

FUGITIVE DUST CHARACTERIZATION IN DOÑA ANA COUNTY, NEW MEXICO

PROJECT NUMBER: A-01-7

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NARRATIVE SUMMARY

Wind-blown dust is an air quality and health concern in many areas along the U.S.-Mexican border, including southern Doña Ana County, N.M. There is a need to understand and quantify the impact of nearby unpaved roads on air quality where people live.

Extensive studies of fugitive dust in the Central Valley of California have been funded by the U.S. Environmental Protection Agency (EPA) and by the California Air Resources Board (CARB), but much less research has been done along the U.S.-Mexican border. A goal of this study was to investigate whether the observed decrease in dust concentration with distance from an unpaved central California road apply to the soil conditions, dust particle size distributions, human activity patterns, and terrain in southern Doña Ana County, N.M.

Experiments were conducted to determine the PM_{10} and $PM_{2.5}$ concentration variation with increasing distance from the road at a fixed height of 1 meter (m) to 2 m above ground level. The data suggest a 75% to 80% reduction in the initial dust concentration within the first 100 m from the road. This result is important because the measurements were taken at the height where humans breathe. Field data were compared to studies in the literature and to calculated predictions for the gravity settling and atmospheric dispersion mechanisms.

As well, calculations revealed that within 70 vehicle trips per day, one would be exceeding the annual PM_{10} standard near an unpaved road. As per the decay rate (0.021/m) calculated for PM_{10} from the field experiments, the concentration per vehicle trip would drop down to approximately 0.6 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) at about 100 m from the road. This would require between 550 and 600 vehicle trips per day to exceed the annual standard for PM_{10} , which is $50 \mu\text{g}/\text{m}^3$.

The results of this study suggest that near-source emission measurements of road dust are important for decisions involving dust control strategies, paving roads, and placement of unpaved roads relative to subdivisions. A follow-up project will take measurements of dust depositions on horizontal and vertical surfaces.

The data gathered from the 2000 and 2001 SCERP-funded research contributed substantially to a recent journal article. The paper "Vehicle Generated Fugitive Dust Transport: Analytic Models and Field Study," submitted to *Atmospheric Environment*, reports the results of a field study at Dugway, Utah, that was based on techniques and preliminary data developed during the Doña Ana County studies. A publication in a peer-reviewed journal based on concentration decrease at breathing height with distance from an unpaved road is expected to result from this study.

The University of Utah portion of this SCERP project has supported a University of Utah Master's Degree student, Gauri Seshadri. She used these results in her Master of Science thesis in Chemical and Fuels Engineering, which was successfully defended in Fall 2002. This SCERP project also provided a field research opportunity for Master of Science in Public Health student Jared Mowrer. This work is part of Mowrer's thesis, which has also been successfully defended.

FUGITIVE DUST CHARACTERIZATION IN DOÑA ANA COUNTY, NEW MEXICO

PROJECT NUMBER: A-01-07

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INTRODUCTION

Wind-blown dust is an air quality and health concern in many areas along the U.S.-Mexican border, including southern Doña Ana County, New Mexico. There is a need to understand and quantify the impact of nearby unpaved roads on air quality where people live. Experiments were conducted to determine the PM₁₀ and PM_{2.5} concentration variation with increasing distance from the road at a fixed height of 1 meter (m) to 2 m above ground level (AGL). The data suggest a 75% to 80% reduction in the initial dust concentration within the first 100 m from the road. This result is important because the measurements were taken at the height where humans breathe. A comparison of data found in the literature (Claiborn, et al. 1995; Watson, et al. 1996) to the experimental results is made in this report. In addition, the experimental trend is also compared to the different particle mechanisms occurring in the atmosphere, namely gravitational settling (Hinds 1982) and dispersion (Claiborn, et al. 1995; Seinfeld and Pandis 1998).

Studies by the Desert Research Institute (DRI) in Nevada and in California's San Joaquin Valley (Watson, et al. 1996) showed a large (greater than 90%) decrease in dust concentration within 100 m of an unpaved road (Watson, et al. 1996; Watson, Chow and Pace 2000). This rapid decrease in concentration with distance implies that dust control on roads near populated areas will be effective in reducing exposure. Extensive studies of fugitive dust in the Central Valley of California have been funded by the U.S. Environmental Protection Agency (EPA) and by the California Air Resources Board (CARB) (Watson, et al. 1998a; Watson, Chow and Pace 2000; Watson, et al. 1998b).

Experiments were conducted mainly in Doña Ana County, N.M. and in Dugway, Utah (Veranth, Pardyjak and Seshadri 2002). The Doña Ana climate is generally mild and semiarid, averaging 350 days of clear weather annually. The county has experienced numerous exceedances of the 24-hour National Ambient Air Quality Standard (NAAQS) concentration limit for PM₁₀ of 150 µg/m³, and it is in violation of the PM₁₀ NAAQS (New Mexico Environment Department Air Quality Bureau 2000). Dugway is in a remote area with a very low population. They are both arid regions and have soils that are quite susceptible to wind and vehicle pick-up.

RESEARCH OBJECTIVES

This study investigated whether the observed decrease in dust concentration found in central California apply to the soil conditions, dust particle size distributions, human activity patterns, and terrain in southern Doña Ana County, N.M. and Dugway, Utah.

The task consisted of:

- A study to quantify the decrease in dust concentration (PM_{10} and $PM_{2.5}$) measured at breathing height downwind of unpaved roads
- A study focused on the changes in particle size and concentration as wind moves airborne dust from undeveloped grazing areas into populated areas
- Taking measurements with collocated DustTraks to study the size distribution of road dust
- Taking gravimetric measurements of PM_{10} and $PM_{2.5}$ at the test sites

RESEARCH METHODOLOGY/APPROACHES

This chapter covers data from four separate field experiments that were conducted over a period of one year. The research objectives and sampling methods, originally based on work by Watson (Watson, et al. 1998a; Watson, Chow and Pace 2000; Watson, et al. 1998b), evolved during this time.

Field Sites

Four sites were selected for the experiments, including:

- Jornada road in Las Cruces, N.M. (Veranth and Seshadri 2001)
- Dugway, Utah (Veranth, Pardyjak and Seshadri 2002)
- Eight Mile Road, Utah
- Achenback Canyon Road, Las Cruces

Complete descriptions of these test sites are provided in Table 1. Test roads near other sources of dust were avoided to prevent confusing contributions from emissions other than those from the road. Roads selected for the field experiments had sparse traffic and undeveloped land on both sides. The number of car trips past the sampling stations was reasonably controlled and there was access to set up the sampling instruments as needed. There were no obstructions larger than about 2 m to 2.5 m on either side of the road for a distance of 2 kilometers (km) or more. The terrain was generally flat, which minimized topographic influence on local wind patterns. This is important so that the dust travels naturally due to vehicle wakes and ambient winds toward the measurement samplers (EPA 1998). In addition, the vegetation on both sides of the roads mainly consisted of plants and weeds that were about 1 m to 1.5 m in height (mostly mesquite and sage).

Test Roads

The unpaved test roads selected were usually 400 m to 500 m in length extending outward from the sampling location (i.e. approximately 1 km total in length). The road length was much greater than the distance to the downwind samplers. The test roads were considered as a line source for fugitive dust.

