Measurement of PM_{10} Emission Rates from Roadways in Las Vegas, Nevada Using a SCAMPER Mobile Platform with Real-Time Sensors

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ABSTRACT

Based on emission factors derived from the AP-42 algorithm, particulate matter from paved roads has been estimated to be a major source of PM_{10} of geologic origin. This is an empirical formula based on upwind-downwind measurement of PM_{10} concentrations and is dependent solely on the silt loading of the pavement and the weight of vehicles. In order to estimate emissions it is therefore necessary to measure the silt loadings on roadways. This is a time-consuming and often dangerous measurement, as active traffic lanes must be closed. As an alternative, we measured PM_{10} concentrations in front of and behind a moving vehicle to estimate the emission factors for vehicle on paved roads. This approach, called SCAMPER (System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways) allows rapid emission estimates for entire roadways. Light scattering optical sensors were used to measure PM_{10} concentrations with a time resolution of several 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. As a first approximation the emission factor was based on the concentration difference between upwind and downwind and the frontal area of the test vehicle. This method was tested on roadways in Las Vegas in a collaborative comparison study with researchers from the Desert Research Institute, who also used a moving platform (TRAKER) to estimate emission rates from the roadways. Both techniques are useful for quickly surveying large areas and for investigating hot spots on roadways caused by greater than normal deposition of PM_{10} forming debris.

INTRODUCTION

Many areas in the United States consistently exceed both the State and Federal PM_{10} air quality standards. To formulate effective mitigation approaches, the sources of the PM must be accurately known. Receptor modeling has shown that PM_{10} of geologic origin is often a significant contributor to the concentrations in areas that are in non-attainment[1]. A significant portion of this geologic material has been estimated to originate from paved

roads[2,3]. A number of studies have been conducted to determine the contribution of paved roads to measured concentrations of PM_{10} [2,4,5,6,7,8,9,10]. These studies used upwind-downwind sampling by filtration to determine the net mass emission due to the roadway.

The studies conducted by Cowherd and co-workers primarily in the Midwest using industrial roads resulted in an empirical expression relating the PM emission rate with the silt loading of the road. This expression was incorporated 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:

Equation (1) $E = k(sL/2)^{0.65} (W/3)^{1.5}$ 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) is an empirical equation derived by measuring the total flux across roadways using a PM_{10} monitoring array and based solely on surface silt loading. The AP-42 states that the sL reaches an equilibrium value without the addition of fresh material. If equilibrium is attained, then the emission rate should go to zero, although this is not what the equation predicts. Therefore, it is difficult to understand how this equation could be universally applicable unless the material is continuously replaced.

A method to measure PM_{10} emissions from paved roads in real-time has recently been developed and evaluated in southern California[11,12]. In this approach the PM_{10} concentrations were measured 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 of the test vehicle. 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. The method has been named SCAMPER: System of Continuous Aerosol Monitoring of Particulate Emissions from Roadways

The objective of this project was to measure PM emission rates from roadways in the Las Vegas area of Nevada and compare them with a technique developed by researchers at the Desert Research Institute (DRI)[13].

APPROACH

We determined vehicle PM emission factors by measuring the PM concentrations in front of and behind the vehicle using real-time sensors. We have previously measured the PM_{10} concentrations in the vehicle's wake and found that the frontal area of the vehicle is approximately the area of the wake[12]. We also concluded that the PM_{10} concentration measured at the centerline of the vehicle 4m behind it is representative of the PM_{10} concentration of the wake. The PM_{10} emission rate in units of mass per unit distance can therefore be determined by multiplying the net concentration change by the frontal area of the vehicle.

Isokinetic Sampling Probe

Collecting particulate samples from a vehicle moving at speeds of 0 mph to 60 mph required designing an inlet that would provide, as much as possible, isokinetic sampling at all speeds. Figure 1 shows the design of the inlet. To slow the flow to that of the sample flow rate of the DustTrak without creating a virtual impactor, excess air is pulled across a hollow, cylindrical filter that is open on both ends. A PC monitors the vehicle speed and controls the bypass flow rate by using a combination of three set flows, to produce a reading of near 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 airstream has the same energy as the ambient airstream. The output of the pressure transducer is recorded by the PC.

