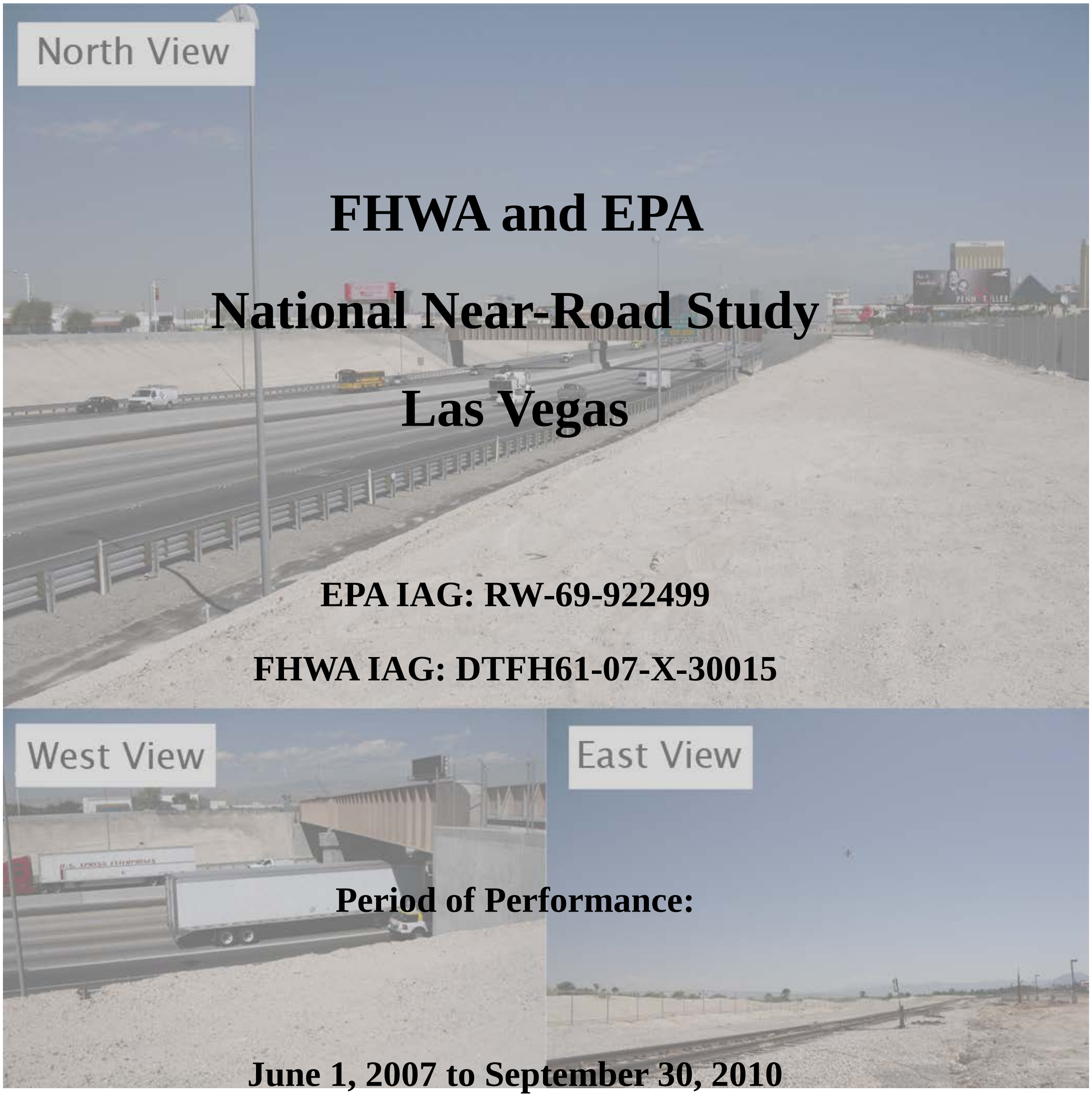

FHWA and EPA

National Near-Road Study

Las Vegas

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<tr><td colspan="3">16. Abstract: This report provides a summary of a field study conducted in Las Vegas, NV from mid-December 2008 thru mid-December 2009. The objective of this research study has been to determine Mobile Source Air Toxic (MSAT) concentrations and variations in concentrations as a function of distance from the highway and to establish relationships between MSAT concentrations as related to highway traffic flows including traffic count, vehicle types and speeds, meteorological conditions such as wind speed and wind direction; and other pollutants primarily emitted from motor vehicles. EPA/FHWA Near Road Team Daniel L. Costa, EPA, David D. Kryak, EPA Gayle S.W. Hagler, EPA, Douglas McKinney, EPA James Hirtz, EPA, Carlos Nunez, EPA William Mitchell, EPA, Richard W. Baldauf, EPA Eben Thoma, EPA, Carry W. Croghan, EPA Alan Vette, EPA. Victoria Martinez, FHWA, Karen Perritt, FHWA. Kevin Black, FHWA</td></tr>
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Executive Summary

Part I: Study Overview

In 2002, the Sierra Club legally challenged the U.S. Department of Transportation (DOT) Federal Highway Administration (FHWA) and the Nevada Department of Transportation's (NDOT) National Environmental Policy Act (NEPA) environmental document related to the proposed widening of U.S. 95 in Las Vegas, Nevada, including the assessment of impacts of mobile source air toxics (MSATs) from the proposed project. FHWA entered into a Settlement Agreement with Nevada DOT and the Sierra Club, wherein the FHWA agreed to undertake a research effort to characterize the impact and behavior of particulate matter with aerodynamic diameter less than 2.5 microns ($PM_{2.5}$) and MSATs near highways.[1] The FHWA Administrator contacted all 50 States requesting that the States participate in this research study. Two States, Nevada and Michigan, volunteered to support a monitoring site while a number of other States provided funding for the project.

The FHWA and U.S. Environmental Protection Agency (U.S. EPA) determined that it would be in the best interest of both organizations to implement this project in a collaborative manner, allowing a more effective utilization of staffing and resources. One of the first steps of the project implementation was the selection of a suitable ambient air monitoring site in or around Las Vegas, Nevada.

The objective of the study conducted under this protocol was:

- To determine MSAT concentrations and variations in concentrations as a function of distance from the highway.
- To establish relationships between MSAT concentrations as related to highway traffic flows including traffic count, vehicle types, and speed; meteorological conditions such as wind speed and wind direction; and other air pollutants emitted from motor vehicles such as carbon monoxide (CO) and oxides of nitrogen (NO_X).[2]

This report focuses on carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO_2), oxides of nitrogen (NO_X), black carbon (BC), particulate matter < 10 microns (PM_{10}), $PM_{2.5}$, PM Coarse, and MSAT (1-3, butadiene, benzene, acrolein, formaldehyde, acetaldehyde) measurements.

FHWA's "detailed monitoring protocol" outlined a uniform approach to conduct this study, as well as future related studies, for evaluating mobile source contributions to air toxic compounds and $PM_{2.5}$ and their dispersion patterns[2]. This protocol was peer reviewed by other federal agencies (EPA and DOE), State environmental and transportation agencies, the Sierra Club, and academic institutions. A more detailed examination of the monitoring protocol indicates that for each city, continuous monitoring and integrated sample collection was required at four monitoring sites located at distances ranging from roadside to 300 meters (m). In addition, wind speed and wind direction was required at each site. Moreover, monitoring for the complete suite of meteorological parameters was required at the monitoring station positioned 50 to 150 m from the roadway (100 m downwind).

Part II: Site Selection

The site selection process consisted of a series of seven steps (1) determine site selection criteria[2]; (2) develop list of candidate sites and supporting information; (3) apply site selection filter ("coarse" and "fine"), (4) site visit; (5) select candidate site(s) via team discussion; (6) obtain site access permission(s); and (7) implement site logistics. This process resulted in the selection of a location along I-15, just south of the "Las Vegas Strip".[3]

Of the almost two dozen sites evaluated, the I-15 site was considered the "optimal" site of all the monitoring sites considered[3]. This site had the most advantages and fewest disadvantages of all the monitoring sites considered in meeting the project objectives.

Figure 1. Map of Las Vegas Monitoring Sites.

This site had high AADT (206,000 AADT for 2006), no noise walls, meteorological and traffic data availability, manageable site logistics including right-of-way (ROW) access, and favorable wind direction[3]. Of the disadvantages, this site had a modest "cut" at that location, but only for a short distance. The roadway passed under a railroad bridge (Figure 1) and returned to at/near grade conditions. In addition, McCarran International Airport, a source of vehicle and aircraft emissions, was nearby, with runways approximately 1 km due east, and ground equipment and terminals approximately 5 km northeast of the site. However, the predominant winds at this location generally maintain the monitoring site upwind of the airport activities.

Part III: Analytical Instruments and Methods

The analytical methods implemented during this study followed EPA standard methods and Federal Reference Methods for performing ambient air measurements when applicable. The following table summarizes the measurements taken at each monitoring site.

Table 1. Summary of Measurements Conducted at Each Monitoring Site.

Measurements	20 Meter Roadside	100 Meter Downwind	300 Meter Downwind	100 Meter Upwind
TO-11A Cartridge sampling	X	X	X	X
TO-15 Canister sampling	X	X	X	X
Continuous gas monitoring (CO, NO_x)	X	X	X	X
Continuous black carbon monitoring (Aethalometer)	X	X	X	X
Continuous fine particle (TEOM)	X	X	X	X
Integrated $PM_{2.5}$ (FRM)	X	X	X	X
Wind speed/wind direction	X	X	X	X
Meteorological monitoring (temp, RH, etc.)		X		
Sound Meter	X	X		
Video Camera	X	X		X
Cut Section Monitoring (3-CO & 3-Aethalometers)	X			

Enhancements to the study protocol included 3-additional CO monitors and 3-additional aethalometers to more fully characterize the freeway "cut-section", and sound meter and video camera to monitor train and plane activity from the railroad and nearby airport, respectively. The video was also used to validate traffic count information received from NDOT.

Most analyzers deployed for this study performed well with the exception of the TEOMs. Further details on these difficulties can be found in the main report. An instrument upgrade was performed in the field by technical staff from ThermoScientific in late November 2009 and early December 2009. These upgrades improved instrument performance and stability. Due to issues with instrument performance and stability during most of the study, the data for this instrument is problematic. Results are presented in this report although it is very difficult to draw conclusions from the current analyses.

Part IV: Data Management, Analysis and Validation

Figure 2 provides a conceptual flow diagram of the data management process utilized in this study. This report includes process details, data analysis, and validation procedures as well as the Quality Assurance Project Plan (QAPP) that was developed for this study.

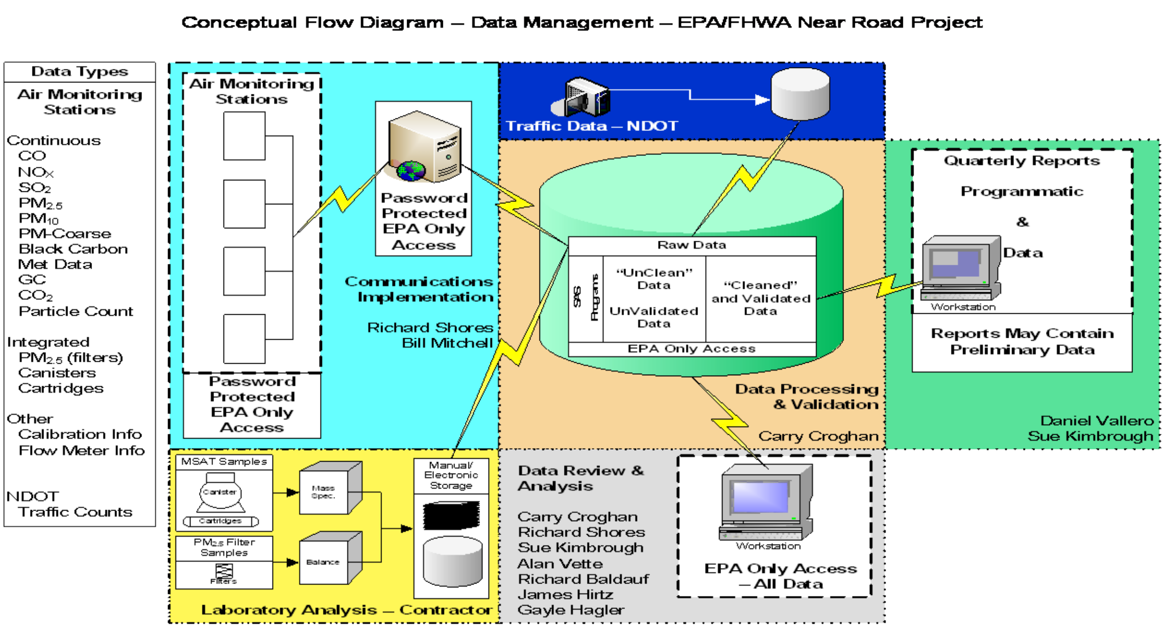

Figure 2. Flow Diagram - Data Management

More detailed information is included the report and appendices regarding data management, analysis, and validation.

Part V: Results and Discussion

During this study gigabytes of data were collected—including data from continuous monitors such as the CO, NO_X, BC and TEOM (PM_{10}, $PM_{2.5}$, PM Coarse) analyzers,; integrated sample data; traffic data and video data. Results (i.e., data and graphs) presented herein were selected based on the original objectives of the study: "…to determine MSAT concentrations and variations in concentrations as a function of distance from the highway, and to establish relationships between MSAT concentrations as related to highway traffic flows including traffic count, vehicle types, and speed; and meteorological conditions such as wind speed and wind direction; and other pollutants primarily emitted from motor vehicles such as CO, NO, NO_2, NO_X and BC."[2]

Traffic Activity. Traffic data indicated a tri-modal distribution as opposed to a more typical urban bi-modal distribution with morning and evening rush hour events (Figure 3). Several factors may have led to this atypical result. Since Las Vegas is a recreation destination, many travelers do not adhere to typical urban driving activities of morning and evening commutes. Many businesses in Las Vegas cater to these visitors; thus employee commutes may also not be standard. In addition, I-15 carries both inter- and intra- state traffic and is a North American Free Trade (NAFTA) corridor that attracts traffic throughout the day. These trends were consistent across all months of the study.

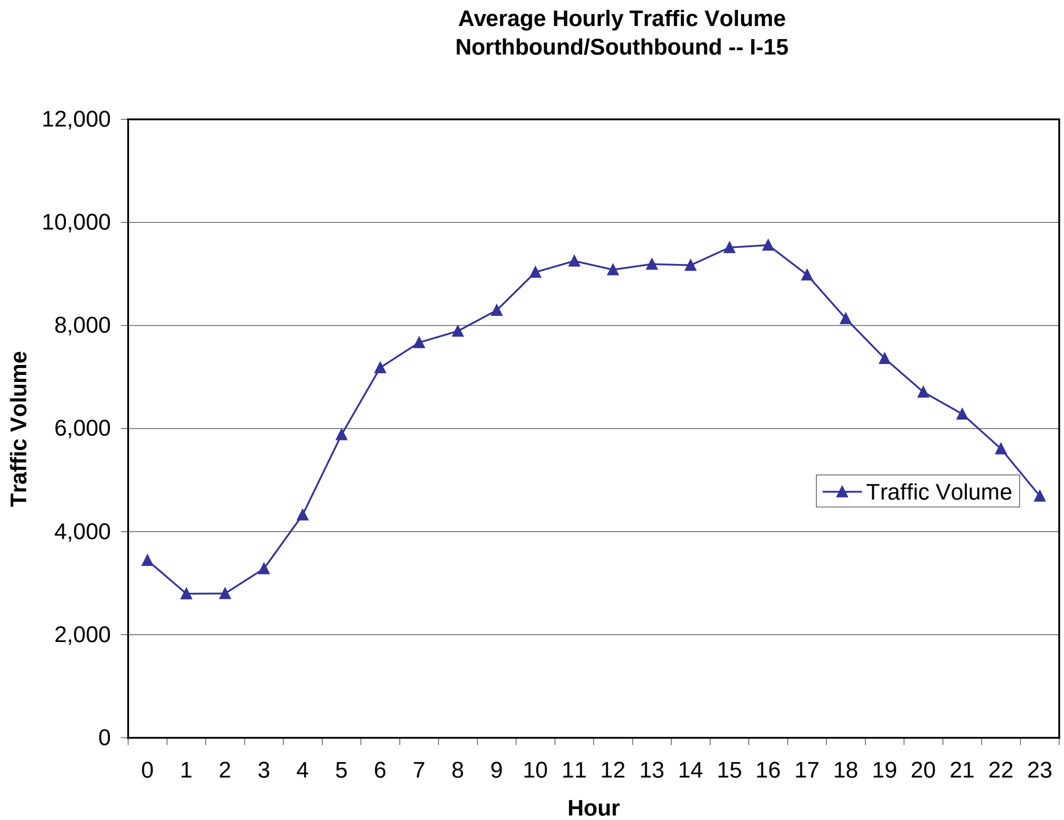

Figure 3. Average Hourly Traffic Volume at I-15 Site from Dec. 2008 through Dec. 2009.

Meteorology. Figure 4 shows wind rose data collected at the closest station to I-15, approximately 20 m to the east of the highway. During the study, winds were predominately from the southwest quadrant, indicating that the monitoring transect typically contained one upwind station 100 m west of I-15 and three downwind stations east of the highway. Figure 4 shows an occasionally strong easterly wind during the time period from midnight until approximately 3 p.m. During this time, the station to the west of I-15 experienced impacts from the highway.

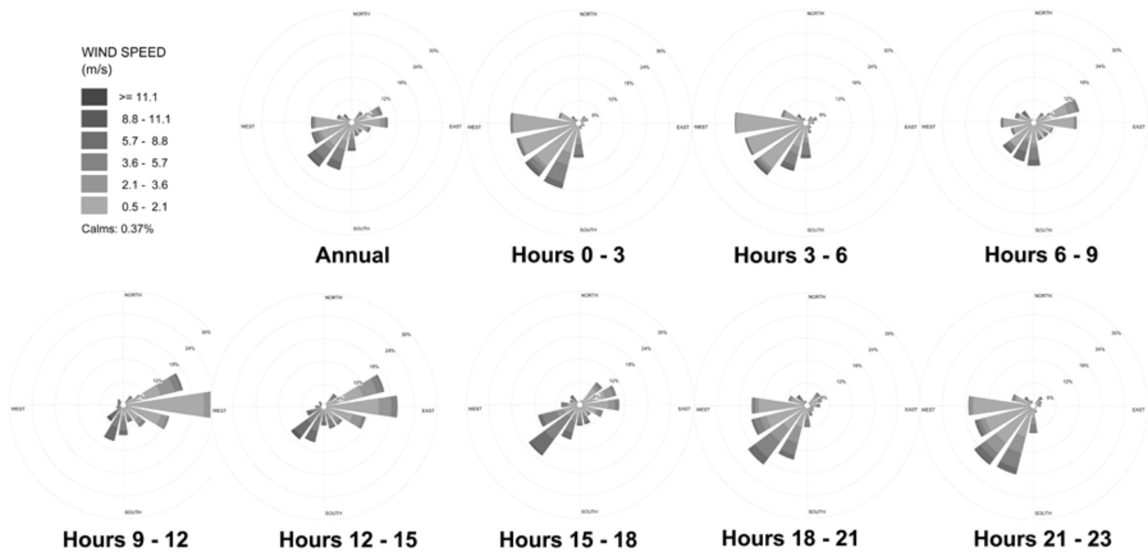

Figure 4. Wind Roses from the station 300 m east of I-15 from Dec. 2008 to Dec. 2009 separated by time of day.

Air Quality – Continuous Analyzers.

Figure 5 shows the average NO_2 concentration measured at each of the four monitoring stations during the entire study period, as well as similar average concentrations of related pollutants NO and NO_x. Note that the data in Figure 5 represents all wind directions and wind speeds. Figure 5 shows that concentrations on average for all of these pollutants were higher closest to the highway, although the NO and NO_x gradients were steeper than NO_2. Since NO is the primarily emitted pollutant from motor vehicles and accounts for the majority of NOx emissions, steeper gradients for these pollutants were expected. While some studies have shown a bi-modal NO_2 gradient away from the road, with a peak near the road and another peak further from the road, these results indicated that long-term average concentrations were approximately 20 percent higher closest to the highway. Figure 6 shows NO_2 concentrations as a function of wind direction and wind speed. This figure shows peak concentrations of around 75 ppb, and high concentrations occurred during hourly average winds from multiple directions. Given that, on average, the highest concentrations occurred at the station closest to the highway, these results likely suggest a number of factors. Since NO_2 primarily occurs from secondary formation, there may be a significant background concentration of this pollutant. Elevated concentrations at the near-road station were influenced by direct transport from the highway due to prevailing winds from the west, increased time for the transformation of NO to NO_2 during parallel winds, and potentially upwind meandering of traffic-related pollutants even when winds occurred from the east.[4] Emissions from Las Vegas Boulevard and operations at nearby McCarran International Airport may have contributed to the elevated background NO_2 concentrations during wind events from the east.

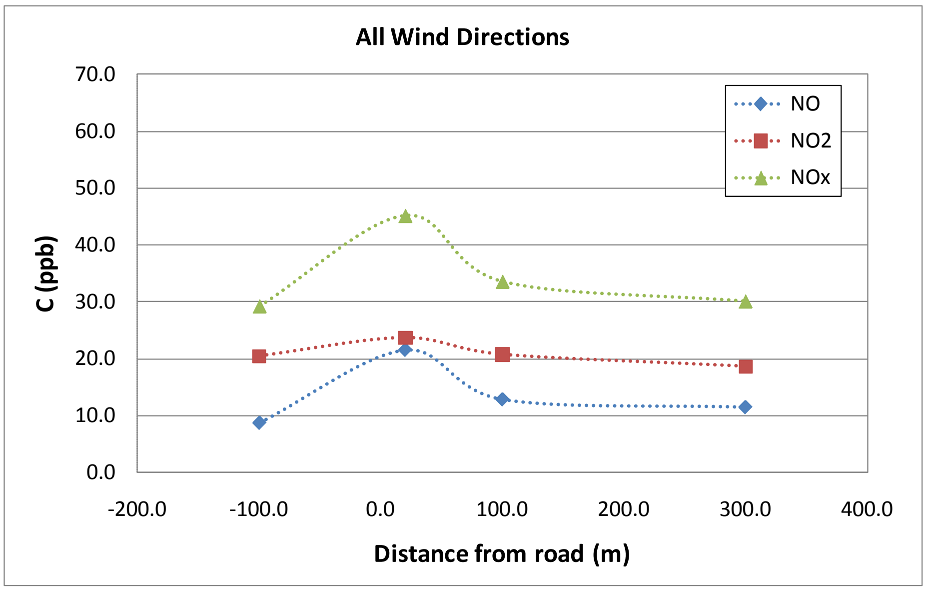

Figure 5. Average concentrations of NO, NO_2 and NO_x measured at all four monitoring stations indicating long-term trends in concentration gradients for each pollutant.

Figure 5 note: The lines connecting the points are provided as a visual aid to the reader and do not imply statistically significant differences in concentrations.

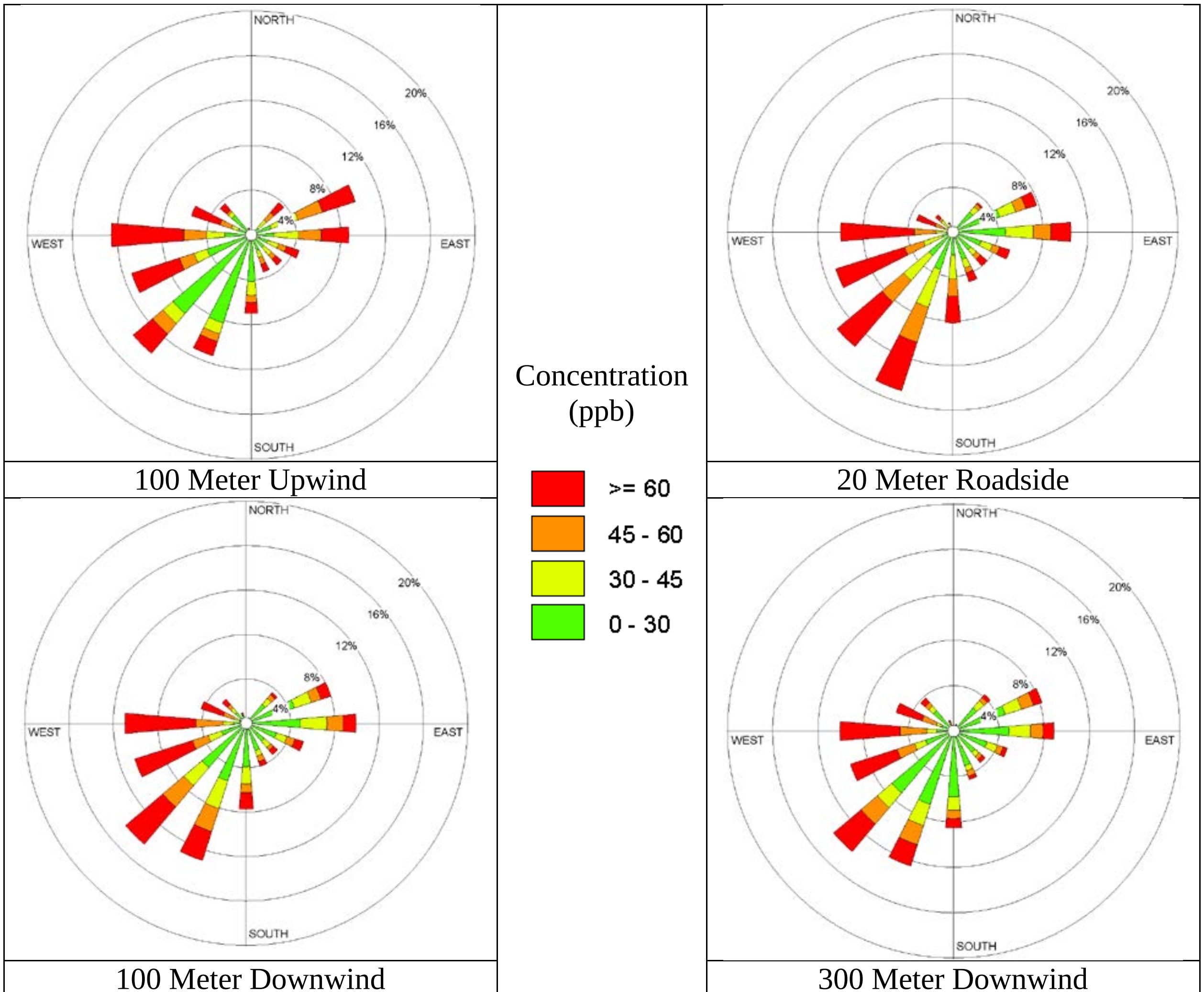

Figure 6. Pollution Rose for NO_2 for all stations, all wind directions.

Note that higher average NO, NO_2 and NO_X concentrations and generally steeper gradients were observed during conditions when the winds are from the roadway as opposed to all wind directions (Figure 7). This was also observed in CO concentration plots, Figure 8 and Figure 9.

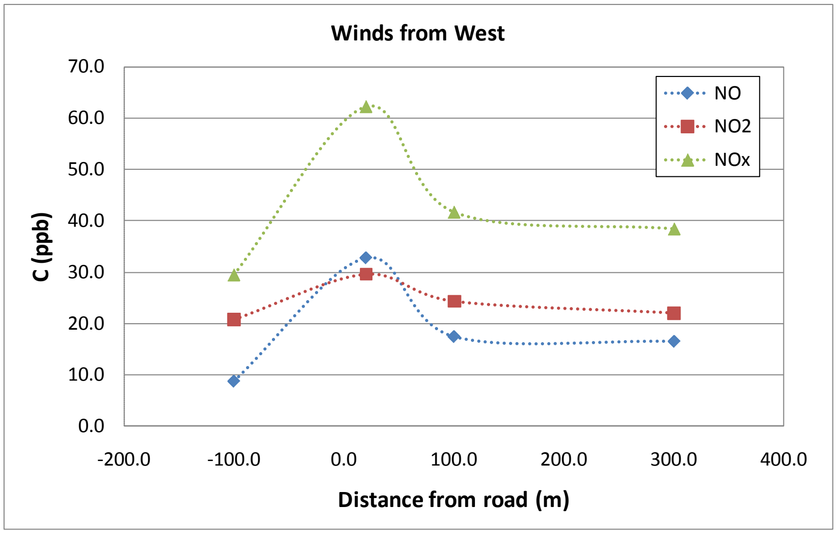

Figure 7 Average concentrations of NO, NO_2, and NO_x measured at all four monitoring stations indicating long-term trends in concentration gradients for each pollutant—winds from west.

Figure 7 note: The lines connecting the points are provided as a visual aid to the reader and do not imply statistically significant differences in concentrations.

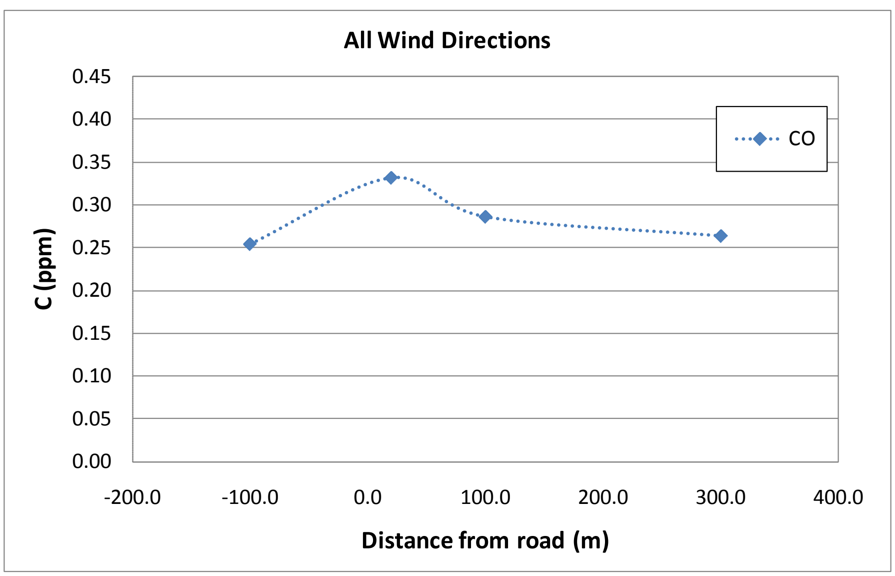

Figure 8 Average CO concentrations – winds from all wind directions.

Figure 8 note: The lines connecting the points are provided as a visual aid to the reader and do not imply statistically significant differences in concentrations.

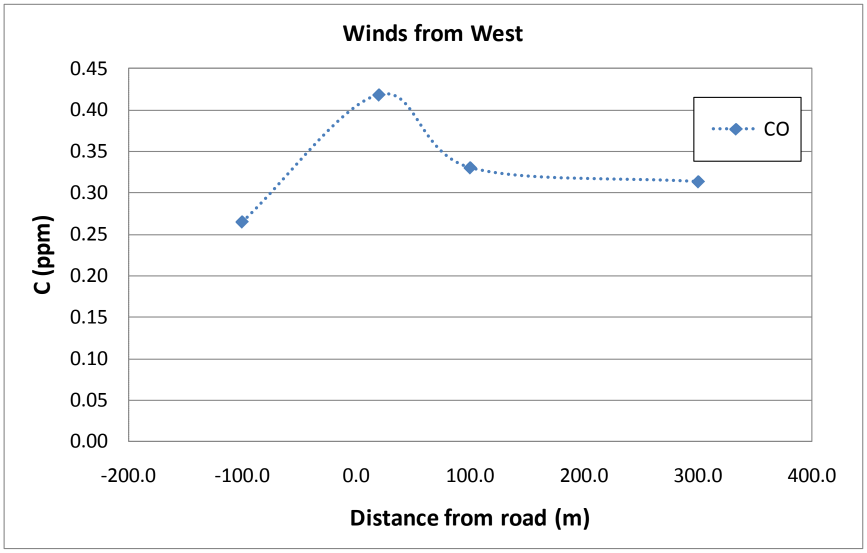

Figure 9. Average CO Concentrations -- winds from west.

Figure 9 note: The lines connecting the points are provided as a visual aid to the reader and do not imply statistically significant differences in concentrations.

Air Quality – Integrated Samples -- VOC

Table 2 shows the number of observations, mean and 95% confidence intervals for the VOC data (TO-15 method). As shown in Table 2, Station 2 exhibits higher values for two of the pollutants (benzene). This may be due to influences from other nearby sources such as Las Vegas Blvd., McCarran International Airport, nearby truck parking lot as shown in Figures 48 and 49 in the main body of the report.

Table 2. VOC -- averages for all wind directions (12/15/2008-12/15/2009)

Site name	Distance from Road	N (Obs.)	Mean (ppb)	95% CI (ppb)
1,3-Butadiene				
Station 4	100 Meter Upwind	251	0.05	0.04-0.05
Station 1	20 Meter Roadside	276	0.06	0.05-0.07
Station 2	100 Meter Downwind	246	0.06	0.05-0.07
Station 3	300 Meter Downwind	246	0.03	0.03-0.04
Benzene				
Station 4	100 Meter Upwind	251	0.20	0.18-0.22
Station 1	20 Meter Roadside	276	0.22	0.20-0.24
Station 2	100 Meter Downwind	246	0.32	0.29-0.35
Station 3	300 Meter Downwind	246	0.16	0.15-0.18

NOTE: Data are for valid samples only.

Data Caveats– Integrated Samples -- VOC

A more complete discussion of data caveats may be found in the main body of the report. The VOC data were not background corrected. This was deemed unnecessary as the field blank values were either zero or below the method detection limit. It should be noted that acrolein values for the TO-15 method (canister) are problematic. Prior to June 18, 2009 the GC/MS system was not optimized for acrolein analysis. In addition, there is low confidence with all acrolein values due to potential contamination of Summa passivated canisters associated with the "growth" of acrolein inside cleaned canisters. Acrolein concentrations inside cleaned canisters containing zero humidified air have been shown to increase over time due to causes that are unknown at this time. For these reasons, acrolein data are not reported for the TO-15 method (Table 2).

Air Quality – Integrated Samples -- Carbonyl

Table 3 shows the number of observations, mean and 95 percent confidence intervals for the carbonyl data (TO-11a method). Acetaldehyde measurements at Station 1 were approximately 10 percent higher than at Station 4. Acetaldehyde measured at Station 1 versus Station 2 was virtually the same. Formaldehyde measurements at Station 1 were approximately 18 percent higher and 10 percent higher than at Station 2 and 4, respectively. Acrolein measurements at Station 1 were approximately 14 percent higher than at Station 2. Acrolein measured at Station 1 versus Station 4 was virtually the same. Box-whisker plots (Figures 50 – 55) show all three pollutants for all wind conditions and downwind conditions.

Table 3. Carbonyl -- averages for all wind directions (12/20/2008-12/16/2009)

Site name	Distance from Road	N (Obs.)	Mean (ppb)	95% CI (ppb)
Acetaldehyde				
Station 4	100 Meter Upwind	279	1.02	0.94-1.11
Station 1	20 Meter Roadside	308	1.12	1.02-1.22
Station 2	100 Meter Downwind	225	1.11	1.00-1.21
Station 3	300 Meter Downwind	---	---	---
Formaldehyde				
Station 4	100 Meter Upwind	279	2.91	2.73-3.10
Station 1	20 Meter Roadside	308	3.18	2.97-3.39
Station 2	100 Meter Downwind	225	2.62	2.45-2.79
Station 3	300 Meter Downwind	---	---	---
Acrolein				
Station 4	100 Meter Upwind	279	0.27	0.26-0.29
Station 1	20 Meter Roadside	308	0.27	0.25-0.28
Station 2	100 Meter Downwind	225	0.27	0.25-0.29
Station 3	300 Meter Downwind	---	---	---

NOTE: Data are for valid samples only.

Data Caveats– Integrated Samples -- Carbonyl

As shown in Table 3, the study did not provide any usable data for Station 3. The instrument at Station 3 had problems throughout the life of the study. Thus, all carbonyl data collected at Station 3 is considered invalid. Background corrections were not performed on the formaldehyde data. This was deemed unnecessary as the field blank values were either zero or below the method detection limit. Background corrections were performed on the acetaldehyde and acrolein data. A more complete discussion of the background corrections performed on the acetaldehyde and acrolein data may be found in the main body of this report.

Air Quality – Integrated Samples – $PM_{2.5}$

A summary of $PM_{2.5}$ averages and confidence intervals are shown in Table 4. Figure 10 shows box-whisker plots $PM_{2.5}$ integrated filter samples. As shown in Table 4 and Figure 10, the 20 m site (Station 1) has an observed higher mean $PM_{2.5}$ concentration than the other sites. Station 1 is approximately 19 percent, 11 percent, and 9 percent higher than Station 2, 3, and 4 respectively.

Table 4. $PM_{2.5}$ Filters -- averages for all wind directions (12/20/2008-12/15/2009)

Site name	Distance from Road	N (Obs.)	Mean (µg/m^3)	95% CI (µg/m^3)
Station 4	100 Meter Upwind	30	9.20	7.63-10.79
Station 1	20 Meter Roadside	29	10.03	8.56-11.50
Station 2	100 Meter Downwind	30	8.42	6.99-9.85
Station 3	300 Meter Downwind	29	9.05	7.51-10.58

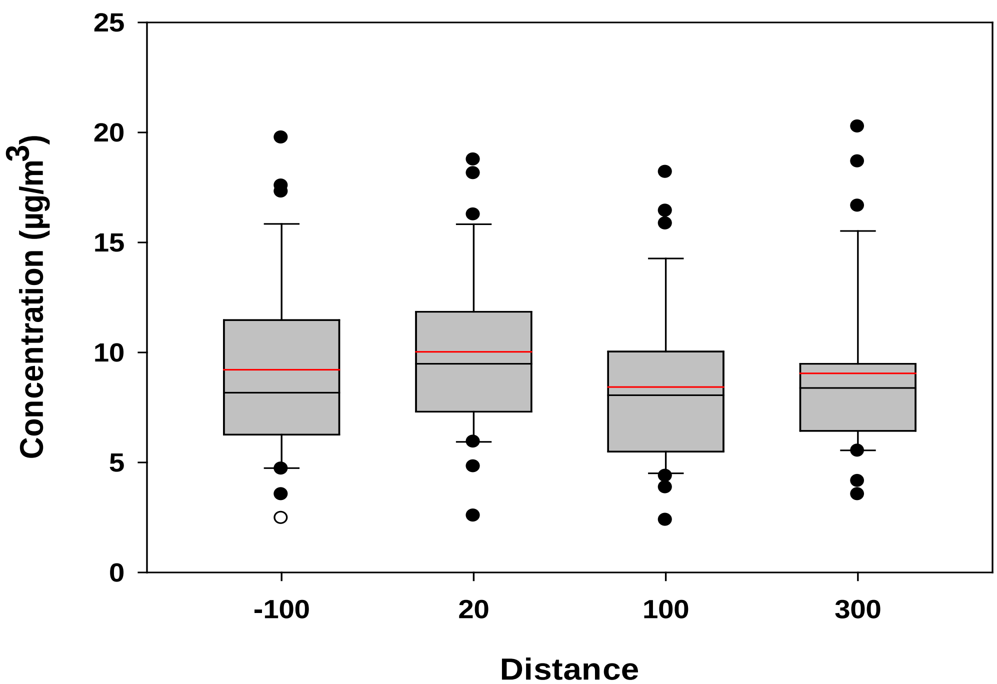

Figure 10 Box-Whisker Plot for $PM_{2.5}$ for all stations, all sample times, all wind directions.

Part VI: Summary

This report provides a summary of a field study conducted in Las Vegas, NV from mid-December 2008 thru mid-December 2009. The objective of this research study has been to determine MSAT concentrations and variations in concentrations as a function of distance from the highway and to establish relationships between MSAT concentrations as related to highway traffic flows including traffic count, vehicle types and speeds, meteorological conditions, such as wind speed and wind direction, and other pollutants primarily emitted from motor vehicles such as CO, NO, NO_2, NO_X, BC, PM_{10}, $PM_{2.5}$, PM Coarse, and MSATs. More detailed statistical and analytical results may be found in the main body of this report. These detailed results support the following preliminary conclusions:

- Concentration gradients are observed for gaseous pollutants and black carbon associated with distance from roadway.
- Higher pollutant concentrations are observed with higher traffic volumes, although higher wind speeds during peak traffic periods (especially during the morning commute) can offset this effect and increase atmospheric mixing height.
- Effect of wind speed appears to be a factor with regards to concentration gradient (e.g., dilution effect).
- Non I-15 sources may be larger contributors than previously expected (Figure 48 and Figure 49), for example:
    - Impact of near-by parking lot may be a factor at 100 m downwind and 300 m downwind sites.
    - Las Vegas Boulevard (300 m downwind site)
    - Airport and other potential sources

Preliminary results of this study provide indications that highway vehicle emissions impact near-road air quality. Known highway vehicle pollutants such as CO, NO, NO_2, NO_X and BC have elevated concentrations in a near-road environment and decrease as one moves away from the road. Additional analysis of the data is needed to more accurately quantify the effect of wind speed as well as other near-road effects.

Part VII: Lessons Learned

Costs, timeliness, and other operational factors are just some of the site implementation variables that are difficult to control. These implementation variables include site access and permissions, electrical connectivity, security, communications, site operators, and equipment. Costs may be estimated but there may be factors beyond one's control that influence the outcome of the costs. An example of this was that in order to obtain electrical services for the Las Vegas study site, electrical conduit needed to be installed underground. This underground installation encountered a caliche geological formation, which is hardened sedimentary rock prevalent in the Las Vegas area. This necessitated the use of jackhammers to install the underground conduit; a much more expensive operation than the use of the typical backhoe. An additional example was the performance of an analytical instrument utilized in the study. This instrument had both design and manufacturing issues that only became apparent after the instruments had been deployed. The remedy for this situation was that the manufacturer performed an "in the field upgrade." Projects of this nature present myriad challenges both from a programmatic and technical perspective.

Access to sites owned by private citizens can be challenging. Adjacent property owners may understand the necessity of improving the state-of-the-science, benefiting the community at-large and have a desire to be a "good" citizen, but existing lease and financial issues are a deterrent to participation. In addition, liability, insurance compensation, hassle factor(s), and other real and perceived issues present obstacles to site access.

Electrical and communications companies have numerous requirements for obtaining their services. This process requires interactions with utility companies as well as local (i.e., county or city) inspections departments.

Part VIII: Uncertainties

Study Design. This study focused on a single location (freeway) in one city. Additional locations will be needed to fully assess air pollutant concentration gradients from different roadway types; different traffic patterns; geographic locations; meteorological conditions, and other factors.

Methods. The analytical methods implemented during this study followed EPA standard methods and Federal Reference Methods for performing ambient air measurements. Refinements to methods can and do occur over the course of time due to improved technologies and measurement techniques, however the most current technologies and techniques were implemented for this study

Data. Uncertainties in the data may be considered in two parts: overall data integrity, individual measurements. Electronic data streaming was utilized whenever possible to lessen the chance of human error (i.e., transcription error) and ensure overall data integrity. When hardcopy data sheets, notes, and chain-of-custody forms were utilized, an EPA staff member reviewed the hardcopy and verified the data. Quality assurance of the data (i.e., individual measurements) is an on-going process and often occurs during more specific data analysis. Given that this project generated gigabytes of data, thorough quality assurance of the data is an on-going activity.

Part IX: Conclusions

The FHWA and EPA collaborated on a research effort to characterize the impact and behavior of particulate matter with aerodynamic diameter less than 2.5 microns ($PM_{2.5}$), MSATs near highways and other pollutants primarily emitted from motor vehicles such as CO, NO, NO_2, NO_X and BC. This study was conducted from mid-December 2008 thru mid-December 2009. The preliminary results of this study have been summarized in this Executive Summary and are described in more detail in the following sections of this report. Additional data analysis will be required over the coming months to adequately assess the significance and implications of the results of this study.

FHWA and EPA

National Near-Road Study

1 Introduction

In 2002, the Sierra Club legally challenged the U.S. Department of Transportation (DOT) Federal Highway Administration (FHWA) and the Nevada Department of Transportation's (NDOT) National Environmental Policy Act (NEPA) document related to the proposed widening of U.S. 95 in Las Vegas, Nevada, including the assessment of impacts of mobile source air toxics (MSATs) from the proposed project. FHWA entered into a Settlement Agreement with Nevada DOT and the Sierra Club, wherein the FHWA agreed to undertake a research effort to characterize the impact and behavior of particulate matter with aerodynamic diameter less than 2.5 microns ($PM_{2.5}$) and MSATs near highways.[1] The Federal Highway Administrator contacted all 50 States requesting that the States participate in this research study. Two States volunteered: Nevada and Michigan.

The FHWA and U.S. Environmental Protection Agency (EPA) determined that it would be in the best interest of both organizations to implement this project in a collaborative manner, allowing a more effective utilization of staffing and resources. One of the first steps of the project implementation has been the selection of a suitable ambient air monitoring site in or around Las Vegas, Nevada.

2 Background

The objective of the study was to determine MSAT concentrations and variations in concentrations as a function of distance from the highway and to establish relationships between MSAT concentrations as related to highway traffic flows including traffic count, vehicle types, and speed; and meteorological conditions such as wind speed and wind direction.[2]

Studies have demonstrated that spatial gradients of several traffic-emitted air pollutants (e.g., NO_x, CO, elemental or black carbon, ultrafine and coarse particles, and mobile source air toxics) decrease with distance from the road, generally returning to levels comparable to concentrations upwind of the road within a few hundred meters downwind[5,6]. Some studies show that fine particulate matter ($PM_{2.5}$) is only moderately impacted by traffic with greater contributions of ultrafine and coarse particles[5,6]. The extent of the spatial impacts of traffic related air pollutants is related to factors including the type of roadway, traffic volume and intensity, and meteorology[5,6,7,8]. The areal extent of traffic generated particles, especially ultrafine particles, has been shown to vary diurnally and seasonally with the greatest spatial extent of the roadway plume occurring at night and during winter[9,10]. The composition of PM near roads is also impacted by traffic emissions with greater quantities of a number of metals including copper, iron, and antimony[11,12]. While most studies have focused on the criteria air pollutants PM, CO, and NOx, less information exists concerning the spatial distribution of MSATs near-roadways[1,7,13].

This report describes the methods and initial results from research conducted to evaluate mobile source contributions to criteria, air toxics and $PM_{2.5}$ pollutant concentrations, and their dispersion patterns near a highway in Las Vegas, Nevada.[2]

3 Study Design

The objective of the research study is to determine pollutant concentrations and the variation of pollutant concentrations as a function of distance from the highway (Figure 11). Additional important considerations of the study include establishing relationships between pollutant concentrations as related to highway traffic characteristics including traffic count, vehicle types and speeds, and meteorological conditions such as wind speed and wind direction. This study provided detailed concentration data and distributions of motor vehicle emitted pollutants including regulated gases, air toxics, and particulate matter.[3]

3.1 Detailed Monitoring Protocol

FHWA's "detailed monitoring protocol" outlines a uniform approach to conduct all studies for evaluating mobile source contributions to air toxic compounds and $PM_{2.5}$ and their dispersion patterns[2]. A more detailed examination of the monitoring protocol indicates that for each city, continuous monitoring and integrated sample collection were required at four monitoring sites (Figure 11). In addition, wind speed and wind direction was required at each site. Moreover, monitoring for the complete suite of meteorological parameters was required at the monitoring station positioned 50 to 150 m from the roadway (100 m downwind). Table 1 summarizes the measurements taken at each monitoring site and Table 5 summarizes measurement parameters, sampling approach, and instruments.