Sampling and Characterization of Surface Material

Soil samples were collected from the test site. A whiskbroom and dustpan were used to remove the loose surface material from the hard road base. Approximately 1 kilogram (kg) to 2 kg were collected for silt analysis. This was done in accordance with the procedure described for unpaved roads in Appendix C.1 of AP-42 (EPA 1995). The samples were then sent to DRI to be analyzed for silt fraction. Silt is defined as particles less than 75 micrometers (μm) in diameter; silt content can be determined by measuring the proportion of loose, dry surface dust that passes through a 200-mesh screen, using the ASTM-C-136 method. Refer to Table 1 for the silt percentage of the soil samples.

Vehicle Type and Traffic Monitoring

Different test vehicles have been used at the different test sites (Table 1), ranging from a passenger car to a pickup truck weighing approximately one ton to three tons. The test vehicles were always driven at constant speed. The test vehicles traveled up and down on these roads at approximately 30 mph to 40 mph to create dust emissions. Between three and four replicate sets of car trips were taken at every location. Extra traffic (vehicles apart from the test vehicle) on the road was logged, including each vehicle type and vehicle speed. Trips with the test vehicle were skipped when another vehicle passed the sampling station, thus keeping the number of trips per sample constant. The trip times were manually logged.

Meteorological Instrumentation

Davis Monitor-II weather stations (product number 7440) were the main instruments used to measure the wind speed and wind direction in all the experiments. They consist of a wind vane that monitors the wind direction and a four-cup anemometer that records the wind speed. Sonic anemometers were used for the Dugway experiment (Veranth, Pardyjak and Seshadri 2002). The Sonic Anemometer is a microcomputer-based wind sensor capable of measuring wind velocity in one, two, or three axes with reliable accuracy. The vane anemometer was also used in some of the experiments. The instruments were attached to either the upwind monitoring station or the nearest downwind station. Data recording was done once every minute with the vane anemometer, the Davis weather station, and once every second with the sonic anemometer. The average wind speeds and the stability class have also been recorded in Table 1 for each of the test sites.

PM₁₀ and PM_{2.5} Sampling

DustTraks (Model 8520 DustTrak TM, TSI Incorporated, Shoreview, Minn.) were used to measure PM₁₀ and PM_{2.5} dust concentrations upwind and downwind of the test sites. The number of DustTraks varied with each experiment depending upon the budget and the sampling strategy. The DustTrak uses a 90° light scattering laser diode sensor and has a range of between 0.001 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) and 100 $\mu\text{g}/\text{m}^3$. The DustTrak uses a battery pack with four size C batteries or AC power to power a pump that draws ambient air through an inlet at a sampling rate of 1.7 liter per minute (L/min). A single-stage impactor achieves the aerosol size cut

point. PM₁₀, PM_{2.5} and PM_{1.0} configurations are available with the instrument. The latter two inlets use a greased impaction plate. Quality checks for the DustTraks included:

- Daily inspection of the impactor inlets, with cleaning whenever particle deposits were observed
- Filter checks for zero readings before and after every run
- Flow rate checks before and after every run
- Daily collocation of the DustTraks to check for precision between the instruments
- Factory calibration using a standard test dust prior to shipment to verify the accuracy of the conversion from light scattering to calculated PM₁₀ mass

The sampling date, start time, stop time, sampler ID, sampler position, and flow rate were recorded in the lab notebook.

Sampling Pattern

A controlled sampling pattern was used where between four and 10 car trips with the DustTraks were placed at a fixed location. The sampling (logging) time was set at five seconds (s) so that the DustTraks would be able to capture the dust peak. Table 1 lists the various sampling patterns and logging intervals used for the different experiments.

Sampling was done only when the mean wind direction remained within 45° of perpendicular to the unpaved road. Measuring the ambient aerosol for PM₁₀ and PM_{2.5} was done using a modified form of the upwind-downwind method (EPA 1998; Hesketh and Frank L. Cross 1983). This method is suitable for measuring dust emissions from open dust sources. The basic method implemented here uses the measurement of dust concentration both upwind and downwind of the unpaved road.

Upwind Sampling

Two methods were used to measure the background level of PM₁₀ and PM_{2.5} being transported upwind. In some cases, an instrument was placed between 50 m and 100 m upwind of the road. Alternatively, the downwind instrument readings during periods of no vehicle activity were averaged and used as the background level. Background values were less than 1% of the dust concentration resulting from vehicle activity. Therefore, the background concentration had no significant effect on the results.

Small-scale wind gusts and thermal updrafts (dust devils) did confound the measurements. These intense, short duration winds could pick up sufficient soil dust from disturbed areas to create clouds comparable to vehicles. Sampling was stopped when this problem became severe.

Downwind Sampling

The sampling was done in line with the prevailing wind direction. One DustTrak was treated as a reference and was kept at the nearest downwind station. The purpose

of this was to record all the activities occurring at the source, including recording the initial size of the dust cloud generated by the moving vehicle. The reference DustTrak was stationary throughout the entire experiment. Apart from the reference DustTrak, there were three to four more sampling locations downwind where the rest of the DustTraks were placed. The sampling locations varied from 10 m to 200 m downwind of the road. Refer to Table 1 for the sampling locations of the different experiments. The DustTraks were placed at 1 m and 2 m AGL, depending on the experiment. The start and the stop time that a sampler was at a location were noted. During this time the dust concentration was recorded at five-second intervals (varied for the initial experiments). The experiments were done for both PM₁₀ and PM_{2.5} at 1 m and 2 m AGL.

Collocation of the Three DustTraks with Different Size Inlets

Three DustTrak monitors installed with different size inlets—PM₁₀, PM_{2.5} and PM_{1.0}—were collocated at the Achenback test sites. The basic goal was to study the size distribution of the fugitive dust particles under field conditions for two different test sites and at two different distances downwind of the road. The sampling was done at 10 m and 40 m downwind of the road for 20 car trips on two separate days.

Gravimetric Measurement of PM₁₀

A portable PM₁₀ MiniVol[®] sampler (Airmetrics, Inc.) was used to obtain the gravimetric measurement of PM₁₀ at the Achenback test sites. The MiniVol uses a rechargeable battery pack to power a pump that draws air through a single filter pack at a flow rate of 5 L/min. The MiniVol ran the entire time of sampling on a particular day for between three and four hours, approximately. This experiment was conducted on three days. Teflon filter (Gelman Teflon™ 47 millimeter [mm] diameter, 2 mm) and polycarbonate filters (Millipore polycarbonate membrane filter, 47 mm diameter, 0.2 mm GTTP) were used. The filters were both tared and weighed on an analytical microbalance.

PM₁₀ and PM_{2.5} Concentration—Theory

From theory, one can obtain an equation for the expected decrease in dust concentration with distance assuming vertical gravity settling and horizontal wind transport. Stoke's law gives the terminal settling velocity of aerosol particles undergoing gravitational settling in still air (Hinds 1982; Perry and Chilton 1973) as:

$$V_{TS} = \frac{\rho_p d^2 g}{18\eta} \quad (1)$$

Where,

V_{TS} is terminal settling velocity of the particle, cm/s

ρ is density of the particle, gm/cm³

d is diameter of the particle, cm

g is acceleration due to gravity, cm/s²

η is kinematic viscosity, gm/cm/s

The terminal settling velocity is defined as “the velocity at which the drag force of the air on the particle is exactly equal and opposite of the gravitational force” (Hinds 1982). Unfortunately, the atmosphere is not still and behaves in a rather complex manner. Most of the measurements have been taken in the middle of the day when there was high atmospheric instability.

