EFFECTIVE CONTROL MEASURES AT HIGH PARTICULATE POLLUTION AREAS: Analysis of Data from the 2000 Phoenix Greenwood Study

FINAL REPORT 496

Prepared by:
Till E. Stoeckenius & Sandhya Rao
ENVIRON International Corporation
101 Rowland Way, Suite 220
Novato, CA 94945

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Phoenix, Arizona 85007
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16. Abstract

Annual average PM_{10} concentrations at the Greenwood monitoring station in western Phoenix have exceeded EPA's annual average air quality standard and are higher on average than values observed at the West Phoenix monitor, which is located just 2.2 miles (3.5 km) to the northwest. While the West Phoenix site is in a residential area away from any major thoroughfares, the Greenwood monitor is located just 330 feet (0.10 km) south of I-10 and within a half mile of the heavily traveled I-10/I-17 interchange. Data collected during a field measurement program conducted in the spring of 2000 were analyzed to determine the extent to which the nearby roadways influence PM_{10} levels at Greenwood. Analyses of the field data showed evidence of stronger on-road mobile source impacts at Greenwood than at other nearby sites, including West Phoenix. Dispersion modeling of mobile source emissions showed that on-road sources contribute 3.6 to 4.2 times as much PM_{10} at Greenwood as at three nearby sites (West Phoenix, Autoyard, and the Phoenix Supersite). These results were combined with monitoring data, a recent $PM_{2.5}$ emissions inventory for Phoenix, and results of a receptor modeling study at Supersite to estimate that the average on-road mobile source PM_{10} impact at Greenwood is approximately 30 $\mu g/m^3$,which represents 54% of the total observed PM_{10}. Local traffic sources within roughly a half-mile radius of Greenwood are estimated to account for 66% of the total mobile source impact or approximately 20 $\mu g/m^3$ or 36% of the total observed PM_{10}.

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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
	AREA			
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
	VOLUME			
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.			
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
	ILLUMINATION			
fc	foot candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
	FORCE AND PRESSURE OR STRESS			
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm^2	Square millimeters	0.0016	square inches	in^2
m^2	Square meters	10.764	square feet	ft^2
m^2	Square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
	VOLUME			
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	Cubic meters	35.315	cubic feet	ft^3
m^3	Cubic meters	1.308	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
	TEMPERATURE (exact)			
°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
	FORCE AND PRESSURE OR STRESS			
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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LIST OF ACRONYMS

AADT	annual average daily traffic
ADEQ	Arizona Department of Environmental Quality
AZ DEQ	Arizona Department of Environmental Quality
CO	carbon monoxide
EC	elemental carbon
EPA, U.S. EPA	United States Environmental Protection Agency
MAG	Maricopa Association of Governments
NAAQS	National Ambient Air Quality Standard
(NH4)2SO4	ammonium sulfate
NH4NO3	ammonium nitrate
NO	nitrogen oxide
NO_2	nitrogen dioxide
NO_x:	nitrogen oxides
O_3	ozone
OC	organic carbon
OMC	organic mass determined from total organic carbon
PM	suspended particulate matter (unspecified size range)
PM_{10}	suspended particulate matter with aerodynamic diameter less than 10 μm
$PM_{2.5}$	suspended particulate matter with aerodynamic diameter less than 2.5 μm
ppb	parts per billion
SIP	State Implementation Plan
TEOM	tapered element oscillating microbalance
VMT	vehicle-miles of travel

EXECUTIVE SUMMARY

Ambient concentrations of particulate matter (PM) with aerodynamic diameters less than 10 μm (PM_{10}) have exceeded U.S. EPA's National Ambient Air Quality Standard (NAAQS) in the Phoenix metropolitan area in recent years. Of the three suburban sites in residential areas that have recorded exceedances, the Greenwood monitoring station typically records a significantly higher annual average, despite the fact that it is located just 2.2 miles (3.5 km) from the West Phoenix monitor. While the West Phoenix site is in a residential area away from any major thoroughfares, the Greenwood monitor is located just 330 feet (0.10 km) south of I-10 and within a half mile of the heavily traveled I-10/I-17 interchange.

In the 1999 State Implementation Plan (SIP) for PM_{10}, the Maricopa Association of Governments (MAG) noted that eliminating exceedances at the Greenwood monitor will be critical to achieving attainment of the annual average NAAQS. This raised questions regarding the impact at Greenwood of PM_{10} emissions from traffic on the heavily traveled freeways and arterials located in the immediate vicinity of this site relative to those at the West Phoenix site.

With funding from the Arizona Department of Transportation's Arizona Transportation Research Center, the Arizona Department of Environmental Quality (ADEQ) conducted an intensive air monitoring study in the Greenwood area during the spring of 2000. Hourly and integrated 6- and 24-hour PM samples were collected at Greenwood, West Phoenix, and at a new site located at 33rd Avenue and Washington Street (Autoyard). Fine and coarse PM fractions from the integrated filter samples were analyzed for carbon, ions, and metals.

Our study analyzed data from the Greenwood field study with the specific intent of estimating the PM_{10} impact at Greenwood from nearby traffic sources and comparing these impacts with those observed at other monitoring sites in the area.

Our results show that high concentrations of PM_{10} at the Greenwood monitoring site in Phoenix are attributable in large part to the site's location close to two major interstate highways. Comparisons of hourly PM_{10} at Greenwood with Supersite and Autoyard are consistent with the hypothesis that Supersite PM_{10} represents an urban background level to which additional mass is added from local sources in the vicinity of Greenwood and Autoyard. The amplitude of the morning PM_{10} peak at Greenwood is much larger than at Supersite, indicating a stronger influence of mobile sources at Greenwood. Hourly PM_{10} concentrations at Autoyard above about 75 $\mu g/m^3$ are generally associated with lower values at Greenwood, indicating a stronger impact from local sources at Autoyard (industrial activity or travel on unpaved surfaces and associated trackout of material onto paved roads). Correlations of hourly PM_{10} with carbon monoxide (CO) at Greenwood and Autoyard also suggest that sources other than on-road mobile are impacting Autoyard (or on-road mobile emission factors in the vicinity of these sites are higher than in the

vicinity of Greenwood, possibly due to higher heavy-duty truck activity or higher roadway silt loading due, for example, to trackout from dirt lots).

Analysis of speciated PM samples collected at Greenwood and Autoyard showed very similar compositions at these two sites with nearly two-thirds of PM_{10} attributed to inorganic primary particulate and about one fourth to organic matter (data from West Phoenix were invalidated due to discrepancies between measured and reconstructed fine mass). Analysis of six-hour samples showed that elemental carbon fractions are larger in the 12:00 a.m. to 6:00 a.m. and 6:00 a.m. to 12:00 p.m. samples that at other times of the day, consistent with greater combustion source activity, most likely from motor vehicles.

A series of dispersion modeling analyses were conducted to estimate the impact of on-road mobile source emissions on PM_{10} levels at Greenwood in relation to impacts at Supersite, West Phoenix and Autoyard. Since mobile source road dust emission factors are highly variable and difficult to estimate accurately and the collection and analysis of spatially and temporally disaggregated data on vehicle fleet mix and average speeds was outside the scope of this study, modeling was performed on a relative basis assuming mobile source PM_{10} emissions are directly proportional to vehicle miles traveled (VMT). Traffic count data were used to derive VMT estimates by roadway segment, hour of day and day of week. Results from the dispersion model showed that on-road mobile source impacts are estimated to be 3.6 to 4.2 times greater at Greenwood than at Autoyard, West Phoenix, or Supersite. This reflects the fact that the Greenwood monitor is located very close to two heavily traveled major interstate highways that are frequently upwind of the site, whereas the other three monitoring sites are further removed from the direct influence of vehicle traffic on paved roads.

Results of the dispersion modeling analysis were combined with ambient PM_{10} and $PM_{2.5}$ monitoring data, results of an earlier receptor modeling study, and the Maricopa County $PM_{2.5}$ emissions inventory, to derive an estimated annual average PM_{10} contribution from on-road mobile sources at Greenwood of 29.7 $\mu g/m^3$, which represents 54% of total observed PM_{10}. This compares with an estimated contribution of 8.2 $\mu g/m^3$ or 24% of total PM_{10} at Supersite.

The mobile source impact estimates described above are for all on-road mobile sources in the study region. Additional dispersion modeling was conducted to estimate the impact of just those road segments in the immediate vicinity (i.e., within about a half-mile radius) of the Greenwood monitor. Results show that travel on the local road segments around Greenwood contribute 66% of the total from all on-road sources on an annual average basis. This represents an impact from local sources of 19.6 $\mu g/m^3$ or 36% of the total annual average PM_{10}.

Estimates of PM impacts from mobile sources developed in this study are subject to considerable uncertainty as they are based on a series of simplifying assumptions as well as emissions estimates and receptor modeling results that are themselves subject to uncertainty. Of particular note is the assumption that the entire difference in average PM_{10} between Greenwood and Supersite is attributable to the greater impact of on-road

sources at Greenwood. To the extent that this assumption does not hold (or that the grams per VMT emission factor at Greenwood is higher than at Supersite), the estimated fraction of PM_{10} attributable to mobile sources at Greenwood will be biased high. Another source of uncertainty worth noting is that estimates of the dispersion of on-road emissions at receptors close to a major highway are sensitive to the manner in which the roadway line source is parameterized in the dispersion model. Sensitivity analyses with alternative source parameterizations could be performed to further investigate the magnitude of this effect.

Given the significant impact of on-road mobile source emissions on PM_{10} levels at the Greenwood monitoring site, future progress in reaching attainment of the NAAQS for PM_{10} will depend on reducing emissions from this source sector. Examination of the potential impact of any particular mobile source control measures in reducing PM_{10} at Greenwood (or elsewhere) in the future was beyond the scope of this study. However, given the sensitivity of PM_{10} levels at Greenwood to emissions from local traffic sources (as compared to urban-wide traffic), it may be desirable to consider control measures specifically designed to reduce local emissions. Such measures might include improved mass transit along the major travel corridors near Greenwood, or more frequent and efficient street sweeping in the immediate area to reduce roadway silt loadings.

1. INTRODUCTION

Ambient concentrations of particulate matter (PM) with aerodynamic diameters less than 10 μm (PM_{10}) have exceeded U.S. EPA's National Ambient Air Quality Standard (NAAQS) in the Phoenix metropolitan area in recent years. Six sites have exceeded the annual NAAQS in the 10-year period ending in 2003 (Table 1).

Table 1. Phoenix area monitoring sites exceeding the annual average PM_{10} standard.

Site ID	City	Address	Land Use	Location Type
40139812	Phoenix	2702 Ac Ester Brook Blvd	Commercial	Urban – City Center
40134006	Gilbert	15400 South Higley Road	Industrial	Suburban
40134003	Phoenix	33 W Tamarisk Ave	Residential	Urban – City Center
40130021	Chandler	1475 E Pecos Rd-Chandler Station	Residential	Suburban
40133010	Phoenix	1128 N. 27th Ave-Greenwood Station	Residential	Suburban
40130019	Phoenix	3847 W Earl Dr-West Phoenix Station	Residential	Suburban

Of the three suburban sites in residential areas (shaded rows in Table 1), the Greenwood monitoring station (ID=40133010) frequently records the highest annual average, despite the fact that it is located just 2.2 miles (3.5 km) from the West Phoenix monitor (ID=40130019). While the West Phoenix site is in a residential area away from any major thoroughfares, the Greenwood monitor is located just 330 feet (0.10 km) south of I-10 and within a half mile of the heavily traveled I-10/I-17 interchange (see Figure 1). PM_{10} levels at Greenwood tend to be slightly higher on average than those at West Phoenix.

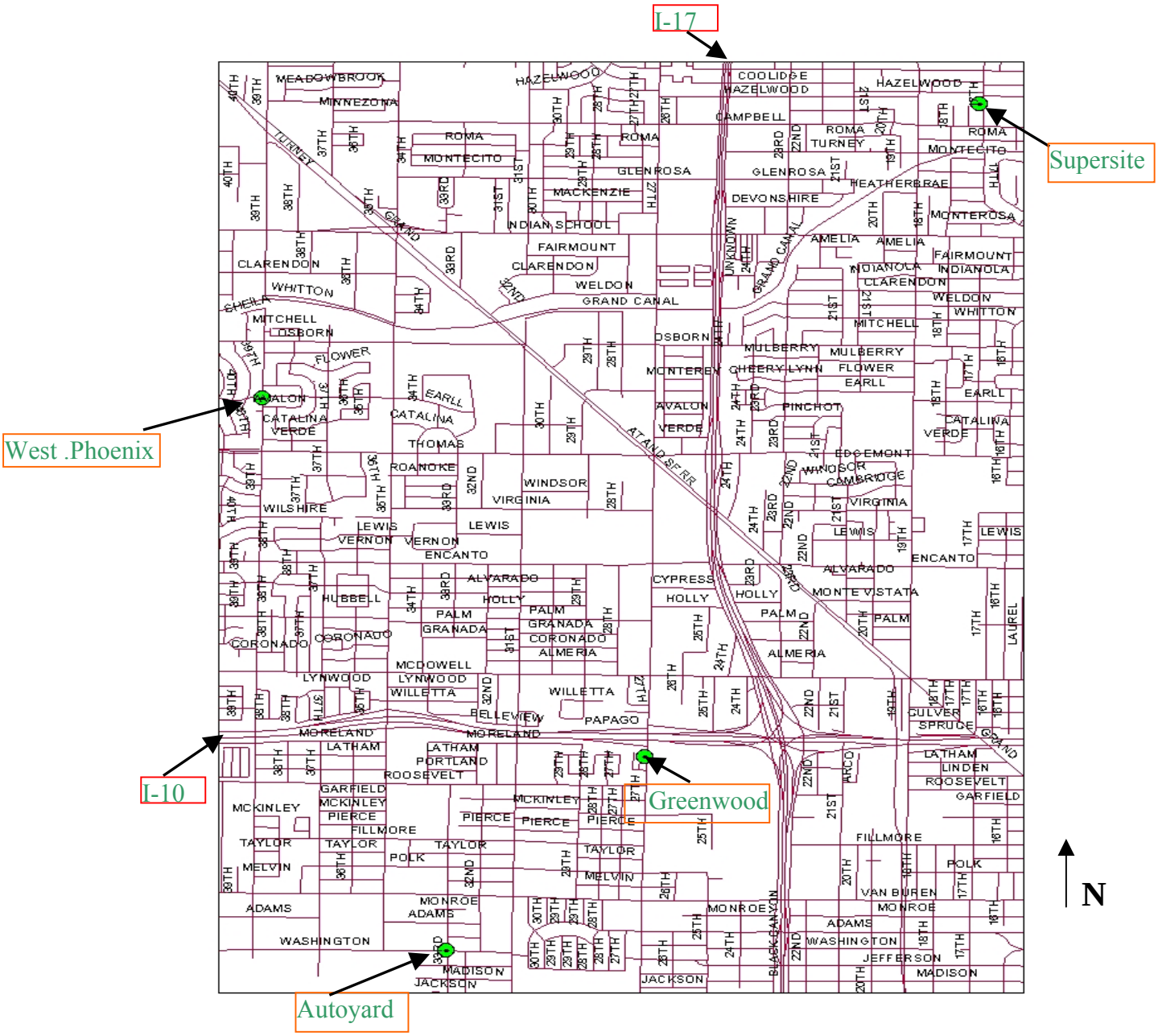

Figure 1. West Phoenix area PM_{10} monitoring sites and road network.

