
GL- Sufficient QA/QC procedures have been implemented in presenting the data.	No response required.
WP- Procedures that assure the fact that reliable measurements were made in all phases of this experiment are documented. However, I once again stumble over the meaning of "method". Until we have a modeling system that takes the silt loads as a dynamic quantity, and propagates them to a reasonable ambient quantity, we are just erecting an edifice to support an "emperor who has no clothes".	This reviewer was contacted to clarify his position. He is amenable to amending his view of MM vs. the AP-42 method, pending review of the TSD, which is designed to resolve basic questions about road dust emission factor determination.

Question 7. Has this method been shown to be equivalent to a standard reference method? If so, what are the limits of applicability of the calibration factors that have been developed for the mobile monitoring method?	
DO- This method is superior to the AP-42 test method for determining roadway emission factors. It can provide better spatial and temporal information than the AP-42 method and it probably provides more accurate results. Although it would be good to have compared the measurements to ambient reference method PM10 and PM2.5 samplers, the spatial and temporal variability in roadway emission inventories is likely much higher than the benefit that would be gained in providing more accurate measures of PM. It would be a refinement that is likely within the noise of emissions variability, and therefore would not provide much improvement in the overall inventory.	The reviewer was contacted to clarify his comment. The reviewer was referring to the desirability of standard roadside calibrations in areas where mobile monitoring is to be applied so that any differences in road dust characteristics are accounted for. Alternatively, the reviewer endorses suspending local road dust in a chamber where the monitoring device is compared against a FRM monitor such as an R&P Partisol.
CA- The standard reference method for the mobile monitoring techniques is the horizontal flux tower measurements of PM-10 in grams per VKT. PM measurements by the mobile monitoring vehicles were found to be correlated with the tower values ($R^2 = 0.47-0.75$). To obtain PM-10 emission factors, the raw signals from the vehicles were multiplied by 0.54, for TRAKER I, 0.92, for TRAKER II and 20, for SCAMPER. While it would be ideal for areas applying the mobile technologies to perform horizontal flux tower measurements to develop local calibration factors, the factors produced by Clark County should be useful for other urban areas with similar climates and soil characteristics.	No response required.
PF- The Method Evaluation guidance instructions identified three areas for which the characteristics of the method must be specified for purposes of method standardization. Some areas would require further work to bring the document closer to a standard. The areas are: Physical description: the document contains plenty of detail on the equipment and testing process used. The basic sampling equipment components are commercially available. Performance specifications: this topic needs further development. The term only appeared in two places in the report, the introductory statements (Sec 2, page iv) and in objective 6 for Phase IV (Sec 1.1, pg 2). I was unable to locate firm summary statements on expectations of performance specifications from the mobile methods. Section 7 shows summary figures of emission factors, and section 8 has qualitative discussion of the perceived success of the program and a brief summary of the calibration factors and associated correlations for the three methods. A standard method should contain clear statements on the expected accuracy and uncertainty that an investigator could expect by following the method. Measurement comparisons: Sections 6 and 7 do contain many results presented in a variety of ways. Some precision statements are made in Section 7.1, but not enough to robustly assess the method.	The reviewer makes valid statements about specifics required for method standardization. A separate method specifications or standardization document will be prepared which relies on the subject mobile monitoring comparison study as a demonstration of the validity of the method and its advantages over the traditional AP-42 method. The method standardization document will describe step-by-step method implementation and expected outcomes in comparison with traditional methods, including uncertainty analysis.

DI- The mobile monitoring methods were validated by the instrumentation on the flux tower. Although variability in wind speed and direction may have introduced uncertainty in the results, I think the QA/QC procedures address this factor. Also, have studies been conducted that support the equivalency of upwind/downwind vs. downwind methods?	Upon followup contact, the reviewer is questioning whether a downwind tower is sufficient in the calibration process. Other studies have shown that under light traffic conditions, background concentration can be reliability determined from the downwind tower monitors during periods when no vehicles are passing the tower.
EW- The mobile monitoring method used in this study has been shown to be generally equivalent to the flux tower method. Because the AP-42 emission factor equation is based on the flux tower method, emission factors based on the mobile monitoring method has also been shown to be generally equivalent to the road silt/vehicle weight-based emission factors. The absence of vehicle speed in the AP-42 equation, and the findings of this study and others regarding the significance of vehicle speed on emission rates, suggests that an emission factor equation based on the mobile monitoring studies may be an improvement over the AP-42 equation that is based on the flux tower method for measuring PM_{10} entrained from paved road travel. This work, however, should be delayed until further analysis or research into the variability between mobile method and flux tower measurements can be completed. The calibration factors that have been developed for the mobile monitoring method, as shown in Table 6-4 of the study, should not be used outside the range of vehicle speeds used in this study. This conclusion is based on the study findings regarding the significance of vehicular speed on emission measurements.	As stated in response to an earlier comment, uncertainty analysis shows that the mobile monitoring method is more reliable than the traditional AP-42 method, provided that the calibration of the mobile monitoring system is performed over a vehicle speed range that is sufficiently representative of paved road conditions. This will be demonstrated in the new TSD for mobile monitoring. Also in response to an earlier comment, it was stated that to the extent possible, the test vehicle speed will be restricted to the value or range of values for which the calibration was developed. However, mobile monitoring data may be collected outside of the calibrated speed range but with somewhat less reliability unless supplementary data on speed applicability of a given monitoring system can be used to demonstrate that the full reliability applies. For example, in the case of the mobile monitoring technologies demonstrated in the Clark County study, the monitors were calibrated over a speed range of 25 mph to 45 mph, but monitoring over a speed range of 10 mph (the effective dust entrainment threshold) to 60 mph will still provide useful data. This will be discussed further in the TSD for mobile monitoring.

EW- There may be an error in the conversion factor reported in Table 6-4 for the SCAMPER. Equation 6.4, p. 77, shows that the ratio of silt-based calculated emissions to SCAMPER calibrated measurements is 12, not 20 shown in Table 6-4. If the value of 20 in Table 6-4 is correct, then the text needs to be expanded to explain this difference.	In an earlier study, the frontal area of the SCAMPER test vehicle was used to derive an independent calibration factor of 12, as compared to value of 20 derived from standard roadside calibration in the current study.
GL- It appears the calibration factors are specific to the study area and new calibration factors would need to be developed for each new area. This may be an issue until such a time that sufficient data was collected that demonstrates factors were determined to be fully representative for a greater region, such as the South Coast Air Basin.	Any calibration factor developed for a specific test vehicle/sampling configuration should remain valid in different regions of the country, unless the road dust characteristics are markedly different. This point will be clarified in the TSD.
WP- I have a large philosophical problem with this question. The question assumes the existing AP-42 (silt loading) method to be a standard reference method, and that the purpose of the Clark County experiments is to improve the ease of generating some parameters that will serve to "calibrate" to the standard reference method of "street vacuuming". It further assumes that the existing AP-42 (silt loading) method stands on the pedestal of inviolable first principles of physics and chemistry, and is, therefore, fundamentally correct, and thus useful in making estimates for all applications (beyond its original utility as a two-parameter estimate of track-out emissions). Those assumptions are, unfortunately, incorrect.	As stated in response to an earlier comment, mobile monitoring is completely independent of the "existing AP-42 silt loading method." It is intended to be a preferred alternative to the traditional method and its associated difficulties of "street vacuuming."

