

**DETAILED MONITORING PROTOCOL**

**For**

**U.S. 95 Settlement Agreement**

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**Prepared for**

**Kevin Black  
Contracting Officer's Task Representative**

**Federal Highway Administration  
400 Seventh Street, SW  
Washington, DC 20590**

**by**

**BATTELLE  
505 King Avenue  
Columbus, OH 43201-2693**

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## **ABBREVIATIONS**

AADT	annual average daily traffic
ACN	acetonitrile
ADQ	audit of data quality
ANOVA	Analysis of Variance
AVI	automated vehicle identification
BAM	beta attenuation monitor
BC	black carbon
BFB	bromofluorobenzene
CCTV	closed circuit television cameras
CFR	Code of Federal Regulations
CO	carbon monoxide
COC	chain of custody
DQI	data quality indicator
DQO	data quality objective
DNPH	dinitrophenyl hydrazine
DPM	diesel particulate matter
EC	elemental carbon
ETC	electronic toll collection
DOT	Department of Transportation
FHWA	Federal Highway Administration
FRM	Federal Reference Method
GC/MS	gas chromatography/mass spectrometry
HPLC	high performance liquid chromatography
HPMS	Highway Performance Monitoring System
ILD	inductive loop detector
IR	infrared
IS	internal standard
ITS	Intelligent Transportation Systems
LDL	lower detectable limit
MDL	method detection limit
MFC	mass flow controller
MSAT	mobile source air toxic



NPAP	National Performance Audit Program
NDIR	non-dispersive infrared spectrophotometry
NEPA	National Environmental Policy Act
NIST	National Institute of Standards and Technology
NO <sub>x</sub>	nitrogen oxide
O <sub>3</sub>	ozone
PE	performance evaluation
PM <sub>2.5</sub>	particulate matter with aerodynamic diameter less than 2.5 microns
ppbv	parts per billion by volume
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
QMP	quality management plan
RFID	radio frequency identification
RH	relative humidity
RSD	relative standard deviation
SIM	single ion monitoring
SIS	Selected Ion Storage
SOP	standard operating procedure
TEOM	tapered element oscillating microbalance
TSA	technical systems audit
USEPA	U.S. Environmental Protection Agency
UV	ultra-violet
VID	video image detection
VOC	volatile organic compound

## **GLOSSARY**

Aethalometer	A commercial instrument used to continuously measure “black carbon,” and recommended for use in the studies to be conducted under this Protocol as a surrogate measurement for diesel particulate matter.
BAM	Beta attenuation monitor – Any of a number of commercial instruments used to continuously measure particulate matter mass and recommended for use in the studies to be conducted under this Protocol as a surrogate measurement for PM <sub>2.5</sub> .
MSATs	Mobile source air toxics – A group of compounds identified by the USEPA as being common pollutants in mobile source emissions. For this Protocol the following MSATs are of interest: acetaldehyde, acrolein, benzene, 1,3-butadiene, formaldehyde, and diesel particulate matter (DPM).
TEOM	Tapered element oscillating microbalance monitor - A commercial instrument used to continuously measure particulate matter mass and recommended for use in the studies to be conducted under this Protocol as a surrogate measurement for PM <sub>2.5</sub> .
TO-11A	Method TO-11A – A standard method, recommended by the USEPA, used for the determination of formaldehyde and other carbonyl compounds (aldehydes and ketones) in ambient air.
TO-15	Method TO-15 – A standard method, recommended by the USEPA, used for the sampling and analysis of volatile organic compounds (VOCs) in ambient air including the MSATs benzene and 1,3-butadiene.

## **1.0 INTRODUCTION**

### **1.1 History**

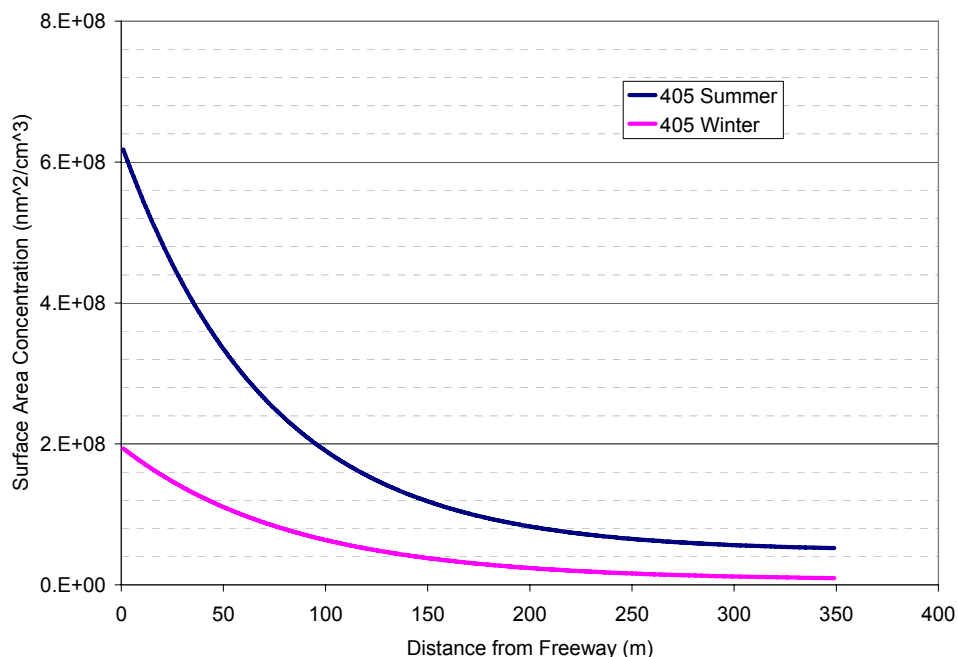
The Federal Highway Administration (FHWA) was involved in a legal action concerning the U.S. 95 Widening Project in Las Vegas, Nevada. In that action, the Sierra Club challenged FHWA's and the Nevada Department of Transportation's (DOT) assessment, presented in the National Environmental Policy Act (NEPA) environmental document, of impacts of mobile source air toxics (MSATs) from the proposed project. To resolve the situation, FHWA entered into a Settlement Agreement with Nevada DOT and the Sierra Club. The Settlement Agreement is provided in Appendix A of this Protocol.

In this Settlement Agreement, 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. As part of this Agreement, FHWA agreed to develop a "detailed protocol" outlining a uniform approach to conducting all studies for evaluating mobile source contributions to air toxic compounds and  $PM_{2.5}$  and their dispersion patterns in up to five highway locations. In addition, FHWA was required under the Agreement to prioritize a list of potential study locations, or if necessary, prepare to conduct its own study at one highway location. The Agreement is intended to promote field measurement of the contribution of mobile sources to  $PM_{2.5}$  and MSATs, but is not intended to characterize the potential human health impacts of public exposure to MSATs or  $PM_{2.5}$ .

### **1.2 Monitoring Objective**

The objective of the studies to be conducted under this Protocol is 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. To meet this objective, up to five year-long studies may be performed at different selected sites.

As an example of the dispersion of pollutants away from a highway, Figure 1-1 shows the results of a recent study in which the concentration of airborne particles was characterized as a function of distance from a highway (Freeway 405 in Los Angeles).<sup>1</sup> These results suggest that the vast majority of dispersion for occurs within 300 meters of the highway, and that the initial pollutant concentration varies depending on the season.



**Figure 1-1. Example of Pollutant Dispersion as a Function of Distance from a Highway.**

It is expected that the studies conducted under this Protocol will generate data that can be used to characterize similar types of dispersion patterns as well as relationships between various traffic and meteorological parameters and the concentrations of MSATs.

### 1.3 Purpose of Document

The purpose of this Detailed Protocol is to specify how to conduct the field studies called for by the Settlement Agreement, i.e., addressing the impact of mobile sources on PM<sub>2.5</sub> and MSAT concentrations near highly traveled roadways. This Protocol has been developed to address all aspects of the field studies called for in the Settlement Agreement, including selection of the study location; placement and setup of sampling sites; application of appropriate sampling and analysis methods, including monitoring of surrogate or indicator compounds; coordination of chemical sampling with meteorological and traffic monitoring over defined sampling periods and study durations; quality assurance activities; and analysis of the study data. Furthermore, the Protocol defines and recommends the logistical process to be followed when more than one such field study is to be carried out, such that simultaneous or sequential studies can benefit from concurrent or previous efforts.

The primary goal of this Protocol is to provide understandable and readily implementable procedures and guidance that can be used by any organization carrying out such a mobile source field study. It is expected that the multiple field studies required under the Settlement Agreement may be carried out by the FHWA or its contractor(s), or by state DOT's or their contractors. Consequently, the

Protocol is sufficiently detailed but widely applicable, so that field studies carried out by diverse agencies in widely different parts of the United States will have a consistent scope and produce data of comparable breadth and quality.

This Protocol is a generic document and does not include site-specific procedures. For each monitoring study, a site-specific test plan should be developed that includes the exact locations and installation of monitoring sites, specific procedures for the use of monitoring equipment deployed for the study, the identification of key personnel and their responsibilities, and other pertinent information that is not addressed in this Protocol.

#### **1.4 Associated Settlement Requirements**

Although not directly a part of the monitoring studies to be conducted under this Protocol, the Settlement Agreement calls for the development of an emission inventory from data collected during these studies. Additional information regarding emission inventory development is provided in Section 7.3.

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## **2.0 MONITORING STUDY DESIGN**

The study design presented here is based on the hypothesis that MSAT concentrations are greater than background concentrations near a heavily traveled roadway, and fall to near background levels within 300 meters (m) (approximately 1,000 feet) from the roadway.<sup>1-3</sup> To meet the objective of these studies, a suitable monitoring schedule must be adopted to appropriately characterize representative conditions and temporal patterns in pollutant concentration, established monitoring techniques must be used to reliably measure the pollutants of interest, and siting of the monitoring stations must allow for spatial characterization of the pollutants near the roadway. In general, the recommendations call for continuous monitoring of a few select surrogate species throughout the monitoring study, augmented with integrated sampling of specific MSATs following a pre-determined sampling schedule. The following discussion briefly describes the sampling schedule to be adopted for studies conducted under this Protocol, the criteria for selection of the study locations, and the requirements (in terms of data quality indicators) of the measurement methods to be employed. Recommendations for the selection of monitoring site locations and monitoring methods are made in Sections 3 and 4 of this Protocol.

### **2.1 Sampling Schedule**

A number of potential sampling schedules were considered for implementation in the studies to be conducted under this Protocol. These options included the collection of various numbers of samples per day, various sampling period durations, as well as intensive seasonal sampling or routine periodic sampling. After considerable discussion, the FHWA and Sierra Club agreed upon a single sampling schedule that was felt would meet the requirements of the Settlement Agreement. The sampling schedule agreed upon by FHWA and Sierra Club calls for the collection of nine (9) 1-hour samples during a 24-hour period on a 1-in-12 day schedule. During each sampling day two of the 1-hour samples should be collected within the three-hour period centered on the morning peak traffic period. For all sampling days, one of these samples should be collected during the hour corresponding to the typical peak in the morning traffic. The second sample should be collected during the hour either preceding or following the peak hour, on an alternating basis every other sampling day. The other seven samples should be collected on an equally spaced basis (i.e., every third hour) over the other 21 hours of the sampling day. Furthermore, the sampling schedule should rotate each sampling day such that the collection times shift by one hour for the seven samples collected outside of the morning peak traffic period. Table 2-1 shows an example of

this sampling schedule for the first five sampling days, in which the morning peak traffic period was assumed to be 7:00-8:00 a.m. This same schedule is shown illustratively in Figure 2-1 in which the times in the first column indicate the starting time for sample collection and each block represents one hour. In this figure, if a sample starts at 0:00 the sample end time will be 1:00. For convenience, the borders of the assumed morning peak traffic period have been made bolder than those for other hours.

**Table 2-1. Example Rotating Sampling Schedule for 9-samples-per-day Plan**

	<b>Day 1</b>	<b>Day 2</b>	<b>Day 3</b>	<b>Day 4</b>	<b>Day 5</b>
Sample 1	0:00-1:00	1:00-2:00	2:00-3:00	0:00-1:00	1:00-2:00
Sample 2	3:00-4:00	4:00-5:00	5:00-6:00	3:00-4:00	4:00-5:00
Sample 3	6:00-7:00	7:00-8:00	6:00-7:00	7:00-8:00	6:00-7:00
Sample 4	7:00-8:00	8:00-9:00	7:00-8:00	8:00-9:00	7:00-8:00
Sample 5	9:00-10:00	10:00-11:00	11:00-12:00	9:00-10:00	10:00-11:00
Sample 6	12:00-13:00	13:00-14:00	14:00-15:00	12:00-13:00	13:00-14:00
Sample 7	15:00-16:00	16:00-17:00	17:00-18:00	15:00-16:00	16:00-17:00
Sample 8	18:00-19:00	19:00-20:00	20:00-21:00	18:00-19:00	19:00-20:00
Sample 9	21:00-22:00	22:00-23:00	23:00-0:00	21:00-22:00	22:00-23:00

For each study conducted under this Protocol, the exact sampling schedule should be tailored to specific traffic patterns in the respective monitoring study locations. At least one year of historical data should be used to identify the peak hour in the morning traffic pattern for each monitoring study location prior to implementation of the monitoring study. An inspection of the continuous surrogate monitoring data should be conducted within the first month of monitoring to verify that the peak traffic period was properly selected and that the study-specific monitoring schedule is appropriate for the monitoring study location.

This sampling schedule allows for the measurement of MSAT concentrations with a high time resolution (hourly) during two hours of the morning traffic peak while also allowing measurement of MSAT concentrations on a routine basis throughout the remainder of each sampling day. By rotating the sampling schedule, data are collected for each individual hour of the day at several times throughout the year.





## **2.2 Site Selection Criteria**

To meet the study objective it is important to select study locations that are representative of common highway locations and are likely to yield useful data to establish pollutant concentration variations related to highway traffic. Criteria that should be used during selection of study locations have been established for the following parameters:

- Annual average daily traffic (AADT)
- Geometric considerations
- Topography
- Geographic location
- Data availability
- Climate and meteorology
- PM<sub>2.5</sub> nonattainment status.

Section 3 of this Protocol describes the criteria that should be adopted for each of these parameters. Once an appropriate study location is selected, it is important to position the monitoring sites optimally.

Monitoring should be conducted at each of three monitoring sites located at distances of 0-10 m, 100 ±50 m (approximately 300±150 feet), and 300 ±50 m (approximately 1,000 ±150 feet) from the roadway, and at one additional monitoring site, chosen to serve as a background site, located approximately 1,000 m (approximately 3,000 feet) from the roadway and not located near any major pollutant source. It was assumed in the development of this Protocol that appropriate study locations will be selected and that monitor siting will be done such that there is minimal influence on MSAT concentrations at the monitoring sites from sources other than the roadway. It is assumed that this minimal influence is regional in nature and influences all the monitoring sites uniformly.

## **2.3 MSAT and Surrogate Monitoring Methods**

Mobile sources emit a wide variety of pollutants. Of particular interest for this Protocol are the PM<sub>2.5</sub> and the following MSATs: acetaldehyde, acrolein, benzene, 1,3-butadiene, formaldehyde, and diesel particulate matter (DPM). However, since monitoring of these species is relatively labor intensive and costly, this Protocol calls for a combined approach in which selected MSATs are monitored on a routine periodic basis using time-integrated sampling techniques, and several surrogate species that are indicators of vehicle emissions are monitored continuously.

The successful completion of these monitoring studies relies on appropriate monitoring of MSATs and surrogate compounds. The monitoring methods recommended for the characterization of most of the MSAT concentrations are standard monitoring methods that have been adopted by the

USEPA. However, since there is no recognized method for monitoring of DPM, these studies will include surrogate monitoring for characterization of DPM concentrations. Table 2-2 lists the MSATs that must be measured during each of the monitoring studies and the recommended monitoring method for each.

**Table 2-2. MSATs and Recommended Monitoring Methods**

<b>MSAT</b>	<b>Recommended Monitoring Method</b>
Acetaldehyde	DNPH cartridges-HPLC analysis (USEPA Method TO-11A)
Acrolein	DNPH cartridges-HPLC analysis (USEPA TO-11A)
Benzene	Canister sampling-GC/MS analysis (USEPA Method TO-15)
1,3-Butadiene	Canister sampling-GC/MS analysis (USEPA Method TO-15)
Diesel particulate matter	Surrogate monitoring
Formaldehyde	DNPH cartridges-HPLC analysis (USEPA Method TO-11A)

In addition to the methods listed in Table 2-2 for monitoring MSATs, additional monitoring will be conducted for the characterization of several key surrogate species. Carbon monoxide, nitrogen oxides, black carbon, and PM<sub>2.5</sub> will all be measured to provide supporting data regarding vehicle emissions.

Section 4.1 describes the MSAT and surrogate monitoring to be conducted during the studies conducted under this Protocol.

## **2.4 Meteorological Monitoring**

Meteorological monitoring during the studies conducted under this Protocol should be conducted to characterize the ambient conditions during each study. At one of the monitoring sites away from the roadway, monitoring should include the measurement of wind speed, wind direction, ambient temperature, barometric pressure, relative humidity, solar radiation, and precipitation. Additionally, it is recommended that wind speed and wind direction be monitored at each of the sites.

Section 4.2 presents the recommended specifications for the meteorological sensors to be used during the studies conducted under this Protocol.

## **2.5 Traffic Monitoring**

Traffic monitoring must be conducted during the studies conducted under this Protocol, in order to collect real time hourly traffic data during the same periods that air quality monitoring data are collected. These data include traffic volumes, speeds, and vehicle classifications. Preferably, the locations selected for these studies have appropriate traffic monitoring systems already installed. Every

effort should be made to select study locations that have good existing traffic monitoring collection systems in place, and available for the studies to be conducted under this Protocol. However, if sites without suitable traffic monitoring systems in place are selected, the contractor conducting the monitoring study(ies) must insure that appropriate traffic monitoring systems are selected and installed prior to beginning the study(ies). Consequently, the intended use of the traffic monitoring data must be considered.

Vehicle counting and classification data are used for a variety of purposes including measurement of the capacity and usage of roadways and highways as well as in the assessment of maintenance requirements. The most prevalent data currently collected include traffic volumes, vehicle speeds, and vehicle classifications. A number of options are available in selecting equipment for sampling these traffic data.

Vehicle detection equipment in use today can be characterized as either non-intrusive or intrusive. Non-intrusive equipment does not require the installation of the sensor directly onto or into the roadway surface. The sensors for non-intrusive technologies are mounted overhead or on the side of the roadway. Offsets from the mainline or edge of pavement are variable depending on the manufacturer. Non-intrusive technologies include video image processors, microwave radar detectors, active and passive infrared sensors, ultrasound sensors, and passive acoustic array sensors.

Intrusive technologies are devices that are installed directly on the pavement surface, in saw-cut or holes in the road surfaces, by tunneling under the surface, or by anchoring directly to the pavement surface. Intrusive technologies include fiber optic sensors, inductive loops, magnetometers, micro loops, pneumatic road tubes, piezoelectric cables, and other weigh-in-motion sensors.

Section 4.3 presents a summary of types of traffic monitoring equipment that may be used in the studies conducted under this Protocol.

### **3.0 STUDY LOCATION AND MONITORING SITE SELECTION**

This Protocol is designed to assess the concentrations and dispersion of PM<sub>2.5</sub> and MSAT emissions at major highway locations in the United States. To meet this objective it is important to select study locations that are representative of common highway locations and are likely to yield useful data to establish pollutant concentration variations related to highway traffic. Criteria that should be used during selection of study locations have been established for the following parameters:

- Annual average daily traffic (AADT)
- Geometric considerations
- Topography
- Geographic location
- Data availability
- Climate and meteorology
- PM<sub>2.5</sub> nonattainment status

The criteria presented in this Protocol for selection of study locations is meant to provide guidance to agencies who will be conducting the monitoring studies, and should be considered as recommendations of features or parameters that would likely yield the most useful data. Locations that do not meet these selection criteria may be included in a monitoring study if there are other overriding considerations that favor their selection.

#### **3.1 Study Location Selection Criteria**

Selection of the study locations should take into consideration the data quality indicators defined above. Of particular interest for selection of study locations is the representativeness of the location. The locations selected for each of the monitoring studies should be representative of a typical high-volume highway. Representativeness should be established in terms of the AADT of the study location, the geometric construction of the study location, topographical features of the study location, as well as climate and historical meteorological conditions of the location. Additionally, locations should be selected for which appropriate traffic monitoring systems are in operation or can be installed for the study.

##### **3.1.1 Average annual daily traffic**

Only locations with more than 150,000 AADT should initially be considered for inclusion in a monitoring study. However, if no appropriate study locations with an AADT exceeding 150,000 can be

identified, locations with smaller AADTs can be considered as potential study locations. Furthermore, study locations should be selected for which traffic count and/or fleet mix are expected to vary substantially on a time-of-day, day-of-week, or seasonal scale. This variation is the key to statistical analysis of results and influences the statistical power of the study. Historical traffic data from candidate study locations should be analyzed to assess variations in hourly, daily, and seasonal traffic patterns by vehicle type.

Locations with large temporal variations in traffic patterns of one or more vehicle types should be considered more attractive than locations with more uniform patterns assuming sampling schedules adopted for pollutant monitoring can adequately capture the expected temporal variations in pollutant concentrations. For example, Figure 3-1 shows a typical urban diurnal traffic pattern in which there are large temporal variations in the traffic patterns for cars on rural and urban roadways as well as for trucks operating during normal weekday business hours, but little variation in the traffic pattern for through trucks. Locations that show traffic patterns similar to that shown in this figure will likely be easier to interpret in terms of pollutant emissions and dispersion than locations showing less variation in traffic patterns.

Variations in the direction of traffic flow should also be taken into account. Since the monitoring stations for these studies will likely be placed only (or predominantly) on one side of the road, large variations in the direction of traffic flow may influence measured pollutant concentrations.

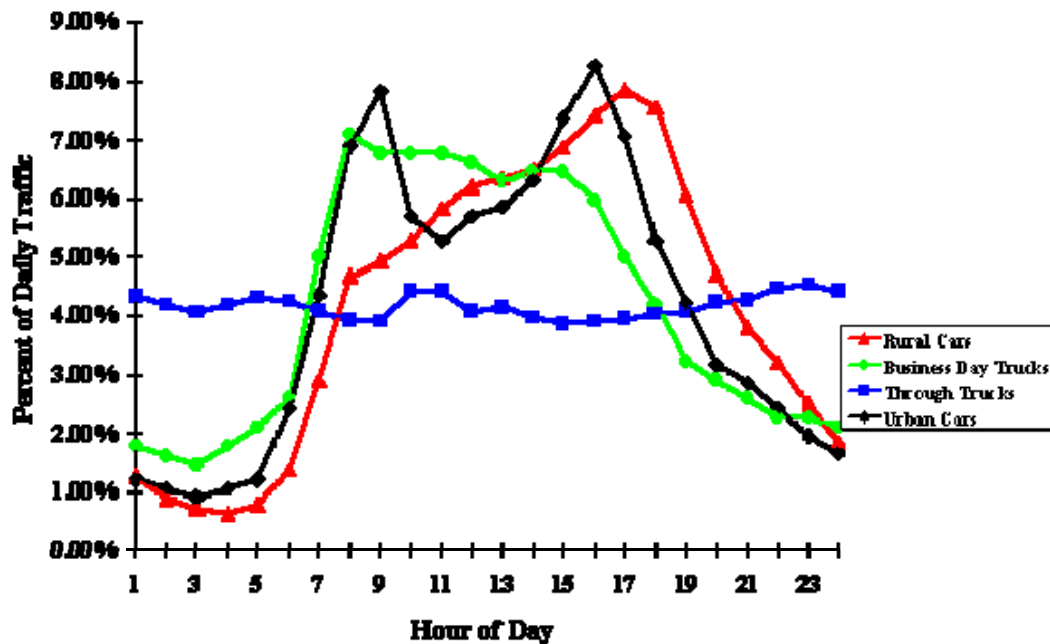


Figure 3-1. Illustration of typical urban diurnal traffic patterns.

### **3.1.2 Geometric Considerations**

The physical layout of potential study locations, including the arrangement of roadways, ramps, and interchanges should be considered during the selection process. Greater geometric complexity (i.e., a location that includes two or more roadways with AADT exceeding 150,000 and multiple ramps or interchanges) makes a study location less attractive because of difficulty in properly locating the monitoring sites within the 300 m target distance from the roadway and in interpretation of the impact of roadway emissions. However, if an appropriate location of complex geometry meets the other selection criteria in this Protocol, it should be considered for inclusion in a monitoring study.

In general, the study locations should be selected to provide relatively easy interpretation of roadway source contributions. Study locations should not be selected for which other major sources are within 1 kilometer of any of the monitoring sites. Other major sources may include but are not limited to:

- Large arterial roadways (AADT > 25,000)
- Large industrial operations
- Combustion sources (e.g., power plants, agricultural burning)

Furthermore, it is important to have appropriate candidate locations for the installation of the monitoring stations. Access to public land is likely to be advantageous for placement of semi-permanent (i.e., at least 1 year) monitoring stations. Recommendations regarding the monitoring sites are provided in Section 3.3.

### **3.1.3 Topography**

Only locations that have relatively flat terrain around the roadway should be considered for selection as a study location. Relatively flat terrain is required to ensure that the mobile source emission plume impacts the monitoring sites in an unperturbed manner. Study locations should avoid features such as steep embankments close to the roadway. The study locations ideally will be selected such that the average terrain does not exceed 5% grade over any 100 m section of land within 300 m distance from the roadway where the monitoring sites are located. If study locations do not meet this criterion, every effort should be made to ensure that topographical features do not adversely impact the dispersion of pollutants from the roadway.