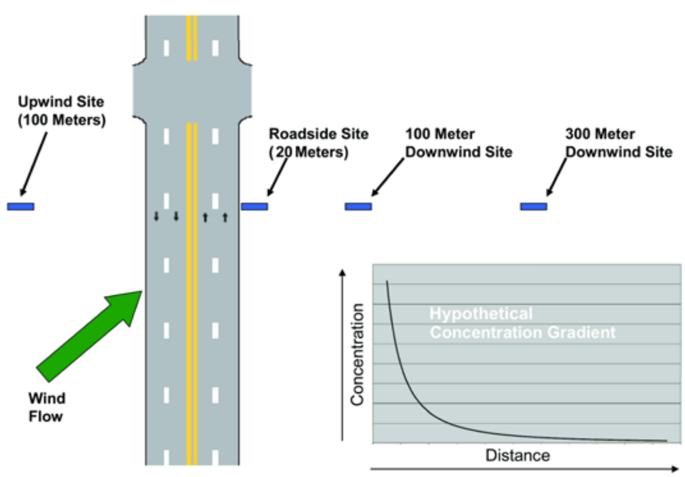

Figure 11. Illustration of Monitoring Site Locations.

Table 5. Summary of Measurement Parameters, Sampling Approach and Instruments.

Measurement Parameter	Sampling Approach	Instrument Data				
		Make/Model	Accuracy	Precision	Detection Limit	Sample Type and Frequency
Carbon Monoxide (CO)	nondispersive infrared	EC 9830T	± 5% 0-1000ppb	0.5% of reading	25 ppb	
		Serinus 30	< 1%	20 ppb or 0.1 % of reading	40 ppb	
Oxides of nitrogen (NO_x)	chemiluminescence	EC 9841B	< 1%	0.5 ppb	0.5 ppb	
Black Carbon (BC)	Aethalometer	Magee – Aethalometer, Models AE16 and AE20	1:1 comparison w/ EC on filters	Repeatability: 1 part in 10,000	0.1 µg/m^3 w 1 min res.	
$PM_{2.5}$	$PM_{2.5}$ FRM method	FRM BGI PQ200				24-hour integrated 1-in-12 day schedule 1 sample each day at each road-side location
$PM_{2.5}$	TEOM	Thermo TEOM – 1405DF	±0.75%	±2.0 µg/m³ (1-hour ave), ±1.0 µg/m³ (24-hour ave)	0.1 µg/m³	Continuous (5 minute)
PM_{10}						
PM Coarse						
Acetaldehyde	USEPA Method TO-11A	Atec 2200 Cartridge Sampler	± 2 %	± 2 %	N/A	1-hour integrated 1-in-12 day schedule 9 samples each day at each road-side location
Formaldehyde						
Acrolein	USEPA Method TO-15	Entech 1800 Canister Sampler	± 2 %	± 2 %	N/A	
Benzene						
1,3-Butadiene						
Wind Speed	sonic anemometer	RM Young Model 81000	±0.05 m/s	std. dev. 0.05 m/s at 12 m/s	0.01 m/s	Continuous (5 minute)
Wind Direction			± 5°	± 10°	0.1°	
Air Temperature	temperature probe	Vaisala HMP45D	±0.2°C at 20° C	0.1 ° C	0.1 ° C	
% Relative Humidity	relative humidity sensor	Vaisala HMP45A	±2%RH from 0…90% RH)	1% RH	1% RH	

Measurement Parameter	Sampling Approach	Instrument Data				
		Make/Model	Accuracy	Precision	Detection Limit	Sample Type and Frequency
Rain Gauge	rain bucket	Ecotech Rain Gauge	+/- 5% at 25-50 mm/hour	± 1mm	± 1mm	
Solar Radiation	solar radiation	MetOne 394 Pyranometer	±5% from 0…2800 watts meter[2]	±1% constancy from -20°C to +40°C	9 mV/kwatt meter-2, approx	
Sound	microphone	Extech 407764	±1.5dB (under reference conditions)	0.1dB	0.1dB	
Video	video	Axix 223M Vivotek SD7151	N/A			Continuous (15 minutes)
Vehicle Count	radar	NDOT Data and Equipment (Wavetronix)				
Vehicle Speed						
Vehicle Type						

1. Accuracy and precision in terms of ultrafine particle concentration is difficult to determine in the field due the lack of particle concentration standards. However, particle counters are routinely verified in the field for accuracy in flow rate. Precision was estimated in this study by collocating UFP samplers prior to use of instruments in the field.

3.2 Study Design Enhancements

Enhancements to the study protocol included 3-additional CO monitors and 3-additional aethalometers to more fully characterize the freeway "cut-section" and sound meter and video camera to monitor train and plane activity from the railroad and nearby airport, respectively. The video was also used to validate traffic count information received from NDOT.

3.3 Site Location

The site selection process consisted of a series of seven steps: (1) determine site selection criteria[2]; (2) develop list of candidate sites and supporting information; (3) apply site selection filter ("coarse" and "fine"); (4) site visit; (5) select candidate site(s) via team discussion; (6) obtain site access permission(s); and (7) implement site logistics. This process resulted in the selection of a location along I-15, just south of the "Las Vegas Strip".[3]

This site was considered the optimal site of all the candidate monitoring sites[3]. This site has high AADT (206,000 AADT for 2006), no noise walls, meteorological and traffic data availability, manageable site logistics including ROW access, and favorable wind direction[3]. This location is shown in Figure 1.

4 Site Selection Methodology and Site Selection Criteria

4.1 Methods

The site selection process consisted of a series of seven steps as shown in Table 6 and Figure 12. Each of these steps has varying degrees of complexity due to "real-world" issues. The first step, determining site selection criteria (Table 7), had been developed by FHWA prior to the site selection process and documented in the monitoring protocol [2]. The follow-on steps (Table 6) include: (1) determine site selection criteria; (2) develop list of candidate sites and supporting information; (3) apply site selection filter ("coarse" and "fine"), (4) site visit; (5) select candidate site(s) via team discussion; (6) obtain site access permission(s); and (7) implement site logistics.

Table 6. Site Selection Process Steps.

Step	Site Selection Steps	Method	Comment
1	Determine Site Selection Criteria	Monitoring Protocol	Developed by. FHWA
2	Develop List of Candidate Sites	GIS Data; Site Visit(s)	Additional sites added as information is developed.
3	Apply Coarse Site Selection Filter	Team Discussions, Management Input	Eliminate sites below acceptable minimums.
4	Site Visit	Field Trip	Application of Fine Site Selection Filter
5	Select Candidate Site(s)	Team Discussions, Management Input	
6	Obtain Site Access Permissions	Contact Property Owners	If property owners do not grant permission, then the site is dropped from further consideration.
7	Site Logistics (i.e., physical access, utilities – electrical and communications)	Site Visit(s), Contact Utility Companies	

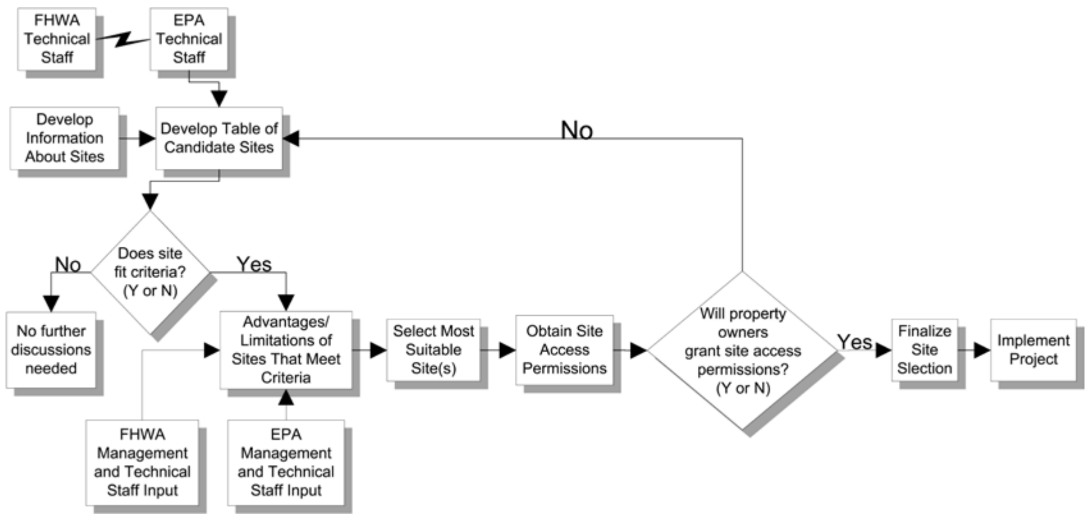

Figure 12. Decision Process Schematic.

Table 7. Selection Considerations and Settlement Agreement Criteria.

Selection Considerations	Monitoring Protocol Criteria
AADT (> 150,000)	Only sites with more than 150,000 annual average daily traffic (AADT) are considered as candidates.
Geometric Design	The geometric design of the facility, including the layout of ramps, interchanges and similar facilities, will be taken into account. Where geometric design impedes effective data collection on MSATs and $PM_{2.5}$, those sites will be excluded from further consideration.
Topology (i.e., Noise Barriers, Road Elevation)	Sites located in terrain making measurement of MSAT concentrations difficult or that raise questions of interpretation of any results will not be considered. For example, sharply sloping terrain away from a roadway could result in under representation of MSAT and $PM_{2.5}$ concentration levels on monitors in close proximity to the roadway simply because the plume misses the monitor as it disperses.
Geographic Location	Criteria applicable to representing geographic diversity within theUnited States as opposed to within any given city. Thus, this criterion is not explicitly included in Table 3.
Availability of Data (Traffic Volume Data)	Any location where data, including automated traffic monitoring data, meteorological or MSAT concentration data, is not readily available or instrumentation cannot be brought in to collect such data will not be considered for inclusion in the study.
Meteorology	Sites will be selected based on their local climates to assess the impact of climate on dispersion of emissions and atmospheric processes that affect chemical reactions and phase changes in the ambient air.
While not explicitly included in the Monitoring Protocol, the following selection criteria were deemed important to the selection process and were included.	
Downwind Sampling	Any location where proper siting of downwind sampling sites is restricted due to topology, existing structures, meteorology, etc., may exclude otherwise suitable sites for consideration and inclusion in this study.

Selection Considerations	Monitoring Protocol Criteria
Potentially confounding air pollutant sources	The presence of confounding emission sources may exclude otherwise suitable sites for consideration and inclusion in this study.
Site Access (Admin/Physical)	Any location where site access, is restricted or prohibited either due to administrative or physical issues, will not be considered for inclusion in the study.

4.2 Candidate Site Listing

The purpose of any site selection process is to gather and analyze sufficient data that would lead one to draw informed conclusions regarding the selection of the most appropriate site for the monitoring that will be performed in Las Vegas, NV.

A list of candidate sites was developed using the monitoring protocol's site selection criteria. We used geographic information system (GIS) data, tools and techniques and on-site visits by project team members as a means of developing supporting information regarding each potential site. The Nevada Department of Transportation (NDOT) provided annual average daily traffic (AADT) counts and their associated spatial coordinate locations. Other types of spatial data (e.g., street network) were downloaded from the Clark County GIS web site as well as other relevant web sites. Non-spatial data (meteorological data) were downloaded from the National Climatic Data Center for Las Vegas, NV. ArcGIS 9.2 was used to create the maps for the site selection process. WRPLOT View by Lakes Environmental was used to create wind rose plots for the meteorological data. In addition, site visits provided information not readily available elsewhere or provided information not easily gained from site maps.

Initially, the targeted site to conduct the monitoring in Las Vegas, NV was at the O.K. Adcock Elementary School. This was one of the three schools named in the settlement agreement. However, after further investigation and analysis it became apparent that a more formalized site selection process to either confirm or deny the suitability of this site for our project would be required. During this process, the O.K. Adcock Elementary School became increasingly less acceptable as the optimal site owing to the presence of large noise barriers (> 15 feet in height), very poor quality wind rose data (prevailing winds channeled down roadway as opposed to across), lack of access for site installation (no access at roadside due to noise barriers) and the roadway being below grade. In essence, the O.K. Adcock site is on top of an urban canyon.

Thus, it became necessary to expand our search for a more optimal site through a more formal process.

Stepping through the process, a list of 19 of the 22 sites was developed (See Table 8). Three additional sites were added during an on-site visit to Las Vegas during the Spring of 2007. This list contains sites that are located along interstate or U.S. highways, State highways or major streets that would be of interest to a project of this nature. At this point, the list also included sites that might be below certain minimum requirements (e.g., AADT < 100,000).

Table 8. Table of All Sites Considered.

Candidate Locations		Selection Considerations						
		AADT (2006)	Topology		Meteorology	Traffic Volume Data	Downwind Sampling	Nearby Sources
			Noise Barriers	Road Elevation				
Interstate/US Highway								
1	O.K. Adcock School	Y	Y	BG	NW	Y	S	N
2	Fyfe/Western Schools	Y	Y	AtG/BG	NW	Y	S	N
3	Sunset/Lake Meade Interchange – US95	N	N	AtG/BG	SW	N	S	CM/S
4	I-215 (Between Warm Springs/Robindale)	Y	Y	AG	SW	N	S	N
5	I-215 (Vicinity of E. Pebble Rd)	N	P	AtG/AG	SW	N	S	N
6	I-215 (East of I-15)	Y	N	BG	SW	N	S	M
14	Flamingo & I-15	Y	N	AtG	SW	N	C	UT
15	I-215 (Eastern & Pebble)	N	N	AG	SW	N	S	N
16	US95 (Kelso Dunes/Auto Mall)	N	N	AtG	SW	N	S	CM/S
17	US95 (Gibson/Sunset Area)	N	N	AtG	SW	N	S	S
18	US95 (Sunset & I-515)	N	N	AtG	SW	N	S	S
19	I-15 (Martinez School)	N	N	AtG	NW		C	RS
20	I-15 (Vicinity of Ensworth)	Y	N	BG / Modest Cut	SW	Y	S	M
21	US95/Lake Meade Blvd.	N	N	AG	W	N	CM/S	UT
22	I-215 (Vicinity of Jones Road)	N	N	AtG	W/SW	N	S	N
Major Street								
7	E. Flamingo Rd	N	N	AtG	SW	N	CM	UT
8	W. Flamingo Rd / S. Decatur Blvd	N	N	AtG	SW	N	CM	UT
State Highway								
9	W. Summerlin Pkwy (1)	N	Y	AtG	NW	N	R	N/C
10	W. Summerlin Pkwy (2)	N	Y	AtG	NW	N	R	N/C
11	US95 East of Rancho Dr.	N	P	BG	NW	N	R/S	N/C
12	W. Summerlin Pkwy (3)	N	P	AtG	NW	N	R/S	N/C
13	W. Summerlin Pkwy (4)	N	P	AtG	NW	N	R/S	N/C
Selection Considerations		**Table Legend**						

Candidate Locations		Selection Considerations						
		AADT (2006)	Topology		Meteorology	Traffic Volume Data	Downwind Sampling	Nearby Sources
			Noise Barriers	Road Elevation				
AADT		> 150, 000 = Y (Yes); otherwise N (No)						
Topology	Noise Barriers	Yes/No; P = Partial						
	Road Elevation	AG = Above Grade; BG = Below Grade; At Grade = AtG						
Meteorology		SW = McCarran – SW winds; NW = North LV – NW winds; W = Westerly winds						
Traffic Volume Data		Operational = Y (Yes); otherwise N (No)						
Downwind Sampling		R = Residential; C = Complex (mixed commercial) ; S = Semi-open fields;						
Nearby Sources		N = None; UT = Urban Traffic; M = McCarran International Airport; S = Sand/gravel; RS = Railroad/Scrap Yards; C = Construction Possible Construction; CM = Commercial; R = Residential						

4.3 Application of Coarse Site Selection Filter

A series of joint-agency team meetings were held which resulted in reducing the number of sites from a list of 22 to approximately four sites. [14,15] This step involved a review of the full table of candidate sites and eliminating sites that obviously did not meet minimum site criteria requirements (Table 7). After applying the site selection criteria as a set of "filters" we eliminated most candidate sites. For example, the first filter eliminated sites with low AADT (i.e., < 100,000). Further, the presence of extensive noise barriers eliminated additional sites. Other filters, complex geometric design or lack of available traffic volume data eliminated additional sites. Other criteria of interest, while not explicitly stated in the monitoring protocol, include restricted downwind sampling, presence of confounding air pollutant sources and site access (administrative and physical).

4.4 Ground Truthing

During the first site visit to Las Vegas, all sites considered to be primary sites were visited, i.e., Sites 6, 11, 1 and 15. However, these sites were considered to be unsuitable based on previously unforeseen factors that had not been readily obvious from our earlier analysis. These factors included the roadway being above/below grade and presence of noise barriers. Site 19, which was also visited, was deemed to be unsuitable for several reasons: confounding winds, adjacent railroad (main line) and the presence of confounding air pollutant sources (nearby vehicle scrappage plants). Moreover, the Nevada Department of Transportation (NDOT) staff provided information indicating that this location would be in the path of an upcoming "design-build" highway project thus making this location unsuitable.

During this site visit the remaining, available candidate sites were also eliminated. It was also during this visit that three additional sites were added to the list of candidate sites (Table 8). These additional sites were added based on "real-world" observations at these locations and how well these locations met the site selection criteria. It is important to note that it is not always possible to determine the most suitable sites without an actual site visit. Thus, sites may be added or deleted based on factors not previously known. In this case, these additional candidate sites were Sites 20, 21 and 22. Site 20 was deemed the most promising for several reasons: high AADT (> 190,000), lack of noise barriers, road being at or near grade, acceptable downwind sampling, and acceptable meteorology.

An important component of "ground truthing" during the site visit was to obtain information from local sources. For purposes of this project, both NDOT and Clark County Department of Air Quality and Environmental Management (DAQEM) staff provided information regarding local meteorological and road conditions that would have been difficult, if not impossible, to obtain otherwise. Too often, local resources are overlooked during a decision process such as this which can in turn lead to poor decisionmaking [14,15].

4.5 Geospatial Tools

Historically, the use of spatial tools (e.g., GIS) in decision processes has been somewhat problematic in part due to the magnitude of the data required by a GIS, perception and reality of operating GIS software, and the level-of-knowledge required by end-users to manipulate data in a GIS. [16,17] In the last 15 years, GIS data have become more readily available in both quantity and quality. Moreover, the realization of easy-to-use GIS software and GIS tools (in a Microsoft Windows® environment) has made implementation of GIS-based decision support tools more practical.

An example of the use of GIS as an environmental site selection decision support tool is its use in siting a landfill [18]. Required typical data layers include: the location of suitable soils, wells, surface water sources, residential areas, schools, airports, roads, etc. From these data layers queries are formulated to provide the most suitable site(s). For example, a landfill should not be in the vicinity of an airport due to safety issues (i.e., aircraft striking birds) but would require suitable soil (i.e., soils with low permeability). A landfill should not be in the vicinity of wells or other water sources due to the issue of landfill leaching. Quantitative weighting criteria are associated with the siting criteria as well as elements of the data layers (e.g., certain types of soils would be more suitable than others and thus would have applicable quantitative values) [18].

Landfill siting by GIS has both similarities and differences to the near-road monitoring siting described by this report. Data layers relevant to near-road air quality monitoring are shown in Table 9. Numerous maps and based on near-road monitor site selection criteria (Table 7) were applied; advantages and disadvantages of each site were considered, with the ultimate decision that Site 20 would be the optimal site. The significant difference between air monitoring site selection process and the landfill example is that the former did not explicitly assign quantitative values to the selection criteria [16,19]. However, during the site visit and subsequent discussions quantitative values were implicitly assigned to the selection criteria. For example, sites with high AADT (> 150,000) were more highly “valued’ than sites with a lower AADT; and sites without noise barriers were “valued” more highly than sites with noise barriers. Thus, the decision process may appear to be based on a high degree of subjectivity given the lack of assigning quantitative values to the selection criteria. The process of intra-team communication and application of our site selection criteria [16,19] appropriately led to the selection of a site for this project based on numerous criteria.

ArcGIS 9.2 [20] was used to create the maps used in the site selection process. Spatial data were downloaded from the Clark County GIS web site as well as other relevant web sites. Table 9 shows the sources of data used for this site selection process. It should be noted that the use of maps for the site selection process is only a tool in the site selection process. It is very important in this process to perform site visits, establish contacts with State/local transportation agencies and environmental agencies. Typically, these groups will be able to provide up-to-date information as to site conditions that may ultimately influence site selection decisions.

Table 9. Spatial and Non-Spatial Data Inputs.

Data Input	Source	Comments
Spatial Data		
AADT	Nevada DOT	http://www.nevadadot.com/reports_pubs/traffic_report/2005/pdfs/Clark.pdf
		Excel spreadsheet with X, Y coordinates of AADT station locations and AADT counts.
Topology	Clark County GIS web site	http://gisgate.co.clark.nv.us/gismo/gismo.htm
	U.S. EPA/U.S. FHWA Personnel	Site visits by EPA/ FHWA personnel.
Potentially confounding air pollutant sources	U.S. EPA/U.S. FHWA Personnel	Site visits by EPA/FHWA personnel.
	Clark County GIS web site	http://gisgate.co.clark.nv.us/gismo/gismo.htm
Street Data	Clark County GIS web site	http://gisgate.co.clark.nv.us/gismo/gismo.htm
Points of Interest		
Administrative Boundaries		
Schools		
Aerial Imagery	GlobeXplorer	ImageConnect Service (ArcGIS)
	Google Earth	http://earth.google.com/
Non-spatial Data		
Selection Criteria	Settlement Agreement	http://www.fhwa.dot.gov/environment/airtoxicmsat/setagree.pdf
	Monitoring Protocol	http://www.fhwa.dot.gov/environment/airtoxicmsat/FinalDMPJune.pdf
Geometric Design, Geographic Location	Aerial Photos – Digital Globe – October 2005	Aerial images downloaded using ArcGIS tools.
Availability of Traffic Volume Data	Nevada DOT	Conference calls, site visit by EPA/ FHWA personnel.
Meteorology	National Climatic Data Center	http://cdo.ncdc.noaa.gov/CDO/cdo
	Clark County Air Quality	http://www.ccairquality.org/archives/index.html
Downwind Sampling	U.S. EPA/U.S. FHWA Personnel	Site visits by EPA/FHWA personnel.

4.6 Site Selection — Results and Discussion

Following the application of the selection criteria[14,15,21], the candidate sites were further prioritized during a series of team discussions between EPA and FHWA staff. The pros and cons of each site were discussed. Site 20 met or exceeded the AADT requirements (> 150,000), did not have noise barriers, did have acceptable downwind sampling and acceptable meteorology. An additional feature of this site was the availability of traffic count data. Traffic monitoring equipment was already installed and operating in the vicinity of this location.

Proper siting of downwind sampling locations was an important criterion for this project. Any location where proper siting of downwind sampling sites was restricted due to topology, existing structures, meteorology, or other conditions, excluded otherwise suitable sites for consideration and inclusion in this study. Meteorological conditions in Las Vegas were problematic as the city is located in a valley surrounded by mountains that channel the wind as shown in Figure 13. This channeling of wind presented technical challenges in site selection and achieving proper wind flow from the source to the detector (i.e., gas analyzers). As shown in Figure 14, the wind direction for Site 20 did have acceptable meteorological conditions. Site 20, on the other hand, is 1 km west of McCarran International Airport (nearby source) and is slightly below grade (modest cut) as shown in Figure 15. Another feature of note at this location was a spur line of the Union Pacific Railroad (UPRR). This is a commodity line that runs approximately 12 miles from Las Vegas, NV to Henderson, NV and passes this site twice a day (once in the morning and returns in the afternoon).

A construction project, in the vicinity of Site 20, involved the conversion of the inner shoulders and median to express lanes (lanes in either direction of travel). Based on information from the NDOT design engineer, there was minimal impact to our monitoring project for the following reasons: (1) construction involved the addition of center lanes—our project was on the shoulder behind a guardrail to the east of any construction activity; (2) the segment of roadway carries > 200,000 vehicles per day – diesel emissions from construction equipment were overwhelmed by the sheer volume of the on-highway vehicles; and (3) construction vehicles were not operated in "front of monitoring station" 24-hours per day—construction activity occurred along a 5-6 mile stretch of the freeway. Therefore, while not perfect, Site 20 was still a viable site.

Right-of-way (ROW) access was needed from both Nevada DOT and the UPRR. Other property owners in the vicinity of our location were reluctant to permit access to their property. Property owners may be reluctant to grant ROW access for a variety of reasons, including liability, financial issues, or suspicion of government activities. Therefore, access to any given property was not guaranteed. and researchers must be prepared for a long involved access process.

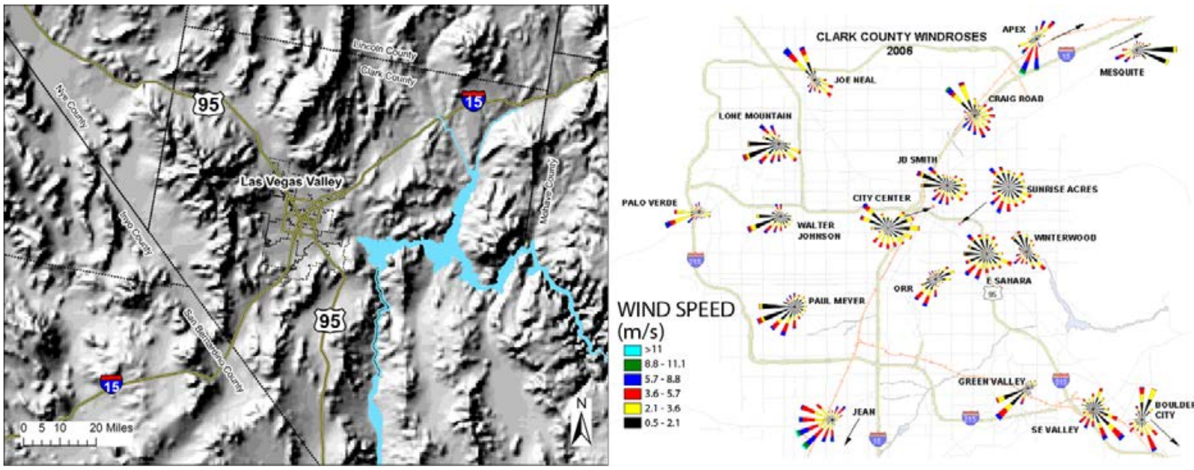

Figure 13. Las Vegas Topographic and Meteorological Conditions.

Source: Adapted from [22]

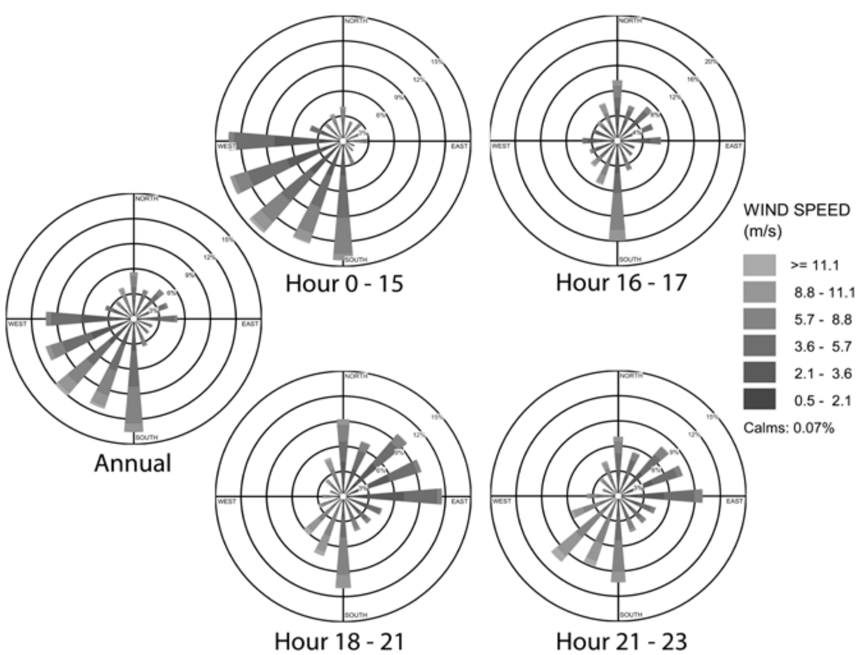

Figure 14. Wind Roses for Site 20 (McCarran International Airport).

Figure 15. Photos of Site 20.

The project participants recognized that no perfect air monitoring site was possible; trade-offs were a factor of the Las Vegas study and would be a factor with almost any other environmental study conducted within any other city. It was a question of balancing benefits with risks and costs. The selection was further complicated by external constraints and drivers. The principal constraint was the legal mandates of the Settlement Agreement, especially the data that must be derived pursuant to the monitoring protocol. Few, if any, design decisions can be made exclusively from a single perspective. These decisions can be visualized as attractions within a force field. If the factors are evenly distributed and weighted, the diagram might appear as that in Figure 16a and b. But, as a given differential force increases, that factor will progressively drive the decision. In the present case study, the decision is most directly influenced by legal requirements, but also needs to be scientifically credible and economically feasible (Figure 16a).

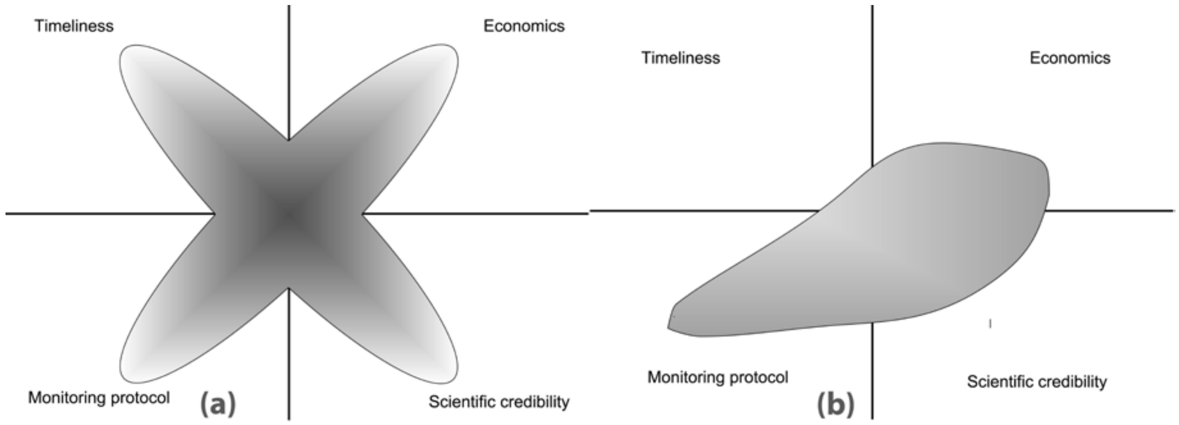

Figure 16a. Decision Force Field – Equal Weight Factors. (b). Decision Force Field – Unequal Weight Factors. Source: Adapted from D. Vallero and C. Brasier. (2008). *Sustainable Design: The Science of Sustainability and Green Engineering.* John Wiley & Sons, Inc. Hoboken, NJ.

As shown in Figure 16a, a number of factors have nearly equal weight in a design decision, Figure 16b indicates a decision that is most strongly influenced by legal constraints and drivers. For example, the stronger the influence of a factor (e.g., high AADT), the greater the decision will be drawn to that perspective. If the monitoring protocol is somewhat ambiguous, a number of alternatives are available, costs are flexible, and scientific credibility is minimally impacted, the design has a relatively large degree of latitude and elasticity. Note that all factors drive the decision, but that the monitoring protocol and other legal instruments have the greatest influence on the decision.

There is also the question of the best use of resources for this project. For example, a site could be chosen that would call for additional monitoring (and concomitantly additional resources) to overcome certain physical constraints (i.e., above/below grade, noise barriers); or, a site could be chosen that has some other issue such as low AADT or where traffic monitoring equipment would have to be installed. Some sites that would otherwise be favorable are near open areas, such as desert land that is prone to fugitive dust (common in unpaved or un-irrigated areas in Las Vegas).

Site 20 had high AADT (206,000 AADT for 2006), no noise barriers, meteorological and traffic data availability, manageable site logistics including right-of-way access, “clean geometric design", and favorable wind direction. Clean geometric design was defined as a facility that did not impede the effective data collection of MSATs and $PM_{2.5}$ [2]. For example, a clean geometric design would be a site that did not include multiple on/off ramps, interchanges, or other complicating facility characteristics. Of the disadvantages, Site 20 had a modest "cut" at that location and only for a short distance. The roadway passed under a railroad bridge (Figure 15) and returned to at/near grade conditions. Thus, this site was much more suitable than the urban canyon situation that exists with the O.K. Adcock site. In addition, McCarran International Airport, a source of vehicle and aircraft emissions, was approximately 1 km due east of Site 20; however the predominant winds at this location generally maintain the monitoring site upwind of the airport. The wind blows predominately from the southwest quadrant until approximately 3:00 pm. Beginning at about 3:00 pm in the afternoon, the winds shift and become more variable. In the late afternoon and early evening (6-9:00 pm), the winds are predominately from the east and northeast. Then, after 9:00 pm, the winds shift again into a more variable pattern. After midnight the winds return to blow predominately from the southwest. The wind roses shown in Figure 14 have been developed from meteorological data downloaded from the National Climatic Data Center, Years 1977 – 2007.

4.7 Site Logistics

Site logistics included, but were not limited to, obtaining site access permissions, gaining access to electrical power, communications connectivity, county/city permits, or arranging for security fencing. Site logistics, while not explicitly included in the monitoring protocol, was mission critical. Any location where site logistics, was restricted or prohibited either due to administrative or physical issues, was highly problematic and eliminated a site from further development. For this specific project, obtaining site access permissions, obtaining the proper electrical feed, communications connectivity and being able to establish security fencing was vital to the project.

Electrical and communications connectivity is also a very challenging activity. Utility companies have a multitude of requirements for obtaining their services. This is a very involved process that requires interactions with utility companies as well as local (i.e., county or city) inspections departments. Implementation of site logistics may require more time than is needed to obtain ambient air measurements for a given project.

4.8 Site Selection Summary/Conclusions

Site 20 was the site of choice with the most advantages and fewest disadvantages compared to other monitoring sites that have been considered. Site 20 had high AADT (206,000 AADT for 2006), no noise barriers, meteorological and traffic data availability, manageable site logistics including ROW access, and favorable wind direction. We attempted to develop the site somewhat further south than our final location. This would have been the more ideal location as the 20-meter roadside site would have been an at-grade site. However, the property owners would not agree to allow site access.

Meetings, teleconferences, site visits, and written reportsare key activities to any site selection process. These activities ensure that all interested parties are aware of the selection process. Moreover, this ensures that the pros and cons of each site are thoroughly considered and discussed and trade-offs among the various sites are weighed. Throughout this process, trade-offs will and do occur. For example, an ideal site for the air quality modelers (e.g., complex terrain) is not necessarily an ideal site from the perspective of the field researchers (e.g., less complex terrain, site access, etc.). For this project, a group consensus was reached, culminating in a written report for FHWA and U.S. EPA management.

5 Analytical Instruments and Methods

5.1 Data Logging and Time Synchronization

All continuous analyzer data were recorded using an Ecotech 9400TP data logger. These loggers were programmed to record continuous data (averages) at 5-minute intervals. Moreover, these data loggers were time synchronized to National Institute of Standards and Technology (NIST) time by accessing the NIST internet web site hourly and adjusting the data loggers' internal time clock accordingly.

5.2 WinAQMS and WinCollect Software

Ecotech WinAQMS server software was loaded onto the data loggers to handle communications between the continuous analyzers and the data loggers[23]. Ecotech WinCollect software was loaded onto a Windows XP workstation at the EPA Facility in RTP, NC to monitor and determine instrument status and performance, perform remote calibrations, determine data validity and download data from the remote field site to the Near-Road database[24]. This data was loaded into a SAS database for further quality assurance (QA) and data analysis.

5.3 Traffic Activity

Traffic data (vehicle count, vehicle speed, vehicle length) was obtained from the Nevada Department of Transportation's Freeway and Arterial System of Transportation (FAST). This data was an ASCII text file that was sent electronically to EPA. The traffic count system used by FAST is a radar-based system capable of counting and classifying vehicles by length. Each station is equipped with a 10.525 GHz frequency modulated continuous wave (FMCW) radar detector to continuously monitor vehicle length and speed, which includes volumetric flow over multiple lanes with a detection range up to 200 feet. The system can accommodate 6 classes. This traffic data was compiled approximately every 15 minutes and subsequently every hour to provide up to date information on traffic conditions.

Traffic data collected from FAST included two detector sites, one site monitoring the south bound traffic and the second site monitoring the north bound traffic, refer to Table 10. These monitors are located about 400 meters south of the I-15 site. The monitors detect actual free-flow highway conditions without disturbances from on or off exit ramps.

Table 10. Primary Traffic Detectors for I-15 Monitoring Study.

Freeway Segment	Latitude	Longitude
	Decimal Degrees	
I-15 Northbound	36.0724	-115.1803
I-15 Southbound	36.0733	-115.1811

The traffic data totals are always higher than the bin totals, this may indicate that the radar signal from the detector can not provide an appropriate length for binning but recognizes a vehicle present. The differences observed maybe due to partial occlusion of a smaller vehicle by a larger vehicle or improper mounting of the instruments. This trend is seen at both traffic locations.

To help account for these differences a traffic count based upon video recordings were done for sample hours to help determine if the traffic detectors were bias high or low in respect to traffic counts and fleet mix. Vehicles less than 30 feet of length were considered gasoline light-duty (LD) vehicles while vehicles over 30 feet were considered diesel heavy-duty (HD) engines. This comparison of video data with the data loggers will provide a qualitative comparison since visual counts of the vehicles are subject to some level of human error as well. Refer to Figure 17 for a comparison of selected target hours.

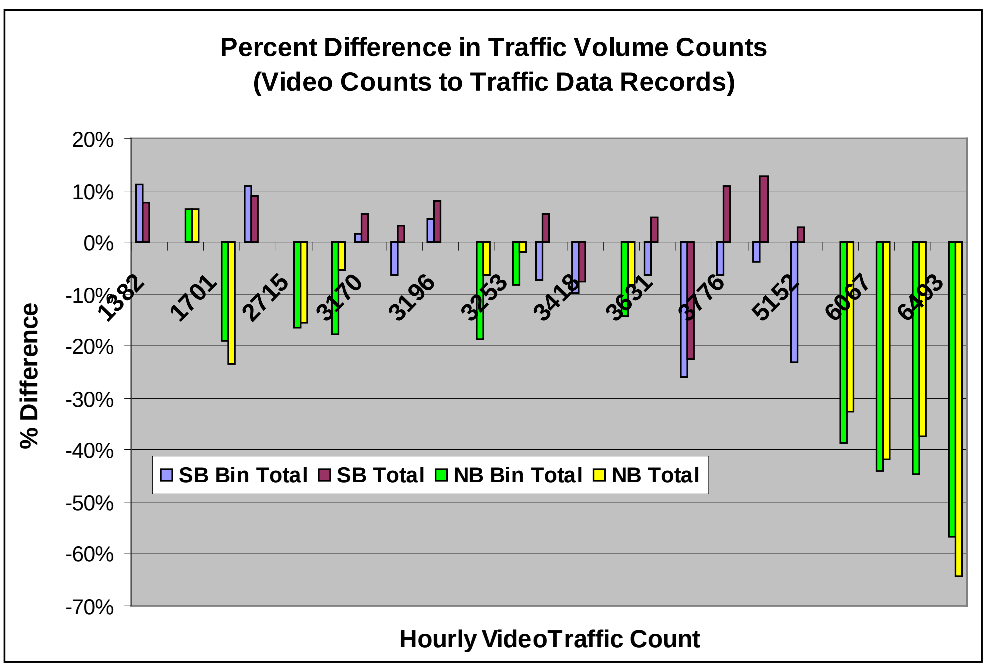

Figure 17. Traffic Count Comparison of Video Data with Traffic Data for I-15.

A quantitative review of the hourly video data with the traffic data logger for Traffic Totals provides a better comparison than the Bin Total for 8 of the 12 hours evaluated for the south-bound (SB) lanes and approximately 9 for the 11 hours for the north-bound (NB) lanes. A further review of the NB data indicates a bias, with the video data providing a significantly lower traffic count than what is recorded with the data loggers. This bias is seen over 90 percent of the time, with percent differences increasing when traffic volume increases. The percent difference ranges from 1 percent to 58 percent, which may result in a two-fold reduction in emissions.

A similar sensitivity analysis was also conducted to compare traffic counts of HD and LD vehicles to determine if a similar bias exists in the traffic data, refer to Figure 18. The average hourly percent difference for HD at times can be rather large approaching 75 percent with an average percent difference for both North and Southbound traffic of about 25 percent. A similar analysis for LD vehicles indicates a bias of the traffic counters over-reporting the NB traffic on an average of 30 percent.

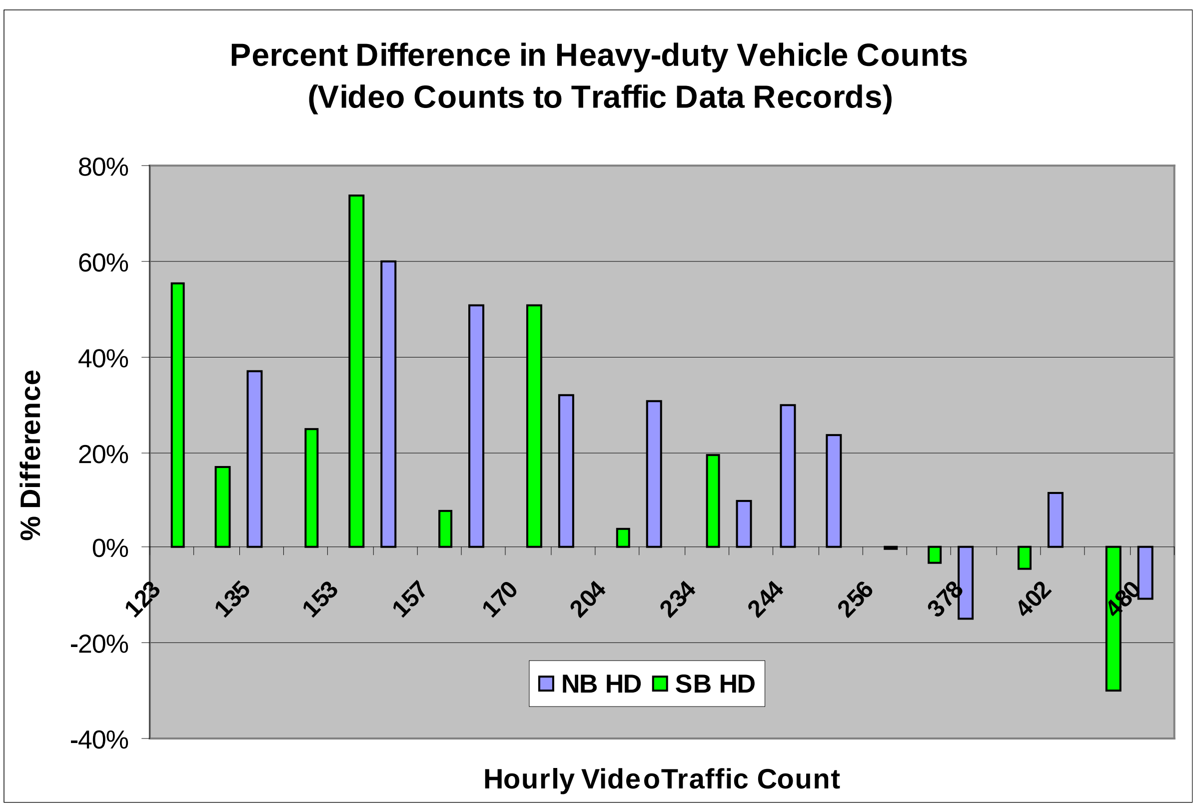

Figure 18. Traffic Count Comparison of Video Data with Traffic Data for HD vehicles on I-15.

A review of the traffic data identifies several periods in time in which the traffic counts and fleet mix do not agree. Some of these anomalies we were able to validate with video evaluations while others show a significant variation with other temporal time periods. Two episodes that were investigated provide an example of why calibrations and evaluations of the traffic data are important.

Episode 1: December 15, 2008 – March 10, 2009

During this period of time the percent HD vehicles for the NB I-15 traffic detector averaged 27%, and then on March 10, 2009 at 6:00 am the HD% changed to 11 percent. The traffic detector from this point thru March 2010 reported an average HD fleet mix of 9 percent. An investigation of this event with the Nevada Regional Transportation Center (RTC) did not identify a cause for this dramatic change in HD percentage.

Episode 2: September 28, 2009 – December 28, 2010

During this period of time the NB traffic volume significantly dropped from an average traffic flow of 3400 vehicles/hour to 1417 vehicles/hour, a 58 percent drop in volume. The NB detector also went off-line on December 28, 2009 and did not come back up until January 22, 2010. A comparison of the video data with the data logger for three hours during this period confirmed the differences; refer to Table 11 with an average percent difference of 61 percent. Investigation of this event with the Nevada RTC did not identify a cause for this dramatic change in traffic volume.

Table 11. Comparison of Video Traffic Count with Traffic Data Logger.

Comparison of Video Traffic Count with Traffic Data Logger										
Las Vegas. NV 1-15 Near-road Study										
		Northbound - Video			**Northbound Traffic Monitor**			**% Difference**		
Date	**Hour**	**LD**	**HD**	**Total**	**LD**	**HD**	**Total**	**LD**	**HD**	**Total**
October 16, 2009	19	4788	196	4984	1596	92	1688	67%	53%	66%
November 21, 2009	8	4728	328	5056	1401	100	1501	70%	70%	70%
December 27, 2009	2	1135	29	1164	599	39	638	47%	-34%	45%
Average										61%

A review of the traffic data log during this period revealed the NB traffic lanes were reduced from 3 lanes to 2 lanes of flow, while a review of traffic video indicates 4 lanes of traffic flow for the NB. Also after December 28, 2009, the NB Detector was switched off with no traffic data being recorded, the monitor was not re-activated until January 22, 2010, at which time it started recording 4 lanes of traffic flow and returns to a normal vehicular flow of 3,900 vehicles/hour. This review of the data indicates the detector was not properly sited to account for all NB lanes during this period. A review of the SB traffic data did not identify any significant abnormal operations.

Traffic speed was recorded by the FAST traffic sensors. Intuitively and based on our own project experiences, as traffic volume increases traffic speed decreases. This is shown explicitly in Figure 19, as traffic volume increases, traffic speed decreases.