In the 1999 State Implementation Plan (SIP) for PM_{10}, the Maricopa Association of Governments (MAG) noted that eliminating exceedances at the Greenwood monitor will be critical to achieving attainment of the annual average NAAQS. This raised questions regarding the impact at Greenwood of PM_{10} emissions from traffic on the heavily traveled freeways and arterials located in the immediate vicinity of this site relative to those at the West Phoenix site. These questions could not be fully addressed by the

Eulerian grid modeling performed for the 1999 SIP, because of the relatively coarse (one mile) resolution at which that modeling was conducted. At this resolution, emissions from I-10 and 27th Avenue would be smeared out over a 1 mi^2 area in the model, resulting in underestimation of the relative impact of on-road mobile sources at the Greenwood site.

With funding from the Arizona Department of Transportation (ADOT) Arizona Transportation Research Center, the Arizona Department of Environmental Quality (ADEQ) conducted an intensive air monitoring study in the Greenwood area during the spring of 2000. Hourly and integrated 6- and 24-hour PM samples were collected at Greenwood, West Phoenix, and at a new site located at 33rd Avenue and Washington Street. (Autoyard). Fine and coarse PM fractions from the integrated filter samples were analyzed for carbon, ions, and metals. The available data are described in more detail in Section 2. ADEQ subsequently contracted with ENVIRON to analyze the field study data with the specific intent of estimating the PM_{10} impact at Greenwood from nearby traffic sources and comparing these impacts with those observed at the other monitoring sites.

2. DATA

ADEQ conducted a special field study in the Greenwood area during the spring of 2000, which included air quality, and meteorological monitoring as described below. Some limited data to support development of an emissions inventory was also collected in connection with this effort. These included aerial photographs, traffic count data, and point source emissions data compiled by MAG.

Aerometric data from the spring 2000 Greenwood field study include hourly PM_{10} mass measurements from tapered element oscillating microbalance (TOEM) instruments located at the Greenwood, West Phoenix, and Autoyard monitoring sites; TEOM data was also collected during this period at the Supersite monitor located at 4530 N. 17th Avenue (see Figure 1). Twenty-four-hour and six-hour dichotomous ($PM_{2.5}$ and PM_{10}) filter samples were collected at Greenwood, West Phoenix and Autoyard on alternating one in six-day schedules: a 24-hour integrated sample was collected on day 1, 6, 12, etc., and four six-hour samples were collected on days 3, 9, 15, etc. These samples were collected on both Teflon filters (for total mass and elemental analysis) and quartz filters (for analysis of ions and carbon). Routine hourly air quality and surface meteorological measurements were also available to varying extents during most of the study period at sites other than Autoyard. Air quality was measured for carbon monoxide (CO), nitrous oxide (NO), nitrous dioxide (NO_2), oxides of nitrogen (NO_X), and ozone (O_3).

A summary of the data collected for the Greenwood field study is presented below. Unfortunately, some of these data were only available to the authors when our analysis was already nearly completed, limiting the extent to which we were able to analyze them:

Hourly TEOM PM_{10} data
Greenwood: most days 3/1/00 – 5/30/00 plus selected periods in earlier years
Autoyard: 3/17/00 – 4/17/00
West Phoenix: 4/13/00 – 4/17/00
Supersite: 3/1/00 – 4/30/00

Six-day, six-hour dichotomous speciated (Teflon filter)
Greenwood: 3/22/00 – 5/21/00
Autoyard: 3/22/00 – 5/21/00
West Phoenix: 3/22/00 – 5/21/00

Six-day, six-hour dichotomous speciated (quartz filter)
Greenwood: 3/22/00 – 5/21/00
Autoyard: 3/22/00 – 5/21/00
West Phoenix: 3/22/00 – 5/21/00

Six-day 24-hour dichotomous mass
Greenwood: 1/4/97 – 12/27/01

Six-day 24-hour dichotomous speciated (Teflon filter)
Greenwood: 3/19/00 – 5/18/00
Autoyard: 3/19/00 – 5/18/00
West Phoenix: 3/19/00 – 5/18/00

Six-day 24-hour dichotomous speciated (quartz filter)
Greenwood: none
Autoyard: 3/19/00 – 5/18/00
W.Phoenix: 3/19/00 – 5/18/00

Hourly Meteorological and Selected Air Quality Data
Greenwood: 3/1/00 – 5/31/00; CO, NO, NO2, NOx, Wind Direction., Wind Speed, Temperature.
Autoyard: none
West Phoenix: 3/1/00 – 5/31/00: CO, NO, NO2, NOx, O3, Wind Direction., Wind Speed, Temperature.
Supersite: 2/1/00 - 5/31/00: CO, NO, NO2, NOx, O3, Relative. Humidity., Standard. Deviation of Wind Direction., Wind Direction., Wind Speed, Temperature.

All data were received from ADEQ in the form of a very large number of spreadsheets and text files, which were largely undocumented. Considerable effort was expended in identifying data sources, merging the data files, and placing data in a consistent format for further processing. Duplicate data were identified and removed and discrepancies between overlapping files were resolved with assistance from ADEQ staff. Although no formal data validation efforts were undertaken as part of our analysis, in some cases questions arose regarding the validity of specific portions of the database. We attempted to resolve these questions through discussions with ADEQ wherever possible. Of particular note in this regard was the determination by ADEQ that only four days of valid TEOM data are available for West Phoenix (from midday on April 13, 2000 to midday on April 17, 2000). In addition, our calculations of reconstructed fine ($PM_{2.5}$) mass based on standard procedures[1] using the speciated data collected at West Phoenix did not agree well with the reported total $PM_{2.5}$ mass from the Teflon filter at this site: the reconstructed fine mass exceeded the total mass by 24% on average for the 24-hour integrated samples (excluding the large discrepancy from filter number tWP0003, which was reported as "scratched"). The reconstructed fine mass excluding the estimated soil component exceeded the Teflon filter total $PM_{2.5}$ mass at West Phoenix for all 24-hour samples except one. This problem was not encountered with the Autoyard or Greenwood data and led us, after consultation with ADEQ, to treat the West Phoenix speciation as invalid.

3. ANALYSIS

Data from the 2000 Greenwood PM field study were analyzed to obtain information on the contribution of on-road mobile source PM emissions to PM_{10} levels at the Greenwood monitoring site and to contrast mobile source impacts at Greenwood with mobile source impacts at nearby monitoring sites. Exploratory analyses of the data were conducted to look for evidence of enhanced on-road mobile source influence at Greenwood and to contrast PM air quality at Greenwood with conditions at the nearby West Phoenix and Autoyard sites. This was followed by a dispersion modeling study designed to provide a quantitative estimate of PM_{10} mass contributed by on-road mobile sources at each monitoring site.

QUALITATIVE EVALUATION OF MOBILE SOURCE IMPACTS AT GREENWOOD

Several different data analysis approaches (inter-site correlations of hourly PM_{10} concentrations, examination of diurnal PM_{10} patterns, correlations of PM_{10} with CO and wind direction, and analysis of speciated PM data) were used to address the question regarding the contribution of mobile source impacts to PM_{10} at Greenwood relative to West Phoenix, Autoyard, and the Supersite (see site locations in Figure 1).

Site-to-Site Correlations

Temporal correlations in PM_{10} levels from site to site provide an indication of the extent to which sites are influenced by common sources of emissions. Hourly PM_{10} from the TEOMs were used to examine temporal relationships between the Greenwood, Autoyard and Supersite monitoring sites (insufficient data were available from West Phoenix for inclusion in this analysis). Figure 2 illustrates the relationship between PM_{10} at Greenwood and Supersite. Because the data from both sites exhibit isolated extreme values, hours in which concentrations at one or both sites exceeded 140 $\mu g/m^3$ have been removed from this figure. (Only 3.1% of hours with valid data were excluded as a result of this screening.) Although the data exhibit some variability, there appears to be a fairly close relationship between PM levels at these two sites with concentrations at Greenwood nearly always being greater than those at Supersite. This is consistent with the hypothesis that values at Supersite typically represent an urban background level to which local sources in the vicinity of Greenwood add additional PM.

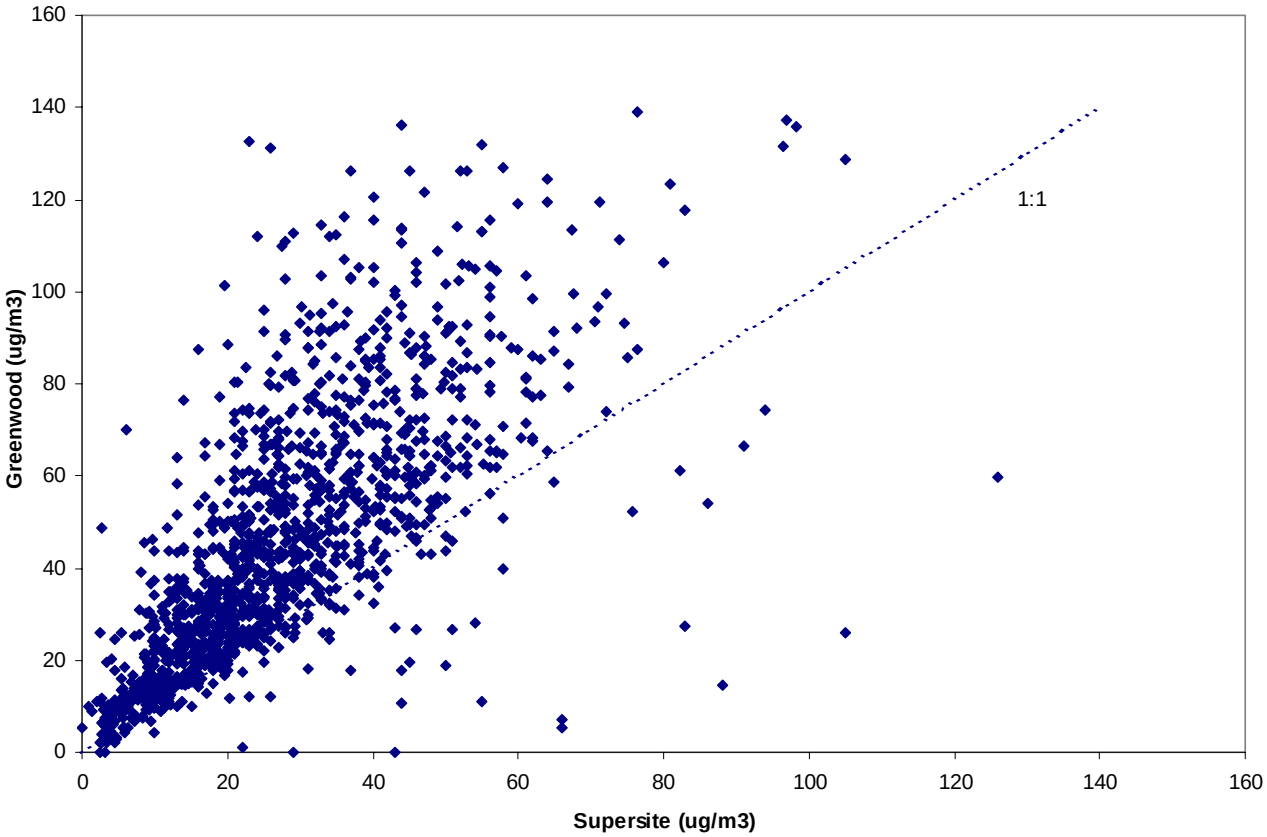

Figure 2. Hourly PM_{10} mass from TEOM measurements at Greenwood and Supersite monitoring stations (March 2000 – April 2000), values greater than 150 $\mu g/m^3$ (5% of all hours) not shown.

Setting aside for the sake of argument hours during which the concentration at Supersite exceeds that at Greenwood, a linear regression of the remaining data shows a slope of 1.40 ± 0.03 and an intercept of 9.54 ± 1.01 with an R-square of 0.61 (where the uncertainty intervals represent one standard error). Taken at face value, this result suggests a local source contribution to Greenwood averaging 9.54 $\mu g/m^3$. This conclusion must be treated with considerable caution, however, as: 1) it is based on censored data (hours greater than 140 $\mu g/m^3$ at either site and hours with Supersite greater than Greenwood removed) and; 2) analysis of the regression residuals reveals some heteroscedasticity (the residuals grow increasingly negative as the concentration at Supersite increases), thus casting some doubt on the accuracy of the intercept term. Nevertheless, this estimate of local source contribution at Greenwood serves as a useful reference for the discussion on dispersion modeling results presented at the end of this section.

Correlation of hourly PM_{10} at Greenwood with values at Autoyard (Figure 3) shows values at Autoyard above approximately 75 $\mu g/m^3$ are generally associated with lower values at Greenwood, indicating source impacts at Autoyard which are not equaled at

Greenwood. These sources are not likely to be from vehicle travel on paved roads since Autoyard is further away from major roadways than Greenwood and may instead represent local industrial activities or travel on unpaved surfaces near Autoyard. Under the right wind conditions, it is also possible that these sources are contributing to the excess PM_{10} at Greenwood relative to Supersite at these relatively high hourly concentrations.