### **3.1.4 Geographic Location**

Ideally, the selected study locations would be distributed across the United States, in large part to assure that representative meteorological conditions apply across the study locations. However, the voluntary nature of this effort may limit the applicability of this desired representation. Nonetheless, geographic distribution and diversity of traffic density, population, and meteorological regimes should be considered during final selection of the study locations. For example, selection of only coastal study

locations in large urban areas might not be ideal, even if those locations were in widely different parts of the country, because of similarities in coastal meteorology at all such locations. To assure diversity in geographic locations, it is recommended that if possible, at least one study location be in each of the following areas of the United States:

- West/Southwest
- Pacific or Gulf Coast
- Northeast urban corridor
- Upper Midwest (Great Lakes)
- Southeast

### **3.1.5 Data Availability**

This selection consideration refers to supporting data needed not only for selection of the study location, but for performance of the air quality field study in that location. Such data might include AADT or other traffic measures, meteorological data, PM<sub>2.5</sub> data, or MSAT concentration data from other monitoring programs. Study location selection should include considerations associated with not merely the existence or absence of such data, but the extent or quality of such data, if it exists. Thus it is recommended that for two sites equal in other ways, the site that provides greater access to current data of these types would be the preferred choice. Data resources might include:

- Nearby airports
- Nearby state or local air monitoring sites
- State Departments of Transportation

Table 3-1 provides a summary of potential data types and data sources that may be useful



**Table 3-1. Summary of Potential Sources of Available Background Data**

Data Type	Data Source and Type	Comments (availability)
Traffic		
Volume	State DOT	Counts, HPMS, historic records
Type	State DOT	Registration data, surveys
Speed	State DOT	Traffic Monitors
Meteorological		
Wind Speed	State Air Agency/Airport	Historic records
Wind Direction	State Air Agency/Airport	Historic records
Temperature	State Air Agency/Airport	Historic records
etc	State Air Agency/Airport	Historic records
Air Quality		Historic records
MSATs	State Air Agency/EPA	Historic records
Others	State Air Agency/EPA	Historic records

### **3.1.6 Climate and Meteorology**

This factor refers not only to the broad meteorological regime characteristic of each location, which is applicable to the Geographic Location criterion above, but also to local meteorology. Such local meteorological effects are often tied to local geography, e.g., nearby mountains or coastal locations. Consequently, selection of study locations must include an assessment of the large-scale geography, in addition to local-scale topography.

Historical meteorological data should be reviewed to assess the following important parameters:

- Prevailing seasonal wind direction
- Diurnal wind patterns
- Annual average rainfall

Two examples of potential study locations are shown in Appendix B. One location is along a section of U.S. 95 in Las Vegas, Nevada. The second location is in Denver, Colorado. For each candidate study location, historical traffic and meteorological data were collected and evaluated against selection criteria described above. Also, topographic and geometric information was obtained from topographical maps and from aerial photographs and used to evaluate the suitability of these sites as potential study locations.

Prior to actual site selection it may be necessary to conduct short-term meteorological measurements to ensure that study location and monitoring site selection is appropriate. NCHRP Report

479 “Short-Term Monitoring for Compliance with Air Quality Systems”<sup>4</sup> may be helpful in determining the length of a short-term measurement program.

### **3.1.7 PM<sub>2.5</sub> Nonattainment Status**

The status of the potential study locations regarding attainment of the PM<sub>2.5</sub> National Ambient Air Quality Standard (NAAQS) should be considered during the selection process. Locations that are in non-attainment for the PM<sub>2.5</sub> NAAQS should be considered as preferred locations. However, locations that are in attainment should not be excluded from consideration solely on this factor.

## **3.2 Monitoring Site Selection**

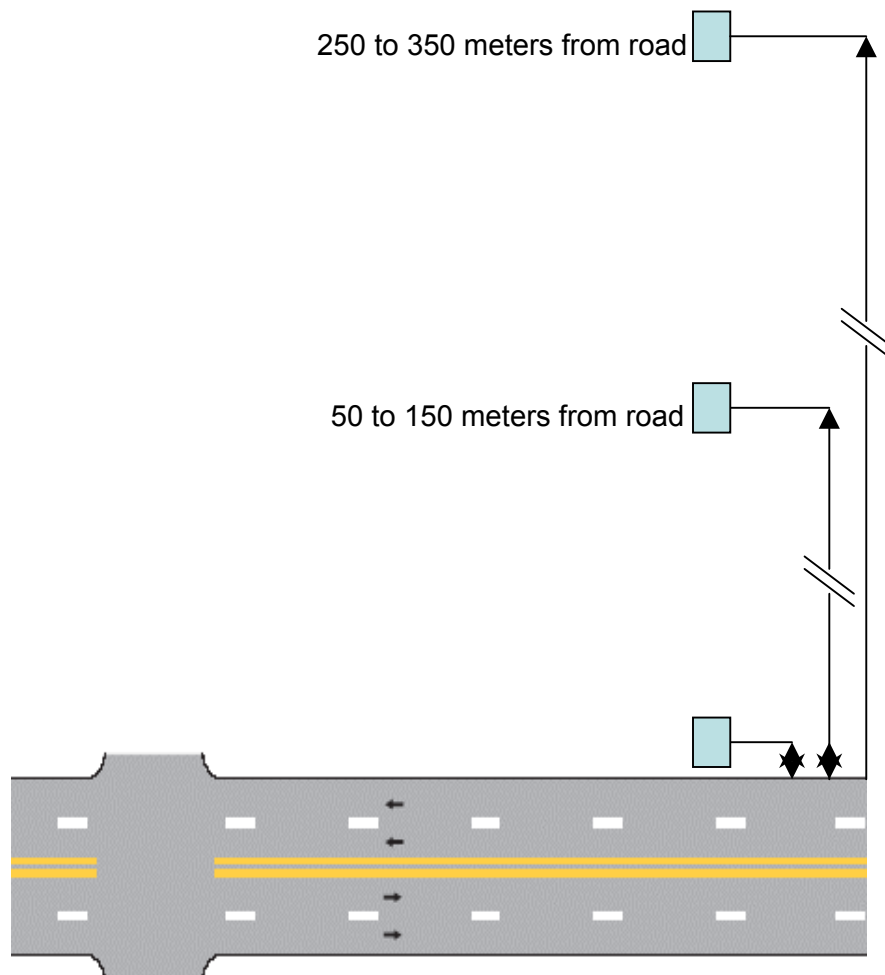
Once a study location has been selected, the siting of each monitoring station must be carefully considered. Selection of the individual monitoring sites within a study location is critical for the successful completion of a monitoring study. It should be noted that the chemical reactivity of the target MSATs and surrogate compounds is of no consequence to the study design because of the small spatial scale of the studies. That is, even with wind speeds as little as 2 mph, the transport time of the MSATs and surrogates from the roadway to the most distant monitoring site is only a few minutes. That transport time is insufficient for atmospheric processes to substantially affect the emitted chemicals.

Considerations for selection of monitoring sites include the general area-wide factors described above as well as more site-specific issues described below.

### **3.2.1 MSAT/Surrogate and Meteorological Monitoring Site Locations**

For each of the monitoring studies, a minimum of four monitoring sites should be selected at which pollutant monitoring (MSAT and surrogate) should be conducted. The monitoring sites should be selected such that one site is within 10 m of the roadway, a second site is between 50 and 150 m of the roadway, and a third site is between 250 and 350 m of the roadway. These three sites should be oriented in a line that is perpendicular to the section of roadway being studied. Figure 3-2 illustrates the recommended orientation of the monitoring sites relative to the roadway. A fourth monitoring site should be located at least 1,000 m from the roadway and from any other significant source of pollution.

Since site operators will be required to visit the sites frequently, sites should be selected that allow for limited public access but relatively easy access for the site operator. If sites with easy public access are selected for the placement of the monitoring stations, these sites may be targets for vandalism and may require the installation of security fencing to protect the monitoring stations.



**Figure 3-2. Illustration of recommended monitoring site locations.**

Exact placement of the monitoring stations should be based on considerations of a variety of site specific factors in addition to those described in Section 3.2.3. Factors that should be considered include:

- Availability of existing structures that may be used to house monitoring equipment
- Availability of electrical power and telephone service
- Obstructions which may alter air flow patterns at the site
- Ease of access
- Security of the site
- Local traffic near the site.

Continuous monitoring and integrated sample collection should be conducted at each of the monitoring sites as described in Section 4 and Section 5 of this Protocol. In addition, wind speed and wind direction should be monitored at each monitoring site. Monitoring for the complete suite of meteorological parameters should be conducted at a minimum of one of the downwind monitoring sites. To avoid localized influences from traffic, the meteorological monitoring should not be conducted at the monitoring site closest to the road, unless this monitoring is augmented by meteorological monitoring at one of the further downwind monitoring stations. It is recommended that the meteorological monitoring be conducted at the monitoring station positioned 50 to 150 m from the roadway. Table 3-2 summarizes the measurements to be taken at each monitoring site. Descriptions of the measurement techniques are presented in Section 4.

**Table 3-2. Summary of Measurements Made at Each Monitoring Site**

Monitoring Site	Measurements
0-10 m from roadway <sup>a</sup>	TO-11A Cartridge sampling TO-15 Canister sampling Continuous gas monitoring (CO, NO <sub>x</sub> ) Continuous black carbon monitoring (Aethalometer) Continuous fine particle (TEOM or BAM) Integrated PM <sub>2.5</sub> (FRM) Wind speed/wind direction
50-150 m from roadway <sup>b</sup>	TO-11A Cartridge sampling TO-15 Canister sampling Continuous gas monitoring (CO, NO <sub>x</sub> ) Continuous black carbon monitoring (Aethalometer) Continuous fine particle (TEOM or BAM) Integrated PM <sub>2.5</sub> (FRM) Wind speed/wind direction Meteorological monitoring (temp, RH, etc.)
250-350 m from roadway	TO-11A Cartridge sampling TO-15 Canister sampling Continuous gas monitoring (CO, NO <sub>x</sub> ) Continuous black carbon monitoring (Aethalometer) Continuous fine particle (TEOM or BAM) Integrated PM <sub>2.5</sub> (FRM) Wind speed/wind direction
Background	TO-11A Cartridge sampling TO-15 Canister sampling Continuous gas monitoring (CO, NO <sub>x</sub> ) Continuous black carbon monitoring (Aethalometer) Continuous fine particle (TEOM or BAM) Integrated PM <sub>2.5</sub> (FRM) Wind speed/wind direction

- a. Traffic measurements are to be made at the roadway but are not included in this table.  
b. Meteorological monitoring can be conducted at any of the three sites that are removed from the roadway.

### **3.2.1.1 Instrument Shelter Requirements Placement**

To help ensure proper performance, the analyzers and supporting equipment should be installed and operated in a temperature-controlled environment. An insulated instrument shelter should be used to protect the analyzers from precipitation and adverse weather conditions, maintain operating temperature within the analyzers' temperature range requirements, and provide security and electrical power. The environmental control of the shelter should be sufficient to minimize fluctuations in shelter temperature. The recommended shelter temperature range is 20° C to 30° C, and daily changes in temperature should not exceed 5° C over a 24-hour period. Condensation of moisture must be prevented, and it may be necessary to impose seasonal temperature ranges to assure remaining above the ambient dewpoint.

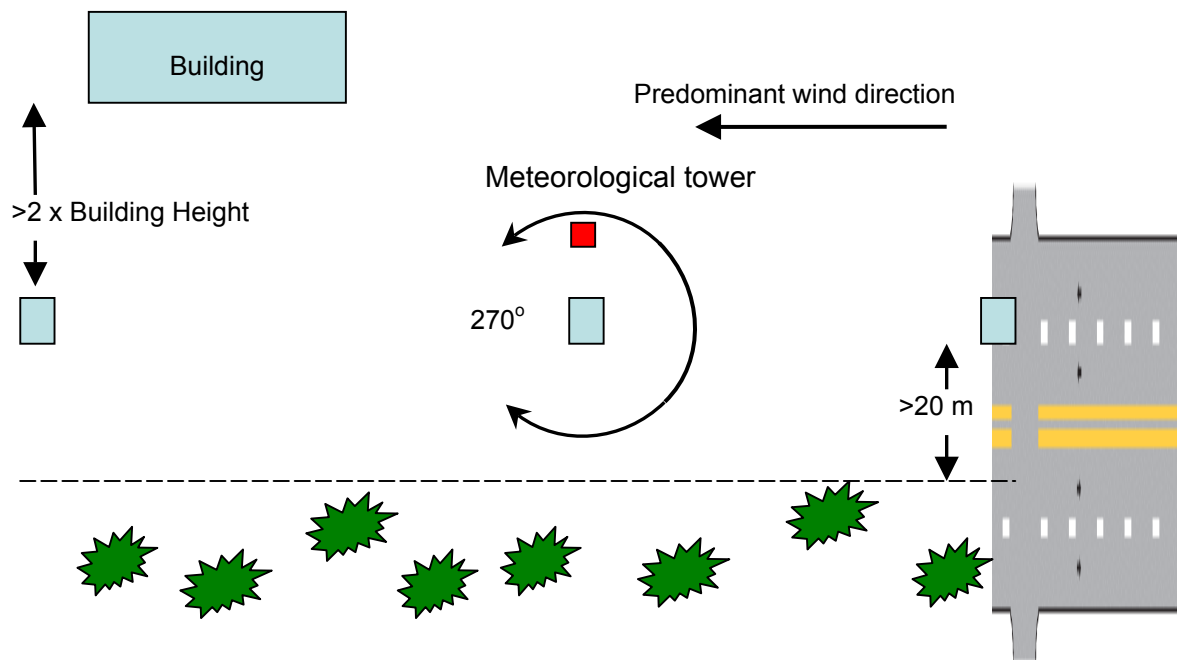
Small office trailers may be suitable for use as instrument shelters. The instrument shelters may be permanent structures, temporary shelters, or mobile facilities. Each shelter will require electrical power and may require telephone access. Security fences may be required if the monitoring stations are located in areas with unrestricted public access.

### **3.2.1.2 MSAT/Surrogate and Meteorological Monitor Siting**

Once the instrument shelters are installed, the pollutant monitors should be installed to ensure representative sampling of the ambient air. Siting of the pollutant monitors should follow the criteria in Chapter 40 of the Code of Federal Regulations (CFR), Part 58, Appendix E. The installation of the instrument shelter should allow for the sample probe inlets for the gas monitors and the continuous aerosol instruments these monitors to be  $3 \pm 1/2$  m above ground level, with at least 1 m of vertical and horizontal separation from supporting structures. The probes should be positioned with at least 270° of unrestricted airflow including the predominant wind direction that should be from the roadway to the monitoring site. The probes should be separated from the drip line of nearby trees or structures by at least 20 m and be positioned at least twice as far from nearby obstacles as the height of the obstacles. See Section 5.1.1 for a discussion of the sampling probe and other sampling requirements.

Installation of the PM<sub>2.5</sub> samplers should allow for the inlet of the samplers to be 2 to 3 m above ground level. If the sampler is located on a roof or other structure, then there should be a minimum of 2 m separation from walls, parapets, or other obstructions. The samplers should be placed at least 20 m from the dripline of nearby trees and must be 10 m from the dripline when the tree(s) acts as an obstruction. The sampler should also be located away from obstacles such as buildings, so that the distance between obstacles and the sampler is at least twice the height that the obstacle protrudes above the sampler. There should be unrestricted airflow in an arc of at least 270° around the sampler. Since the intent of these studies is to measure the pollutant concentrations at various distances from a road, there should be no significant obstruction between the road and each of the monitor stations (with the exception of the

background site), even though other spacing from obstruction criteria are met. Furthermore, the predominant wind direction based on historical data should be included in the 270° arc. Figure 3-3 shows an illustration of an acceptable installation of three monitoring stations in the vicinity of potential obstructions.



**Figure 3-3. Illustration of acceptable installation of monitoring stations near potential obstructions.**

The meteorological sensors should be installed on a meteorological tower at a position 10 m above ground level. Ideally, the meteorological tower and sensors should be located over level, open terrain at a distance of at least ten times the height of any nearby obstruction. However, for these studies this criterion may not be met, in which case the placement of the meteorological tower should ensure that the horizontal distance to obstructions (e.g., buildings, trees, etc.) is as great as is feasible. Many of the siting criteria for the monitoring stations should also be considered when selecting a location for the placement of the monitoring tower.

Figure 3-4 shows an example of a monitoring station with an instrument trailer, meteorological tower and particulate matter samplers.



**Figure 3-4. Photograph of an example monitoring station.**

### **3.2.2 Traffic Monitoring Site Locations**

It is recommended that sites that have ongoing continuous traffic monitoring programs be given primary consideration for inclusion in these studies. Unlike for meteorological and pollutant monitoring, for which monitoring systems will almost certainly need to be installed for the studies conducted under this Protocol, it is likely that many study locations have the existing traffic monitoring systems already installed. In fact, every effort should be made to select a study location with existing an traffic monitoring infrastructure. Many states have deployed Intelligent Transportation Systems (ITS) on major roadway corridors to help address congestion and improve incident management. As a consideration in the study selection process, it is recommended that a comprehensive inventory of the existing detection infrastructure at the potential study locations to be compiled and evaluated.

It is likely that in evaluating these inventories, three distinct scenarios will present themselves and can be considered during the study location process:

- Roadways with ITS equipment that provide all detection and monitoring capabilities
- Roadways with ITS equipment that provide only partial detection and monitoring capabilities
- Roadways with no ITS equipment deployed

### **3.2.2.1 Roadway with ITS equipment - all detection and monitoring capabilities**

Locations selected along a corridor that has full ITS detection and monitoring capabilities, including video detection, should become priority locations for consideration. No additional equipment would be required and minor operational costs for data collection would be incurred.

A typical freeway ITS deployment will focus on addressing roadway congestion by improving incident management capabilities of the operating and responding agencies. Systems most often include closed circuit television cameras (CCTV) for incident verification and some type of roadway detection to provide enhanced incident detection capabilities. Options that are most prevalent, and most cost effective, include inductive loop detectors or microwave/radar devices. Spacing of these devices are typically one quarter to one half mile and the data collected can be used for automated incident detection algorithms within central operating software. The spacing of the monitoring devices is sufficiently close that exact placement of the monitoring stations relative to the traffic monitors should still allow for accurate correlation between the traffic data and the pollutant data.

With this typical ITS deployment, traffic volume and speed data is likely being collected and stored at a regional operations center. However, vehicle classification data can often be a missing element. Spacing of loop detectors is often greater than required to develop this parameter and vehicle classification information based on the length of a vehicle from newer type radar/microwave detectors at a spot location is limited at best. Since vehicle classification is considered an important parameter for the studies to be conducted under this Protocol this capability should be available for each of the monitoring studies.

An ideal candidate study location would be one that utilizes video incident detection equipment as an element of the ITS deployment rather than or in addition to loops or microwave/radar devices. All of the required data – speed, volume, and vehicle classification – can be collected from this system. Data could easily be accessed from existing databases and also correlated against historical system data. CCTV recording could be achieved through the VIDs equipment or utilizing the separate CCTV coverage along the roadway.

Under this scenario, existing detection equipment would allow for the collection of all required vehicular data. Quality Assurance can be achieved through a comparison of sampling periods to historical data as well as visual verification. Operational costs would be minimal and include accessing existing databases and extracting sampling data as well as a manual review of the recorded CCTV images.



### **3.2.2.2 Roadway with ITS equipment - partial detection and monitoring capabilities**

A second scenario is a roadway that has some ITS deployment, but not in a configuration that would provide all of the required traffic data. This scenario would require an expansion of the existing detection infrastructure with one or more additional pieces of equipment to obtain all of the necessary data. Site specific issues will need to be addressed that would consider geometry, utility connections and security for example. Prioritization can be done considering implementation and operating costs at each specific location.

As described in Section 3.1.5.1, many ITS deployments are designed to provide enhanced incident management capabilities to help address congestion. CCTV coverage for incident verification is most prevalent; however, the level and sophistication of vehicle detection can vary. Options that are most common include inductive loop detectors or microwave/radar devices. Unfortunately, many deployments have single detector stations at spot locations rather than spaced for automated detection algorithms or in a configuration necessary for accurate vehicle classification sampling.

Various options can be considered to supplement the typical ITS deployment described under this scenario. In each of these options, recorded video from installed permanent CCTV should be evaluated to ensure verification of data.

One option to supplement the existing infrastructure is to deploy additional loop detectors. Vehicle classification data can be collected by spacing sampling loop detectors in a paired configuration. A second inductive loop could be installed and configured to capture vehicle classification data. Depending on the controller platform in use, vehicle classifier equipment may also need to be installed.

A second option involves the addition of radar/microwave devices. Limited vehicle classification data can be collected by adding radar/microwave devices. Several manufacturers' equipment can be easily mounted and configured on existing highway light poles or other structures and are provided as stand alone, portable battery powered units. Height and offset requirements would need to be considered in the placement of this equipment.

A third option is to use permanent count station data with existing CCTV coverage. Permanent count stations are installed along major roadways in most states to collect data for the Highway Performance Monitoring System (HPMS). Stations typically include inductive loop detectors and piezoelectric sensors which, when combined, record traffic volumes, speeds and vehicle classifications.

### **3.2.2.3 Roadway with no ITS equipment**

A third scenario is implementation on a roadway with no existing detection or ITS capabilities. Deployment of a portable, trailer-mounted unit with detection and video recording capabilities is one

approach. A second would be to add video recording capabilities to a permanent count station already collecting traffic data along the corridor if available.

Implementing temporary sampling and monitoring capabilities along with video recording capability along the facility would be a challenge. One option would be to deploy trailer mounted devices similar to a portable variable message sign configuration. Detection equipment and CCTV are mounted on the trailer unit and data and video images can be stored locally within the unit or sent to a remote site using wireless communications. Security of this unit will need to be considered.

Another option would be to utilize a location which currently has a permanent count station, but unlike Scenario 2, does not have an adjacent permanent CCTV installation. A portable video camera system would be required under this scenario for the visual verification and also provide QA/QC capabilities at this site. Site specific camera mounting and security issues would need to be considered.

## **4.0 MONITORING METHODS**

### **4.1 MSAT and Surrogate Monitoring Methods**

#### **4.1.1 USEPA Method TO-11A<sup>5</sup> for the Collection and Analysis of Aldehydes and Ketones**

TO-11A is a method used for the determination of formaldehyde and other carbonyl compounds (aldehydes and ketones) in ambient air that relies on reaction of the carbonyl compounds with 2,4-dinitrophenyl hydrazine (DNPH) to produce characteristic DNPH-carbonyl derivatives. This method uses a DNPH coated-solid adsorbent for the collection of carbonyls from an ambient air sample, followed by high performance liquid chromatographic (HPLC) analysis of the collected DNPH derivatives. The method calls for the use of commercially available pre-coated DNPH cartridges for sample collection. These cartridges are used as received and discarded after a single use. The collected and uncollected cartridges should be stored in culture tubes with polypropylene caps and placed in cold storage when not in use.

In the TO-11A method, ambient air is drawn through the DNPH cartridge at a known sampling rate of 100 to 2,000 milliliters per minute (ml/min) for an appropriate period of time. The sampling rate and time are dependent upon the expected carbonyl concentrations in the test atmosphere. After sampling, the sample cartridges and field blanks are individually capped and should be placed in shipping tubes with polypropylene caps. The capped tubes are then refrigerated to subambient temperature ( $\sim 4^{\circ}\text{C}$ ), and returned to the laboratory for analysis. In the laboratory, the cartridges are washed by gravity feed elution with 5 ml of acetonitrile from a plastic syringe reservoir to a graduated test tube or a 5 ml volumetric flask. The eluate is then diluted to a known volume and refrigerated until analysis.

For determining formaldehyde and other carbonyls, the DNPH-formaldehyde derivatives are analyzed by isocratic reverse phase HPLC with an ultraviolet (UV) absorption detector operated at 360 nm. The HPLC system is operated in the linear gradient program mode. For quantitative evaluation of formaldehyde and other carbonyl compounds, a cartridge blank is likewise desorbed and analyzed. Formaldehyde and other carbonyl compounds in the sample eluate are identified and quantified by comparison of their retention times and peak heights or peak areas with those from analysis of standard solutions. Typically,  $\text{C}_1$  to  $\text{C}_{10}$  carbonyl compounds are measured effectively to less than 0.5 parts per billion by volume (ppbv) (i.e.,  $1 \times 10^{-9}$  v/v) using this method.

#### **4.1.2 USEPA Method TO-15<sup>6</sup> for the sampling and analysis of VOCs in ambient air**

TO-15 is a standard method used for the sampling and analysis of volatile organic compounds (VOCs) in ambient air including the MSATs benzene and 1,3-butadiene. VOCs are defined here as organic compounds having a vapor pressure greater than 10 Torr. In this method, whole ambient air is sampled collected in a specially-prepared evacuated stainless steel canister. After the air sample is collected, the canister valve is closed and the canister is transported to the laboratory for analysis.

The analysis of the collected samples involves the use of a high resolution gas chromatograph coupled to a mass spectrometer (GC/MS). To analyze the sample, a known volume of sample is directed from the canister through a solid multisorbent concentrator. A portion of the water vapor in the sample breaks through the concentrator during sampling, to a degree depending on the multisorbent composition, duration of sampling, and other factors. Water content of the sample can be further reduced by dry purging the concentrator with helium while retaining target compounds. After the concentration and drying steps are completed, the VOCs are thermally desorbed, entrained in a carrier gas stream, and then focused in a small volume by trapping on a reduced temperature trap or small volume multisorbent trap. The sample is then released by thermal desorption and carried onto a gas chromatographic column for separation.

After separation, the analytes are detected in the mass spectrometer. If the mass spectrometer is a linear quadrupole system, it is operated either by continuously scanning a wide range of mass to charge ratios (SCAN mode) or by monitoring select ion monitoring mode (SIM) of compounds on the target list. If the mass spectrometer is based on a standard ion trap design, only a scanning mode is used (note however, that the Selected Ion Storage (SIS) mode for the ion trap has features of the SIM mode). For any given compound, the intensity of the primary ion fragment is compared with the system response to the primary fragment for known amounts of the compound to determine the compound concentration in the sample. The stability of benzene and 1,3-butadiene in the collected air sample is sufficient that accurate analyses can be obtained at least 14 days after sample collection.

#### **4.1.3 Carbon Monoxide**

Carbon monoxide (CO) is produced from the incomplete combustion of carbonaceous fuels. In urban areas, automobiles are a substantial source of CO, and thus CO is recommended for measurement as a surrogate for vehicle emissions. It is expected that patterns in CO concentration may correlate well with MSAT concentrations.

The standard reference method for the determination of ambient CO is non-dispersive infrared spectrophotometry (NDIR). The NDIR CO measurement principle is the absorption of infrared (IR) radiation, with a wavelength of 4.7 micrometers ( $\mu\text{m}$ ), by CO. The USEPA has designated a number of

commercial CO analyzers as Federal Reference Methods (FRM).<sup>7</sup> For each of these monitoring studies, FRM-designated CO analyzers should be used for the continuous monitoring of CO.