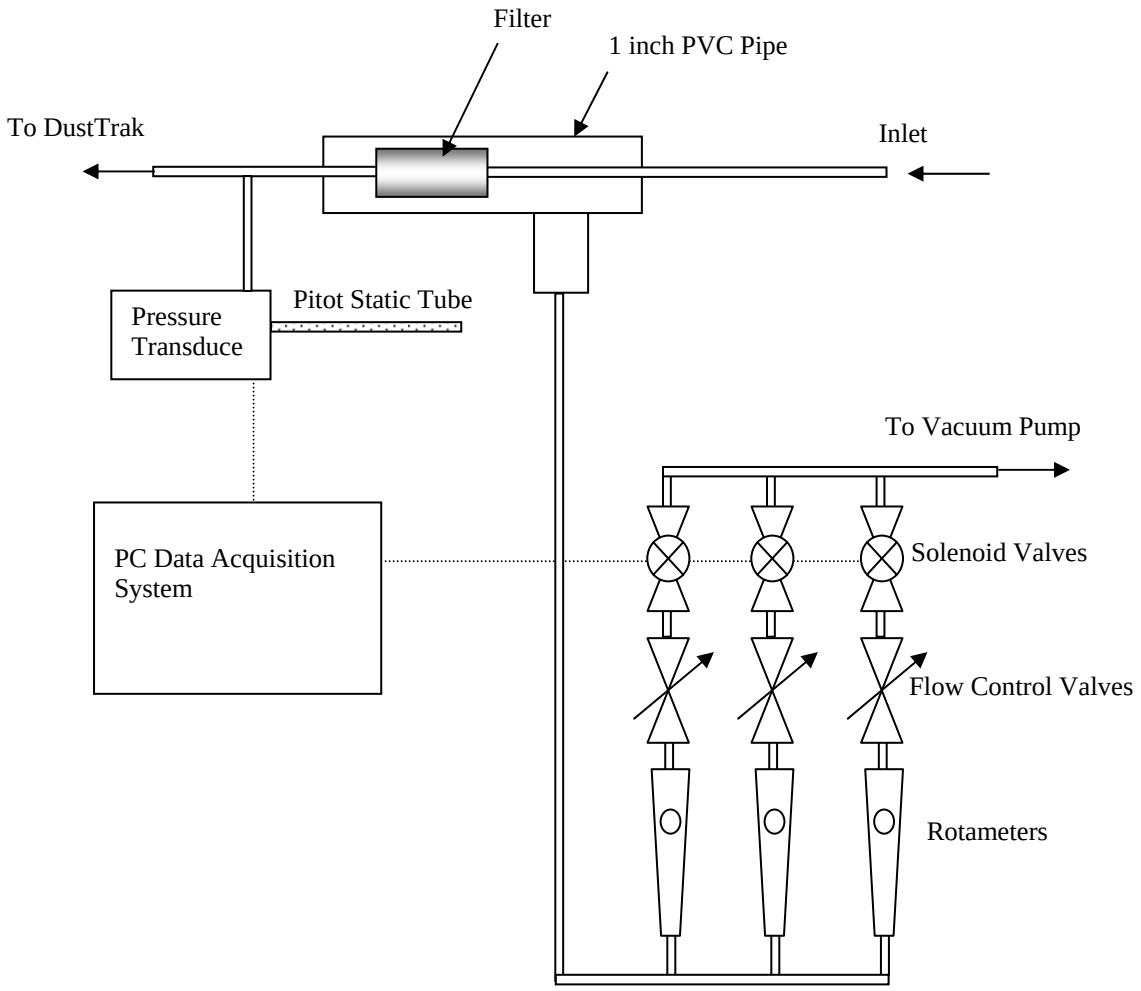
Probe Locations

The front probe was located 1.5 m above the ground and 0.5m in front of the front bumper of the test vehicle, a Jeep Cherokee. From our studies to determine concentrations in the vehicle wake, the sampling position behind the vehicle was optimized. This position, 4m from the back of the test vehicle 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.

Instrumentation and Data Collection

DustTrak (ThermoSystems, Inc.) light scattering PM sensors with PM_{10} inlets were used and operated on the fastest time constant (2-second running average). DustTraks were zeroed at the start of the test per the instruction manual. The factory calibration was used. A Garmin GPS Map76 global positioning system was used to determine vehicle location and speed. Data from GPS and PM_{10} measuring devices was collected with a PC. Data was stored as one-second averages. The PC also was used to automatically adjust

Figure 1. Schematic diagram of the isokinetic sampling probe.