Consider a system that has a mono-disperse aerosol present in a chamber of height H , (Figure 1); assume that the aerosol is stirred vigorously (Hinds 1982). In addition, also assume the concentration uniform in the chamber at all times (Levenspiel 1972) and diffusion, resuspension, and deposition on the walls negligible. The settling velocity of the particles is superimposed on the vertical components of convective velocity. Because the up and down components of convective velocity are equal and cancel out over a time period long compared to their period, each particle will have an average net velocity equal to its terminal settling velocity V_{TS} . The particulate concentration decreases with time; however, the rate of removal is also decreasing with time since it is proportional to the number of particles left suspended in the chamber, which even though uniformly mixed, is decreasing. The portion removed, dn/n , during an interval of time, dt , is long compared to convective motion and small compared to the rate of particle decay. This is given by

$$\frac{dn}{n} = -\frac{V_{TS}dt}{H} \quad (2)$$

Integrating Equation 2 for an initial condition of $n = n_0$ at $t = 0$ gives an exponential decay with time, and as such, never reaches zero.

$$\frac{n(t)}{n_0} = \exp\left(\frac{-V_{TS}t}{H}\right) \quad (3)$$

Equation 3 is derived for a single size bin, but the result is applicable for poly-disperse aerosols as well. Larger size particles will settle down much faster than smaller size particles because the terminal settling velocity increases with the square of the particle diameter.

From a Lagrangian point of view, consider the box to be traveling in the downwind direction at a velocity of u m/s. One of the assumptions made is that there is no vertical movement of dust beyond the box (no vertical flux), and it has a constant box size, which implies a stable atmosphere. Let the box be at $x = 0$ m at $t = 0$ s, where x is the perpendicular distance from the unpaved road. At time $t = t$ sec the box would have traveled a distance of u (m/s) times t (s).

$$x = ut \quad (4)$$

For a differential increment of time,

$$dx = udt$$

$$dt = \frac{dx}{u}$$

(5)

Substituting for dt in Equation 2,

$$\frac{dn}{n} = -\left(\frac{V_{TS}}{H}\right) \frac{dx}{u}$$

(6)

Integrating the above equation with an initial condition of $n = n_0$ at $x = 0$ gives the following exponential decay:

$$\frac{n(x)}{n_0} = \exp\left(\frac{-V_{TS}x}{Hu}\right)$$

(7)

Therefore, from theory, we expect an exponential decay of concentration of particles in the air with distance from the road at a fixed height.

The DustTraks report the data as dust concentration versus time. These data were downloaded from the DustTraks and transferred to a spreadsheet where they were edited to retain the periods of controlled vehicle activity and exclude setup and shutdown periods. The amount of dust that resulted from vehicle travel was calculated as a time average value ($\text{mg sec}/\text{m}^3 \text{ trip}$) over fixed sampling intervals as given in Equation 8 (i.e., the DustTrak concentrations were averaged for the entire period of time that the sampling run was going on). An mathematical average of all the time average concentration values was calculated for the particular test sites. These values were then normalized with respect to the time average concentration measured at the reference station. An exponential curve using Microsoft Excel was fit to the data. This is an empirical fit to the data, and the functional form was based on the theoretical analysis as derived in an earlier section.

$$\text{TimeAverageConcentration} = \bar{C} = \frac{\int C(t)dt}{\int dt}$$

(8)

Where,

C is mass concentration as recorded by the DustTraks, mg/m^3

t is time of the sampling run, s

The concentration of dust resulting from a vehicle pass was sufficiently high that subtracting background had a negligible effect on the integral. The exponential fit to the time average concentration versus distance data gives an equation of the form:

$$C(x) = C_0 \exp(-kx) \quad (9)$$

Where,

$C(x)$ is mass concentration at any given distance x from the road

C_0 is concentration at the zero height

x is perpendicular distance from the unpaved road in the downwind direction, m

k is exponential decay term, m^{-1}

PROBLEMS/ISSUES ENCOUNTERED

The intended study to focus on the changes in particle size and concentration as wind moves airborne dust from undeveloped grazing areas into populated areas was not completed, as there were no periods of high winds while the sampling team was in the field. The MiniVol samplers used for taking gravimetric measurements broke down on the field and replicate filter samples could not be obtained.

RESULTS

Typical Data

Absolute PM_{10} concentration recorded by the DustTraks was plotted as a function of time and distance away from the source (unpaved road). A typical test is given in Figure 2. The difference in the absolute magnitudes of the peak readings at a particular sampling station demonstrates the variability of dust observed during the tests. Figure 2 also shows the difference in absolute magnitudes of the PM_{10} concentration at different downwind distances from the road.

Wind Speed Measurements

Wind speed was measured on three different days at three heights: 2 feet (ft), 5 ft, and 10 ft AGL at Achenback Canyon Road. Data logging was done once every minute. The variation of wind speed versus height was plotted for Achenback Canyon Road for the 26th, 27th and 28th of March 2002. By applying a logarithmic equation fit to the data set using Microsoft Excel, the local friction velocity (u_*) (Panofsky and Dutton 1984) was calculated. The friction velocity for Achenback Road was determined to lie between 0.2 m/s and 0.3 m/s. This is shown in Figure 3.

Horizontal Variation in PM_{10} Dust Concentration

The measured PM_{10} concentration at 1 m or 2 m AGL was found to decrease rapidly with downwind distance. The results of concentration versus distance for the six current project studies are shown in Figure 4. A consensus fit of the normalized time average concentration with respect to the value at the reference location (sampling station nearest to the unpaved road) has been plotted. The results of multiple studies showed an 80% to 90% decrease in the dust concentration within the first 100 m from the source. The squares represent the measurements made at 2 m and

the diamonds represent measurements made 1 m AGL. The bold line represents the consensus fit to the decay rates for all the test sites (see Table 2), and the dashed line represents one standard deviation.

Horizontal Variation in PM_{2.5} Dust Concentration

The horizontal concentration profile was also plotted for PM_{2.5} at 1 m and 2 m AGL, and the results for the different test sites are compared with each other in Figure 5. The results are shown for five current project studies. PM_{2.5} measurements made at both 1 m (diamonds) and 2 m (squares) AGL are shown. The values are normalized with respect to the value at the reference location. There is a 70% to 80% reduction from the original dust concentration generated at the source within 100 m from the road. The bold line represents the consensus fit to the decay rates for all the test sites (see Table 2), and the dashed line represents one standard deviation. The data presented are normalized to the value at the closest measurement station to allow for a direct comparison between the different sites, even though their absolute magnitudes were different.

Table 2 summarizes the exponential decay term for all the sites for both PM₁₀ and PM_{2.5}. The decay term for PM₁₀ is 0.021 ± 0.008 and for PM_{2.5} it is 0.022 ± 0.010 . From this table, it can be observed that the decay for PM₁₀ is quite comparable to the decay for PM_{2.5}.