Question 8. How is this method superior/inferior to the traditional AP-42 emission factor test method? What are the limits of applicability of the mobile monitoring method?	
DO- The superiority of the mobile monitoring methods is in their ability to easily measure changes in spatial and temporal road dust emission factors. Even the simplest application of this method could be used to find relative differences in higher or lower roadway emissions. Control efficiency estimates can be fairly accurate, even with minimally calibrated equipment. The relative effects of vehicle speed, roadway surface types and other characteristics can be tested by simple measurements. The accuracy of the overall emission estimates can be improved if an effort is made to calibrate the monitoring equipment to the local road dust particle size distribution.	The issues of variations in the local road dust particle size distribution will be addressed in the TSD and the method standardization document.
CA- The mobile monitoring technologies are superior to the AP-42 emission factor method, because they collect PM data from a larger and more diverse sample of roads than can be measured by vacuuming techniques. It is difficult to identify representative locations for the limited number of vacuum samples that can be collected. As noted in the Phase IV report, vacuum samples can not be performed on major arterials and freeways, due to safety concerns. So mobile monitoring is the only practical way to measure paved road emission rates on high-traffic facilities. The mobile monitoring technologies should be applied under typical meteorological conditions (not when it is raining or high winds have deposited soil on the roads.) In addition, the mobile monitoring emission rates should not be applied to VMT that is operating at speeds less than 10 mph.	The TSD and the method standardization document will identify the weather and traffic conditions under which mobile monitoring should not be performed.
PF- The mobile methods are superior to AP-42 when emission factors are wanted for a variety of paved roads, potentially under changing conditions and for roads where manual surface sampling is impractical or unsafe. The limits of applicability seem to be the uncertainty associated with the calibration factors needed to translate mobile system data to mass emission factors.	No response required.
DI- I think the greatest benefit with the proposed method is the ability to obtain more detailed PM10 emission factors by roadway classifications. The current AP-42 method only distinguishes two types of roadways - low ADT and high ADT. The proposed method can improve the spatial and temporal resolution of paved road emission inventories. Another advantage with the mobile monitoring method is the frequency in which roadway characteristics can be updated. Monitoring key roadway segments can provide air quality planners additional timely information to evaluate control measure effectiveness. The studies used test vehicles representing approximate vehicle weights of the vehicle fleet in the Las Vegas Valley. Average vehicle weights will probably be different for each roadway classification. This may be a limiting factor, but can be overcome.	The issue of potential variations of fleet average vehicle weight across roadway classifications will be addressed briefly in the TSD and the method standardization document.

EW- The mobile monitoring method of data collection is superior to the traditional AP-42 road silt sampling method for all of the reasons stated in the study. A mobile monitoring method can measure silt levels every 100 feet on tens of miles of roads per day, whereas the silt sweeping method – with the same personnel allocation – can collect silt level data at only 5 to 10 segments 100 feet long per day. Additionally, the mobile monitoring method can be safely used 24 hours per day on all types of roadways. The silt sweeping method suffers from safety problems that prohibit its use on freeways and during the night. Generally, our understanding of paved road emission dynamics will improve as we expand the database of silt measurements. Mobile monitoring methods have the potential of increasing the rate by which we collect data by three to four orders of magnitude. This benefit alone warrants that we encourage the use of this method now to collect data that will expand and improve upon our understanding of paved road silt dynamics. The mobile monitoring method is currently an excellent approach for collecting road silt data in a relative sense. At constant speed, a mobile monitor should do well in mapping geographical and temporal fluctuations in silt levels. This data is vitally needed to identify hot spots and their sources, and to quantify the benefits of control strategies that prevent or remove silt from roadway surfaces. Until the variability between mobile monitor measurements and silt-based AP-42 factors are explained, however, mobile monitor measurements should not be used to compute emission inventories but instead can be used to compute silt levels on road links traversed by mobile monitors from the correspondence between silt sweeping values and mobile monitored values simultaneously measured on the same road links. Care should be taken, however, to conduct all of the mobile monitoring in such a program at a uniform speed so as to eliminate the influences of speed in extrapolating from a few road links to many.	In response to an earlier comment, it was stated that to the extent possible, the test vehicle speed will be restricted to the value or range of values for which the calibration was developed. However, mobile monitoring data may be collected outside of the calibrated speed range but with somewhat less reliability unless supplementary data on speed applicability of a given monitoring system can be used to demonstrate that the full reliability applies. For example, in the case of the mobile monitoring technologies demonstrated in the Clark County study, the monitors were calibrated over a speed range of 25 mph to 45 mph, but monitoring over a speed range of 10 mph (the effective dust entrainment threshold) to 60 mph will still provide useful data. This will be discussed further in the TSD for mobile monitoring. Finally, the TSD will explain the relationship between the mobile monitoring method and the traditional AP-42 silt-based method for calculating road dust emission factors, recognizing that both methods are tied to plume flux profiling as a reference standard.
GL- The methodology is superior in that information on various types of roads under varying conditions could be collected without the need to obtain paved road silt samples. The methodology could also be used to obtain data on seasonal variabilities which may allow agencies to develop targeted control measures.	No response required.
WP- The mobile technology method is no better or worse than the existing street vacuum method in providing silt loads. I note that taking the resultant numbers and applying them to what we perceive to be an ill-fitting model, is a much larger problem that needs to be solved.	The mobile monitoring method is independent of the traditional silt-based method. This will be clarified in the TSD.

Question 9. Do you have any other comments?	
CA- I recommend that EPA Region IX approve Clark County's use of mobile monitoring methods to develop a paved road dust emission inventory for their PM-10 Maintenance Plan, as discussed in Section 7.4 of the Phase IV report.	No response required.
PF- Section 7.4, 3rd paragraph - Use of default silt loading values in AP-42 in lieu of acquiring local silt measurements does not necessarily degrade quality and confidence of AP-42 emission estimates. Using locally-based loading information could improve the modeled estimates, but the confidence in AP-42 for its intended purposes is not degraded.	The test report will be clarified to make the point that without local silt loading data, EPA's rating of the emission factor drops from A to C (based on a reference supplied by Clark County).
PF- Section 7.4 – limitations on utilization of refined emission estimates exist in that transportation models are not currently able to address sub-classifications of functional road class. While plans exist to improve the models, the current situation does place an upper limit on the value of the refined space and time resolution provided by mobile technology. Improvements in measurements and modeling continue to drive each other forward to improved performance, so this should not be a severe limitation on developing the mobile methods.	No response required.
PF- Section 8.1, 1st paragraph – I am concerned that the tower measurements are considered as the standard for comparisons. EPA will ask if the new method is shown to be equivalent to a standard method, which is the AP-42 silt method. The tower could still be the basis of calibrating the mobile sensors. It would take revising some discussion and information presentations.	Both the traditional AP-42 silt-based method and the mobile monitoring method are "calibrated" against the plume flux profiling method as a standard.
PF- Section 8.2 – The studies were focused on paved road estimates. Thus the statements on mobile having similar advantages for unpaved roads and being a preeminent method for road dust at stationary sources are stretching the optimism too far.	The test report gives several references to studies where mobile monitoring technologies were applied to unpaved roads, with similar advantages over the traditional AP-42 method for unpaved roads.
PF- "Bottom line" – are the mobile technologies a suitable alternative to AP-42 for PM10 emission factors for paved roads? My qualitative response is a cautious yes, when the scope and application are based on reasonable assurance in the acceptable levels of uncertainty in the calibration factors being applicable to the conditions being tested.	No response required.