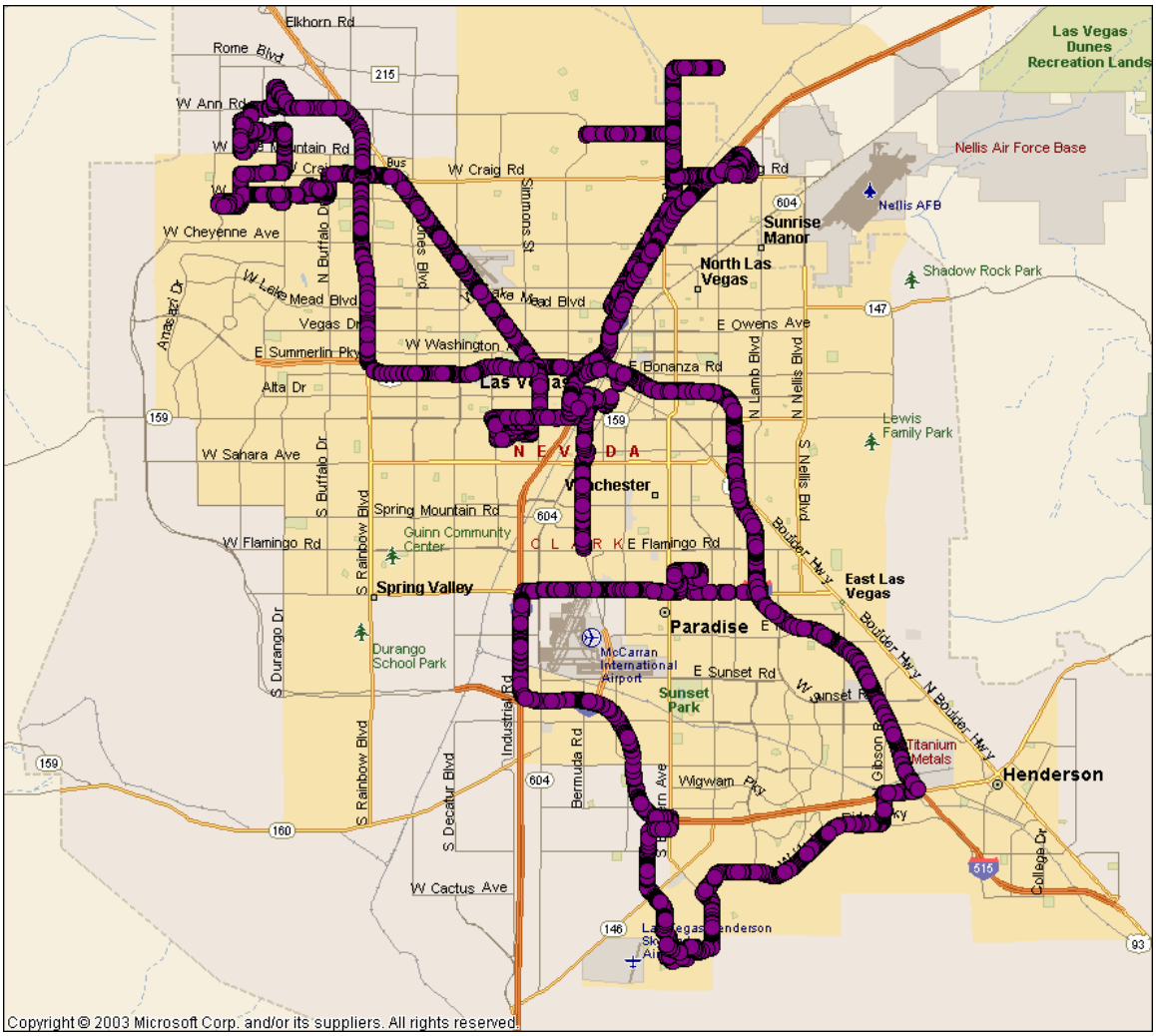


the sample inlet bypass flow to maintain isokinetic particle sampling using a 10-second running average of vehicle speed determined the GPS.

Test Route

Staff at the Clark County Department of Air Quality Management designed the test route. It was designed to include representative roads of all types and included roads near major construction activities. Figure 2 shows a map of the test route for which we report data.