Size Distribution Measured by Collocated Instruments

Collocated measurements from the three DustTraks[®] fitted with different size inlets are plotted in Figure 6. The graph shows the particulate matter (PM) ratio measured at 2 m AGL and at 10 m and 40 m downwind of the unpaved roads at both the highway gravel and native soil Achenback Canyon Road test sites. There is a 40% to 60% uncertainty in the data sets and thus sufficient difference could not be obtained between the two sites. However, PM_{2.5} was found to lie between 15% and 20%, and PM_{1.0} was found to lie between 3% and 5% of PM₁₀ for both the test sites.

Gravimetric Measurement

Gravimetric measurement of PM₁₀ was made at the Achenback Road test site using PM₁₀ MiniVol samplers. The MiniVol ran for between three and four hours on three different days. The filters gave inconclusive results as the final weight lied within the uncertainty of the analytical balance used. In addition, replicate filter samples could not be obtained. A minimum time needed to get a good sample weight on the MiniVol located 10 m horizontal and 1 m vertical was found to be at least six to eight hours with the level of vehicle activity used in the Achenback road experiments.

CONCLUSIONS

The consensus fit to the experimental data for PM₁₀ horizontal decay has been compared to other previous literature studies (Watson, Chow, and Pace 2000; (Claiborn, et al. 1995), done on the same. This is given in Figure 7. Data plotted for the two literature studies are directly read from the graphs in the papers. Error bars represent one standard deviation. The solid gray line represents the consensus for

all of the six experimental field data results, and the thin dashed line represents one standard deviation of the data. The triangles represent data from Watson, et al., where MiniVols were used to measure PM_{10} concentration, and the squares represent Claiborn, et al., where tracer experiments (i.e. gas dispersion) were compared to PM_{10} measurements near the road. The data are normalized to the concentration values measured at 15 m away from the road for each experiment, as this was a common distance measured by both Watson and Claiborn. The experimental data correspond very well to both their test results.

Table 2 indicates that both PM_{10} and $PM_{2.5}$ have very similar decay rates. This goes against what is expected from theory since the terminal settling velocity, V_{TS} , increases with the square of the particle diameter (d^2) as given in Equation 1. If the decrease were solely due to gravitational settling, one would expect a much flatter profile for $PM_{2.5}$ compared to PM_{10} since PM_{10} is larger than $PM_{2.5}$. This study measures PM_{10} and $PM_{2.5}$ concentration at only one height AGL. The decrease in the observed concentrations and the similar $PM_{2.5}$ decay to PM_{10} suggests that the observed concentration decrease is principally due to dispersion of the dust cloud (dilution due to mixing with clean air). Therefore, it is not necessary that the PM_{10} and the $PM_{2.5}$ are actually decreasing with distance from the unpaved road. The results for the horizontal decay for PM_{10} and $PM_{2.5}$ at 2 m AGL do not give us an indication as to whether the PM_{10} and $PM_{2.5}$ are being dispersed vertically in the atmosphere or not. Unfortunately, dispersion models assume a point source, and the model constants (Hinds 1982; Seinfeld and Pandis 1998) are estimated for distances of 100 m and greater from the source. In this experiment, we have a line source with initial height comparable to the height of the vehicle and are interested in the concentration profiles within the first 100 m from the unpaved road.

The decay of PM_{10} size particles within a height of 2 m AGL due to gravitational settling alone (Hinds 1982) was calculated. In addition, a decay rate from the dispersion model, using the constants from Claiborn, et al. (1995) was calculated. These two different particle-removing mechanisms have been plotted and compared to the experimental decay results calculated for PM_{10} in Figure 8. It compares the experimental range (dashed line) to the gravitational (dark line) and dispersion (gray line) settling velocities calculated for a particle size of PM_{10} . The range shown is the maximum and minimum exponential decay rates obtained by the field tests. The data are normalized with respect to the concentration at 10 m from the road. The data have been calculated for a height of 2 m above ground level and a wind speed of 2 m/s with a stability class A. The dispersion fit deviates before the reference location, as the model assumes the dust source to be a point.

Gravity settling gives a flat profile and pure dispersion yields a steep profile. The experimental results lie between these two mechanisms. Gravity settling is too slow for the removal of particles when compared to the measured decay of PM_{10} .

The decrease in concentration at a fixed height AGL could be either due to removal or dilution of particles in the atmosphere. To know the separate effects of deposition

and dispersion, we need to measure the horizontal flux. Determining the horizontal flux was not a part of this year's field study.

Another hypothesis is that PM₁₀ contains a major fraction of PM_{2.5} particles, which is causing a similar decay trend for both the size ranges. Yet another possibility is that the DustTraks is overestimating the fraction of PM_{2.5} in the ambient aerosol. This could be an artifact of change in the empirical calibration used by the DustTrak to convert light scattering to mass as the size distribution changes (Etyemezian 2002). This effect needs to be tested for future studies.

The PM_{2.5} experiments conducted were important from a research standpoint. An intensive literature search on the databases COMPENDEX, Science Citation Index, SciFinder Scholar, Scirus Science Index, and GeoBase reported no previous studies on PM_{2.5} concentration versus distance at a fixed height.

Whatever the mechanisms may be of PM₁₀ decay, all the test results and previous literature studies indicate that there is a definite significant reduction of PM₁₀ by about 75% to 80% of the initial dust concentration within the first 100 m of the unpaved road at a fixed height of 1 m to 2 m AGL. This suggests that near-source emission measurements of road dust are important in assessing the exposure changes resulting from various policy alternatives.

From a perspective of human health, the above result is useful in the following way: consider a house situated at the edge of an unpaved road.

$$C_{Total} = C_{Background} + \Delta C_{Road} \quad (10)$$

If the road increases the total PM₁₀ concentration (C_{Total}) to exceed the annual average NAAQS (CFR 1997) of 50 µg/m³, then the contribution of the nearby road must equal or exceed

$$\Delta C_{Road} \geq 50 - C_{Background} \quad (11)$$

$$\Delta C_{Road} = \bar{C}nt \quad (12)$$

Where,

\bar{C} is the time averaged PM₁₀ concentration when a vehicle goes by on the unpaved road, µg /m³

n is the number of vehicle trips per day

t is the time duration of each trip passing the house—s/trip

From Equations 11 and 12, the number of vehicle trips per day on the unpaved road needed to exceed the annual average PM₁₀ standard as set by NAAQS can be determined.

Assuming a set of reasonable values as per the field data collected,

$$C_{\text{Background}} = 10 \mu\text{g}/\text{m}^3$$

$$\bar{C} = 5 \text{ mg}/\text{m}^3 = 5000 \mu\text{g}/\text{m}^3$$

$$t = 10 \text{ s}/\text{trip near the house}$$

$$50 \frac{\mu\text{g}}{\text{m}^3} = 10 \frac{\mu\text{g}}{\text{m}^3} + \frac{5000 \frac{\mu\text{g sec}}{\text{m}^3 \text{ trip}} \times 10 \frac{\text{sec}}{\text{trip}} \times n \frac{\text{trips}}{\text{day}}}{3600 \frac{\text{sec}}{\text{hour}} \times 24 \frac{\text{hours}}{\text{day}}}$$

$$n \cong 70 \frac{\text{trips}}{\text{day}}$$

The above calculation implies that within 70 vehicle trips per day, one would be exceeding the annual PM₁₀ standard near the unpaved road. As per the decay rate (0.021/m) calculated for PM₁₀ from the field experiments, the concentration per vehicle trip would drop down to approximately 0.6 mg/m³ at about 100 m from the road. This would require between 550 and 600 vehicle trips per day to exceed the annual standard for PM₁₀, which is 50 μg/m³. This result is significant for decisions involving dust control strategies, paving roads, and placement of unpaved roads relative to subdivisions.