#### **4.1.4 Nitrogen Oxides**

Nitrogen oxides (NO and NO<sub>2</sub>, collectively called NO<sub>x</sub>) are emitted from all combustion sources, including motor vehicles. Nitrogen oxide monitoring should be carried out as a surrogate for vehicle emissions in general. Nitrogen oxides should be measured using any of several continuous chemiluminescence instruments that are commercially available and that have been designated by the USEPA as being an Automated Equivalent Method.<sup>7</sup>

The chemiluminescence approach is based on the gas-phase reaction of NO with excess ozone (O<sub>3</sub>), which produces a characteristic near-infrared luminescence (broad-band radiation from 500 to 3,000 nm, with a maximum intensity at approximately 1,100 nm) with an intensity that is proportional to the concentration of NO.

To determine the concentration of NO by chemiluminescence, the sample gas flow is mixed with O<sub>3</sub> in a reaction chamber causing electronic excitation and relaxation reactions to occur. The chemiluminescence that results from these reactions is monitored by an optically filtered high-sensitivity photomultiplier, that responds to NO<sub>2</sub> chemiluminescence emission at wavelengths longer than 600 nm. The electronic signal produced in the photomultiplier is proportional to the NO concentration in the sample air. Measurement of NO<sub>x</sub> is achieved by means of a heated converter that reduces NO<sub>2</sub> to NO for measurements. For the studies conducted under this Protocol, NO, NO<sub>2</sub>, and NO<sub>x</sub> concentrations should all be reported.

#### **4.1.5 Black Carbon**

A major component of urban aerosol is elemental carbon (EC), which is frequently called “soot”. EC is emitted from all types of combustion, including from diesel exhaust. Although EC is not a unique surrogate for motor vehicle, in the absence of other common EC sources (i.e., woodsmoke), EC can serve as an indicator of diesel emissions. Thus monitoring of EC as an indicator for diesel emissions should be conducted for studies under this Protocol. Monitoring for EC can be achieved using an Aethalometer which is a commercial instrument that provides a near real-time readout of the concentration of “black carbon” (BC) in ambient air. Black carbon is operationally defined by the Aethalometer and comprises a subset of EC, but is highly correlated to EC concentrations. The Aethalometer measures the airborne concentration of BC using a continuous filtration and optical measurement method to give a continuous readout of aerosol optical absorption. During operation, the Aethalometer draws the air sample through an inlet port, typically at a flow rate of a few liters per minute, and collects the particulate sample on a quartz fiber filter tape. As the sample collects on the tape, a continuous optical analysis is conducted to

monitor the attenuation of light through the tape. That attenuation is due almost entirely to absorption of light by BC in the collected particles. The analysis gives one new reading usually every 1 to 5 minutes based on the requirements of the user.

#### **4.1.6 PM<sub>2.5</sub> and Surrogates for PM<sub>2.5</sub>**

Fine particulate matter (referred to as PM<sub>2.5</sub>) is component of vehicle emissions and should be measured as a surrogate for vehicle exhaust. The only accepted means of measuring PM<sub>2.5</sub> is the filter based FRM<sup>8</sup> that involves the collection of a 24-hour average PM<sub>2.5</sub> sample. Monitoring for PM<sub>2.5</sub> should be conducted using FRM designated PM<sub>2.5</sub> samplers.<sup>7</sup> In addition to the PM<sub>2.5</sub> FRM measurements, continuous surrogate measurements of fine particle concentrations should also be made using commercially available instruments, e.g., either a beta attenuation monitor (BAM) or a tapered element oscillating microbalance (TEOM) monitor. Prior to implementation of either of these monitors into a monitoring study, the limitations of these techniques should be understood. Because of the nature of the measurement techniques employed in these monitors, their respective responses to aerosols will be dependent upon the aerosol properties and will not necessarily agree with one another, or with the PM<sub>2.5</sub> FRM.

#### **4.1.7 Summary**

Table 4-1 present a summary of the recommended monitoring methods for the MSATs and surrogate compounds to be measured during the studies conducted under this Protocol. Included in this table are values for some of the key data quality indicators (DQIs) that are recommended. Discussions of these DQIs are given below.

**Table 4-1. Summary of Pollutant Measurements and DQIs**

Pollutant	Sampling Approach	Accuracy	Precision	Data Completeness
Carbon monoxide (surrogate)	Continuous monitoring (NDIR FRM CO analyzer)	20%	10%	80%
Nitrogen oxides (surrogate)	Continuous monitoring (Chemiluminescence NO <sub>x</sub> analyzer)	20%	10%	80%
Black carbon (surrogate)	Continuous monitoring (Aethalometer)	5%	5%	80%
PM <sub>2.5</sub> (surrogate)	Continuous monitoring (Beta gauge or TEOM)	5%	5%	80%
PM <sub>2.5</sub> (surrogate)	Integrated filter sampling (PM <sub>2.5</sub> FRM method)	5%	5%	90%
Acetaldehyde (MSAT)	Integrated sampling/HPLC analysis (USEPA Method TO-11A)	10%	5% for flow rate 10% for HPLC	90%
Acrolein (MSAT)	Integrated sampling/HPLC analysis (USEPA Method TO-11A)	10%	5% for flow rate 10% for HPLC	90%
Benzene (MSAT)	Canister sampling-GC/MS analysis (USEPA Method TO-15)	10%	5% for flow rate 10% for GC/MS	90%
1,3-Butadiene (MSAT)	Canister sampling-GC/MS analysis (USEPA Method TO-15)	10%	5% for flow rate 10% for GC/MS	90%
Formaldehyde (MSAT)	Integrated sampling/HPLC analysis (USEPA Method TO-11A)	10%	5% for flow rate 10% for HPLC	90%

#### 4.1.7.1 Accuracy

Accuracy is defined as the agreement between a measured value and the true value for a given parameter. Accuracy includes components of random error associated with variability from imprecision and systematic error associated with instrumental bias. Accuracy should be determined for the MSAT and surrogate monitoring systems and for the meteorological sensors. For the continuous gas analyzers (CO and NO<sub>x</sub>) accuracy should be assessed by challenging each analyzer with audit gases of known and certified concentration using a flow dilution system checked against a National Institute of Standards and Technology (NIST) traceable flow standard. Accuracy should be expressed in terms of a percent difference between the measured concentration and the known concentration of the audit gas. Particulate matter standards do not exist, therefore, accuracy for the continuous aerosol monitors and the integrated PM<sub>2.5</sub> samplers should be established based on flow rate audit measurements, as is customary for these methods. For the meteorological sensors, accuracy should be assessed by comparisons to collocated transfer standards.

Accuracy of the MSAT integrated methods (canister sampling/GC/MS analysis and DNPH cartridges/HPLC analysis) is assessed in two ways, i.e., by sampling flow checks and by laboratory calibrations. The air sampling flow rates of the MSAT sampling methods should be audited in the field, using NIST-traceable flow standards. The GC/MS and HPLC analytical methods are calibrated using

commercially prepared gas standards, and using liquid phase standards of the carbonyl compounds, respectively. Accuracy thus depends on the quality of these primary standards, and the variability of the method calibration results. Accuracy of these laboratory calibrations should be assessed by comparison of independent standards in the laboratory.

Values for the accuracy DQIs should be established for each study prior to initiation of the monitoring. Recommended values for accuracy DQIs for the pollutant measurements are  $\pm 20\%$  for the continuous gas analyzers;  $\pm 5\%$  in flow rate for the continuous aerosol monitors, the  $PM_{2.5}$  samplers, and the MSAT samplers; and  $\pm 10\%$  for the MSAT laboratory analytical methods. For the meteorological sensors, the recommended accuracy DQIs are set equal to those recommended by the U.S Environmental Protection Agency (USEPA).<sup>8</sup>

#### **4.1.7.2 Precision**

Precision is an assessment of the mutual agreement among multiple independent measurements under similar conditions. For the continuous gas analyzers, precision should be assessed by challenging each analyzer with a standard gas of constant known concentration at least once every 2 weeks during the monitoring period. Since generation and delivery of constant known concentrations of aerosols is impractical for these studies, precision does not need to be assessed directly for the continuous aerosol monitors or the  $PM_{2.5}$  samplers. However, at least one of the monitoring sites should be equipped with duplicate monitoring systems for some part of the study if feasible. If duplicate monitors are used at one site, precision can be established by comparison of simultaneous measurements from the duplicate monitors. An additional estimate of precision for the aerosol monitors,  $PM_{2.5}$  samplers, and MSAT samplers can be based on the variation of the flow audits conducted periodically for these devices. Precision does not need to be assessed for the meteorological sensors since repeated measurements under stable conditions will not be practical during these studies.

In addition to assessing the precision of the sample flow rates for the MSAT samplers, the precision of the laboratory analytical methods for the MSATs should be assessed. This can be done both in terms of the variability in the calibration curves obtained with the respective gaseous or liquid phase standards over the duration of the study, and the variability of repeated analyses of the same standard or sample. The former provides an estimate of the long-term precision of the analysis, and the latter provides a measure of precision in individual sample analysis.



The recommended precision tolerance for the continuous surrogate (CO and NO<sub>x</sub>) monitors is  $\pm 10\%$  as relative standard deviation (RSD), calculated from the periodic challenges with calibration gas during the study. The recommended precision for flow checks on the continuous aerosol monitors, the PM<sub>2.5</sub> samplers, and the MSAT samplers is  $\pm 5\%$ , with a recommended tolerance of duplicate PM<sub>2.5</sub> mass results from paired samplers of  $\pm 10\%$ . The precision of the GC/MS and HPLC analytical methods for volatile organics and carbonyl compounds, respectively, is recommended to be within 10% as RSD.

#### **4.1.7.3 Data Completeness**

Data completeness is a measure of the amount data actually collected compared with the amount of data that could be collected for a given measurement. For the continuous monitoring systems (i.e., gas analyzers, continuous aerosol analyzers, meteorological sensors), data completeness will be determined from the number of valid hourly measurements that were made divided by the total number of hourly periods during the monitoring study. This ratio multiplied by 100 provides data completeness in terms of percentage. For the MSAT and PM<sub>2.5</sub> samplers, data completeness will be determined from the number of valid samples collected, divided by the number of sampling periods, multiplied by 100.

Recommended minimum values for data completeness DQIs are 80% for the continuous measurements and 90% for the MSAT and meteorological measurements.

#### **4.1.7.4 Representativeness**

Data collected from these studies should be representative of the actual conditions during the monitoring study. Representativeness is ensured through proper site selection, sample collection and handling, and sample analysis. Chapter 40 of the CFR, Part 58, Appendix E provides guidance on instrument siting to help ensure representativeness of the measurements.

No quantitative values are recommended for representativeness of DQIs.

## **4.2 Meteorological Monitoring**

Meteorological monitoring should include the measurement of wind speed, wind direction, ambient temperature, barometric pressure, relative humidity, solar radiation, and precipitation. The meteorological sensor used for each monitoring study should meet the specifications recommended by the USEPA in "Meteorological Monitoring Guidance for Regulatory Modeling Applications."<sup>8</sup> Table 4-2 presents the recommended specifications for the meteorological sensors that should be used for these studies. The use of averaging times of 10 seconds or less is recommended.

**Table 4-2. Recommended Specifications for Meteorological Sensors**

Variable	Range	Accuracy	Resolution	Time/Distance Constants
Wind Speed	0.5 to 50 m/s	±0.2 m/s + 5%	0.1 m/s	5 m (63% response)
Wind Direction	0 to 360°	±5°	1°	5 m (50% recovery)
Air Temperature	-20 to 40°C	±0.5° C	0.1°C	60 seconds (63% response)
Dew Point	-30 to 30°C	±1.5°C	0.1°C	30 min
Relative Humidity	0 to 100% RH	±3% RH	±5% RH @ >90% RH	0.5% RH 60 seconds (63% response)
Solar Radiation	0 to 1200 W/m <sup>2</sup>	±5%	10 W/m <sup>2</sup>	60 seconds (99% response)
Barometric Pressure	800 to 1100 hPa	±3 hPa	0.5 hPa	60 seconds (63% response)
Precipitation	0 to 30 mm/hour	±10%	0.25 mm	60 seconds (63% response)

### 4.3 Traffic Detection/Monitoring Equipment

The following sections present brief summaries of the current traffic counting and vehicle classification technologies that might be used for studies conducted under this Protocol. Since traffic monitoring is likely to be an on-going effort at the study locations selected, the discussion below is largely for informative purposes only. However in the event that traffic monitoring is not already conducted at a study location and that a contractor conducting a study under this Protocol must implement the traffic monitoring, a summary table is presented in Section 4.3.3 presenting capabilities and the advantages and disadvantages of the different traffic monitoring systems. Table 4-3 presents recommended values for some key DQIs for traffic monitoring systems.

**Table 4-3. Recommended DQI Values for Traffic Monitoring Equipment**

Variable	Accuracy	Data Completeness
Vehicle Count	80%	90%
Vehicle Speed	80%	90%
Vehicle Classification	70%	80%

### **4.3.1 Intrusive Options**

#### **4.3.1.1 Inductive Loop Detector (ILD)**

The most prevalent type of vehicle detector currently in use is the inductive loop detector (ILD). The ILD has a long history of use at individual signalized intersections as well as multiple signal systems. It has also been widely used in freeway monitoring systems and as a key component in automated incident detection.

An ILD consists of the following components:

- One or more turns of insulated wire wound in a shallow slot sawed in the pavement
- A lead-in cable from the curbside pullbox to the intersection controller cabinet
- A detector electronics unit housed in a controller cabinet

As a vehicle passes over an ILD, the electrical inductance is decreased and an electronic amplifier detects this change. This change is processed and used to measure volume and occupancy. Loops are installed as a single installation, in the case of a minor roadway approach to an intersection, or in multiple loop configurations. Loops placed in pairs are used to determine vehicle speed as well as vehicle classification information.

#### **4.3.1.2 Fiber Optic Sensors**

Fiber optic sensors consist of fiber optic cables installed in the pavement that measure variations in light due to compression from an overhead source (i.e. vehicle axles, foot traffic, etc.) When a vertical load is applied to the sensor, a small amount of light escapes from the sensor fiber causing the light level at the sensor output to decrease. The amount of the light is compared to a factory set reference by the optical interface for producing an output signal. Fiber optic sensors are insensitive to adjacent lane vibrations. Control electronics can be located long distances away from the sensors due to the low loss of the optical fiber.

#### **4.3.1.3 Magnetic Sensors**

Detection using magnetic sensors is achieved by placing the device directly within the pavement or within a buried conduit and measuring the change in the vertical component of the earth's magnetic field. When a vehicle passes over the magnetometer, a voltage change is detected and causes a closure of an output relay. This change is used as a vehicle count or passage measurement.

#### **4.3.1.4 Piezoelectric/Weigh-in-Motion**

Piezoelectric sensors are axle sensors installed within the roadway surface to register changes in piezoelectric energy when a vehicle passes over the sensor. These detectors register the overall change in energy from the passing vehicle and translate that into a corresponding weight. They are widely used in weigh-in-motion applications.

#### **4.3.1.5 Pneumatic Road Tube**

Pneumatic road tubes are simply tubes installed across one or more lanes of a roadway with brackets. These tubes are connected to a control box off of the roadway. When vertical loads are applied to these tubes (i.e. through vehicular axles), bursts of air are forced through the tube to the control box and are registered as an axle. This method is very simple and effective in counting vehicles and can be used in pairs to register vehicle speeds (with the assumption of standard vehicle lengths between axles). It is not effective for detecting vehicle presence or classification.

### **4.3.2 Non-Intrusive Options**

#### **4.3.2.1 Radar/Microwave Detectors**

Radar and microwave type detectors are similar in that both transmit microwave energy toward an area of roadway from a detector mounted overhead. In the case of radar, a measurement of energy reflected back from the roadway is used to determine vehicle speed based on the Doppler effect. The microwave detector measures the time it takes to transmit a pulse from the detector to the roadway and back. The presence of a vehicle is detected by the difference in time of this pulse reflection with and without a vehicle in the roadway.

#### **4.3.2.2 Infrared Detectors**

Infrared detectors are classified as active or passive. In the active system, the detection zone is illuminated with low power infrared energy supplied by light emitting diodes. The infrared energy reflected off vehicles within the detection zones is used by real time signal processing within the unit to determine presence of a vehicle. The passive system is a similar design but uses an energy detector element to measure passage or motion change only. This detection technology can give traffic volume, vehicle classification, and speed.

#### **4.3.2.3 Passive Acoustic Array Sensors**

Passive acoustic array sensors are acoustical sensors that can detect changes in background noise from a passing vehicle. The sensors are mounted non-intrusively on an existing overhead bridge or

adjacent pole. Based on the vehicle characteristics, the acoustical changes can be detected, counted and classified.

#### **4.3.2.4 Video Detection**

Video Image Detection (VIDs) is one of the newer forms of roadway detection that has been developed over the last decade. VIDs utilize closed circuit television cameras with microprocessor hardware and software to analyze images of the roadway. Real time data within a defined zone can be collected including volume, speed, occupancy, and vehicle classification. VIDs have become a proven technology option. However, installation and operational costs are comparatively higher than other type detection devices and need to be carefully evaluated for individual applications.

#### **4.3.2.5 Automated Vehicle Identification (AVI)**

With the proliferation of electronic toll collection throughout the nation, automatic vehicle identification has become increasingly attainable on a wide scale. Automatic vehicle identification systems utilize radio frequency identification (RFID) tags mounted inside a vehicle to collect traffic data from a reader or series of readers along the roadway. These readers could be the same readers used for electronic toll collection (ETC) or could be additional readers mounted off the roadway between toll plazas. Vehicle information such as classification is stored within the tags and uploaded to the readers when the vehicle passes within range. When readers are utilized in pairs, vehicle speeds can also be easily computed.

#### **4.3.3 Summary**

Table 4-4 presents a summary of currently available traffic detectors and their capabilities. Each detector type discussed above is listed along with associated advantages and disadvantages. The traffic data that are collected for the studies conducted under this Protocol should be logged at least hourly for easy synchronization with the pollutant and meteorological data collection and at a minimum must be collected during all MSAT integrated sampling periods. Continuous data collection for the duration of each monitoring study is recommended, to allow for correlation with the continuous surrogate data.

Some ongoing debate exists within the industry that revolves around the accuracy and appropriateness of vehicle classification data from many detectors. Several newer models of radar/microwave type devices use measured vehicle length as a surrogate for vehicle classification. The accuracy of the data is assumed to be at a level that would require visual verification. These factors should be considered when determining which technologies should be used for the studies conducted under this Protocol.

**Table 4-4. Summary of Traffic Monitoring Detectors and Capabilities**

Detector	Installation	Volume	Speed	Class	Advantages	Disadvantages
<b>Intrusive</b>						
Inductive Loops	In Pavement	√	√ (1)		Easy to install. Relatively inexpensive.	In-pavement installation requires saw cutting and lane closures.
Fiber Optic Sensors	In Pavement	√	√ (1)		Easy to install. Relatively inexpensive.	In-pavement installation requires saw cutting or boring for conduit.
Magnetic Sensors	In Pavement	√	√ (1)		Easy to install. Relatively inexpensive.	Poorly defined detection zone susceptible to errors.
Piezoelectric/Weigh in Motion	In Pavement	√	√ (1)		Easy to install. Relatively inexpensive.	In-pavement installation requires saw cutting or boring for conduit.
Pneumatic Road Tube	In Pavement	√	√ (1)		Easy to install. Relatively inexpensive.	Susceptible to breakage/removal with large volumes of traffic.
<b>Non-Intrusive</b>						
Radar/Microwave	Overhead/Adjacent	√	√	√ (2)	Non-invasive installation. Quick implementation.	Setback and line of sight requirements.
Infrared	Overhead	√	√ (1)		Non-invasive installation.	Accuracy can be susceptible to environmental conditions.
Passive Acoustic Array	Overhead	√			Non-invasive installation.	Accuracy can be susceptible to adjacent noise sources.
Video	Overhead/Adjacent	√	√	√	Can measure all parameters.	Relatively expensive. Maintenance of detection zone alignment required.
AVI	Overhead/Adjacent	√	√ (3)	√ (3)	Utilizes existing ETC infrastructure for traffic data collection.	Relatively expensive. Vehicles to be detected require a tag to be installed.

√ (1) - When used in pairs.

√ (2) - Limited.

√ (3) - With additional equipment at ETC locations.

Also, identification of diesel vehicle percentages cannot be obtained from typical vehicle classification data collection methodologies. In the absence of diesel classification capabilities, diesel vehicle percentages may be obtained from the USEPA's MOBILE emission factor model or from state agencies which typically maintain the diesel vehicle percentages based on vehicle registration data. If appropriate local data are not available, the default MOBILE data, which is based upon national data, can be used as estimations for diesel classification.

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## **5.0 MONITORING AND ANALYSIS PROCEDURES**

For each monitoring study conducted under this Protocol, both integrated sampling and continuous monitoring will be conducted. This section describes the methods to be used for the collection of integrated samples and for the collection of continuous monitoring data. Additionally, it describes the recommended sampling schedule that has been developed for the collection of the integrated samples, and the methods that should be used for the analysis of the collected samples.

### **5.1 Integrated Sampling**

The collection of integrated samples for these studies should be conducted according to the established USEPA methods described below. It is anticipated that the agencies conducting these studies are familiar with these methods, so only brief discussions of the methods and procedures are presented here. Complete descriptions of the procedures and the requirements of the methods are provided in the references cited.

#### **5.1.1 Method TO-11A and Method TO-15**

Integrated sampling should be conducted during each monitoring study to characterize MSAT concentrations, using the procedures described in Methods TO-11A<sup>5</sup> and TO-15.<sup>6</sup> Additional guidance and recommendations on the implantation of these methods can be found in the USEPA's Technical Assistance Document for the National Ambient Air Toxics Trends and Assessment Program.<sup>9</sup>

The sampling inlet and manifold recommendations for Method TO-11A and Method TO-15 are similar to those for the gas analyzers described above. If sufficient ports are available on the gas analyzer manifold for the recommended number of canisters and DNPH tubes, the use of the gas analyzer manifold is acceptable. If not, a similar inlet and manifold should be installed for the collection of the TO-11A and TO-15 samples.

For Method TO-11A, samples should be collected using commercially available sample cartridges, which consist of a plastic housing containing silica gel solid sorbent coated with DNPH. Since ozone has been identified as an interferent in the measurement of carbonyl compounds, it is important to remove the ambient ozone from the sample air stream prior to exposure to the sample cartridge. For these studies, a temperature controlled ozone scrubber as described in USEPA's Technical Assistance Document for the National Ambient Air Toxics Trends and Assessment Program<sup>9</sup> should be used to remove ambient ozone. The sample is collected on the sample cartridge by drawing air through the cartridge at a controlled flow rate using an oil-free vacuum pump. The flow rate through the cartridge should be controlled using a mass flow controller (MFC) or an adjustable orifice with a mass flow meter. An electronic timer in conjunction with an electric-pulse-operated solenoid valve should be used to allow

unattended sample collection. An elapsed time indicator should be used to measure the actual duration of the sampling. All fittings and tubing that contacts the sample stream should be either stainless steel or Teflon.

For Method TO-15, sample should be collected in passivated stainless steel sample canisters with a bellows valve attached at the inlet of each unit and an appropriate vacuum gauge used to measure the initial and final pressure in the canisters. An adjustable electronic MFC is recommended to maintain a constant sampling rate during the sample collection, or a critical orifice can be used if a MFC is not available. A sintered stainless steel in-line filter should be used to remove particulate material from the sample air being collected. An electronic timer in conjunction with an electric-pulse-operated solenoid valve should be used to allow unattended sample collection. An elapsed time indicator should be used to measure the actual duration of the sampling. Stainless steel tubing and fittings should be used in the sampling lines and transfer lines to avoid sample contamination.

### **5.1.2 PM<sub>2.5</sub> Filter Sample Collection**

PM<sub>2.5</sub> samples should be collected following the sampler manufacturer's recommended procedures and in adherence with the Reference Method for the Determination of Fine Particulate Matter as PM<sub>2.5</sub> in the Atmosphere.<sup>9</sup> Briefly, the PM<sub>2.5</sub> reference method calls for the collection of ambient air on a pre-weighed 47 mm Teflon filter. The sample is collected at a flow rate of 16.7 l/min for a period of 24 hours. Sampling is conducted from midnight to midnight and for these studies the sampling schedule should be established to coincide with the monitoring schedules used by state or local air monitoring agencies.

Appropriate sample handling procedures must be in place to provide safeguards against contamination of the samples or loss of sample material during handling and post-sampling shipment. The filters should be pre-numbered with unique identification numbers and must meet the requirements of the Reference Method. Disposable, powder-free gloves should be worn while handling filters both in the laboratory and in the field. Inspection of the individual filters should be conducted prior to use to ensure integrity of the filters.

## **5.2 Continuous Monitoring**

Continuous monitoring of surrogate species (CO, NO<sub>x</sub>, BC, PM<sub>2.5</sub>), meteorological conditions and traffic parameters should be conducted for the entire duration of each monitoring study. That duration is recommended to be one full year, to ensure coverage of all meteorological conditions and seasonal traffic effects in the study location. At a minimum, data from all of the continuous monitoring systems should be recorded on an hourly average basis.

## **5.2.1 Continuous Surrogate Monitoring**

### **5.2.1.1 Gas Monitoring**

At each monitoring station, ambient air for the CO and NO<sub>x</sub> analyzers should be drawn through a glass manifold using a high volume blower and supplied to the continuous analyzers by allowing each analyzer to individually sample the air from the manifold using separate sampling ports. Figure 5-1 shows an example sampling manifold that is used in routine monitoring and may be used for gas sampling in these studies. A “candy cane” inlet or inverted funnel should be used on the inlet of the sampling line to prevent water or debris from being introduced into the line. The face of the sampling inlet should be at least 3 feet from the top of the instrument shelter roof. The sample should be drawn through the sample inlet and into the manifold. If necessary the air should be drawn through the sampling system using a small blower which should be installed at the exit of the sampling manifold. Separate sampling lines should be used for the individual analyzers and Teflon couplers should be used on the sampling ports to ensure that the sampling lines draw air from inside the manifold and not from the shelter air. A tee fitting should be used to connect each analyzer inlet line to the sampling manifold and a glass moisture trap should be used to collect liquid water and other foreign objects that may have entered the inlet. This trap should be routinely checked and emptied as necessary. Exhaust from the analyzers and the blower should be vented to the outdoor air and not influence the sample inlet.