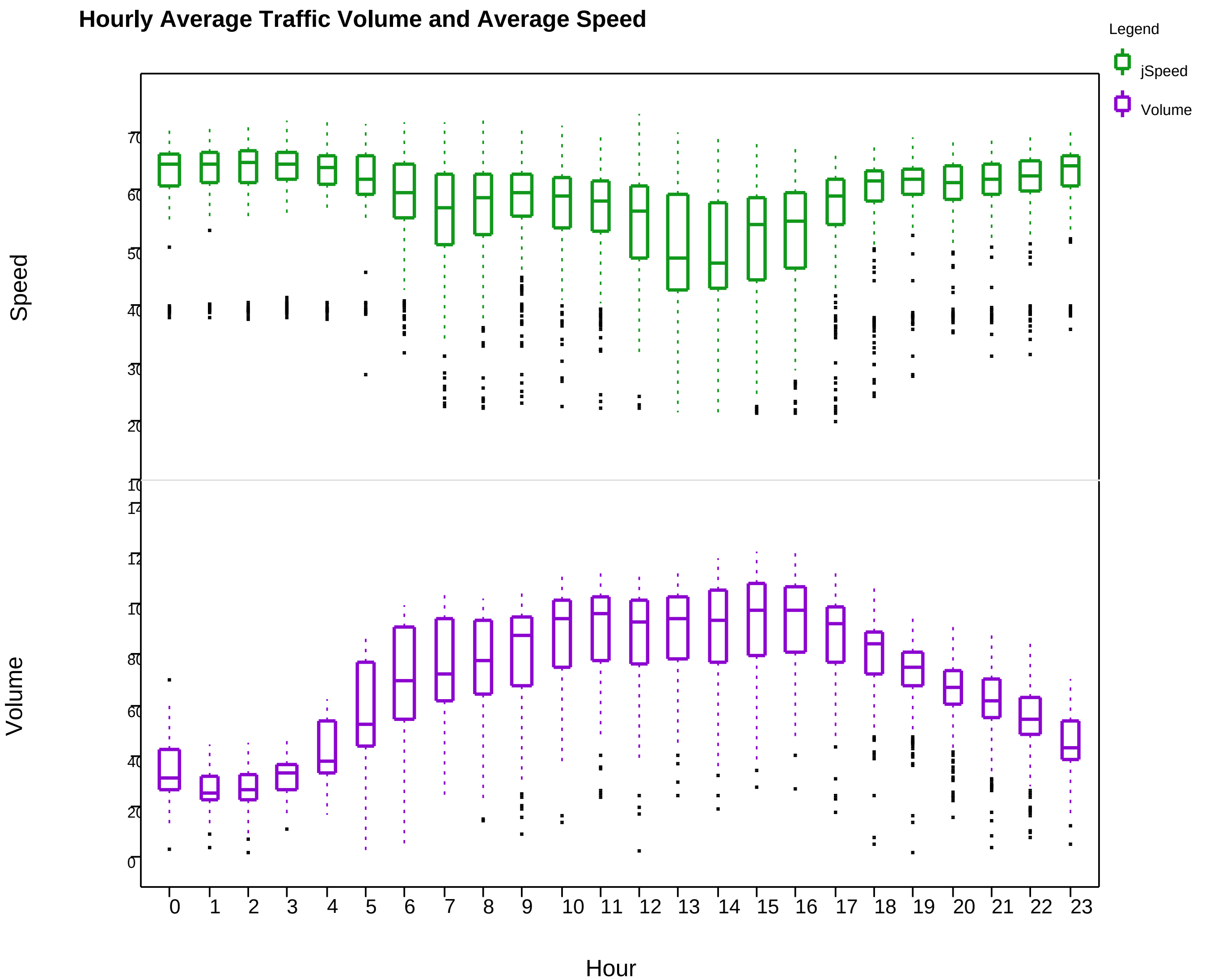

Figure 19. Hourly Average Traffic Volume and Average Speed -- I-15.

5.4 Meteorology

Meteorological monitoring characterized ambient conditions during the day and included measurements for: wind speed, wind direction, ambient temperature, relative humidity, solar radiation, and precipitation. Wind speed and wind direction were characterized by sonic anemometers (R.M. Young Model 81000 Ultrasonic Anemometers). Temperature and relative humidity were characterized by Vaisala HMP45D and Vaisala HMP45A probes, respectively. Solar radiation was measured by a MetOne 394 Pyranometer and precipitation was measured by a rain bucket (Ecotech Rainmaster 1000).

5.5 Continuous Analyzers

5.5.1 Gaseous Pollutants

Gas analyzers (Table 1, Table 12) meeting EPA Federal Reference Method (FRM) or equivalent method criteria collected measurements of CO, NO, NO_2, NO_X, at 100 meters upwind, 20 meter roadside, 100 meters downwind and 300 meters downwind from the freeway. The sample height in all cases was at approximately 3 meters above the ground. Data was logged continuously for 5-minute averaging periods over the course of the study period (Table 13). Multi-point calibrations occurred at the beginning of the study while zero and span checks were run every night over the course of the study period.

5.5.2 Black Carbon

Black carbon (BC) was measured continuously at each station using dual-wavelength rackmount Aethalometers (Table 1, Table 12) at 100 meters upwind, 20-meter roadside, 100 meters downwind and 300 meters downwind from the freeway. The sample height in all cases was at approximately 3 meters above the ground. Data was logged continuously for 5-minute averaging periods over the course of the study period (Table 13).

The Aethalometer continuously measures BC at 5-minute intervals by pulling air through a small spot on the sample filter and detecting incremental changes in light attenuation at a specific wavelength. Once the sample spot is loaded to a certain limit, the instrument automatically pauses, rotates the filter tape through to a new clean spot, and begins sampling again; this translates to a 10-minute gap in the data approximately twice per day in the Las Vegas data set. The main wavelength of light used to detect BC is 880 nm, in the red region of the visible spectrum. In addition, this instrument also detects light attenuation at 370 nm and is a qualitative indicator of additional particulate organics which may absorb light at near-ultraviolet wavelengths.

Black carbon values are calculated by the below equation,

$$BC = \Delta ATN * A / SG * Q * \Delta t \qquad (1)$$

where, BC is the concentration of black carbon in the sample (units of ng/m^{-3}), ΔATN is the change in optical attenuation due to light absorbing particles accumulating on a filter, A is the spot area of filter, Q is the flow rate of air through filter, Δt is the change in time, SG is specific attenuation cross-section for the aerosol black carbon deposit on this filter (16.6 m^2/g). SG is an empirical value that was defined by the manufacturer as the ratio of the mass of elemental carbon (measured using a thermal-optical process) and the detected light absorption of the same sample on a filter.

BC data was automatically logged by two methods during the Las Vegas monitoring period—internally logging its full set of data fields (17 columns of data) at 5 minute intervals to a compact flash card, which was downloaded approximately quarterly during the study, and directly logging only the BC concentration estimated from the instrument's analog output to the station database. The analog data was used during the course of the monitoring study to observe the instrument's performance, however the digital data logged to the compact flash card was used as the primary data for analysis, per manufacturer's recommendations.

Further details may be found in Appendix 13.

5.5.3 Particulate

Particulate analyzers (Table 1, Table 12) meeting EPA FRM or equivalent method criteria collected measurements of PM-Coarse (particles that have an aerodynamic diameter ranging from 2.5 to 10µm) , PM_{10} and $PM_{2.5}$, at 100 meters upwind, 20 meter roadside, 100 meters downwind and 300 meters downwind from the freeway. Aethalometers and continuous particle counters (Table 12) measured black carbon and particle counts at 100 meters upwind, 20 meter roadside, 100 meters downwind and 300 meters downwind from the freeway. The sample height was at approximately 3 meters above the ground. Data was logged continuously for 5-minute averaging periods over the course of the study period (Table 13).

Continuous PM-Coarse, PM_{10} and $PM_{2.5}$ measurements were collected by four Thermo Electron Tapered Element Oscillating Microbalances (TEOM) Model 1405-DF at a flow rate of 16.7 liters/minute (L/min) (1.0 m3/hour). The data were recorded as 5-minute averages (Table 13).

5.5.4 Integrated Samples – VOC, Carbonyl, Particulate

Specific MSATs of interest for this study included: 1,3-butadiene, benzene, acrolein, formaldehyde and acetaldehyde. MSAT samples were collected using EPA standard methods: 1) TO-15 and 2) TO-11A. The integrated samples were collected on a 1-in12 day ambient air quality monitoring schedule that corresponded to the schedule posted on EPA's website[25] and followed by State/local air agencies for ambient air quality monitoring. The EPA $PM_{2.5}$ FRM was used for the collection of $PM_{2.5}$ integrated samples.

5.5.4.1 EPA Compendium Method TO-15 – Canister – VOC

Collection of canister samples by the TO-15 method calls for the atmosphere to be sampled by the introduction of air into a specially-prepared stainless steel canister. An Entech Model 1816 programmable multi-canister automated sampler was used to accurately regulate the filling of the sample canisters with air. Evacuated SUMMA passivated 6 liter (L) canisters were filled to near ambient pressure. A nominal flow rate of 75 milliliter/minute (mL/min) was maintained over a 1-h sampling period for a total sampled volume of approximately 4.5 L. Evacuated canisters received from the laboratory and ready for sampling were placed on the Entech sampling system by attaching each canister's valve to individual sampling ports. The initial pressure was measured for each canister to insure that every canister falls within an acceptable pressure range (<0.5 psia). Any canisters above the acceptable range were replaced with one that met the initial pressure criteria (0.5 psia). With the canisters attached, each port was leak checked to ensure that fittings had been properly tightened and the samples would not leak prior to and after collection. Sample labels printed with the individual sample codes were affixed to the canister tags for sample identification. The sampler was programmed for the scheduled sampling times and flow rates. Timers and solenoids within the Entech sampler were activated and deactivated allowing sample collection based on the entered sampling program. After the air samples were collected, the canister valves were closed and the canister prepared for shipment to the laboratory for analysis. Sample collection information such as initial and final pressures, initial and final times, canister id number, etc. were either hand recorded on a data collection form for subsequent entry in the electronic data form or entered directly into the electronic data form. Chain-of-custody (COC) sheets were generated and the samples were shipped to the laboratory. Upon receipt at the laboratory, the canister sample label was compared against the datasheet and the COC sheet. Any discrepancies were resolved at that time. The samples were stored until the laboratory analysis of the canisters had been completed.

5.5.4.2 EPA Compendium Method TO-11A – Cartridges – Carbonyl

The EPA Compendium TO-11A DNPH carbonyl method was implemented in Las Vegas for the collection and analysis of air samples for formaldehyde and acetaldehyde. DNPH sampling cartridges are commercially available for this method and were purchased and provided for field sampling. Air samples for carbonyls on DNPH cartridges were collected using an ATEC 8010 automated sampler manufactured by Atmospheric Technology (ATEC). This was the same instrument used for the DNSH cartridge sampling. The instrument is a microprocessor controlled sampler that can be programmed to draw ambient air at a constant rate through various types of sampling cartridges for designated time periods. The sampler consists of two units (channels) each having 10 active sampling ports and one non-active port. Channel 1 (ports 1-10) was used for the DNPH samplers and Channel 2 (ports 11- 20) was used for the DNSH samplers. DNPH samples were collected at a flow rate of 1.00 lpm for a 1-hour time period.

Nine DNPH cartridges were attached to the ATEC's Teflon sampling lines and labeled with the sample collection code. A leak check of each cartridge was performed using the leak check feature of the Atec sampler. This ensured that the cartridges were installed properly. A light blocking sleeve was installed around each cartridge to reduce artifacts due to light sensitivity. The sampler was programmed with the flow, start time and end time for each cartridge channel. During sampling, solenoid valves associated with each cartridge was activated/deactivated based on the programmed sampling schedule. Upon completion of sampling, the cartridges were removed, capped, secured for shipment, and returned via overnight delivery to the EPA RTP facility. Sample collection information such as initial and final flow rates, initial and final times, canister ID number, etc. were either hand recorded on a data collection form for subsequent entry in the electronic data form or entered directly into the electronic data form. COC sheets were generated and the samples shipped to the laboratory. While awaiting shipping, samples were stored in an on-site refrigerator. A cooler with frozen blue ice packs was used to ship the cartridges.

5.5.4.3 Particulate

A BGI PQ 200A $PM_{2.5}$ Federal reference method (FRM) sampler was used for the collection of $PM_{2.5}$ integrated samples. Cassettes loaded with pre-weighed 46.2 mm Teflon filters were prepared at the EPA RTP facility by EPA contractor staff and shipped to Las Vegas field staff. Filter IDs were linked to unique sample codes generated and printed by data collection spreadsheets. Samples were collected over a 24-hour period beginning at midnight of the sampling day. Flow rates and pressures were recorded by the sampler. At completion, the filter was removed and flow rates and pressures were transcribed onto the data collection spreadsheets. The filter cassettes were removed, packed for shipment, and returned by overnight delivery to EPA RTP.

Table 12. Summary of Measurement Parameters, Sampling Approach, Instruments, and DQI Goals for Project.

Measurement Parameter	Sampling Approach	Instrument Data				DQI Goals		
		Make/Model	Accuracy	Precision	Detection Limit	Accuracy	Precision	Completeness
Gas Analyzers								
Carbon Monoxide	(NDIR FRM CO analyzer)	EC 9830T	± 5% 0-1000ppb	0.5% of reading	25 ppb	20%	95 % CI +/- 20 %	80%
Oxides of nitrogen	Chemiluminescence	EC 9841B	< 1%	0.5 ppb	0.5 ppb	20%	95 % CI +/- 20 %	80%
Carbon monoxide	(NDIR FRM CO analyzer)	Serinus 30	< 1%	20 ppb or 0.1 % of reading	40 ppb	20%	95 % CI +/- 20 %	80%
Particulate Samplers								
Black Carbon	(Aethalometer)	Magee - Aethalometer	1:1 comparison w/ EC on filters	Repeatability: 1 part in 10,000	0.1 µg/m^3 w 1 min res.	+/- 0.035 µm^3	+/- 0.035 µm^3	80%
$PM_{2.5}$	($PM_{2.5}$ FRM method)	FRM BGI PQ200				20%	95 % CI +/- 20 %	90%
$PM_{2.5}$ PM_{10} PM Coarse	(TEOM)	Thermo TEOM – 1405DF	±0.75%	±2.0 µg/m³ (1-hour ave), ±1.0 µg/m³ (24-hour ave)	0.1 µg/m³	20%	95 % CI +/- 20 %	80%
Air Toxics								
Acetaldehyde	USEPA Method TO-11A	Atec 2200 Cartridge Sampler	± 2 %	± 2 %	N/A	25%	10% for flow rate 20% for HPLC	80%
Formaldehyde						25%	10% for flow rate 20% for HPLC	80%
Acrolein	USEPA Method TO-15	Entech 1800 Canister Sampler	± 2 %	± 2 %	N/A	25%	10% for flow rate 20% for GC/MS	80%
Benzene						25%	10% for flow rate 20% for GC/MS	80%
1,3-Butadiene						25%	10% for flow rate 20% for GC/MS	80%
Meteorological Instruments								
Wind Speed	Sonic anemometer	RM Young Model 81000	±0.05 m/s	std. dev. 0.05 m/s at 12 m/s	0.01 m/s	20%	95 % CI +/- 20 %	90%
Wind Direction			± 5°	± 10°	0.1°	20%	95 % CI +/- 20 %	90%

Measurement Parameter	Sampling Approach	Instrument Data				DQI Goals		
		Make/Model	Accuracy	Precision	Detection Limit	Accuracy	Precision	Completeness
Air Temperature	Temperature probe	Vaisala HMP45D	±0.2°C at 20° C	0.1 ° C	0.1 ° C	20%	95 % CI +/- 20 %	90%
% Relative Humidity	Relative humidity sensor	Vaisala HMP45A	±2%RH from 0…90% RH)	1% RH	1% RH	20%	95 % CI +/- 20 %	90%
Rain Gauge	Rain bucket	Ecotech Rain Gauge	+/- 5% at 25-50 mm/hour	± 1mm	± 1mm	20%	95 % CI +/- 20 %	90%
Solar Radiation	solar radiation	MetOne 394 Pyranometer	±5% from 0…2800 watts meter[2]	±1% constancy from -20°C to +40°C	9 mV/kwatt meter-2, approx	20%	95 % CI +/- 20 %	90%
Other								
Sound	Microphone	Extech 407764	±1.5dB (under reference conditions)	0.1dB	0.1dB	20%	95 % CI +/- 20 %	80%
Video	Video	Axix 223M Vivotek SD7151						
Vehicle Count								
Vehicle Speed	Radar	NDOT Data and Equipment				20%	95 % CI +/- 20 %	80%
Vehicle Type								

2. Accuracy and precision in terms of ultrafine particle concentration is difficult to determine in the field due the lack of particle concentration standards. However, particle counters are routinely verified in the field for accuracy in flow rate. Precision was estimated in this study by collocating UFP samplers prior to use of instruments in the field.

Table 13. Summary of Data Types, Pollutants, Methods and Sample Types and Frequency.

Data Type	Pollutant or Covariate	Method	Sample Type and Frequency
Mobile Source Air Toxics	Benzene 1,3-butadiene	TO-15	1-hour integrated 1-in-12 day schedule 9 samples each day at each road-side location
	Formaldehyde Acetaldehyde Acrolein	TO-11A	
Mobile Source Related Air Pollutants	CO	NDIR	Continuous
	NO, NO_2, NOx	Chemiluminescence	
	Black carbon	Aethalometer	
	$PM_{2.5}$	TEOM	
	PM_{10}		
	PM-Coarse		
	$PM_{2.5}$	FRM	24-hour integrated 1-in-12 day schedule 1 sample each day at each road-side location
Traffic	Vehicle count Vehicle length Vehicle speed	Radar	Continuous
Meteorology	Wind speed/direction; Temperature Relative humidity	RM Young Sonic Anemometer; Vaisala Temp/Humidity	
Sound	Decibels	Sound meter	
Video	Images	Video camera	Semi-continuous

Most analyzers deployed for this study performed well. The ThermoScientific TEOM 1405-DF was upgraded in the field by technical staff from ThermoScientific in late November 2009 and early December 2009. These upgrades improved instrument performance and stability.

6 Data Management, Analysis and Validation

It should be noted that with the extremely large data sets that are a result of the data collection efforts for this project, it will take a significant amount of staff time to thoroughly quality assure the data. Moreover, data analysis will also require a significant amount of staff time. Both activities are ongoing processes.

6.1 Data Management

6.1.1 Purpose/Background

The following section identifies the processes and procedures that were used to acquire, transmit, transform, reduce, analyze, store, and retrieve data. These processes and procedures will maintain the data integrity and validity through application of the identified data custody protocols. Figure 2 shows the data flow from the shelters, lab analysis and NDOT traffic data to raw data storage, data review, and analysis.

6.1.2 Data Recording

The majority of the data collected for this study was recorded electronically. Field/lab personnel/teams used EPA-provided forms and checklists or develop documents as needed to accomplish data recording (EPA/FHWA Near-Road QAPP). To accomplish this, each monitoring site was equipped with data loggers. A data logger was set up to record each air quality monitor's output, perform specific data manipulations, and format the resulting data in preparation for downloading and subsequent loading to a SAS database(s). Data collected from real-time monitors (e.g., gas analyzers, sonic anemometers, etc.) were recovered via computers on a daily or near-daily basis.

Data that required manual entry, such as those obtained from the integrated particulate samplers or MSAT canister and DNPH sampling, were entered into a custom designed Excel spreadsheet that was used to generate sample labels, record data, and generate sample tracking forms for the integrated VOC, carbonyl and $PM_{2.5}$ samples. The spreadsheet generated the unique sample codes and labels for each sampling day, location, time period, and sample type. All sample collection parameters (e.g., pressures, flows) were hand recorded on a printed blank form by the field operator at the time of sample collection. This information was then entered by the field operator into the electronic data collection form where embedded formulas made all necessary calculations and generated a summary page later entered into the study database. From this information, the chain-of-custody (COC)/tracking forms were generated and printed. Information recorded in the electronic data sheet included sample start and end times, pressures, and flow rates. The electronic files were copied to a dedicated flash drive that was shipped with the samples from the field to the EPA RTP facility. At this point EPA staff retrieved the data files from the flash drive, verified the data entries, made necessary corrections and delivered the corrected field files to the database administrator. All datasheet entries made by the field site operator were 100 percent verified at the laboratory by EPA staff. Verification compares the original handwritten datasheets to the field generated electronic datasheet. This electronic datasheet formed the basis of the final EPA database for the integrated samples. The spreadsheets were designed to reduce human error and provide a simple, effective means to collect and process a large number of samples. After laboratory analysis, EPA contractor staff provides the analysis data in Excel spread sheet format that was imported by the Database Administrator (DBA), into the database. Linkages between the field data and the laboratory analysis were made using the field sample codes.

Nevada DOT traffic data were uploaded to the FTP Science Server approximately every two weeks by an NDOT FAST staff member. This data was in the form of an ASCII text file. These data were transmitted to the EPA DBA for entry into a SAS dataset.

6.1.3 Field and Laboratory Data Validation

Data validation occurred at each level of data collection and reporting with each activity recorded in laboratory notebooks. Data were conditionally validated after collection and after analysis. Conditional validation was the acknowledgment that field and laboratory staff did not or did notice problems with sample collection or analysis of a particular sample. Conditional validation helped identify problems during collection, storage, shipping, and analysis that may invalidate samples. Questionable data—defined as unusual values which the DBA determines can find no basis for being invalidated, were considered valid and annotated as such in the database. EPA is in the process of reviewing the database and making final determinations of data validity.

6.1.3.1 Instrument Performance Assessment Procedures

Each day, data was accessed using WinCollect software. Graphical reports were run to determine instrument status and data validity. Examples of these graphical reports are shown in the Appendices.

Instrument issues were identified and noted in a logbook at the computer being used to run WinCollect. The graphs and any instrument issues were noted in an email to the site operator, EPA and contractor staff.

6.1.3.2 Laboratory Data Verification

Data validation continued with the inspection of received samples/documents and the integration of the laboratory analyses with the corresponding field monitoring data. Validation consisted of an assessment of the reasonableness of the data, determination of data completeness, and comparison to the criteria defined for each specific parameter (such as pump flow rates, sampling duration, etc). Analytical data not appearing to be valid or not meeting validation criteria were flagged in the database.

6.1.4 Data Reduction

Original data will be kept and archived as a part of the project's record keeping. This archiving activity was carried out by the EPA DBA.

Data recorded on a continuous basis by data loggers were electronically retrieved on a weekly or near-weekly basis by the EPA DBA. In the event that continuously logged data was not electronically transmitted, the data would be sent to the EPA DBA via DVD or other appropriate media. (This use of DVD or other media never occurred for the continuous analyzers. This only occurred for video data.) Non-continuous data, such as filter samples, canister or cartridge samples, were first analyzed by laboratory analysis. In any event, all data were submitted to the EPA DBA for this project and entered into the SAS database(s). The only exception was the video data. The video data would have consumed too many network resources and thus was maintained on external hard drives.

6.1.5 Data Related Organizational Deliverables

The Field Site operator was responsible for ensuring the data loggers, computers, and communications were in good working order so that data were retrieved on a weekly or near-weekly basis by the EPA DBA.

Continuous data that were retrieved on a weekly or near-weekly basis by the EPA DBA included:

- Meteorological data:
  - Wind speed
  - Wind direction
- Real time CO, NO, NO_2, NO_X, black carbon, coarse PM, $PM_{2.5}$, $PM_{10.}$
- Traffic data:
  - Vehicle Count
  - Vehicle Type (length)
  - Vehicle Speed

The Field Site operator was responsible for ensuring that non-continuous samples were recorded properly in logbooks, chain-of-custody forms. This data included:

- Integrated PM Filter samples
- VOC data from samples collected via Summa canister, DNPH cartridge

The Field Site operator was responsible for ensuring that all logbooks, chain-of-custody forms, notes, and other records were maintained in an orderly fashion so that a complete record of the project was documented.

Laboratory analysis staff was responsible for reporting the laboratory analytical results for the canister, DNPH and PM2.5 integrated samples to EPA. The data were provided in electronic format, Excel data worksheets. The data were reviewed for completeness. If any changes were necessary, the data were investigated and changes documented in both the hardcopy and electronic files. The data were then submitted to the DBA for inclusion in the study database.

The following table lists the data-related deliverables, format of each deliverable, and personnel responsible.

Table 14. Data-related deliverables.

Deliverable	Custodian	Person Delivered To	Format
CO, NO, NO2, NO_X,	Field Site Operator	EPA DBA	Electronic
BC			
Coarse PM, PM_{10}, $PM_{2.5}$			
Meteorological Data			
DNPH Cartridge Sample Collection Information	Field Site Operator/Lab Tech	EPA DBA	Electronic
Canister Sample Collection Information			
PM Filter Sample Collection Information			
DNPH Cartridge Laboratory Data	Laboratory Staff	EPA WAM, EPA WAM Delivers to DBA	Electronic
Canister Laboratory Data			
PM Filter Laboratory Data			
Traffic Data	NDOT Staff/EPA Staff	EPA DBA	Electronic

6.1.6 Data Completeness

The DBA for this project developed a SAS program that provided an overview of the data completeness for this project. This table was updated as required by the needs of the project (weekly, bi-weekly, monthly, etc.). This table provided at a glance the overall instrument up-time versus instrument maintenance, failures or other field site issues. The tables shown below are for the time period of mid-December 2008 thru mid-December 2009.

Table 15. Summary of Data Completeness across by Site for Major Parameters.

Parameter	Station ID				
	Total	Station 1 20 m roadside	Station 2 100 m downwind	Station 3 300 m downwind	Station 4 100 m upwind
CO	93	94	94	93	92
NO	95	97	96	95	93
NO_2	95	97	96	95	93
NO_x	95	97	96	95	93
PM_{10}	87	88	89	85	86
$PM_{2.5}$	87	88	91	83	83
PM Coarse	88	89	88	85	90
Wind Direction	92	93	91	89	97
Wind Speed	100	100	100	100	100
Traffic	> 99 (est.)				

Black Carbon – Digital Data

Site name	Distance from Road	N[a] (hours)	Completeness[b] Time span: 12/15/2008-12/15/2009
Station 1	20 m roadside	8503	97%
Station 2	100 m downwind	7838	89%
Station 3	300 m downwind	7913	90%
Station 4	100 m upwind	8755	100%

[a]A complete hour of sampling was set at a minimum of 10 five minute data points (50 min)

[b]Note that the completeness <100% is largely due a delayed start to sampling for several instruments. Incomplete time periods due to instrumentation error was generally less than 1%.

Sample	% Total
TO-15 canisters (VOCs)	82
TO-11 cartridges (aldehydes)	68
PM2.5 Filters	83

6.1.7 Data Storage and Retrieval

The EPA Project Officer will be consulted prior to disposal of records. The EPA DBA or similar designee is responsible for archiving, storage, and retrieval of all field and laboratory data files developed during the study at EPA. Copies of all study information (records/data) are retained and archived in accordance with Federal record storage guidelines.

6.1.8 Data Dictionary

The data dictionary provides a description of each database variable including range (minimum, maximum), type (numeric, alpha), missing value codes, and error flags (See Appendix). Descriptive information required to understand or interpret variables, including calculations or other manipulation, was included for each variable, as needed. This data dictionary is an on-going effort and is refined on an as needed basis.

6.2 Data Review, Verification, and Validation

The purpose of this section is to identify the procedures, and responsible parties that performed data review, verification and validation. Data verification is the process of evaluating the completeness, correctness, and conformance/compliance of a specific data set against the method, procedural, or contractual requirements. Data validation is an analytical- and sample-specific process that extends the evaluation of data beyond method, procedural, or contractual compliance (i.e. data verification) to determine the analytical quality of a specific data set.

Verification and validation of the procedures used to collect and analyze data are critical to the goals of this project and are performed after data collection, but prior to performing the flux calculations and uncertainty determinations. Study personnel were responsible for ensuring that the sampling methods, quality control protocols, and validation methods were followed and completed.

6.2.1 Validating and Verifying Data

Ideally, data undergoing evaluation should be compared to actual events. However, exceptional field events may occur, and field and laboratory activities may negatively affect the integrity of samples. In addition, some of the QC checks may indicate that the data failed to meet the acceptance criteria. Data identified as suspect, or does not meet the acceptance criteria, were flagged as indicated in the appendix.

6.2.2 Verification

As the continuous and non-continuous data were being compiled, a review of the data was conducted for completeness and data entry accuracy. All raw data that were hand entered from data sheets was checked prior to entry to the appropriate database. Once the data were entered, the data were reviewed for routine data outliers and conformance to acceptance criteria. Unacceptable or questionable data was flagged appropriately.

6.2.3 Validation

Validation of measurement data required two stages, one at the measurement value level and the second at the batch level. Records of all invalid samples were retained in the appropriate database. Information included a brief summary of why the sample was invalidated along with the associated flags. Logbook notes and field data sheets have more detailed information regarding the reason a sample was flagged. These documents were retrieved from the field sites and are stored at EPA.

The flags listed in Appendices were used to indicate that individual samples, or samples from a particular instrument, were invalidated.

6.3 Data Analysis

6.3.1 Statistical Analysis – Overall Project

The data analyses recommended below focused on the most basic issues of roadway emission impacts:

- To what extent do roadway traffic emissions elevate concentrations of MSATs and vehicle emission surrogates above background levels?
- Over what spatial scale do roadway emissions cause significant elevation of MSAT and surrogate compound levels above the upwind background?
- What are the long-term (e.g., annual) and daily average concentrations of MSATs and vehicle emission surrogates within the spatial scale of impact of roadway emissions?

Additional data analyses may address additional questions such as the respective impacts of meteorological conditions, traffic volume, vehicle type, or other variables.

Given the complexity of the data set, multivariate analysis approaches using statistical analysis software such as JMP or SAS will be necessary to assess the impact of various parameters of interest on the pollutant dispersion. However, emphasis has been placed on reporting clear and understandable results from the statistical analysis. The field studies were conducted to understand the relation of mobile source emissions to key air contaminants and to determine if there is a statistically significant difference between the pollutant concentration measured at each site and the background concentration.

Data were analyzed using a combination of programs, including MATLAB version R2009b, Microsoft Excel 2007, JMP 8/9 and Sigma Plot 11/12. The data analysis included calculating summary statistics of data for each site for all wind conditions and for winds only from the West (downwind) (+/- 60 degrees from perpendicular), estimating concentration gradients for winds from the West, and observing concentrations as a function of wind direction for all winds.

7 Results and Discussion

The study design, methods, and general data trends are the focus of this report. An assessment of one of the data quality indicator (DQI) goals as stated in the quality assurance project plan (QAPP) is shown in Table 15 for certain major parameters. As may be seen in Table 15, the DQI goal for data completeness was met or exceeded.

7.1 Traffic Activity

Traffic data (Figure 3) indicated a tri-modal traffic distribution as opposed to a bi-modal distribution. This is believed to be the result of several factors: 1) Las Vegas is not typical commuter city; 2) Las Vegas is a recreation destination for many travelers; 3) shift changes in Las Vegas are later or earlier in the day depending on the employer; 4) study site is along an interstate that carries both inter- and intra- state traffic; and 5) I-15 is a North American Free Trade (NAFTA) corridor.

Monthly traffic volumes shown in Figure 20 also indicate a tri-modal traffic distribution as opposed to a bi-modal distribution. Figure 21 shows the average daily traffic volume by the day of the week for each month. Even though the traffic data for December is only for part of the month (site operation began mid-December, 2008), traffic volume for December is much higher than for the remainder of the project. This is believed to be the result of Las Vegas being a recreation destination during the December holiday period.

Box-whisker plots for weekday and weekend traffic volume (Figure 22) and seasonal traffic volume (Figure 23) are shown on the following pages.

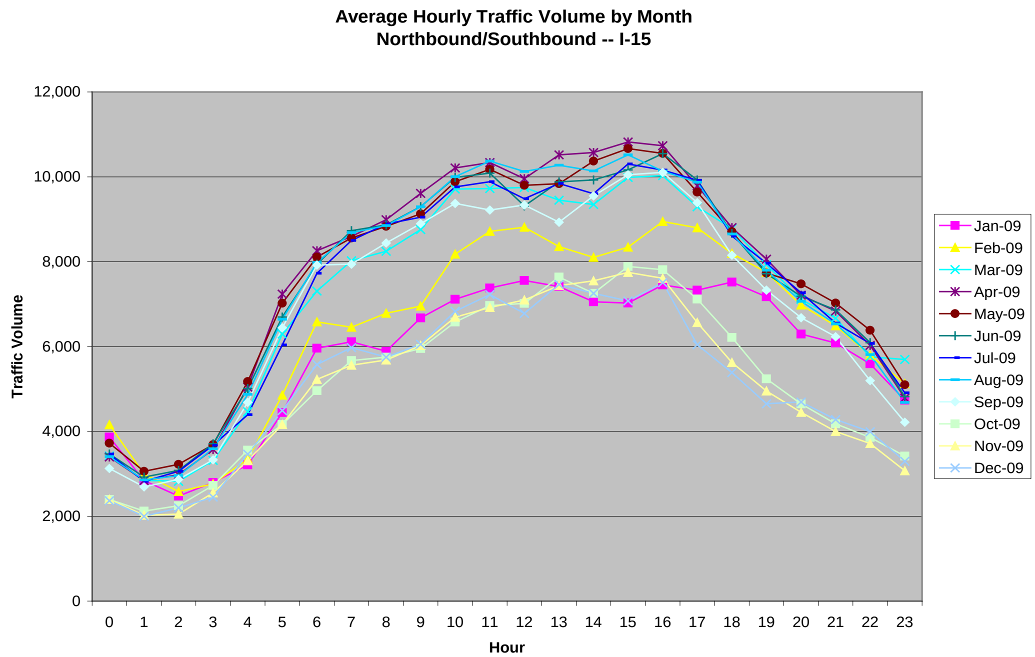

Figure 20. Average Hourly Traffic Volume by Month at I-15 Site.

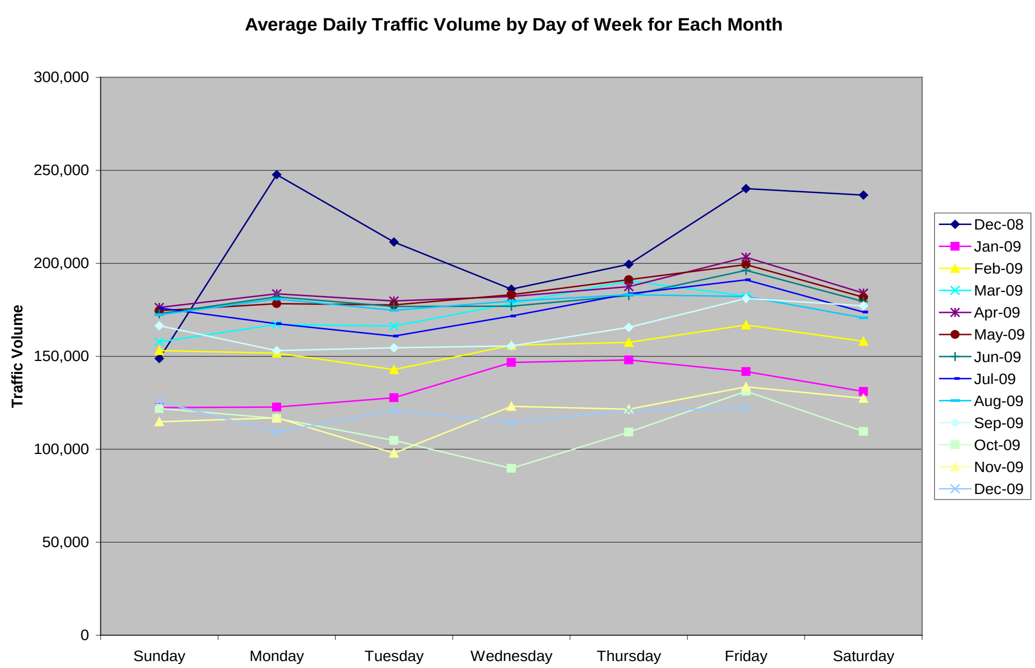

Figure 21. Average Daily Traffic Volume by Day-of-Week at I-15 Site.

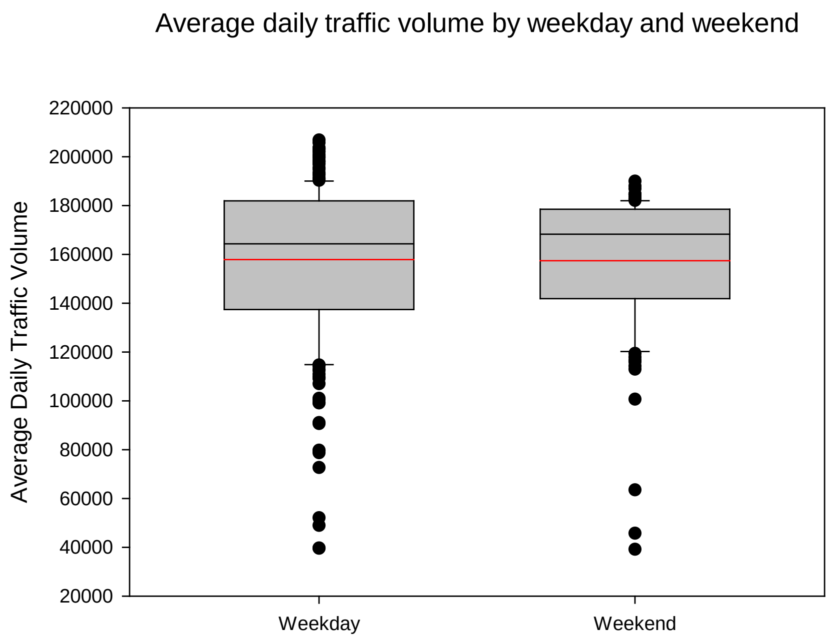

Figure 22. Box-Whisker Plot -- average hourly traffic volume by weekday and weekend[1].

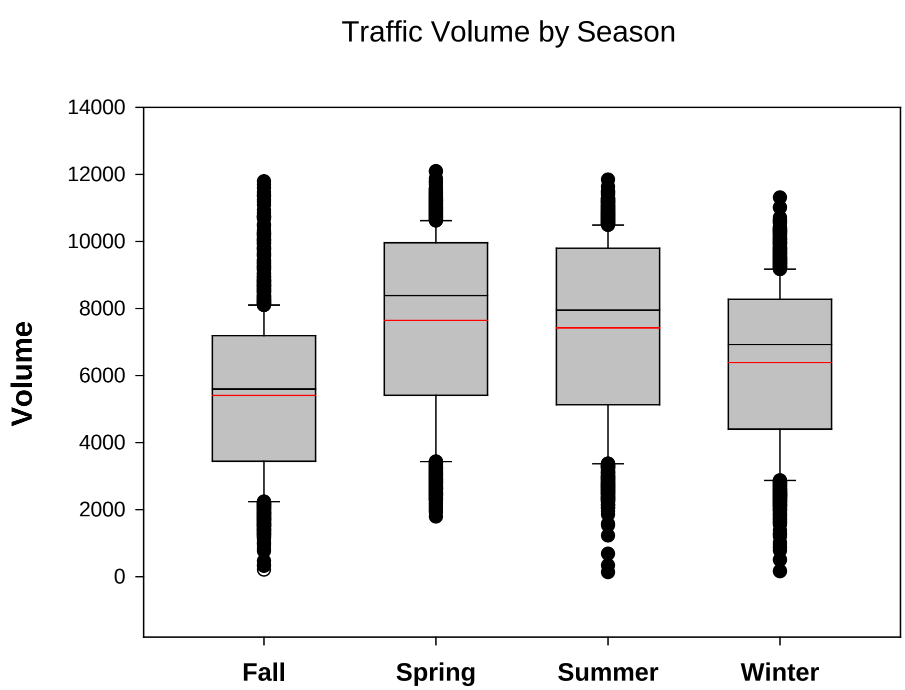

Figure 23. Box-Whisker Plot -- average hourly traffic volume by season.

[1] The boundary of the box closest to zero indicates the 25th percentile, the line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. Points above the whiskers are outliers. The red line within the box marks the mean.

7.2 Meteorology

Las Vegas meteorological conditions can be problematic as the city is located in a valley surrounded by mountains that channel the wind. This channeling of wind presented technical challenges in site selection[3] and operation and achieving proper wind flow from the source to the detector (i.e., gas analyzers). The topographic and meteorological conditions are shown in Figure 13.

Meteorological data from nearby McCarran International Airport shows (Figure 14) that the wind blows predominately from the southwest quadrant until approximately 3PM. Beginning at about 3PM in the afternoon, the winds shift and become more variable. In the late afternoon early evening (6-9PM), the winds are predominately from the east and northeast. Then, after 9PM the winds shift again into a more variable pattern. After midnight the winds blow predominately from the southwest.

Figure 4 shows wind rose data collected by the R.M. Young sonic anemometers at the closest station to I-15, approximately 20 m to the east of the highway. During the study, winds were predominately from the southwest quadrant, indicating that the monitoring transect typically contained one upwind station 100 m west of I-15 and three downwind stations east of the highway. Figure 4 does show an occasionally strong easterly wind during the time period from midnight until approximately 3 p.m. During this time, the station to the west of I-15 experienced impacts from the highway.

7.3 Continuous Analyzers

7.3.1 CO and NO_X

Figure 24 and Figure 25 show the mean hourly CO concentrations by site from all wind directions and winds from road, respectively. The mean CO concentration for the 20 meter road is approximately 26 percent higher than the 100-meter upwind site (Figure 24) for all wind directions. The mean CO concentration for the 20-meter road is approximately 60 percent higher than the 100-meter upwind site (Figure 25) for downwind conditions (winds from road).

Figure 26 shows the mean CO concentration by hour for all stations when winds are from the road. Figure 27 shows the mean CO concentration by hour for all four stations when the winds are from the road vs. hourly average traffic.

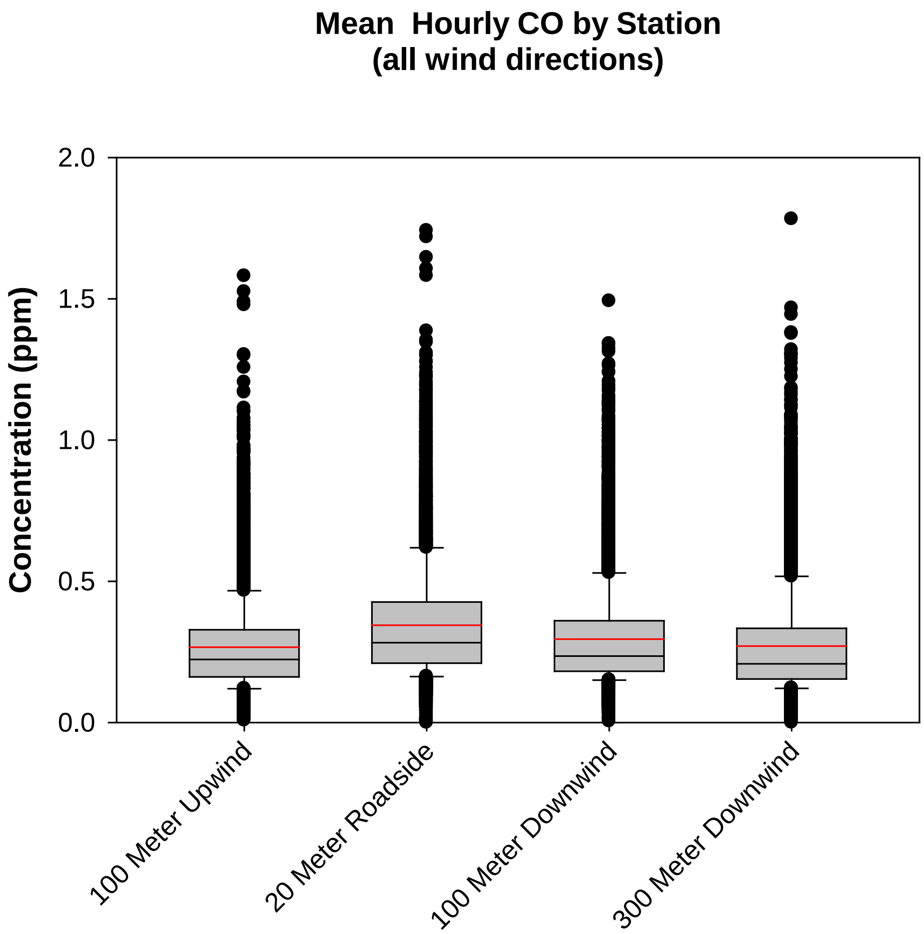

Figure 24. Box-Whisker Plot Mean CO Concentration by Site (all wind directions).

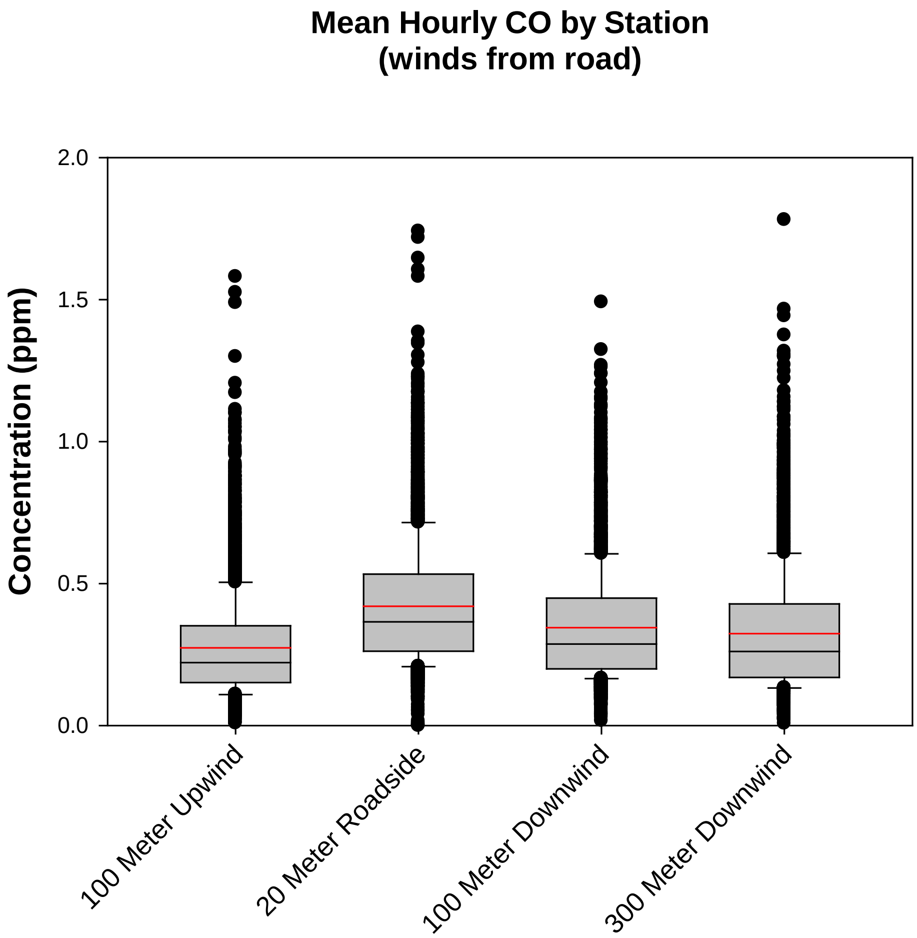

Figure 25. Box-Whisker Plot Mean CO Concentration by Site (winds from road).