Figure 2. Map of the test route used to measure PM_{10} emissions from the roadways.



RESULTS

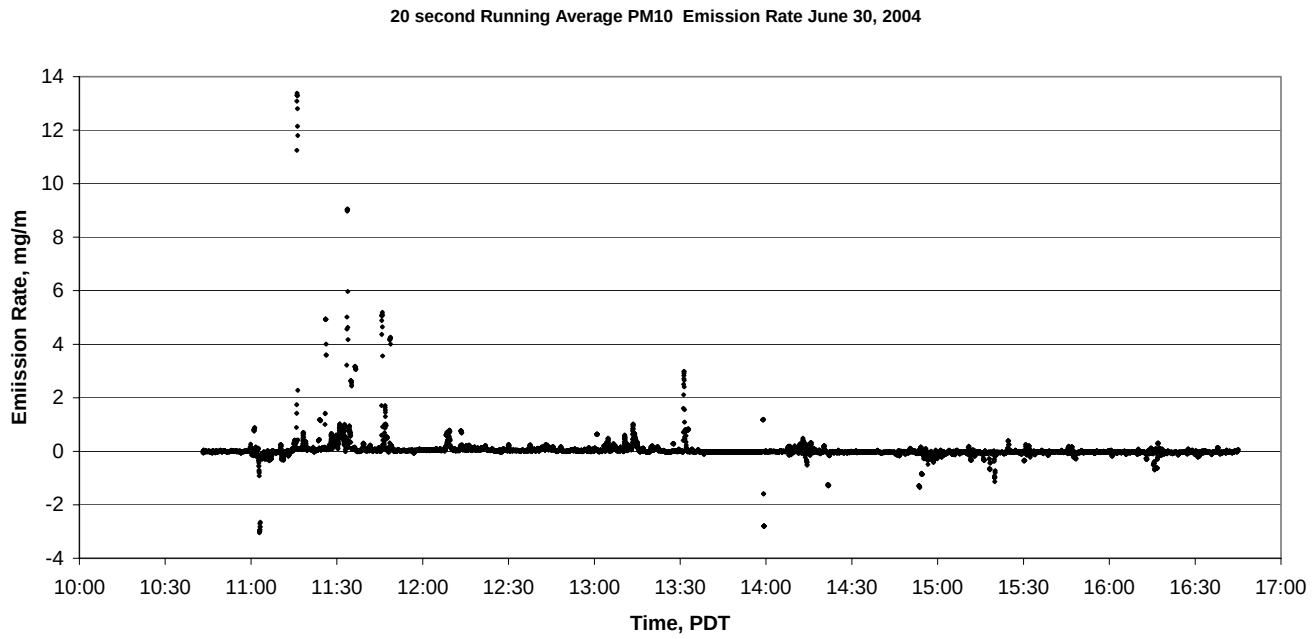
Summary of PM_{10} Emission Measurements

The test route was driven on two days, June 30, 2004 and July 1, 2004. The drive started in the late morning and ended in the early afternoon on both days. On the first test day the SCAMPER followed the TRAKER and on the second day the TRAKER followed the SCAMPER. In order to allow comparisons of the emission data with that from DRI, the SCAMPER DustTrak data was aligned by time with the TRAKER by comparing high emission "events" observed by both and the DRI GPS locations were used. PM_{10} emissions per meter were calculated by multiplying the frontal area of the Jeep (2.9 m^2) by the net PM_{10} concentration (rear less front in mg/m^3).

Figure 3 shows the emission rates for the first sampling day calculated as a running 20-second average for the time period in which data are available from both the front and rear DustTraks. We used this averaging period to reduce the noise. All times were included, we did not remove times during which the vehicle was stopped. In such situations the front and rear DustTrak measurements are essentially the same and the emission rate is therefore near zero. Removing times when the vehicle was stopped would also be difficult due to the significant periods when GPS data is not available. This occurred because the GPS satellite signals were not of sufficient quality for the GPS to output a location. These weak signals are often due to obstructions such as buildings, trees, underpasses, overpasses, and similar obstructions.