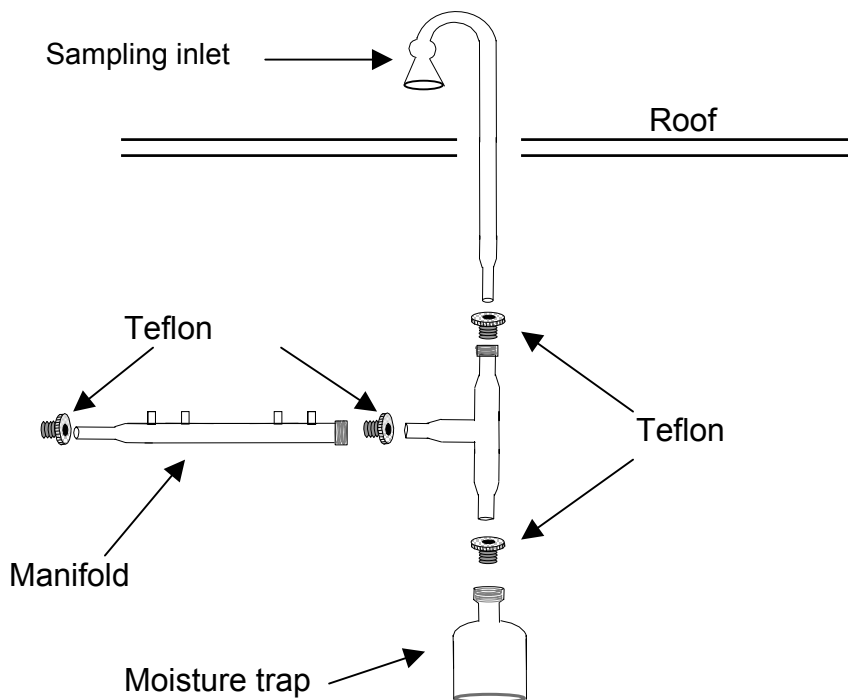


Figure 5-1. Example sampling manifold.

In designing and installing a sampling manifold, the residence time of the pollutants in the sampling lines should be considered. Although 20-second residence time is the maximum allowed as specified in 40 CFR 58, Appendix E, it is recommended that the residence time within the sampling system be less than 10 seconds. If the volume of the sampling system does not allow this to occur, then a blower motor or other device (such as a vacuum pump) can be used to increase flow rate and decrease the residence time. The residence time for a sample manifold system is determined in the following way. First the total volume of the cane (inlet), manifold, and sample lines must be determined using the following equation:

$$Volume = C_v + M_v + L_v \quad \text{Eq. 5-1}$$

where:

$C_v$  = Volume of the sample cane or inlet and extensions

$M_v$  = Volume of the sample manifold and moisture trap

$L_v$  = Volume of the instrument lines from the manifold to the instrument bulkhead

The volume of each component of the sampling system must be measured individually. To measure the volume of the components (assuming they are cylindrical in shape), use the following equation:

$$V = \pi * (d / 2)^2 * L \quad \text{Eq. 5-2}$$

where:

$V$  = volume of the component,  $\text{cm}^3$

$\pi$  = 3.14

$L$  = Length of the component, cm

$d$  = inside diameter of the component, cm

Once the total volume is determined, divide the total volume by the total sample flow rate of all instruments to calculate the residence time in the inlet. If the residence time is greater than 20 seconds, attach a blower or vacuum pump to increase the flow rate and decrease the residence time.

The gas analyzers should be installed in the instrument shelter with short sampling lines connecting each analyzer to separate ports on the manifold. The gas analyzers should be operated based on the manufacturer's recommended procedures and in the configuration in which they were granted Reference Method designation.

With continuous use, the sample inlet and manifold can accumulate deposits of particulate material and other potential contaminants. At least quarterly, the sample inlet and manifold should be cleaned to remove any foreign materials that may have accumulated. The sampling system should be disassembled and the individual components should be cleaned using distilled water (i.e., only high purity distilled water, no organic solvents or soaps) and a long-handled bottle brush. The components should then be rinsed with the distilled water and allowed to dry completely before reassembling.

#### **5.2.1.2 Continuous Black Carbon Monitoring**

For these monitoring studies, it is recommended that an Aethelometer be used to measure BC as an indicator for DPM. Since ambient BC particles are typically small (i.e., generally  $<0.3 \mu\text{m}$  diameter), the sampling requirements are less stringent than those for the BAM or TEOM. Nonetheless the sampling system used should be designed to minimize particle loss during sampling. The manufacturer recommends that  $\frac{1}{4}$ " ID black tubing (i.e., carbon impregnated Teflon) be used for sampling. If possible, the sampling line should run vertically to at least 1 m above the roof of the shelter. The sampling line should include an  $180^\circ$  turn over at the top with a radius of at least 10 cm. The inlet should be protected to avoid rain or insects from entering the sampling line. An inverted funnel with screen mesh covering

the face of the funnel can be used on the inlet of the sampling line and should provide sufficient protection from rain and insects.

Once installed, a data disk should be installed, and the Aethalometer can be powered on to start data collection. The flow rate should be verified (5 l/min) to ensure proper operation and the sampling time base for the Aethalometer should be set to 5 minutes. The data disk should be replaced at least monthly.

### **5.2.1.3 Continuous PM<sub>2.5</sub> Monitoring**

For these monitoring studies, it is recommended that either a BAM or a TEOM be used as a surrogate for PM<sub>2.5</sub>. For the installation of either a BAM or TEOM, it is recommended that a straight line-of-sight be available from the inlet on the BAM or TEOM vertically through the roof of the instrument shelter. The BAM or TEOM should be placed on a flat surface beneath the opening in the roof, and a sampling line should be installed based on the manufacturer's recommendations. Typically, sampling kits are available from the vendors to assist in the proper installation of these monitors. A PM<sub>2.5</sub> cyclone should be installed on the end of the sampling line to provide appropriate size selectivity.

After installation the BAMs or TEOMs should be configured to operate according to the manufacturer's recommendations and should be set to record data at least hourly. The sampling flow rates should be verified and other manufacturer's recommended diagnostics should be checked to ensure proper operation.

### **5.2.2 Continuous Meteorological Monitoring**

For these monitoring studies, meteorological monitoring should be conducted at one of the monitoring sites located away from the roadway (i.e., between 50 and 150 m, or between 250 and 350 m). The meteorological sensors should be mounted on a meteorological tower which has been installed according to the siting recommendations described in Section 3.2.3. The placement of the meteorological tower should allow for a representative measurement of the ambient conditions at the monitoring site. Furthermore, it is recommended that wind speed and wind direction be measured at each of the monitoring sites.

After installation, the data from the sensors should be captured using a suitable data logger and recorded on at least an hourly basis.

### **5.2.3 Continuous Traffic Monitoring**

Continuous traffic monitoring must be conducted for each of the monitoring studies completed under this Protocol. It is highly recommended that the monitoring study location be selected in an area where continuous traffic monitoring is already conducted by a State Department of Transportation or

other similar agency. If such a location is selected, the hourly traffic data should be provided by the collecting agency to the contractor conducting the monitoring study along with any supporting quality assurance documentation.

If a study location is selected where traffic monitoring is not already conducted, the contractor conducting the study should coordinate with the State Department of Transportation or similar agency to arrange for traffic monitoring equipment to be installed and operated. Traffic monitoring should be conducted as closely to the study location as feasible, and should include the collection of hourly traffic count, vehicle speed, and vehicle classification data if feasible. Upon installation of traffic monitoring equipment, a visual check should be conducted to insure proper operation of the equipment.

### **5.3 Recommended Integrated Sampling Schedule**

As described in Section 2 of this Protocol, the sampling schedule for the TO-11A and TO-15 methods should include 1-in-12 day sampling, with nine (9) 1-hour samples collected during each 24-hour sampling period. The 1-in-12 day sampling schedule should be established to coincide with the schedules followed by state and local air quality agencies in conducting sampling in the USEPA's monitoring networks. Sample collection should be performed such that two of the 1-hour samples are collected during the 3-hour period centered on the morning traffic peak. One of these samples should always be collected on the middle hour of this period representing the peak in the morning traffic. The other of these two samples should be collected alternately either during the hour preceding the peak hour or the hour immediately after the peak hour. The other seven samples should be collected in an equally spaced basis covering the other 21 hours of the sampling day. The schedule for these seven samples should rotate by one-hour for each sampling day such that after three sampling days, all 24 hours of the day have been sampled at least once.

Prior to implementation of a sampling schedule for a given monitoring study, at least one year of historical traffic data should be used to determine the actual peak in the morning traffic pattern for the study location. The MSAT sampling schedule should then be designed around the actual peak traffic data. An example of a potential sampling schedule assuming that the peak hour in the morning traffic occurs between 7:00 and 8:00 a.m. is presented in Section 2.1 of this Protocol.

### **5.4 Sample Analysis**

Analysis of the integrated samples collected during these studies should be analyzed according to established USEPA methods. It is anticipated that the agencies conducting these studies are familiar with these methods, and have in-house laboratories capable of meeting the requirements of these methods, or have contract laboratories that are capable of meeting the requirements of these methods, so only brief

discussions of the methods and procedures are presented here. Complete descriptions of the procedures and the requirements of the methods are provided in the references cited.

#### **5.4.1 Analysis by USEPA Method TO-11A**

After sample collection the DNPH cartridges should be sealed in foil pouches and sent to an established analytical laboratory for extraction and analysis. The cartridges should be extracted and analyzed according to the procedures described in Method TO-11A. Additional guidance and recommended practices are presented in the USEPA's Technical Assistance Document for the National Ambient Air Toxics Trends and Assessment Program.<sup>10</sup>

Upon receipt of the samples, the samples should be placed in a sealable bag with a COC and stored in a refrigerator at  $<4^{\circ}\text{C}$  until extraction. Extraction should occur within 2 weeks of the sampling episode. To extract the samples, the cartridges should be removed from the refrigerator and connected to a clean, solid phase extraction manifold. Using a glass or disposable polypropylene syringe attached to the cartridge, 5 ml of acetonitrile (ACN) should be back flushed from the syringe through the cartridge and into a 5-ml volumetric flask. The flask should then be diluted with ACN to the 5-ml mark and transferred to vials for analysis. Samples may be stored under refrigeration ( $4^{\circ}\text{C}$ ) for up to 30 days, but must be analyzed within 30 days of extraction.

Prior to analysis the HPLC should be calibrated, and method detection limits should be established. When the calibration and method detection limits (MDLs) meet acceptance criteria, the sample vials should be placed into a carousel and loaded onto the instrument. An injection size of sample extract geared to the manufacturer's specifications for the analytical instrument should be performed with an automatic sample injector. A mobile phase gradient of water, ACN and methanol should be used to perform the analytical separation at a flow rate of 1.0 ml/min. Each sequence loaded onto the instrument should start with an ACN instrument blank followed by a QC standard, another ACN instrument blank, the method blanks for each lot of samples to be analyzed followed by the samples. A QC standard should be analyzed every 12 hours to ensure that the instrument is within calibration and the retention times for the compounds have not shifted. The sequence should be completed with a third ACN instrument blank, a final QC standard, and a final ACN instrument blank. For the ACN to meet acceptance criteria, the compound concentrations must be less than or equal to 5 times the method detection limits.

#### **5.4.2 Analysis by USEPA Method TO-15**

After sample collection the sample canisters should be sent to an established analytical laboratory for analysis. Prior to sample analysis, a system check should be performed on the GC/MS system to ensure proper operation of the instrumentation. After the daily system performance check, calibration



laboratory control standard, and daily system blank criteria have met acceptance criteria, the collected samples can be analyzed.

To analyze the samples, the sample canisters are connected to the inlet ports autosampler and the canister valves are opened. A specified volume of a single sample out of a canister along with the specified volume of the bromofluorobenzene (BFB)/internal standard (IS) mixture should be collected and cryogenically trapped using the autosampler preconcentrator while the GC oven is cooled to  $-50^{\circ}\text{C}$ . The trapped sample should then be thermally desorbed onto the head of the GC column, at which point the GC should begin the temperature program.

The ISs for each analysis completed in the 24-hour GC/MS analysis period should be compared to those in the most recent calibration. The responses of each IS in the sample should be within  $\pm 40\%$  of the mean area response of those of the ISs in the multipoint calibration and the retention time of each IS should be within 0.06 min of the retention time of those in the calibration or the samples should be reanalyzed. If the area response for any IS changes by more than  $\pm 40\%$  between the sample and the most recent calibration, the GC/MS system should be inspected for malfunction and corrections made as appropriate. When corrections are made, a calibration check sample must be analyzed to determine whether the multipoint calibration is valid. If acceptance criteria are not met, recalibration is necessary. Reanalysis of samples analyzed while the GC/MS system was malfunctioning is likely to be necessary.

### **5.4.3 PM<sub>2.5</sub> Gravimetric Analysis**

Filters to be used for PM<sub>2.5</sub> sampling should be equilibrated in a temperature and humidity controlled laboratory, as specified in the Reference Method, for at least 24 hours prior to both pre-sample and post-sample weighing. Specifically, filters must be conditioned at the same conditions (relative humidity (RH) within  $\pm 5$  percent RH) before the pre- and postsampling weighings. Mean RH must be held between 30 and 40 percent, with a variability of not more than  $\pm 5$  percent over 24 hours. However, where it can be shown that the mean ambient RH during sampling is less than 30 percent, conditioning is permissible at a mean RH within  $\pm 5$  percent RH of the mean ambient RH, but in no case less than 20 percent RH. Mean temperature should be held between 20 and 23 $^{\circ}\text{C}$ , with a variability of not more than  $\pm 2^{\circ}\text{C}$  over 24 hours. RH and temperature should be measured and recorded on a continuous basis during filter conditioning (either by a recording hygrothermograph or by electronic instruments).

An appropriate analytical balance is required for the measurement of filter weights. The balance should be calibrated prior to each weighing session, and a variety of calibration and QC checks should be conducted during each weighing session to assure the quality of the gravimetric measurements.

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## **6.0 QUALITY ASSURANCE/QUALITY CONTROL**

Quality Assurance (QA) consists of the systems and procedures designed into a program to establish quality as an inherent part of the program. Quality Control (QC) consists of the practical checks and assessments done to maintain and document the performance of measurement systems. QA procedures for the each monitoring study should include:

- Designation of a contractor's QA Officer for each monitoring study
- Preparation of a Quality Management Plan (QMP) for the study that is consistent with USEPA guidelines for such documents
- Distribution of the QMP to all involved parties
- Preparation of a quality assurance project plan (QAPP) specific to the study location, that includes requirements for QA/QC, and auditing of field activities
- Organization of a kickoff meeting before data collection begins to review quality requirements with all involved parties
- Planning, performance, and reporting of audits, such as a Technical Systems Audit in which adherence to the Detailed Protocol, the QMP, the study-specific QAPP, and required QC procedures is assessed.

Although discussion of these procedures is not detailed in this document, adherence to these requirements should be required of any contractor or agency conducting one of the planned field studies. QC procedures included in this Protocol address calibration and assessment of monitoring instruments, sample collection or handling procedures, laboratory analyses, and assessments of data quality. Such procedures are based on established methods or procedures, including:

- Operation manuals for continuous monitors, integrated samplers, or other equipment
- Published methods including the PM<sub>2.5</sub> FRM, or USEPA Methods such as TO-11A or TO-15
- Laboratory procedures, including standard operating procedures (SOP's) established by the analytical laboratory
- Written auditing procedures, requiring (e.g.) challenges with independent standards or comparisons with other methods.

The QC procedures to be implemented in the studies conducted under this Protocol must be specified in the study-specific QAPP. Assessments of data quality must be based on data quality objectives (DQO's) established according to USEPA guidelines before any data collection takes place. The DQO process considers what quality of data is required to meet the study goals, and then sets criteria for data quality (e.g., accuracy, precision, completeness) to meet those goals.

## 6.1 Instrument Calibration

### 6.1.1 Gas Analyzer Calibration

Calibration of all monitoring and analytical equipment is essential to ensure the quality of the data collected. A multipoint calibration includes a minimum of four points (three spaced over the expected range and a zero point), generated by the calibration system. Although more points may be preferable, most current gas analyzers provide inherently linear response over their entire operating range; therefore, four points should be sufficient. Multipoint calibrations must be done prior to the analyzer being put into service and at least every 6 months thereafter. Additional calibrations should be conducted if any of the following conditions occur:

- Level 1 span check difference exceeds 15 percent
- Significant maintenance activities are conducted on the analyzer
- Measured concentration values during direct comparison audit differ from the certified standard values by  $\pm 15$  percent.

The analyzers should be calibrated *in-situ* without disturbing the normal sampling inlet system to the degree possible. Analyzer-specific SOPs should be developed based on the manufacturer's recommended calibration procedures. However, the following steps outline the multipoint calibration procedure for the gas analyzers. If appropriate, a NIST-traceable multicomponent gas mixture (i.e., CO, NO in N<sub>2</sub>) may be used to calibrate multiple gas analyzers.

The responses of the analyzer should be analyzed by linear regression to assess the results of the calibration. Acceptance criteria for the linear regressions are left to the discretion of the monitoring agency, but the following are suggested: slope,  $1 \pm 0.10$ ; intercept, zero  $\pm 1 \times$  analyzer lower detectable limit (LDL) or  $\pm 1\%$  of the tested range (whichever is greater); and correlation coefficient ( $r$ ),  $> 0.995$ , where the  $\pm$  values represent 95% confidence intervals. Regardless of what criteria are selected, the analyzer still must also pass audit tests, which require an absolute difference between the analyzer reading and the standard gas concentration of no more than 15 percent.

### 6.1.2 PM<sub>2.5</sub> Sampler Calibration

Calibration of the PM<sub>2.5</sub> samplers includes a multi-point calibration of the sampling flow rate, as well as calibrations of the internal temperature and pressure sensors. Procedures for calibration of the

PM<sub>2.5</sub> samplers should be included in SOPs for each instrument and should be developed based on the manufacturer's recommended calibration procedures, and in compliance with the requirements of the PM<sub>2.5</sub> Federal Reference Method.<sup>8</sup> Additional guidance can be on calibration of PM<sub>2.5</sub> samplers can be found in the USEPA's Quality Assurance Guidance Document 2.12: Monitoring PM<sub>2.5</sub> in Ambient Air Using Designated Reference or Class I Equivalent Methods.<sup>11</sup>

Calibration of the aerosol monitors must be done prior to the analyzer being put into service and at least every 6 months thereafter. Additional calibrations should be conducted if any of the following conditions are met:

- Major maintenance activities are performed on the samplers
- Audits of the flow rate indicate differences of greater than 5% from the nominal flow rate or greater than 4% from the audit flow rate measurement
- Audits of the temperature sensor show differences exceeding 2° C
- Audits of the pressure sensor show differences exceeding 10 mm Hg.

### **6.1.3 Continuous Aerosol Monitor Calibration**

Calibration of the aerosol monitors (i.e., Aethalometer and BAM or TEOM) is based on the calibration of the sampling flow rate of each instrument and is similar to the procedure for the calibration of the PM<sub>2.5</sub> sampler. For each monitoring study conducted under this Protocol, SOPs for each of the aerosol monitors used be developed based on the manufacturer's recommended calibration procedures. In general, a NIST-certified flow transfer standard should be used accurately measure the instrumental flow rate at one or more flow settings. If differences in the measured flow rate and the displayed flow rate exist, the SOP or appropriate operator's manual should be consulted for procedures on flow rate adjustments.

Calibration of the aerosol monitors must be done prior to the analyzer being put into service and at least every 6 months thereafter. Additional calibrations should be conducted if any major maintenance activities are performed on the aerosol monitors/samplers, or if audits of the flow rate indicate differences of greater than 2% from the nominal flow rate or greater than 4% from the audit flow rate measurement.

### **6.1.4 Meteorological Sensor Calibration**

Meteorological sensors used for the studies conducted under this Protocol should be factory calibrated prior to being put into service and every 6 months thereafter. Sensors can be calibrated *in situ* using a NIST-traceable transfer standard, or can be returned to the manufacturer for recalibration. If sensors are returned to the factory for calibration, the timing of the calibration should be coordinated to

avoid the loss of meteorological data during integrated sampling periods. Table 6-1 presents the criteria for the meteorological sensor calibration.

**Table 6-1. Calibration Criteria for Meteorological Sensors**

Variable	Accuracy
Wind Direction	±5°
Wind Speed	±0.2 m/s + 5%
Air Temperature	±0.5° C
Relative Humidity	±3% RH
Barometric Pressure	±3 hPa
Solar Radiation	±5%
Dew Point	±1.5° C
Precipitation	±10%

#### **6.1.5 Calibration of Analytical Laboratory Instrumentation**

Accurate analysis of the samples collected in the studies conducted under this Protocol requires the appropriate calibration of the instrumentation used for the analyses. Procedures for the calibration of these instruments are provided in the respective monitoring methods (e.g., HPLC for TO-11A, GC/MS for TO-15, analytical balance for PM<sub>2.5</sub> FRM). These methods provide prescriptive descriptions of the requirements for instrument calibration as well as the calibration checks and other method-specific quality control requirements. Laboratories conducting these analyses for studies conducted under this Protocol should be familiar with the requirements of the respective methods and should have SOPs in place for performance of the required calibrations and calibration checks.

#### **6.1.6 Calibration of Traffic Monitoring Equipment**

Traffic monitoring equipment/data provided by the State Department of Transportation or similar entity should be accompanied by the appropriate calibration records of the traffic monitoring equipment. These records along with any supporting QA/QC documentation should be reviewed by the contractor conducting the monitoring studies to insure that the use of the existing traffic monitoring equipment meets the data quality needs of the study.

If new traffic monitoring equipment must be installed for any of the studies conducted under this Protocol, the contractor conducting the monitoring study must insure that the traffic monitoring equipment is properly calibrated according to existing standards or the manufacturer's recommendations.

## **6.2 QC Checks**

A variety of QC checks should be conducted in the field to ensure that the continuous monitors and the integrated sampling equipment are operating properly. In addition to QC activities conducted in the field, TO-11A, TO-15, and the PM<sub>2.5</sub> FRM all have associated laboratory QC activities that are required. Procedures and acceptance criteria for the QC checks required for the laboratory analyses are described in the respective methods and include continuing calibration checks and analysis of blank samples. Laboratories conducting these analyses for studies conducted under this Protocol should be familiar with the requirements of the respective methods and should have SOPs in place for performance of the required QC checks. This section focuses on the QC checks to be conducted in the field.

### **6.2.1 Level 1 Zero/Span Calibration Checks**

Level 1 zero and span checks are conducted to assess if the gas analyzers are operating properly and to assess if any drift in instrument response has occurred. These checks should be conducted nightly if the calibration system/gas analyzers used can be programmed to automatically perform these checks. The Level 1 checks are conducted by challenging the analyzer first with zero air and then with a test atmosphere containing a working standard of the target gas at a concentration of between 70 percent and 90 percent of the full measurement range in which the analyzer is operating. For these checks, the challenge gas should be sampled through the entire sampling inlet system, to mimic the actual sampling of ambient air. The results of the Level 1 zero/span checks should be plotted on control charts to graphically illustrate the trends in the response of the analyzer to the challenge gases. If the measured concentrations fall outside of the control limits, the accuracy of the MFC calibration system should be checked with a NIST-traceable flow standard. If the MFC flow accuracy is confirmed, the data recorded since the previously successful Level 1 check should be flagged and the analyzer should be recalibrated using the multipoint calibration procedures described in Section 6.1.1. It is highly recommended that nightly Level 1 checks are conducted; however, if for some reason nightly Level 1 checks cannot be conducted, the precision checks described below can serve as the Level 1 checks.

### **6.2.2 Precision Checks**

At least once every 2 weeks a precision check should be conducted by challenging each gas analyzer with a known concentration of a standard gas mixture to assess the ability of the analyzers to measure a gas under reproducible conditions. The precision checks should be conducted by challenging the gas analyzer with a standard gas of known concentration. The gas must be supplied through all filters, scrubbers, and other conditioners and should be supplied through as much of the sample inlet system as possible. After completion of the precision check, the actual concentration of the working standard and

the measured concentration indicated by the analyzer should be reported along with the percent difference between these values. Precision should be calculated at the end of each calendar quarter.

### **6.2.3 Leak Checks**

Leak checks of the continuous aerosol monitors and PM<sub>2.5</sub> samples should be conducted periodically (e.g., every fifth sampling period) according to the manufacturer's recommended procedures and should meet the respective acceptance criteria. Generally, the leak checks are conducted by disconnecting the sampling line from the instrument inlet and blocking the flow of air into the inlet. The sampling pump is allowed to operate until an appropriate level of vacuum is achieved, after which the pump is turned off and the pressure in the instrument is monitored.

To pass the external leakage test, the difference between the two pressure measurements should not be greater than the number of mm Hg specified for the sampler by the manufacturer, based on the actual interior volume of the sampler, that indicates a leak of less than 80 ml/min. If a leak check fails, the appropriate operator's manual should be consulted for troubleshooting recommendations.

### **6.2.4 Field Blanks**

Field blanks provide data for evaluating contamination introduced into the samples from field activities other than sampling. Field blank should be collected and analyzed for the TO-11A and PM<sub>2.5</sub> methods used in the monitoring studies conducted under this Protocol. Field blanks should be handled like normal samples, with the exception of not actually sampling the air. Blank DNPH samples should be collected by installing the DNPH tubes into the sampler and removing the tubes without drawing any air through the tube. PM<sub>2.5</sub> field blanks should be collected by installing a blank filter into the PM<sub>2.5</sub> sampler and removing it without drawing air through the filter. Blank At least 10% of all samples collected should be field blanks. The field blanks should be selected such that they represent 10% of all sample material lots purchased for the project.

Acceptance criteria for the field blanks should be established in the QAPP for each study prior to initiation of the study. Recommended acceptance criteria for the DNPH tube field blanks are:

- Formaldehyde: < 0.3 µg/cartridge
- Acetaldehyde: < 0.4 µg/cartridge.

Recommended acceptance criteria for the PM<sub>2.5</sub> field blanks are < 30 µg change between weighings.



### 6.3 Audits

To ensure the data quality of the monitoring data collected during each study, a series of QA audits should be conducted. At a minimum, these audits should include performance evaluation (PE) audits, technical systems audits (TSA), and audits of data quality (ADQ).