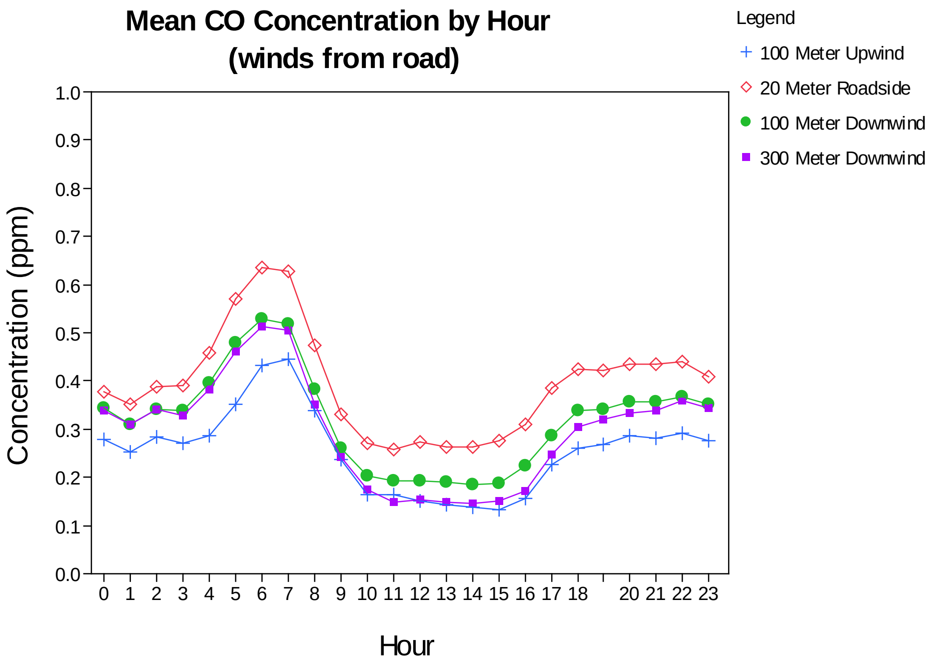

Figure 26. Mean CO Concentration by Hour: all stations (winds from road).

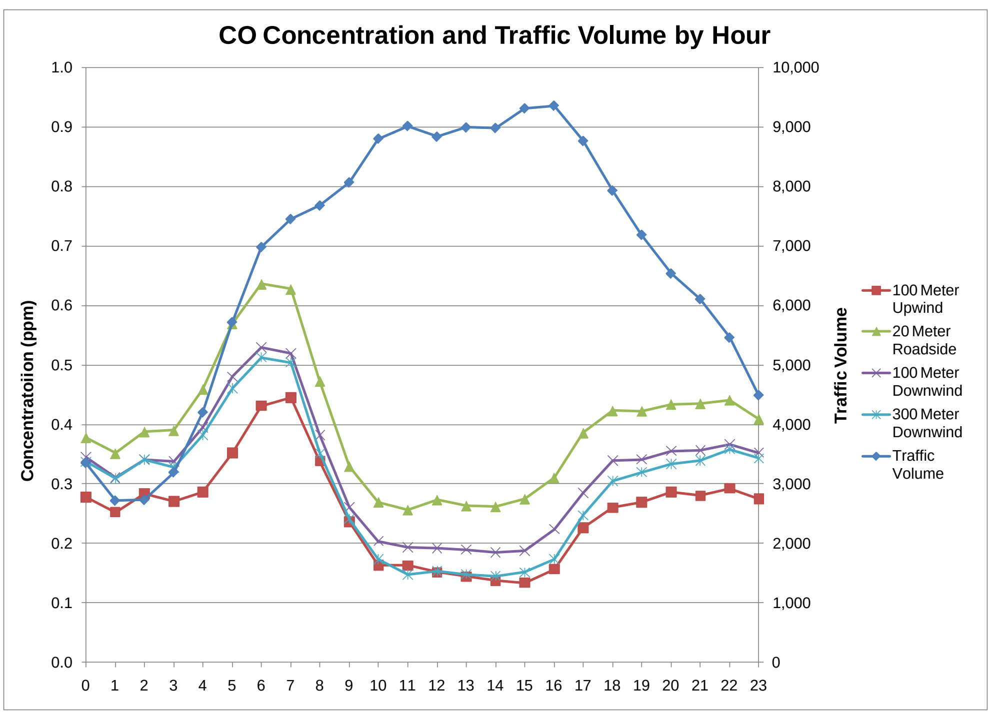

Figure 27. Mean CO Concentration and Traffic Volume by Hour: all stations (winds from road).

When CO concentrations by hour are overlaid with traffic volume (Figure 27), an increase in CO concentration trends with the increase in traffic volume during morning commute hours (5-7 a.m.). However as the morning progresses and traffic volume continues to increase, CO concentrations appear to decrease. CO concentrations appear to peak around 7:00 am, decrease through the morning and early afternoon hours and begin to increase again beginning around 3:00 p.m. This is apparently due to meteorological influences. As the sun rises and solar energy is pumped into the atmosphere, the air is heated and mixing is occurring in the atmosphere both horizontally and vertically. Winds during these morning hours tend to be from the southwest quadrant and typically wind speed increases as the day progresses (Figure 4) until the mid to late afternoon hours. During the mid to late afternoon (3-6 p.m.) wind speed decreases and wind direction is more variable (Figure 4). Due to these meteorological conditions, pollutant concentrations tend to be higher during the morning commute (5-7 a.m.) and appear to decrease even though traffic volume increases throughout the day, peaking about 4 p.m. (Figure 27).

As evidence that meteorological factors play a role in observed pollutant concentrations, Figure 28 is shown. On April 21 and April 22, wind speed is very low and wind direction is variable. Pollutant concentrations (NO, CO and BC) are elevated for these days for Site 1 (20 meter roadside) and Site 4 (100-meter upwind). Pollutant concentrations decrease as the week progresses, This appears to be directly related to a significant increase in wind speed and resultant increased atmospheric mixing.

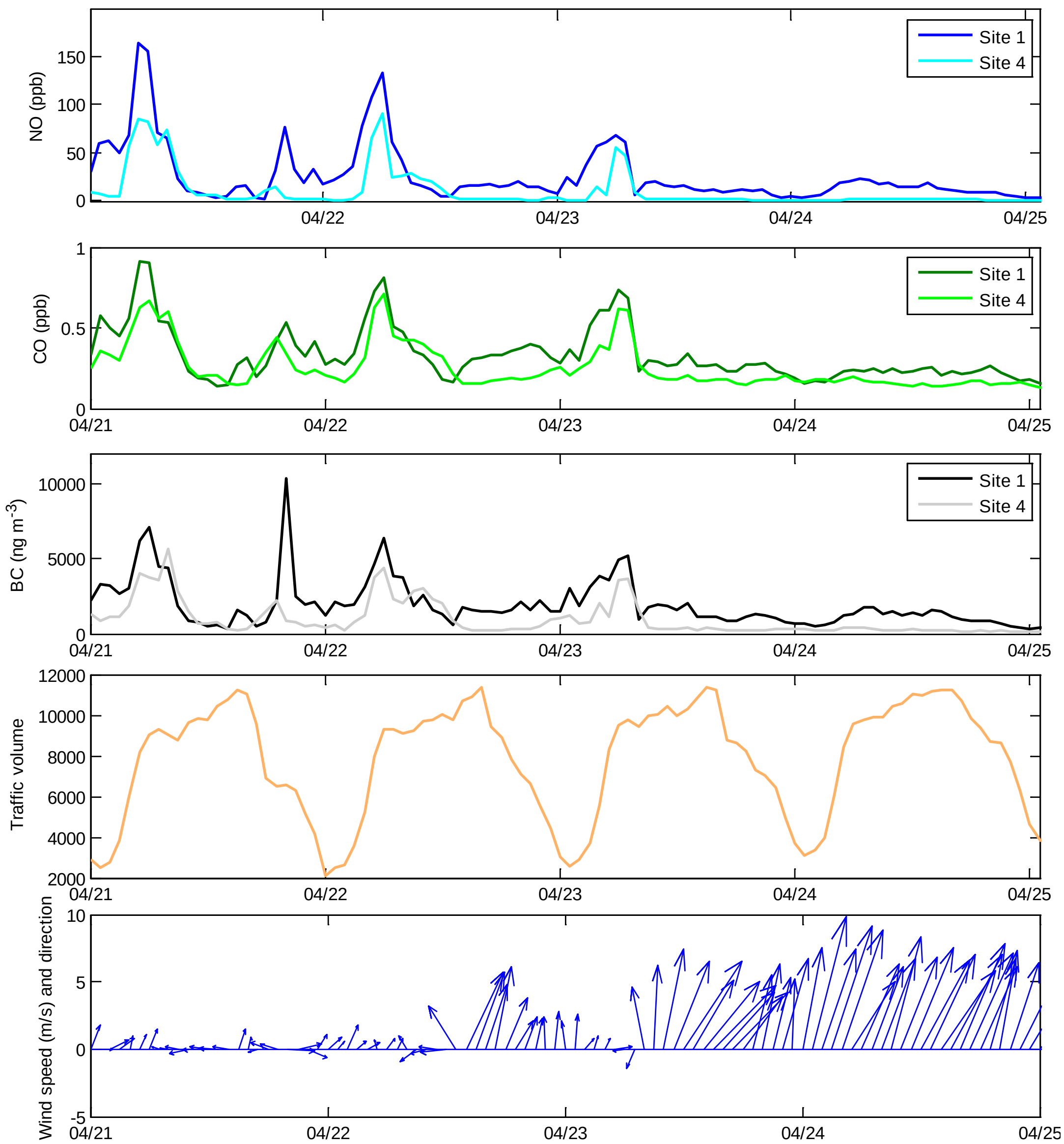

Figure 28. Mean NO, CO, BC Concentration, Traffic Volume and Wind Speed and Wind Direction for a Week in April, 2009.[2]

Additional evidence that meteorological factors play a role in observed pollutant concentrations, Figure 29 is shown. During periods of low wind speed pollutant concentrations (NO, CO and BC) are elevated for Site 1 (20-meter roadside) and Site 4 (100-meter upwind). During periods of high wind speed and strong south-southwesterly winds, pollutant concentrations decrease.

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[2] Arrows in bottom image of Figure 28and Figure 29 point to the direction to where the wind is traveling. Arrow pointing up means "winds from the south", arrow pointing to the right means "wind from the west", or downwind of the highway.

This appears to be directly related to a significant increase in wind speed and resultant increased atmospheric mixing.

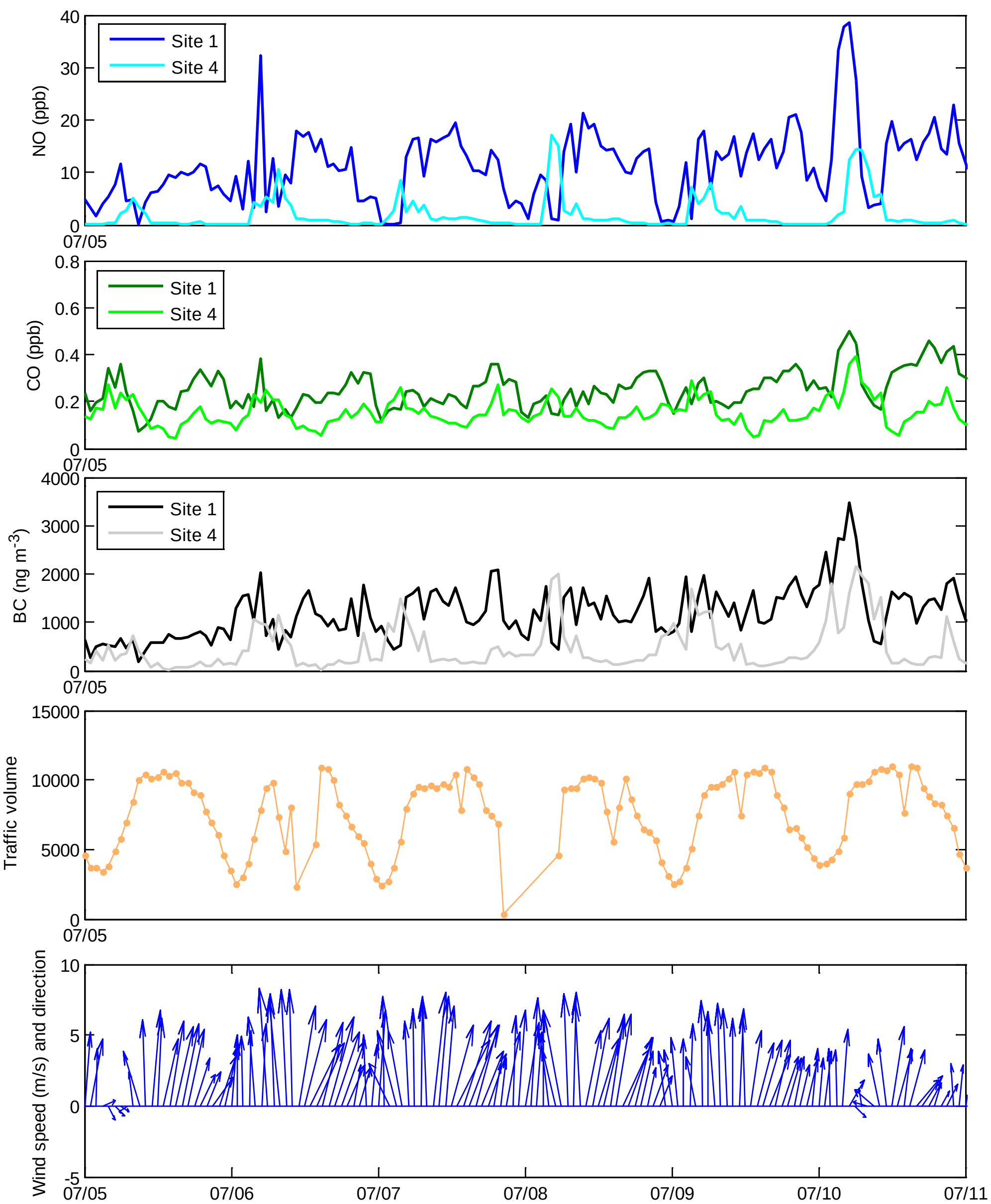


Figure 29. Mean NO, CO, BC Concentration, Traffic Volume and Wind Speed and Wind Direction for a Week in July 2009.[3]

[3] Image four in Figure 29 shows traffic volume. Note that during this time period (July 5-11, 2009) traffic volume is showing greater variability than might be otherwise expected. This is evident during late July 7 – early July 8, 2009 possible due to traffic sensor problems.

Figure 30 and Figure 31 show the mean hourly NO concentrations by site from all wind directions and winds from road, respectively. The mean NO concentration for the 20-meter road is approximately 134 percent higher than the 100 meter upwind site (Figure 30) for all wind directions. The mean NO concentration for the 20-meter road is approximately 336 percent higher than the 100-meter upwind site (Figure 31) for downwind conditions (winds from road). Figure 32 shows the mean NO concentration by hour for all stations when winds are from the road.

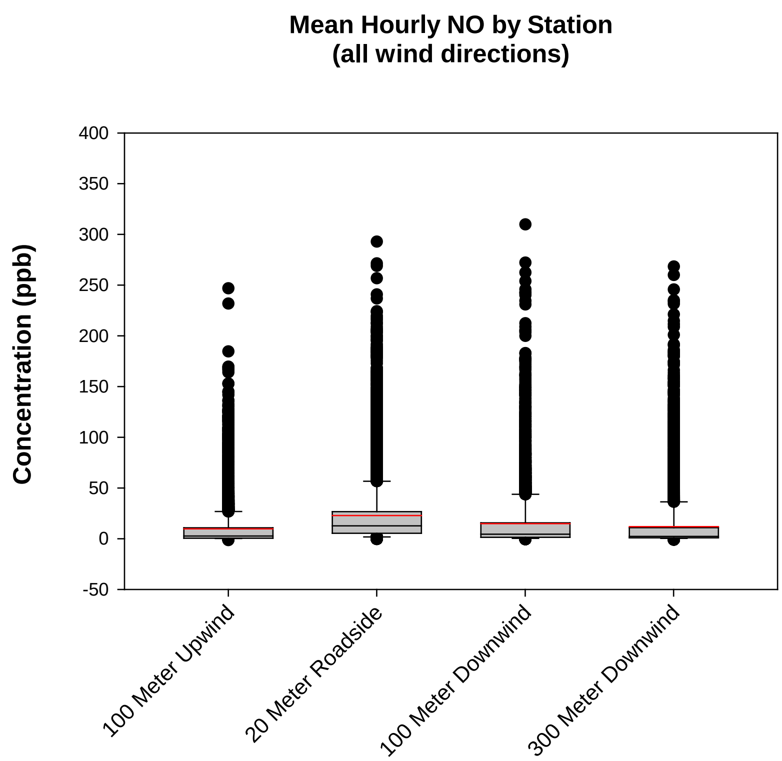


Figure 30. Box-Whisker Plot for NO by Station (all wind directions).

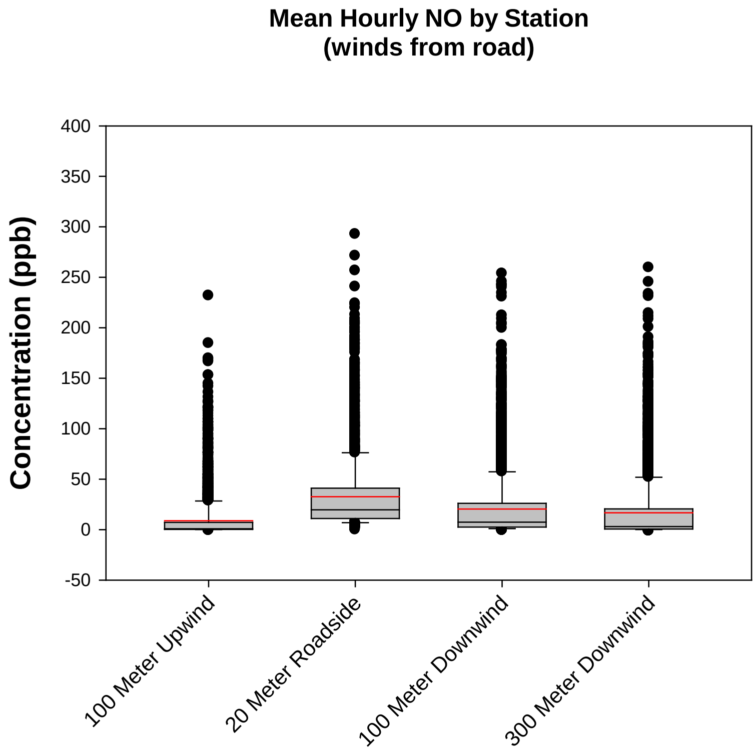
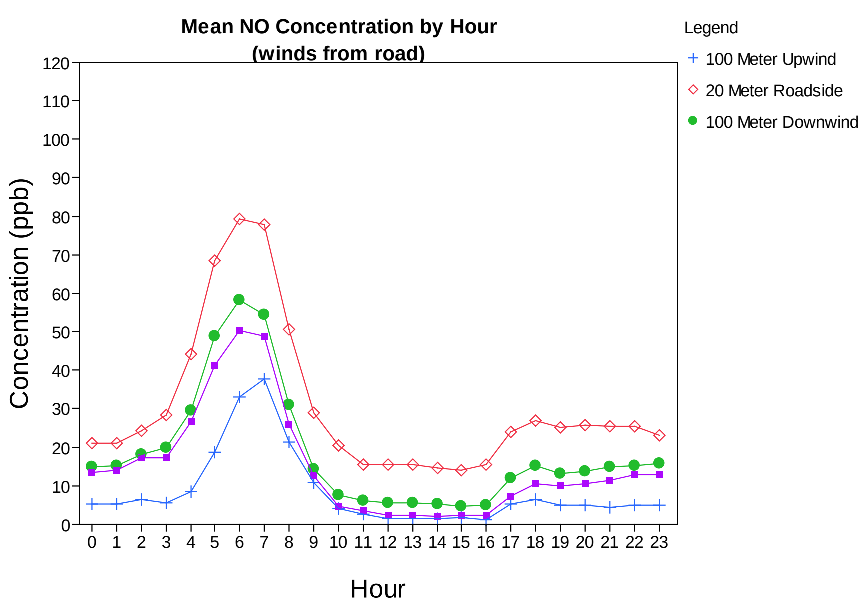


Figure 31. Box-Whisker Plot for NO by Station (winds from road).



Se

Figure 32. Mean NO Concentration by Hour: all stations (winds from road).

Figure 33 and Figure 34 show the mean hourly NO_2 concentrations by site from all wind directions and winds from road, respectively. The mean NO_2 concentration for the 20-meter road is approximately 16 percent higher than the 100-meter upwind site (Figure 33) for all wind directions. The mean NO_2 concentration for the 20-meter road is approximately 46 percent higher than the 100-meter upwind site (Figure 34) for downwind conditions (winds from road). Figure 35 shows the mean NO_2 concentration by hour for all stations when winds are from the road.

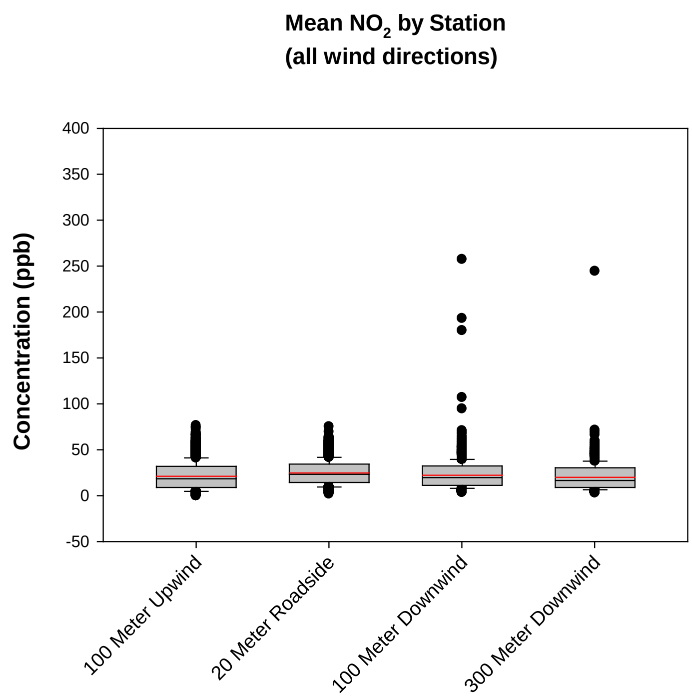


Figure 33. Box-Whisker Plot for NO_2 by Station (all wind directions).

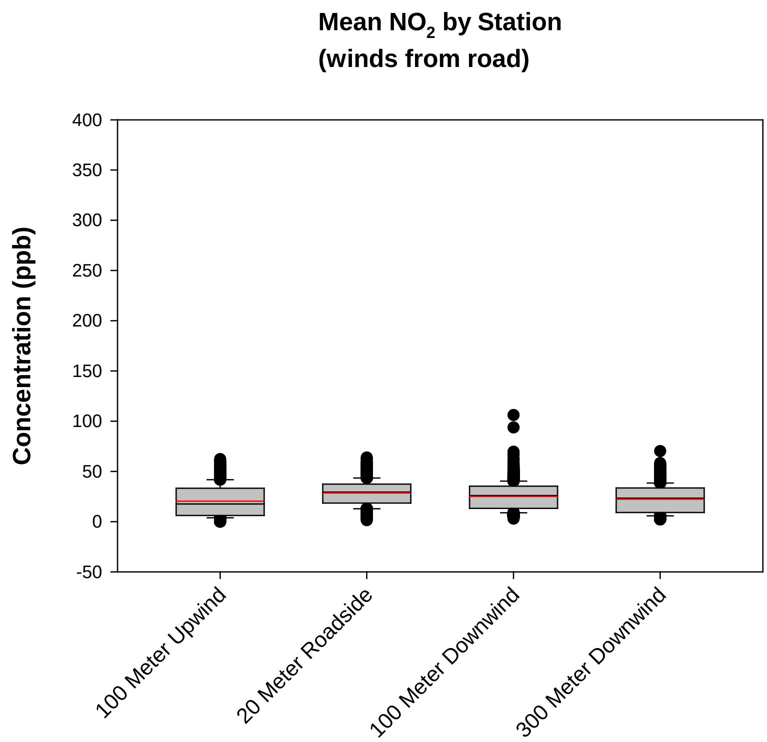


Figure 34. Box-Whisker Plot for NO_2 by Station (winds from road).

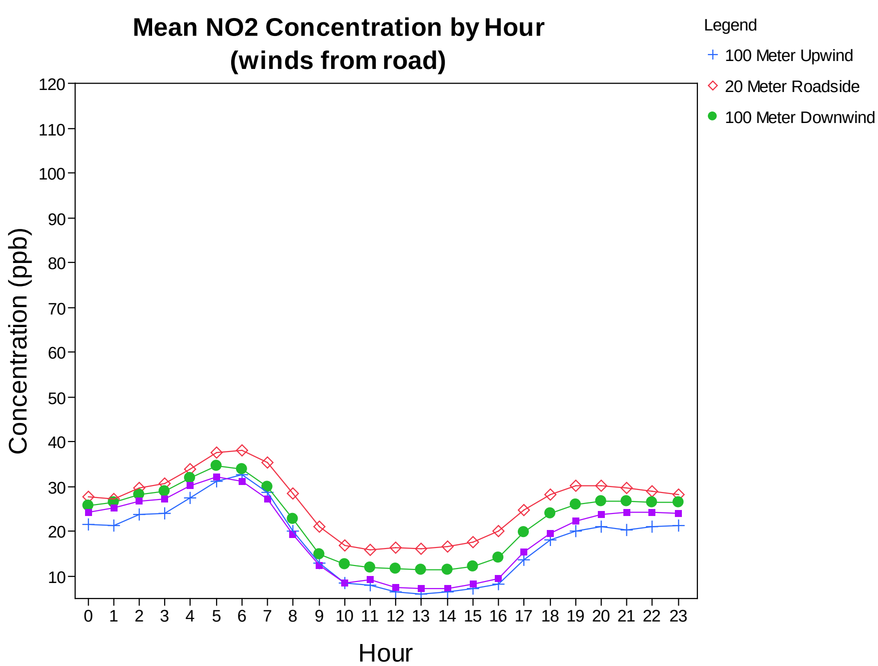


Figure 35. Mean NO_2 Concentration by Hour: all stations (winds from road).

Figure 36 and Figure 37 show the mean hourly NO_X concentrations by site from all wind directions and winds from road, respectively. The mean NO_X concentration for the 20-meter road is approximately 54 percent higher than the 100 meter upwind site (Figure 36) for all wind directions. The mean NO_X concentration for the 20 meter road is approximately 121 percent higher than the 100-meter upwind site (Figure 37) for downwind conditions (winds from road). Figure 38 shows the mean NO_X concentration by hour for all stations when winds are from the road.

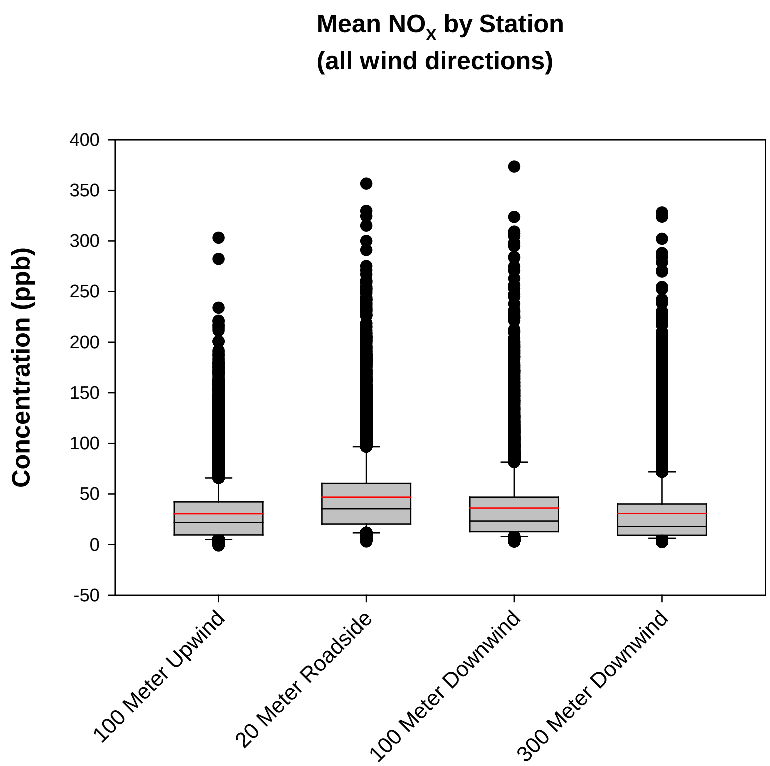


Figure 36. Box-Whisker Plot for NO_X by Station (all wind directions).

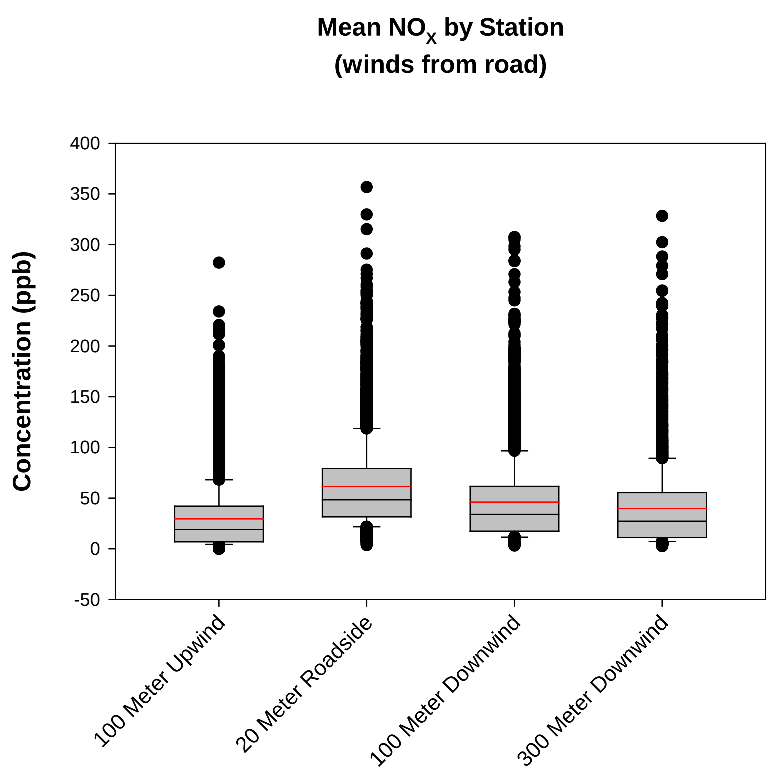


Figure 37. Box-Whisker Plot for NO_X by Station (winds from road).

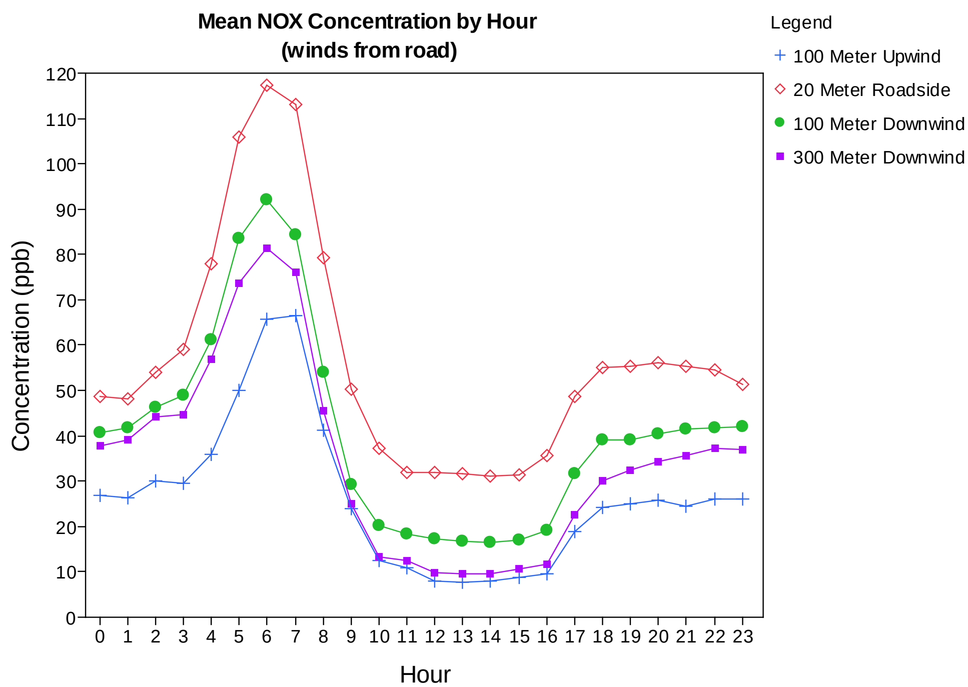


Figure 38. Mean NO_X Concentration by Hour: all stations (winds from road).

Long term averages for NO, NO_2, NO_x, and CO for all wind directions are shown in Table 16 and Table 17.

Example gradient plots for nitric oxide (NO) for two sample days are shown in Figure 39. These plots show that when the wind direction is from the roadway towards the downwind monitors with minimal wind speed, high NO concentrations are observed by the monitors (Figure 39) Moreover, when the wind direction is not from the roadway with higher wind speeds, lower NO concentrations are observed by the monitors (Figure 40). The concentration gradient is still observable in Figure 40, however just not as pronounced as in Figure 39.

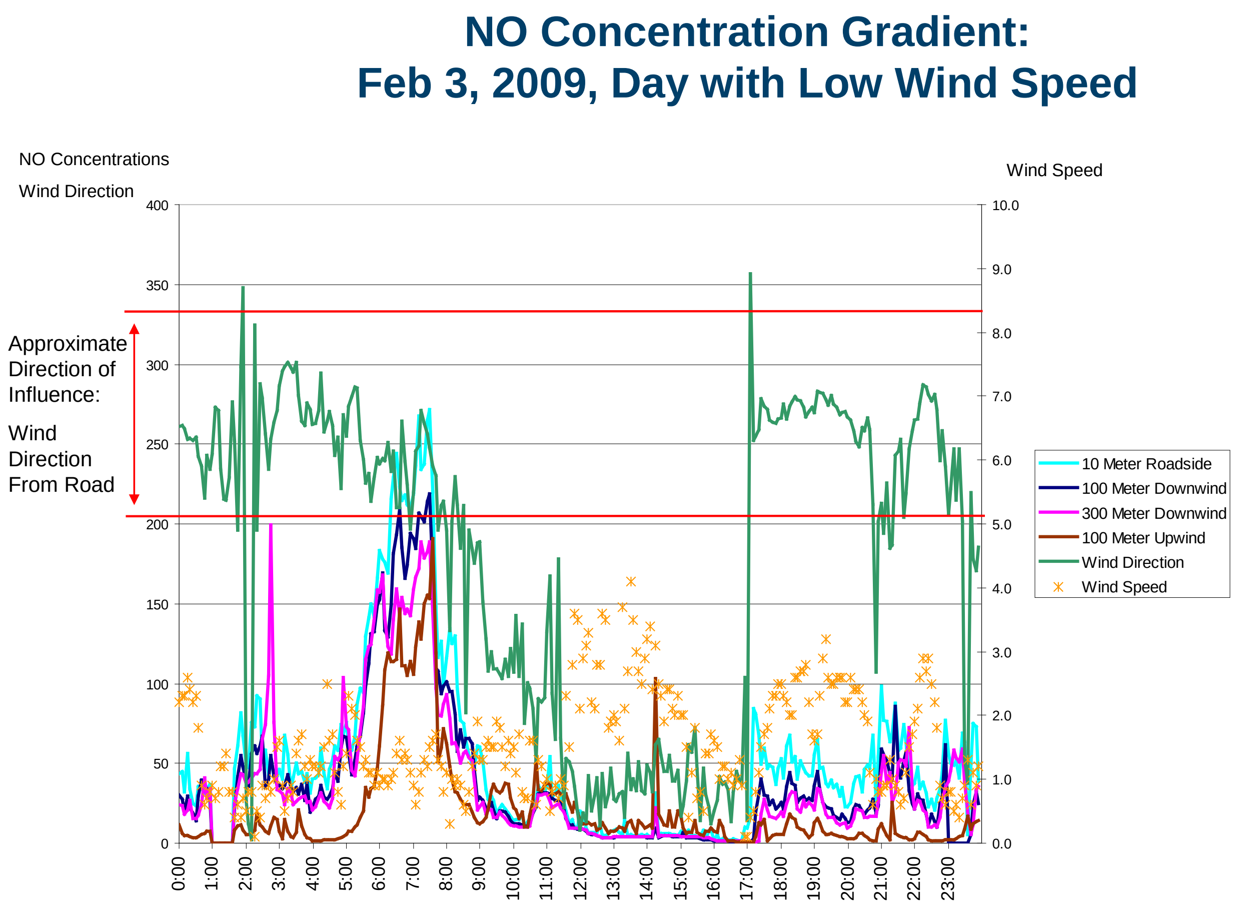


Figure 39 Gradient plots for NO for two sample days at I-15 site—wind direction from roadway towards monitors and low wind speed (concentration in ppb vs time).

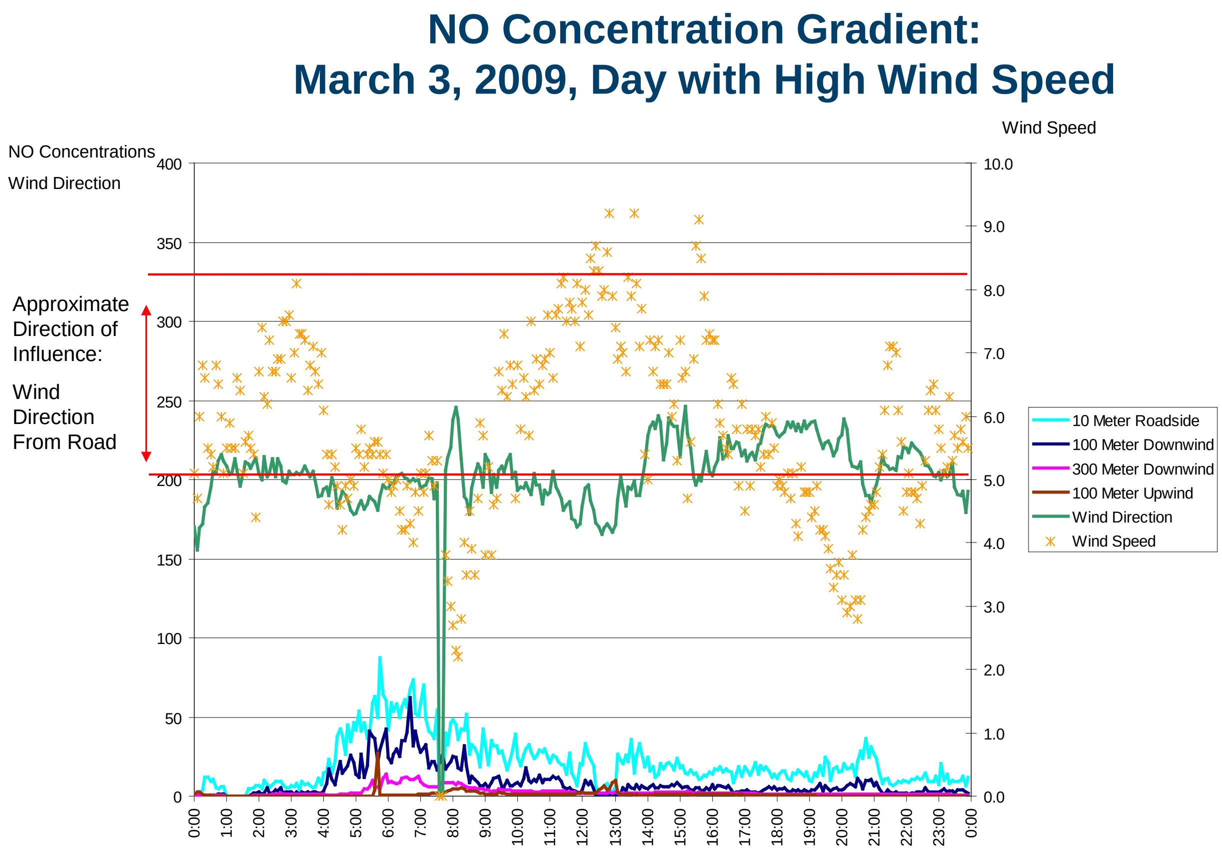


Figure 40 Gradient plots for NO for two sample days at I-15 site—wind direction not from roadway and higher wind speeds (concentration in ppb vs time).

Table 16. Long-term averages at near-road monitoring stations for NO, NO2, NOx, and CO - all wind directions.

Location	Time span	CO (ppm)			NO_2 (ppb)			NO_X (ppb)		
		N	Avg	95% CI	N	Avg	95% CI	N	Avg	95% CI
Station 1: 20 m east	12/15/2008 to 12/15/2009	8535	0.34	0.34 – 0.35	8535	24.10	23.84 – 24.36	8535	46.89	46.04 – 47.72
Station 2: 100 m east	12/15/2008 to 12/15/2009	8556	0.30	0.29 – 0.30	8593	21.26	20.99 – 21.53	8593	36.07	35.31 – 36.83
Station 3: 300 m east	12/15/2008 to 12/15/2009	8544	0.27	0.26 – 0.27	8518	18.69	18.42 – 18.95	8518	30.64	29.94 – 31.35
Station 4: 100 m west	12/15/2008 to 12/15/2009	8482	0.27	0.26 – 0.27	8459	20.73	20.44 – 21.03	8459	30.47	29.85 – 31.08

Table 17. Long-term averages a near-road monitoring stations for NO, NO2, NOx, and CO - winds from the West.

Location	Time span	CO (ppm)			NO_2 (ppb)			NO_X (ppb)		
		N	Avg	95% CI	N	Avg	95% CI	N	Avg	95% CI
Station 1: 20 m east	12/15/2008 to 12/15/2009	3472	0.40	0.39 – 0.40	3473	27.31	26.93 – 27.69	3473	56.08	54.82 – 57.33
Station 2: 100 m east	12/15/2008 to 12/15/2009	3523	0.32	0.32 – 0.33	3539	23.81	23.41 – 24.21	3539	41.16	40.00 – 42.32
Station 3: 300 m east	12/15/2008 to 12/15/2009	3526	0.30	0.29 – 0.31	3513	20.95	20.53 – 21.37	3513	34.86	33.72 – 35.99
Station 4: 100 m west	12/15/2008 to 12/15/2009	3461	0.25	0.25 – 0.26	3448	18.73	18.25 – 19.21	3448	25.32	24.46 – 26.18

7.3.2 Black Carbon

Summaries of the annual BC averages and confidence intervals at each site are presented in Table 18 and shown in Figure 41. Given that two of the stations did not have consistent data collection for the first month of sampling, an 11-month time frame (from 1/15/2009 to 12/15/2009) was selected to compare the average concentrations among the four stations. Data completeness was at 97 percent or higher for the four stations during this time frame. The data show that, on an annual average basis with winds from all directions, the BC annual average at 10 m from the highway is significantly higher than at further distances from the road. In addition, BC average values at 100 m in the predominant downwind direction (east of the highway) are significantly higher than at 100 m in the opposite direction, as well as higher than at 300 m on the downwind side of the road.

Table 18. BC averages for all data (1/15/2009-12/15/2009)

Site name	Distance from Road	N[a] (hours)	Mean (μg/m^{-3})	95% CI (μg/m^{-3})
Station 4	100 Meter Upwind	8032	0.94	0.92-0.96
Station 1	20 Meter Roadside	7779	1.46	1.44-1.49
Station 2	100 Meter Downwind	7807	1.09	1.07-1.11
Station 3	300 Meter Downwind	7866	0.78	0.76-0.80

[a]A complete hour of sampling was set at a minimum of 10 five minute data points

BC hourly values were also isolated for time periods with winds from the west, designated as 270 ± 60 degrees. Selecting only the BC hourly data with 70% or greater of the time period having winds from the West, the mean values at each station provided in Table 19 and shown in Figure 41. On the downwind side of the road, BC values at Station 1 are significantly higher than all other stations. Designating Station 4 as representative of the urban background, under downwind conditions Station 1, Station 2, and Station 3 exceed the urban background by a factor of 2.2, 1.6, and 1.2, respectively. These results suggest that the impact of traffic emissions on near-road air quality likely extends beyond 300 m from the road.

Table 19. BC averages, wind from the West (1/15/2009-12/15/2009)

Site name	Distance from Road	N[a] (hours)	Mean (μg/m^{-3})	95% CI (μg/m^{-3})
Station 4	100 Meter Upwind	1954	0.80	0.77-0.83
Station 1	20 Meter Roadside	1826	1.74	1.69-1.79
Station 2	100 Meter Downwind	1863	1.28	1.24-1.32
Station 3	300 Meter Downwind	1908	0.92	0.89-0.96

[a]A complete hour of downwind sampling was set at a minimum of 70% of the hour with winds from the West (210-330 degrees).

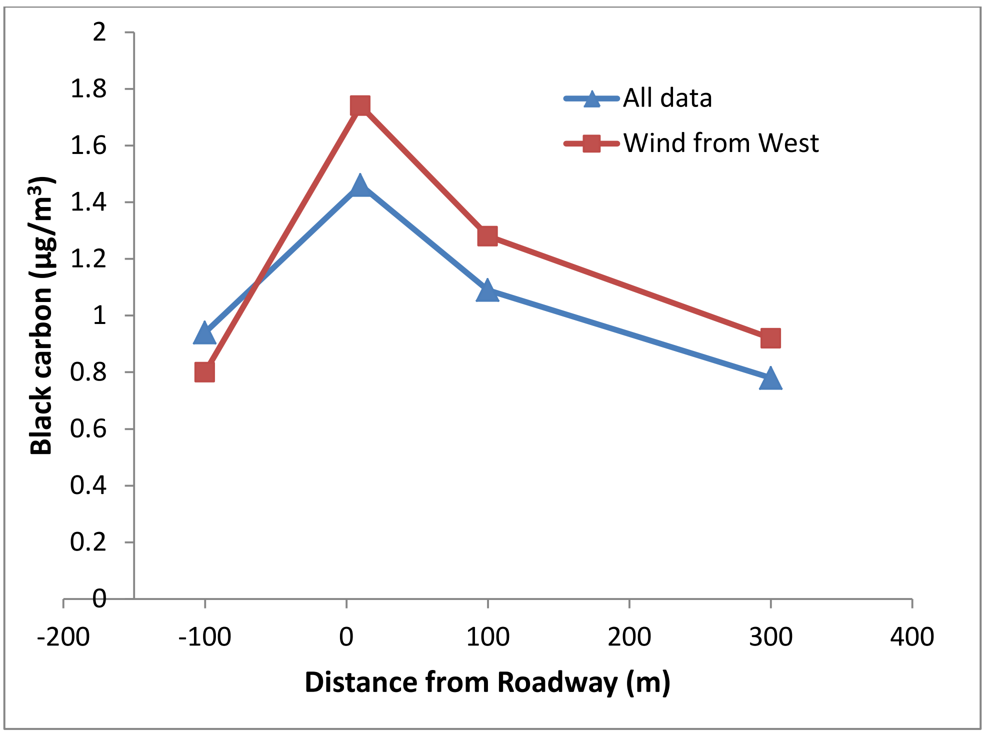


Figure 41. Average black carbon concentrations as a function of distance from the road for all data and during time periods with wind from the West (210-330 degrees).