RECOMMENDATIONS FOR FURTHER RESEARCH

Field experiments are time consuming, labor intensive, and dependant on the weather. Additional studies of this type will strengthen conclusions. Determining the horizontal flux for PM₁₀ and PM_{2.5} is required. Data from the flux experiments will directly correspond to the emission factors calculated for unpaved roads by the EPA and will be valuable for air quality planning.

The road dust partitioning between redeposition and transport measurements need to be repeated with improved methods based on lessons learned from the initial field study, which include the following:

- Do the experiment at different times of the day to get different atmospheric stability conditions; in the early morning there is maximum atmospheric stability and in the late afternoons, the atmosphere becomes highly unstable
- Try to do the experiments over different vegetations to learn how the vegetation affects the fugitive dust
- Do direct SEM measurements of dust depositions on horizontal and vertical surfaces

RESEARCH BENEFITS

The measurements of the decrease in dust concentration at a fixed height provide quantitative data on how much unpaved roads impact nearby residents. It is also

useful for integrating transportation planning, residential zoning, and air quality objectives.

This study provided the New Mexico Department of Environmental Quality Division of Air Quality with local data on fugitive dust in the U.S.-Mexican border region that can be compared to published studies from other geographical areas. This will aid air quality planning and modeling efforts by providing site-specific experimental justification for various assumptions.

This project also has facilitated technical meetings of university faculty with state air quality staff in the planning and modeling groups

The data gathered from the 2000 and 2001 SCERP-funded research contributed substantially to a recent journal article. The paper "Vehicle Generated Fugitive Dust Transport: Analytic Models and Field Study," submitted to *Atmospheric Environment*, reports the results of a field study at Dugway that was based on techniques and preliminary data developed during the Doña Ana County studies. A publication in a peer-reviewed journal based on concentration decrease at breathing height with distance from an unpaved road is expected to result from this study.

The University of Utah portion of this SCERP project has supported a University of Utah Master's Degree student, Gauri Seshadri. Ms. Seshadri participated in both the 2001 and 2002 field studies at sites in Sunland Park, Santa Teresa, Jornada Road, and Achenback Road. She also participated in related Department of Defense-funded wind-blown dust experiments at Ft. Bliss, Tex. She performed most of the office data analysis from these field studies. She used these results in her Master of Science thesis in Chemical and Fuels Engineering, which was successfully defended in Fall 2002. Seshadri is co-author on a publication currently in review for *Atmospheric Environment* and co-author of two presentations at American Association for Aerosol Research national meetings.

This SCERP project also provided a field research opportunity for Master of Science in Public Health student Jared Mowrer. This work is part of Mowrer's thesis, which has been successfully defended.

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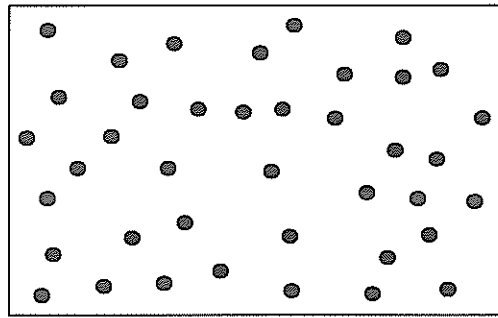
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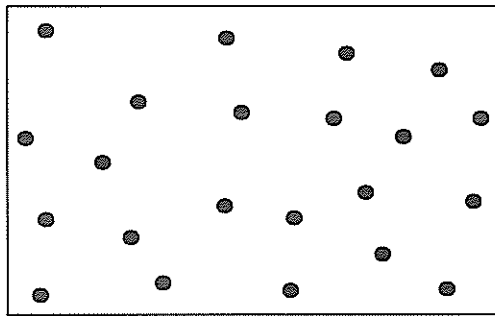
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$t = 0$



$t > 0$

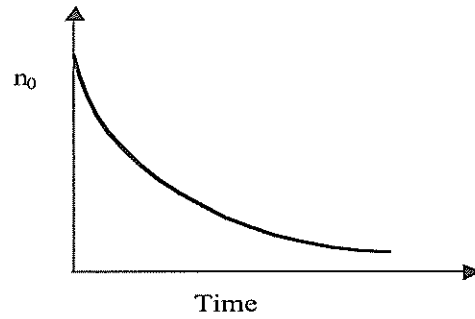


Figure 1. Settling of Mono-Disperse Particles in a Chamber under Stirred Settling Conditions

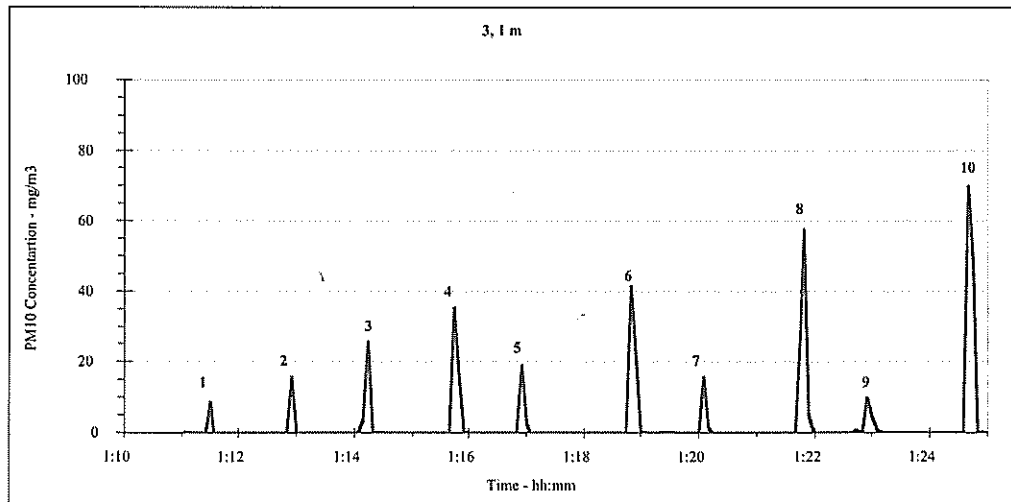
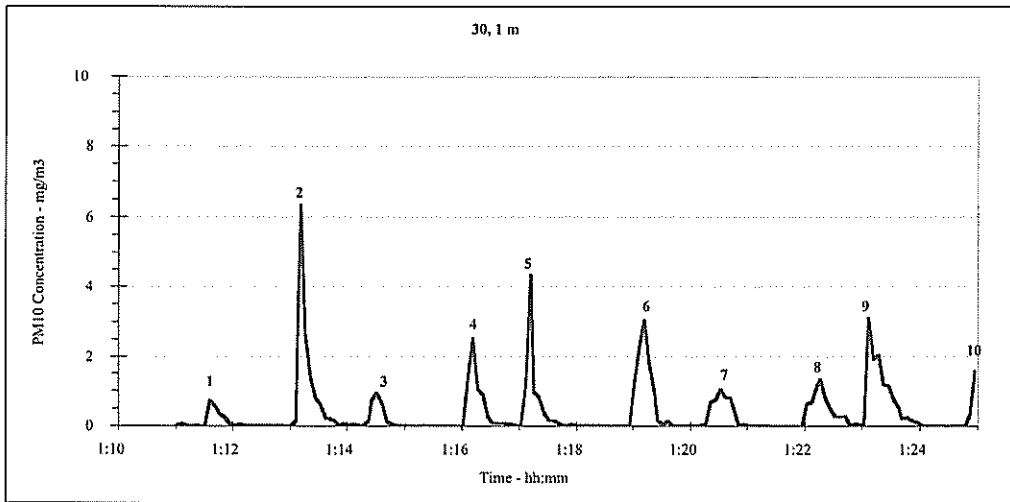
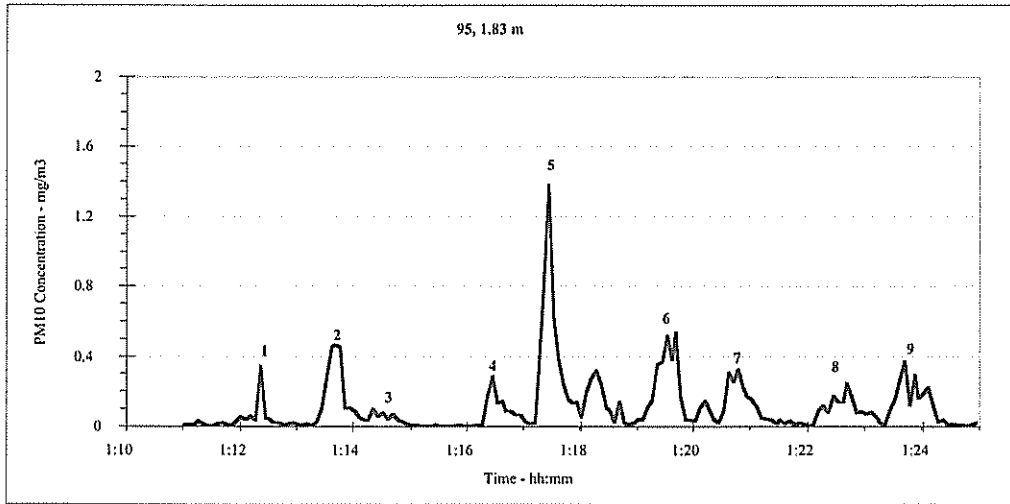