#### 6.3.1 Performance Evaluation Audits

PE samples are used to ensure the performance of the monitoring systems used to collect the pollutant and meteorological data. For the studies conducted under this Protocol, these audits involve challenging the gas monitors with a standard of known concentration, auditing the flow rates of the aerosol monitors, collocating duplicate sensors with the meteorological sensors, challenging the analytical instrumentation with standards of known concentration, and auditing the calibration of the analytical balance with standard weights. All of the PE audits should be done with standards that are independent of those used for the calibration or routine checks of the systems being audited.

##### 6.3.1.1 Gas Analyzers

For the gas analyzers, PE samples involve challenging the analyzers with standards of known concentration that are independent of those standards used to calibrate the analyzers. Generally this challenge is conducted as a blind audit, such that the site operator is not aware of the gas standard concentrations delivered to the analyzers. Clearly, the appropriate concentration values to be used for PE samples will be different for the different gases (CO, and NO<sub>x</sub>). In addition, the appropriate PE concentrations may vary with the analyzer operating range, which is selected based on the characteristics of the monitoring site. Consequently, the recommended concentration ranges for PE samples are given in Table 6-2 relative to the full scale range of the analyzer, rather than in concentration units. At least one PE sample of known concentration is to be delivered to the analyzer from each of the applicable ranges shown in Table 6-2. The indicated ranges are consistent with the requirements of 40 CFR 58, Appendix A, Section 3.2.1.

**Table 6-2. Concentration ranges for PE Samples**

Audit Point	Percent of Full Scale Range <sup>a</sup>
1	3 to 8
2	15 to 20
3	35 to 45
4	80 to 90

a. Applies to operating range of CO or NO<sub>x</sub> analyzer.

PE sample challenges should be conducted at least quarterly on each analyzer and can be conducted (a) by a person outside of the agency or an independent QA group within the agency, or (b) by having an independent audit device, such as used in the National Performance Audit Program (NPAP), sent to the monitoring station. In the former case, an independent audit system or standard is brought to the monitoring station and used to produce working standards of the target gases that are supplied to the analyzers by the auditor. In the latter case, the audit device provided to the monitoring agency produces working standards of the calibration gases that are supplied to the analyzers. The operators and auditor do not know the concentrations of the standards that are produced by the audit equipment. Responses of the analyzers are recorded and provided to the agency that supplied the audit device. That agency compares the responses of the analyzers to the calculated concentrations from the audit device and provides an audit report to the monitoring agency. In both cases, the PE sample audit should be conducted by supplying the analyzer with the PE sample gas in its normal sampling mode such that the audit gas passes through all sample inlet components used during normal ambient sampling.

Both the actual concentration of the PE sample gases and the concentration measured by the analyzer being audited should be reported, along with the percent differences between these concentrations for each audit point. The calculated percent differences are used to confirm the analyzer precision and bias estimates obtained from routine checks.

The PE audit should also include an independent check of the gas flow controllers in the calibration system, using a NIST-traceable flow standard.

#### **6.3.1.2 Aerosol Monitors/PM<sub>2.5</sub> Samplers**

For the continuous aerosol monitors and the PM<sub>2.5</sub> samplers, a PE audit of the sample flow rate should be conducted at least quarterly. For the aerosol monitors, the PE audit should be conducted by measuring the sample flow at the inlet of the monitor using a calibrated flow measurement device with an appropriate measurement range. The audit should be conducted at ambient temperature for readings to be valid. An STP flow device can be used if the temperature is within 5° C of 25° C; in this case skip the next step. Record the flow rate measured by the audit flow meter and the flow rate shown on the aerosol monitor display. If the audit flow meter is a volumetric standard, the measured flow rate may need to be converted to STP for comparison to the aerosol monitor. The flow rate of the aerosol monitors should agree with the audit flow rate within 4%, and within 5% of the nominal flow rate of the monitor. If the flow difference is greater than these tolerances, the operator's manual should be consulted for appropriate corrective action.

### **6.3.1.3 TO-11A and TO-15 Analysis**

PE audits of the analytical instrumentation used for the analysis of the TO-11A and TO-15 samples should involve the analysis of blind audit samples prepared from NIST-traceable standards independent of those used for the calibration and routine QC activities for the respective instrumentation. The audit samples should have concentrations of the target analytes that are within the normal calibration range of the instrumentation and are comparable to the measured concentrations in the ambient air. These audits should be conducted at least quarterly and the acceptance criteria for these PE audits should equal those for routine calibration checks.

### **6.3.1.4 Analytical Balance**

PE audits of the analytical balance used for the gravimetric measurements of the PM<sub>2.5</sub> filters should be conducted at least quarterly using NIST-traceable weights that are independent of those used for the calibration and routine QC checks of the balance. For these PE audits, the balance display should agree with the designated value of the audit weight to within  $\pm 0.020$  mg.

### **6.3.1.5 Meteorological Sensors**

PE audits of the meteorological sensors should be conducted at least quarterly by collocating independent sensors with those installed at the monitoring stations. Acceptance criteria for these PE audits should equal those for accuracy requirements provided in Table 4-2.

### **6.3.1.6 Traffic Monitoring Equipment**

Traffic monitoring equipment/data provided by State DOTs or similar entities should include records of QA/QC activities including any pertinent PE audit results. These QA/QC records along with any supporting documentation should be reviewed by the contractor conducting the monitoring studies to insure that the use of the existing traffic monitoring equipment meets the data quality needs of the study.

If new traffic monitoring equipment must be installed for any of the studies conducted under this Protocol, the contractor conducting the monitoring study must insure implement appropriate QA/QC procedures according to existing standards or the manufacturer's recommendations and conduct PE audits as warranted.

## **6.3.2 Technical Systems Audit**

A TSA is an on-site review and inspection of the operation of an air monitoring station to assess its compliance with established QA/QC procedures and any applicable regulations. TSAs assess whether all procedures for the monitoring program are being followed and documented. A TSA should be conducted immediately before or shortly after the start of monitoring and should be repeated at least every

quarter. TSAs should be performed by an independent auditor who is knowledgeable of the monitoring program but independent of routine operations.

#### **6.4 Preventive Maintenance and Troubleshooting**

Long-term operation of continuous monitoring equipment and integrated gas sampling equipment requires a preventive maintenance program to avoid instrument down-time and data loss. Despite active preventive maintenance, occasional problems may arise with the monitors. A preventive maintenance program should be included in each of the monitoring studies conducted under this Protocol based on the recommended procedures for the equipment installed at the monitoring stations.

## **7.0 DATA MANAGEMENT AND STATISTICAL ANALYSIS**

### **7.1 Data Management**

A large amount of data will be generated in a variety of forms during the completion of the studies conducted under this Protocol. A comprehensive Data Management Plan must be implemented during each study to ensure that the data collected are properly maintained and accurate. This Data Management Plan should provide a process by which a documentation trail is established for all data generated during each study, including all mathematical operations and analyses performed on raw or processed data. Any procedures involving data collection or manipulation (i.e., data recording, validation, transformation, transmittal, reduction, analysis, management, storage) should be addressed in the Data Management Plan. The Plan should include internal verification and validation checks that will be used to ensure data quality. The Data Management Plan should be incorporated into the study-specific QAPP for each study conducted under this Protocol.

The data generated during each study must be reviewed and validated in a timely fashion. Data validation must take place at various stages in the development of the final ambient air concentration data. In the field, those responsible for collection of the samples and the shipment of the samples to the respective analytical laboratories must ensure that appropriate documentation is being maintained, including completed chain of custody (COC) forms and sample collection records. The site operators should periodically contact laboratory support staff to ensure that valid samples are being collected and that the completeness goals for the monitoring study are being met. Site operators should also be responsible for validation and review of data from the gas analyzers, continuous aerosol monitors, and meteorological sensors.

Validation of data generated in the laboratory, including review, is primarily a function of the laboratory staff. Data validation should include the review of results from QC activities including daily calibration samples, ongoing precision and recovery samples, as well as system and field blank samples. Review of these data will allow the technical staff to determine whether established acceptance specifications are being met. If acceptance criteria are not being met, appropriate corrective actions can be undertaken to resolve problems that may exist.

It is recommended that data generated during each study be reviewed by a technical staff member at least within 2 weeks of generation of the data. The reviewer should be familiar with the technical

aspects of the monitoring. This process will serve both as the data review and the data verification, and will ensure that the data have been recorded, transmitted, and processed properly.

All of the field and laboratory data should be validated by a data reviewer prior to assembly of periodic reports of sample results. An independent staff member familiar with quality assurance procedures should conduct a final data review on a predetermined percentage of the data (e.g., at least 10%). The final evaluation and validation of the data must compare the QC results directly to the measurement quality objectives developed for the project.

## **7.2 Statistical Analysis**

The data analyses recommended below focus 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 are suggested that may address additional questions such as the respective impacts of meteorological conditions, traffic volume, vehicle type, etc.

This section discusses how the data collected during each monitoring study are to be analyzed and describes statistical approaches to be used on those data. The data of interest include PM<sub>2.5</sub>, MSAT, and surrogate species concentrations, meteorological data, and traffic data. The latter three types of data are to be monitored continuously and for the subsequent discussion are assumed to be aggregated to one-hour average or integrated data.

Given the complexity of the data set, multivariate analysis approaches using statistical analysis software such as SAS may be necessary to assess the impact of various parameters of interest on the pollutant dispersion. However, emphasis must be placed on reporting clear and understandable results from the statistical analysis. The field studies are being conducted to understand the relation of mobile source emissions to key air contaminants. Since this issue is of public interest, the agencies interested in the study results will require relatively simple findings that can be explained to a wide audience. At a minimum, the data should be analyzed to determine if there is a statistically significant difference between the pollutant concentration measured at each site and the background concentration. The following calculations should be conducted for each monitoring study.

### **7.2.1 Calculation of Average and Peak Concentrations**

For each site, the hourly, daily, monthly, quarterly, and annual average concentrations for each MSAT and surrogate species should be calculated. Because the objective of the monitoring study is characterization of the dispersion of the MSAT and surrogate species from the road, these calculations should be conducted using both those data collected during periods when the average wind direction would result in dispersion of the roadway pollutants in the direction of the monitoring stations (“worst case” peak), and with all data (average). Consequently, the average wind direction during each sampling period should be determined, and periods during which the average wind direction was not within an arc of suitable size (e.g., 120°) centered on a line perpendicular to the road in the direction of the monitoring stations should be excluded from the peak evaluation. The size of that acceptable arc of wind direction should be chosen based on the geometry, roadway dimensions, and presence of obstacles in each study location, however it is recommended that an arc of approximately 120° is a reasonable maximum arc size for most study locations. An example of a suitable arc is illustrated in Figure 7-1, showing peak wind directions (a), and non-peak wind directions (b). For peak calculations, only those wind directions that fall within the 120° arc shown in this figure (i.e., from the road) should be used for determination of the pollutant dispersion. Data excluded these calculations should remain available for average calculations that will be conducted at a later time.

Once the data have been evaluated based on wind direction, the mean and peak concentrations for each MSAT and surrogate species should be determined for each sampling period. In determining the mean concentrations, one half the detection limit should be used for those sample analyses resulting in non detectable concentrations. Although the mean concentration values will be used to determine pollutant dispersion, the peak concentration should be determined to illustrate the “worst case” conditions that were encountered during the study period. The standard deviations should also be calculated and reported to illustrate the variability of the concentrations.

Time sequence plots should be generated to illustrate the temporal patterns (both diurnal and seasonal) in pollutant concentrations during the study period. Appropriate meteorological parameters (e.g., temperature, solar radiation, etc.) or traffic related parameters (e.g., traffic count, vehicle mix, etc.) may be included on these time sequence plots to help illustrate any apparent metrological or traffic dependence on pollutant concentrations. For example, Figure 7-2 is a time sequence plot showing an illustration of the variation in traffic patterns and changes in pollutant concentration over the course of a 24-hour period. Monthly, quarterly, and annual wind roses should also be generated to illustrate the prevailing wind direction during the study period.

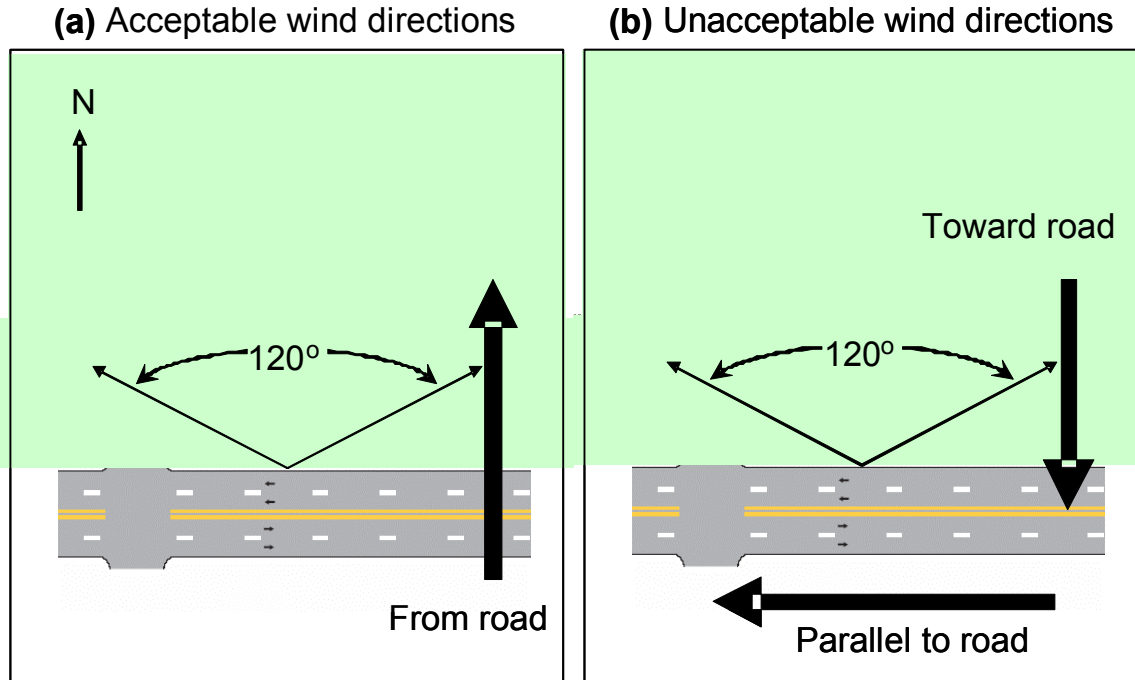


Figure 7-1. Example of peak and non-peak wind directions.

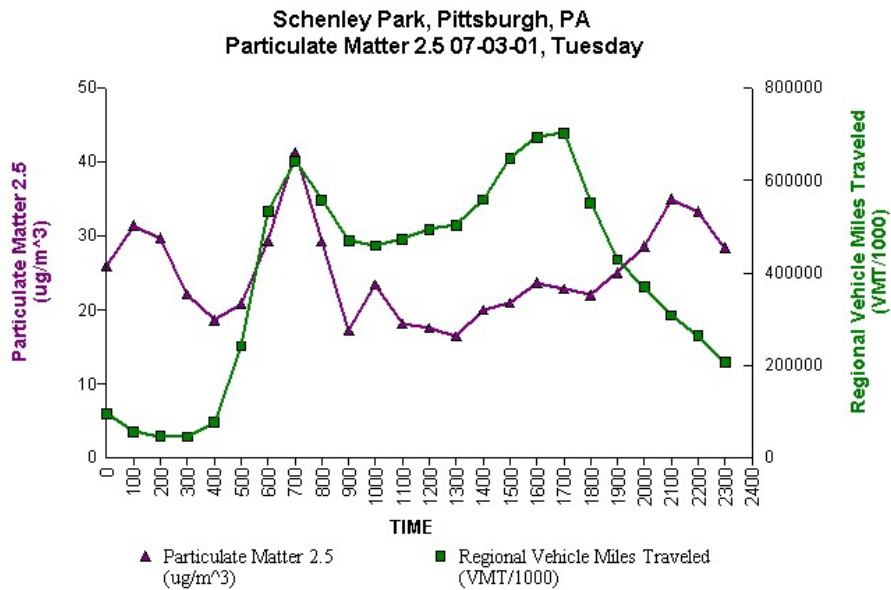


Figure 7-2. Example of Diurnal Variations in Traffic Patterns and Pollutant Concentrations.



### **7.2.1.1 Hourly Averages**

The average concentration of MSATs or surrogate compounds in each of the 24 hours of the day (e.g., 1:00 – 2:00 am, 2:00 – 3:00 am, etc.) should be calculated over extended time periods, to evaluate the respective diurnal concentration pattern of each species at each site. The average concentration over a single hour of the day will simply be the mean of the results from all samples collected during that hour. For example, for the continuously monitored surrogate chemicals, if calculated for an entire year of sampling, the average within each hour of the day will be based on up to 365 hourly values recorded for that hour of the day over the course of a year. On the other hand, hourly values for the MSATs will be based on relatively fewer data points, because of the 1-in-12-day and 9-samples-per-day schedule (see Section 2.1). Specifically, when averaging over one year, the hourly average for the peak hour in the morning traffic period will be based on at most 30 samples, the hourly average of the hour preceding and the hour following that peak hour will be based on at most 15 samples, and the average for all other hours of the day will be based on 10 samples. These differences in the number of data points must be kept in mind if comparisons are made between average concentrations at different times of day. For all measured species, the number of samples available for calculation of hourly averages will be proportionally reduced if calculations address shorter time periods (e.g., quarterly, monthly), but such calculations may still be useful if marked seasonal changes in measured concentrations are observed.

### **7.2.1.2 Daily Averages**

The average concentrations of surrogate and MSAT species over each sampling day may be calculated both before and after removal of data based on the wind direction sector, though the procedures used are different for these species.

For the continuously monitored species, the daily average measured concentration ideally is just the average of 24 hourly data points over the day. However, even if all valid data are included in the average (i.e., the data are not screened by wind direction) the number of valid data points may still be less than 24, due (e.g. due to calibration periods, instrument malfunction, data loss, etc.). In such cases, substitution for the missing data may be made based on reasonable assumptions, or the average may be calculated based on less than 24 hourly values if the number of data points is noted. A reasonable basis for substitution may be that the missing data are in a stable or low concentration regime, as in overnight hours, and thus a neighboring hourly value may be substituted, or that the diurnal pattern in the study location is reproducible and thus a long-term hourly average (see above) may be substituted for the missing value. Such substitution approaches may be implemented based on the observed characteristics of the data from a study location.

Calculation of daily averages from continuously monitored data screened to exclude unwanted wind directions should be conducted with care if the number of remaining data points in a day is relatively small, or if peak traffic periods are under-represented among the remaining hours. As an example general recommendation, a daily average should not be calculated if fewer than 16 hours of data are available for the 24-hour period, or if fewer than 10 hours of data are available from the 6 a.m. to 7 p.m. time period. Any daily averages calculated from incomplete continuous monitoring data should be so indicated.

Calculation of daily averages for MSATs necessarily involves at most nine samples, due to the selected sampling schedule. Furthermore, because of the rotating of sample times from one sampling day to the next, a weighting procedure is recommended that treats each collected sample as representing part of a three-hour section of the day. Specifically, the three-hour morning rush hour period is represented both by the peak hourly sample, and by the sample taken either immediately before or immediately after that peak hour. All other three-hour periods are represented by the one hourly sample taken in that period. As a result, the calculation of daily average MSAT concentrations should be done as follows:

$$DA = \frac{(MP + (2 \times PMP) + 3 \times OH1 + 3 \times OH2 + \dots OH7)}{24} \quad \text{Eq. 7-1}$$

where DA is the MSAT daily average, MP is the hourly value from the morning peak traffic time, PMP is the value from the hour immediately pre- or post-MP, and OH1 through OH7 are the other hourly samples collected the rest of the day. This approach implicitly assumes that the hourly concentration immediately before the morning peak is equivalent to that immediately after, i.e., that the two “shoulders” of the morning peak are equal. In the event that fewer than nine samples per day are available, the calculation should be carried out with the available data, but not with less than seven samples per day, and not unless both the MP and PMP samples are available. Substitution for missing values may be considered, as described above for the continuous data, but should be used with caution due to the relatively smaller number of data points obtained for the MSATs.

### 7.2.1.3 Longer Term Averages

Averages for MSATs, surrogate species, and other measured parameters may be calculated for longer time periods, such as monthly, quarterly, or annually, based on the data compiled in those time periods. Such averages calculated from all valid data are most applicable to characterization of the study location, estimation of local exposures, and evaluation of seasonal differences in air pollutant levels from all sources in the area. The same averages calculated from data screened by wind direction are most

suitable for evaluating the impact of roadway emissions on exposures, and seasonal differences in roadway impact. In comparing longer term averages, the difference between the number of measurements underlying averages for continuously monitored species and the MSATs must be kept in mind.

### 7.2.2 Comparison of Average Concentration Levels

For assessing the spatial scale and concentration impact of roadway emissions, the primary measured response for statistical evaluation will be the mean measured pollutant levels for each roadside location minus the mean level for the same time period at the background location. This calculation should be conducted only with those data collected during periods when the average wind direction would result in dispersion of the roadway pollutants in the direction of the monitoring stations. Consequently, the average wind direction during each sampling period should be determined, and as described above, periods during which the average wind direction was not within an acceptable arc of centered on a line perpendicular to the road in the direction of the monitoring stations should be excluded from this statistical evaluation. Once the data have been evaluated based on wind direction, the averaged difference should be calculated for the subject period, according to Equation 7-2:

$$D_j = \frac{1}{n} \sum_{i=1}^n (C_{i,j} - C_{i,B}) \quad \text{Eq. 7-2}$$

where  $D_j$  is the average concentration difference of a given MSAT, at monitoring site  $j$ ,  $C_{i,j}$  and  $C_{i,B}$  are the concentrations of the MSAT during sampling period  $i$ , at monitoring site  $j$  and the background monitoring site, respectively. This calculation may be applied to any subset of the data, e.g., a single day, all data from a single time period on multiple days, or all data from an extended time period.

The three sets of differences (0 m vs. background, 150 m vs. background, and 300 m vs. background) for each MSAT should then be fit to Analysis of Variance (ANOVA) models. Model diagnostics should be examined to assess if there are any issues associated with outliers or the model assumptions of constant variance and normality of the residuals. If the data are not found to be adequate for the model, appropriate transformations or more general statistical models (e.g., nonparametric) should be considered. Once final statistical models have been fit, comparisons should be performed for each of the mean differences compared to zero, controlling the possible error rate at 5%. From this analysis, it is possible to assess whether statistically significant differences exist between pollutant concentrations at each site as compared to the background site.

This evaluation will be the primary comparison used to address the first two issues bulleted under Section 7.2 above. The extent to which MSAT and other vehicle-related pollutant concentrations exceed

background levels will be determined by the individual and overall concentration differences relative to the background site. The spatial scale of roadway impact will be assessed based on the reduced exceedances of background concentrations at sites more distant from the roadway.

An extension of this analysis can be used to assess diurnal, day-of-the-week, or seasonal patterns in MSAT concentrations and dispersion by evaluating the corresponding temporal data sets.

### 7.2.3 Comparison Between Continuous and Integrated Measurements

The study design calls for the continuous measurement of surrogate species with the expectation that measured concentrations of these surrogates are correlated with concentrations of the measured MSATs. To assess whether this expectation is correct, the average concentrations should be calculated for the surrogate species for each of the time periods corresponding to each of the MSAT sampling times (i.e., each one-hour sampling period). A regression analysis should then be conducted to assess the correlation between the one-hour average concentrations for the MSATs and the corresponding average concentrations for the surrogates at each monitoring site. A strong correlation between concentration levels of MSATs and surrogates will also imply that the average concentration differences between each monitoring site and the background will also be highly correlated for MSATs and the surrogates.

A strong correlation supports the use of surrogates in additional analysis of the collected surrogate data. Equation 7-3 shows a regression model that could be used to determine the strength of the relationships between the relative concentration differences for each of the MSATs and the surrogates:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \varepsilon_i \quad \text{Eq. 7-3}$$

where  $Y_i$  represents the concentration of an MSAT for measurement period  $i$ ,  $X_{i1}$  represents the surrogate concentration measurement for measurement  $i$ , and  $X_{i2}$  represents the effect of the specific monitoring site.  $\beta_0$  is the intercept parameter, and  $\beta_1$  and  $\beta_2$  are parameters associated with surrogate concentration and monitoring site, respectively while  $\varepsilon_i$  represents the random error term.

By appropriate segregation of the data, this analysis can be used to assess temporal dependencies in the correlation between integrated and continuous surrogate measurements.

### 7.2.4 Meteorological Effects/Traffic

After determining whether significant MSAT and surrogate concentration differences exist between each of the monitoring sites and the background site, the influence of meteorological conditions and traffic patterns on the measured pollutant concentrations should be evaluated. Analyses should be performed on each of the meteorological and traffic parameters to determine their statistical significance

on the pollutant concentrations. For these analyses, the collected meteorological data (e.g., temperature, humidity, etc.) and the corresponding traffic data (e.g., traffic count, vehicle classification data, etc.) should be used as parameters in a regression model with the MSAT pollution concentration as the response variable of interest. Both the meteorological data and the traffic data collected during each MSAT monitoring period should be averaged for those periods and used to assess the influence of each parameter on the corresponding pollutant concentration differences.

Equation 7-4 shows an example multivariate model that could be used to assess meteorological and traffic related influences on pollutant concentrations:

$$Y_{i,j} = \mu_j + \beta_j \times C_{i,j} + \sum_k \gamma_k \times X_{i,k} + \varepsilon_i \quad \text{Eq. 7-4}$$

where the  $\mu_j$ , and  $\beta_j$  are intercept and slope parameters specific to each monitoring site,  $X_{i,k}$  is the measurement of the  $k^{\text{th}}$  meteorological or traffic parameter during the  $i^{\text{th}}$  measurement period, the  $\gamma_k$  are the associated slope parameters,  $\varepsilon_i$  is error unexplained by the model, and other notation is as before.

This model should first be used to test which specific meteorological and/or traffic measurements have a statistically significant impact on pollutant concentrations. This should be done using an ANOVA within the regression model. For those factors found significant, relationships between the variables can be investigated and statements made describing the nature of this relationship between pollutant concentration and the significant factors.

If the surrogates have been shown to be suitable indicators of the MSAT concentrations, the measured surrogate concentrations can be used in this model to increase the number of measurements and enhance the statistical power of analyses.