Figure 42 and Figure 43 show the mean hourly BC concentrations by site from all wind directions and winds from road, respectively. The mean BC concentration for the 20-meter road is approximately 55 percent higher than the 100-meter upwind site (Figure 42) for all wind directions. The mean BC concentration for the 20-meter road is approximately 118 percent higher than the 100-meter upwind site (Figure 43) for downwind conditions (winds from road). Figure 44 shows the mean BC concentration by hour for all stations when winds are from the road.

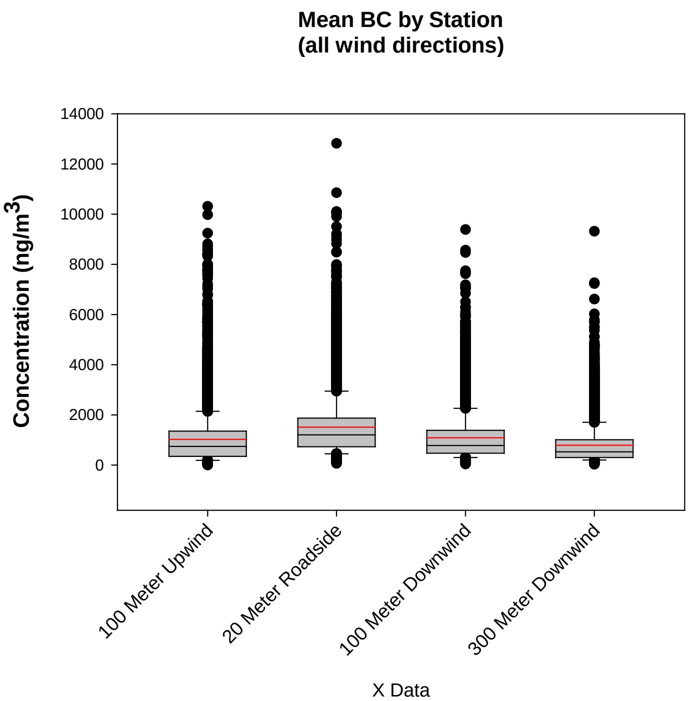


Figure 42. Box-Whisker Plot for BC by Station (all wind directions).

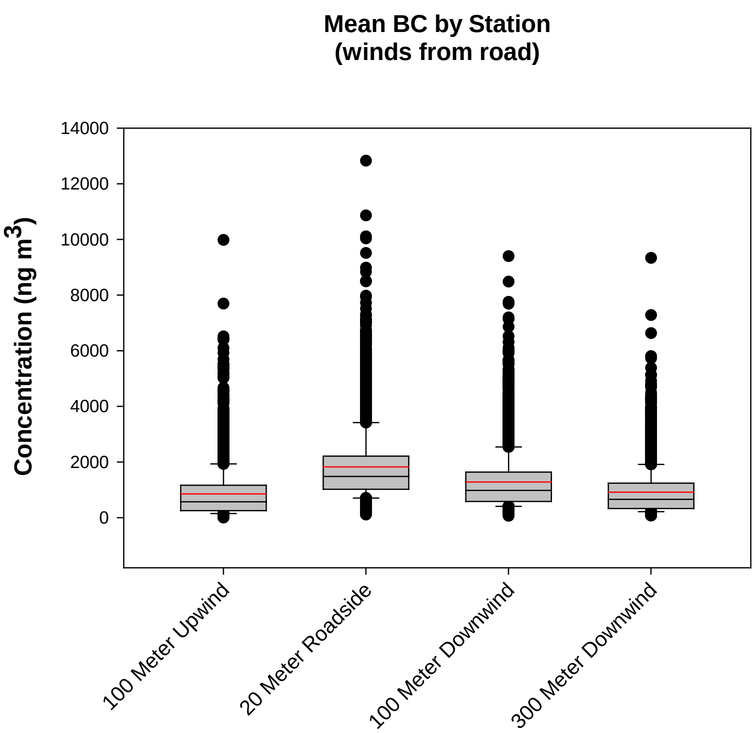


Figure 43. Box-Whisker Plot for Hourly BC by Station (winds from road).

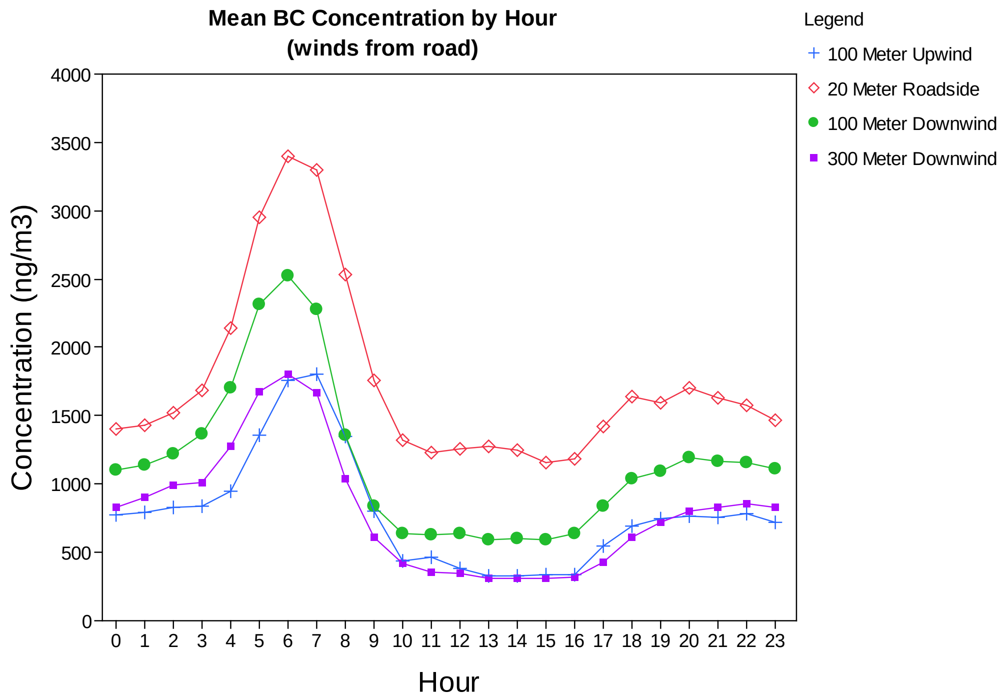


Figure 44. Mean BC Concentration by Hour: all stations (winds from road).

7.4 Continuous Particulate Data (TEOM)

Figure 45 shows box-whisker plots for PM_{10}, $PM_{2.5}$ and PM Coarse. Summaries of PM_{10}, $PM_{2.5}$ and PM Coarse averages and confidence intervals are shown in Table 20 and Table 21. These data were measured by a TEOM 1405 FDMS. Most analyzers deployed for this study performed well with the exception of the TEOMs. This instrument had both design and manufacturing issues that only became apparent after the instruments had been deployed. The remedy for this situation was that the manufacturer performed an "in the field upgrade" by technical staff from ThermoScientific in late November 2009 and early December 2009. While these upgrades improved instrument performance and stability, data collected prior to this time period is problematic. Results are presented in the main body of this report although it is very difficult to draw conclusions from the current analyses.

Table 20. PM_{10}, $PM_{2.5}$ and PM Coarse averages for all wind directions (12/15/2008-01/20/2010)

Site name	Distance from Road	N (hours)	Mean (μg/m³)	95% CI (μg/m³)
PM_{10}				
Station 4 [a]	100 Meter Upwind	326	20.26	19.12-21.40
Station 1	20 Meter Roadside	8228	22.62	22.16-23.07
Station 2	100 Meter Downwind	6517	18.10	17.60-18.59
Station 3 [b]	300 Meter Downwind	3158	20.75	20.12-21.38
$PM_{2.5}$				
Station 4 [a]	100 Meter Upwind	326	8.31	7.83-8.79
Station 1	20 Meter Roadside	8267	8.74	8.60-8.87
Station 2	100 Meter Downwind	6602	7.71	7.45-7.97
Station 3 [b]	300 Meter Downwind	3158	7.84	7.58-8.10
PM Coarse				
Station 4[a]	100 Meter Upwind	326	11.95	11.10-12.80
Station 1	20 Meter Roadside	8317	13.94	13.56-14.33
Station 2	100 Meter Downwind	6368	11.15	10.78-11.52
Station 3 [b]	300 Meter Downwind	3158	13.10	12.59-13.61

[a] Data from Station 4 is from 12/01/2009-01/01/08/2010.
[b] Data from Station 3 is from 07/15/2009-01/01/20/2010

Table 21. PM_{10}, $PM_{2.5}$ and PM Coarse averages for winds from road (12/15/2008-01/20/2010)

Site Name	Distance from Road	N (hours)	Mean (μg/m³)	95% CI (μg/m³)
PM_{10}				
Station 4	100 Meter Upwind	190	20.36	18.81-21.90
Station 1	20 Meter Roadside	3528	25.08	24.35-25.81
Station 2	100 Meter Downwind	2704	19.80	19.09-20.52
Station 3	300 Meter Downwind	1466	21.55	20.70-22.39
$PM_{2.5}$				
Station 4	100 Meter Upwind	190	8.45	7.83-9.07
Station 1	20 Meter Roadside	3551	9.05	8.84-9.26
Station 2	100 Meter Downwind	2731	8.15	7.91-8.39
Station 3	300 Meter Downwind	1466	8.30	7.92-8.68
PM Coarse				
Station 4	100 Meter Upwind	190	11.91	10.77-13.05
Station 1	20 Meter Roadside	3585	16.06	15.43-16.68
Station 2	100 Meter Downwind	2666	12.19	11.61-12.78
Station 3	300 Meter Downwind	1466	13.40	12.73-14.07

[a] Data from Station 4 is from 12/01/2009-01/01/08/2010.
[b] Data from Station 3 is from 07/15/2009-01/01/20/2010.

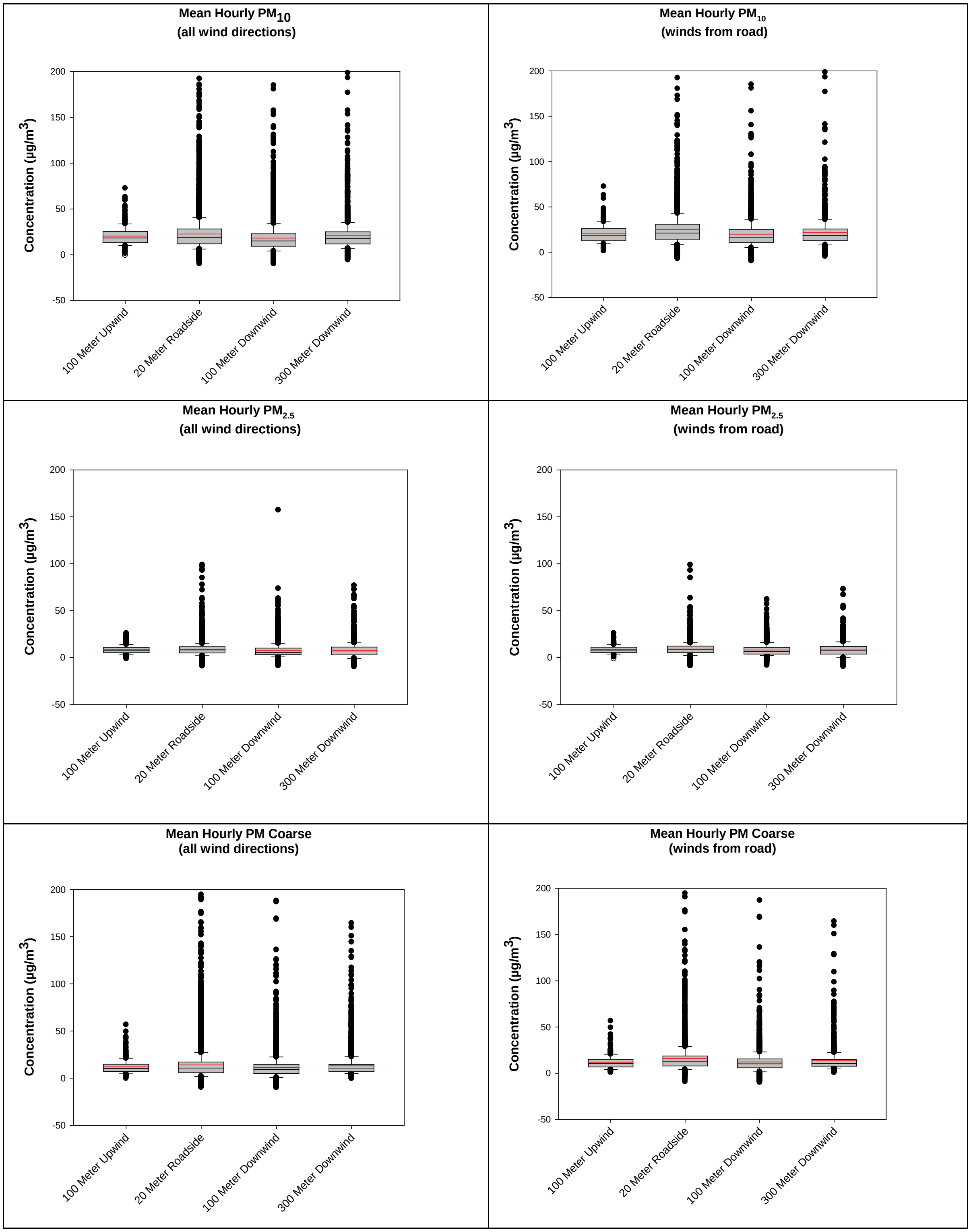


Figure 45 Box-Whisker Plots for PM_{10}, $PM_{2.5}$ and PM Coarse for all stations; all wind directions and winds from road.[4]

[4] Outliers exceeding the maximum y-axis are not shown in Figure 45.

7.5 Integrated Sample Data

7.5.1 Integrated MSAT Data (TO-15 — VOC)

Table 22 shows the number of observations, mean and 95 percent confidence intervals for the VOC data (TO-15 method). As shown in Table 22, Station 2 exhibits higher values for benzene. This may be due to influences from other nearby sources such as Las Vegas Blvd., McCarran International Airport, nearby truck parking lot as shown in Figures 48 and 49.

Table 22. VOC -- averages for all wind directions (12/15/2008-12/15/2009)

Site name	Distance from Road	N (Obs.)	Mean (ppb)	95% CI (ppb)
1,3-Butadiene				
Station 4	100 Meter Upwind	251	0.05	0.04-0.05
Station 1	20 Meter Roadside	276	0.06	0.05-0.07
Station 2	100 Meter Downwind	246	0.06	0.05-0.07
Station 3	300 Meter Downwind	246	0.03	0.03-0.04
Benzene				
Station 4	100 Meter Upwind	251	0.20	0.18-0.22
Station 1	20 Meter Roadside	276	0.22	0.20-0.24
Station 2	100 Meter Downwind	246	0.32	0.29-0.35
Station 3	300 Meter Downwind	246	0.16	0.15-0.18

NOTE: Data are for valid samples only.

7.5.2 Data Caveats– Integrated Samples -- VOC

It should be noted that acrolein values for the TO-15 method (canister) are problematic. Prior to June 18, 2009 the GC/MS system was not optimized for acrolein analysis. In addition, there is low confidence with all acrolein values due to potential contamination of Summa passivated canisters associated with the "growth" of acrolein inside cleaned canisters. Acrolein concentrations inside cleaned canisters containing zero humidified air have been shown to increase over time due to unknown reasons. For these reasons, acrolein data is not reported for the TO-15 method (Table 22). All sample results are presented with no blank or recovery correction. This was deemed unnecessary as the field blank values were either zero or below the method detection limit. Blank and control values may be found in the SAS/JMP data sets.

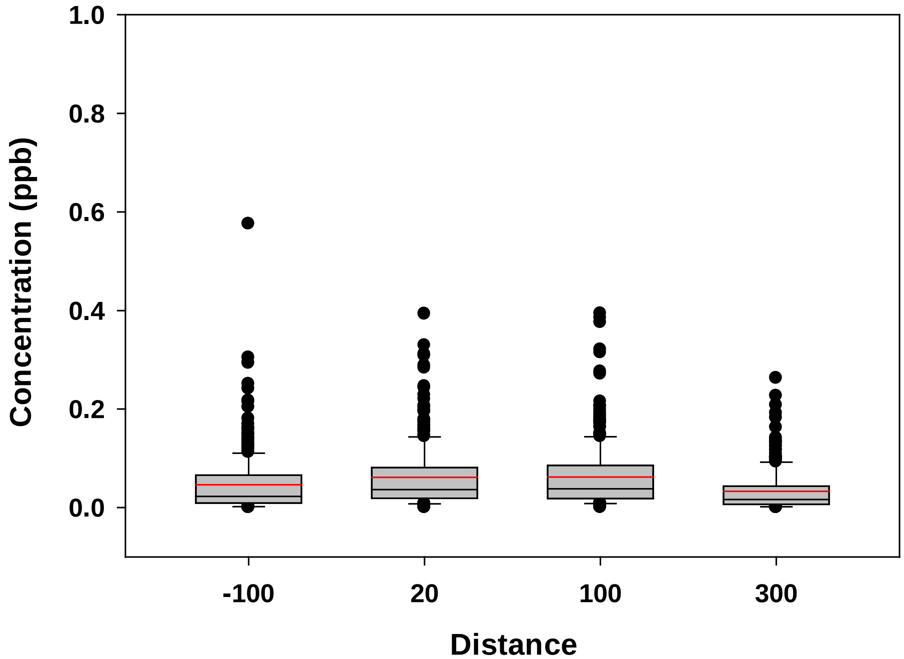


Figure 46 Box-Whisker Plot for 1,3-Butadiene all stations, all sample times, all wind directions.

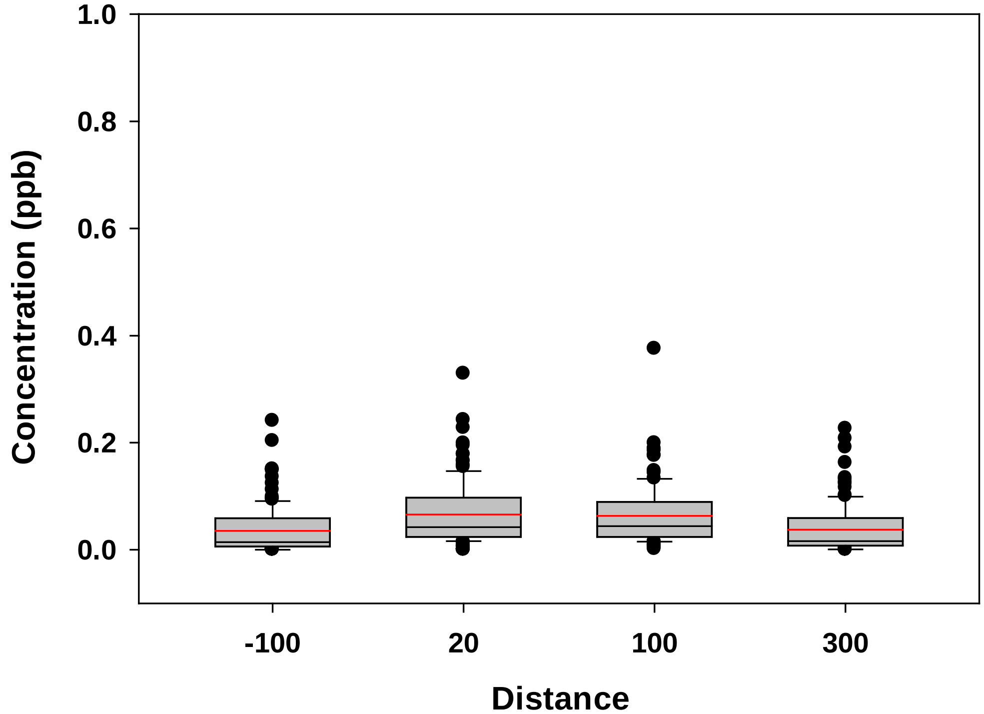


Figure 47 Box-Whisker Plot for 1,3-Butadiene all stations, all sample times, downwind conditions.

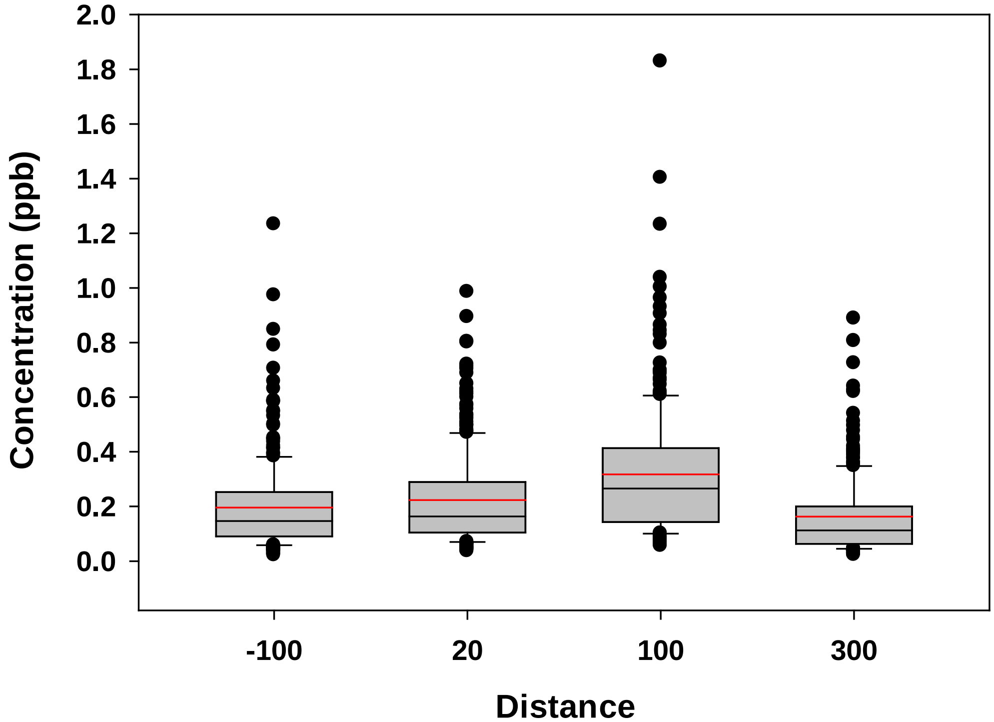


Figure 48 Box-Whisker Plot for Benzene all stations, all sample times, all wind directions.

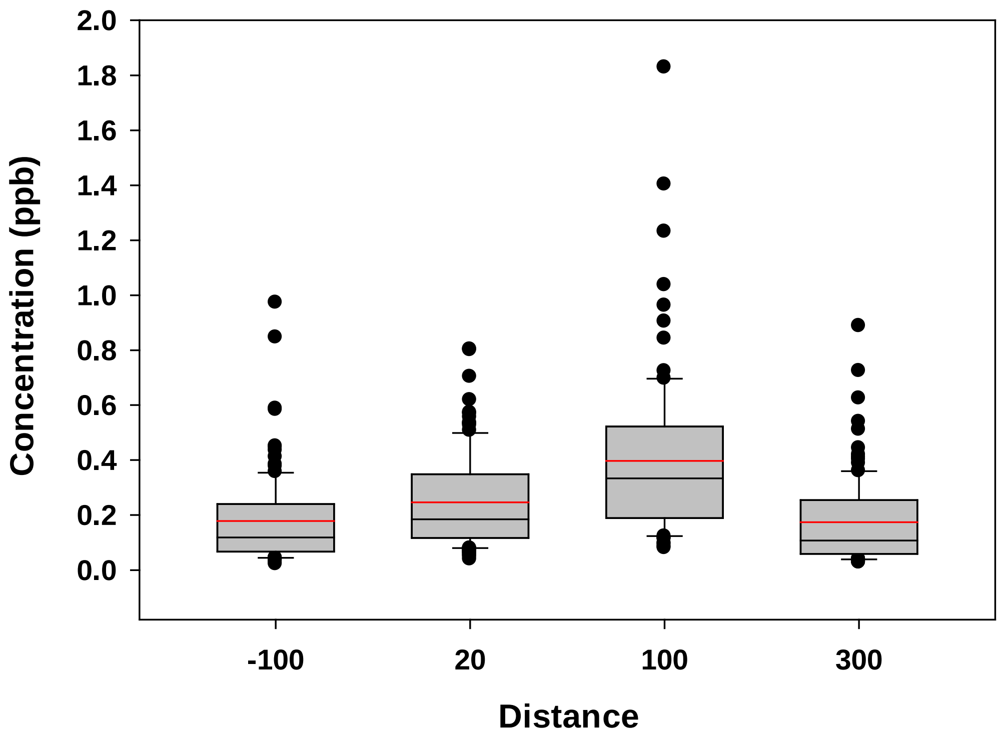


Figure 49 Box-Whisker Plot for Benzene all stations, all sample times, downwind conditions.

7.5.3 Integrated MSAT Data (TO-11a — carbonyl)

Table 23 shows the number of observations, mean and 95 percent confidence intervals for the carbonyl data (TO-11a method). As shown in Table 23, the study did not provide any usable data for Station 3. The instrument at Station 3 had instrument problems throughout the life of the study. Acetaldehyde measurements at Station 1 were approximately 10% higher than at Station 4. Acetaldehyde measured at Station 1 versus Station 2 was virtually the same. Formaldehyde measurements at Station 1 were approximately 18 percent higher and 9 percent higher than at Station 2 and 4, respectively. Acrolein measurements at Station 1 were approximately 14 percent higher than at Station 2. Acrolein measured at Station 1 versus Station 4 was virtually the same. Box-whisker plots (Figures 50 – 55) show all three pollutants for all wind conditions and downwind conditions. All sample results are presented with no blank or recovery correction. Blank and control values may be found in the SAS/JMP data sets.

Table 23. Carbonyl -- averages for all wind directions (12/20/2008-12/16/2009)

Site name	Distance from Road	N (Obs.)	Mean (ppb)	95% CI (ppb)
Acetaldehyde				
Station 4	100 Meter Upwind	279	1.02	0.94-1.11
Station 1	20 Meter Roadside	308	1.12	1.02-1.22
Station 2	100 Meter Downwind	225	1.11	1.00-1.21
Station 3	300 Meter Downwind	---	---	---
Formaldehyde				
Station 4	100 Meter Upwind	279	2.91	2.73-3.10
Station 1	20 Meter Roadside	308	3.18	2.97-3.39
Station 2	100 Meter Downwind	225	2.62	2.45-2.79
Station 3	300 Meter Downwind	---	---	---
Acrolein				
Station 4	100 Meter Upwind	279	0.27	0.26-0.29
Station 1	20 Meter Roadside	308	0.27	0.25-0.28
Station 2	100 Meter Downwind	225	0.27	0.25-0.29
Station 3	300 Meter Downwind	---	---	---

NOTE: Data are for valid samples only.

7.5.4 Data Caveats– Integrated Samples -- Carbonyl

As shown in Table 23, the study did not provide any usable data for Station 3. The instrument at Station 3 had problems throughout the life of the study. Thus, all carbonyl data collected at Station 3 is considered invalid. Background corrections were not performed on the formaldehyde data. This was deemed unnecessary as the field blank values were either zero or below the method detection limit. Background corrections were performed on the acetaldehyde and acrolein data. The EPA Compendium TO-11A DNPH carbonyl method was implemented in Las Vegas for the collection and analysis of air samples for acetaldehyde, formaldehyde and acrolein. A field blank is a DNPH cartridge that is treated in the same manner as a sample cartridge except no sample air is drawn through the field blank. These field blanks are sent back to the laboratory, analyzed and values were reported for acetaldehyde, formaldehyde, and acrolein.

DNPH cartridges are prepared in large batches by a manufacturer (e.g., Sigma-Aldrich). Properly stored DNPH cartridges may be used over several weeks or months. For a year-long study, we purchased DNPH cartridges multiple times to maintain the "freshness" of the cartridges. Thus, our data shows that we used cartridges from multiple batches. Ideally, field blanks should be drawn from the same batch as the sample cartridges. For the Las Vegas study, there were cases when no field blanks were drawn from batches used for sampling. Thus, we had two cases: 1) field blanks drawn from the same batch as field samples; and 2) no field blanks drawn from the same batch as field samples. For case 1, we used the median value by batch by pollutant of the reported field blank values as the background correction. For case 2, we used an overall median value by pollutant for the entire set of reported field blank values for the background correction. If corrected values were calculated as negatives or below the method detection limit, then the corrected values were replaced with the method detection limit value; otherwise the corrected value is the actual calculated value. The SAS/JMP data set reports the uncorrected and corrected data along with the method detection limit values and relevant data flags to indicate how the data were treated.

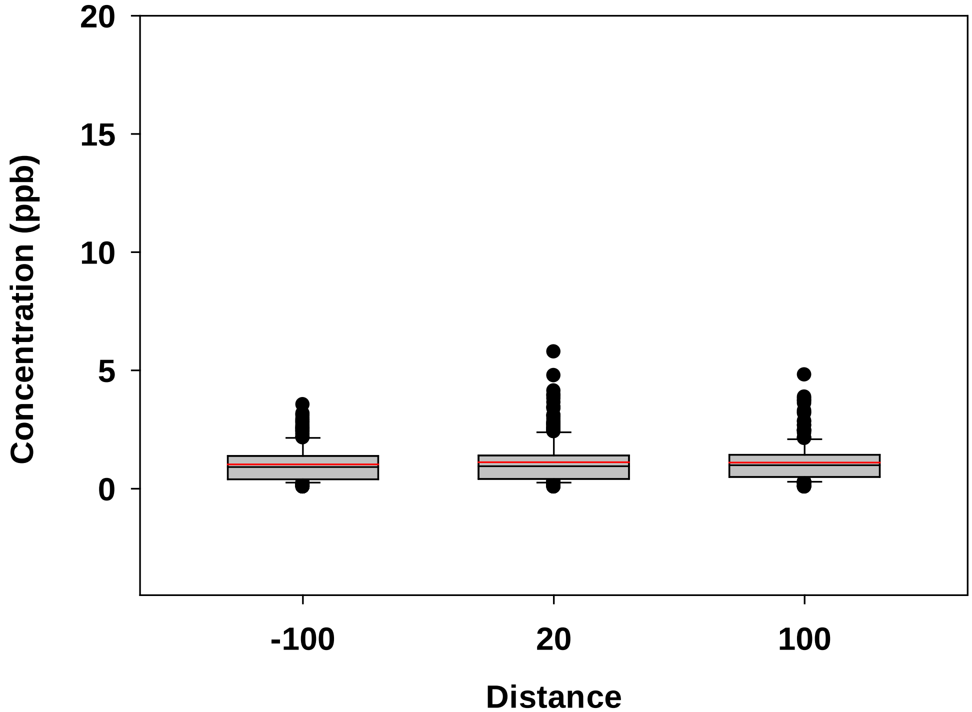


Figure 50 Box-Whisker Plot for Acetaldehyde all stations, all sample times, all wind directions.

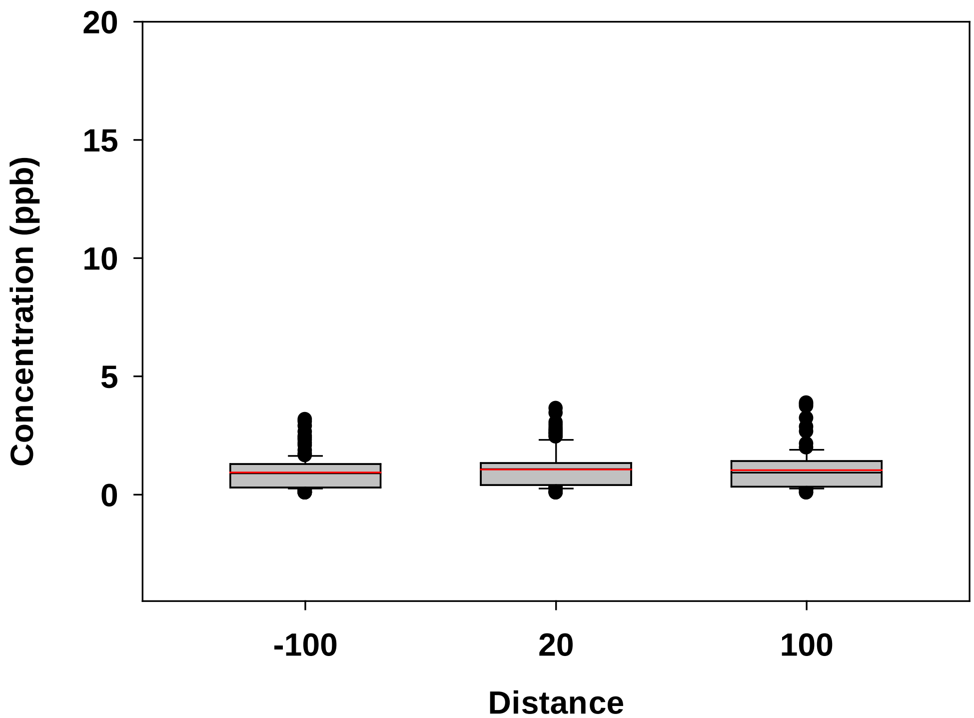


Figure 51 Box-Whisker Plot for Acetaldehyde all stations, all sample times, downwind conditions.

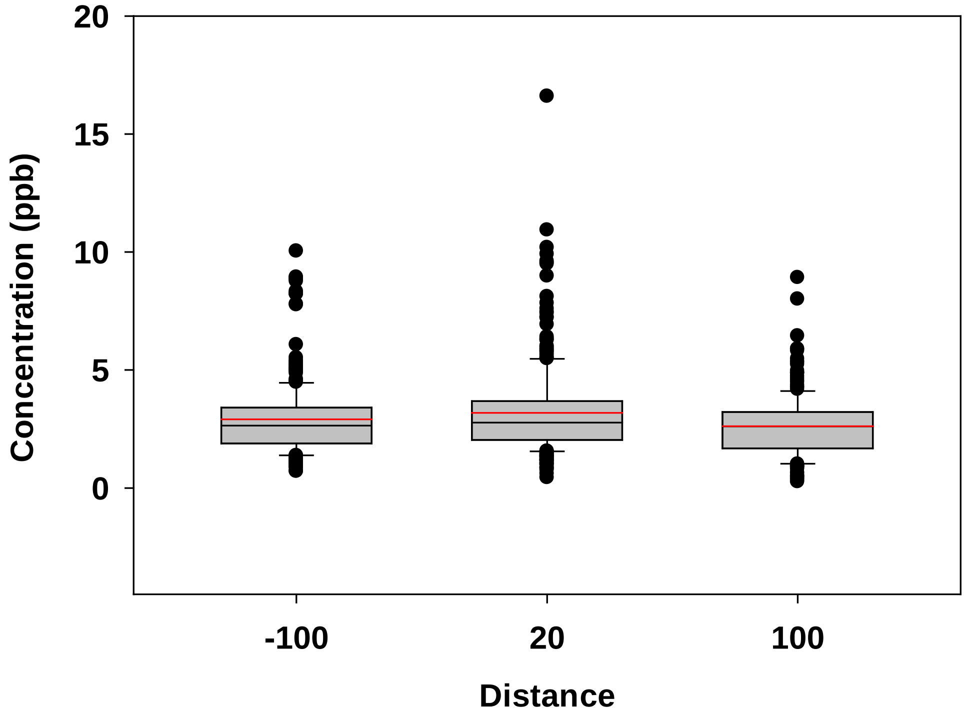


Figure 52 Box-Whisker Plot for Formaldehyde all stations, all sample times, all wind directions.

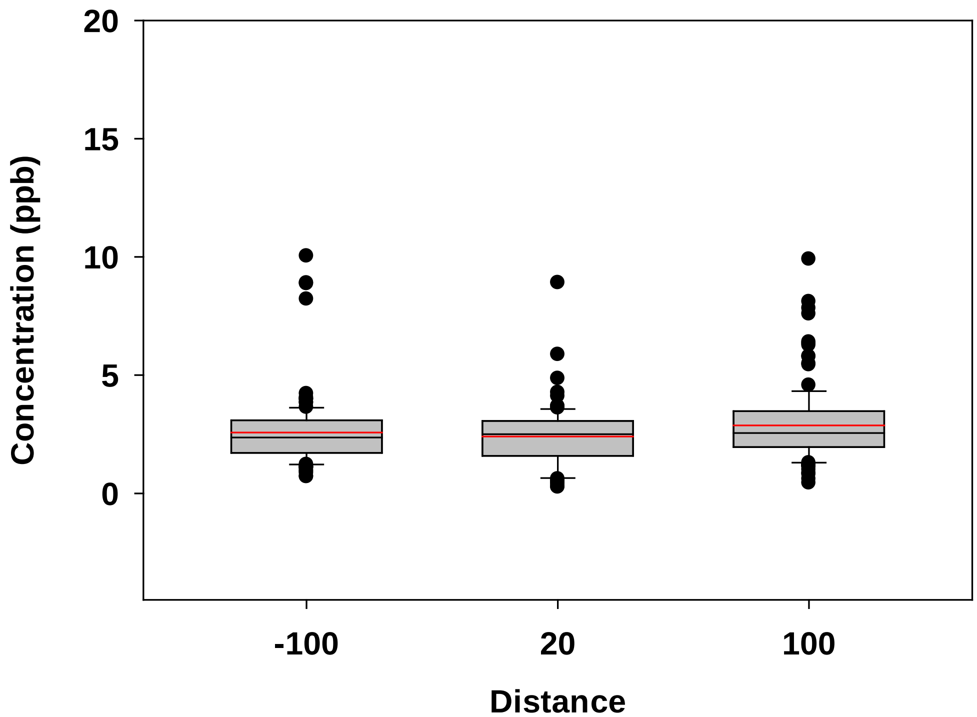


Figure 53 Box-Whisker Plot for Formaldehyde all stations, all sample times, downwind conditions.

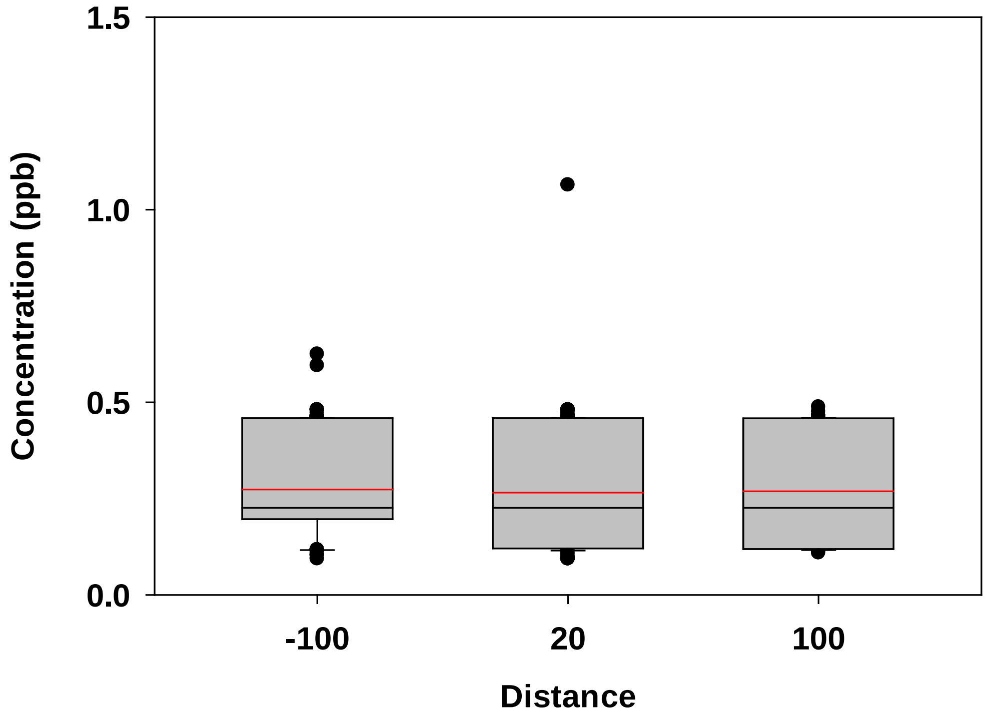


Figure 54 Box-Whisker Plot for Acrolein all stations, all sample times, all wind directions.

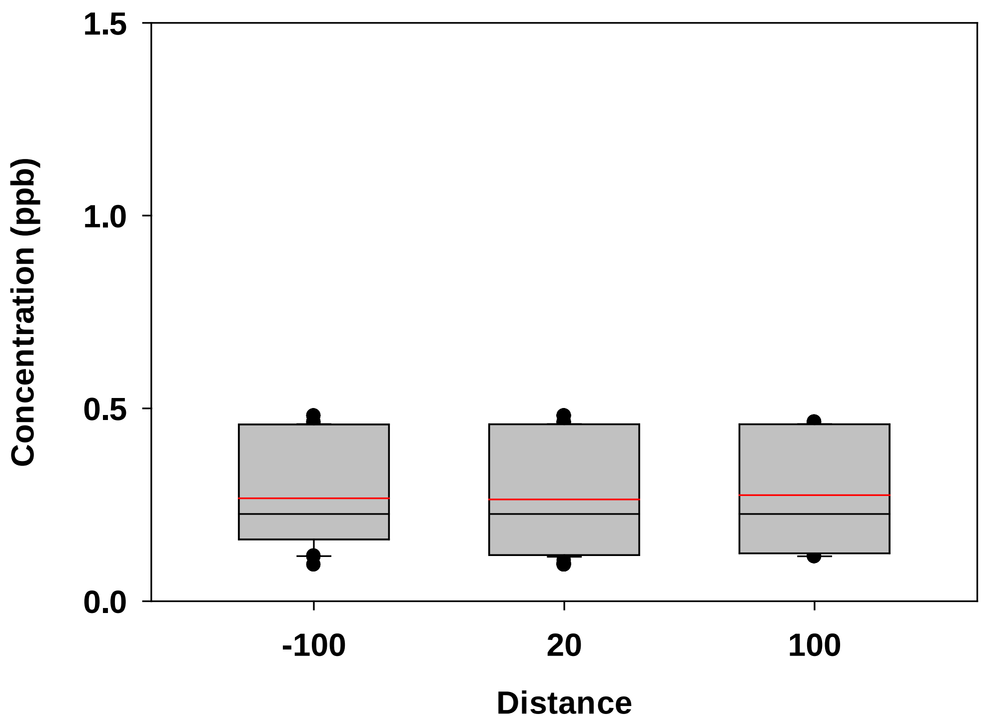


Figure 55 Box-Whisker Plot for Acrolein all stations, all sample times, downwind conditions.

7.5.5 Particulate Data (FRM Filters)

A summary of $PM_{2.5}$ averages and confidence intervals are shown in Table 24. Figure 56 shows box-whisker plots $PM_{2.5}$ integrated filter samples. As shown in Table 24 and Figure 56, the 20 m site (Station 1) has an observed higher mean $PM_{2.5}$ concentration than the other sites. Station 1 is approximately 19%, 11%, and 9% higher than Stations 2, 3, and 4 respectively. Figure 57 shows $PM_{2.5}$ data by date and site.

Table 24. $PM_{2.5}$ Filters -- averages for all wind directions (12/15/2008-12/15/2009)

Site name	Distance from Road	N (Obs.)	Mean (µg m^3)	95% CI (µg m3)
Station 4	100 Meter Upwind	30	9.20	7.63-10.79
Station 1	20 Meter Roadside	29	10.03	8.56-11.50
Station 2	100 Meter Downwind	30	8.42	6.99-9.85
Station 3	300 Meter Downwind	29	9.05	7.51-10.58

NOTE: Data are for valid samples only.

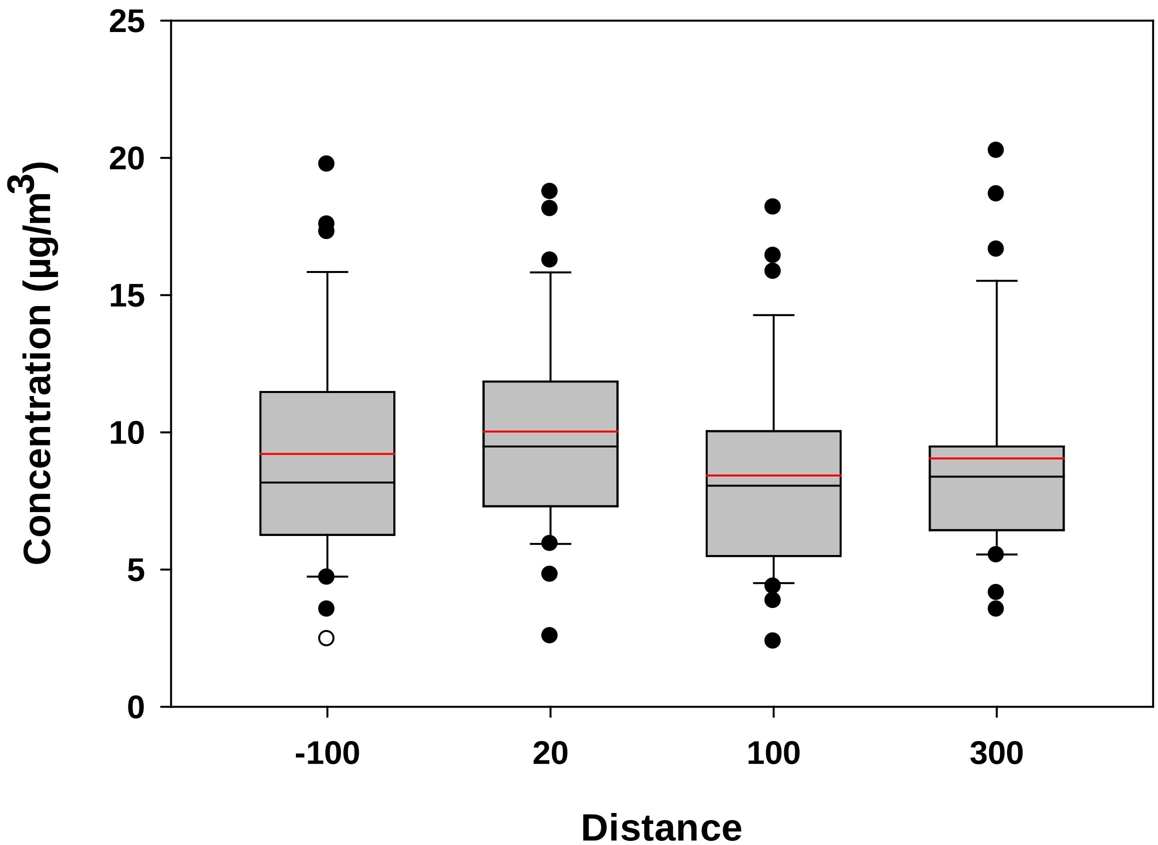


Figure 56 Box-Whisker Plot for $PM_{2.5}$ for all stations, all sample times, all wind directions.