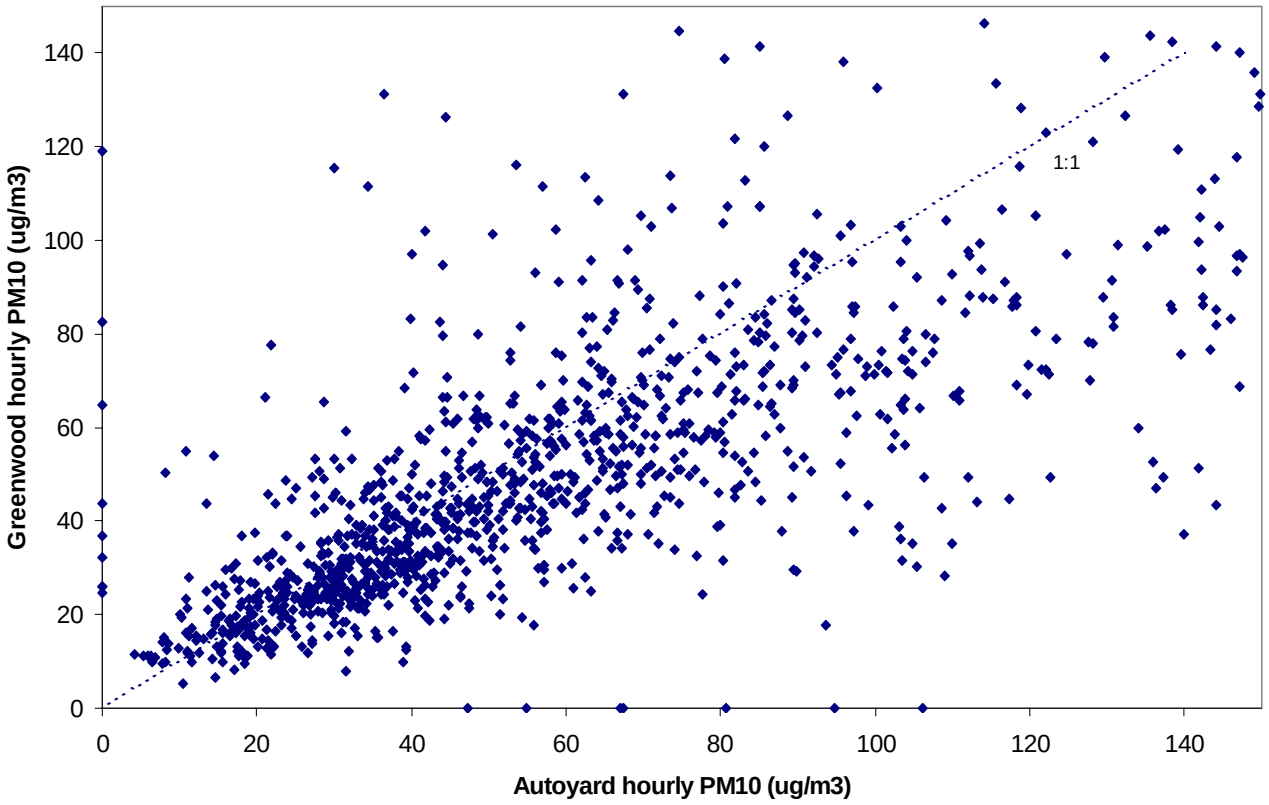

Figure 3. Hourly PM_{10} mass from TEOM measurements at Greenwood and Autoyard monitoring stations (March 16 2000 –May 22, 2000); values greater than 150 µg/m^3 (5% of all hours) not shown.

Diurnal Patterns

TEOM data collected at Greenwood were used to examine average PM_{10} concentrations by hour of day as shown in Figure 4. Also shown are the hourly average CO data. Average PM_{10} at this site increases significantly above overnight values during the 6 a.m. to 8 a.m. morning commute period. Concentrations drop during the middle of the day, primarily as a result of increased dispersion, before rising sharply again in the evening as mixing heights decrease and traffic volumes increase. CO concentrations follow a similar pattern, but the morning CO peak is an hour earlier than the morning PM_{10} peak.

These profiles can be compared with the weekday diurnal vehicle count profile for urban freeways provided by MAG (Figure 5). There appears to be a one-hour difference between the morning traffic peak and the morning PM_{10} peak (PM_{10} is one hour earlier) and the morning CO peak (the CO peak is two hours earlier than the traffic peak). This could be a result of increased dispersion limiting the impact of the peak traffic hour or it could be the result of a difference in the time stamp convention between these data sets. The broader, less well defined afternoon traffic peak does not appear to be associated with an increase in PM_{10} at Greenwood. It is possible that the increased traffic impact is offset by continued enhanced dispersion in the afternoon possibly in combination with a diurnal shift in the prevailing wind direction. It is also interesting to note that overnight PM_{10} levels are nearly constant, whereas traffic drops off considerably. This may reflect the impact of secondary PM from more distant sources.

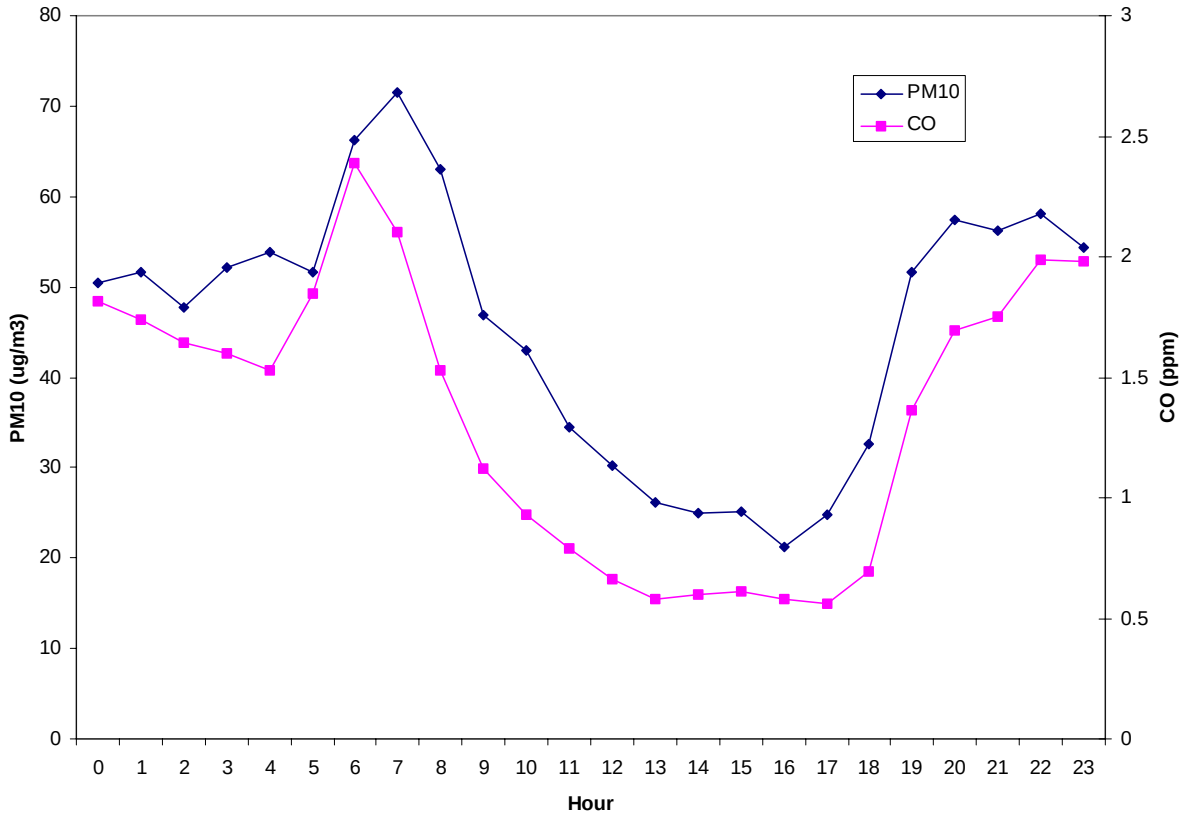

Figure 4. Mean diurnal profiles of PM_{10} and CO concentrations at Greenwood under low wind conditions (less than 6 mph).

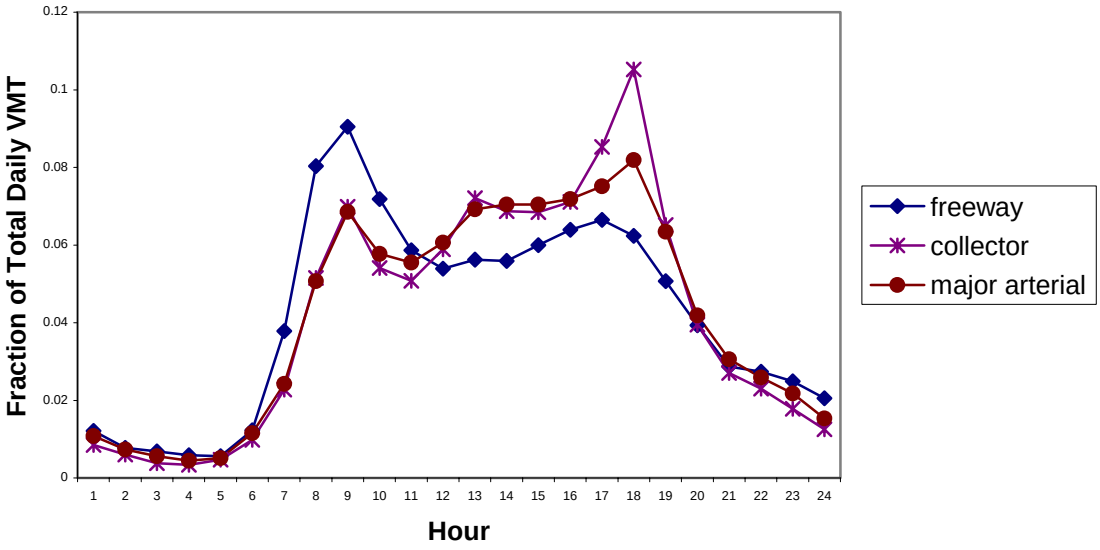

Figure 5. Average weekday diurnal traffic pattern in the Phoenix central business district (source: Maricopa Association of Governments).

Diurnal PM_{10} profiles in the form of hourly median values (the median is used here instead of the mean to reduce the influence of outliers) for Greenwood and Supersite are compared in Figure 6. The morning PM_{10} peak occurs at the same time at both sites but concentrations start to increase at 4 a.m. or 5 a.m. local standard time at Greenwood, and the morning peak represents a much greater increase above the overnight concentration levels than at Supersite where concentrations do not start to increase until about two hours later and the size of the peak is much smaller. This pattern suggests a greater influence of on-road vehicle emissions at Greenwood.

One possible explanation for the earlier start of the morning peak at Greenwood is an early morning increase in local heavy-duty vehicle activity, but data to support this hypothesis were not available. Median concentrations are nearly equal at both sites by late afternoon, consistent with the presence of a well mixed atmosphere over the urban center at that time of day. After the evening concentration peak, there is less of a decline overnight at Greenwood than at Supersite. This is consistent with higher overnight motor vehicle traffic on and near the I-10 and I-17 junction near Greenwood than on the roads near Supersite but local traffic counts by time of day were not available to confirm this. A diurnal shift in prevailing winds (with overnight drainage flow to the southwest) may also be a contributing factor.

Correlation of CO with PM

CO emissions in urban areas are generally dominated by on-road mobile sources making CO a good indicator of mobile source emissions. Hourly CO and PM_{10} (TEOM) data were collected at Greenwood, Autoyard, and Supersite during the spring 2000 field study. Figure 7 shows the correlation of hourly CO with PM_{10} at Greenwood and Autoyard. High wind events (defined as hours with average wind speeds greater than 8 mph) were removed in these plots to avoid periods with high wind-blown dust. PM_{10} is correlated with CO at both sites consistent with a common source (i.e., on-road vehicle travel) but there is considerable scatter and no obvious upper or lower bound on the CO/PM_{10} ratio. The correlation is slightly stronger at Greenwood, consistent with a greater impact from the nearby freeways. A background CO of about 300 ppb is evident at Greenwood but not at Autoyard, suggesting a possible problem with the Autoyard CO readings.

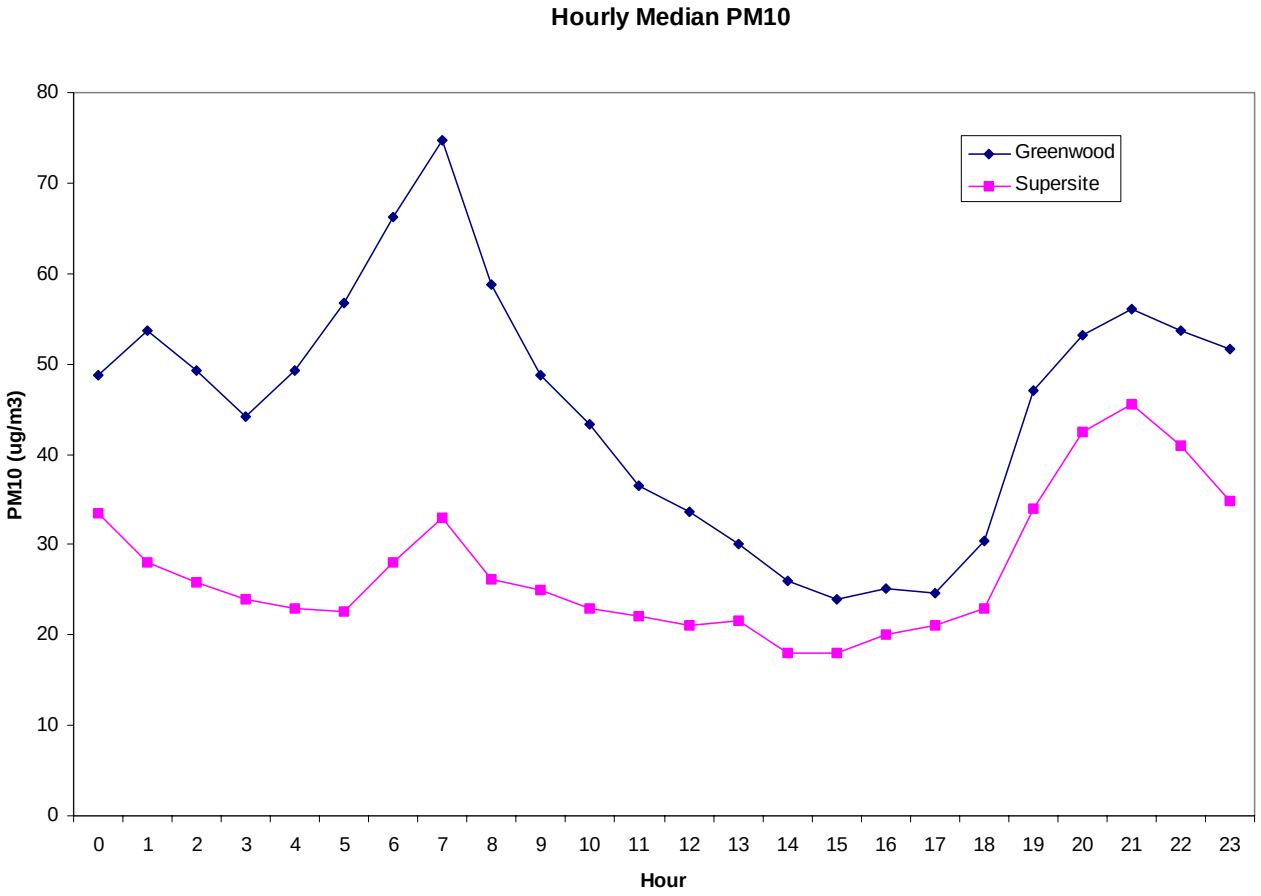

Figure 6. Hourly median PM10 concentrations at Greenwood and Supersite.