Furthermore, this approach can be used to assess the influence of meteorological and traffic related parameters on MSAT concentrations on both a temporal and spatial basis.

### 7.3 Emission Inventory Development

Although not directly a part of the monitoring studies to be conducted under this Protocol, the Settlement Agreement calls for the development of an emission inventory from data collected during these studies. The emission inventories will be developed for baseline conditions and for two time horizons in the future – one at 10 years and one at 20 years. To undertake the emission inventory requirement, Appendix A, Section B, in the Settlement Agreement stated that emission inventories should be developed using the MOBILE6 model, and potentially, an updated version of this model referred to as the “MOVES”. Appendix C of this Protocol provides supplemental information regarding the required inventories and outlines the procedures to be used to develop the inventories.

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## **8.0 REPORTING**

Reporting requirements should be defined for each monitoring study by the agency responsible for the overall completion of the study. At a minimum, the reporting requirements should include monthly status reports, QA/QC audit reports, quarterly data reports, as well as a final report.

### **8.1 Monthly Reports**

Submission of monthly progress reports should be required for each monitoring study. These reports should provide a brief summary of the activities conducted during the reporting period, present a brief description of the data collected during the reporting period, and discuss any problems or issues that arose during the reporting period.

### **8.2 QA/QC Audit Reports**

Each of the QA/QC audits should be documented and reported. At a minimum, all audit reports should include the following:

- Descriptions of the audit procedures
- Results of the audits
- Identification of any adverse findings or potential problems
- Response to adverse findings or potential problems
- Recommendations for resolving problems
- Confirmation that solutions have been implemented and are effective
- Citation of any noteworthy practices that may be of use to others

### **8.3 Quarterly Data Reports**

Quarterly data reports should be submitted within 30 days of completion of each calendar quarter and should include:

- Calculated average concentrations for all MSAT and surrogate species
- Calculated peak concentrations for all MSAT and surrogate species
- Analytical results from all laboratory analyses performed
- Results of calibrations, calibration checks, and QC activities
- Summaries of maintenance activities performed
- Data capture statistics

#### **8.4 Final Report**

A final report should be prepared for each monitoring study that describes all activities conducted during that monitoring study. At a minimum, this report should include:

- All raw and processed pollutant data
- All raw and processed meteorological data
- All raw and processed traffic data
- Calculated average concentrations for all surrogate species
- Calculated monthly, quarterly, and annual average pollutant species
- Calculated monthly, quarterly, and annual average meteorological conditions
- Calculated monthly, quarterly, and annual average traffic count and vehicle classifications results
- Results of calibrations, calibration checks, and QC activities
- Summaries of maintenance activities performed
- Data capture statistics
- Results of statistical analyses performed

A schedule for submission of draft and final versions of these reports should be established in the study-specific QAPPs developed for the monitoring studies.



## 9.0 REFERENCES

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2. Zhu, Y., Hinds, W.C., Kim, S., and Sioutas, C. Concentration and Size Distribution of Ultrafine Particles Near a Major Highway. *J. Air & Waste Manage. Assoc.*, 52 (2002), 1032-1042.
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4. Transportation Research Board, National Cooperative Highway Research Program NCHRP Report 479 Short-Term Monitoring for Compliance with Air Quality Standards, Washington, D.C., 2002.
5. U.S. Environmental Protection Agency, *Compendium Method TO-11A Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC)*, in Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition, EPA/625/R-96/010b, Office of Research and Development, Cincinnati, OH 45268, January 1999.
6. U.S. Environmental Protection Agency, *Compendium Method TO-15: Determination Of Volatile Organic Compounds (VOCs) In Air Collected In Specially-Prepared Canisters And Analyzed By Gas Chromatography/ Mass Spectrometry (GC/MS)*, in Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition, EPA/625/R-96/010b, Office of Research and Development, Cincinnati, OH 45268, January 1999.
7. A current listing of designated Federal Reference and Equivalent Methods is maintained by USEPA at:  
  
<http://www.epa.gov/ttn/amtic/files/ambient/criteria/ref1005.pdf>
8. U.S. Environmental Protection Agency, *Meteorological Monitoring Guidance for Regulatory Modeling Applications*, EPA-454/R-99-005, February, 2000.
9. Title 40, Code of Federal Regulation, Part 50, Appendix L, Reference Method For the Determination of Fine Particulate Matter as PM<sub>2.5</sub> in the Atmosphere, July 1, 2005.
10. U.S. Environmental Protection Agency, *Technical Assistance Document for the National Ambient Air Toxics Trends and Assessment Program*. Office of Air Quality Planning and Standards, Research Triangle Park, NC, 27711, Draft, June 2003.
11. U.S. Environmental Protection Agency, *Quality Assurance Guidance Document 2.12: Monitoring PM<sub>2.5</sub> in Ambient Air Using Designated Reference or Class I Equivalent Methods*, National Exposure Research Laboratory, Research Triangle Park, NC, 27711, November 1998.

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**APPENDIX A**

**US 95 SETTLEMENT AGREEMENT – APPENDIX A**

## **Appendix A**

### **Research on Characterizing Baseline and Expected Future Air Toxics and PM<sub>2.5</sub> Concentrations**

#### **Objective**

The Federal Highway Administration (FHWA) agrees to obtain funding for and implement a research effort to characterize concentration levels in the ambient air adjacent to major highway facilities that are attributable to motor vehicle emissions of PM<sub>2.5</sub> and the 6 priority mobile source air toxics: diesel particulate matter plus diesel exhaust organic gases; benzene; 1,3 butadiene; acetaldehyde; formaldehyde; and acrolein. PM<sub>2.5</sub> will be studied only for highway locations in PM<sub>2.5</sub> nonattainment or maintenance areas. FHWA will study the atmospheric behavior of these emissions at five highway locations (unless, pursuant to Part III of the Agreement, there are less than five locations) throughout the U. S. to characterize the emission plume surrounding the highway and its dispersion pattern away from the roadway.

#### **Background**

FHWA identified the study of ambient air concentrations in proximity to highways as a priority in the FHWA Air Toxics Strategic Workplan. The need for proximity studies have grown out of new research suggesting that the “plume” from the roadway can disperse over varying distances and these distances are a function of the pollutant, microscale meteorology in proximity to the highway, mix of engine types and fuels among the vehicles using the highway, and traffic characteristics, among others. Emissions from new vehicles are decreasing compared to older vehicles which may also result in reductions in aggregate emissions from a highway segment and concentration decreases in the ambient air as older, higher emitting vehicles are replaced. EPA national trend data has shown that aggregate vehicle emissions have been decreasing over time even as the traffic volume has increased. Whether national trends are appropriate to predict the rate of change in emissions at the corridor level depends on local factors such as the rate of local trip growth in a corridor, the rate of vehicle replacement, and local changes in vehicle engine and fuel type (e.g., adding more diesel engine vehicles to a highway segment over time may increase local emissions).

Another major uncertainty is the distance at which the resulting concentrations in the ambient air decline to background levels. To determine this, proximity studies are needed as outlined below. The best method of evaluating this is to establish monitors to sample PM<sub>2.5</sub> and the toxic compounds, the meteorology, local vehicle fleet mix and the traffic characteristics.

## **A. Emissions Monitoring.**

### **Design and Selection Criteria**

#### 1. Detailed Protocol to Govern Monitoring Studies.

The primary focus of the research studies will be to look at both ambient concentrations of mobile source PM<sub>2.5</sub> and air toxics and the vehicle traffic that generates this mobile source component. This will require determining a sampling plan (frequency - hourly, daily) and location of monitors (proximity - both longitudinally along the highways as well as adjacent to it) to determine a concentration profile and the plume dispersion boundaries.

Within 180 days following the effective date of the Settlement Agreement, FHWA will develop a Detailed Protocol that will govern the design and implementation of studies to assess the dispersion of PM<sub>2.5</sub> and MSATs emitted from motor vehicles and gain insights into the atmospheric processes in proximity to major highway facilities. Within 30 days of the effective date of the Settlement Agreement, the Sierra Club may comment to FHWA as to what it believes that the Detailed Protocol should provide. Before finalizing the Detailed Protocol, FHWA will send the Detailed Protocol it has developed to a noted expert in the field, selected by FHWA in consultation with the Sierra Club, for review and comment on the technical approach and specifications contained therein. Also, no less than 30 days prior to the application of the Detailed Protocol to any highway location or contract for consultant services, the Sierra Club will be provided an opportunity to comment on the proposed final Detailed Protocol.

#### 2. Criteria

The Detailed Protocol will include criteria for 1) the selection of study sites within the highway segments selected pursuant to the Settlement Agreement; 2) a sampling plan that will prescribe the study objectives to be satisfied by the selection of monitoring sites, the frequency and duration of sample collection, the chemical species to be monitored, and the measurement method(s) to be applied for each chemical species; 3) the final procedures for quality assurance and quality control regarding monitor operation, sample collection and handling, and laboratory procedures; and 4) the statistical methods to be applied for the purpose of performing analysis of the data obtained from the monitors. The Detailed Protocol shall, at a minimum, include the following practices and procedures.

##### a. Selection of monitoring sites

The selection of monitoring sites at each study location will be consistent with the Protocol that will prescribe, to the extent possible, uniform criteria for selecting the distance between the monitor locations and the edge of the highway right-of-way. The Protocol will provide for as many as five monitors at various distances between the roadway and 300 meters, including one adjacent to the highway, one at approximately

300 meters away from the highway, and one to three monitors in between, depending on local conditions. The monitoring stations directly adjacent to the highway will be consistent with EPA's siting criteria for a microscale monitor (40 CFR Part 58, Appendix E ¶ 8.3). In each metropolitan area where a monitoring study is undertaken, FHWA will also collect data at a distance significantly away (at least 1000 meters) from any known source of MSATs to determine urban background concentrations for comparison purposes.

b. Chemicals to be Measured.

The 6 priority MSATs (see below), PM<sub>2.5</sub> (if applicable) and, to the extent feasible and practical, additional chemical markers selected for the purpose of apportioning emissions between diesel and gasoline engines will be measured at each monitoring site. A suitable surrogate must be selected for diesel particulate matter (DPM) since no method has been developed to measure DPM directly. A suitable measurement method for acrolein must also be identified and implemented since recent EPA data raises doubt that laboratory analysis of monitored samples is adequate. Carbon monoxide concentrations may also be monitored to correlate ambient toxic compounds and PM<sub>2.5</sub> with motor vehicle emissions.

c. Sample Collection.

Data will be collected in such a way as to define variations throughout the day and to determine the likely sources (mobile, stationary, area) to the extent possible. Collection of MSAT and PM<sub>2.5</sub> monitoring data will be coordinated with other data collection activities, such as meteorological, vehicle type and traffic data, to achieve consistency in time periods and data measurement methods to ensure that ambient air concentrations can be effectively correlated with these major variables. Ambient air data will be collected to provide hourly concentrations so that concentrations can be correlated with changes in traffic loads, time of day, vehicle type, meteorology, seasons and other factors that may affect ambient concentrations.

Pollutant	Measurement Methods and Considerations [Methods need to be identified for each pollutant or source tracer]	Comments
Acetaldehyde	Uncertain, may only be able to obtain 3 or 24 hour average	Reactive
Acrolein	Not reliable	Reactive
Benzene	Yes	
1, 3-Butadiene	Yes	Reactive
DPM	No	Must use surrogate
Formaldehyde	Uncertain, may only be able to obtain 3 or 24 hour average	Reactive
TRACERS for apportionment between gasoline and diesel emissions		[SEE ABOVE. TO BE DONE TO THE EXTENT PRACTICAL AND FEASIBLE.]

#### d. Meteorological Data

Each study site will employ a full complement of weather instruments to collect data on wind speed and direction, temperature, relative humidity, and probably solar radiation measurements. Meteorology is the most significant driver of the dispersion of emissions in the ambient air and as such, must be part of any analysis effort designed to study the atmospheric concentrations of pollutants. This is especially true for toxic air compounds because some of them are reactive and thus both chemical reactions in the atmosphere and physical mixing will affect the concentrations measured.

If three or more locations are studied, at least one site will be selected where the local prevailing wind is close to the highway alignment, and one site where the prevailing wind is across the highway alignment.

#### e. Traffic Data.

Traffic data will be collected, at a minimum, during periods when monitors are being operated. At a minimum, traffic volumes, vehicle speeds by time of day, classification as to the vehicle fleet mix of gasoline and diesel vehicles along with other vehicle operating characteristics will likely be important considerations. Traffic data will be collected with automated traffic monitoring equipment (including a visual recording method) to maximize the collection effort which will enable continuous measurement of traffic volume and speeds and, where feasible, classification of the vehicle fleet. The availability of this data will be one of the determining factors for site selection in this study effort.

#### f. Study Locations

Five study locations will be selected as described in Part III of the Settlement Agreement.

The Protocol will contain specific criteria for the selection of highway segments as study locations and the selection of monitoring sites within the study location, including the average annual daily traffic (AADT) on the highway segment, geometric design, topology, geographic location within the US, availability of traffic data, climate and meteorology.

(i) AADT: Only sites with more than 150,000 AADT are considered as candidates. For study locations with more than 150,000 AADT, a range of AADT will be sought to compare data on MSAT concentrations between locations with very high AADT (approximately 300,000 or more) from those with lower AADT (less than 200,000).

(ii) 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. Consideration will be given to select one study site to measure ambient air concentrations in the vicinity of high traffic density associated with multiple ramps and interchanges connecting two or more corridors each with AADT greater than 150,000.

(iii) Topology: 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 underrepresentation 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.

(iv) Geographic Location: Study locations will be selected to represent geographic diversity within the US to account for, among other things, meteorological diversity. It is also important that this study be broad enough to be representative (at least in general terms) of the US as a whole.

(v) Availability of 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.

(vi) Climate and 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.

#### g. Sampling Time Intervals

Data will be collected in the smallest (most frequent) time interval as reasonably possible so that resolution of the sources can be made. This generally refers to making continuous (or semi-continuous) measurements hourly or aggregated into 1 hour intervals. The time interval selected must be consistent for the air quality, traffic and meteorological



instruments. The study length or sampling period will be defined relative to the start and completion of the project. On the US 95 project, if selected, data will be collected before expansion of the current roadway is complete, controlling for other emission sources stemming from construction or other equipment. Data will be collected after the expanded roadway is open to traffic as well, requiring many months or years. A plan to specify periodic sampling will be developed to cover a pre-defined schedule including all times of the day and night through all seasons of the year.

### **B. Emissions Modeling.**

The estimation of baseline and future highway emissions at each monitoring study site will be modeled.

1. Emissions will be modeled using the mobile source emissions factors contained in MOBILE6.2 for the vehicle types found at the study location during the period when ambient air concentrations are being monitored during the baseline sampling period. Emissions for the same mix of vehicles and conditions observed during the baseline sampling period will also be modeled when revised emissions factors are selected by EPA for application through the proposed MOVES emissions model.
2. Modeling assessments of emissions during the baseline sampling period and future emissions for a 10 and 20 year time horizon will also be performed using emissions factors derived from both MOBILE6.2 and MOVES.

### **C. Model to Monitor Studies**

The Parties agree to encourage independent third parties to compare modeled estimates of MSAT and PM<sub>2.5</sub> concentration levels with monitored concentrations for various time periods, meteorological conditions, traffic conditions and other variables. The analysis should attempt to determine conditions or variables that most strongly affect model performance, including whether variance between monitored concentrations and concentrations simulated by the model is consistent over time, or differs depending on changes in variables measured in the monitoring studies.

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## **APPENDIX B**

### **EXAMPLE STUDY LOCATION SELECTION**

**Note:** This appendix presents a description of some potential site-specific parameters that should be considered during the selection of study locations for the studies to be conducted under this Protocol. The example locations used in this description are for illustrative purposes only and should not be construed as suggested or recommended study locations by Battelle or FHWA.

## **B.0 EXAMPLE STUDY LOCATION SELECTION**

This appendix provides two examples of the study location selection process using the U.S. 95 widening project in Las Vegas, Nevada, and Interstate 25 (I-25) in Denver, Colorado. Each example location was examined for potential study sites based on the following criteria:

- Traffic volume
- Geometric construction
- Topographical features
- Climate and meteorological conditions
- Air quality data

The following sections examine each of these criteria with respect to U.S. 95 and I-25. Text in *italics* represents additional evaluations that must be conducted through acquisition of more detailed data or physical evaluations.

### **B.1 Las Vegas U.S. 95 Example Study Location Selection**

The U.S. 95 project includes approximately 10 miles of potential study segments. Figure B-1 presents an aerial photograph of the U.S. 95 project area. As shown in this figure, the stretch of highway included in the U.S. 95 project is bounded by residential neighborhoods, commercial and industrial properties, schools, and parks.

#### **B.1.1 Traffic Volume**

Traffic data were obtained for the potential study locations from the Nevada Department of Transportation 2004 Annual Traffic Report. Traffic volumes as average annual daily traffic (AADT) values were obtained for eight highway segments from the U.S. 95 project. Figure B-1 presents the AADT values derived at each available segment within the U.S. 95 project. As shown in this figure, the AADT values for the U.S. 95 project range from 104,000 to 201,000 AADT. Only the segments with AADT values greater than 150,000 AADT will be considered as potential monitoring study sites.

Based on the depth of this example evaluation, only AADT data were obtained. If available, additional traffic data should be evaluated to assess variations in hourly, daily, and seasonal traffic patterns by vehicle type. Locations with large temporal variations in traffic patterns of one or more vehicle type should be considered more attractive than locations with more consistent patterns. Variations in directional flow should also be evaluated. Since the monitoring stations for these studies will likely be placed only (or predominantly) on one side of the road, large variations in directional flow may influence measured pollutant concentrations.

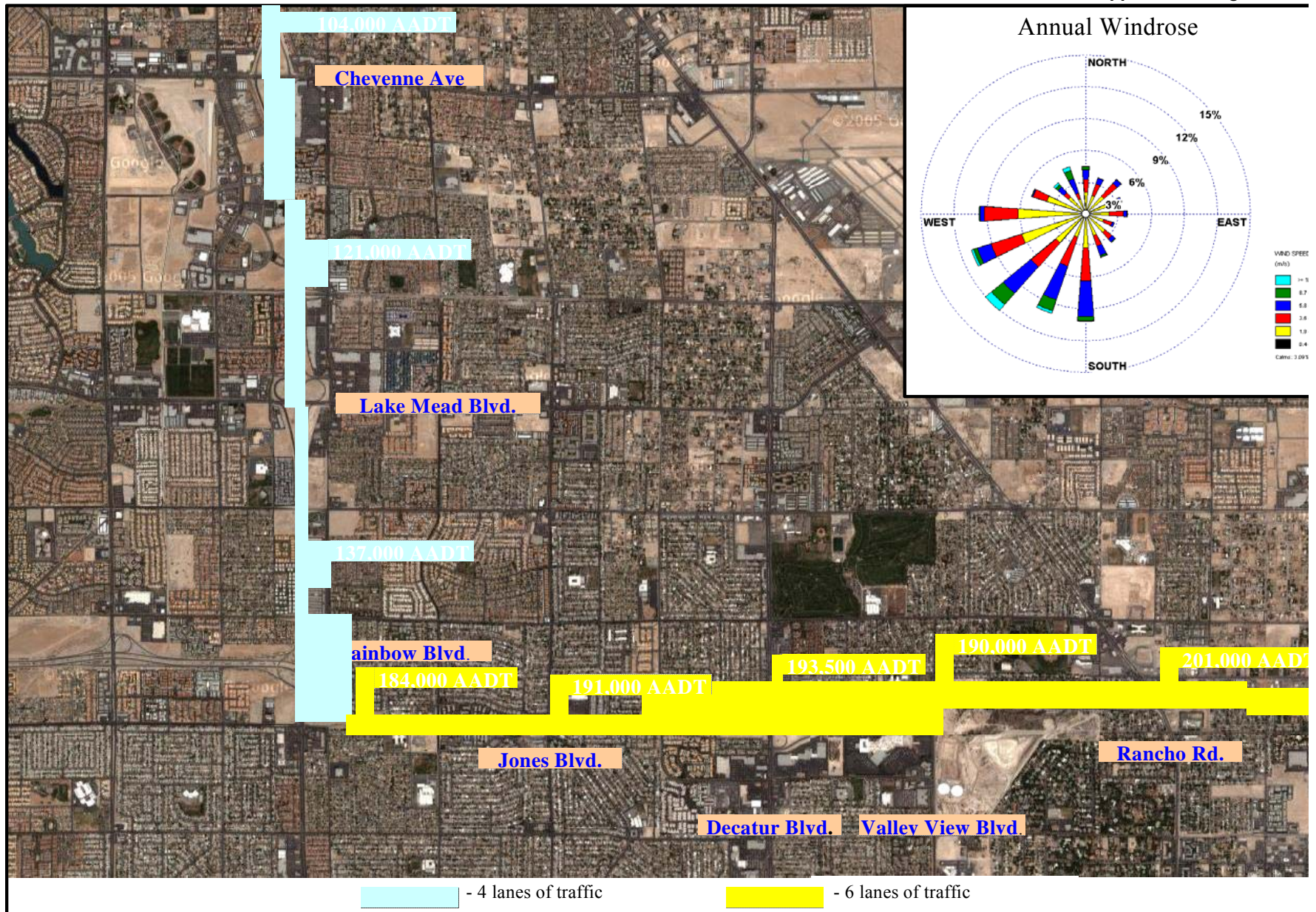


Figure B-1. Overview of U.S. 95 Project Area.

### **B.1.2 Geometric Considerations**

The physical layout of the U.S. 95 widening project was examined to determine potential study locations. The widening project will increase the highway from six to 10 lanes from Martin Luther King Boulevard to Rainbow Boulevard, and from four to six lanes from Rainbow Boulevard to Craig Road. One lane in each direction will be dedicated as a high-occupancy vehicle (HOV) lane. As identified in Figure B-1, the current configuration of U.S. 95 includes six lanes of traffic along the east/west portion of the US95 project and four lanes of traffic along the north/south portions of the project.

A total of three ramps are located along the six lanes of traffic, as well as one underpass. At Rainbow Boulevard a large complex, multi-directional ramp is present that provides the transition from six lanes to four lanes of traffic on U.S. 95. A total of two ramps are located north of Rainbow Boulevard to Craig Road, as well as three underpasses. *All of these geometric considerations must be evaluated during the selection process for potential study locations.* For example, locating a study site near ramps, underpasses, or overpasses may result in impacts at the monitoring sites due to the arterial roadway associated with the ramp, underpass, or overpass.

The study location should be selected to provide relatively easy interpretation of source contributions. Study locations should not be selected for which other major sources are within one kilometer of any of the monitoring sites. Other major sources included but are not limited to:

- Large arterial roadways (AADT > 25,000)
- Large industrial operations
- Combustion sources

Furthermore, it is important to have appropriate candidate locations for the installation of the monitoring stations. Placement of semi-permanent (i.e., at least 1 year) monitoring stations is likely to be feasible only on public land.

The U.S. 95 project was examined to find segments of highway located at least 300 m away from arterial roadways with greater than 25,000 AADT, large industrial operations, or combustion sources. As discussed above, the north/south section of U.S. 95 from Rainbow Boulevard to Craig Road can be excluded from the evaluation, as the traffic volume north of Rainbow Boulevard is less than 150,000 AADT.

### **B.1.3 Topography**

The topography of the east/west portion of the U.S. 95 project is relatively flat with a slight down gradient slope running west to east. Figure B-2 presents a topographical map of the U.S. 95 project area. As shown in this figure, the elevation contours basically run north/south across the study area with a slope of approximately 10 feet per 250 meters. Therefore, no specific study location can be determined from

the overall topography of the area, as there are no significant differences in topography along the entire east/west section of the U.S. 95 project. However, a more in-depth evaluation of roadway topography will have to be conducted to identify any segments unsuitable or better suited for inclusion in the study. For example, segments of the highway located significantly below or above ground level elevation may be excluded due to the localized dispersion characteristics associated with below grade or elevated roadways. *In addition, other road-side structures, such as noise walls, large buildings, and wood lots, must be identified that could act as wind blocks or down wash structures.*

#### **B.1.4 Climate and Meteorology**

This factor refers not only to the broad meteorological regime characteristic of each location, which is applicable to the Geographic Location criterion above, but also to local meteorology. The local meteorological effects are important in determining suitable study locations from the overall project area. As previously discussed, the suitable segments of the U.S. 95 project include those located along the east/west portion of U.S. 95. Therefore, the prevailing wind direction will result in dispersion of highway pollutants in the same direction for any potential study segments. The prevailing wind direction and diurnal wind patterns are critical in selecting potential sites based on locations to other pollutant sources, as discussed under the geometric considerations.

An annual windrose constructed from meteorological data collected at the Las Vegas McCarran International Airport from 1990 through 1992 is included as an inset to Figures B-1 and B-2. Figures B-3 and B-4 present seasonal windroses and diurnal windroses, respectively. As indicated in Figure B-3, the prevailing wind direction during the winter is from the west-southwest and rotates to the south-southwest during the summer months. The diurnal windroses indicate that the wind direction is predominately from the southwest during nighttime hours and is more sporadic during daytime hours with the south-southwest as the predominant daytime wind direction. In addition, the wind speeds during the nighttime hours are much lower than during daytime hours. *These factors must be evaluated for each potential study location based on interferences from other pollutant sources, effects of plume dispersion interferences (i.e., buildings, wood lots, topography), and highway geometric design.*

#### **B.1.5 Air Quality Data**

The USEPA's AirData Website provides access to air pollution data for the entire United States. Within the AirData Website, the Air Quality System (AQS) database provides air monitoring data for ambient concentrations of criteria air pollutants and HAPs at monitoring sites located in primarily urban areas. The AirData Website contains PM<sub>2.5</sub> monitoring data collected at two monitoring stations in Las

Vegas (2801 East Charleston Avenue and 2501 Sunrise Avenue). Both monitors are located approximately 4 km southeast of the US-95/I-15 interchange. The East Charleston monitoring site is located approximately 700 m south of US-95, and the Sunrise monitoring site is approximately 400 m south of US-95. The traffic volume of US-95 in this area is approximately 137,000 AADT. The traffic volume on East Charleston is approximately 32,000 AADT and the largest traffic volume on an arterial street near the Sunrise monitoring station is approximately 34,500 AADT. No ambient air monitoring data were obtained for MSATs in the Las Vegas area from the readily available monitoring data.