PF- Could the mobile methods become a standard method? There is good foundation work laid to this point, but it's a long way to an ASTM standard method, and probably as far to a method widely recognized by EPA.	The TSD and the method standardization document will build a case for standardization of the mobile monitoring method. EPA has been tracking this activity and is likely to recognize mobile monitoring as a standard method.
DI- My experience with these studies has been more as an end user.	No response required.
EW- Because paved road travel constitutes the largest categorical source of PM_{10} emissions in urban areas, the dynamics of paved road travel emission factors warrant significant additional research. Temporal studies of silt level variability over hours, days, and seasons need to be undertaken to determine how these levels vary with fluctuations in traffic levels and what constitutes equilibrium silt conditions. Pathways for depositing soils onto roadways need to be better characterized and understood. The temporal benefits of street sweeping, using both conventional and PM_{10}-efficient sweepers, need to be studied. These studies can be efficiently and cost-effectively completed using mobile monitoring methods.	No response required.
GL- The validity of the data would be greatly improved by conducting a demonstration project based on data collected via the mobile monitoring technologies. Specifically, a modeling effort could be completed to determine if the data collected coincided with speciated ambient data in a specific area. With this, the methodology is a viable alternative for estimating paved road PM10 emissions. Given the history of the AP-42 method, that is not accounting for the eventual stability of emissions versus loadings on paved roads, this method is superior.	The proposed demonstration project brings into play the validity of transport modeling of road dust emissions, which has its separate technical problems. These models tend to over-predict dust impacts significantly, by not accounting for particle removal mechanisms that occur between the roadway source and the receptor point.

WP- Clearly the study report is a disappointment to those of us who were expecting a broader review of an alternative method that would have looked at the shortcomings of the two-parameter existing AP-42 approach. Perhaps it is unfair to second-guess objectives and approaches after the fact, but I share some of the frustration of A. Venkatram (2001), who was concerned that " … disproportionately large resources continue to be spent on collecting useless "silt loadings", required by the model, because incorrect estimates from the model suggest that a large fraction of the total PM_{10} emissions originate from paved roads!"[1]. As indicated earlier, the notion of an exponential decay of the roadway silt is clearly presented in the discussions accompanying Figures 5-7 to 5-9. It should not have been dismissed as quickly as it was. It may be important in the context of the removal of depositions by trackout, spillage, and deliberate addition of sand and salt for wintertime traction control. These depositions are mechanisms by which silt loading increases. All of which points to the silt load being a dynamic quantity that continues to be treated as a fixed parameter. The apparent dependence of reentrainment upon speed, even on paved roads, is shown in Figure 5-11. The unpaved road has an infinite supply of silt, and visible dust serves a tracer, but shouldn't the tire/roadway dynamics be similar in the paved case as well. I would suggest that the speed-dependent unpaved road equation with an appropriate decay rate applied to it might be a candidate for the long needed correction to the constant silt load approach. Wind speed and direction is a constantly varying confounding effect, involved in both the deposition and removal processes. It would be interesting to look at horizontal flux tower data, if it was collected into an archive for additional study, for in-between vehicle passes and the less than ideal (wind speed and direction) cases to shed some light on these complex aeolian processes. As I indicated earlier, it may be time to start all over, at the beginning, and define an emission, an inventory, and how to propagate a dispersed result that allows a comparison to filter estimates. It requires a return to fundamentals. While I had hoped to include some discussion of that here, it would have severely delayed this review. It is also beyond the scope of this review. I do however, hope to produce a discussion white paper in the next several weeks, as the Department prepares to meet with EPA to further discuss the development of a road dust inventory and how to apply it to the sometimes wet, humid, "north eastern territories" of the US. [1] See "Response to comments by Nicholson", at: **Atmospheric Environment** 35 (2001) 187.	There are many issues raised by this series of comments, some of which have been addressed in responses given above. Needless to say, much confusion exists about the role and validity of the traditional AP-42 silt-based method and how effectively it addresses the dynamics of the paved road dust entrainment. The commenter is correct in stating that decay rate data from the Clark County comparison study provides useful information to be evaluated in gaining a better understanding of the effects of trackout, spillage and wintertime abrasives application for snow/ice control. Clear background statements on these issues will be included in the TSD. As noted above, the reviewer is awaiting review of the TSD with the expectation that it will address many of his basic concerns.

Mobile Monitoring Method Specifications

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MOBILE MONITORING METHOD SPECIFICATIONS

1.0 Scope and Application.

1.1 Analyte. Airborne Particulate Matter (PM), specifically $PM_{2.5}$ and PM_{10}.

1.2 Applicability. This method is applicable to the determination of emission factors for vehicle-entrained dust from paved and unpaved roads.

1.3 Data Quality Objectives. This method is intended to provide an alternative to the traditional AP-42 method of obtaining PM emission factors for traffic-entrained dust from paved and unpaved roadways.

2.0 Summary of Method.

This method utilizes a test vehicle that generates a dust plume and monitors the plume's PM concentration using a continuous particle monitor, a global positioning system (GPS), and a data logger. The method is based on the observation that the dust emission intensity of any given portion of roadway is proportional to the intensity of the dust concentration that is monitored. By traveling over the entire road network (or a representative sample of the road network to be characterized), a map of emission intensity is generated. A calibration factor is used to convert the emission intensity to an equivalent emission factor, based on coincident application of the mobile monitoring technology and the traditional AP-42 roadside plume profiling method at representative test sites.

3.0 Definitions. [Reserved]

4.0 Interferences.

4.1 Background Concentrations. In order to remove the contribution of roadway PM emissions (including engine exhaust) from vehicles other than the test vehicle, the PM concentration in front of the test vehicle is monitored simultaneously with the dust plume concentration generated by the test vehicle. In the case of unpaved roads with infrequent traffic, there may be situations where background concentrations are negligible and do not require separate monitoring.

4.2 Cross-winds. In order to prevent cross-winds from altering the alignment of the test vehicle dust plume with the sampling inlet, mobile monitoring should avoid time periods with strong winds. Guidelines for this requirement are found in Section 9.1.2.

5.0 Safety.

5.1 Disclaimer. This method requires operation of a test vehicle in normal traffic conditions, as well as operation of dust plume sampling devices while the vehicle is traveling. Personnel operating this equipment should use caution to avoid a traffic accident.

6.0 Equipment and Supplies.

6.1 Continuous Particle Monitor. The test vehicle dust plume monitor consists of a portable PM_{10} or $PM_{2.5}$ sampling instrument that collects mass concentration data in real time (typically at 1-sec intervals) and operates reliably with the selected environment (interior or exterior) of the test vehicle. The sampling instrument may be battery operated or connected to an alternate power supply which is either part of the test vehicle electrical system or a separate source. In most reported applications of mobile monitoring, a portable laser photometer (light-scattering device) with an internal battery has been used. Because portable continuous particle mass concentration monitors do not comply with Federal Reference Method (FRM) requirements for the specified particle size range (e.g., PM-10) , a controlled study must be performed to develop a conversion factor that can be used to adjust the monitor reading to the true particle concentration.