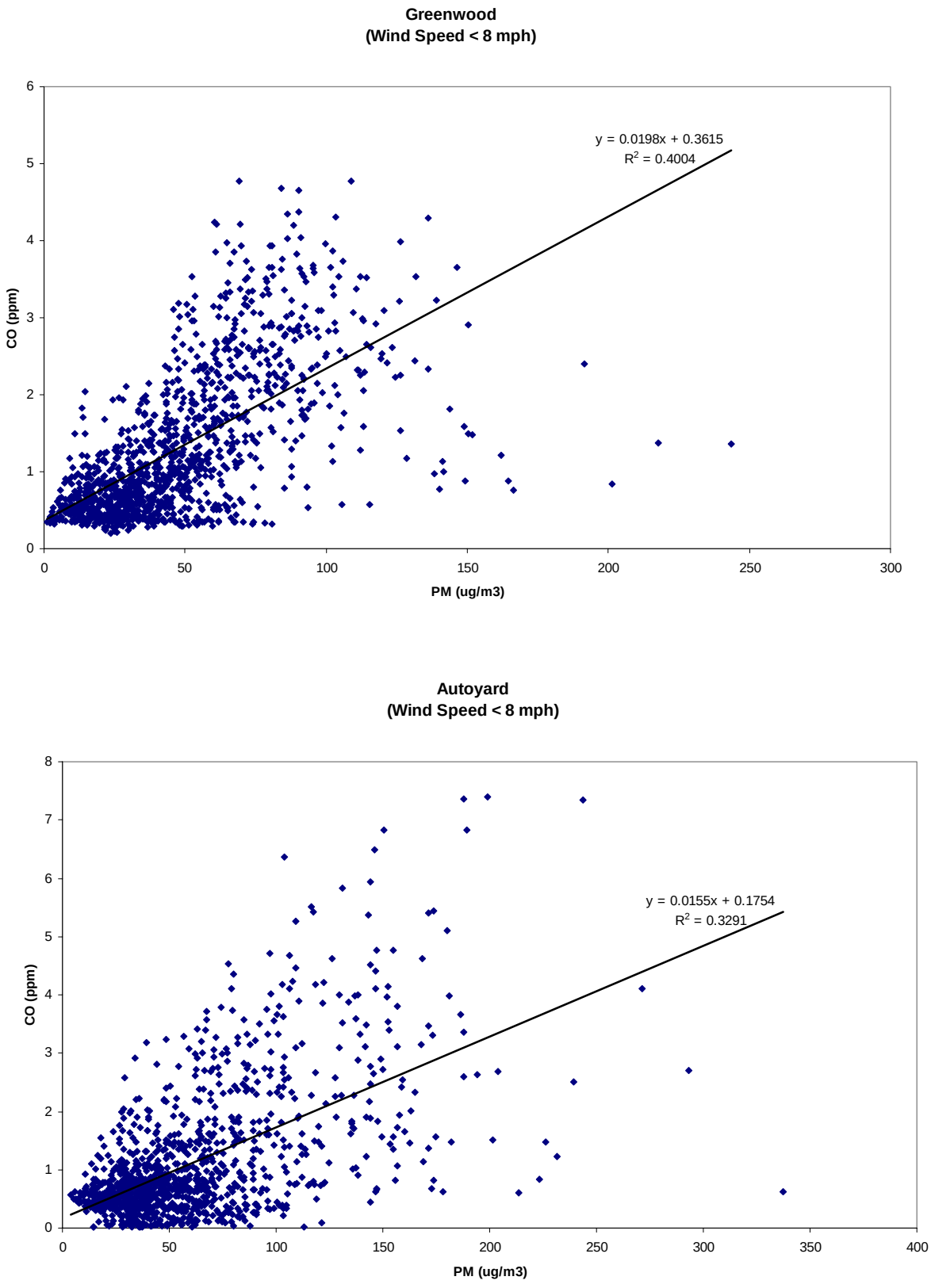

Figure 7. Scatter plots of hourly CO Vs. PM_{10} concentrations at Greenwood (top) and Autoyard (bottom); hours with average wind speed > 8 mph excluded.

Correlations with Wind Direction

Hourly wind speed and direction data were correlated with hourly PM_{10} and CO to gain further insight into the likely relative contribution of on-road mobile sources to PM_{10} at each monitoring site. Plots of hourly PM_{10} vs. wind speed (not shown) show a U-shaped pattern with a minimum at about 6 mph. Concentrations increase below this speed due to stagnation; concentrations increase at greater speeds due to increased generation of wind-blown dust. To better see the relationship between PM_{10} and wind direction from sources other than wind-blown dust, observations with wind speeds above 6 mph were removed and the distributions of PM_{10} and CO calculated by wind direction in each 45 degree compass sector. Results for Greenwood are shown in Figure 8 and for Autoyard in Figure 9. CO concentrations, and to a lesser extent PM_{10} concentrations, are generally higher under north and northeast winds with smaller concentrations under southwest and west winds. This is consistent with enhanced impacts from I-10 freeway and the I-10/I-17 freeway interchange, although the influence of other sources located to the northeast cannot be ruled out. Correlations of meteorological conditions such as wind speeds and mixing heights with wind directions may also be contributing to these differences in PM_{10} with wind direction.

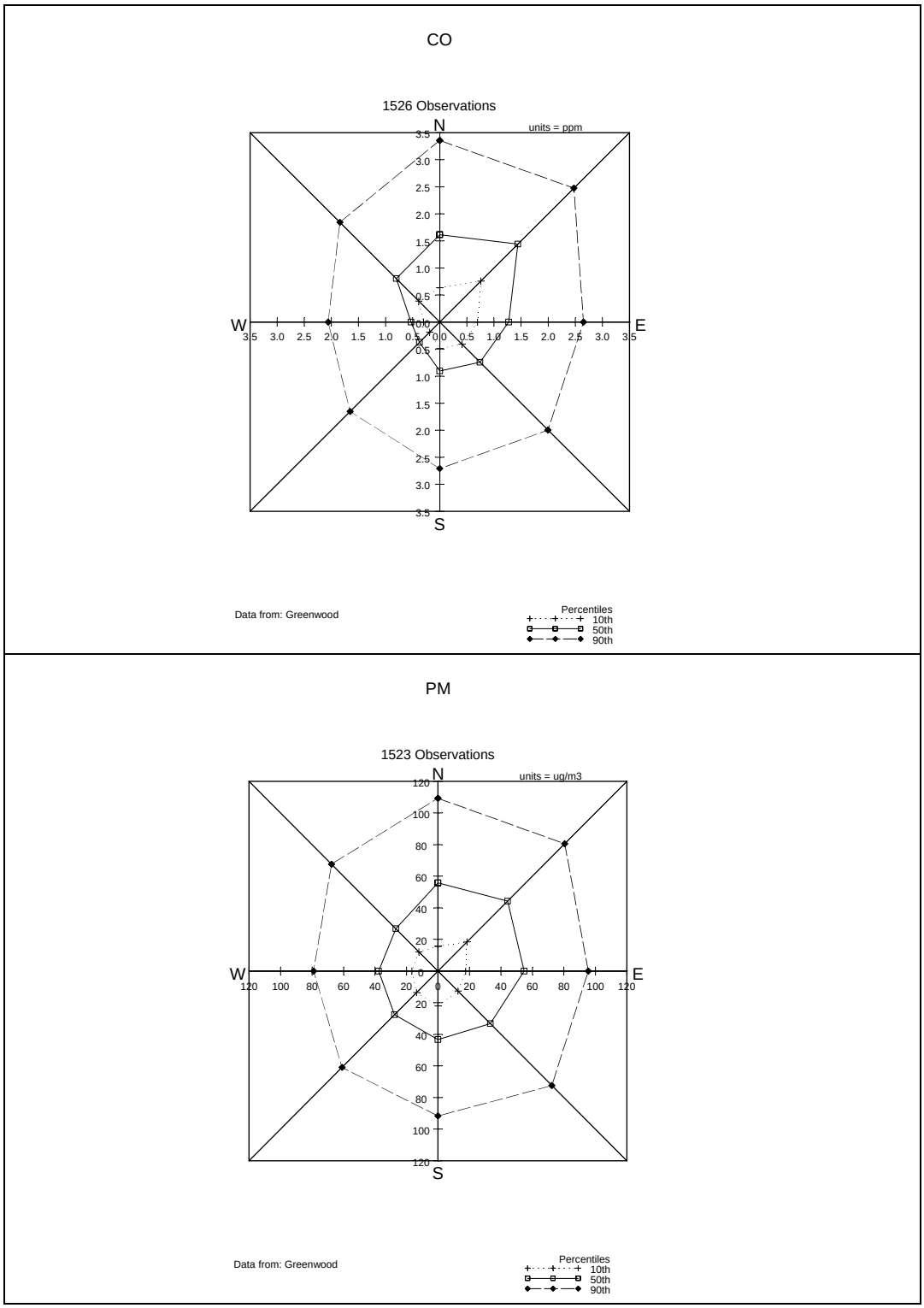

Figure 8. Conditional distributions of hourly CO (top) and PM_{10} (bottom) concentrations in each 45 degree wind direction sector at Greenwood (hours with wind speed < 6 mph only).

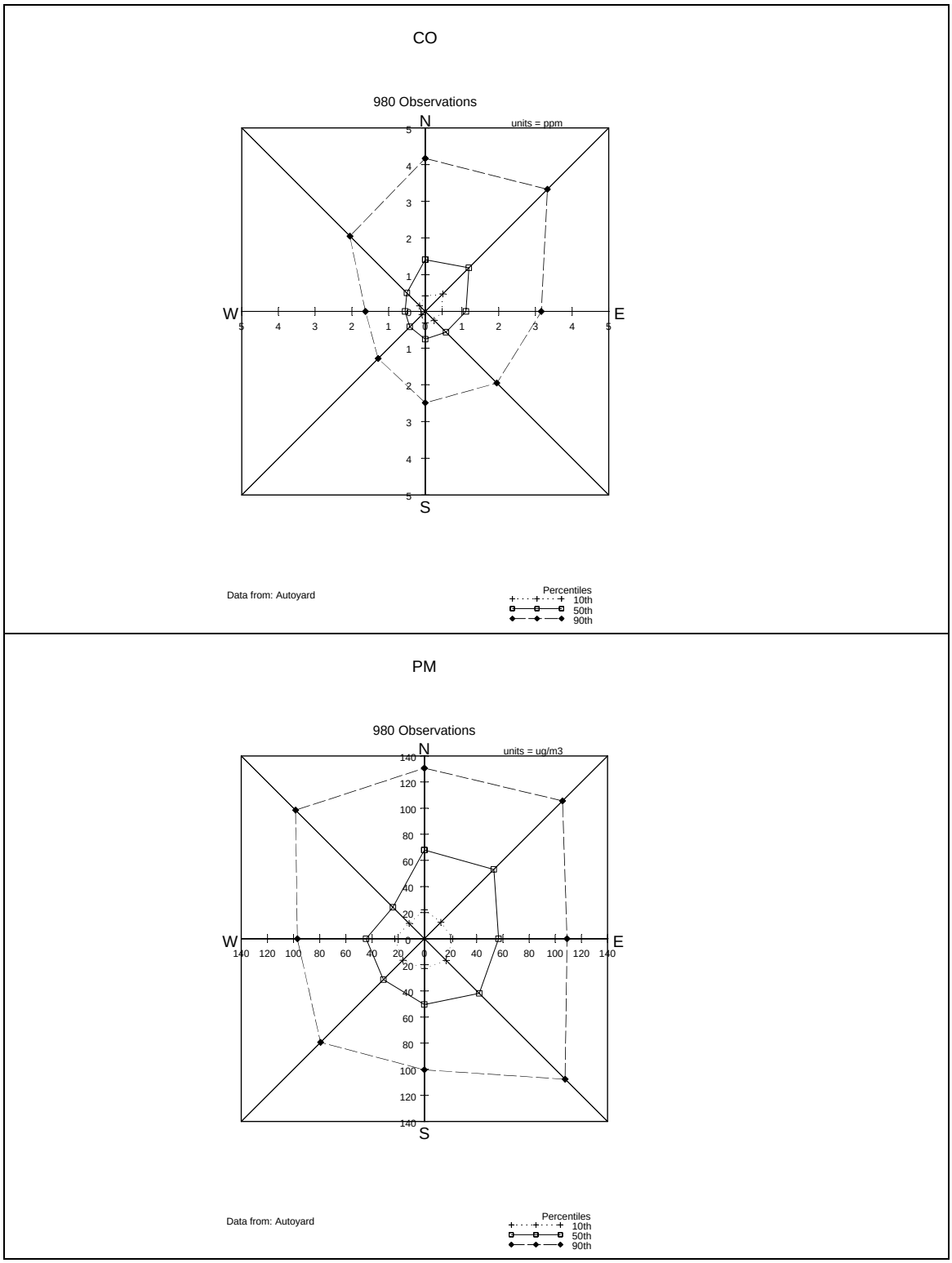

Figure 9. Conditional distributions of hourly CO (top) and PM_{10} (bottom) concentrations in each 45-degree wind direction sector at Autoyard (hours with wind speed < 6 mph only).