The 2004 annual mean PM<sub>2.5</sub> concentrations for the East Charleston and Sunrise monitoring stations are 8.8 and 8.9 µg/m<sup>3</sup>, respectively. The 2004 maximum 24-hour PM<sub>2.5</sub> concentrations for the East Charleston and Sunrise monitoring stations are 31 and 43 µg/m<sup>3</sup>, respectively. Due to the distances from the monitoring stations to US-95 and the amount of traffic estimated for the arterial roads adjacent to the monitors, these ambient PM<sub>2.5</sub> concentrations should be higher than PM<sub>2.5</sub> values measured at a background monitoring site used for this study.

### **B.1.6 Potential Study Sites**

Based on the annual traffic volume data, geometric layout of the U.S. 95 project area, topography, and meteorological data available for Las Vegas, potential study segments were identified and evaluated to determine the best available study location. The potential study segments were identified based on the available traffic volume data and include the following:

- Rainbow (segment from Rainbow Blvd. east to Jones Blvd.)
- Jones (segment from Jones Blvd. east to Decatur Blvd.)
- Decatur (segment from Decatur Blvd. east to Valley View Blvd.)
- Valley View (segment from Valley View Blvd. east to Rancho Rd.)
- Rancho (segment from Rancho Rd. east to Martin Luther King Blvd.)

The Rainbow segment has the lowest traffic volume (184,000 AADT) of the potential segments. Based on review of aerial photographs, the area north of U.S. 95 includes dense residential neighborhoods and multi-family housing; the area south of U.S. 95 includes dense residential neighborhoods, multi-family housing, commercial properties, and potentially an industrial facility. East of the Rainbow segment is the north/south stretch of U.S. 95 with approximately 133,000 AADT traffic volume, as well as numerous ramps to Rainbow Blvd and East Summerlin Parkway.



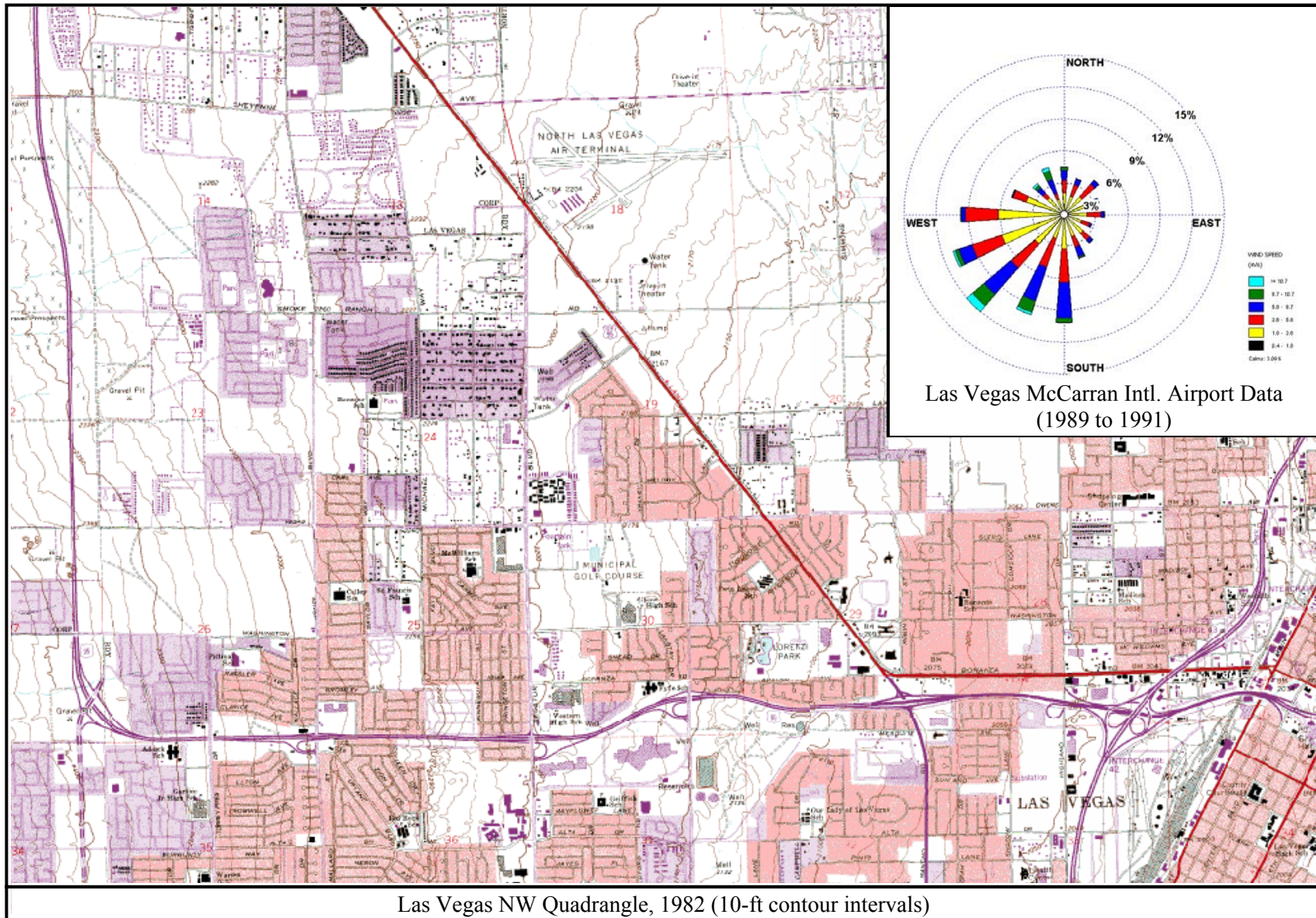


Figure B-2. USGS topographical map of U.S. 95 Project Area.

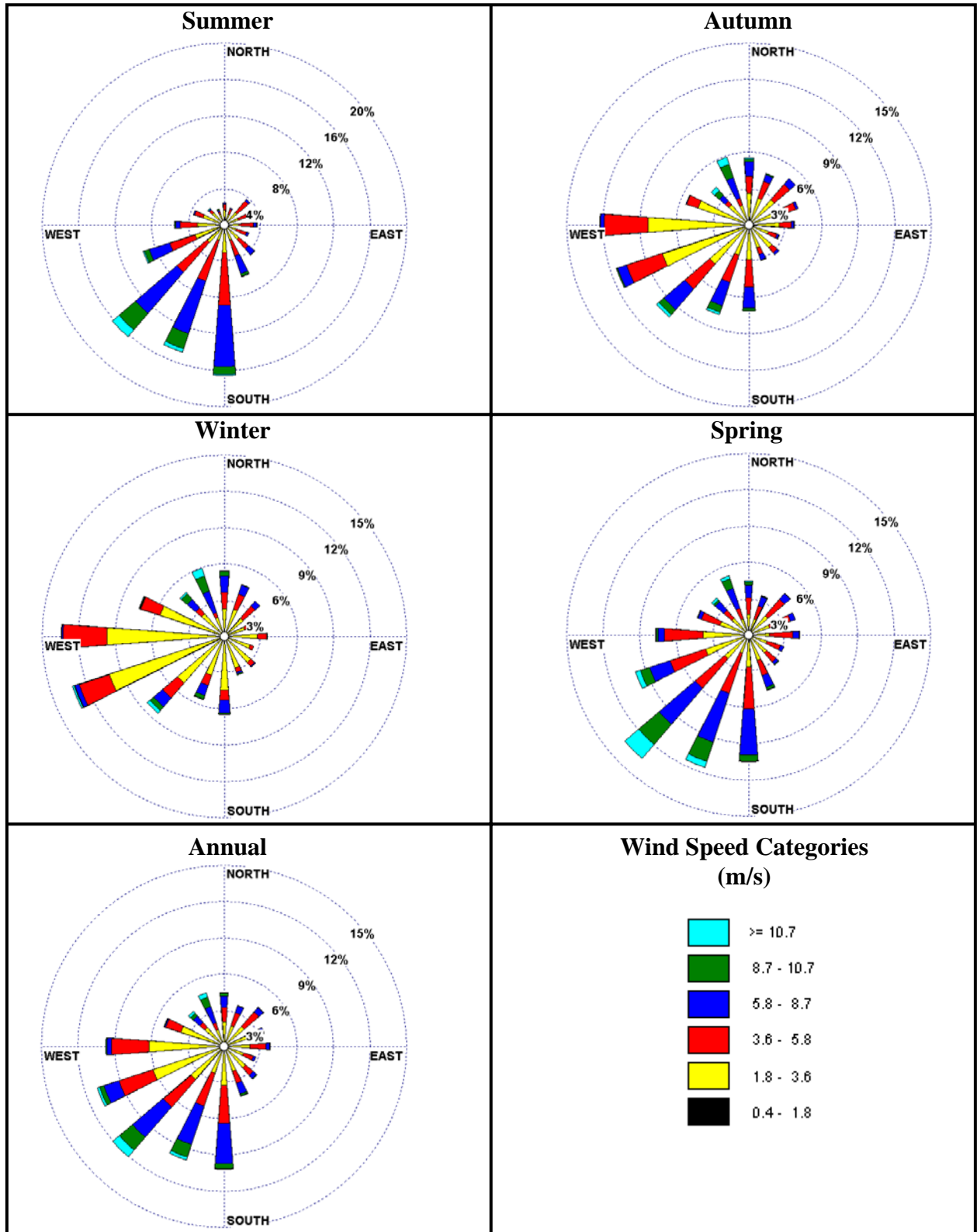


Figure B-3. Seasonal and annual windroses of 1990 through 1992 Las Vegas McCarran International Airport meteorological data.

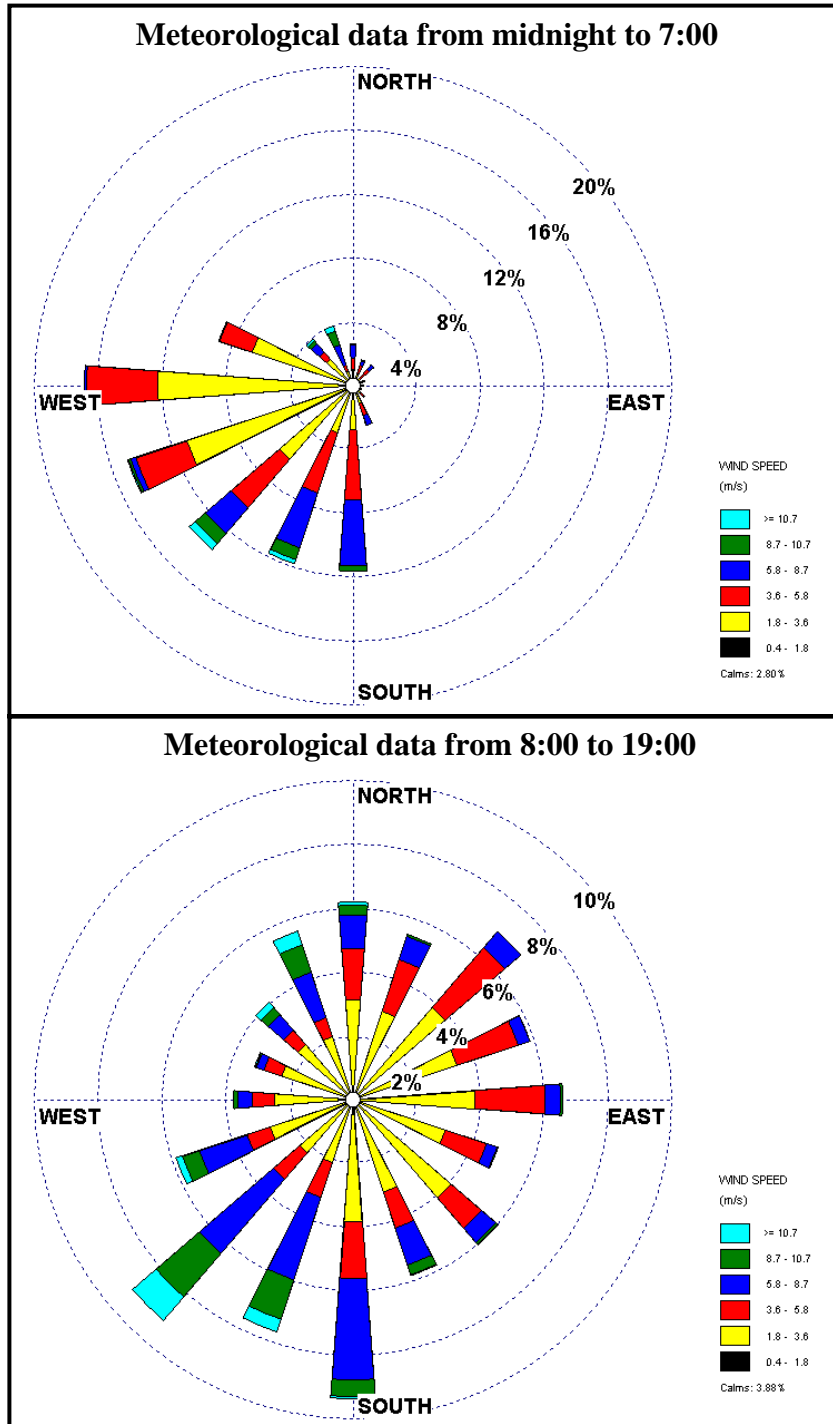


Figure B-4. Diurnal windroses of 1990 through 1992 Las Vegas McCarran International Airport meteorological data.

The Jones segment has a traffic volume of 191,000 AADT. The area north and south of U.S. 95 includes predominately dense residential neighborhoods, as well as industrial or commercial facilities located north of U.S. 95 on the western edge of this segment and south of US95 on the eastern edge of the segment. A thin strip of undeveloped land is located in the center of this segment and north of U.S. 95. This area may potentially be suitable as a study location; however, locating monitors within this thin stretch of vacant land may be difficult due to the proximity of the residential neighborhoods located east and west of this area. In addition, locating a suitable site for a background monitor approximately 1,000 m from this segment of the highway may not be possible.

The Decatur segment has a traffic volume of 193,500 AADT. The area north of U.S. 95 in this segment includes a high school, dense residential neighborhoods, and commercial properties; the area south of U.S. 95 includes a large shopping mall and a large commercial or industrial property. This segment has the greatest potential for a candidate study location due to the large open areas associated with the high school property. Located on the high school property immediately north of U.S. 95 are athletic facilities, such as tennis courts, practice fields, and baseball fields. Based on the predominate wind direction, these open areas provide for the least amount of potential interferences in comparison to the other potential segments. In addition, the east edge of the baseball fields are located more than 300 m from any potentially secondary pollutant sources, such as Decatur Blvd. and Valley View Blvd. Figure B-5 presents an aerial photograph of the Decatur segment and identifies potential monitoring sites locations. A review of the local topography for this area indicates that the elevations for these potential monitoring sites are all within 5 feet of each other (Figure B-6). The only potential interferences associated with this study location are the parking lot of the large shopping mall and the commercial or industrial property south of U.S. 95. However, the large parking lot for the shopping mall is not within the predominate wind direction of the monitoring sites and is beyond 300 m of the closest monitoring site. A more detailed evaluation would have to be conducted to determine if the commercial/industrial facilities, school parking lot, or other potential secondary emission sources could impact the monitoring locations.

Both the Valley View and Rancho segments are potential study segments with annual traffic volumes of 190,000 and 201,000 AADT, respectively. Based on review of aerial photographs of these segments, it appears that the properties adjacent to U.S. 95 in these segments contain numerous industrial facilities. A park is located within the Valley View segment north of U.S. 95; however, a dense residential neighborhood lies between the park and U.S. 95. Based on aerial photographs, a large construction project or industrial property consumes approximately 75 percent of the land south of U.S. 95 within the Valley View segment. This area within the Valley View segment should be further

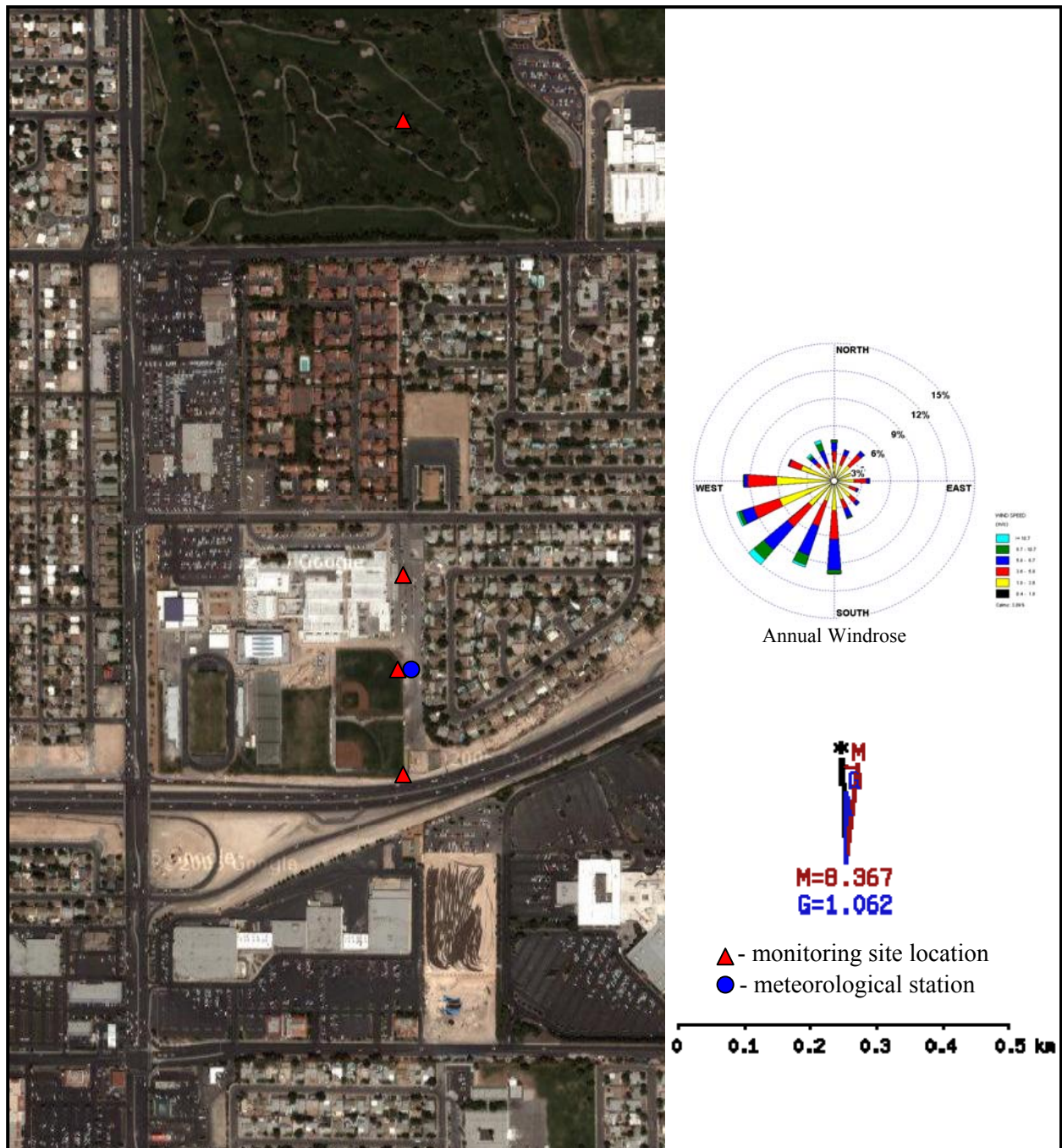


Figure B-5. Aerial photograph of example monitoring site locations along U.S. 95.

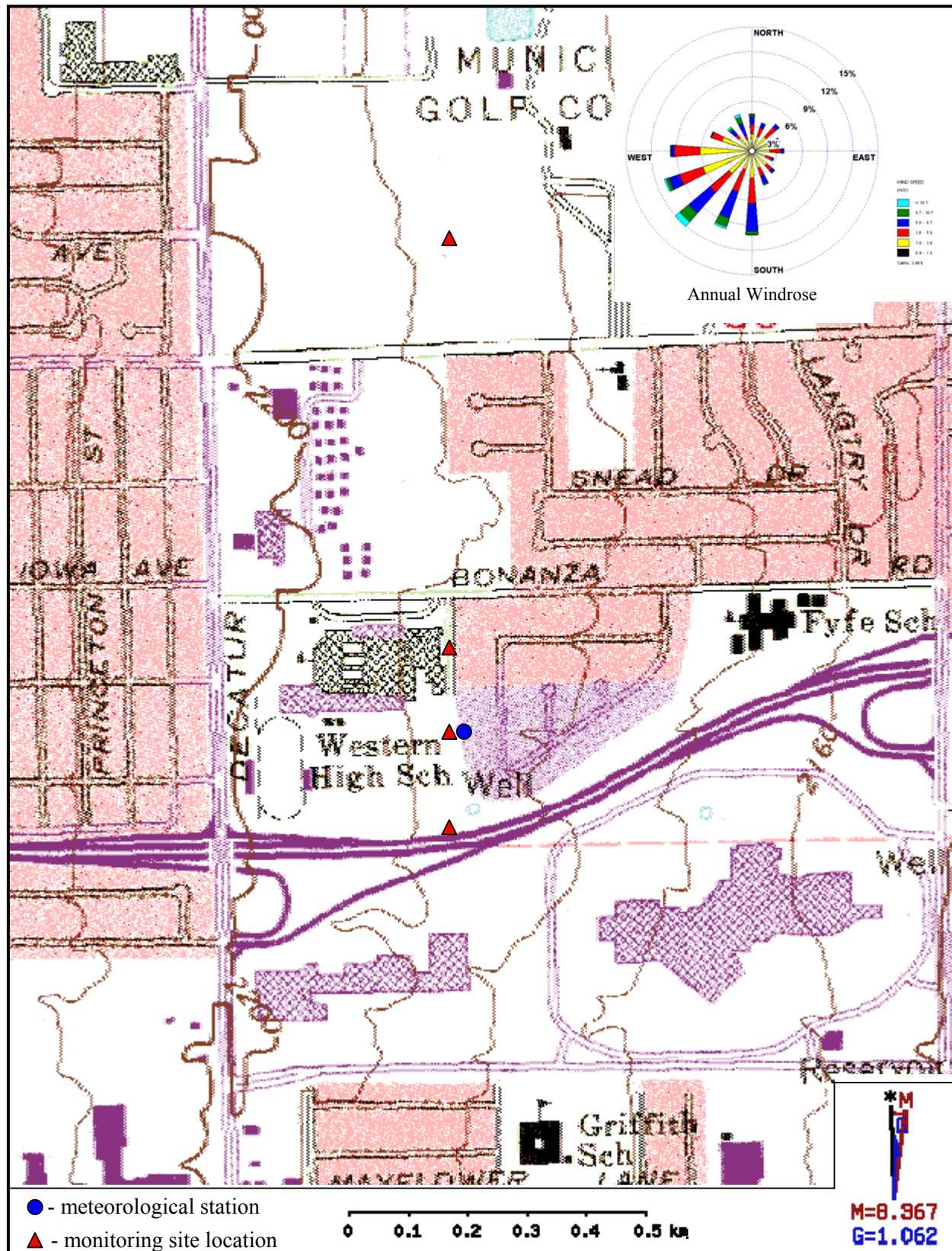


Figure B-6. Local topography of example monitoring site locations along U.S. 95.

evaluated to determine the current land use with respect to potential secondary sources of emissions prior to excluding the segment as a potential study area.

## **B.2 Denver I-25 Example Study Location Selection**

Interstate 25 (I-25) runs north to south for about 300 miles in Colorado from the Wyoming state line to the New Mexico state line. Denver's southeast corridor of I-25 provides the major travel route between two major business districts: the central business district located in the upper end of downtown Denver and the southeast business district located near the interchange of I-25 and I-225. Figure B-7 presents an overview of I-25 from SR 36 (Boulder Turnpike) south through the southeast corridor to Arapahoe Road.

Current transportation projects along I-25 in the Denver area include the Transportation Expansion Project (TREX), the Valley Highway Project, and the Downtown Multimodal Access Plan (DMAP). The TREX project began construction in 2001 and will be completed in 2006. The project is located in the southeast corridor. TREX is a multimodal project that includes widening of I-25 and a light rail line.

The Valley Highway Project includes the reconstruction of I-25 and reconfiguration of interchanges from Logan Street to 6th Avenue, 6th Avenue from I-25 to Federal Boulevard, and the Santa Fe/Kalamath/Consolidated Main Line railroad intersection. The Federal Highway Administration (FHWA) and the Colorado Department of Transportation (CDOT) are in the process of preparing an Environmental Impact Statement (EIS) for the Valley Highway Project.

The Downtown Multimodal Access Plan is a new project of the Department of Public Works. The 25-year plan will include proposals for vehicular, pedestrian, bicycle and rail access into and throughout Downtown Denver. It will also include long-term land-use planning, infrastructure and other elements that will connect downtown Denver to the adjacent communities.

### **B.2.1 Traffic Volume**

Segments of I-25 in the Denver area that contain greater than 150,000 AADT include approximately 20 miles of highway located from Arapahoe Road north to SR 36 (Boulder Turnpike). These segments include an average AADT of approximately 191,000 and a range of 147,400 to 243,300 AADTs. Figure B-8 presents the 2004 AADT values for segments along I-25 between SR 36 and Arapahoe Road.