6.2 Sampling Line. A sampling line provides for a continuous flow of air from the external probe to the continuous particle monitor. It should be constructed so that the dust sample does not accumulate on the interior surface of the line. The appropriate length and diameter of the sampling line must comply with the continuous particle monitor manufacturer specifications. The sampling line may direct the sample stream to/from a sample conditioning component, such as an inertial separator to remove coarse particles from the sample stream, if it can be demonstrated that the conditioning component does not alter the sample within the specified particle size range. Similarly, a dilution system may be utilized if the particle concentrations would otherwise exceed the reliable operating range of the particle monitor. However, the need for a dilution system is avoided by choosing an inlet position further away from the point of dust generation at the tire/road interface.

6.3 Inertial Seperator (Optional). If the point of dust generation is close to the sampling inlet location, an inertial separator may be used to prevent coarse particles (> 10 microns) from building up in the sampling line or otherwise interfering with the sampling system. The inertial separator should be placed in a location near the sampling inlet so that length of that sampling line that may require periodic cleaning is minimized.

6.4 Dilution System (Optional). If the point of dust generation is close to the inlet location, a dilution system may be used to decrease the concentration in the sample stream with background air (filtered or unfiltered) and thereby prevent the particle monitor from exceeding its detection limit. The dilution system should be positioned so that the sample stream has sufficient time to mix with the dilution air before reaching the particle monitor.

6.5 Sampling Inlet (Probe). The inlet (probe) is the apparatus that guides the air sample stream into the sampling line for delivery to the particle monitor. An inlet should be designed and constructed based on the specific nature of the mobile sampling system. The design and material of construction chosen for the inlet should be such that the dust sample will not accumulate on the interior of the inlet. The shape of the inlet opening and the body of the inlet will vary with custom design specifications.

6.5.1 Inlet Designs. Prototype inlets have included round or elongated openings, and inlets with drop-outs for large particles or water droplets. If the inlet is external to the body profile of the test vehicle, it should be pointed in the direction of vehicle travel, so that the primary condition of isokinetic sampling is satisfied. This will assure that oncoming dust particles are not required to make a turn as they enter the probe, which would allow particles with significant inertia to bypass the probe. It is more difficult to achieve the other requirement of isokinetic sampling, which requires adjustment of the intake air speed at the inlet opening so that it matches the speed of the air approaching the inlet. Although isokinetic sampling is important for large particle sampling, it is less important for particles smaller than 10 microns in aerodynamic diameter and is not an issue for particles smaller than 5 microns in aerodynamic diameter.

6.5.2 Inlet Positioning. Prototype inlets have been placed in the front wheel well (directly behind the wheel), on the passenger side of the vehicle just behind the passenger door, and on a trailer 10 ft behind the test vehicle (See Figure 1 where background sampling inlets are in red circles). In the case of the front wheel well locations, inlets have been placed on both sides of the vehicle to account for differences in the loadings across the road. Multiple inlets normally require blending of the sample streams prior to delivery to the particle monitor. Multiple inlets do not increase the representativeness of measurements unless there is an inconsistent lateral pattern of road surface dust loading so that within a travel lane the loading on one side of the test vehicle is alternatively higher and lower than the loading on the other side of the vehicle. An additional inlet on the front of the vehicle is used for background measurements. Inlets are typically placed at a height at least 10 inches off the ground. The most important characteristic to consider when determining the inlet placement is to ensure that, at the inlet position, the dust plume is stable and well-mixed. It should also be noted that the greater the distance between the probe and the points of dust generation (tire/road interface), the more likely the adverse effect of cross winds as a contributor to measurement uncertainty.

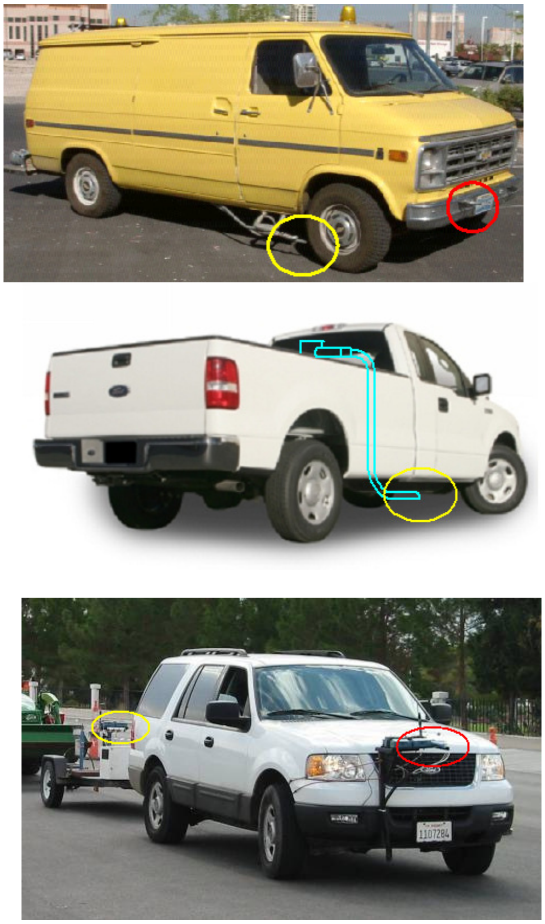

Figure 1 - Inlet Placements

6.6 GPS system. A GPS system with latitude and longitude data output capabilities should be collocated with the continuous particle monitor in order to spatially and temporally resolve the continuous particle monitor data points within the roadway system. The GPS should also have the capability to generate the speed, direction of travel, and rate of acceleration/deceleration in the same time resolution as the continuous particle monitor (usually in 1-sec intervals).

6.7 Data Logger. A data logging system such as a computer is connected to the continuous particle monitor and the GPS system to log monitor and GPS data sets in real time and create emissivity maps (see Section 12.4).

6.8 Test Vehicle. A vehicle should be equipped with all of the above instruments and accessories, with special care given to the fixed positioning of the inlet probe. Because the paved road dust emissions are also dependent on the fleet average vehicle weight, it is important that the weight of the test vehicle correspond closely to the fleet average vehicle weight for the application locality. Typically a light-duty van or truck satisfies this requirement.

6.9 Power Source. Although the critical components of the mobile monitoring instruments are equipped with internal batteries, an additional power source, such as a generator, may be needed to provide power for any flow generation devices (blowers or dilution systems) supporting the mobile monitor.

7.0 Reagents and Standards. [Reserved]

8.0 Sample Collection, Preservation, Storage, and Transport.

8.1 Develop Mobile Monitor Configuration.

8.1.1 Decide whether to use a previously established configuration or construct a new design. If a previously established configuration is selected, its corresponding calibration factor may be used as long as the validity of the calibration factor is upheld, as described in section 9.4. For a new design, a new calibration factor must be determined using the procedure described in section 10.

8.1.2 Steps in Designing a New Configuration.

8.1.2.1 Acquire a particle monitor, GPS system, data logger, and test vehicle.

8.1.2.2 Calibrate the particle monitor to a Federal Reference Method sampler for the particle size range of interest in a controlled test environment. Apply the calibration factor to all data output from the particle monitor to convert apparent concentration values to true concentration values.