Speciated PM Analysis

Particulate matter speciation data were collected at Greenwood, Autoyard and W.est Phoenix during the study period for fine and coarse fractions from both 6-hour and 24-hour integrated Teflon and quartz fiber filter samples. Six hour samples were collected four times a day starting at midnight. Both 6- and 24-hour Teflon filters were analyzed for ions and 24-hour integrated Teflon filter samples also underwent elemental analysis. Quartz fiber filters were analyzed for organic and elemental carbon. Comparisons of total fine mass associated with ions and carbon[2] with gravimetrically determined $PM_{2.5}$ from the 6-hour Teflon filters resulted in average residuals equal to 17%, 16%, and -1.5% of total $PM_{2.5}$ at Greenwood, Autoyard, and West Phoenix, respectively. Consultation with ADEQ personnel failed to identify any explanation for the anomalous result at the West Phoenix location. We therefore determined that the only recourse was to drop the West Phoenix location data from subsequent analyses.

Average composition of PM_{10} at Greenwood and Autoyard are shown in Figure 10. These decompositions are based on average component contributions on the six-hour Teflon and quartz filter results described above; the "soil" component is simply estimated as the difference between the total measured PM_{10} mass and the sum of PM_{10} mass associated with ions and carbon. Thus the "soil" component approximately represents the contribution of inorganic primary PM_{10} sources. Compositions are very similar at these two sites, with nearly two-thirds of PM_{10} attributed to "soil" and about one-quarter to organic matter. An analysis of PM_{10} composition by six-hour sampling period does not show large variations with time of day at either site, although elemental carbon fractions are larger during the two morning periods, suggesting a relatively greater direct impact of primary combustion source emissions, much of which is likely from mobile sources (Figures 11,12).

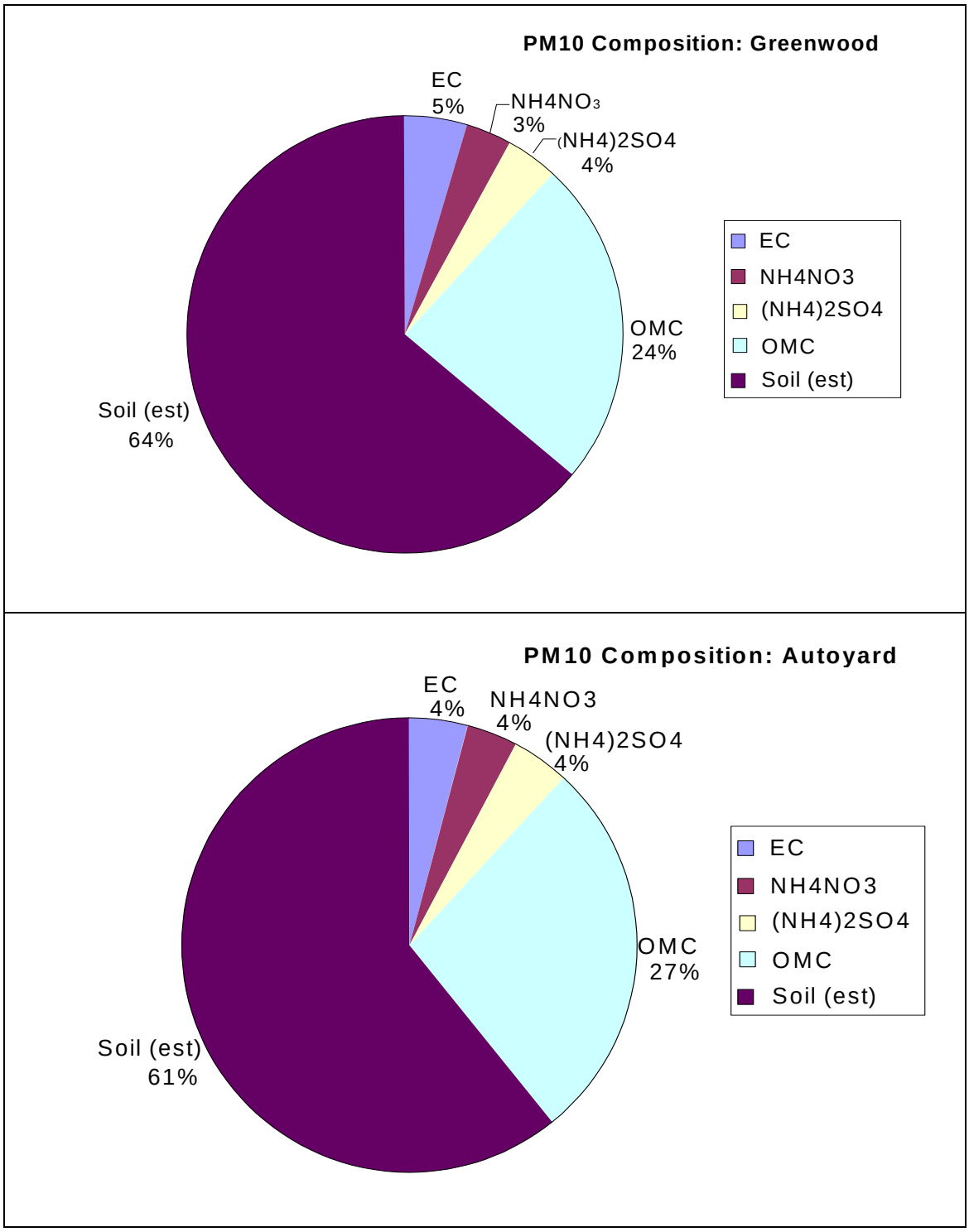

Figure 10. Average composition of PM_{10} samples collected at Greenwood (top) and Autoyard (bottom).

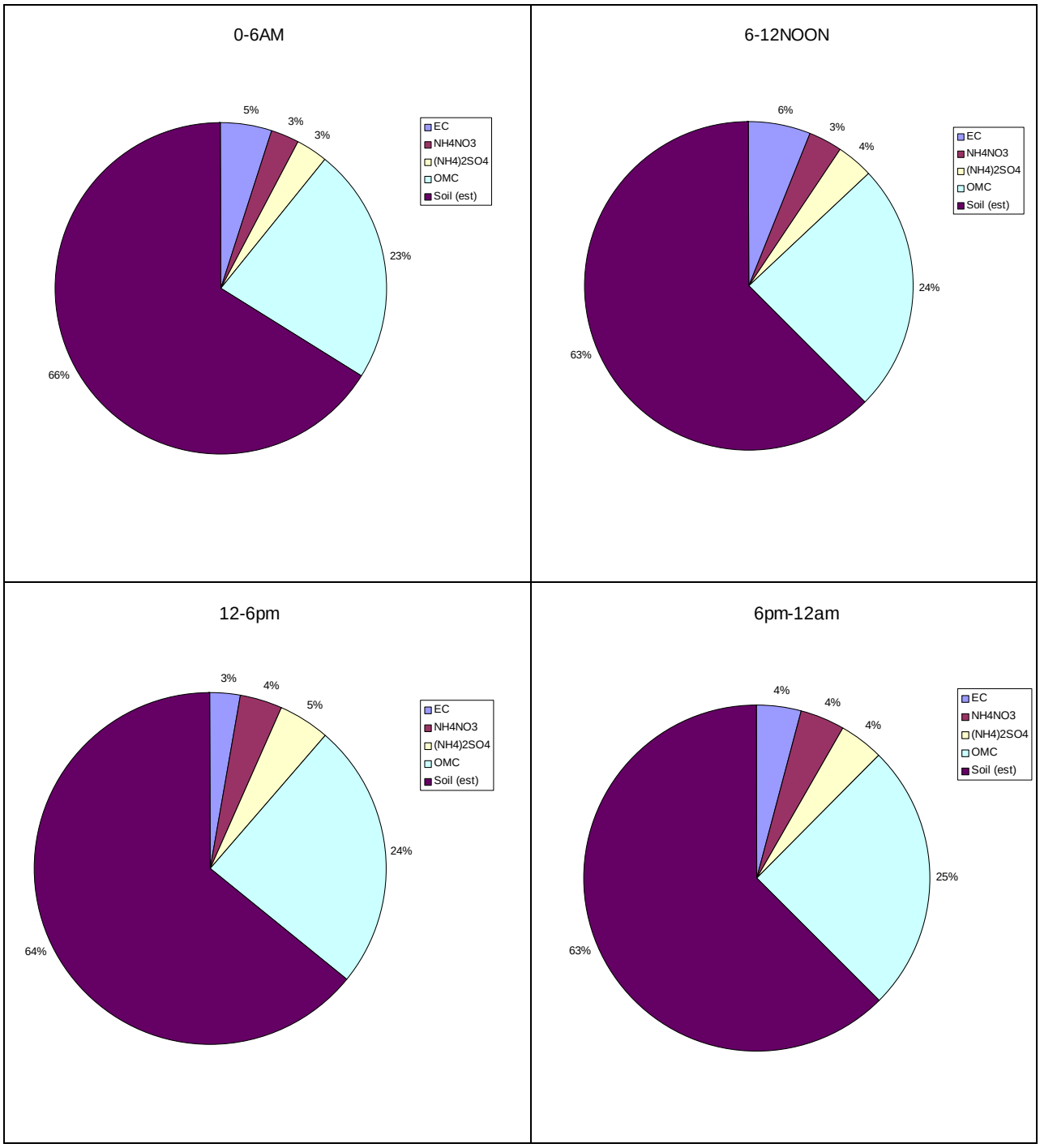

Figure 11. Diurnal variations in PM_{10} composition at Greenwood (see Figure 10).

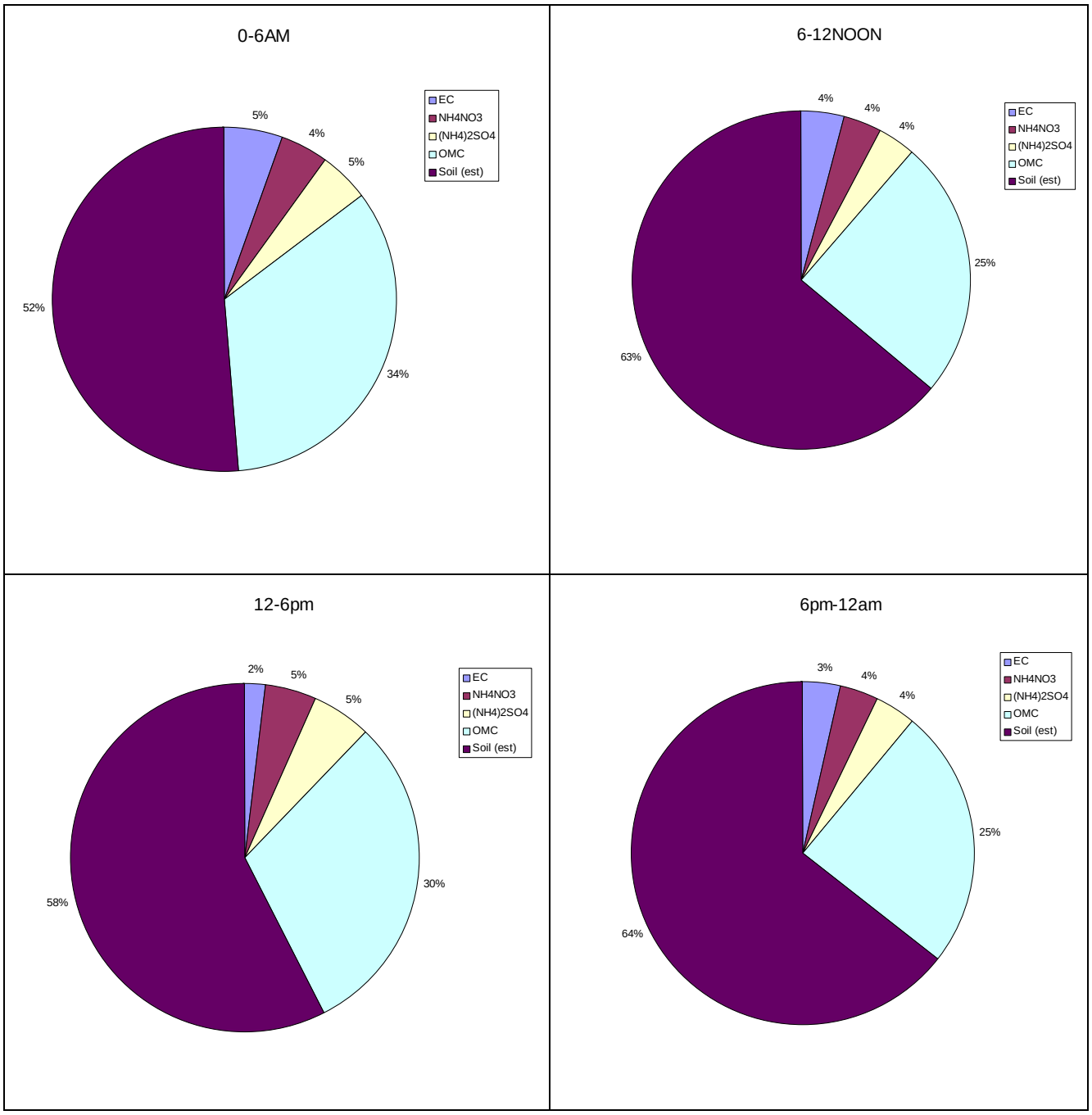

Figure 12. Average PM_{10} composition at Autoyard by time of day (see Figure 10).

Figure 13 shows mean composition of $PM_{2.5}$ at Greenwood and Autoyard based on the six-hour filter samples. Compositions are similar between the two sites with just over half of the $PM_{2.5}$ mass consisting of organic carbonaceous material (OMC). Greenwood has almost 40% more elemental carbon (EC) and a correspondingly smaller "soil" (primary inorganic material) fraction than does Autoyard, consistent with a larger contribution from combustion sources (most likely motor vehicles) at Greenwood relative to Autoyard. Autoyard appears somewhat more heavily impacted by primary inorganic

material, most likely from industrial sources in the area and vehicle travel on unpaved surfaces.