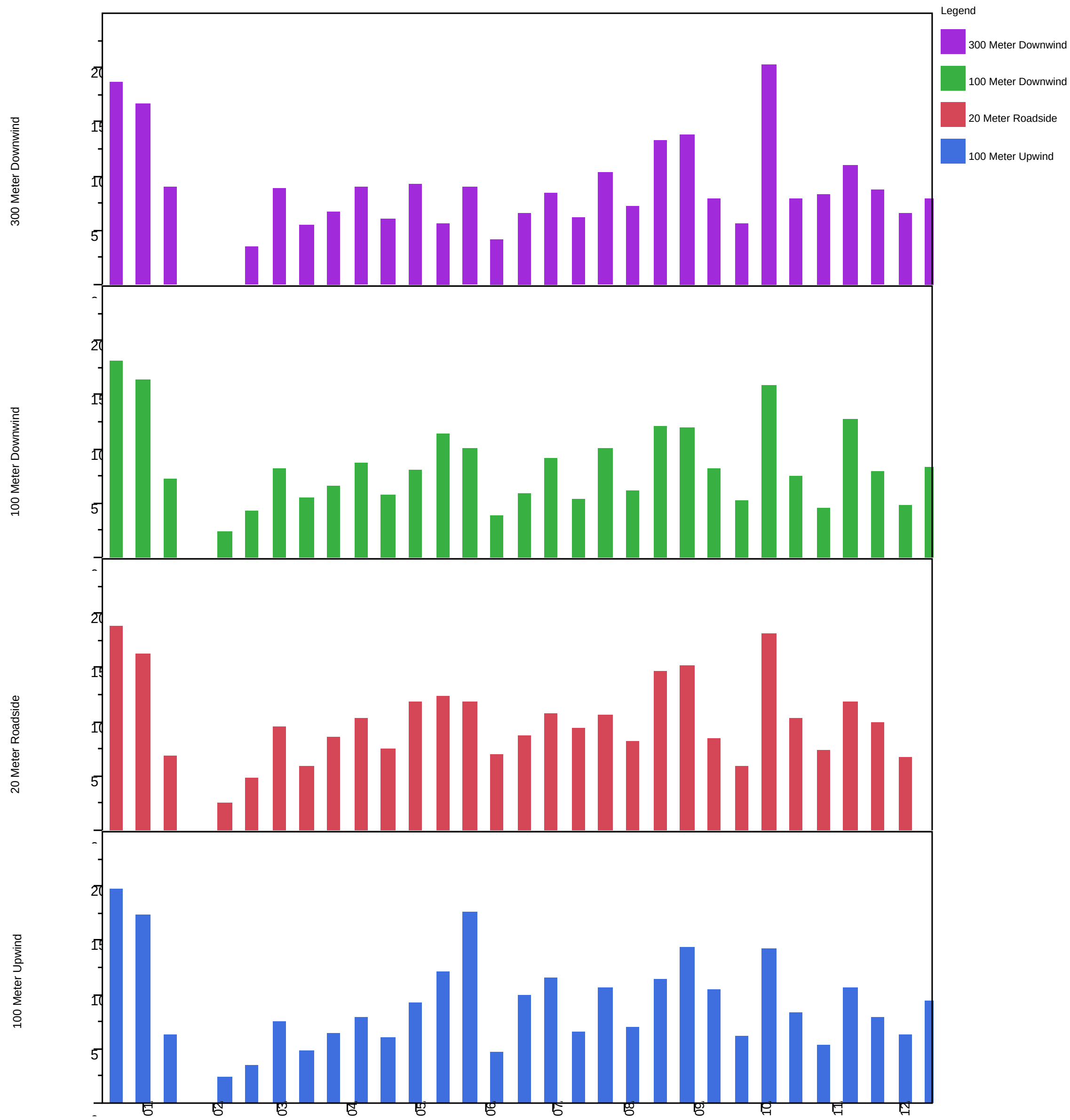


Figure 57 Bar chart for $PM_{2.5}$ ($\mu g/m^3$) for all stations, all sample times, all wind directions.

8 Summary

This report provides a summary of a field study conducted in Las Vegas, NV from Mid-December, 2008 thru Mid-December, 2009. The objective of this research study has been to determine MSAT concentrations and variations in concentrations as a function of distance from the highway and to establish relationships between MSAT concentrations as related to highway traffic flows including traffic count, vehicle types and speeds, and meteorological conditions such as wind speed and wind direction. Preliminary results include the following:

- Concentration gradients are observed for gaseous pollutants associated with distance from roadway, however more analysis is required.
- Higher pollutant concentrations are observed with higher traffic volumes.
- Effect of wind speed appears to be a factor with regards to concentration gradient (e.g., dilution effect) and needs to be investigated further.
- Non I-15 sources may be larger contributors than previously expected, for example:
    - Impact of near-by parking lot may be a factor at Site 2 and Site 3.
    - Las Vegas Boulevard (Site 3).
    - Airport and other potential sources.

Preliminary results of this study provide indications that highway vehicle emissions impact near-road air quality. Known highway vehicle pollutants such as CO, NO, NO_2 and NO_X have elevated concentrations in a near-road environment and decrease as one moves away from the road. Additional analysis of the data is needed to more accurately assess the effect of wind speed as well as other near-road effects.

9 Lessons Learned

Costs, timeliness and other operational factors are just some of the site implementation variables that may be difficult to control. These implementation variables include site access and permissions, electrical connectivity, security, communications, site operators and equipment. Costs may be estimated but there may be factors beyond one's control that influence the outcome of the costs. An example of this was that in order to obtain electrical services for the Las Vegas study site, electrical conduit needed to be installed underground. This underground installation encountered a caliche geological formation, i.e., hardened sedimentary rock prevalent in the Las Vegas area. This necessitated the use of jackhammers to install the underground conduit; a much more expensive operation than the use of the typical backhoe. An additional example was the performance of an analytical instrument utilized in the study. This instrument had both design and manufacturing issues that only became apparent after the instruments had been deployed. The remedy for this situation was that the manufacturer performed an "in the field upgrade". Projects of this nature present myriad challenges both from a programmatic and technical perspective.

Access to sites owned by private citizens can be challenging. Adjacent property owners may understand the necessity of improving the state-of-the-science, benefiting the community at-large and have a desire to be a "good" citizen, but existing lease and financial issues are a deterrent to participation. In addition, liability, insurance compensation, hassle factor(s), and other real and perceived issues present obstacles to site access.

Electrical and communications companies have numerous requirements for obtaining their services. This process requires interactions with utility companies as well as local (i.e., county or city) inspections departments.

10 Uncertainties

Study Design. This study focused on a single location (freeway) in one city. Additional locations will be needed to fully assess air pollutant concentration gradients from different roadway types; different traffic patterns; geographic locations; meteorological conditions, or other characteristics.

Methods. The analytical methods implemented during this study followed EPA standard methods and Federal Reference Methods for performing ambient air measurements. Refinements to methods can and do occur over the course of time due to improved technologies and measurement techniques, however the most current technologies and techniques were implemented for this study.

Data. Uncertainties in the data may be considered in two parts: overall data integrity, individual measurements. Electronic data streaming was utilized whenever possible to lessen the chance of human error (i.e., transcription error) and ensure overall data integrity. When hardcopy data sheets, notes, chain-of-custody forms were utilized; an EPA staff member reviewed the hardcopy and verified the data. Quality assurance of the data (i.e., individual measurements) is an on-going process and often occurs during more specific data analysis. Given that this project generated gigabytes of data, thorough quality assurance of the data is an on-going activity.

11 Conclusions

The FHWA and EPA collaborated on a research effort to characterize the impact and behavior of particulate matter with aerodynamic diameter less than 2.5 microns ($PM_{2.5}$) and MSATs near highways. This study was conducted from mid-December 2008 thru mid-December 2009. The preliminary results of this study have been summarized in the Executive Summary and are described in detail in the previous sections of this report.

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13 Appendix -- Black carbon measurements

13.1 Digital Aethalometer

Black carbon (BC) was measured continuously at each station using dual-wavelength rackmount Aethalometers (Magee Scientific, Inc.), which is displayed in Figure 58. In addition to the main four station monitors, an additional three Aethalometers were operated at station 1 for a several month period of time to evaluate the dispersion of traffic emissions affected by a cut-section in the roadway. This report focuses on the results from the main station monitors that were operated for approximately one year; the results from the cut-section monitoring will be covered in a separate report.

The Aethalometer continuously measures BC at five minute intervals by pulling air through a small spot on the sample filter and detecting incremental changes in light attenuation at a specific wavelength. Once the sample spot is loaded to a certain limit, the instrument automatically pauses, rotates the filter tape through to a new clean spot, and begins sampling again; this translates to a ten minute gap in the data approximately twice per day in the Las Vegas data set. The main wavelength of light used to detect BC is 880 nm, in the red region of the visible spectrum. In addition, this instrument also detects light attenuation at 370 nm and is a qualitative indicator of additional particulate organics which may absorb light at near-ultraviolet wavelengths.

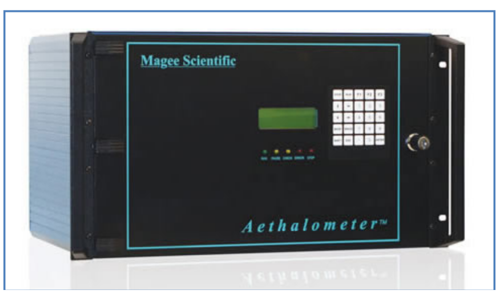


Figure 58 Image of a rackmount Aethalometer (Image source: mageesci.com)

Black carbon values are calculated by the below equation,

$$BC = \Delta ATN * A / SG * Q * \Delta t \qquad (1)$$

where, BC is the concentration of black carbon in the sample (units of ng/m^{-3}), ΔATN is the change in optical attenuation due to light absorbing particles accumulating on a filter, A is the spot area of filter, Q is the flow rate of air through filter, Δt is the change in time, SG is specific attenuation cross-section for the aerosol black carbon deposit on this filter (16.6 m^2/g). SG is an empirical value that was defined by the manufacturer as the ratio of the mass of elemental carbon (measured using a thermal-optical process) and the detected light absorption of the same sample on a filter.

13.2 . Data Review and Validation

13.2.1 Data time synchronization and screening

BC data was automatically logged by two methods during the Las Vegas monitoring period – internally logging its full set of data fields (17 columns of data) at five minute intervals to a compact flash card, which was downloaded approximately quarterly during the study, and directly logging only the BC concentration estimated from the instrument's analog output to the station database. The analog data was used during the course of the monitoring study to observe the instrument's performance, however the digital data logged to the compact flash card was used as the primary data for analysis, per manufacturer's recommendations.

As the digital data timestamp was based on the instrument's internal clock, the first step of data review was to apply any necessary time corrections to the digital data to match it to the station clock. Comparison of analog to digital data streams, as well as viewing the instrument's internal clock, revealed time shifts ranging from 5 minutes to over 24 hours were needed to precisely overlay the data sets for each station. Each instrument's data was reviewed for time periods throughout the year to ensure that the internal instrument clock did not drift to the point that further time correction was needed. Based on the review, the instrument clocks did not appear to drift by more than 5 min within a one year time period. An example of the time adjustment is shown in Figure 59.

The top image (Figure 59) is prior to time alignment; the bottom image is after the digital data timestamp was adjusted to match the station clock. The breaks in the data indicate time periods when an internal filter change occurred.

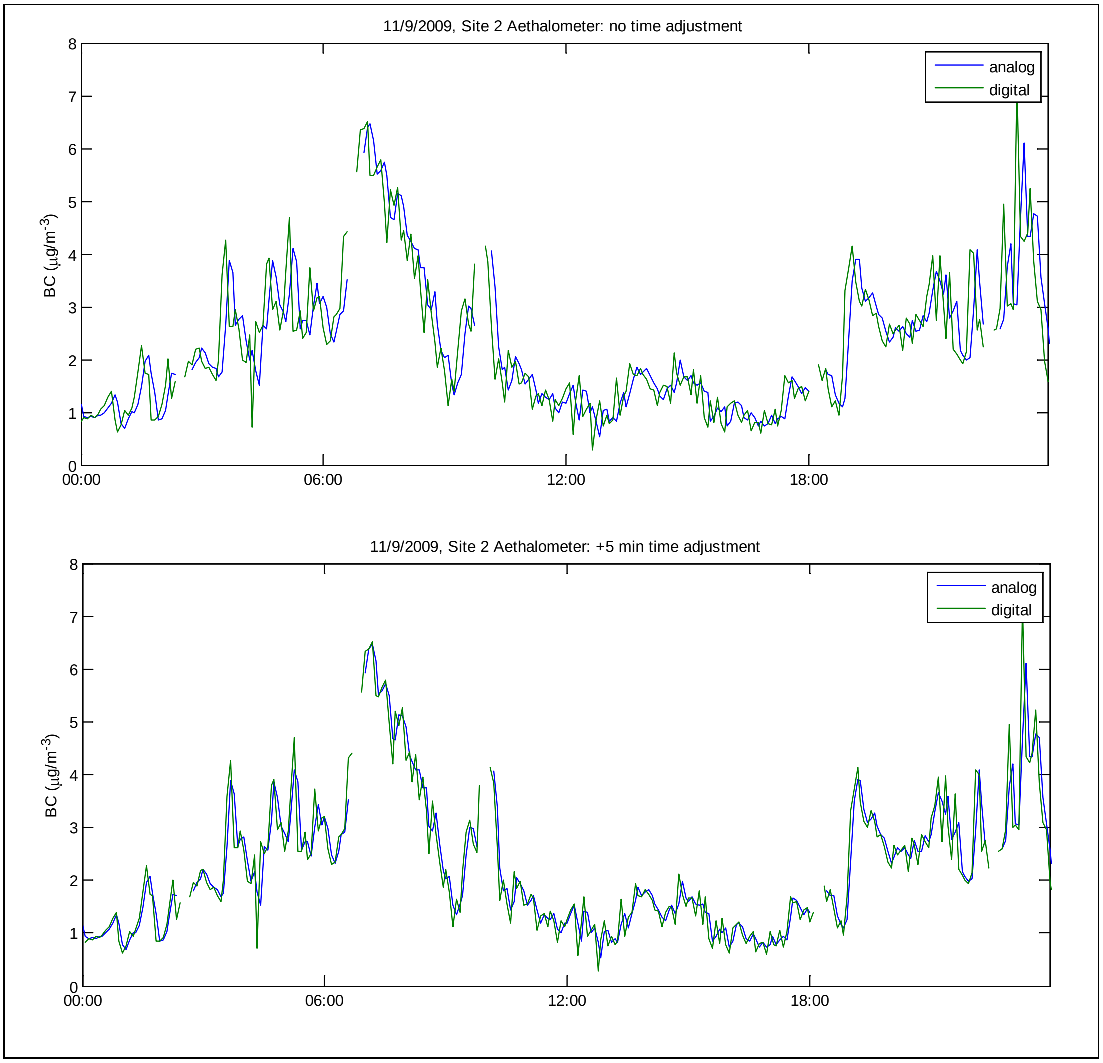


Figure 59 Time alignment of analog (blue) and digital (green) data sets.

An additional screen step for the digital BC data was flagging of any data with erroneous light attenuation values (<0 or >60), which affected <1% of the data. Finally, the data are checked for a known logging error that occurs rarely – when a filter change time period spans midnight, the digital timestamp is off by 24 hrs.

13.2.2 Occurrence of negatives

With BC calculated based upon a 5-minute incremental change in light attenuation through a filter, there are time instances when the BC concentrations are generally so low that the accumulation of particles on the filter are not sufficient to override any noise in the measurement (signal to noise ratio), thus the change in attenuation (ΔATN) may read below zero and a negative BC is reported. Since the change in light attenuation is based upon the previous time period, the following time period may then report an overly positive ΔATN and a higher BC value than reality. The manufacturer recommends that, when negatives occur in the data, one should average the data up to a time increment at which negatives no longer occur. An evaluation of the station 2 BC data is shown in Figure 60, below. In the original 5-minute time series, negatives occur in 2.6% of the data. After averaging up to an hourly time basis, negatives occur in <0.1% of the data. Based upon this evaluation, all data presented in this report are at an hourly time basis and the few, if any, hours of BC data per site that remained negative after averaging were removed from the data set.

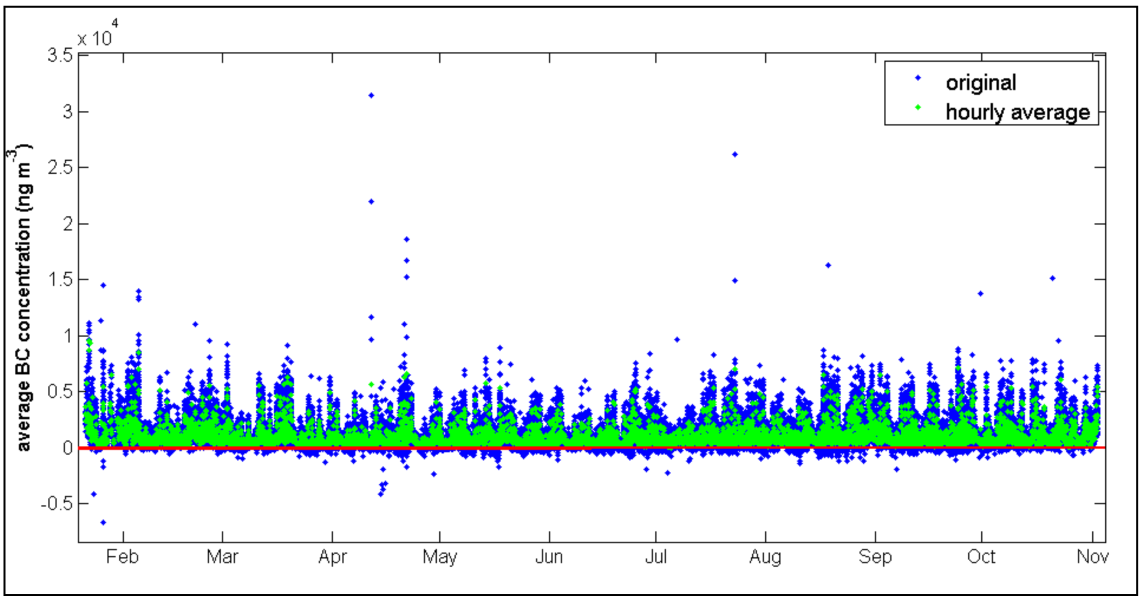


Figure 60 Assessment for negatives occurring in the original data (blue) and hourly averaged data (green) for station 2 during the Las Vegas, NV near-road monitoring study.

13.2.3 Evaluation of filter loading effect

Aethalometers are in widespread use by academic groups and governments to perform continuous monitoring of black carbon in diverse environments. Several research studies have documented that BC values reported by Aethalometers or similar filter-based BC instrumentation may be affected by a filter loading artifact. For example, measured high concentrations of BC in a subway and found that BC values were underpredicted as function of filter loading[26] However, a recent study by measured ambient air quality in India and found that no filter loading effect was detectable in that environment.[27] The explanation for these differing results likely lies in the optical properties of the particles being measured relative to the samples used for original calibrations by the manufacturer. Since this effect is unpredictable, we did several different analyses to determine whether the artifact existed for the Las Vegas data set and held a meeting to discuss whether or not to apply a correction algorithm.

At a mid-way point through the study, an analysis was performed similar to that laid out by looking whether incremental changes (BC at time t+1 minus BC at time t) in BC values revealed a negative bias associated with incremental filter loading.[27] As shown in Figure 61, below, the histogram of the ΔBC_{t+1-t} revealed no positive or negative bias and it appeared no significant filter loading effect was detectable, at that time.

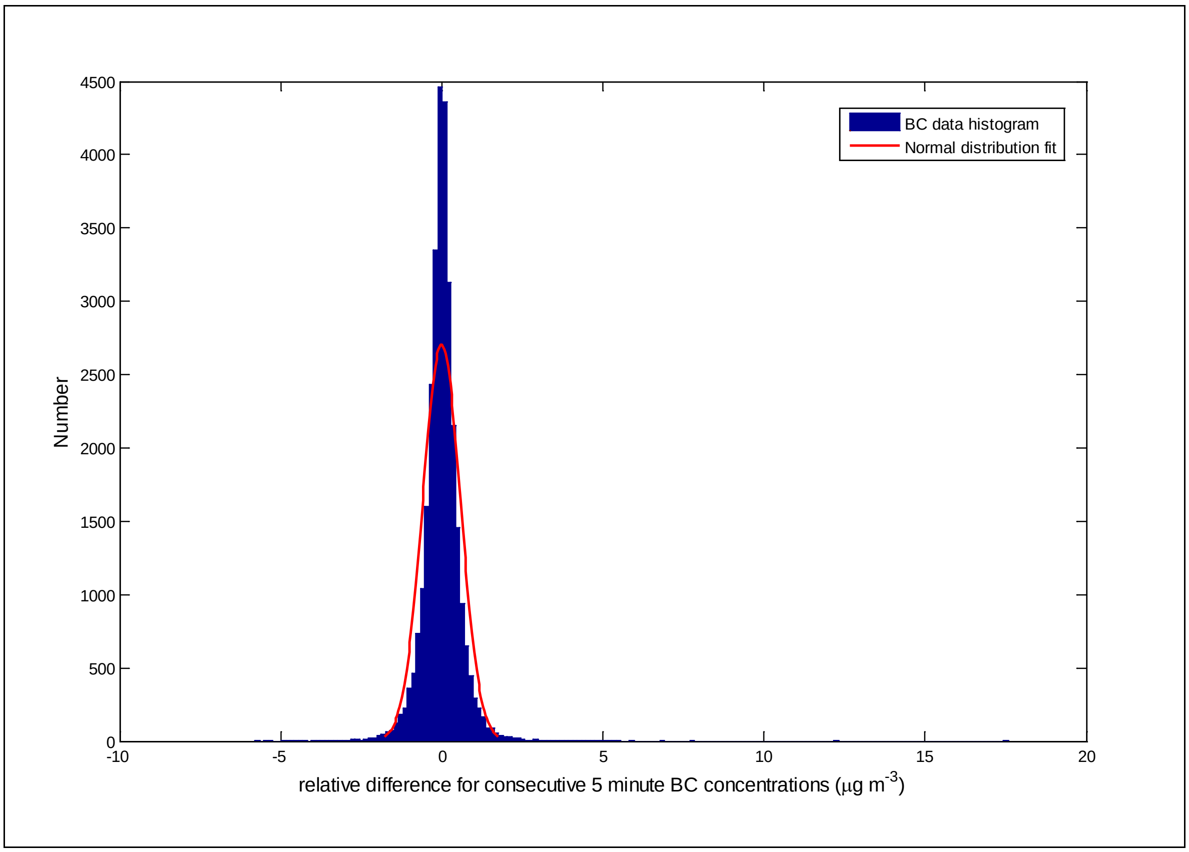


Figure 61 Histogram of differences in consecutive BC concentrations (ΔBC_{t+1-t}) calculated at station 1 over data collected during January through April, 2009. The red line is a normal distribution fitted to the data.

At the conclusion of data collection, another analysis approach was employed to determine whether a filter-loading effect was apparent – the attenuation binning method. BC data points collected over a one year period were aggregated into attenuation bins of unit value (0-1, 1-2, 2-3…up to 44-45). A plot of BC data box plots versus attenuation is shown below in Figure 62. Eliminating the tail end values, where fewest BC data points were collected, a modest negative relationship between BC and ATN is visible (Figure 63). Estimating a k-value from this relationship and applying the filter loading correction, it can be seen that BC values at low ATN values would be relatively unchanged while BC values at high ATN values would be increased slightly (Figure 64).[26] Overall, this analysis estimated that the filter-loading artifact algorithm would modify concentrations by approximately 0 to +25% depending on the filter loading state.

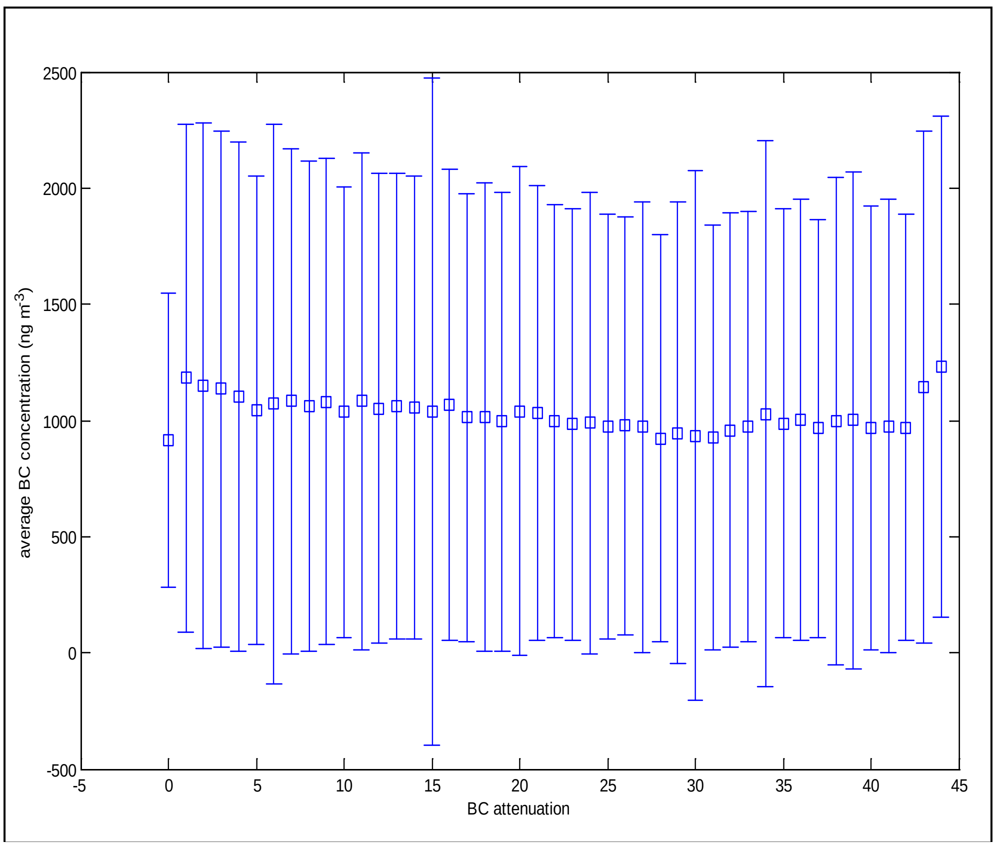


Figure 62 Box and whisker plots of approximately 12 months of 5-minute BC measurements at station 2 aggregated by attenuation bin in one-unit intervals.

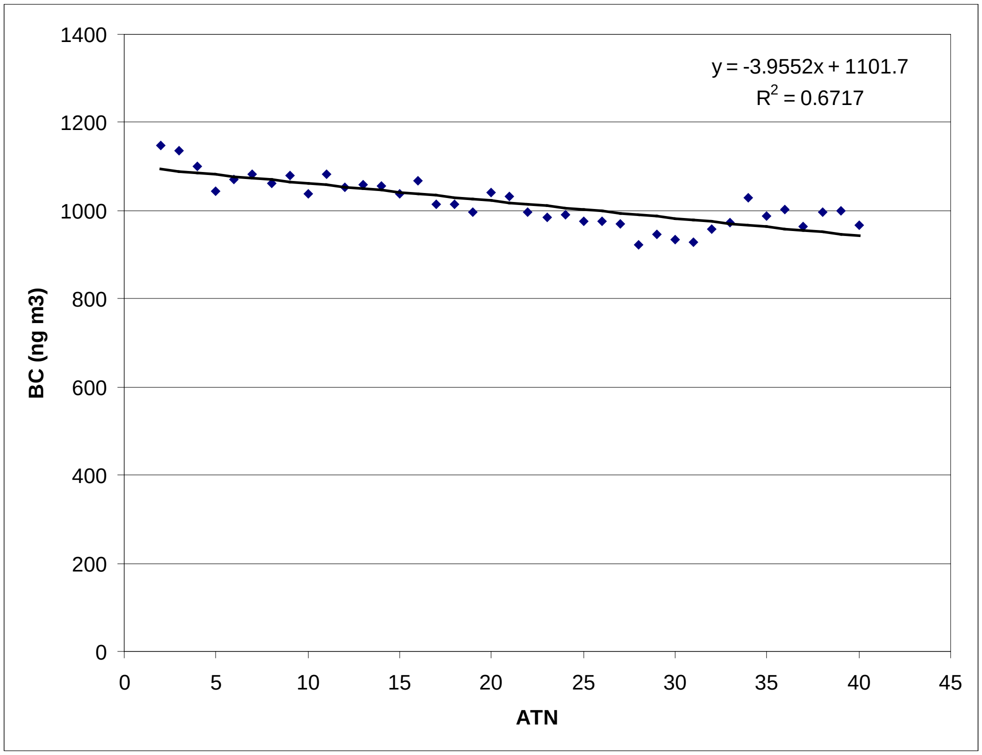


Figure 63 Median BC values of approximately 12 months of 5-minute BC measurements at station 2 aggregated by attenuation bin in one-unit intervals. A linear fit is applied to the data.

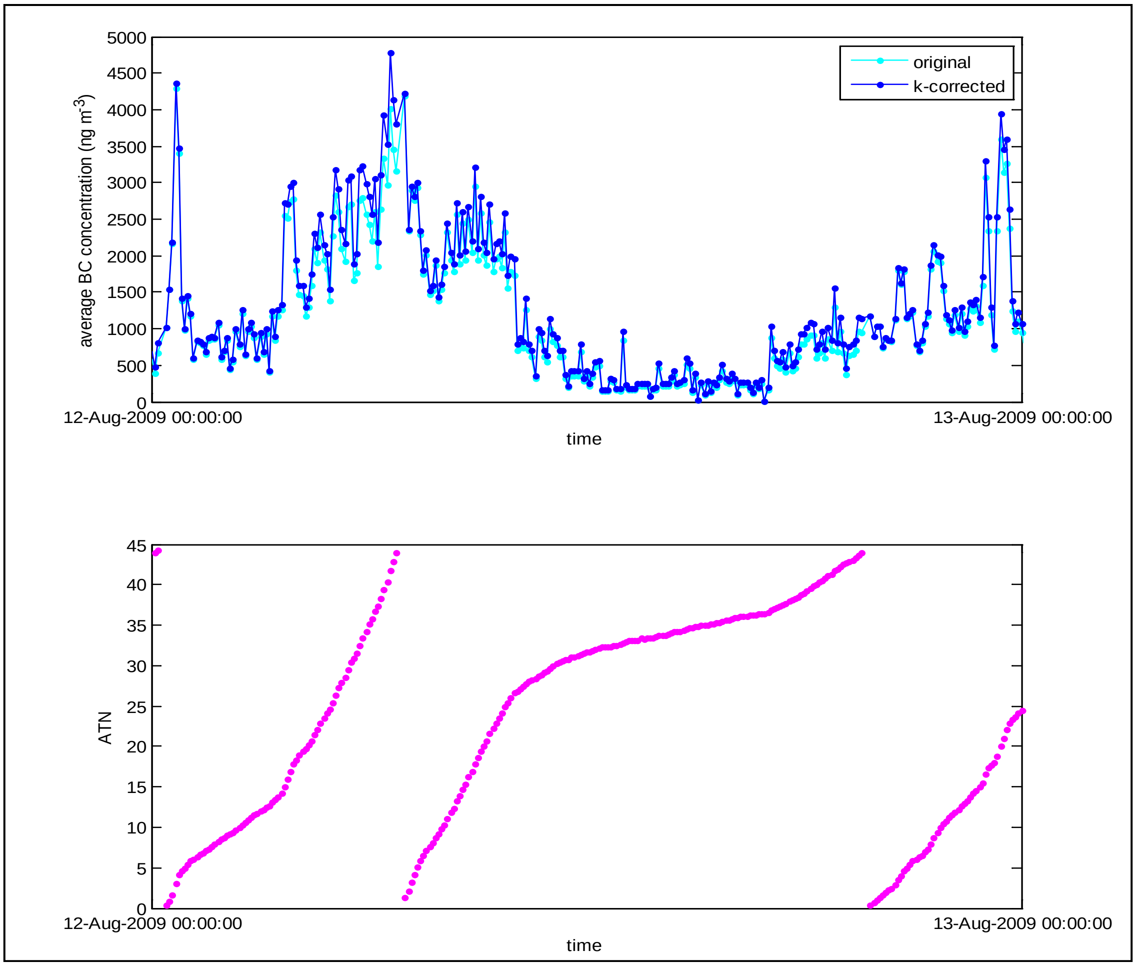


Figure 64 Example of filter-loading corrected versus original data (top) and filter loading attenuation (bottom). At low ATN values, original and k-corrected lines show little difference, while k-corrected BC values are higher than the original at higher ATN values.

One significant concern with applying the k-value correction estimated from the above analyses to the data is that this process essentially assumes that the aerosol optical properties were fixed throughout the measurement period, when in reality the aerosol optical properties likely varied by time of day, day of week, and time of year. Given that a significant amount of data is required to detect the relationship between BC and ATN in an environment with significant ambient fluctuations in concentration, trying to estimate k-values at shorter time increments increases the uncertainty of deriving a reliable value. As the analysis revealed that k-value corrections were relatively minor and given concerns about applying this algorithm without consideration of likely variable aerosol optical properties, it was decided to leave the original data as is for the purposes of this report.

13.3 Data Analysis -- Black carbon measurements

BC data were analyzed using a combination of programs, including MATLAB version R2009b, Microsoft Excel 2007, and JMP 8. The data analysis included calculating summary statistics of data for each site for all wind conditions and for winds only from the West (+/- 60 degrees from perpendicular), estimating concentration gradients for winds from the West, and observing concentrations as a function of wind direction for all winds. The results of these analyses follow in Section 13.4.

13.4 Results and Discussion -- Black carbon measurements

Black carbon data was collected over a one year period at four near-road locations along I-15 in Las Vegas, Nevada. Hourly concentrations were calculated from the raw five-minute data for each station, covering the time period of the official sampling program – December 15, 2008 to December 15, 2009. The completeness of the data per station is reported in Table 25, which ranged from 89% to 100% per station. The primary explanation for incomplete data for stations 2 and 3 is a delay in initiating sampling; consistent data collection began in January, 2009.

Table 25. Completeness of hourly BC data at each site

Site name	Distance from Road	N[a] (hours)	Completeness[b] Time span: 12/15/2008-12/15/2009
Station 1	10 m East	8503	97%
Station 2	100 m East	7838	89%
Station 3	300 m East	7913	90%
Station 4	100 m West	8755	100%

[a]A complete hour of sampling was set at a minimum of 10 five minute data points (50 min)
[b]Note that the completeness <100% is largely due a delayed start to sampling for several instruments. Incomplete time periods due to instrumentation error was generally less than 1%.

Summaries of the annual BC averages and confidence intervals at each site are presented in Table 26 and shown in Figure 65. Given that two of the stations did not have consistent data collection for the first month of sampling, an 11-month time frame (1/15/2009 to 12/15/2009) was selected to compare the average concentrations among the four stations. Data completeness was at 97% or higher for the four stations during this time frame. The data show that, on an annual average basis with winds from all directions, the BC annual average at 10 m from the highway is significantly higher than at further distances from the road. In addition, BC average values at 100 m in the predominant downwind direction (East of the highway) are significantly higher than at 100 m in the opposite direction, as well as higher than at 300 m on the downwind side of the road.

Table 26. BC averages for all data (1/15/2009-12/15/2009)

Site name	Distance from Road	N[a] (hours)	Mean ($\mu g\ m^{-3}$)	95% CI ($\mu g\ m^{-3}$)
Station 1	10 m East	7779	1.46	1.44-1.49
Station 2	100 m East	7807	1.09	1.07-1.11
Station 3	300 m East	7866	0.78	0.76-0.80
Station 4	100 m West	8032	0.94	0.92-0.96

[a]A complete hour of sampling was set at a minimum of 10 five minute data points

BC hourly values were also isolated for time periods with winds from the west, designated as 270 ± 60 degrees. Selecting only the BC hourly data with 70% or greater of the time period having winds from the West, the mean values at each station provided in Table 27 and shown in Figure 65. On the downwind side of the road, BC values at Station 1 are significantly higher than than all other stations. Designating Station 4 as representative of the urban background, under downwind conditions Station 1, Station 2, and Station 3 exceed the urban background by a factor of 2.2, 1.6, and 1.15, respectively. These results suggest that the impact of traffic emissions on near-road air quality likely extends beyond 300 m from the road.

Table 27. BC averages, wind from the West (1/15/2009-12/15/2009)

Site name	Distance from Road	N[a] (hours)	Mean (µg m^{-3})	95% CI (µg m^{-3})
Station 1	10 m East	1826	1.74	1.69-1.79
Station 2	100 m East	1863	1.28	1.24-1.32
Station 3	300 m East	1908	0.92	0.89-0.96
Station 4	100 m West	1954	0.80	0.77-0.83

[a]A complete hour of downwind sampling was set at a minimum of 70% of the hour with winds from the West (210-330 degrees).

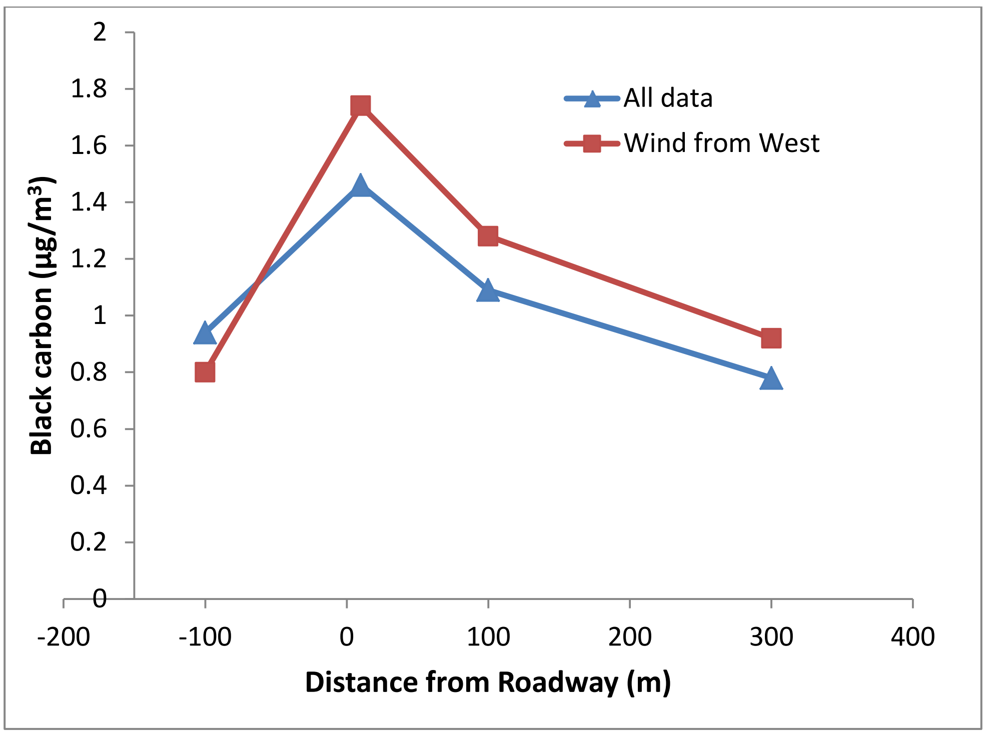


Figure 65 Average black carbon concentrations as a function of distance from the road for all data and during time periods with wind from the West (210-330 degrees).

14 Appendix -- Quality Assurance Project Plan

Attached to this report as a CD.