8.1.2.3 Determine an appropriate location for the sampling inlet on the outside of the vehicle (see section 6.4.1).

8.1.2.4 Design the inlet probe and sampling line in compliance with any specifications from the particle monitor manufacturer.

8.1.2.5 Decide how to synchronize the particle monitor output with the GPS output and to merge the files in the data logger.

8.1.2.6 Provide a supplementary power source if necessary.

8.1.2.7 Calibrate the new mobile monitoring system to an accepted reference method, preferably roadside plume profiling, as described in section 10. Once the calibration factor is determined, that factor should be applied to the emissivity maps created by sampling representative roads within a roadway network.

8.2 Select Sampling Sites and Conditions

8.2.1 Choosing Representative Roads within a Roadway Network.

8.2.1.1 Mobile monitoring should be performed on roadway segments that represent the dominant contributors to the road dust emissions inventory. Of the four roadway classifications (local, collector, arterial, and freeway), emphasis should be placed on arterial and collector roadways because they typically have significant traffic levels combined with significant silt loadings. Generally, local roads do not have enough traffic to make a significant contribution to emission totals, and freeways are found to be clean enough as to not contribute significantly to emission totals. Collector and arterial roadways are the primary sources of PM emissions within a roadway network. Within each category, roadways that are well travelled should be chosen as representative contributors to dust emission totals.

8.2.1.2 Care should be taken to make sure that dust emissivity “hot spots” are included in sampling representation (test vehicle travel route) in proportion to their frequency of occurrence within a specific roadway category. Hot spots are places where road surface dust loadings are elevated because of local effects such as track-out from unpaved roads or construction activities onto paved roads. Hot spots tend to be associated with industrial operations or land development activities involving road or building construction. Hot spots contribute to emission totals at a level that is much greater than normally represented by the length of roadway involved.

8.2.2 Criteria for When to Collect Samples.

8.2.2.1 Time of Day. Based on safety considerations, sample collection should be performed during daylight hours that avoid periods of traffic congestion. Ideally sampling would occur between 10 am and 2 pm.

8.2.2.2 Precipitation Events. Sampling should not occur when roads are wet or icy. After a precipitation event, no sampling should occur until the roads have had ample time to dry out.

8.3 Logging Data. A data logger, such as a computer, should be connected to the Continuous Particle Monitor and the GPS system to accumulate data in real time. These data inputs should be saved in original form to the data logger as well as to external media (e.g. CD, flash drive, or network folder) for back-up. Data collected at vehicle speeds below 10 mph should be flagged as non-representative.

8.3.1 Data Analysis. Dust plume concentration data from the mobile monitoring system (given in mg/m^3 and collected at 1-sec intervals) should be averaged over stretches of continuous travel within a given category of roadway, for example, between major intersections. Any data collected for vehicle speeds below 10 mph should be excluded from averaging. Similarly, data collected for vehicle speeds outside the preferred range corresponding to system calibration conditions should be flagged separately for special consideration. The average concentration values for road segments within a given roadway category should be converted to equivalent emission factors for the particle size range of interest.

9.0 Quality Control.

9.1 Miscellaneous Quality Control Measures.

9.1.1 Vehicle Speed Ranges. All monitoring data associated with vehicle speeds less than or equal to 10 mph should be excluded from analysis. This includes stop-and-go traffic conditions and sharp corners. Similarly, all “fringe” monitoring data collected outside of the speed range under which the mobile monitoring configuration was calibrated should be evaluated for special analysis according to predetermined criteria. Although less reliable, fringe data tend to have lower significance in an emissions inventory because the largest component of traffic-entrained dust emissions is associated with the core speed range typically represented in calibration tests.

9.1.2 Wind Speed Ranges. The acceptable ambient wind speed range is –calm to 15 mph. If wind gusts above 15 mph are observed, testing should not proceed until wind speed subsides.

9.1.3 Acceleration/Deceleration. Travel routes and monitoring periods should be selected so that acceleration/deceleration criteria are met. A mobile system should avoid acceleration/deceleration rates exceeding 1.3 mph/s as more extreme rates can cause particles from brake and tire wear to bias the results.

9.1.4 Wheel Angle (applicable to front wheel probe locations only). Travel routes should be selected so that wheel angle criteria are met. If the sampling inlet is within 2 inches of the tire surface, the wheel angle should not exceed 3 degrees in relation to the straight forward position.

9.2 Continuous Particle Monitor.

9.2.1 Zero check. Follow standard calibration verification procedure recommended by instrument manufacturer or by system designer for custom applications.

9.2.2 Flow check. Follow standard calibration verification procedure recommended by instrument manufacturer or by system designer for custom applications.

9.3 Synchronize Continuous Particle Monitor and GPS system Time Stamps. Set internal clocks for each instrument and periodically note way points at ends of travel routes when test vehicle is stopped to confirm synchronization.

9.4 Validity of Calibration Factor. Any calibration factor developed for a specific test vehicle/sampling configuration should remain valid in different regions of the country, unless (a) the road dust characteristics are significantly different, or (b) the fleet average weight for traffic on paved roads in the study location is significantly different. The difference in road dust characteristics between the calibration area and the application area can be determined by resuspending representative road surface samples from each area. A well-mixed environmental chamber is normally used for this experimentation. The difference is significant if, after normalization to the same silt content, the resuspension fraction of the sample from the application area differs by more than 30 percent in comparison to the resuspension fraction from the calibration area, for the particle size fraction of interest. Similarly, the fleet average vehicle weight in the application should be within 20 percent of the weight of the test vehicle, taking into account the 1.5 power of the weight correction term in the AP-42 emission factor equation for paved roads.

10.0 Calibration and Standardization.

A calibration factor is needed for each mobile monitoring configuration (test vehicle and sampling system), to convert the relative dust emission intensity (measured in terms of dust plume concentration) to an equivalent emission factor for the specified particle size range. Calibration of a mobile monitoring configuration is accomplished by establishing a relationship between the mobile monitor concentration and the equivalent emission factor. Roadside plume flux profiling (traditionally referred to as exposure profiling) is the recognized standard method for calibrating mobile monitoring systems. Three or more test sites (or independent sets of test conditions) should be used for the calibration program, so that a range of road and traffic conditions is represented.

10.1 Calibrating the Continuous Particle Monitor (CPM) to a Federal Reference Method (FRM). The CPM should be collocated with a FRM in a controlled test environment in order to find a calibration factor to correct the CPM reading to a true PM mass concentration measurement.

10.2 Roadside Plume Profiling Calibration Test Site Requirements.

- 10.2.1 The microscale prevailing wind direction during the test period must be approximately perpendicular to the road orientation at the test site, i.e., within 45 degrees.
- 10.2.2 The test site cannot have trees, buildings, or other obstructions in close proximity to the roadway (unobstructed wind flow).
- 10.2.3 The test site must not have significantly elevated topography in close proximately to the roadway on either side.
- 10.2.4 The test site must have access areas on the downwind side of the road for placement of equipment and crew and on the upwind side for equipment.
- 10.2.5 The test site must be located where there is negligible interference from any upwind source of PM in the particle range of interest.
- 10.2.6 The test site must have an uninterrupted, relatively straight travel distance of about ¾ of a mile without any dust controls.
- 10.2.7 The test site should be blocked off from all traffic except for the test vehicle. In the case of divided roads with a sufficiently wide median to accommodate profiling equipment and crew, only one direction of traffic needs to be blocked off.
- 10.2.8 The grade of the road at the test site must be small so that vehicle exhaust emissions are negligible in relation to road dust emissions.