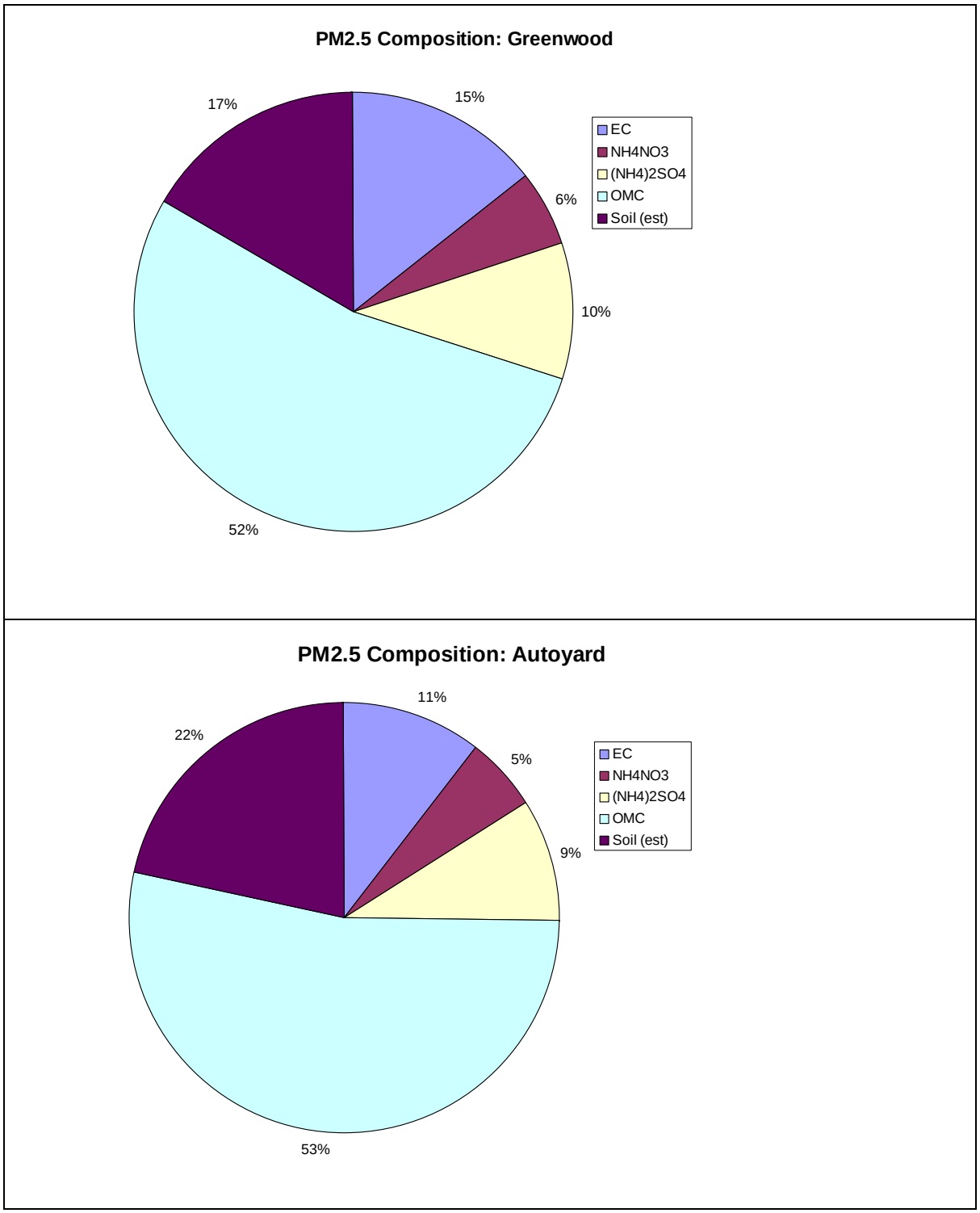

Figure 13. Mean $PM_{2.5}$ composition at Greenwood (top) and Autoyard (bottom) from six-hour samples.

DISPERSION MODELING

Atmospheric dispersion modeling was performed to obtain rough quantitative estimates of the impact of on-road mobile source PM_{10} emissions at the three monitoring sites in the Greenwood study area (Greenwood, Auto Yard, and West Phoenix) and the Supersite monitor. Estimates of impacts from all on-road sources in the study region and just those road segments in the immediate vicinity of the Greenwood monitor were derived as described below.

Emissions

Primary PM emissions from mobile sources fall into three general categories: 1) exhaust, 2) tire and brake wear, and 3) re-entrained road dust. While there are uncertainties in estimates of exhaust and tire and brake wear emissions, these are dwarfed by the very large uncertainties in road dust emissions, which make it impossible to obtain reliable estimates of the mobile source impact at Greenwood directly. However, our focus in this study is on the degree to which the impact of mobile source emissions at Greenwood exceeds the impact of mobile sources at the other study sites. We therefore chose to model the mobile source impacts on a relative rather than an absolute basis using the assumption that tire/brake and road dust emission are directly proportional to vehicle miles traveled (VMT). This eliminates the need to estimate road dust emissions on a gram-per-mile basis. In addition to the relative impact estimates, we combined the dispersion model results with results from a receptor modeling study previously conducted at the Supersite, a recent inventory of PM emissions for Maricopa County, and speciated PM sampling data to estimate the fraction of PM_{10} observed at Greenwood, West Phoenix, and Autoyard that is attributable to on-road mobile sources.

As indicated above, our modeling employed the simplifying assumption that PM emissions are directly proportional to VMT and independent of other factors, including average vehicle speed, driving cycle (i.e., the pattern of accelerations and decelerations), and fleet mix (e.g., relative proportion of cars and trucks). Data on variations in fleet mix from one link on the road network to another are not generally available and derivation of a detailed mobile source inventory based on vehicle fleet characteristics, average travel speeds, etc., was beyond the scope of this study. In any event, relatively little is known about the true functional relationships between average speed, driving cycle, and road dust emissions.

Annual average daily traffic (AADT) VMT data for each link on the road network in the study area were obtained from MAG. (www.mag.maricopa.gov). AADT values for most of the modeling region are shown in Figure 14; additional traffic count data for road segments in the western portions of the domain were supplied by MAG in tabular form. As the two sets of data represented different years, values in Figure 14 were scaled to the tabular data based on count ratios averaged over a series of road segments common to both data sets. Diurnal traffic factors developed by ADOT were used to allocate emissions by hour; allocation factors specific to roadway type (freeway and non-freeway)

and day of week (weekday, Saturday, Sunday) were used. Resulting relative emission values (arbitrary units) by road network link averaged by time of day and day of week are shown in Figure 15.

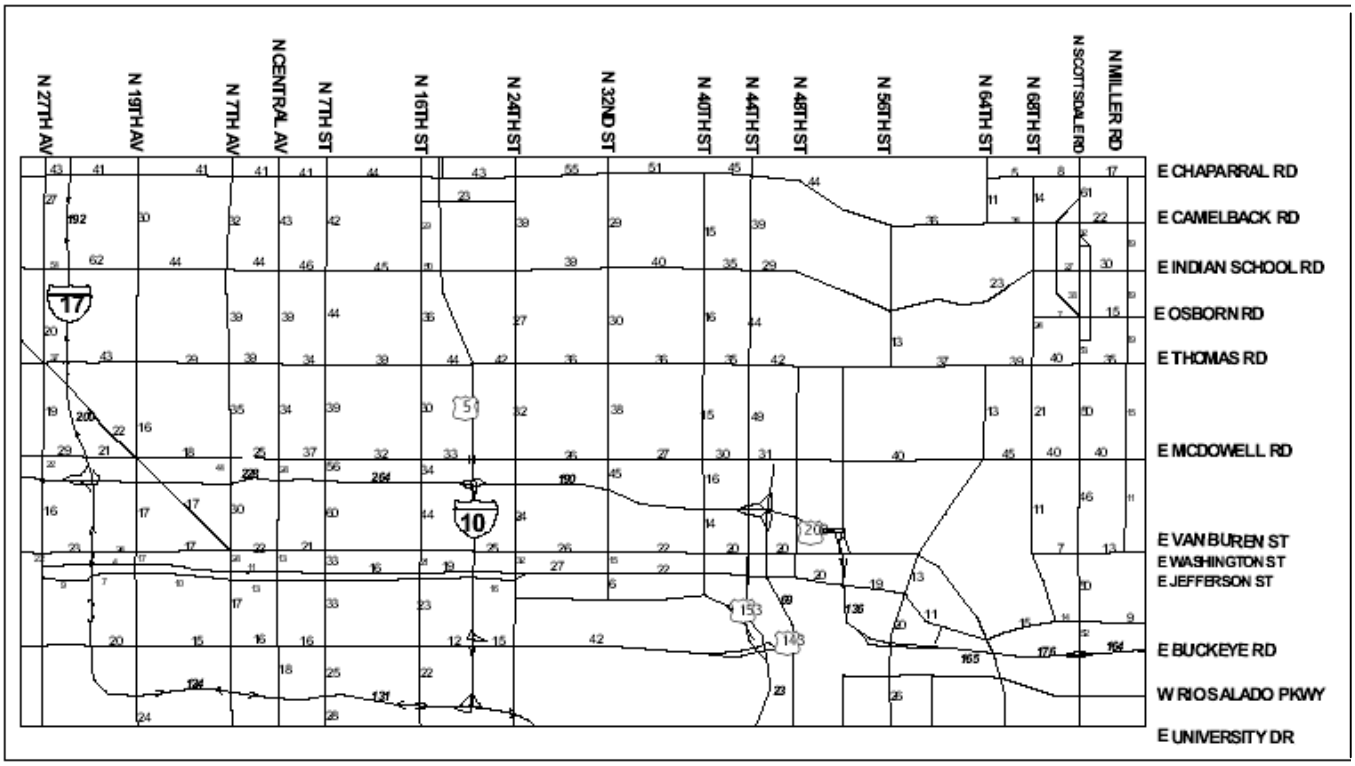

Figure 14. Average annual daily traffic (in thousands of vehicles)on roadway segments within the vicinity of the study area (source: Maricopa Association of Governments).

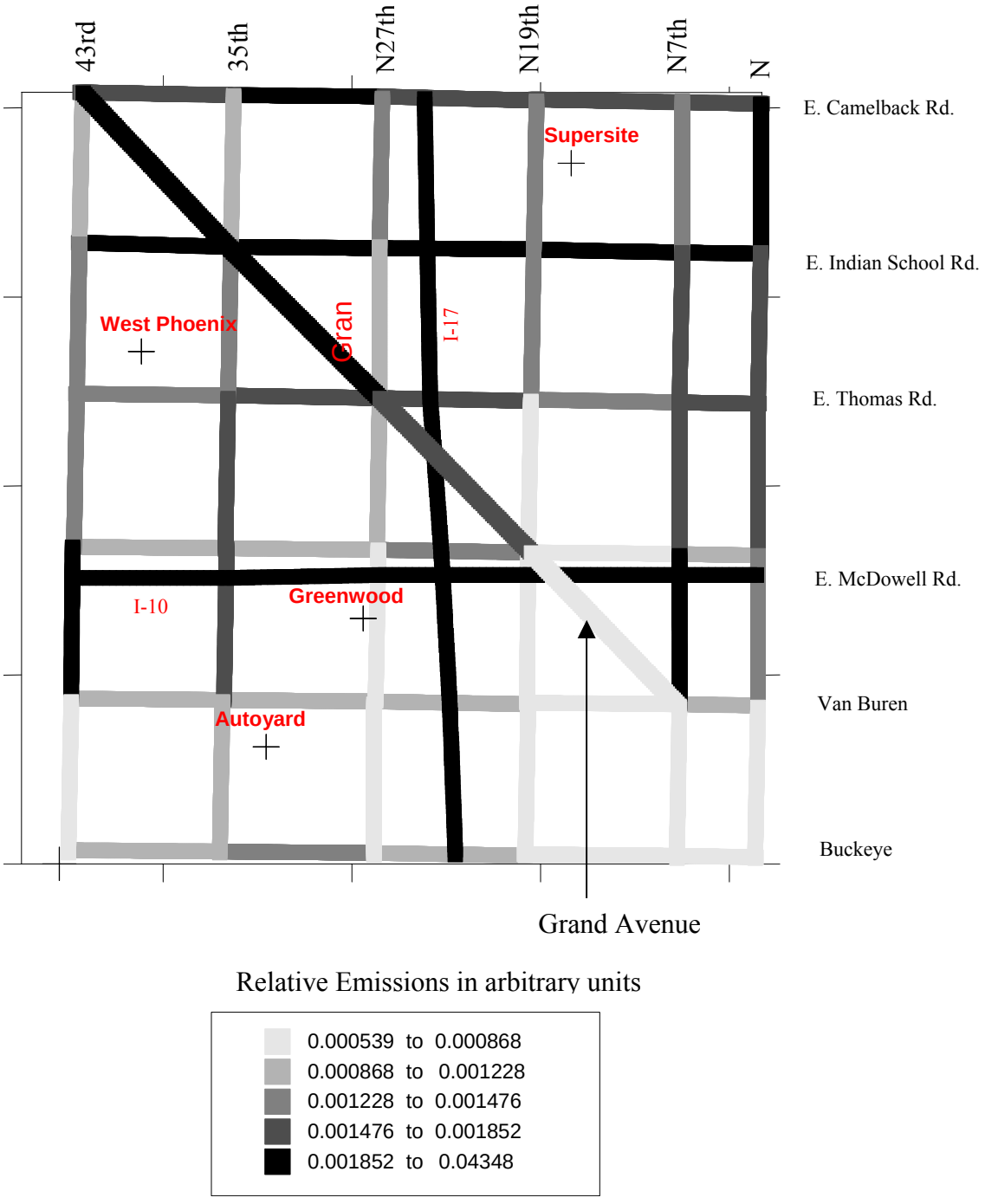

Figure 15. Relative PM_{10} emission factors from the modeling for roadway segments in the study area.