An interesting feature of Figure 3 is that the after 13:40 hours, the bypass flow system failed, and the emission rates drop substantially and are often negative. This is likely due to the non-operation of the isokinetic sampling system. These values show the importance of using the isokinetic sampling port and the importance of using a sampler in front to obtain the net concentration difference. Before bypass failure at 13:40 hours, the average PM_{10} concentration was 0.089 mg/m^3 in the rear and 0.031 mg/m^3 in the front. The correction for the front PM_{10} concentration was therefore 35%. The average emission rate during this period was 0.167 mg/m. Many of the spikes in Figure 3 also correlated with observed construction activities. It should be noted that in our testing of typical roadways in southern California[12], the overall average emission rates were similar, but generally lower, ranging from 0.060 to 0.130 mg/m.

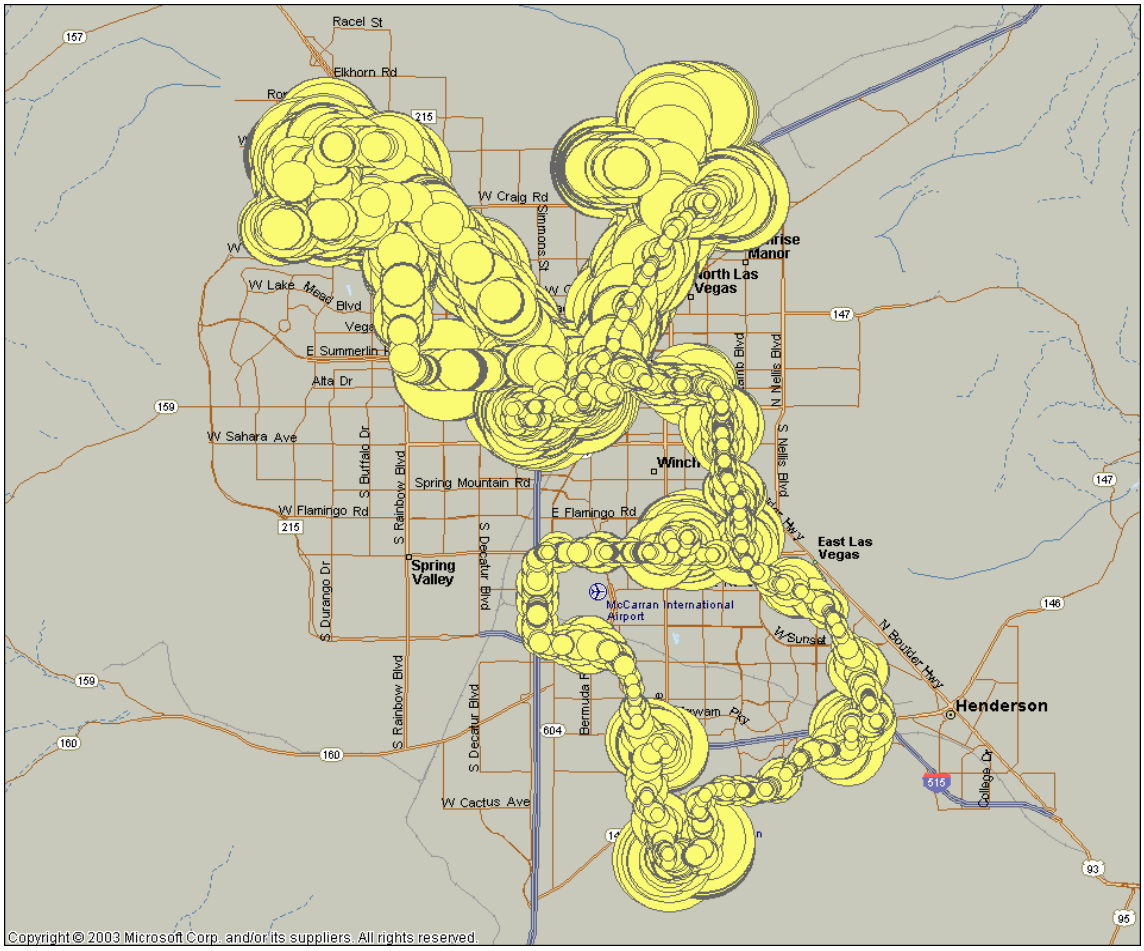
Figure 3. PM_{10} emission rate time series during the test conducted on June 30, 2004.