10.3 Roadside Plume Profiling Result. See references 17.1-17.3 for method description. The result of this method will yield an emission factor in units of g/vmt (grams per vehicle mile traveled) to be correlated with the average of concentration values measured by the mobile monitor as it passes by the profiling test equipment.

10.4 Test Vehicle Speed – Calibration Tests. Because the mobile monitor response has been shown to vary directly with the speed of the test vehicle, it is important to perform the calibration tests at documented vehicle speeds. However, the calibration factor can incorporate a range of test vehicle speeds that are representative of the paved roadway system in the locality of interest.

10.5 Mobile Monitoring Data Set. The data set obtained from the mobile monitor will yield an average concentration value in units of mg/m^3. The data points obtained by the mobile monitor will typically be given in 1-sec intervals. The number of data points collected will depend on the speed of the sampling vehicle. Data points should be collected for ¼ of a mile on either side of the roadside plume profiling tower. The data points used for this calibration can be chosen using GPS coordinates as end points of the test road segment over which the test vehicle speed is maintained at a constant value.

10.6 Derivation of Linear Calibration Factor. A mobile monitoring test is defined as a series of passes in front of the plume profiling tower at a given test site that meets the criteria specified in the previous section. The vehicle may pass in a 1-way or 2-way travel mode. The test vehicle speed range over which the calibration is developed should be divided into 3 equally distributed values, and each speed value should be tested separately. For each calibration, at least 3 mobile monitoring test sites or sets of conditions at the same site must be employed. Variations of test conditions at a given site can be achieved by spreading soil or other representative aggregate material at a uniform rate over the test road segment and allowing the fresh loading to be redistributed by natural traffic prior to the calibration test series. The individual concentration data points for each mobile monitoring test will be averaged, and then compared to the plume profiling result. At least 3 profiling test series must be performed to find a linear calibration factor. See Table 1 in Section 18.0.

11.0 Analytical Procedure.

11.1 Vehicle Class-Roadway Type Combinations based on the National Mobile Inventory Model (NMIM). See Table 2 in section 18.0 for the 18 Vehicle Class-Roadway Type Combinations.

11.1.1 Vehicle Miles Traveled (VMT) by Vehicle Class-Roadway Type Combinations. The procedures for gathering these data and processing them into the required scales and vehicle classes are described in detail in the National Emissions Inventory (NEI) documentation.

11.1.2 Collecting and Reducing Data based on Vehicle Class-Roadway Type Combinations. Emission estimates for entrained road dust within an inventory area are found by multiplying emission factors in lb/VMT (or g/vkt) for each roadway category by VMT values for that category. In turn, the VMT values for a given averaging period (daily, weekly or annually) are obtained by multiplication of traffic counts on representative road segments within a roadway category by the lengths of the segments. The full emission inventory for a defined study locality is complete when all active road segments that pass a significance test have been represented in the calculations. It is assumed that traffic-entrained dust emissions are negligible when traffic speeds are below 10 mph, requiring that this adjustment be made to the emission inventory by subtracting VMT components associated with traffic congestion.

11.2 Inventory Evaluation Month and Calendar Year. MOBILE6 specifies a calendar year and an evaluation month of either January or July. These two parameters determine the fleet composition for which emission factors are generated. For each month of a given inventory year, NMIM writes the MOBILE6 input file using the combination of calendar year and evaluation month shown in Table 3, section 18.0.

12.0 Data Analysis and Calculations.

12.1 Correlating GPS and CPM Data. Because time synchronization between the GPS and CPM is such a critical element for accurately mapping spatial changes in emissions, care should be taken to ensure that the GPS and CPM timestamps are correctly correlated. The easiest way to accomplish this is to begin and end data collection on both systems at exactly the same time, allowing the first and last points to be synchronized. If this method is not practical, most CPMs feature an analog voltage out that corresponds directly to the instantaneous measured concentration value so that, if the test vehicle is stationary, the measured emission rate (voltage) will drop to a constant background value. Then, the timestamps of the period of constant voltage from the CPM can be associated with the timestamps of the GPS data when the test vehicle position is constant.

12.2 Data Reduction. In accordance with the quality control methods prescribed in section 9.0, the data set of concentration values obtained for a particular road segment should be reduced to omit the data points for vehicle speeds below 10 mph, acceleration/deceleration rate exceeding 1.3 mph/s, or wheel angle 3 degrees for wheel well probe locations only. The average of the resultant set of concentration values is to be used in the conversion to an emission factor for the particle size range of interest..

12.3 Deriving Emission Factors. To determine the emission factor for a representative road segment, the concentration values of all valid data points from the continuous monitor over a specific road segment are averaged. See References 17.2 and 17.5 for examples of this procedure. For the most systems, the concentration values are measured directly by the CPM. Then, the calibration factor for the mobile monitor is used to convert the average concentration measured by the monitor into an emission factor for that road segment.

12.4 Creating Emissivity Maps. Emissivity is a term used to indicate emission potential, expressed either as test vehicle plume concentration or equivalent emission factor. In order to generate temporally and spatially justified emissivity maps, GPS location data can be correlated with the time-synchronized CPM emission factors to map the emission potential over a whole segment of road. In order to minimize the noise in individual concentration values, it is recommended that running average of an odd number of concentration values (typically three or five) be used per point on the emissions map. These values can then be used to generate overlays on satellite images or other GIS maps. An example emissivity map is shown in Figure 2 from Reference 17.5, where the emissivity is given in units of g/vkt.