Mobile tailpipe exhaust, tire and brake wear, and road dust PM emissions were modeled using the size distribution assumed in the MOBILE6 emission factor model (EPA, 2002). Particle densities by size bin were obtained from algorithms employed in Environmental Protection Agency's (EPA) PART5 mobile source particulate emission factors model (see EPA, 1995b, Appendix A, Task 4) Table 2 lists the size fractions and densities input to the Industrial Source Complex (ISC) model. Model runs were made both for all three of these source categories combined and for exhaust only since total PM_{10} mass emissions are dominated by road dust, which has a predicted spatial distribution different from the that of the smaller, less dense exhaust particles.

Table 2. PM size fractions and associated densities used in model runs.

ALL SOURCES:			
No	**Particle Diameter (um)**	**Mass Fraction**	**Particle Density**
1	**0.2**	**0.032745674**	**2.403**
2	**2**	**0.226989102**	**2.996**
3	**10**	**0.74022468**	**2.996**
EXHAUST ONLY			
No	**Particle Diameter (um)**	**Mass Fraction**	**Particle Density**
1	**0.02**	**0.897**	**1.500**
2	**2**	**0.02**	**1.500**
3	**10**	**0.083**	**1.500**

Model Setup

Meteorological data for the period 1988 to 1991 were obtained from the National Climatic Data Center. Surface data is based on observations at Sky Harbor Airport; upper air observations are from the closest available sounding (Tucson). Precipitation data were not readily available so only dry deposition was modeled. Precipitation events are relatively rare in Phoenix: the impact of wet deposition on the annual average spatial distribution of mobile source PM is expected to be very small.

ISCST was run with regulatory default options. Plume depletion due to dry deposition was incorporated into the concentration calculations. Flat terrain was assumed. Each road link was modeled as a series of ground level volume sources with initial horizontal dimension (sigma-y) of 7.41 m and vertical dimension (sigma-z) of 0.93 m. These source definitions are based on the procedure recommended for simulating line sources in the ISC User's Manual (EPA, 1995a). ISCST's "urban" dispersion coefficients were used for most runs, but a sensitivity analysis was performed to examine the effect of using the "rural" dispersion option.

Modeling Results

Relative values of annual average PM_{10} concentrations were computed at the Greenwood, Autoyard, West Phoenix, and Supersite monitoring locations shown in Figure 1. As expected, mobile source impacts are highest at Greenwood, followed in order by Supersite, West Phoenix and Autoyard. Since emissions used in the model are of arbitrary units as discussed above, we summarized the predicted annual average concentrations relative to Greenwood (see Table 3). Ratios of concentrations at Autoyard, West Phoenix and Supersite to Greenwood are slightly higher for the exhaust-only run compared to the all-sources run as a greater proportion of the larger road dust particles deposit closer to the source. Results from a sensitivity run using the ISCST "rural" dispersion option for 1991 produced ratios of annual average concentrations at Autoyard, West Phoenix and Supersite to the concentration at Greenwood that ranged from 15% to 20% larger than the values shown in Table 3.

Table 3. ISCST predicted annual average PM_{10} concentrations using urban dispersion option (results scaled to predicted concentration at Greenwood).

	All Sources				Exhaust Only					
Receptor Site	**1991**	**1989**	**1988**	**Avg.**	**1991**	**1990**	**1989**	**1988**	**1987**	**Avg.**
Greenwood	1.000	1.000	1.000		1.000	1.000	1.000	1.000	1.000	
Autoyard	0.232	0.241	0.243	0.239	0.246	0.249	0.258	0.272	0.245	0.254
West Phoenix	0.275	0.250	0.250	0.258	0.301	0.298	0.273	0.261	0.265	0.279
Supersite	0.294	0.284	0.259	0.279	0.320	0.308	0.316	0.281	0.213	0.287

Table 3 clearly shows that the Greenwood monitor is much more heavily impacted by mobile sources than the other monitoring locations: overall, the total PM_{10} impact from all on-road mobile sources is estimated to be between 3.6 and 4.2 times greater at Greenwood than at the other three sites.

Quantitative Estimates of Mobile Source Contributions

While the dispersion model results described above do not by themselves provide an estimate of the mobile source PM_{10} impact at Greenwood, we can use these results in combination with ambient PM_{10} and $PM_{2.5}$ monitoring data, results of an earlier receptor modeling study and the Maricopa County $PM_{2.5}$ emissions inventory to arrive at such an estimate. This approach requires obtaining values for the following quantities:

- Ratios of predicted annual average PM_{10} concentration at each monitoring site to predicted concentration at Greenwood.
- Observed annual average PM_{10} concentrations.
- Estimated contribution of primary PM from combustion sources to annual average $PM_{2.5}$.
- Fraction of primary $PM_{2.5}$ from combustion sources contributed by on-road mobile exhaust emissions.
- Average $PM_{2.5}/PM_{10}$ concentration ratios.

Predicted annual average exhaust PM_{10} at each monitoring site relative to Greenwood were presented in Table 3. Observed annual average PM_{10} concentrations are

summarized in Table 4.[6] Monitoring at Greenwood began in 1997; data completeness was greater than or equal to 97% in all years except in 1997 when it was 93%. Annual averages at Greenwood exceed those at West Phoenix by an average of 7.6 $\mu g/m^3$ and those at Supersite by an average of 20.7 $\mu g/m^3$.

Table 4. Annual average monitored PM_{10} concentrations ($\mu g/m^3$).

Year	W.Phoenix (WP)	Supersite (SS)	Greenwood (GW)	Difference GW-WP	Difference GW-SS
2001	43	30.3	49	6	18.7
2000	52.5	36.3	61	8.5	24.7
1999	51.3	35.1	56	4.7	20.9
1998	39	31	48	9	17
1997	51	39	61	10	22
1996	45	34			
1995	44	31			
average (all available years)	46.5	33.8	55	7.64	20.66
average (1997-2001)	47.4	34.3	55	7.6	20.7

Although the predicted annual averages from ISCST are for 1987 to 1991, they can be used in conjunction with the 1997 to 2001 monitoring data in our calculations since meteorological conditions when averaged over these four- and five-year periods, respectively, can be expected to be very similar. This assumption seems reasonable given the relatively small year-to-year variations in both predicted and observed annual average concentrations. Overall, year-to-year differences in predicted PM_{10} ratios to Greenwood are small (95% confidence intervals for the ratios at Autoyard and West Phoenix are ± 4% and ±7 %, respectively). Ratios of the predicted annual average at Supersite to that at Greenwood are fairly constant for 1989to 1991 but are smaller in 1988 and 1987, resulting in a ± 15% confidence interval based on results for the entire 1987 to 1991 period. This suggests a greater sensitivity of on-road mobile impact to average wind direction at Supersite than at the other sites. In the ambient data, the year-to-year variability is equally small: the 95% confidence interval for both the Greenwood-Supersite and Greenwood-West Phoenix annual average differences is ± 5% of the average PM_{10} concentration.

An estimate of the contribution of combustion sources to $PM_{2.5}$ at the Supersite (67% ± 15%) is available from the Chemical Mass Balance (CMB) modeling performed for the 1999 Phoenix Brown Cloud study (MAG, 1999). This source apportionment basically assigns all $PM_{2.5}$ mass, other than sulfate, nitrate, and geological, to combustion sources (which are therefore likely to include such things as meat cooking and wood burning). These CMB results cannot be used to reliably distinguish on-road mobile exhaust emissions from other sources. We therefore turned to the Maricopa County $PM_{2.5}$ emissions inventory to obtain an estimate of the fraction of all combustion emissions contributed by on-road mobile sources. A compilation of the year 2002 $PM_{2.5}$ inventory was recently prepared by Pollack et al. (2003)[8] and is summarized in Table 5. From the values in this table we calculate that on-road mobile tailpipe emissions constitute 25% of all combustion emissions. This assumes that $PM_{2.5}$ from the major point sources is primarily from fuel combustion and that tire and brake wear contribution

to on-road mobile $PM_{2.5}$ emissions are negligible in comparison to road dust. These assumptions are necessary because the summary in Table 5 does not distinguish between combustion and other types of PM point sources and does not split out the tire and brake wear separately from vehicle tailpipe emissions.

Table 5. Maricopa County 2002 annual $PM_{2.5}$ emissions with and without adjustment for reconciliation of geological component. Tons per Year (TPY, short tons); Source: Pollack et al., 2003. C for Combustion, F for Fire, & G for Geological.

Category	Subcategory	Unadjusted $PM_{2.5}$ TPY	C/F/T	Adjusted $PM_{2.5}$ TPY
Point sources:	Pts>5TPY PM_{10}, or >10TPY NO_x or SO_x	725	C	725
Area sources:	Industrial natural gas	18	C	18
	Industrial fuel oil	5	C	5
	Commercial/institutional natural gas	5	C	5
	Commercial/institutional fuel oil	2	C	2
	Residential natural gas	61	C	61
	Residential wood combustion	315	F	315
	Agricultural burning	72	F	72
	Open burning	23	F	23
	Wildfires	262	F	262
	Structure and vehicle fires	76	F	76
	Charcoal grilling	355	F	355
	Agricultural tillage / harvesting	867	G	38
	Feedlots	17	G	1
	Construction activity	4,595	G	202
	Windblown dust (geogenic wind erosion)	5,222	G	230
	Other process fugitives	96	C	96
Area Total		11,990		1,761
Off-road sources:	Agricultural Equipment	61	C	61
	Airport Ground Support Equipment	4	C	4
	Commercial Equipment	129	C	129
	Construction and Mining Equipment	922	C	922
	Industrial Equipment	111	C	111
	Lawn and Garden Equipment	117	C	117
	Logging Equipment	3	C	3
	Pleasure Craft	11	C	11
	Railroad Equipment	4	C	4
	Recreational Equipment	3	C	3
	Aircraft	717	C	717
	Locomotives	80	C	80
Off-Road Total		2,163	C	2,163
Onroad sources:	Vehicle tailpipe, brake and tire wear	1,363	C	1,363
	Paved road dust	6,445	G	284
	Unpaved road dust (including road dust)	2,181	G	96
Biogenic sources:	Biogenic sources	na		na
TOTAL		25,267		6,403

For the point sources, we note that in the 2002 inventory a sizable fraction of the reported PM_{10} is estimated to be in the coarse ($PM_{10} - PM_{2.5}$) size fraction. In most cases, combustion sources are assigned primarily $PM_{2.5}$, so the presence of a sizable amount of point source coarse emissions in the inventory suggests that some point sources in the inventory probably represent non-combustion sources. If we assume for the sake of argument that the point source $PM_{2.5}$ emissions of 725 tons per year (TPY) is all from non-combustion processes, then the tailpipe fraction of total combustion $PM_{2.5}$ would be 28% instead of 25%. In reality, however, most of the reported point source $PM_{2.5}$ is likely to be from combustion so 25% is likely to be a better estimate of the tailpipe fraction than 28%.

Combining the 25% tailpipe fraction from the emission inventory with the CMB results discussed above, we see that tailpipe emissions contribute 25% of 67% or 17% of total ambient $PM_{2.5}$ at Supersite. To determine the corresponding PM_{10} fraction, we need an estimate of the average $PM_{2.5}/PM_{10}$ ratio at Supersite. Based on an analysis of six years of dichotomous sampler data collected every sixth day, the average $PM_{2.5}/PM_{10}$ ratio is 0.316.[10] Based on this result, we estimate that tailpipe PM_{10} emissions contribute to 17% of 31.6% which equals 5.4% of total ambient PM_{10} on average.

Using the information developed above, we can compute the estimated impact of tailpipe exhaust PM_{10} at the Greenwood monitor as the product of:

a) the predicted ratio of exhaust impacts at Greenwood vs. Supersite (3.6:1, from the ISCST results),
b) the fraction of ambient PM_{10} at Supersite attributable to exhaust emissions (5.4%), and
c) the average PM_{10} concentration at Supersite (34.3 $\mu g/m^3$).

Taking the product of these three quantities yields a value of 6.67 $\mu g/m^3$ for the estimated average impact of tailpipe exhaust PM_{10} emissions at Greenwood. This compares with an estimated impact of 1.85 $\mu g/m^3$ at West Phoenix (derived in the same manner but using the predicted ratio of exhaust impacts at West Phoenix vs. Supersite which equals 1.0:1; see Table 3). Similarly, this compares with an estimated impact of 2.04 $\mu g/m^3$ at Autoyard (based on the predicted exhaust ratio of Autoyard to Supersite of 1.1:1).

An estimate of the impact of tire and brake wear plus re-entrained road dust emissions at Greenwood can also be derived from the information developed above if we assume that all of the difference in average PM_{10} between Greenwood and Supersite is due to the greater amount of vehicle traffic around Greenwood, i.e., the contribution of PM_{10} sources other than on-road mobile is assumed to be the same at Greenwood as at Supersite.[11] A detailed investigation of this assumption via an analysis of a spatially disaggregated emissions inventory is beyond the scope of our analysis. Given the more industrial nature of land use in the area of western Phoenix south of I-10, however, it is likely that non-mobile source contributions of PM_{10} are likely to be greater at Greenwood than at Supersite. As discussed below, this means that estimates of on-road mobile impacts at Greenwood developed under this assumption are likely to be too high.

Assuming the impact of sources other than on-road mobile on ambient PM_{10} is the same at Greenwood as at Supersite as discussed above, the impact of tire and brake plus re-entrained road dust at Greenwood, $PM10_{GW}^{d}$, is given by

$$PM10_{GW}^{d} = R_d \{ [PM10_{GW} - PM10_{SS} - \alpha PM10_{SS}(R_e-1)] / (R_d - 1) \}$$

where

- R_d is the ISCST predicted ratio of tire and brake wear plus re-entrained road dust PM_{10} emissions at Greenwood vs. Supersite from Table 3 (1/0.28 = 3.6),
- R_e is the ISCST predicted ratio of vehicle exhaust primary PM_{10} emissions at Greenwood vs. Supersite from Table 3 (1/0.29 = 3.4),
- α is the fraction of PM_{10} at Supersite attributed to vehicle exhaust primary PM_{10} emissions (5.4% as per above discussion), and
- $PM10_{GW}$ and $PM10_{SS}$ are the observed average PM_{10} concentrations at Greenwood (55 $\mu g/m^3$) and Supersite (34 $\mu g/m^3$), respectively (from Table 4).