The PM_{10} emission rates are plotted in the maps shown in Figures 4 through 6 using circles to denote the PM_{10} emission rates. Figure 4 shows the entire test route (including periods when the pumps for the isokinetic probe were not operational), while Figure 5 shows an example of greater resolution than that shown in Figure 4. Figure 6 is an example of maximum resolution. At this resolution we can see which side of a divided highway the test vehicle is traveling on. “Hot spots” are clearly discernable in all of these figures.

Figure 7 shows the emission rates calculated as a running 20-second average for the time period of the second test day in which data are available for both the front and rear DustTraks. This test run started an hour earlier and we tried to drive at speeds similar to the first tgest run. There are again a few periods where the emission rate is negative, most likely due to “events” that affect the front and rear DustTraks unequally. The overall average PM_{10} concentration measured by the front DustTrak was 0.024 mg/m^3, while that of the rear was 0.066 mg/m^3. The correction on the average was therefore about 36%, essentially the same as on the previous day. The average emission rate was 0.130 mg/m during this period.

Figure 4. PM_{10} Emission factors plotted during the test route on June 30, 2004.



PM10Emission Rate, mg/m

- 0.0677 to 4.6154
- 0.0314 to 0.0676
- 0.0156 to 0.0313
- 0.0062 to 0.0155
- -0.0041 to 0.0061
- -0.0117 to -0.0042
- -0.0282 to -0.0118
- -1.0491 to -0.0283

Figure 5. PM_{10} emission factors plotted with greater resolution during the test route on June 30, 2004.