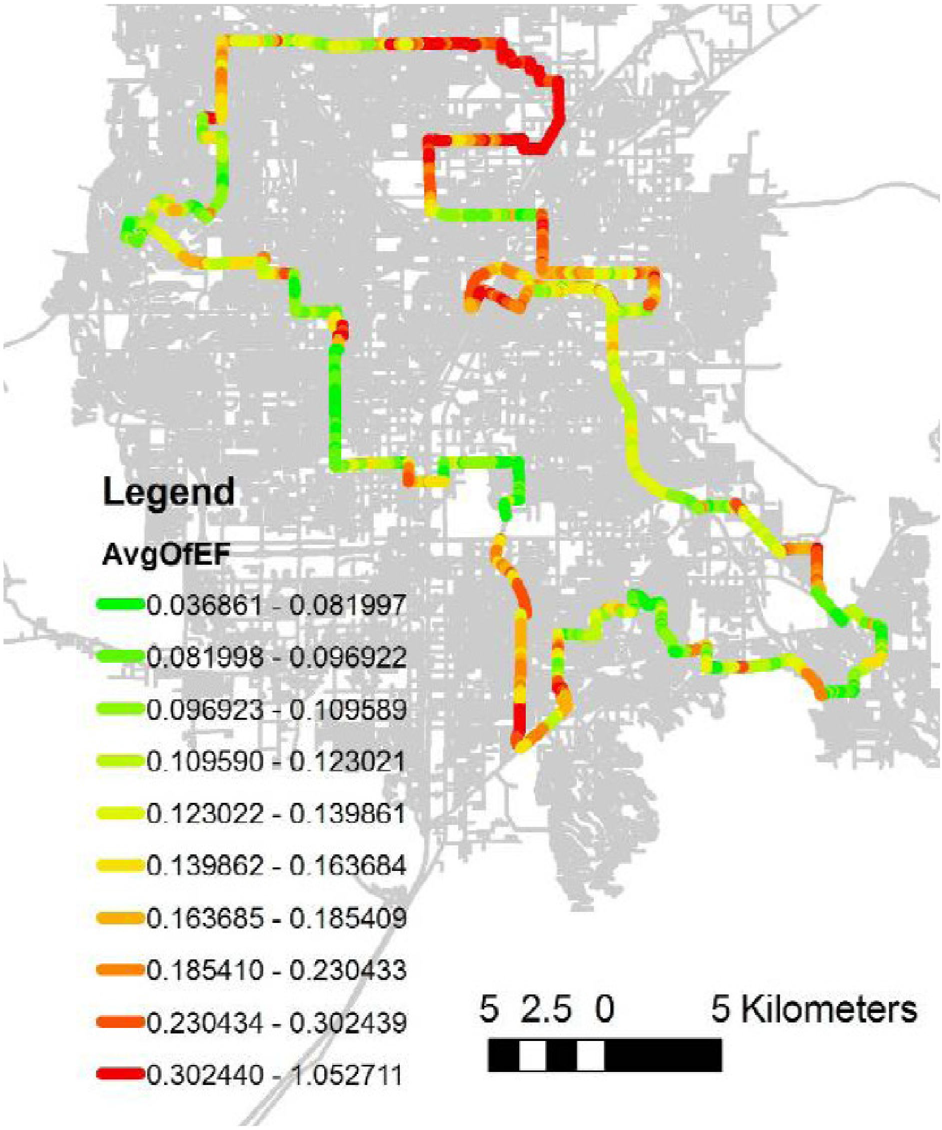

Figure 2 - Example Emissivity Map

12.5 Converting to Class-Specific Emission Factors. The process described in section 12.1 can be repeated for each road class to determine emission factors for each category of roads for which an emission factor needs to be determined.

13.0 Method Performance.

13.1 Reliability.

13.1.1 Test Vehicle Speed. To the extent possible, the speed of the calibrated mobile monitoring test vehicle should be restricted to the value or range of values for which the calibration was developed. However, mobile monitoring data may be collected outside of the calibrated speed range but with somewhat less reliability unless supplementary data on speed applicability of a calibration can be used to demonstrate that the full reliability applies. For example, in the case of the mobile monitoring technologies demonstrated in the Clark County study, the monitors were calibrated over a speed range of 25 mph to 45 mph, but monitoring over a speed range of 10 mph (the effective dust entrainment threshold) to 60 mph will still provide useful data.

13.1.2 Test Vehicle Weight. Because the paved road dust emissions are also dependent on the fleet average vehicle weight, it is important that the weight of the test vehicle correspond closely to the fleet average vehicle weight for the application locality. If this criterion is not met, a correction to the emission factor will need to be made based on collocated roadside profiling or on the current AP-42 relationship between emissions and fleet average vehicle weight.

13.2 Validity. Any calibration factor developed for a specific test vehicle/sampling configuration should remain valid in different regions of the country, unless (a) the road dust characteristics are markedly different, or (b) the fleet average weight for traffic on paved roads in the study location is different. In either case, a new calibration factor must be developed, unless prior studies have generated test data that can be used to make reliable adjustments to the original calibration factor. For example, a well mixed environmental chamber with approved reference particulate samplers can be used to compare the properties of (a) entrained dust from a new roadway study area and (b) entrained dust from the locality where the mobile monitor calibration was performed.

13.3 Uncertainty. The primary source of uncertainty in the mobile monitoring method is the calibration factor for the specific test vehicle/sampling system configuration. This uncertainty can be evaluated in terms of the agreement between emission projected from the mobile monitoring method and the emission factors measured by the reference method (roadside plume flux profiling)

13.3.1 Statistical Analysis. In the statistical analysis process, a method of cross-validation is used, which involves removing one test data point (pair of projected and observed emission factors) from the data set and using the best-fit linear relationship determined from the remaining points to project the missing emission factor. A reference level of uncertainty is obtained from a similar analysis of the test data set used to derive the AP-42 emission factor equation for paved road dust. See Reference 17.2 for more detail on comparative levels of uncertainty between (a) the AP-42 emission factor for paved roads and (b) prototype mobile monitoring systems.

13.3.2 Case Study. In the uncertainty analysis of TRAKER and SCAMPER mobile monitoring configurations tested in the Clark County study, a higher percentage of mobile monitoring test results fall within the specified factor as compared to the AP-42 test data. This indicates a lower level of uncertainty for mobile monitoring as compared to the traditional AP-42 method when actual silt loading values are used in predicting the measured emission factors. If default silt loading values are used in predicting road dust emission factors with the AP-42 emission factor equation, an even higher level of uncertainty would be expected. This analysis clearly indicates that linear equations used to generate the calibration factors for the TRAKER and SCAMPER systems on average have lower uncertainty than the AP-42 emission factor equation for paved roads. This is not surprising when it is realized that the AP-42 equation was developed from test data collected under a much broader range of conditions at many locations across the country.

13.3.3 Spatial Resolution. Even if it were to be assumed that the uncertainty levels of the two methods are similar, there is a second significant source of uncertainty in the traditional AP-42 method that has no uncertainty counterpart in the mobile monitoring method. Whereas the AP-42 method requires a priori judgments as to where to collect silt loading samples, the mobile monitoring method provides for rapid characterization of a large segment of a roadway system. Even if only an uncalibrated mobile monitor were available in a particular study area, it could be used as an effective tool to locate silt loading collection points in implementing the traditional AP-42 method.

14.0 Pollution Prevention. [Reserved]

15.0 Waste Management. [Reserved]

16.0 Alternative Procedures.

16.1 Calibration of Mobile Monitor against AP-42 Silt Loading Emission Factors.

16.1.1 AP-42 Silt Loading Result. See reference 17.6 for method description. The result of this method will yield an emission factor in units of g/vmt (grams per vehicle mile traveled).

16.1.2 Mobile Monitoring Data Set. The data set obtained from the mobile monitor will yield an average concentration value in units of mg/m^3. The data points obtained by the mobile monitor will typically be given in 1-sec intervals. The number of data points collected will depend on the speed of the sampling vehicle. Data points should be collected for ¼ of a mile on either side of the silt loading sampling location. The data points used for this calibration can be chosen using GPS coordinates as end points.

16.1.3 Derivation of Linear Calibration Factor. If conditions do not allow for calibration to the plume profiling method, the results of an AP-42 silt-loading study could serve as the basis for calibrating mobile monitoring concentrations to emission factors. Silt loading measurements would be input to the AP-42 emission factor equation in order to determine emission factors for each test site.

16.1.4 Uncertainty. The method would have a much higher uncertainty because it would combine the uncertainties of the mobile monitoring method with the traditional AP-42 method.

16.2 Utilizing Mobile Monitoring to Optimize Silt Loading Sampling Locations. An uncalibrated mobile monitoring system to perform AP-42 silt loading test procedures. The number of locations depends on the size of the roadway network to be characterized.