To see why this is so, note that the quantity inside the curly braces {} represents the PM_{10} impact of tire and brake plus re-entrained road dust emissions at Supersite and that this quantity is calculated by subtracting from the total PM_{10} difference ($PM10_{GW} - PM10_{SS}$) the difference between exhaust PM_{10} at Greenwood ($\alpha PM10_{SS}R_e$) and the exhaust PM_{10} at Supersite ($\alpha PM10_{SS}$), which leaves the difference in tire/brake plus road dust impacts. Dividing this difference by $R_d - 1$ gives the tire/brake plus road dust impact at Supersite. This is then multiplied by R_d to get the tire/brake plus road dust impact at Greenwood.

Application of the above equation yields an estimate of 23.0 $\mu g/m^3$ for the tire/brake plus road dust impact at Greenwood. Together with the estimated exhaust PM_{10} impact at Greenwood of 6.67 $\mu g/m^3$, the total PM_{10} impact from on-road mobile sources at Greenwood is estimated at 29.7 $\mu g/m^3$ which represents 54% of the total PM_{10} at Greenwood. At Supersite, the estimated tire/brake plus road dust impact is 0.28 * 23.0 = 6.4 $\mu g/m^3$ which, combined with the estimated tailpipe PM_{10} impact of 1.8 $\mu g/m^3$ derived above yields a total on-road mobile source impact of 8.2 $\mu g/m^3$ which represents 24.1% of the total PM_{10} at Supersite. These results are summarized in Table 6.

Table 6. Estimated contributions to PM_{10} ($\mu g/m^3$) from on-road mobile sources.

Site	Tailpipe Emissions	Tire/Brake + Road Dust	Total
Greenwood	6.7	23.0	29.7
West Phoenix	1.8	--	--
Autoyard	2.0	--	--
Supersite	1.8	6.4	8.2

As noted previously, the estimate of on-road mobile impacts at Greenwood derived above is based on the assumption that the entire difference in average PM_{10} between Greenwood and Supersite is attributable to the greater on-road mobile source activity in the vicinity of Greenwood and the fact that the Greenwood monitor is located very close

to two major interstate highways. The PM_{10} emission rates per unit of activity (VMT) are assumed to be the same in both locations. There are reasons to suspect that this assumption may not be entirely valid: the area west of I-17 near (and especially south of) I-10 is of a more industrial nature and examination of aerial photos suggests that there are more dirt lots in this area (which imply an increase in travel on non-paved surfaces and potential for track-out of dirt onto paved roads). It is interesting to note that annual average PM_{10} concentrations at West Phoenix are also higher than at Supersite (average difference of 14.0 $\mu g/m^3$ or 34% for years when data were also collected at Greenwood,see Table 4), while the ISCST modeling results (Table 3) indicate that the on-road mobile impacts should be almost equal at these two sites (average Supersite/West Phoenix ratio of 1.08 for all sources). This suggests that nearly all of the West Phoenix – Supersite mean difference (14/1.08 = 13 $\mu g/m^3$) represents impacts of non-mobile sources or higher per-VMT emission factors for mobile sources in the vicinity of West Phoenix (from, for example, a higher proportion of diesel VMT, increased silt loading, etc.). If we subtract this "potential non-mobile" portion from the Greenwood – Supersite difference of 21 $\mu g/m^3$, we are left with a difference of 8 $\mu g/m^3$. When this reduced difference is used in the above equation, the computed tire and brake plus road dust impact at Greenwood turns out to be 3.6 $\mu g/m^3$ instead of 23.0 $\mu g/m^3$, which is inconsistent with the estimated tailpipe emissions impact of 6.7 $\mu g/m^3$. Although all of these estimates are subject to significant uncertainty, one possible explanation for this result is that there are local PM_{10} sources impacting West Phoenix that are not impacting Greenwood. Aerial photos of the West Phoenix location show many potential light industrial sources but no obvious major PM_{10} sources. Unfortunately, the hourly TEOM and speciated filter samples needed to further investigate source impacts at West Phoenix are not available. It is interesting to note that linear regressions of annual average PM_{10} at Greenwood with West Phoenix and Supersite (Figure 16) show a close relationship between Greenwood and Supersite (consistent with a dominating influence from mobile sources) and a less consistent relationship between Greenwood and West Phoenix. This result is consistent with the hypothesis that other, more variable sources of emissions are influencing the West Phoenix site to a greater extent than at Autoyard.

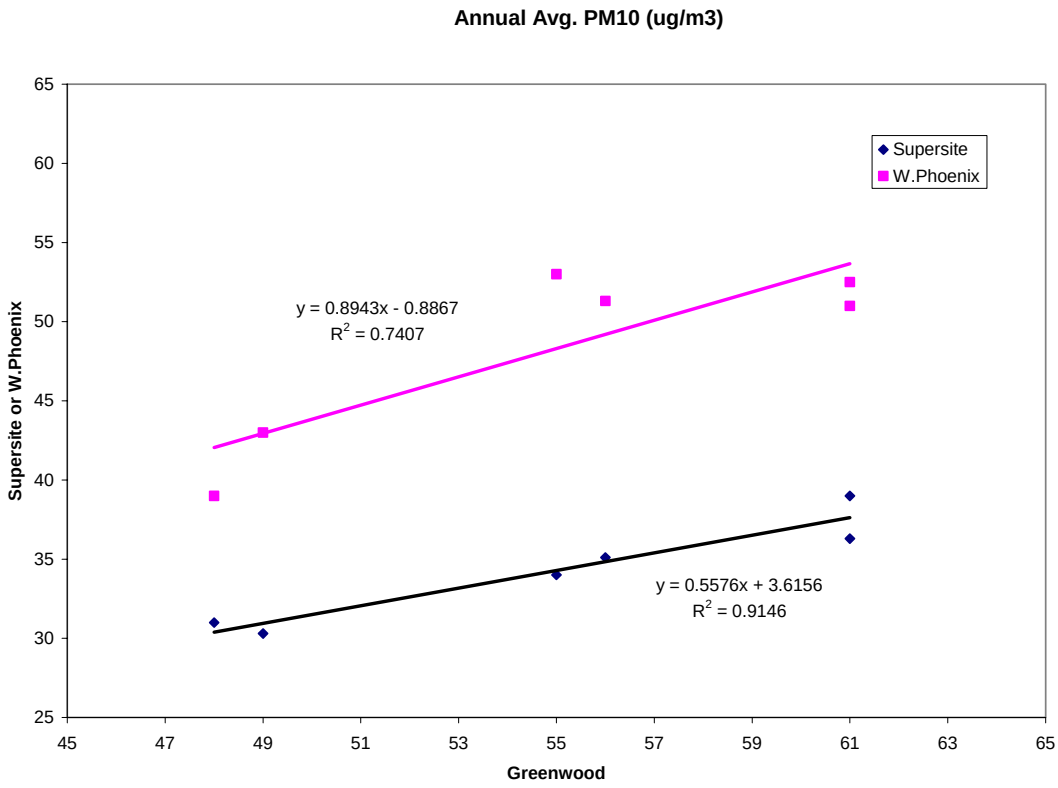

Figure 16. Regressions of annual average PM_{10} at Greenwood with Supersite and West Phoenix.

Impact of Local Vehicle Activity on Road Segments Near Greenwood

Model results described above were extended to examine the impact of emissions from just vehicles operating within the immediate vicinity of the Greenwood monitoring site as compared to vehicle activity over the entire road network throughout the modeling domain. Roadway segments within approximately a half-mile radius of Greenwood were designated as "local." These included the following segments:

1. McDowell Road between 31st Avenue and I-17
2. I-10 between 31st Avenue and I-17
3. 27th Avenue between McDowell Road and I-10
4. 27th Avenue between I-10 and halfway to Van Buren Road (?)
5. I-17 between I-10 and McDowell Road
6. I-17 between I-10 and halfway to Van Buren Road (?)

Table 7 lists the fraction of vehicle emission impacts from the entire modeling domain accounted for by activity on just the above road segments. At Greenwood, the local road segments account for 66% of the total on-road mobile impact. As we would expect, the relative impact of road segments near Greenwood is much smaller at the other monitoring sites. Applying the impact ratio at Greenwood from Table 7 to the estimate of total on-road mobile impact developed above (29.7 $\mu g/m^3$) results in an estimated impact from local vehicle activity at Greenwood of 0.66 * 29.7 = 19.6 $\mu g/m^3$, which represents 36% of

the average observed PM_{10} concentration at Greenwood. This value roughly twice the local source contribution estimate of 9.5 $\mu g/m^3$ derived previously from the regression of hourly PM_{10} at Greenwood against Supersite.

Table 7. Fraction of total on-road mobile source impacts attributable to vehicle activity in the immediate vicinity of the Greenwood monitoring site (based on ISCST modeling results for 1991).

	Exhaust+Tire/Brake+Road Dust	Exhaust Only
Greenwood	66%	62%
Autoyard	9%	9%
West Phoenix	7%	7%
Supersite	1%	1%

4. SUMMARY AND CONCLUSIONS

High concentrations of PM_{10} at the Greenwood monitoring site in Phoenix have been shown in this study to be attributable in large part to the site's location close to two major interstate highways. Comparisons of hourly PM_{10} at Greenwood with Supersite and Autoyard are consistent with the hypothesis that Supersite PM_{10} represents an urban background level to which additional mass is added from local sources in the vicinity of Greenwood and Autoyard. The amplitude of the morning PM_{10} peak at Greenwood is much larger than at Supersite, indicating a stronger influence of mobile sources at Greenwood. Hourly PM_{10} at Autoyard above approximately 75 $\mu g/m^3$ are generally associated with lower values at Greenwood, indicating a stronger impact from local sources at Autoyard (industrial activity or travel on unpaved surfaces and associated trackout of material onto paved roads). Correlations of hourly PM_{10} with CO at Greenwood and Autoyard also suggest that sources other than on-road mobile are impacting Autoyard (or on-road mobile emission factors in the vicinity of these sites are higher than in the vicinity of Greenwood, possibly due to higher heavy-duty truck activity or higher roadway silt loading due, for example, to trackout from dirt lots).

Analysis of speciated PM samples collected at Greenwood and Autoyard showed very similar compositions at these two sites, with nearly two-thirds of PM_{10} attributed to inorganic primary particulate and about one fourth to organic matter (data from West Phoenix were invalidated due to discrepancies between measured and reconstructed fine mass). Analysis of six-hour samples showed that elemental carbon fractions are larger in the 0:00 a.m. to 6:00 a.m. and 6:00 a.m. to 12:00 p.m. samples than at other times of the day, consistent with greater combustion source activity, most likely from motor vehicles.

A series of dispersion modeling analyses were conducted to estimate the impact of on-road mobile source emissions on PM_{10} levels at Greenwood in relation to impacts at Supersite, West Phoenix and Autoyard. Since mobile source road dust emission factors are highly variable and difficult to estimate accurately and the collection and analysis of spatially and temporally disaggregated data on vehicle fleet mix and average speeds was outside the scope of this study, modeling was performed on a relative basis assuming mobile source PM_{10} emissions are directly proportional to VMT. Traffic count data were used to derive VMT estimates by roadway segment, hour of day, and day of week. Results from the dispersion model showed that on-road mobile source impacts are estimated to be 3.6 to 4.2 times greater at Greenwood than at Autoyard, West Phoenix or Supersite. This reflects the fact that the Greenwood monitor is located very close to two heavily traveled major interstate highways that are frequently upwind of the site, whereas the other three monitoring sites are further removed from the direct influence of vehicle traffic on paved roads.

Results of the dispersion modeling analysis were combined with ambient PM_{10} and $PM_{2.5}$ monitoring data, results of an earlier receptor modeling study, and the Maricopa County$PM_{2.5}$ emissions inventory, to derive an estimated annual average PM_{10} contribution from on-road mobile sources at Greenwood of 29.7 $\mu g/m^3$,which represents

54% of total observed PM_{10}. This compares with an estimated contribution of 8.2 $\mu g/m^3$ or 24% of total PM_{10} at Supersite.

The mobile source impact estimates described above are for all on-road mobile sources in the study region. Additional dispersion modeling was conducted to estimate the impact of just those road segments in the immediate vicinity (i.e., within about a half-mile radius) of the Greenwood monitor. Results show that travel on the local road segments around Greenwood contribute 66% of the total from all on-road sources on an annual average basis. This represents an impact from local sources of 19.6 $\mu g/m^3$ or 36% of the total annual average PM_{10}.

Estimates of PM impacts from mobile sources developed in this study are subject to considerable uncertainty as they are based on a series of simplifying assumptions as well as emissions estimates and receptor modeling results that are themselves subject to uncertainty. Of particular note is the assumption that the entire difference in average PM_{10} between Greenwood and Supersite is attributable to the greater impact of on-road sources at Greenwood. To the extent that this assumption does not hold (or that the g/VMT emission factor at Greenwood is higher than at Supersite), the estimated fraction of PM_{10} attributable to mobile sources at Greenwood will be biased high. Another source of uncertainty worth noting is that estimates of the dispersion of on-road emissions at receptors close to a major highway are sensitive to the manner in which the roadway line source is parameterized in the dispersion model. Sensitivity analyses with alternative source parameterizations could be performed to further investigate the magnitude of this effect.

Given the significant impact of on-road mobile source emissions on PM_{10} levels at the Greenwood monitoring site, future progress in reaching attainment of the NAAQS for PM_{10} will depend on reducing emissions from this source sector. Examination of the potential impact of any particular mobile source control measures in reducing PM_{10} at Greenwood (or elsewhere) in the future was beyond the scope of this study. However, given the sensitivity of PM_{10} levels at Greenwood to emissions from local traffic sources (as compared to urban wide traffic), it may be desirable to consider control measures specifically designed to reduce local emissions. Such measures might include improved mass transit along the major freeway corridors near Greenwood, or more frequent and efficient street sweeping in the immediate vicinity to reduce roadway silt loadings.

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11. Alternatively, we can use the modeling results for West Phoenix (or Autoyard) and assume that the contribution of sources other than on-road mobile is the same at Greenwood as at one or the other of these sites. While this would increase our confidence in the assumption somewhat (since West Phoenix and especially Autoyard are located closer to Greenwood), it is not a feasible alternative since long-term monitoring data needed to estimate average $PM_{2.5}/PM_{10}$ ratios, PM_{10} concentrations, and $PM_{2.5}$ receptor modeling results (needed to estimate the combustion source contribution) are not available at West Phoenix or Autoyard.