15 Appendix -- Data Dictionary – Parameters, Descriptions/Labels.

Parameters, descriptions/labels – Min/Max Ranges									
						range			
variable location	SAS variable name	column label from WinCollect	unit from WinCollect	description from WinCollect	Labels	Min	Max	other requirements	comments
1	ID			Station id	Station Id	Station1 Station2 Station3 Station4			
2	DateTime			Date and time of sample	12/15/2009 thru end-of-study in LV	12/15/2009	12/15/2010		end-of-study 12/15/2010
3	RT	RT	C	RT	rack temperature	10	40		
4	O_Vref	O Vref	V	0 Voltage ref	0 voltage reference	0	0		
5	Vref	5 Vref	V	5 Voltage ref	5 voltage reference	5	5.1		
6	NO	NO	ppb	Nitrogen Oxide	Nitrogen Oxide	0	400		
7	NO2	NO2	ppb	Nitrogen Dioxide	Nitrogen Dioxide	-10	500		
8	NOx	NOx	ppb	Oxides of Nitrogen	Oxides of Nitrogen	-10	1000		

Parameters, descriptions/labels – Min/Max Ranges

						range			
variable location	SAS variable name	column label from WinCollect	unit from WinCollect	description from WinCollect	Labels	Min	Max	other requirements	comments
9	NOx_Flow	NOx Flow	Lpm	NOx Flow	NOx Flow	0.5	0.65		
10	NOx_Pres	NOx Pres	Torr	NOx Pressure	NOx Pressure	140	160		
11	CO	CO	ppm	Carbon Monoxide	Carbon Monoxide	0	100		
12	CO_Flow	CO Flow	Lpm	CO Flow	CO Flow	0.85	1		
13	CO_Chass	CO Chass	C	CO Chassis Temp	CO Chassis Temp	25	50		
14	PM10	PM10	µg/m³	Particulate PM 10	TEOM Particulate PM 10	0	700		
15	PM2_5	PM2.5	µg/m³	PM2.5	TEOM Particulate PM2.5	0	200		
16	PM_Coars	PM Coars	µg/m³	PM Coarse	TEOM Particulate PM Coarse	0	600		
17	TEOM_Sta	TEOM Sta	Status	TEOM Status	TEOM Status	0			operating normally

Parameters, descriptions/labels – Min/Max Ranges									
						range			
variable location	SAS variable name	column label from WinCollect	unit from WinCollect	description from WinCollect	Labels	Min	Max	other requirements	comments
18	TEOM_Op	TEOM Op	Mode	TEOM Operatng	TEOM Operating Mode	4			operating normally
19	Filter_A	Filter A	%	FilterLoad A	TEOM Filter Loading on Filter A	0	100		
20	Filter_B	Filter B	%	Filter Load B	TEOM Filter Loading on Filter B	0	100		
21	Mflow_A	Mflow A	Lpm	Mass flow A	TEOM Mass Flow A	2	4		
22	MFlow_B	MFlow B	Lpm	Mass Flow B	TEOM Mass Flow B	1	2.5		
23	VFlow_A	VFlow A	Lpm	Vol Flow A	TEOM Volumetric Flow A	1.5	4		
24	VFlow_B	VFlow B	Lpm	Vol Flow B	TEOM Volumetric Flow B	2	3.5		
25	MFlowBy	MFlowBy	Lpm	Mass Flow Bypass	TEOM Mass Flow Bypass	10	14		
26	VFlowBy	VFlowBy	Lpm	Vol Flow Bypass	TEOM Volumetric Flow Bypass	10	15		

Parameters, descriptions/labels – Min/Max Ranges

						range			
variable location	SAS variable name	column label from WinCollect	unit from WinCollect	description from WinCollect	Labels	Min	Max	other requirements	comments
27	TEOM_Vac	TEOM Vac	atm	TEOM Vaccuum	TEOM Vaccuum	0.25	0.5		
28	Noise_A	Noise A		Noise A	TEOM Noise A	0	0.5		
29	Noise_B	Noise B		Noise B	TEOM Noise B	0	1		
30	FreqA	FreqA	Hz	Frequency A	TEOM Frequency A	230	280		
31	FreqB	FreqB	Hz	Frequency B	TEOM Frequency B	210	270		
32	TEOM_AT	TEOM AT	C	TEOM air temp	TEOM Air Temperature	-20	50		
33	TEOM_RH	TEOM RH	%	TEOM RH	TEOM Relative Humidity	0	100		
34	TEOM_BP	TEOM BP	atm	TEOM BP	TEOM Barometric Pressure	0.8	1		
35	Dew_Poin	Dew Poin	C	Dew Point	TEOM Dew Point	-20	30		
36	Aeth	Aeth	µg/m³	Aethalometer	Aethalometer	0	60		

Parameters, descriptions/labels – Min/Max Ranges

						range			
variable location	SAS variable name	column label from WinCollect	unit from WinCollect	description from WinCollect	Labels	Min	Max	other requirements	comments
37	U	U	m/s	U	Orthogonal u wind velocity/direction	-20	20		u-axis aligned east-west
38	V	V	m/s	V	Orthogonal v wind velocity/direction	-20	20		v-axis aligned north-south
39	W	W	m/s	W	Orthogonal w wind velocity/direction	-20	20		w-axis updraft
40	Azimuth	Azimuth	Deg	Azimuth	Wind Direction in the U-V Plane	0	360		
41	D_WS	2D WS	m/s	2D WS	Wind Speed in the U-V Plane	0	30		
42	D_WS0	3D WS	m/s	3D WS	Wind Speed in 3-dimensional space	0	30		
43	Elevatio	Elevatio	ded	Elevatio	ELEVATION is the ±90.0º wind elevation angle relative to the u-v plane	-20	90		

Parameters, descriptions/labels – Min/Max Ranges									
						range			
variable location	SAS variable name	column label from WinCollect	unit from WinCollect	description from WinCollect	Labels	Min	Max	other requirements	comments
44	SOS	SOS	m/s	SOS	Speed of sound	330	360		
45	Sonic_T	Sonic T	C	Sonic Temperature	SOS derived from sonic temperature	-20	50		
46	Young_Er	Young Er		Young Error	Error Code Field	0			
47	RT_F	RT-F	F	Rack temp	Rack temperature	55	100		
48	D_WS_V	2D WS-V	m/s	2D WS-Vector	Wind Speed in the U-V Plane	0	60		
49	D_WD_V	2D WD-V	Deg	2D WD-Vector	Wind Direction in the U-V Plane	0	360		
50	D_Sigma	2D Sigma		2D Sigma	Standard Deviation in the U-V Plane	0	120		
51	D_WS_V0	3D WS-V	m/s	3D WS-Vector	Wind Speed in 3-dimensional space	0	15		
52	D_WD_V0	3D WD-V	Deg	3D WD-Vector	Wind Direction in 3-dimensional space	0	360		

Parameters, descriptions/labels – Min/Max Ranges

						range			
variable location	SAS variable name	column label from WinCollect	unit from WinCollect	description from WinCollect	Labels	Min	Max	other requirements	comments
53	D_Sigma0	3D Sigma		3D Sigma	Standard Deviation in 3-dimensional space	0	120		
54	GasCal_S	GasCal S		GasCal Status	Zero Gas Calibration Status (pressure - psi)	0	10		
58	Vaisala	Vaisala	C	Vaisala Air temp	Vaisala Air Temperature	-30	45		
59	Vaisala_1	Vaisala	%	Vaisala RH	Vaisala Relative Humidity	0	100		
60	RG	RG	mm	Rain Gauge	Ecotech Rain Gauge	0	150		
61	SR	SR	W/m^2	Solar Radiation	Solar Radiation	0	2000		Negative values occur at night
80	date			Date of sample		12/15/2009	1/15/2010		
81	time			Time of Sample		12:00:01 AM	11:59:00 PM		

Parameters, descriptions/labels – Min/Max Ranges									
						range			
variable location	SAS variable name	column label from WinCollect	unit from WinCollect	description from WinCollect	Labels	Min	Max	other requirements	comments
82	location			Location of Sample	Station Id	Station1 Station2 Station3 Station4			
	Sound	SoundLevel	db		Sound level in decibels	40	120		

Integrated Samples – VOC

Variables for VOC Data (samples collected using Summa Canisters: Method TO-15):

id = station1, station2, station3, station4
location = 10 meter, 100 meter, 300 meter, Upwind
SampleType = Field Blank, Field Control, Field Duplicate, Lab Duplicate, Sample
SampleDateTime = Date and Time of Sample
Buta_ppb = 1,3-Butadiene (ppb)
Benz_ppb = Benzene (ppb)
Acrolein_ppb = Acrolein (ppb)
Flag_VOC = 0 or 1; 0 = valid data; 1 = invalid data (relates to the entire sample, across all pollutants)
Flag_Buta = 0 or 1; 0 = valid data; 1 = invalid data
Flag_Benz = 0 or 1; 0 = valid data; 1 = invalid data
Flag_Acrolein = 0 or 1; 0 = valid data; 1 = invalid data

Integrated Samples – Carbonyl

Variables for Carbonyl Data (samples collected using cartridges: Method TO-11A):

id = station1, station2, station3, station4
location = 10 meter, 100 meter, 300 meter, Upwind
SampleType = Field Blank, Field Control, Field Duplicate, Lab Duplicate, Sample
SampleDateTime = Date and Time of Sample
Acetaldehyde_ppb = Acetaldehyde (ppb)
Acrolein_ppb = Acrolein (ppb)
Formaldehyde_ppb = Formaldehyde (ppb)
Acetaldehyde_detect '<' (below method detection limit)
Acrolein_detect '<' (below method detection limit)
Formaldehyde_detect '<' (below method detection limit)
Flag_Carbonyl = 0 or 1; 0 = valid data; 1 = invalid data (relates to the entire sample, across all pollutants)
Flag_Acetaldehyde = 0 or 1; 0 = valid data; 1 = invalid data
Flag_Acrolein = 0 or 1; 0 = valid data; 1 = invalid data
Flag_Formaldehyde = 0 or 1; 0 = valid data; 1 = invalid data

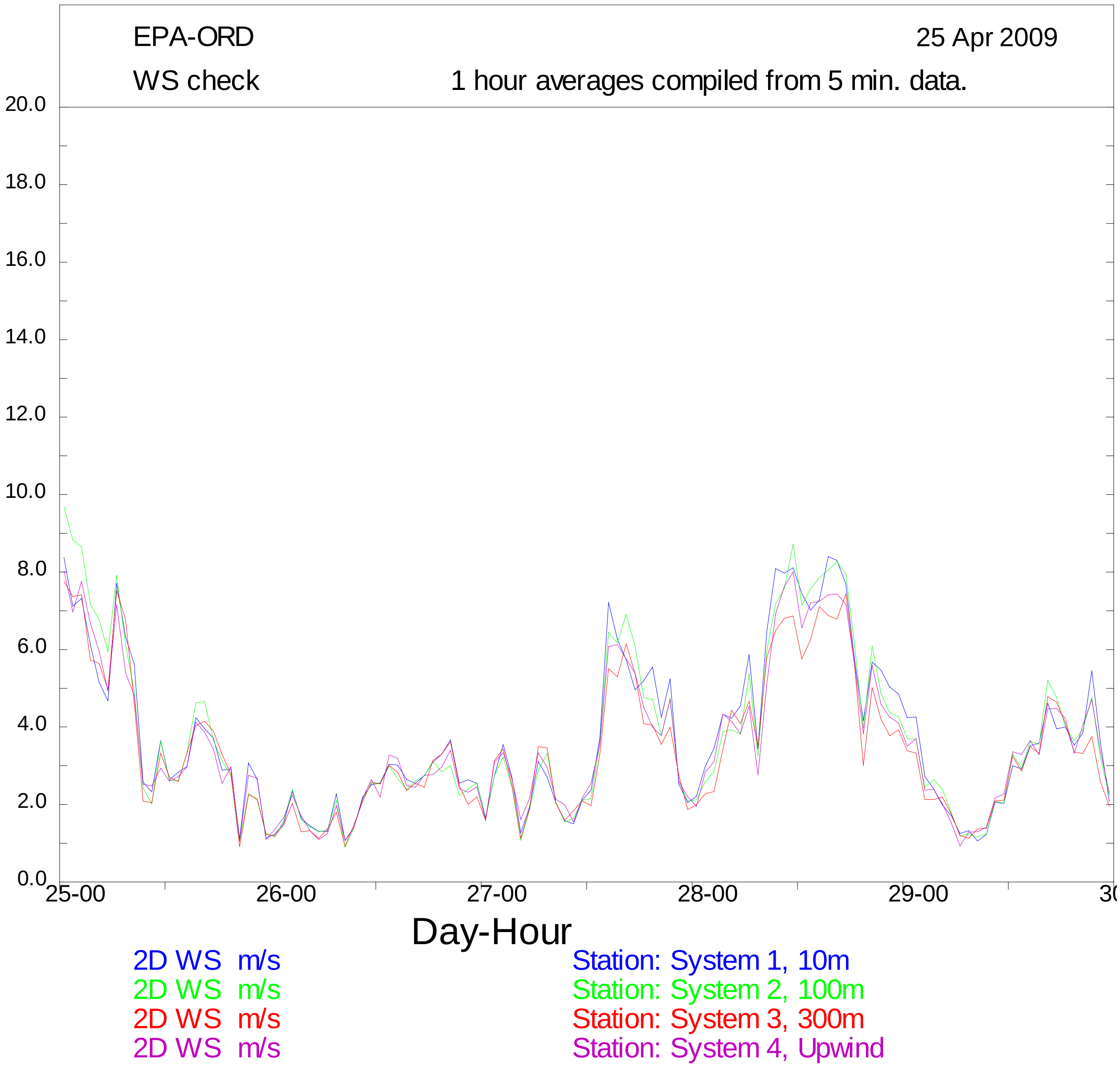
Integrated Samples – $PM_{2.5}$

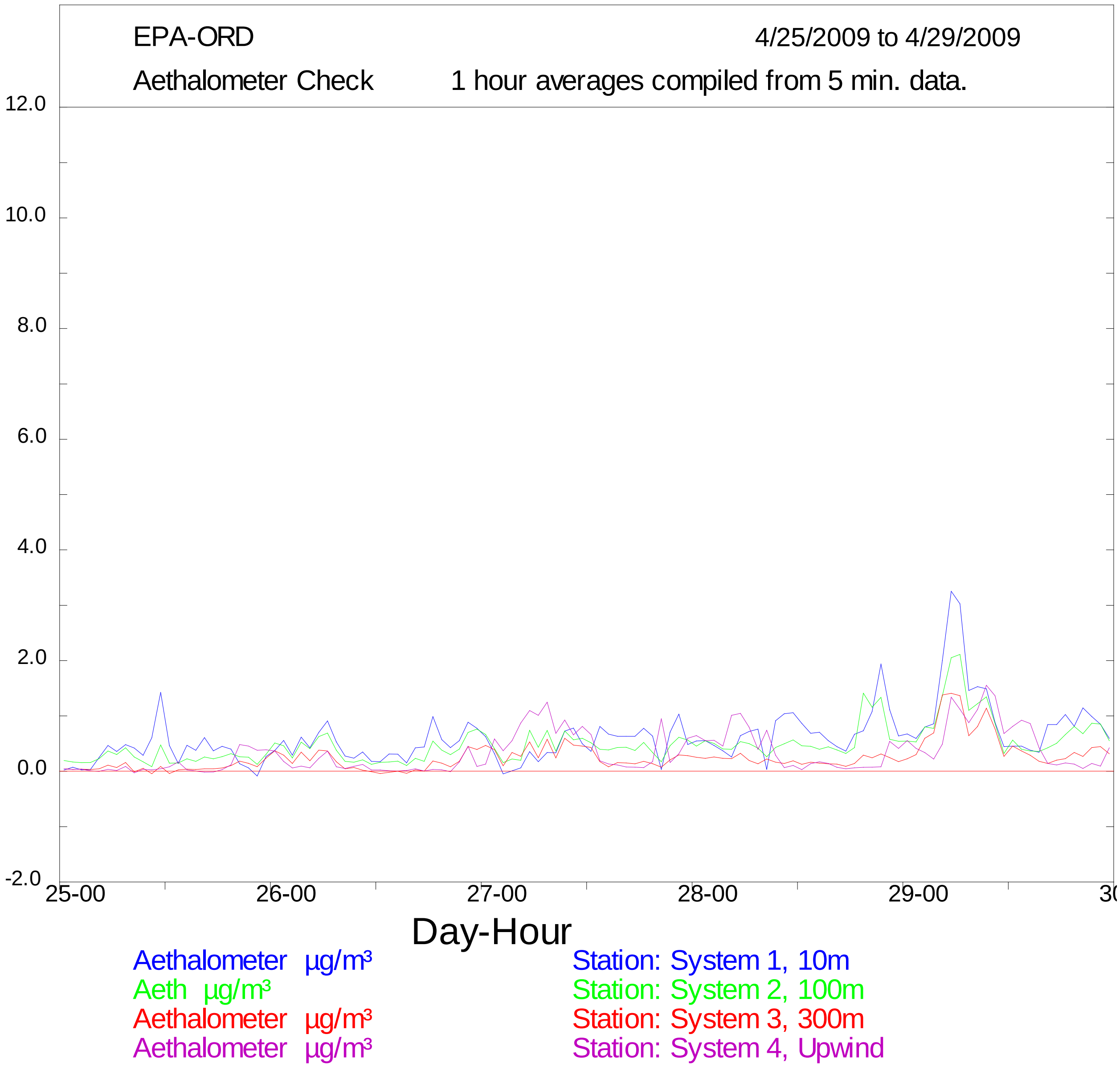
The following is a list of the variables in the $PM_{2.5}$ data set.

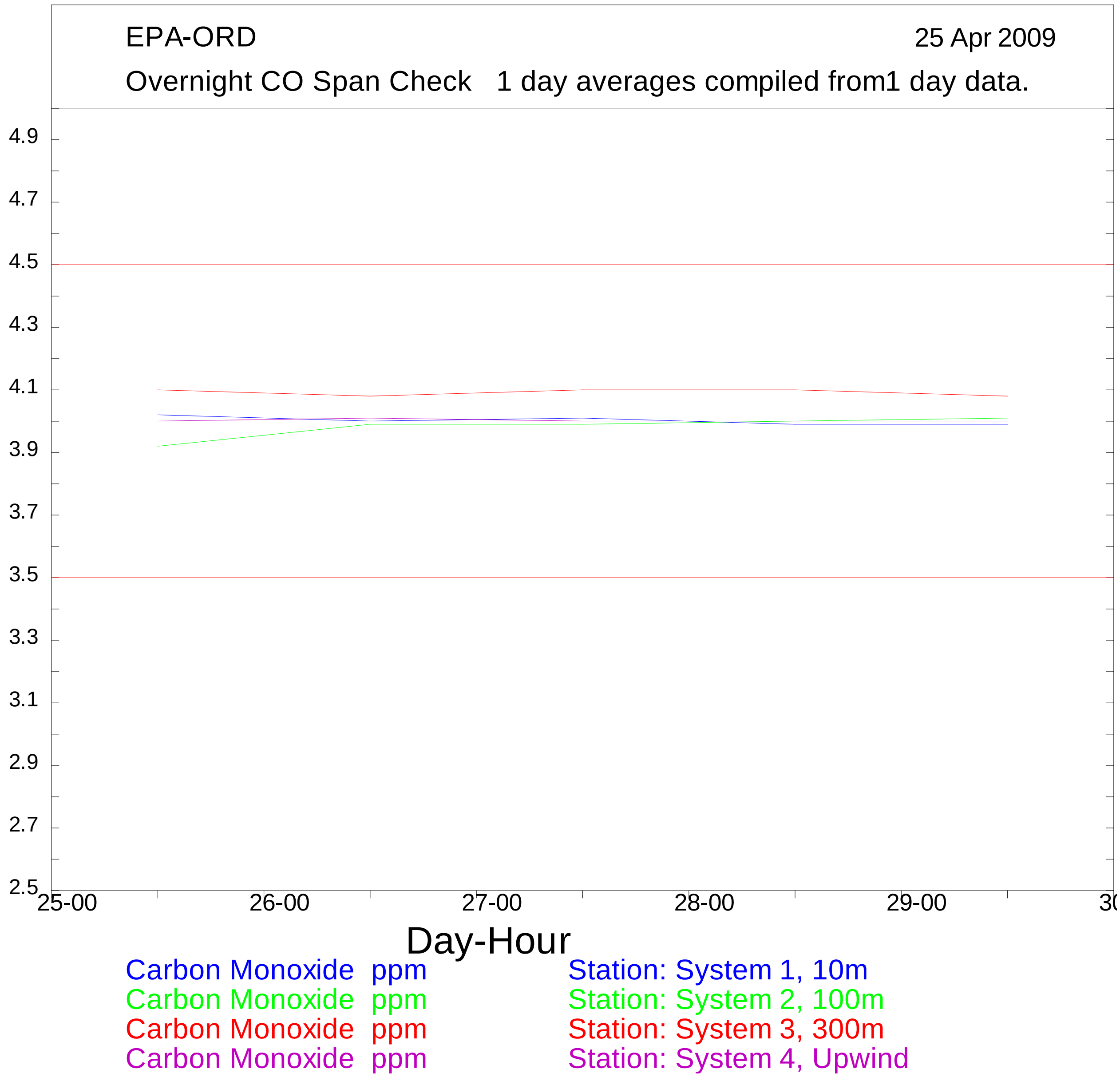
id = station identification
SampleType = Sample, Field Duplicate, Field Blank,
Date = Date Sample Collected
Flag_PM = 0 or 1; 0 = valid data; 1 = invalid data
location = Upwind, 10 meter, 100 meter, 300 meter
PM2_5mg_m3 = PM2.5 in µg/m^3

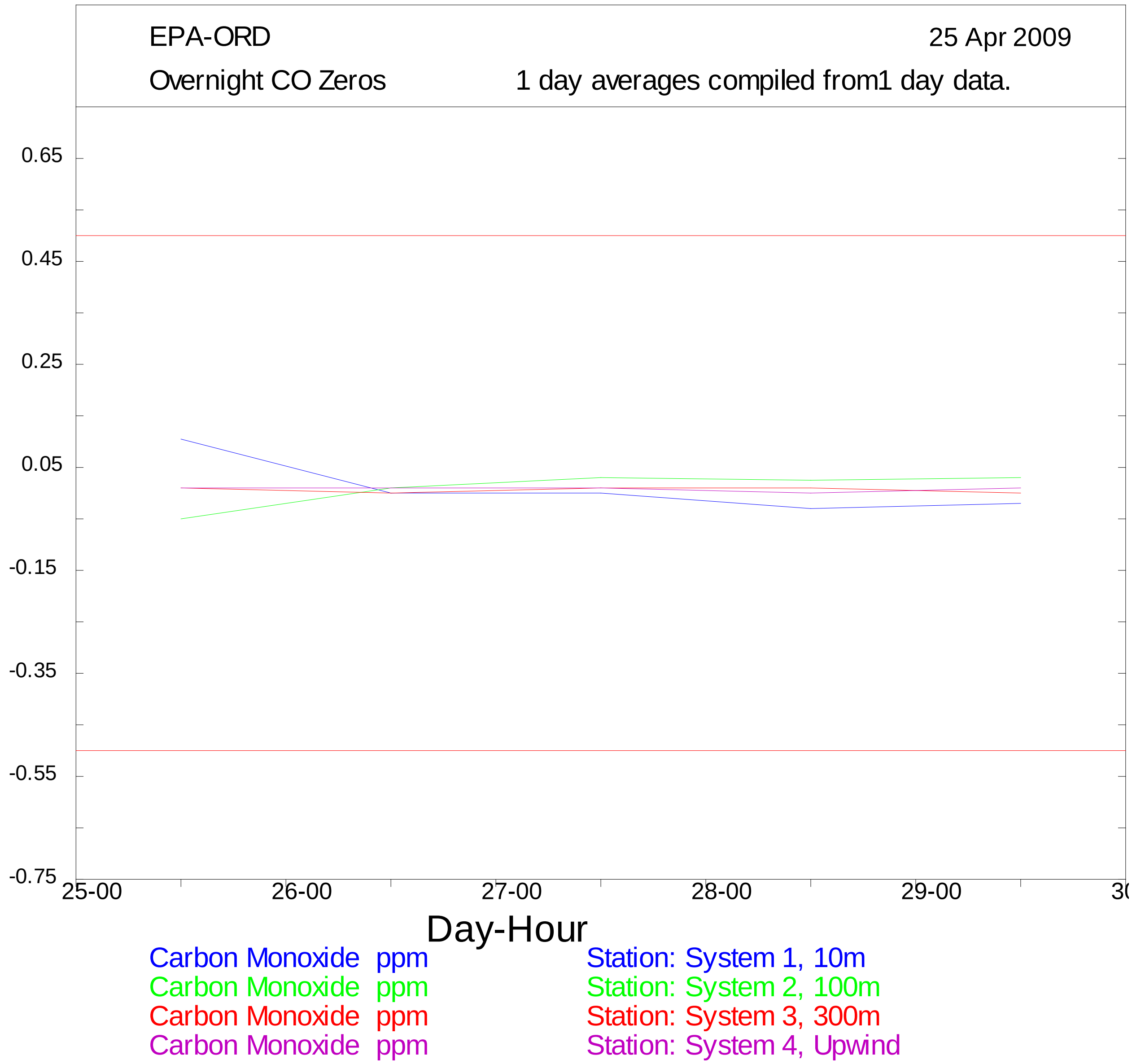
16 Appendix -- Data Validation / Instrument Checks

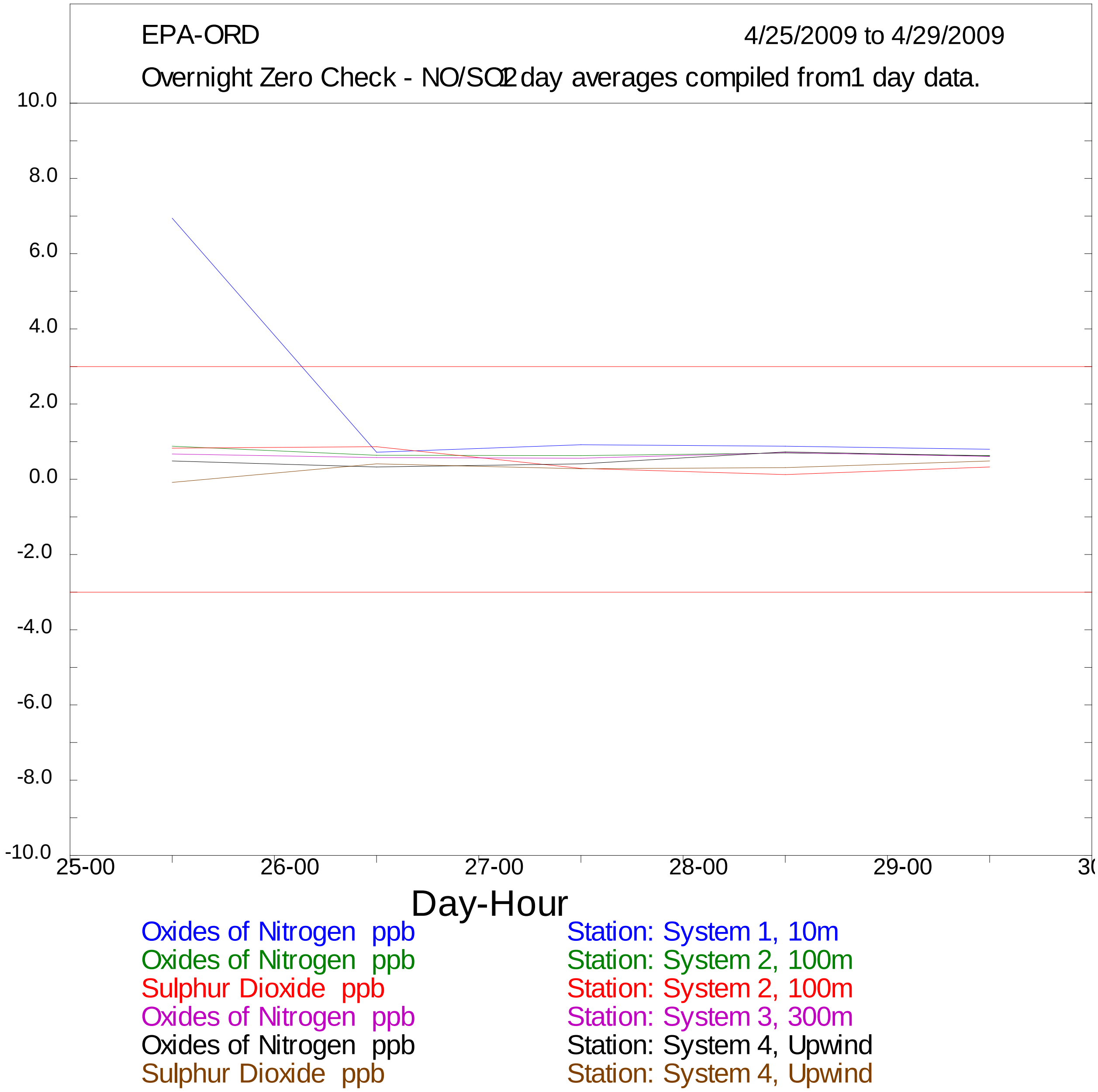
Each day, data was accessed using WinCollect. Graphical reports were run to determine instrument status and data validity. Examples of these graphical reports are shown on the following pages. Instrument issues were identified and noted in a logbook at the computer being used to run WinCollect. The graphs and any instrument issues were noted in an email to the site operator, EPA and contractor staff.

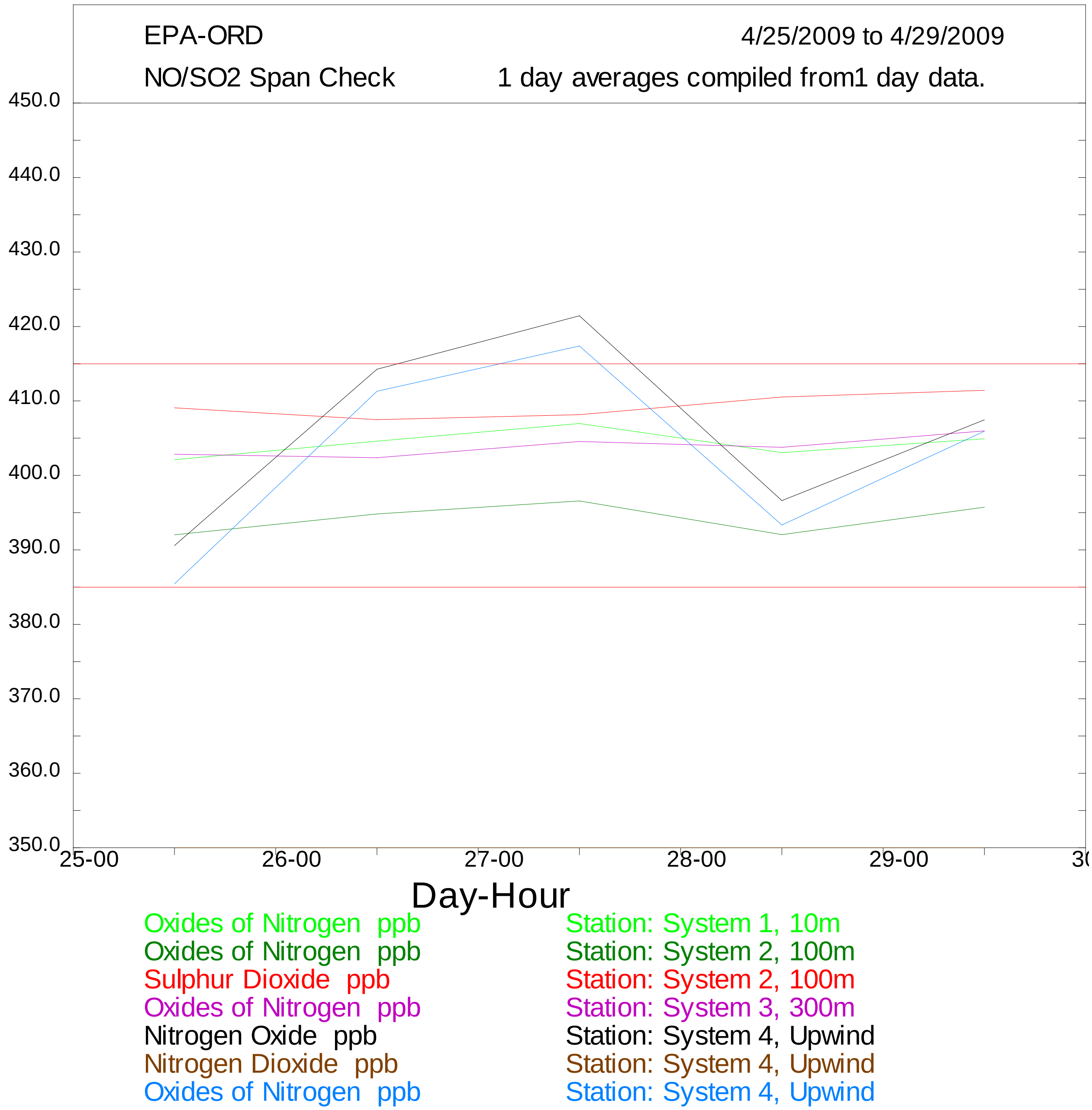

EPA-ORD
25 Apr 2009
WS check
1 hour averages compiled from 5 min. data.
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
2D WS m/s
2D WS m/s
2D WS m/s
2D WS m/s
Station: System 1, 10m
Station: System 2, 100m
Station: System 3, 300m
Station: System 4, Upwind

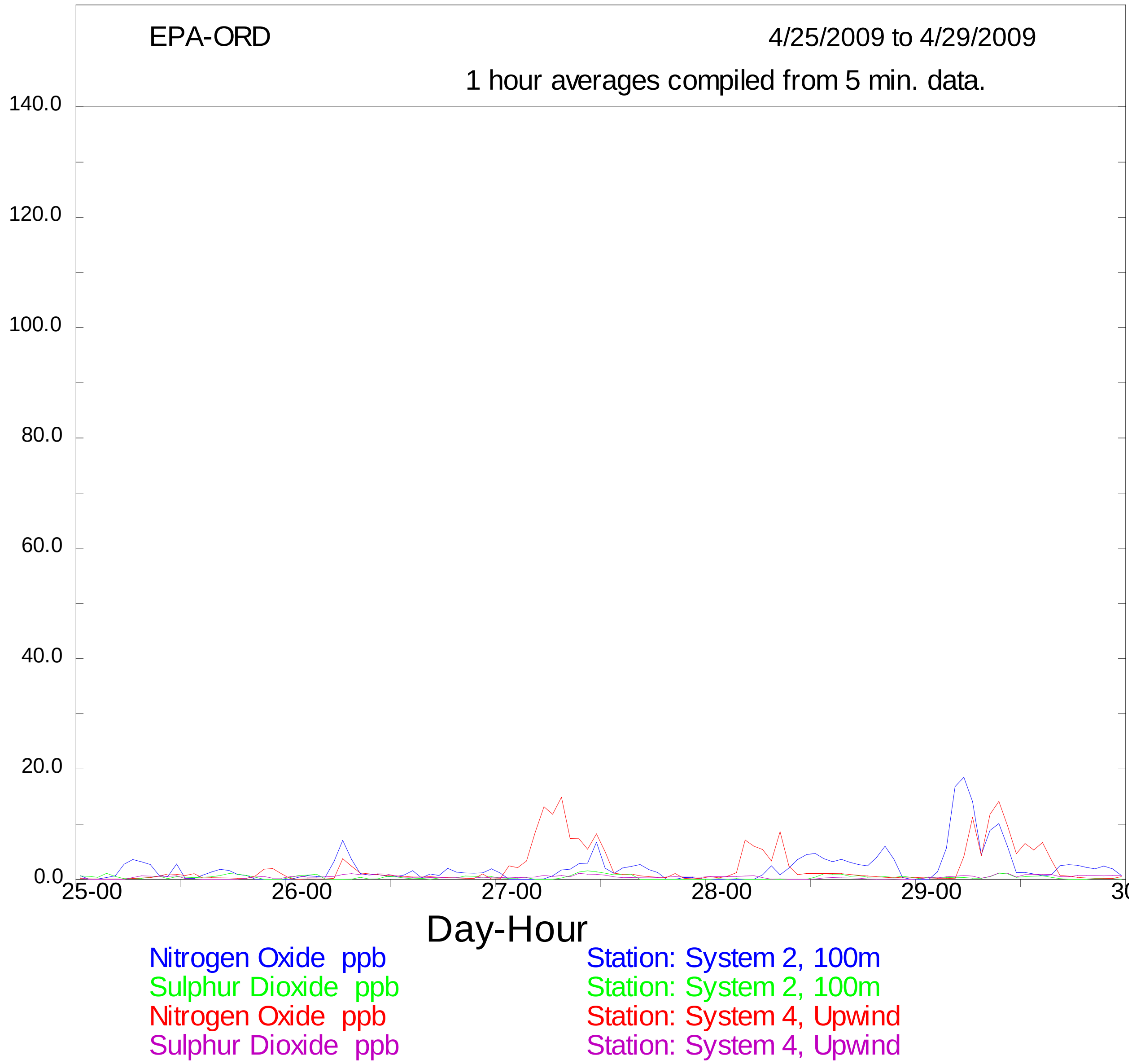

EPA-ORD
4/25/2009 to 4/29/2009
Aethalometer Check
1 hour averages compiled from 5 min. data.
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
Aethalometer µg/m³
Station: System 1, 10m
Aeth µg/m³
Station: System 2, 100m
Aethalometer µg/m³
Station: System 3, 300m
Aethalometer µg/m³
Station: System 4, Upwind

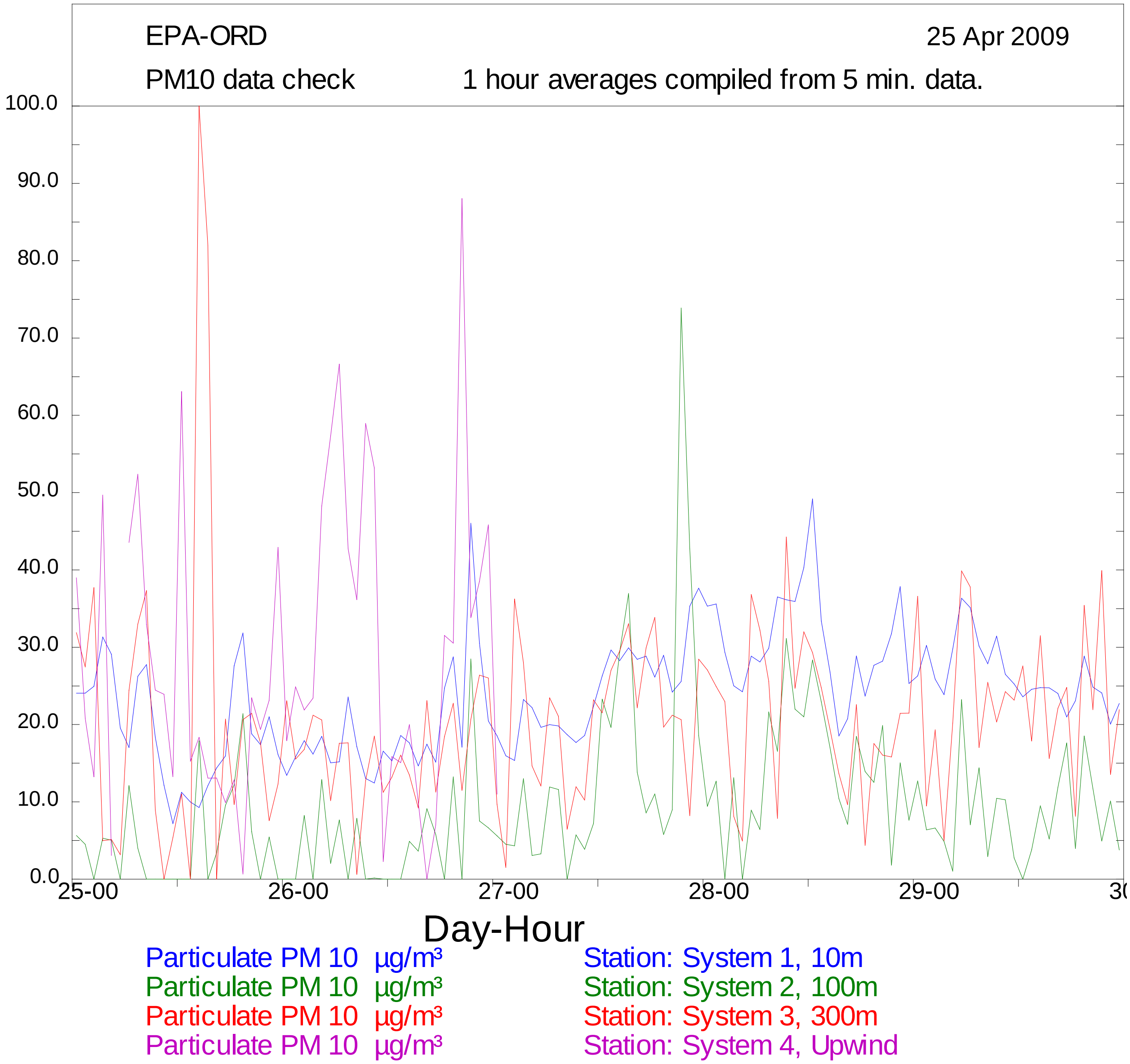

EPA-ORD
25 Apr 2009
Overnight CO Span Check 1 day averages compiled from1 day data.
4.9
4.7
4.5
4.3
4.1
3.9
3.7
3.5
3.3
3.1
2.9
2.7
2.5
25-00
26-00
27-00
28-00
29-00
Day-Hour
Carbon Monoxide ppm Station: System 1, 10m
Carbon Monoxide ppm Station: System 2, 100m
Carbon Monoxide ppm Station: System 3, 300m
Carbon Monoxide ppm Station: System 4, Upwind

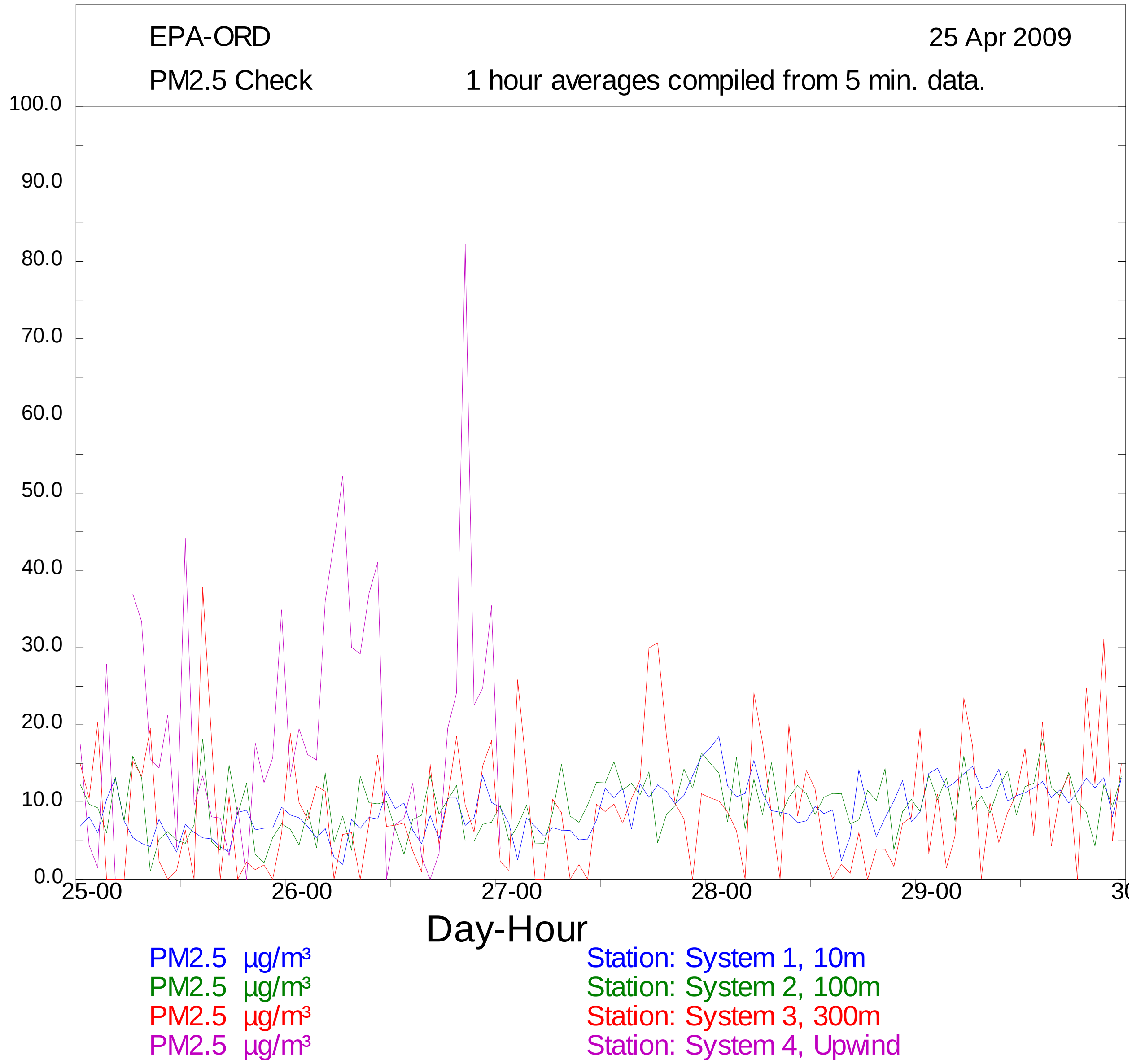

EPA-ORD
25 Apr 2009
Overnight CO Zeros
1 day averages compiled from1 day data.
0.65
0.45
0.25
0.05
-0.15
-0.35
-0.55
-0.75
25-00
26-00
27-00
28-00
29-00
Day-Hour
Carbon Monoxide ppm
Station: System 1, 10m
Carbon Monoxide ppm
Station: System 2, 100m
Carbon Monoxide ppm
Station: System 3, 300m
Carbon Monoxide ppm
Station: System 4, Upwind


EPA-ORD
4/25/2009 to 4/29/2009
Overnight Zero Check - NO/SO2
1 day averages compiled from1 day data.
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
-8.0
-10.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
Oxides of Nitrogen ppb
Station: System 1, 10m
Oxides of Nitrogen ppb
Station: System 2, 100m
Sulphur Dioxide ppb
Station: System 2, 100m
Oxides of Nitrogen ppb
Station: System 3, 300m
Oxides of Nitrogen ppb
Station: System 4, Upwind
Sulphur Dioxide ppb
Station: System 4, Upwind

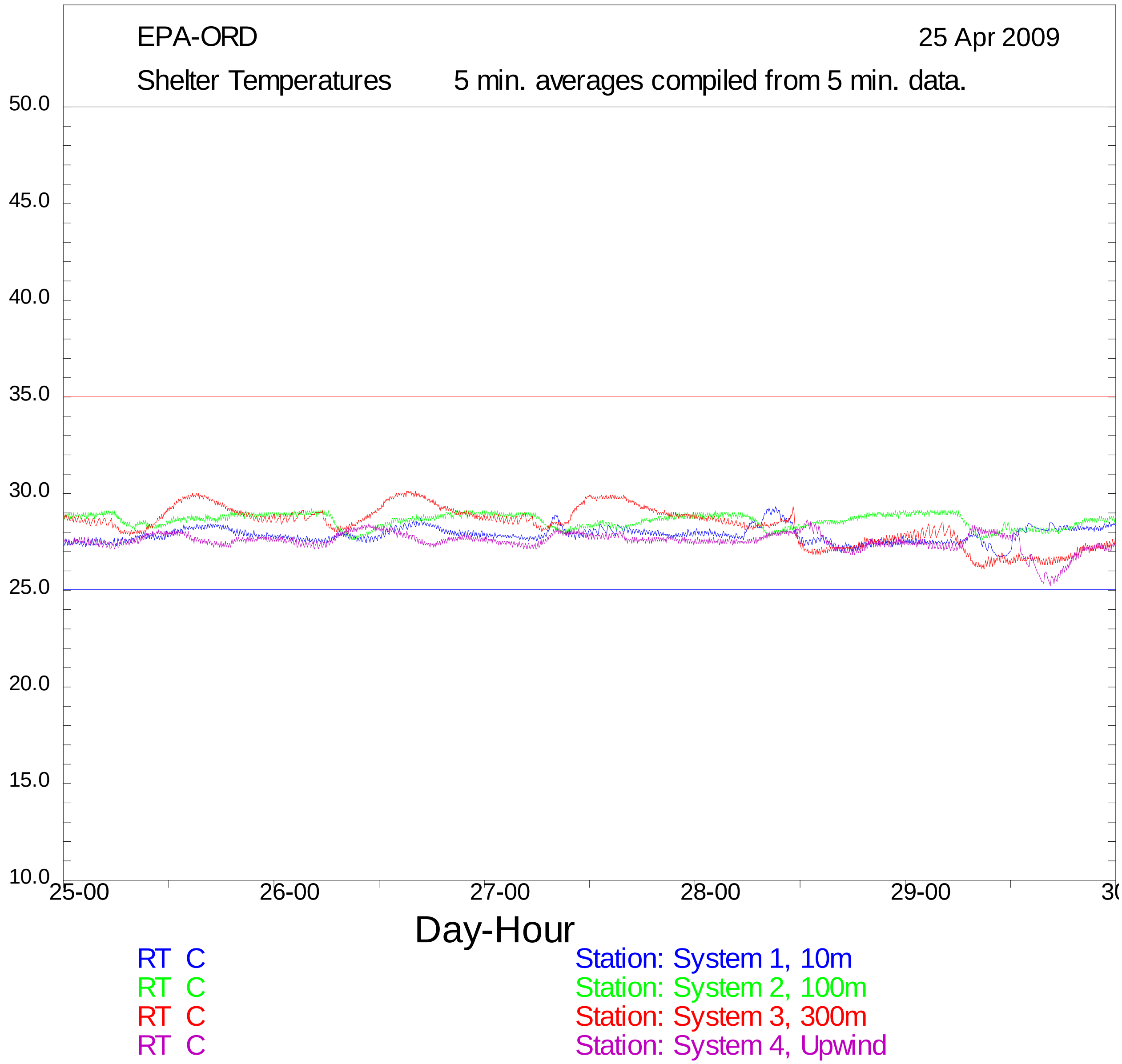

EPA-ORD
4/25/2009 to 4/29/2009
NO/SO2 Span Check
1 day averages compiled from1 day data.
450.0
440.0
430.0
420.0
410.0
400.0
390.0
380.0
370.0
360.0
350.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
Oxides of Nitrogen ppb
Station: System 1, 10m
Oxides of Nitrogen ppb
Station: System 2, 100m
Sulphur Dioxide ppb
Station: System 2, 100m
Oxides of Nitrogen ppb
Station: System 3, 300m
Nitrogen Oxide ppb
Station: System 4, Upwind
Nitrogen Dioxide ppb
Station: System 4, Upwind
Oxides of Nitrogen ppb
Station: System 4, Upwind

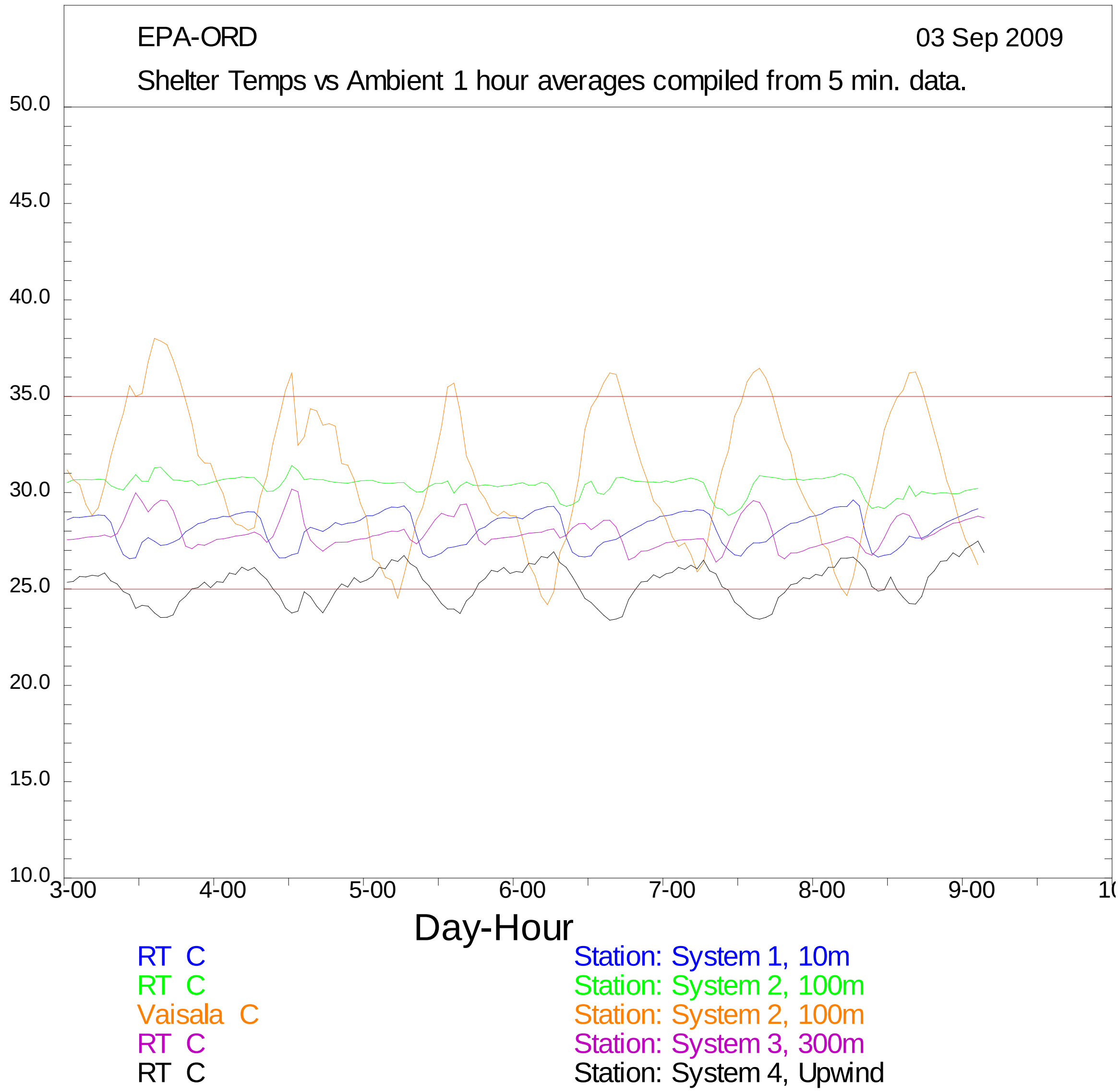

EPA-ORD
4/25/2009 to 4/29/2009
1 hour averages compiled from 5 min. data.
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
Nitrogen Oxide ppb
Sulphur Dioxide ppb
Nitrogen Oxide ppb
Sulphur Dioxide ppb
Station: System 2, 100m
Station: System 2, 100m
Station: System 4, Upwind
Station: System 4, Upwind