17.0 References.

17.1 C. Cowherd, Jr., et al., *Development of Emission Factors for Fugitive Dust Sources*, EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

17.2 C. Cowherd, Jr, *Technical Support Document for Mobile Monitoring Technologies,* Prepared for Clark County Department of Air Quality and Environmental Management, January 2009.

17.3 Pyle, B. E. and J. D. McCain, *Critical Review of Open Source Particulate Emission Measurements -- Part II: Field Comparison*. Work Assignment 002, EPA Contract 68-02-3936. 600S286072. February 1986. http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=7172830

17.4 EPA, *Air Superfund National Technical Guidance Study Series Volume 2 Estimation of Baseline Air Emissions At Superfund Sites 450189002* http://www.p2pays.org/ref/10/09762.pdf

17.5 Langston, R., Merle, R. Jr., Etyemezian, V., Kuhns, H., Gillies, J., Dongzi, Z., Fitz, D., Bumiller, K., James, D., Teng, H., *Clark County (Nevada) Paved Road Dust Emission Studies in Support of Mobile Monitoring Technologies,* Prepared for Clark County Department of Air Quality and Environmental Management, December 2008.

17.6 EPA Office of Transportation and Air Quality. *National Inventory Model (NMIM), a Consolidated Emissions Modeling System for MOBILE6 and NONROAD*. EPA 420-R-05-024. December 2005. http://www.epa.gov/otaq/models/nmim/420r05024.pdf.

17.7 EPA Office of Air Quality Planning and Standards. *Compilation of Air Pollutant Emission Factors (AP-42)* Fifth Edition, Research Triangle Park NC, 1995.

17.8 Ftiz, Dennis R. Draft Final Report, *Measurements of PM10 Emission Factors from Paved Roads in Clark County, NV*, Prepared for Clark County Department of Air Quality Management's Roadway Dust Sampling Evaluation Phase II, 2005.

18.0 Tables, Diagrams, Flowcharts, and Validation Data.

Table 1 - Calibration Data Flow

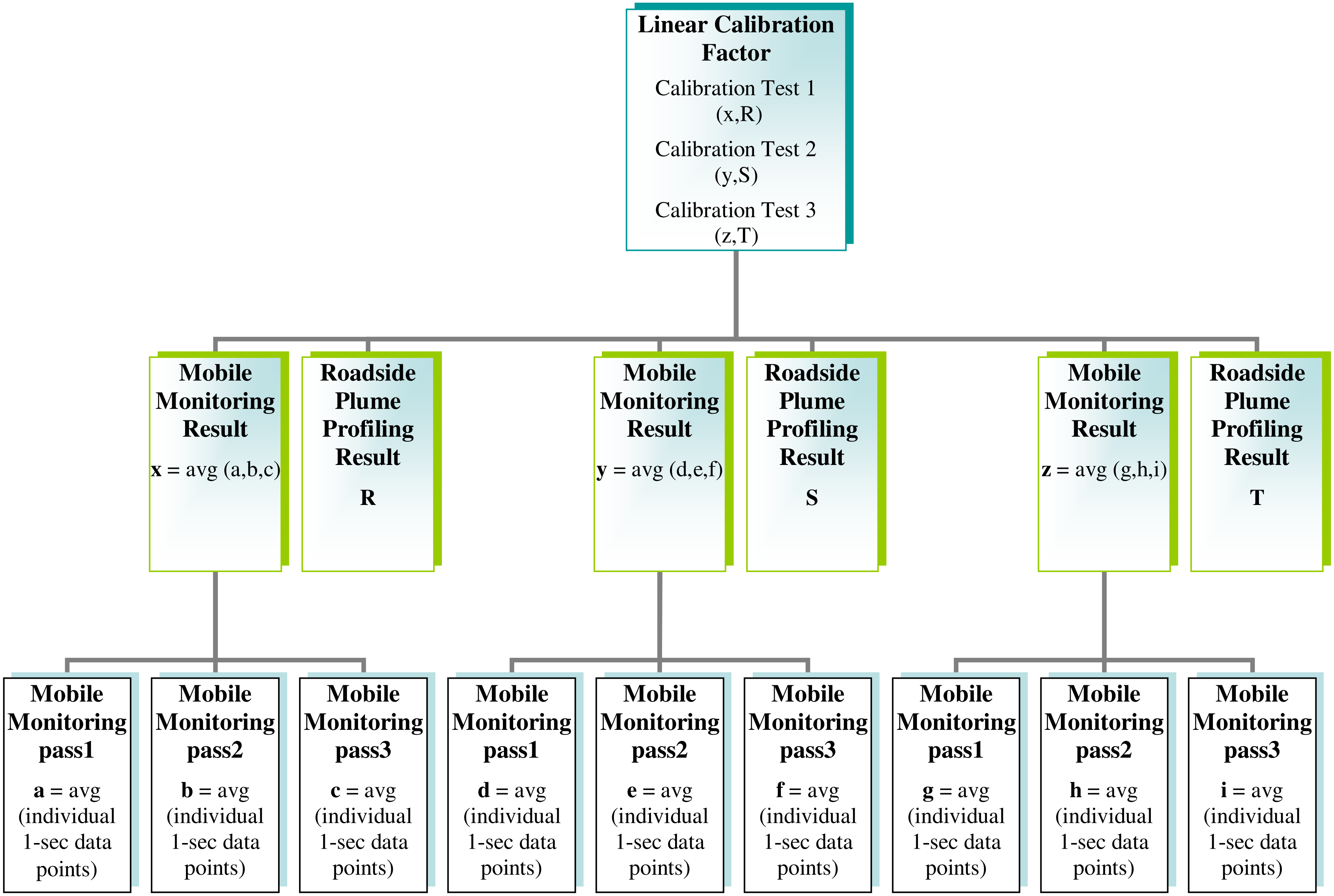

Table 2 - Mobile 6 Vehicle and Road Classifications

M6 Vtypes	Road Types	M6 Ftype
LDV	Rural Interstate	Freeway
LDT		
HDV		
LDV	Urban Interstate	
LDT		
HDV		
LDV	Urban Freeways & Expressway	
LDT		
HDV		
LDV,LDT	Rural Principal Arterial	Arterial
LDV,LDT	Rural Minor Arterial	
HDV	Rural Principal Arterial	
LDV,LDT	Rural Major Collector	
LDV,LDT	Rural Minor Collector, Rural Local	
HDV	Rural Minor Arterial	
LDV,LDT	Urban Principal Arterial, Urban Minor Arterial, Urban Collector	
HDV	Rural Major Collector, Rural Minor Collector, Rural Local	
HDV	Urban Principal Arterial, Urban Minor Arterial, Urban Collector	

* Reference MOBILE6.2 User Guide, Appendix B

LDV = MOBILE6 Vehicle Types 1 and 16.
LDT = MOBILE6 Vehicle Types 2-5.
HDV = MOBILE6 Vehicle Types 6-15.

Table 3 – Mobile6 Month and Year Conventions

NMIM Month of Inventory Year Y	MOBILE6 calendar year	MOBILE6 evaluation month
1	Y	1
2	Y	1
3	Y	1
4	Y	7
5	Y	7
6	Y	7
7	Y	7
8	Y	7
9	Y	7
10	Y+1	1
11	Y+1	1
12	Y+1	1