Figure 2. Typical Data for PM₁₀ Concentration vs. Time

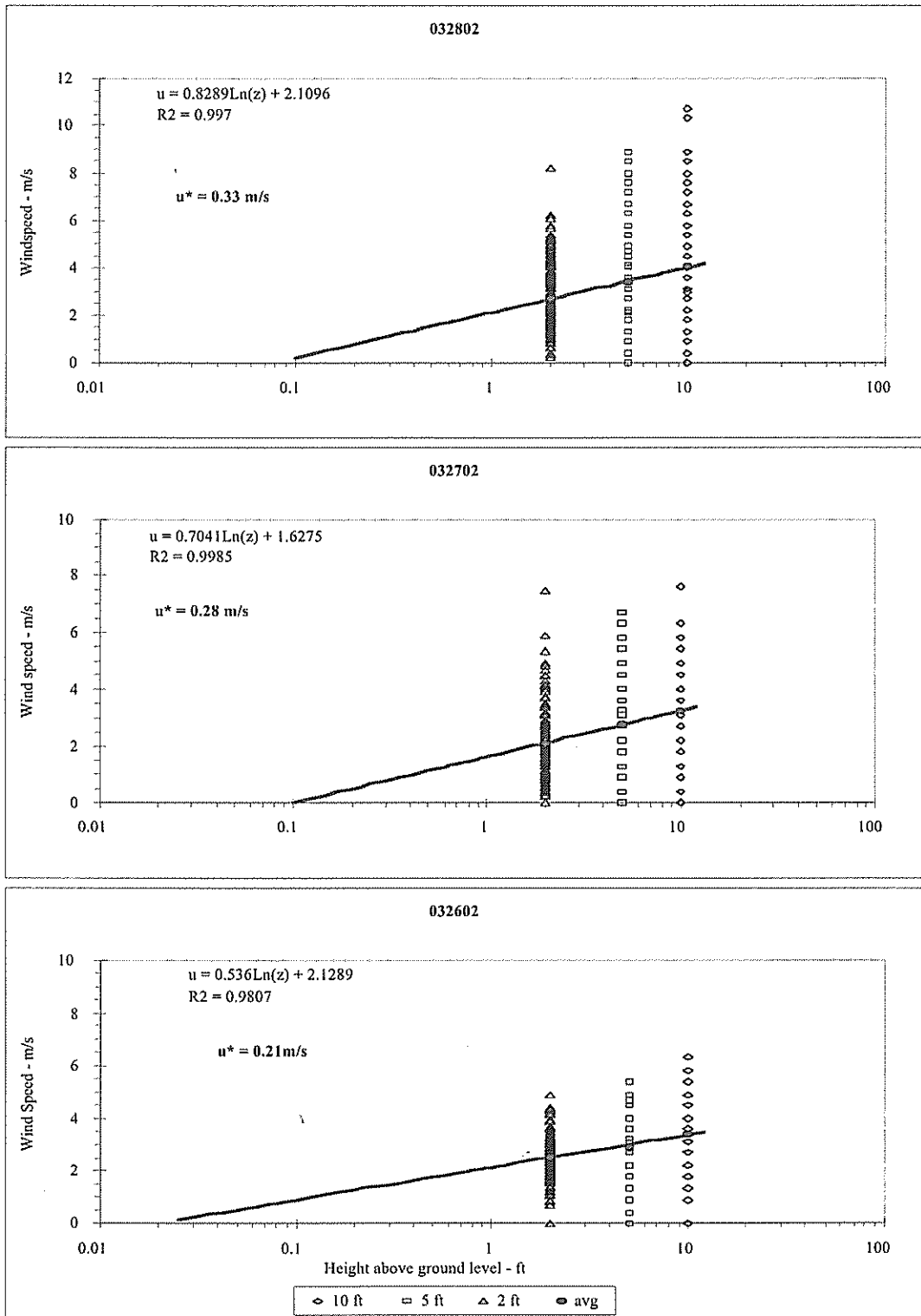


Figure 3. Wind Speed vs. Height at Achenback Canyon Road Test Sites

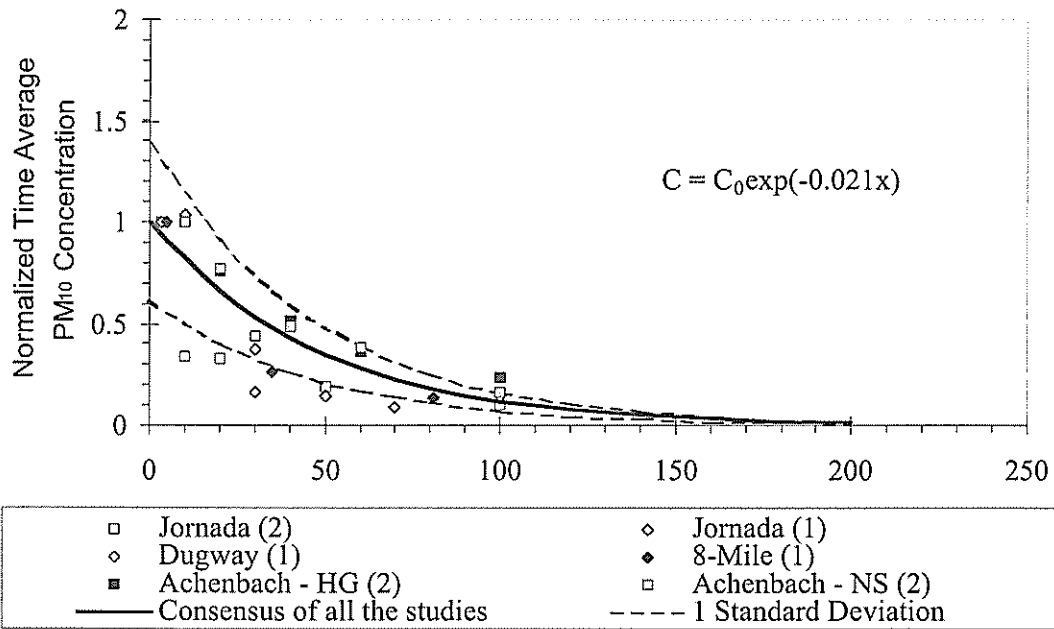


Figure 4. PM₁₀ Horizontal Decay with Distance from the Road

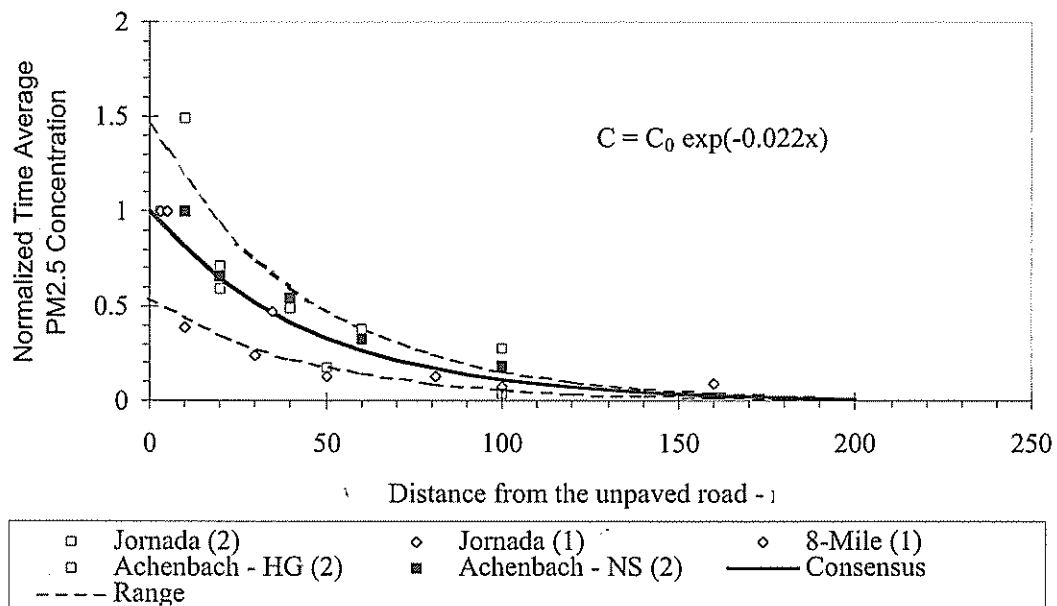


Figure 5. PM_{2.5} Horizontal Decay with Distance from the Road

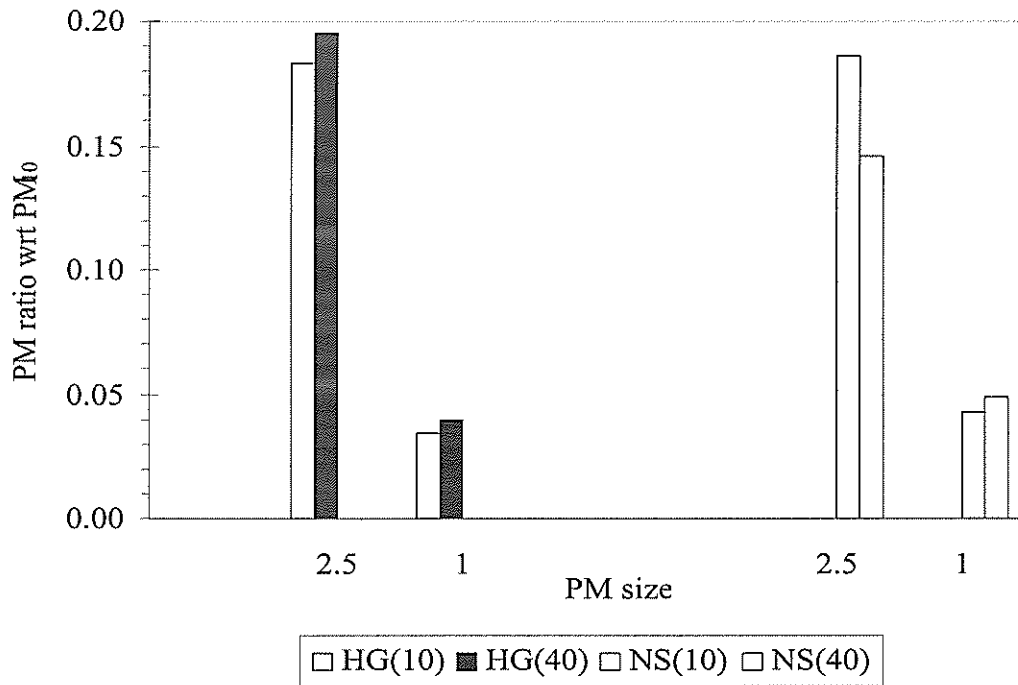


Figure 6. PM size distribution at Achenback Canyon road test sites

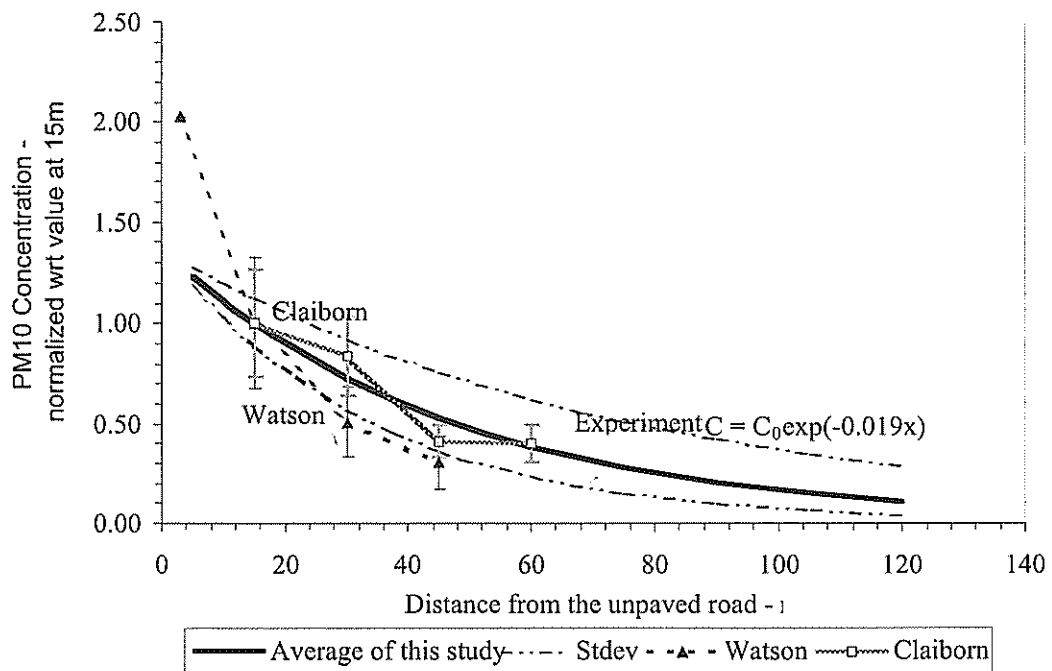


Figure 7. Experimental Results Compared to Two Literature Studies

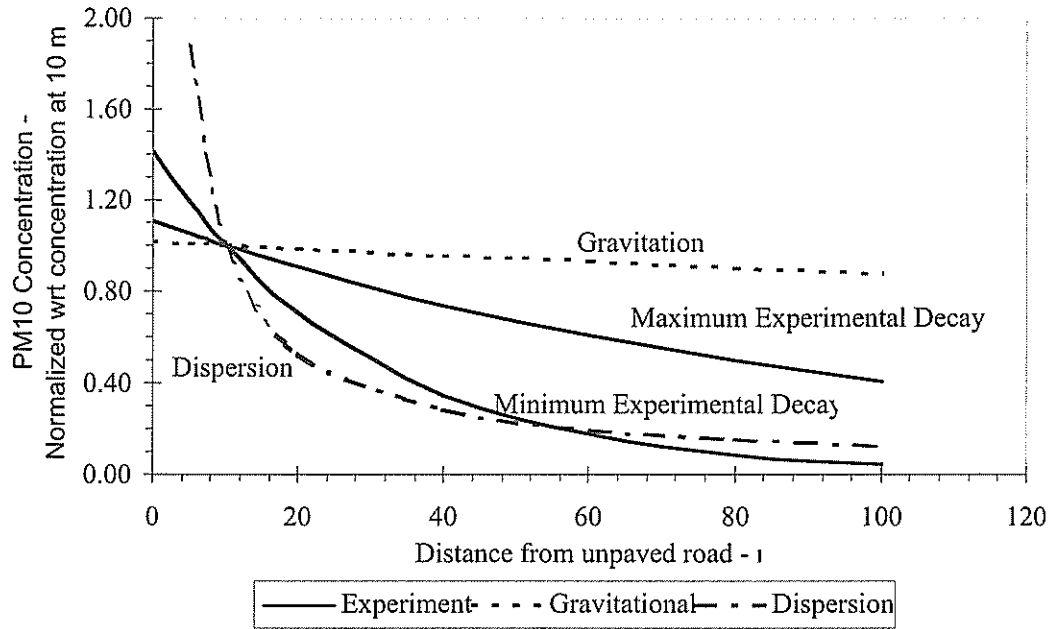


Figure 8. Comparison of PM₁₀ Experimental Results to Decay Mechanisms

Table 1. Field Study Conditions for all the Test Sites

| Experiment Site | Date of Expt. | Soil Type | Silt % | GPS Units | Type of meteorological instrument | Wind speed measured at (m AGL) | Average wind speed (m/s) | Stability class |
|--|---------------|--|--------|-----------------------------|---|--------------------------------|--------------------------|-----------------|
| Jornada road, Las Cruces, NM | 03/13/01 | Rural grazing soil unit ST on USDA map | 23.9 | 13 03 37 12E 35 90 230N | Davis monitor - II weather stations | 2 | 23 | A |
| | 03/19/01 | | | | | | < 2 | AB |
| | 03/21/01 | | | | | | 23 | AB |