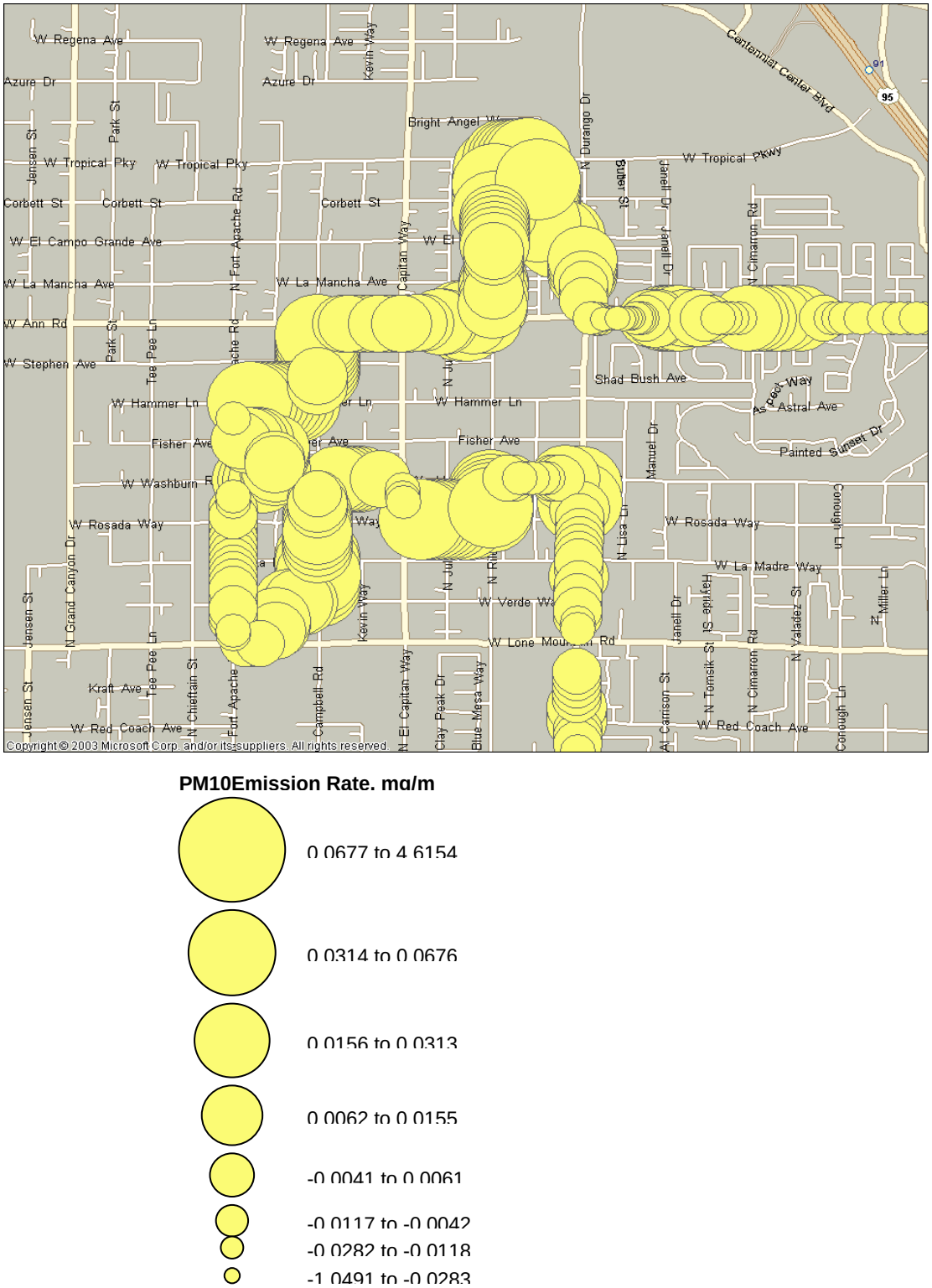
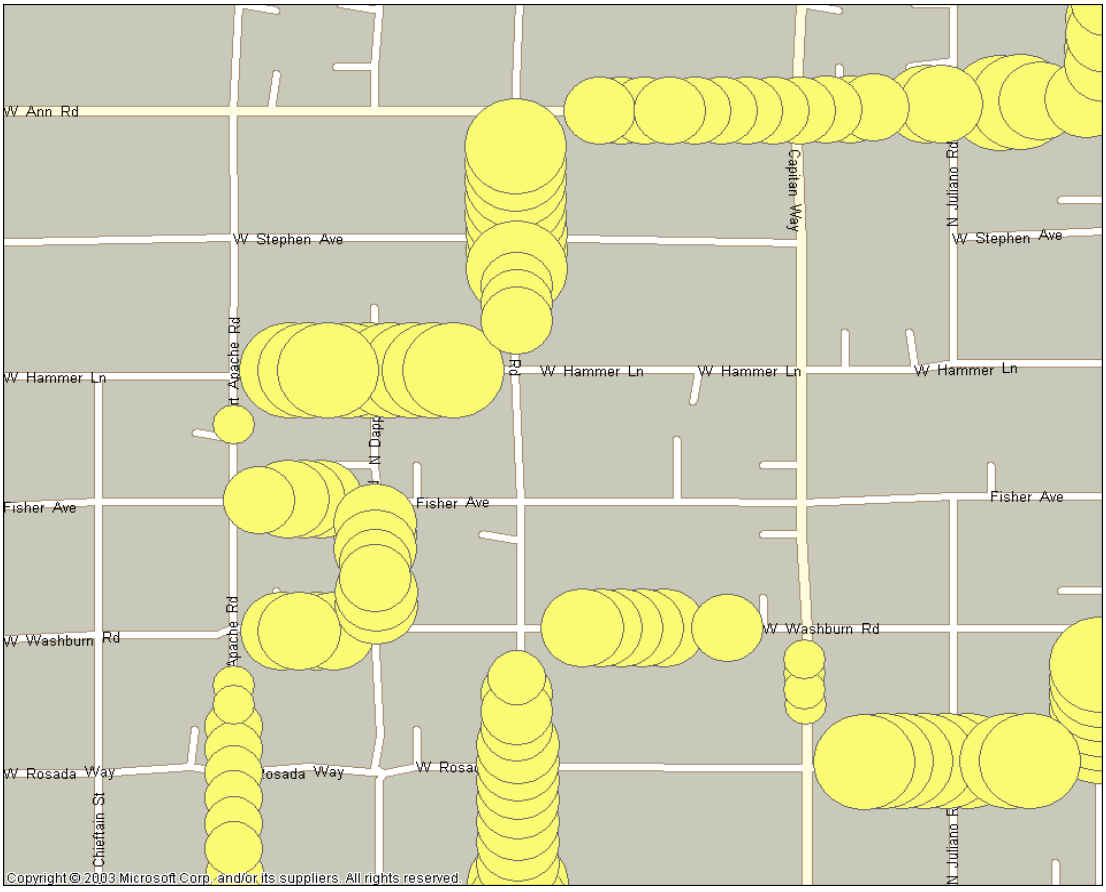


Figure 6. PM_{10} emission factors plotted with greatest resolution during the test route on June 30, 2004.