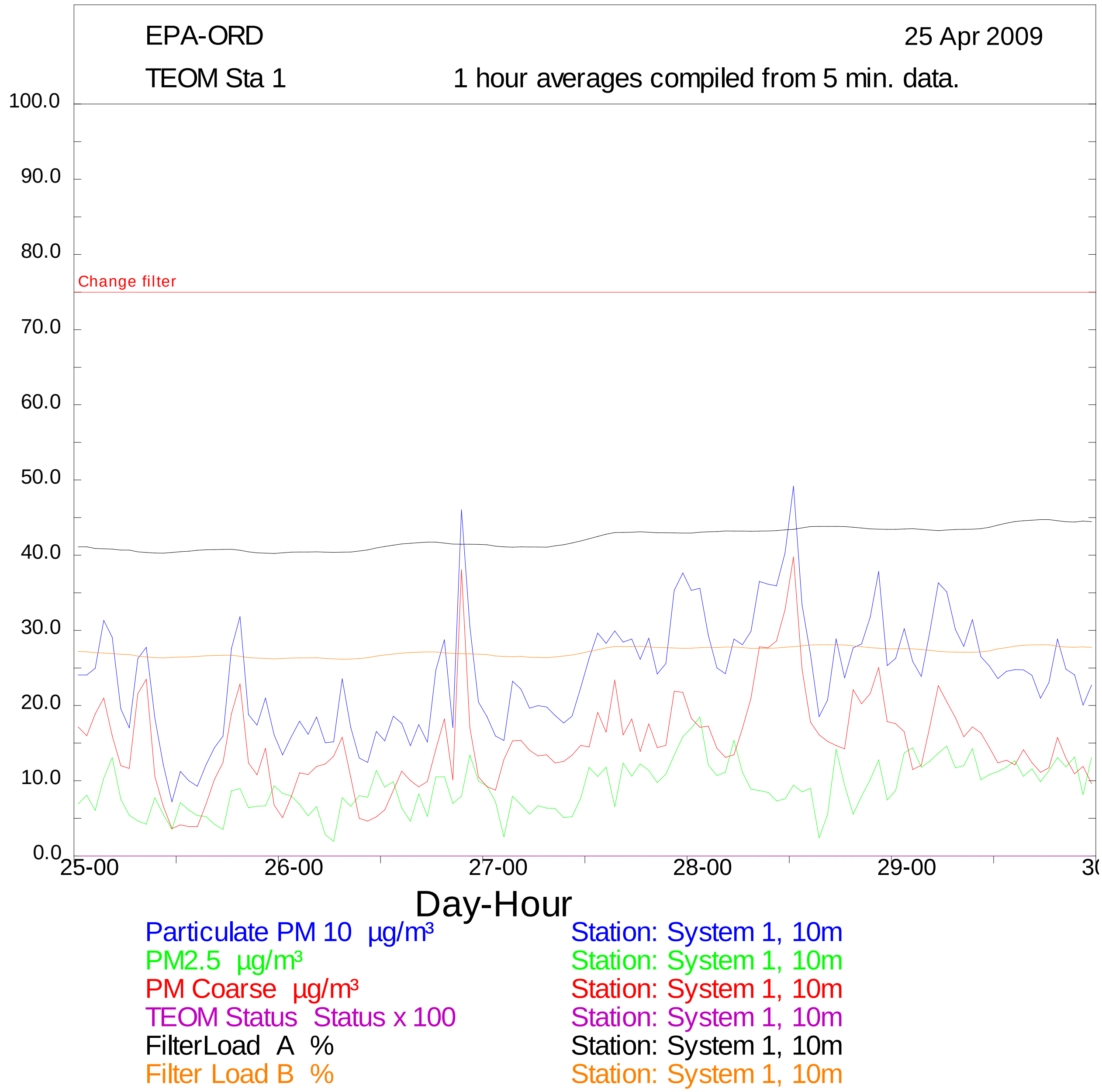

EPA-ORD
25 Apr 2009
PM10 data check
1 hour averages compiled from 5 min. data.
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
Particulate PM 10 µg/m³ Station: System 1, 10m
Particulate PM 10 µg/m³ Station: System 2, 100m
Particulate PM 10 µg/m³ Station: System 3, 300m
Particulate PM 10 µg/m³ Station: System 4, Upwind

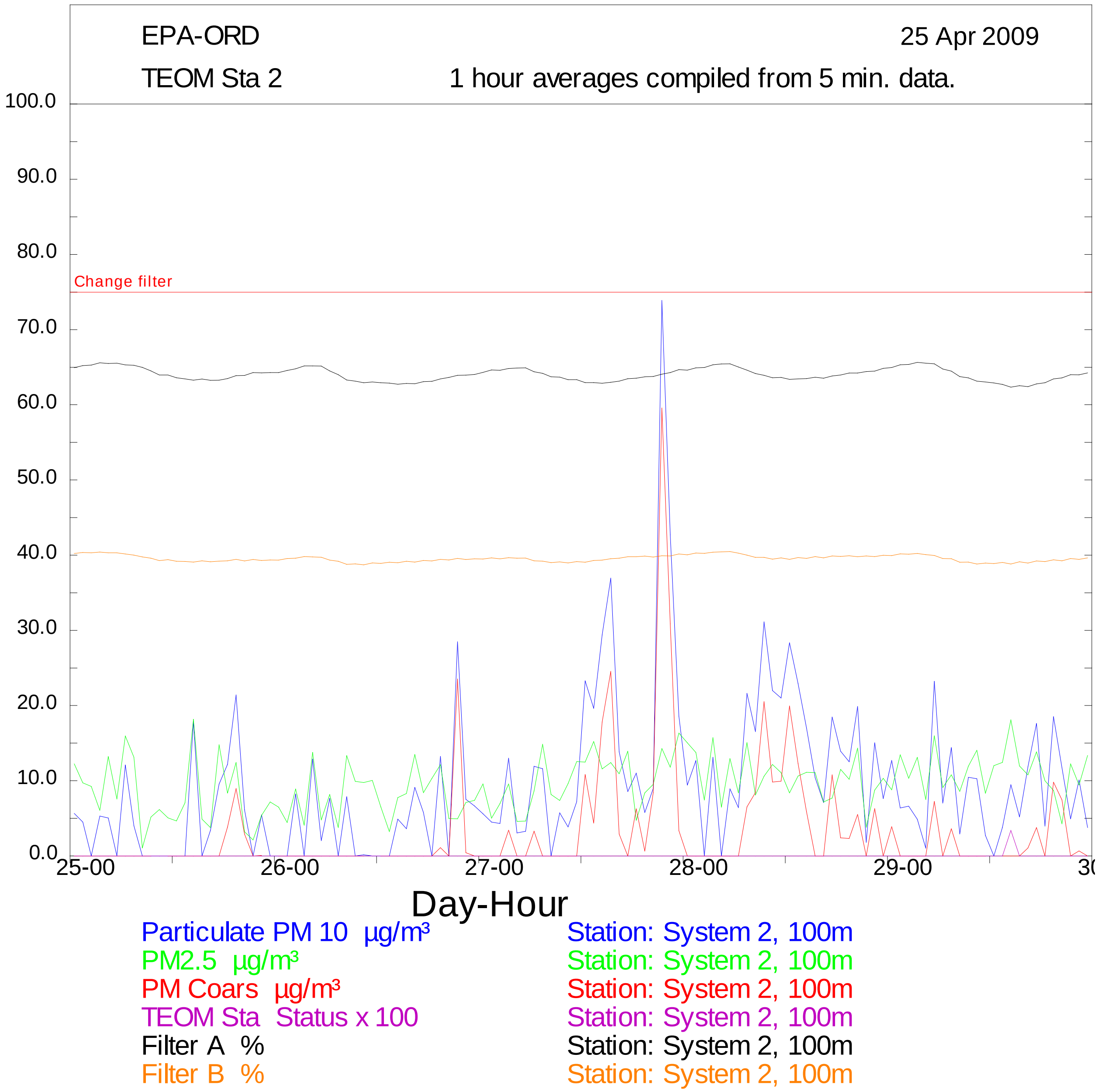


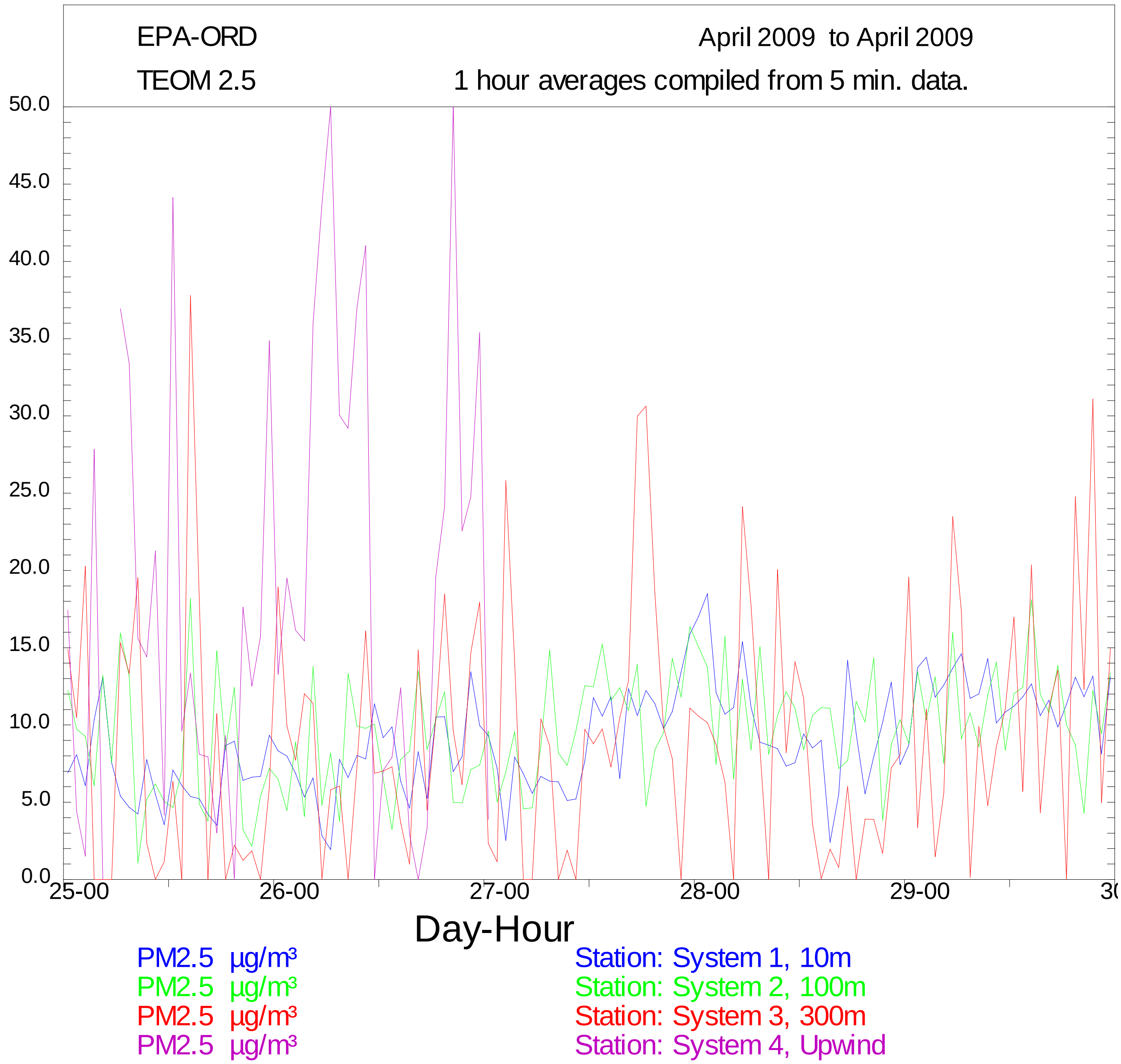
EPA-ORD
25 Apr 2009
PM2.5 Check
1 hour averages compiled from 5 min. data.
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
PM2.5 µg/m³
Station: System 1, 10m
PM2.5 µg/m³
Station: System 2, 100m
PM2.5 µg/m³
Station: System 3, 300m
PM2.5 µg/m³
Station: System 4, Upwind

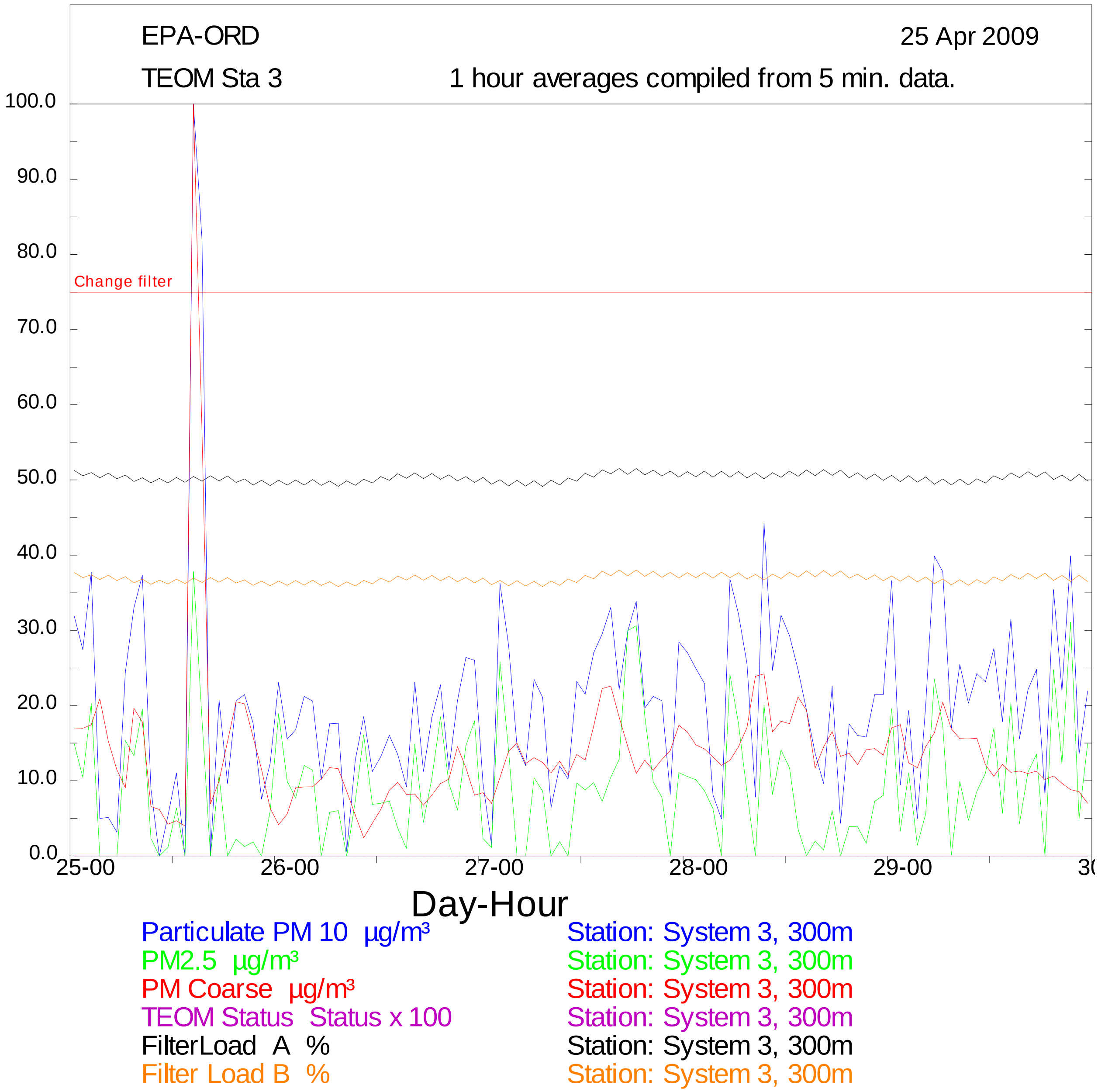

EPA-ORD
25 Apr 2009
Shelter Temperatures
5 min. averages compiled from 5 min. data.
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
RT C
RT C
RT C
RT C
Station: System 1, 10m
Station: System 2, 100m
Station: System 3, 300m
Station: System 4, Upwind


EPA-ORD
03 Sep 2009
Shelter Temps vs Ambient 1 hour averages compiled from 5 min. data.
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
3-00
4-00
5-00
6-00
7-00
8-00
9-00
Day-Hour
RT C
RT C
Vaisala C
RT C
RT C
Station: System 1, 10m
Station: System 2, 100m
Station: System 2, 100m
Station: System 3, 300m
Station: System 4, Upwind

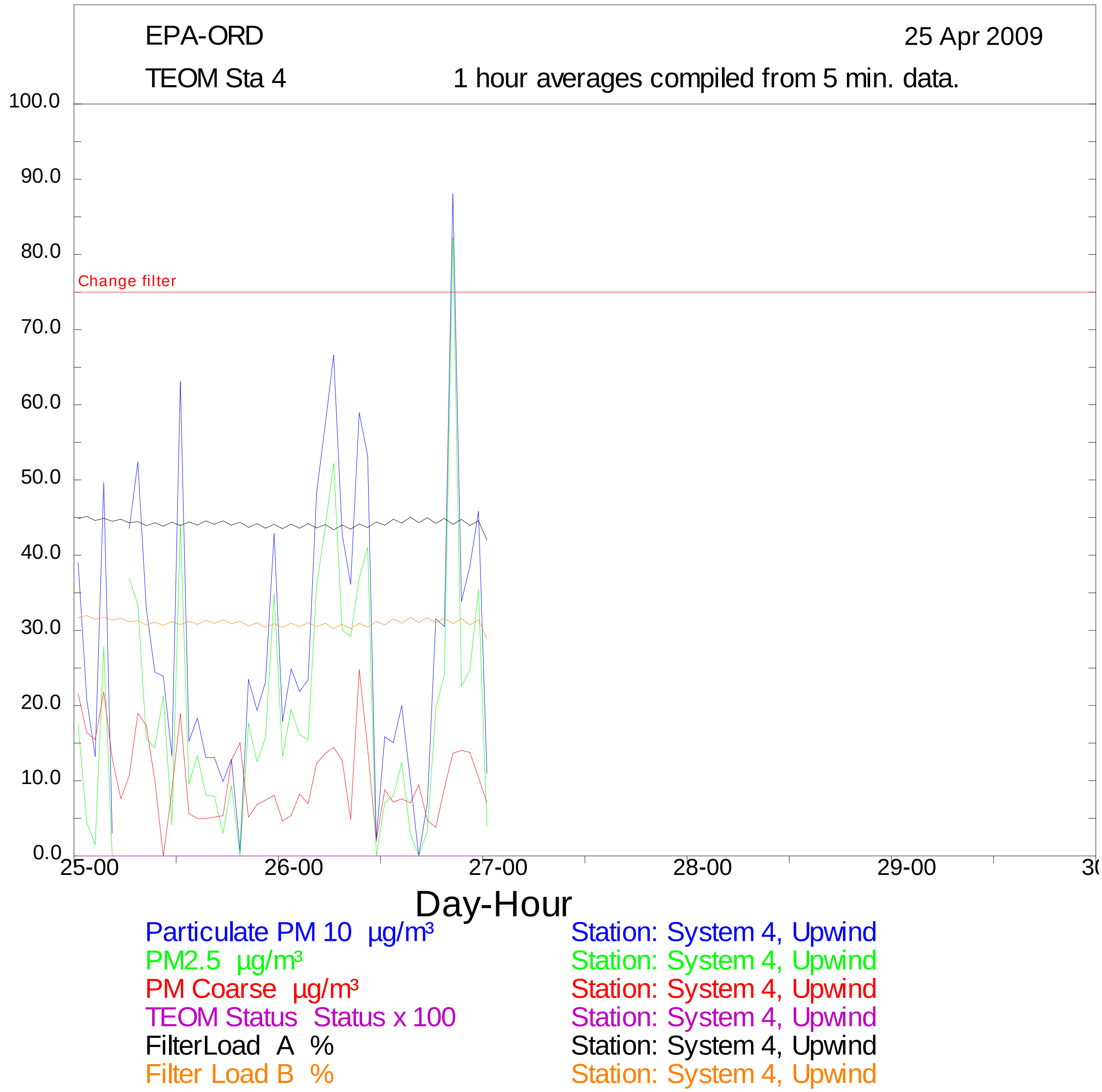

EPA-ORD
25 Apr 2009
TEOM Sta 1
1 hour averages compiled from 5 min. data.
100.0
90.0
80.0
Change filter
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
Particulate PM 10 µg/m³
Station: System 1, 10m
PM2.5 µg/m³
Station: System 1, 10m
PM Coarse µg/m³
Station: System 1, 10m
TEOM Status Status x 100
Station: System 1, 10m
FilterLoad A %
Station: System 1, 10m
Filter Load B %
Station: System 1, 10m

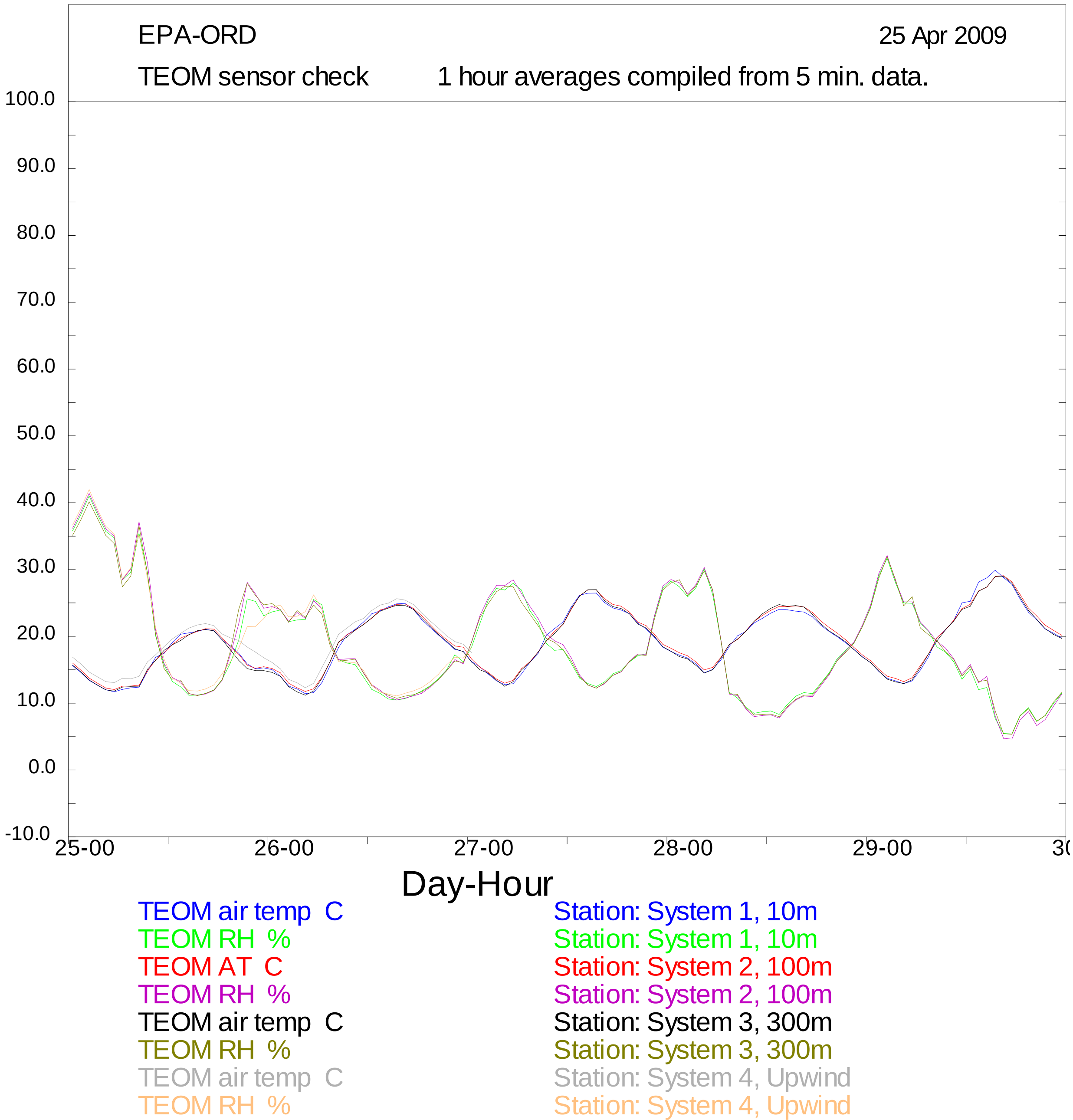

EPA-ORD
25 Apr 2009
TEOM Sta 2
1 hour averages compiled from 5 min. data.
100.0
90.0
80.0
Change filter
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
Particulate PM 10 µg/m³
Station: System 2, 100m
PM2.5 µg/m³
Station: System 2, 100m
PM Coars µg/m³
Station: System 2, 100m
TEOM Sta Status x 100
Station: System 2, 100m
Filter A %
Station: System 2, 100m
Filter B %
Station: System 2, 100m

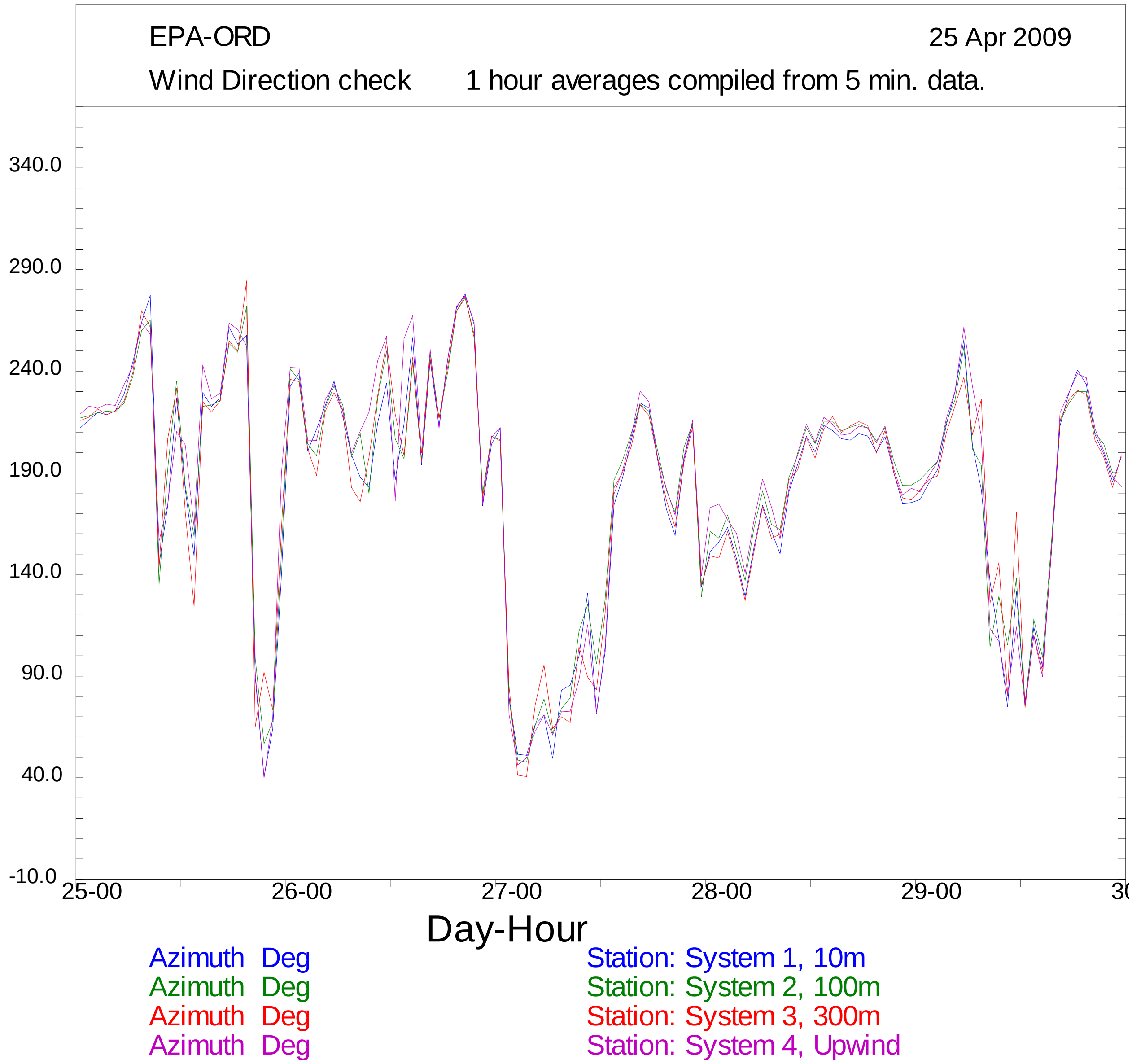

EPA-ORD
TEOM 2.5
April 2009 to April 2009
1 hour averages compiled from 5 min. data.
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
PM2.5 µg/m³
PM2.5 µg/m³
PM2.5 µg/m³
PM2.5 µg/m³
Station: System 1, 10m
Station: System 2, 100m
Station: System 3, 300m
Station: System 4, Upwind



EPA-ORD
25 Apr 2009
TEOM Sta 3
1 hour averages compiled from 5 min. data.
100.0
90.0
80.0
Change filter
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
Particulate PM 10 µg/m³
Station: System 3, 300m
PM2.5 µg/m³
Station: System 3, 300m
PM Coarse µg/m³
Station: System 3, 300m
TEOM Status Status x 100
Station: System 3, 300m
FilterLoad A %
Station: System 3, 300m
Filter Load B %
Station: System 3, 300m


EPA-ORD
25 Apr 2009
TEOM Sta 4
1 hour averages compiled from 5 min. data.
100.0
90.0
80.0
Change filter
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
Particulate PM 10 µg/m³
Station: System 4, Upwind
PM2.5 µg/m³
Station: System 4, Upwind
PM Coarse µg/m³
Station: System 4, Upwind
TEOM Status Status x 100
Station: System 4, Upwind
FilterLoad A %
Station: System 4, Upwind
Filter Load B %
Station: System 4, Upwind


EPA-ORD
25 Apr 2009
TEOM sensor check
1 hour averages compiled from 5 min. data.
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
TEOM air temp C
TEOM RH %
TEOM AT C
TEOM RH %
TEOM air temp C
TEOM RH %
TEOM air temp C
TEOM RH %
Station: System 1, 10m
Station: System 1, 10m
Station: System 2, 100m
Station: System 2, 100m
Station: System 3, 300m
Station: System 3, 300m
Station: System 4, Upwind
Station: System 4, Upwind



EPA-ORD
25 Apr 2009
Wind Direction check
1 hour averages compiled from 5 min. data.
340.0
290.0
240.0
190.0
140.0
90.0
40.0
-10.0
25-00
26-00
27-00
28-00
29-00
Day-Hour
Azimuth Deg
Azimuth Deg
Azimuth Deg
Azimuth Deg
Station: System 1, 10m
Station: System 2, 100m
Station: System 3, 300m
Station: System 4, Upwind

17 Appendix -- Data Checks

Level 1

1. Check to see if all variables are listed in each file. Continuous data has all variables for all stations even if station does not have that specific instrument installed.
2. Sound data, traffic, spans, zeros, integrated ($PM_{2.5}$, 1,3-butadiene, benzene, acrolein, formaldehyde, acetaldehyde) data are either recorded in separate files or recorded and stored in separate files.

Measurements	20 Meter Roadside	100 Meter Downwind	300 Meter Downwind	100 Meter Upwind
Continuous Analyzer Data -- Data stored by Station ID – 4 separate files.				
Continuous gas monitoring (CO, NO_x)	X	X	X	X
Continuous black carbon monitoring (Aethalometer)	X	X	X	X
Continuous fine particle (TEOM)	X	X	X	X
Wind speed/wind direction	X	X	X	X
Meteorological monitoring (temp, RH, etc.)		X		
Integrated -- VOC data stored as separate file, $PM_{2.5}$ data stored as separate file.				
TO-11A Cartridge sampling	X	X	X	X
TO-15 Canister sampling	X	X	X	X
Integrated $PM_{2.5}$ (FRM)	X	X	X	X
Other Continuous – Stored as separate files by pollutant or type (sound, video, etc.)				
Sound Meter	X	X		
Video Camera	X	X		X
Traffic Data – Stored as a separate file – Data is from Nevada DOT.				

Level 2 Check

1. Check to see if zero volt reference channel (0_Vref) is equal to zero and five volt reference channel (Vref) = 5.03. Five volt reference channel value is shelter specific. (All other records should be labeled as invalid.)
2. Check to see if continuous data are being recorded every five minutes.
3. Check to see if continuous GC data are being recorded every 30 minutes
4. Check between continuous analyzer data files to determine if time sync is correct. For example, data points are being recorded every 5 minutes. The time stamp for each file should be…. 00:05, 00:10, 00:15….23:55.

5. Check to see if traffic data contains both north bound and sound bound data.
6. Check to see if traffic data is being reported every 15 minutes (approx.).

Level 3 Check

1. Perform summary statistics and inspect for variability issues
2. Check traffic data to determine if sum of traffic volume by length bins is approximately equal to total volume count.
3. Check Outliers: Values that are 3 standard deviations from the mean
4. LowHigh: Check the lowest 5 values and the highest 5 values for all parameters.
5. Jumps: Checks to see if data quickly rises and then drops. There are macro variables that control the sensitivity (need to discuss sensitivity of the macro variables).

18 Appendix -- Data Rules/Flags

General Rules – All Stations		
Where O_Vref is ≠ 0, then mark as invalid all data from all continuous analyzers		
When NO = negative, mark NO as invalid		
When NO = negative, mark NO2 as invalid		
When NO = negative, mark NOx as invalid		
When NO = negative, mark Nox_Flow as invalid		
When NO = negative, mark Nox_Pres as invalid		
When CO = negative, mark as invalid data		
When CO = negative, CO_Flo is invalid		
When CO = negative, CO_Chass is invalid		
When TEOM_Sta ≠ 0 and TEOM_Op ≠ 4, then mark as invalid all TEOM parameters for that record		
PM10; PM2.5; PM Coars; TEOM Sta; TEOM Op; Filter A; Filter B; Mflow A; MFlow B; VFlow A; VFlow B; MFlowBy; VFlowBy; TEOM Vac; Noise A; Noise B; FreqA; FreqB; TEOM AT; TEOM RH; TEOM BP; Dew Poin		
When TEOM Filter_A or TEOM Filter_B > 75, then mark all TEOM parameters as invalid		
PM10; PM2.5; PM Coars; TEOM Sta; TEOM Op; Filter A; Filter B; Mflow A; MFlow B; VFlow A; VFlow B; MFlowBy; VFlowBy; TEOM Vac; Noise A; Noise B; FreqA; FreqB; TEOM AT; TEOM RH; TEOM BP; Dew Poin		
When Aeth < 0, then mark as invalid Aeth data		
When Aeth > 15, then mark data as outliers		
When Aeth_1 < 0, then mark as invaild Aeth_1 data		
When Aeth_2 < 0, then mark as invalid Aeth_2 data		
When Aeth_3 < 0, then mark as invalid Aeth_3 data		
When Vaisala_1 < 0, then mark all Vaisala parameters invalid (Vaisala, Vaisala_1)		

General Rules – All Stations			
When GasCal_S = 3 or 6 or 7 or 15 or 18 or 19, mark all gas analyzer parameter data invalid: NO; NO2; Nox; NOx Flow; NOx Pres; CO; CO Flow; CO Chass.			
GasCal_S	1 = zero (calibration)		
	2 = span 400 ppb NO/CO		
	3 = error		
	4 = manual zero/span activity		
	5 = span 100 ppb NO/CO (every 11 days)		
	6 = error		
	7 = error		
	8 = span 400 ppb SO2		
	11 = span 100 ppb SO2 (every 11 days)		
	14 = manual zero/span activity		
	15 = error		
	17 = manual zero/span activitiy		
	18 = error		
	19 = error		
When NO > 450, then mark as outlier (NO, NO2, NOX) for that record			
When CO > 2.25, then mark as outlier (CO) for that record			
When PM10 > 400, mark data as outliers			
When PM2_5 > 100, mark data as outliers			
When PM_Coars < 0, mark PM_Coars as invalid			
When Aeth > 15, then mark data as outliers			

19 Appendix – Data Dictionary – WinCollect

Electronic Excel File

20 Appendix – "Core Measurements" File – SAS Dataset

SAS Dataset

21 Appendix – Digital Aethalometer

SAS Dataset

22 Appendix -- Traffic

SAS Dataset

23 Appendix – Integrated Sample Data – PM Filters

SAS Dataset

The table is a summary of all of the samples collected from December 15, 2008 thru December 15, 2009.

December 15, 2008 thru December 15, 2009						
Sample Type	**# of Samples**	**% by Sample Type**	**# of Samples w/ No Sample Collection Errors/Warnings (Flag_PM = 0)**	**% of Samples w/ No Sample Collection Errors/Warnings (Flag_PM = 0)**	**# of Samples w/ Sample Collection Errors/Warnings (Flag_PM = 1)**	**% of Samples w/ Sample Collection Errors/Warnings (Flag_PM = 1)**
Field Blank	30	16	28	17	2	10
Field Duplicates	31	17	19	12	12	60
Samples	124	67	118	72	6	30
Total	185		165		20	

Note: invalid data may be due to instrument malfunction, torn filter, etc.

The following is a list of the variables in the PM2.5 data set.

id = station identification
SampleType = Sample, Field Duplicate, Field Blank,
Date = Date Sample Collected
Flag_PM = 0 or 1; 0 = valid data; 1 = invalid data
location = Upwind, 10 meter, 100 meter, 300 meter
PM2_5mg_m3 = PM2.5 in µg/m^3

24 Appendix – Integrated Sample Data – VOC (TO-15)

SAS Dataset

Variables for VOC Data (samples collected using Summa Canisters: Method TO-15).

id = station1, station2, station3, station4
location = 10 meter, 100 meter, 300 meter, Upwind
SampleType = Field Blank, Field Control, Field Duplicate, Lab Duplicate, Sample
SampleDateTime = Date and Time of Sample
Buta_ppb = 1,3-Butadiene (ppb)
Benz_ppb = Benzene (ppb)
Acrolein_ppb = Acrolein (ppb)
Flag_VOC = 0 or 1; 0 = valid data; 1 = invalid data (relates to the entire sample, across all pollutants)
Flag_Buta = 0 or 1; 0 = valid data; 1 = invalid data
Flag_Benz = 0 or 1; 0 = valid data; 1 = invalid data
Flag_Acrolein = 0 or 1; 0 = valid data; 1 = invalid data
FieldComments = text field
AnalysisComments = text field
LabComments = text field
fcom = text field

December 15, 2008 thru December 15, 2009
1,3-Butadiene

SampleType	# of Samples	% by Sample Type	# of Samples w/ No Sample Collection Errors/ Warnings (Flag_Buta = 0)	% of Samples w/ No Sample Collection Errors/Warnings (Flag_Buta = 0)	# of Samples w/ Sample Collection Errors/ Warnings (Flag_Buta = 1)	% of Samples w/ Sample Collection Errors/ Warnings (Flag_Buta = 1)
Field Blank	70	5	55	4	15	1
Field Control	70	5	56	4	14	1
Field Dup	71	5	52	3	19	1
Lab Dup	108	7	89	6	19	1
Sample	1225	79	1019	66	206	13
Total	1544		1271		273	

Benzene

SampleType	# of Samples	% by Sample Type	# of Samples w/ No Sample Collection Errors/ Flag_Benz Warnings (Flag_Benz = 0)	% of Samples w/ No Sample Collection Errors/ Flag_Benz Warnings (Flag_Benz = 0)	# of Samples w/ Sample Collection Errors/ Warnings (Flag_Benz = 1)	% of Samples w/ Sample Collection Errors/ Warnings (Flag_Benz = 1)
Field Blank	70	5	55	4	15	1
Field Control	70	5	56	4	14	1
Field Dup	71	5	52	3	19	1
Lab Dup	108	7	89	6	19	1
Sample	1225	79	1019	66	206	13
Total	1544		1271		273	

Acrolein

SampleType	# of Samples	% by Sample Type	# of Samples w/ No Sample Collection Errors/ AcroleinWarnings (Flag_Acrolein = 0)	% of Samples w/ No Sample Collection Errors/ Acrolein Warnings (Flag_Acrolein = 0)	# of Samples w/ Sample Collection Errors/ Warnings (Flag_ Acrolein = 1)	% of Samples w/ Sample Collection Errors/ Warnings (Flag_ Acrolein = 1)
Field Blank	70	5	28	2	42	3
Field Control	70	5	29	2	41	3
Field Dup	71	5	28	2	43	3
Lab Dup	108	7	54	3	54	3
Sample	1225	79	511	33	714	46
Total	1544		650		894	

25 Appendix – Integrated Sample Data – Cartridges

SAS Dataset

December 15, 2008 thru December 16, 2009

Acetaldehyde

SampleType	# of Samples	% by Sample Type	# of Samples w/ No Sample Collection Errors/ Warnings (Flag_ Acetaldehyde = 0)	% of Samples w/ No Sample Collection Errors/ Warnings (Flag_ Acetaldehyde = 0)	# of Samples w/ Sample Collection Errors/ Warnings (Flag_ Acetaldehyde = 1)	% of Samples w/ Sample Collection Errors/ Warnings (Flag_ Acetaldehyde = 1)
Field Blank	67	5	53	4	14	1
Field Control	72	5	51	4	21	1
Field Dup	67	5	33	2	34	2
Lab Dup	2	0	0	0	2	0
Sample	1211	85	832	59	379	27
Total	1419		969		450	

Formaldehyde

SampleType	# of Samples	% by Sample Type	# of Samples w/ No Sample Collection Errors/ Warnings (Flag_ Formaldehyde = 0)	% of Samples w/ No Sample Collection Errors/ Warnings (Flag_ Formaldehyde = 0)	# of Samples w/ Sample Collection Errors/ Warnings (Flag_ Formaldehyde = 1)	% of Samples w/ Sample Collection Errors/ Warnings (Flag_ Formaldehyde = 1)
Field Blank	67	5	53	4	14	1
Field Control	72	5	51	4	21	1
Field Dup	67	5	33	2	34	2
Lab Dup	2	0	0	0	2	0
Sample	1211	85	832	59	379	27
Total	1419		969		450	

Acrolein

SampleType	# of Samples	% by Sample Type	# of Samples w/ No Sample Collection Errors/ Warnings (Flag_ Acrolein = 0)	% of Samples w/ No Sample Collection Errors/ Warnings (Flag_ Acrolein = 0)	# of Samples w/ Sample Collection Errors/ Warnings (Flag_ Acrolein = 1)	% of Samples w/ Sample Collection Errors/ Warnings (Flag_ Acrolein = 1)
Field Blank	67	5	53	4	14	1
Field Control	72	5	51	4	21	1
Field Dup	67	5	33	2	34	2
Lab Dup	2	0	0	0	2	0
Sample	1211	85	832	59	379	27
Total	1419		969		450	

Variables for Carbonyl Data (samples collected using cartridges: Method TO-11A).

id = station1, station2, station3, station4
location = 10 meter, 100 meter, 300 meter, Upwind
SampleType = Field Blank, Field Control, Field Duplicate, Lab Duplicate, Sample
SampleDateTime = Date and Time of Sample
Acetaldehyde = $\mu g/m^3$
Acrolein = $\mu g/m^3$
Formaldehyde = $\mu g/m^3$
BATCH = batch number of DNSH cartridge
Flag_Carbonyl = 0 or 1; 0 = valid data; 1 = invalid data (relates to the entire sample, across all pollutants)
Flag_Acetaldehyde = 0 or 1; 0 = valid data; 1 = invalid data
Flag_Acrolein = 0 or 1; 0 = valid data; 1 = invalid data
Flag_Formaldehyde = 0 or 1; 0 = valid data; 1 = invalid data
Data_Review_Comment = text field
Acetaldehyde_mdl = method detection limit for acetaldehyde ($\mu g/m^3$)
Acrolein_mdl = method detection limit for acrolein $\mu g/m^3$
Formaldehyde_mdl = method detection limit for formaldehyde ($\mu g/m^3$)
Acetaldehyde_ppb = Acetaldehyde (ppb) (uncorrected for background)
Acrolein_ppb = Acrolein (ppb) (uncorrected for background)
Formaldehyde_ppb = Formaldehyde (ppb) (uncorrected for background)
Acetaldehyde_ppb_mdl = Acetaldehyde (ppb) method detection limit
Acrolein_ppb_mdl = Acrolein (ppb) method detection limit
Formaldehyde_ppb_mdl = Formaldehyde (ppb) method detection limit
Acetaldehyde_detect = 0 or 1; 0 = method detection limit value substitution (only occurs when measured value – background = negative value); 1 = actual value
Acrolein_detect = 0 or 1; 0 = method detection limit value substitution (only occurs when measured value – background = negative value); 1 = actual value
Formaldehyde_detect = 0 or 1; 0 = method detection limit substitution; 1 = below method detection limit
Acetaldehyde_BL = Acetaldehyde ($\mu g/m^3$) background value
Acetaldehyde_ppb_BL = Acetaldehyde (ppb) background value
Acrolein_BL = Acrolein ($\mu g/m^3$) background value
Acrolein_ppb_BL = Acrolein (ppb) background value
Acetaldehyde_BLCorrected = Acetaldehyde background corrected ($\mu g/m^3$)
Acrolein_BLCorrected = Acrolein background corrected ($\mu g/m^3$)
Acetaldehyde_ppb_BLCorrected = Acetaldehyde (ppb) background corrected
Acrolein_ppb_BLCorrected = Acrolein (ppb) background corrected
fcom = text field (field comment)