| Dugway Proving Ground, UT | 09/26/01 | Mix of native soil and granular imported road fill | 16.6 | 40° 12.6' N 113° 10.6' W | Sonic anemometer | 4, 8, 16, 32 | 23 | E |
| Eight mile road, Tooele County, UT | 10/08/01 | County road on native silty loam soil | 14.8 | 12 3 47 5xxE 44 88 5xxN | None | NA | 23 | B |
| Achenback Canyon road (highway gravel), Las Cruces, NM | 03/26/02 | Highway gravel mixed with native soil | 5.5 | 106 39 457 W 32 17 279 N | Davis monitor - II weather stations + Vane anemometer | 3.05, 1.52, 0.61 | 23 | A |
| | 03/27/02 | | | | | | 23 | A |
| Achenback Canyon road (native soil), Las Cruces, NM | 03/28/02 | Native soil | 7.5 | 106 39 950W 32 17 238 N | Davis monitor - II weather stations + Vane anemometer | 3.05, 1.52, 0.61 | 23 | A |

Table 1. Continued

| Experiment site | Test vehicle | Vehicle speed - mph | Sampling pattern per location | # Of Trips | DustTrak logging time - s | Distance from road - m | | | | | Measured |
|-------------------------------------|-------------------|---------------------|-------------------------------|------------|---------------------------|------------------------|----------------|----------------|----------------|--------------------------------------|--------------------------------------|
| | | | | | | X ₀ (ref) | X ₁ | X ₂ | X ₃ | X ₄ | |