PM10 Emission Rate, mg/m

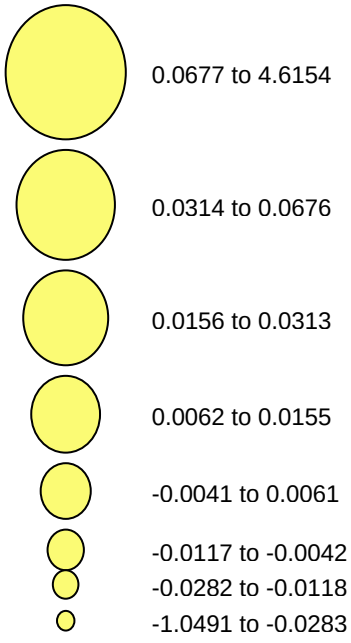
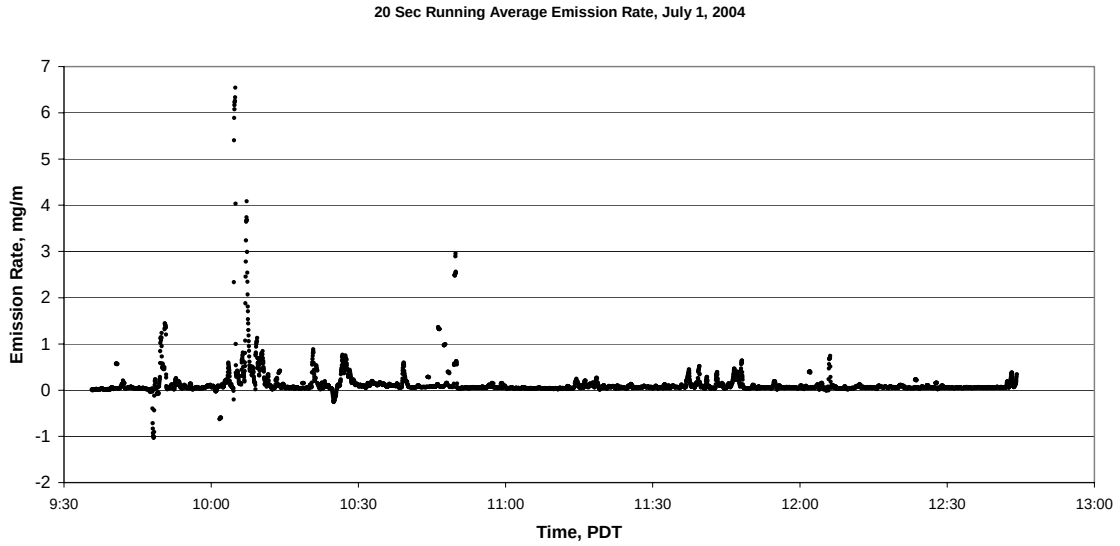


Figure 7. PM_{10} emission rate time series during the test conducted on June 30, 2004.



CONCLUSIONS

Data were available for both days for the first part of the route (roughly the first half) when either reliable data (when the isokinetic sampling was controlled by PC on the first day) or when both front and rear DustTrak data were available on the second day). The first part of the route covered areas in the northwest with the highest PM_{10} emission rates, which were often greater than two orders of magnitude higher than typical streets. Despite this variability, the peak PM_{10} emission rates were within a factor of two for the two days of sampling. The average PM_{10} emission rates were very similar, 0.167 mg/m on the first day compared with 0.130 mg/m on the second sampling day. In our experience, this level of reproducibility is far greater than can be obtained from silt sampling. We attribute this precision to this method that integrates the PM_{10} emission rate over the entire roadway rather than small test sections.

What we have not established was the calibration of the DustTraks for the Las Vegas PM_{10} encountered during our sampling. In our previous studies in southern California we compared the DustTrak PM_{10} response to PM_{10} determined by filter collection showed the DustTrak to response to be approximately twice as high, but with 50% scatter. References

from other studies range from the DustTrak giving values equal to a reference filter to being three times too high. If the factor of two relationship holds for the sampling conducted in Las Vegas, the emission rates reported above would need to be divided by two.

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KEY WORDS

Paved road, PM, PM_{10}, dust, emissions