| Jomada road, NM | Westphalia van | 30 | 5 min | 52 | 60 | 3 | 10 | 20 | 50 | 100 | PM ₁₀ |
| | | | 4 car trips | 103 | 15 | 3 | 10 | 30 | 50 | - | PM ₁₀ , PM _{2.5} |
| | | | 4 car trips | 141 | 15 | 3 | 10 | 30 | 50 | 100 | PM ₁₀ |
| Dugway UT | Ford pickup truck | 20 | 30 car trips | 30 | 5 | 3 | 30 | 70 | - | PM ₁₀ | |
| Eight mile road, UT | Ford pickup truck | 30 | 54 car trips | 54 | 5 | 5 | 35 | 81 | 160 | PM ₁₀ , PM _{2.5} | |
| Achenback road (highway gravel), NM | Chevy Impala | 30 | 10 car trips | 91 | 5 | 10 | 20 | 40 | 60 | 100 | PM ₁₀ , PM _{2.5} |
| | | 30 | 10 car trips | 80 | 5 | 10 | 20 | 40 | 60 | 100 | PM ₁₀ , PM _{2.5} |
| Achenback road (native soil), NM | Chevy Impala | 30 | 10 car trips | 129 | 5 | 10 | 20 | 40 | 60 | 100 | PM ₁₀ , PM _{2.5} |

Table 2. K-Value Table

| Site | Height- above ground level - m | k - value | |
|--------------------------|-----------------------------------|------------------|-------------------|
| | | PM ₁₀ | PM _{2.5} |
| Jornada Rd, NM | 1 | 0.022 | 0.024 |
| Jornada Rd, NM | 2 | 0.020 | 0.037 |
| Dugway, UT | 1 | 0.035 | - |
| Eight mile Rd, UT | 1 | 0.010 | 0.015 |
| Achenback Rd - HG, NM | 2 | 0.016 | 0.014 |
| Achenback Rd - NS, NM | 2 | 0.020 | 0.020 |
| | Average | 0.021 | 0.022 |
| | Std. Dev. | 0.008 | 0.010 |
| | Count | 6 | 5 |