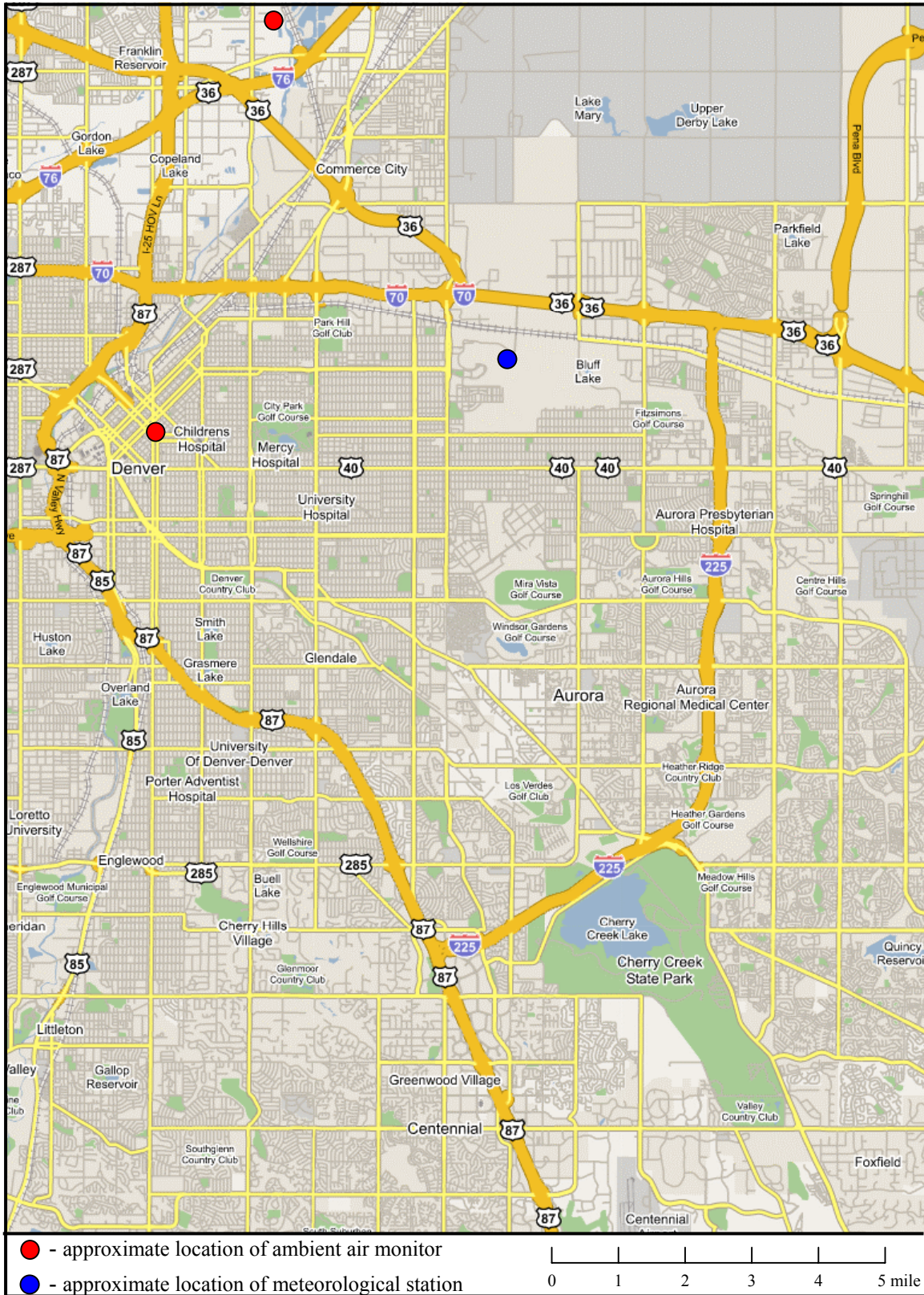


Figure B-7. Overview of I-25 (SR 87) in Denver, Colorado.



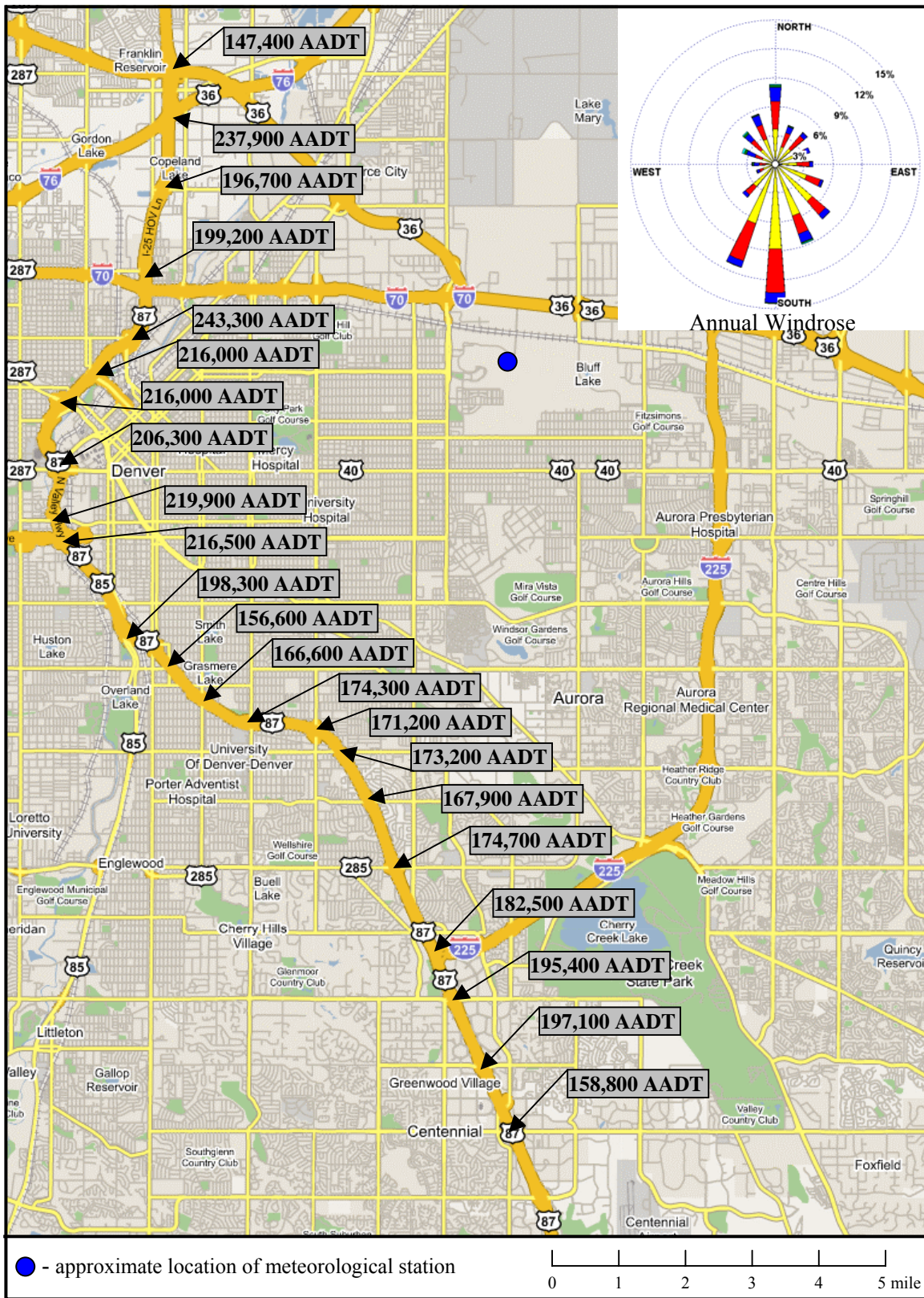


Figure B-8. Map of potential study segments on I-25 in Denver, Colorado.

## B.2.2 Geometric Considerations

Based on review of aerial photographs and USGS topographic maps, the following land uses within the I-25 corridor were determined:

- From SR 36 south to Lincoln Street includes a significant number of industrial facilities with some dense residential and commercial properties.
- From Lincoln Street south to I-225 includes predominantly dense residential neighborhoods with some commercial properties.
- From I-225 south to Arapahoe Road consist mainly of large commercial office buildings with some industrial facilities and dense residential neighborhoods.

Based on potential contributions of MSATs and  $PM_{2.5}$  from industrial sources, the section of I-25 from SR 35 south to Lincoln Street should be avoided when selecting potential monitoring sites. Similarly, the traffic volume on arterial roadways during the morning and evening traffic peaks due to the large commercial office buildings limits the number of suitable study locations from I-225 south to Arapahoe Road. *Therefore, the stretch of I-25 from Lincoln Street south to I-225 should be further evaluated to determine traffic volumes on arterial roadways in order to find study areas with the least potential impacts from other major sources of MSATs and  $PM_{2.5}$ .*

*As previously discussed, potential study sites also will need to be evaluated for potential dispersion interferences along I-25, such as ramps, underpasses, overpasses, noise walls, and below-grade or elevated traffic lanes.*

## B.2.3 Local Meteorological Data

Figure B-9 presents annual, daytime, and nighttime windroses for meteorological data collected from the Denver Stapleton International Airport from 1990 to 1992. As shown in this figure, the predominant wind direction in the Denver area is from the south. However, there is a significant difference in the diurnal wind pattern with a daytime wind pattern predominantly out of the north and a nighttime wind pattern predominantly out of the south. This change in the daily wind pattern presents difficulty in determining the most representative monitoring site locations. Placing monitoring sites north of I-25 will potentially result in the monitors being upwind of I-25 for the majority of the day, but could be downwind or crosswind from I-25 during a significant portion of the day when the daily traffic volume is at its highest. Placing the monitoring sites south of I-25 will potentially result in the monitors being upwind of I-25 during the highest traffic conditions, but will certainly be downwind of the monitors during the nighttime hours. In addition, based on the predominantly north-south direction of I-25, there are only a few sections of I-25 that would allow for monitors to be placed perpendicular to the highway in

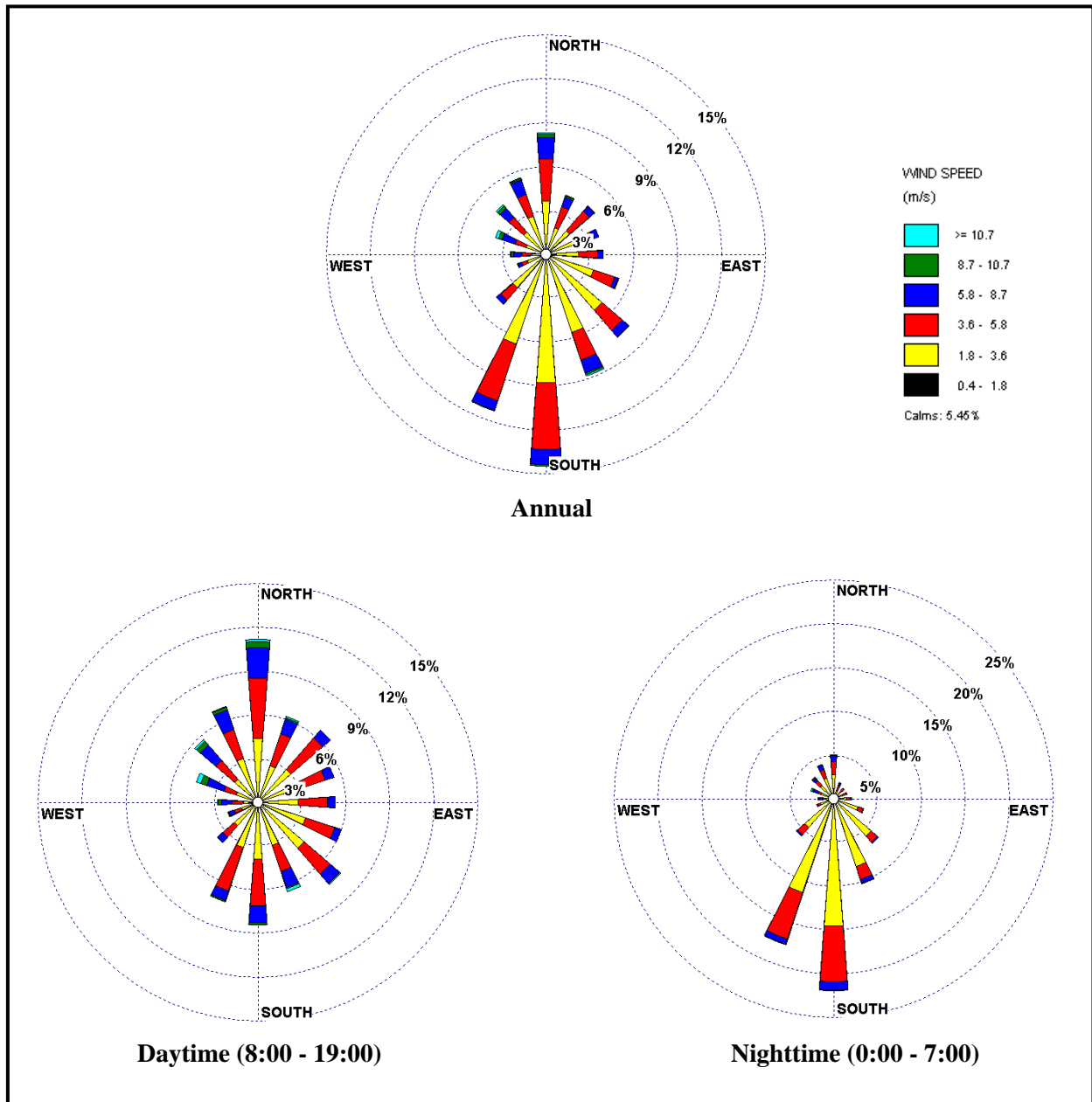


Figure B-9. Annual, daytime, and nighttime windroses from 1900 to 1992 Denver Stapleton International Airport meteorological data.

the north or south direction. Based on these findings, it can be concluded that identifying potential study locations along I-25 in the Denver area that meet the local meteorological criteria will be difficult.

#### **B.2.4 Topography**

Denver is located at the along the transition of the great plains of eastern Colorado with the north-south trending front range of the Rocky Mountains. The topography of the along I-25 in the Denver area is relatively flat with a majority of land within 300 m of I-25 at less than a 5% slope. The topography around the I-25 corridor is influenced by the South Platte River and the Clear Creek. The topography between US 36 and I-70 is relatively flat due to the convergence of the South Platte River and Clear Creek. From approximately I-70 south to US 85, I-25 is located adjacent to the South Platte River, which results in a steady increase in elevation westward from the South Platte River basin. As I-25 runs eastward from the South Platter River, the topography of the land surrounding I-25 flattens out to an average slope of approximately 2% within 300 m of the interstate. *Prior to identifying potential study areas, a more in-depth evaluation of the highway specific topography associated with I-25 will have to be conducted. For example, segments of the highway located significantly below or above ground level elevation may be excluded due to the localized dispersion characteristics associated with these types of roadways. In addition, other road-side structures, such as noise walls, large buildings, and wood lots, must be identified that could act as wind blocks or down wash structures.*

#### **B.2.5 Air Quality Data**

The USEPA's AirData Website contains monitoring data for acetaldehyde, benzene, 1,3-butadiene, formaldehyde, and PM<sub>2.5</sub> from two monitoring sites in the Denver area (78<sup>th</sup> Avenue/Steele Street and 2105 Broadway). The Broadway monitoring site is located in the downtown area of Denver approximately 2 km east of I-25. The 78<sup>th</sup> Avenue/Steele Street monitoring site is located north of SR36 and I-76 approximately 2.8 km east of I-25 and 1.1 km northwest of I-76. Figure B-7 indicates the approximate location of the monitoring sites. Table B-2 presents the 2003 annual average 24-hour concentrations and maximum 24-hour concentrations of acetaldehyde, benzene, 1,3-butadiene, and formaldehydes, and presents the annual mean and maximum 24-hour PM<sub>2.5</sub> concentrations measured at the monitoring sites.

As shown in Figure B-7, the 78<sup>th</sup> Avenue monitoring site is located in an area that can be categorized as a background site in respect to the distance to I-25 or I-76, to major arterial roads, or other potential sources of MSATs or PM<sub>2.5</sub>. The Broadway monitoring site is located in downtown Denver in proximity to I-25, major arterial roads, and other potential emission sources such as several railroad lines.

The ambient concentrations of acetaldehyde, benzene, 1,3-butadiene, and formaldehyde at the Broadway monitoring site are approximately 41%, 22%, 19%, and 119% higher than the 78<sup>th</sup> Avenue site, respectively. These values indicate that the siting location for the background monitor is critical in order to obtain concentrations representative of the background conditions of the study area.

**Table B-2. Summary of the 2003 Ambient Air MSAT and PM<sub>2.5</sub> Concentrations in the Denver Area, µg/m<sup>3</sup>**

Pollutant	Broadway Monitoring Site		78 <sup>th</sup> Ave/Steele St Monitoring Site	
	Annual 24-hour Average Concentration	Maximum 24-hour Concentration	Annual 24-hour Average Concentration	Maximum 24-hour Concentration
Acetaldehyde	3.48	5.49	2.47	3.42
Benzene	2.73	5.21	2.24	4.57
1,3-butadiene	0.25	0.55	0.21	0.55
formaldehyde	6.22	10.09	2.84	3.94
PM <sub>2.5</sub>	10.5 <sup>a</sup>	33	NA <sup>b</sup>	NA

a. Value represents the mean annual concentration for PM<sub>2.5</sub>.

b. NA indicates data not available.

### B.2.6 Potential Study Sites

Based on the annual traffic volume data, geometric layout of the I-25 corridor, topography, and meteorological data, three potential study segments were identified and evaluated to determine the best available study location. The potential study segments were identified based on the varying land use types along the I-25 corridor and include the following:

- Northern segment including I-25 from SR 36 south to Lincoln Street
- Middle segment including I-25 from Lincoln Street south to I-225
- Southern segment including I-25 from I-225 south to Arapahoe Road

As previously indicated, the northern segment passes through numerous industrial facilities in addition to dense residential neighborhoods and commercial properties. This segment of I-25 runs predominantly north/south, while the predominant wind direction is from the south. The northern half of this segment is relatively flat, but the southern half of this segment that runs adjacent to the South Platte River and has an upward slope of approximately 6% along the eastern side of I-25. Based on the site selection criteria, this segment is the least desirable due to the number of other potential emission sources, the predominant wind direction in line with I-25, and the topographic features along the southern portion of the segment.

The middle segment is surrounded by predominantly dense residential neighborhoods with some commercial properties. This segment of I-25 runs mainly northwest/southeast with a small section that runs directly east/west. The topography perpendicular to I-25 in this segment is relatively flat, as the

slope contours run north/south throughout this segment. This segment provides the most potential for selecting suitable monitoring locations for this study. Figure B-10 presents an example of a potential study location within this segment. As shown in this figure, the potential study location is north of I-25, which provides monitors located downwind of I-25. This location provides sufficient area to locate the monitors more than 300 m from other potentially significant emission sources, such as major arterial roads. In addition, all of the monitors, except of possibly the background monitor, would be located at approximately the same elevation, and no significant obstructions are located within this area.

The southern segment is located in an area that consists mainly of large commercial office buildings with some industrial facilities and dense residential neighborhoods. This segment runs mainly northwest/southeast. The topography of this area is relatively flat with less than 5% slope within 300 m of the I-25. Based on the site selection criteria, this segment is less desirable than the middle segment due to the proximity of major arterial roads, the predominant wind direction, and limited areas of unobscured open spaces within 300 m of I-25.

It should be noted that even though it may be possible to locate a suitable study area along I-25 based on the traffic volume, geometric design, topography, and predominant wind direction, the distinct change in daytime and nighttime wind directions does not make this area the most desirable study location. Obtaining sufficient data from this area to distinguish the diurnal dispersion patterns of the MSATs and PM<sub>2.5</sub> may not be achievable. A more detailed review of the local meteorological conditions should be conducted in order to determine if a study location (i.e., downwind) is available that would allow for collection of the diurnal traffic pattern emissions from I-25.

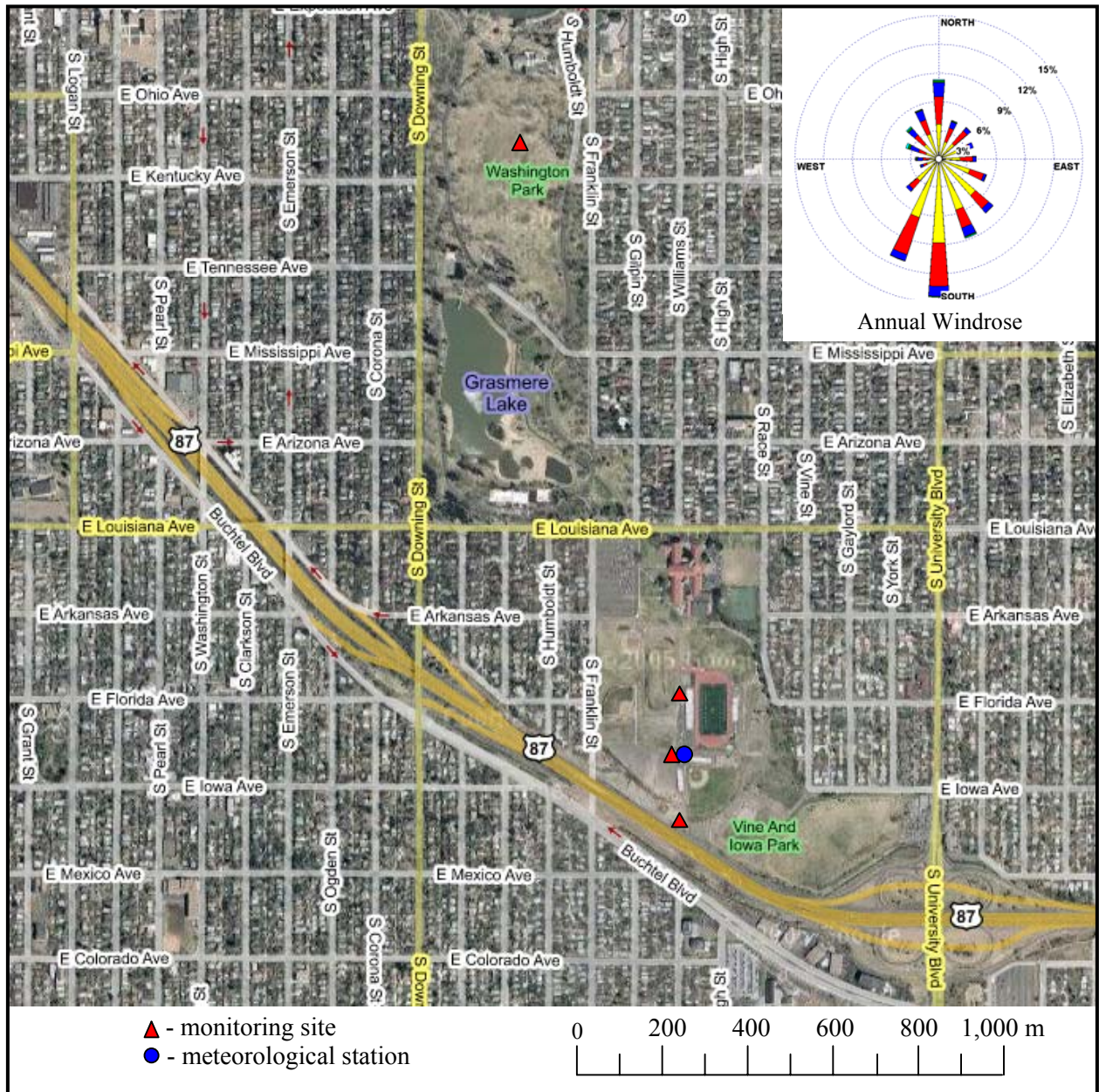


Figure B-10. Aerial photograph of example monitoring site locations along I-25.

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## **APPENDIX C**

### **PROTOCOL FOR CONDUCTING MOBILE SOURCE INVENTORIES FOR THE FHWA MSAT PROXIMITY (US95) STUDY**

**Protocol for Conducting Mobile Source Inventories  
for the FHWA MSAT Proximity (US95) Study**

**Introduction**

The Settlement Agreement between FHWA and Sierra Club for the US95 lawsuit required that FHWA perform an analysis of six mobile source air toxic compounds (MSATs) concentrations in close proximity to “in service” highways in up to five locations in the US. Close proximity was defined as up to 1000 feet from the highway. This distance was selected since some reports indicate that concentrations generated near highways dissipate to urban background levels at this distance. Appendix A, Section A, of the Agreement outlined the process for collecting concentration data for these six “priority” MSATs in addition to traffic and meteorological data. The MSATs for which measurements are required include acetaldehyde, acrolein, benzene, 1-3-butadiene, DPM, and formaldehyde.

In addition to the requirement to collect and analyze the concentration data, the Settlement Agreement also required that emission inventories be developed for baseline (current) conditions and for two time horizons in the future – one at 10 years and one at 20 years. The purpose for the current year inventory is to establish the emissions that exist. These emissions should correspond or certainly influence the concentrations being measured at the study site. The purpose for the two future inventories at 10 and 20 years is to determine the trend of the forecast emissions, and presumably, the resulting concentrations. To undertake the emission inventory requirement, Appendix A, Section B, in the Settlement Agreement stated that emission inventories should be developed using the MOBILE6 model, and potentially, an updated version of this model referred to as the “MOVES”. The “supplemental” section of the protocol described below discusses the required inventories and outlines the procedures to be used to develop the inventories.

**Inventory Development**

As stated in the Settlement Agreement, Appendix A, Section B, emission inventories for the six MSATs are to be developed for three time horizons – present, 10 years and 20 years. This requires calculating emission factors for the vehicles traveling along the highway being studied and determining the number of vehicles referred to as the volume of vehicles. The equation below defines the relationship between the emissions, emission rate and traffic volume and the basis for developing the inventory:

$$\text{Emissions} = \text{Emission Factor} \times \text{Activity level} \quad (1)$$

where

Emissions = the total mass of a compound emitted,

Emission factor = the rate that the emissions are emitted (on a time or distance basis) into the ambient air, typically expressed in grams per mile and,

Activity level = the volume or number of vehicles generating emissions over some defined distance or time (typically expressed as the emissions generated over a one mile stretch and referred to as vehicle miles traveled or VMT).

The MOBILE6 model is the tool that is stated should be used for calculating the emission factor. An alternate model, EMFAC, presumably should be considered for any study conducted in California since California uses the EMFAC Model to develop emission factors just as the remaining states use the MOBILE model. Although the use of MOBILE6 for a California site can be considered if a California site is selected, this option should be discussed with FHWA before any California highway site inventory is developed. The MOBILE and EMFAC models are designed to calculate emission factors for “regional” inventories, which are not the purpose of this exercise to develop an inventory at a specific site. Unfortunately, EPA has endorsed no other methods currently available so these models are the methods suggested for this study.

Other analysis methods employ the MOBILE6 model for developing inventories including the NMIM inventory model and the CONCEPT model for estimating the contribution of emissions along specific highway segments or “links” for an entire regional network. NMIM is used for developing emission inventories on a countywide basis and may not be useful for this exercise. The CONCEPT model is used in conjunction with a traffic modeling tool, T3, to adjust the outputs of standard traffic forecast models such as EMME2 and Transplan and enables the calculation of an emission inventory along a specific highway link. The adjusted traffic data is used with the CONCEPT-generated emission factor for that link to provide an emission inventory along the specific link of interest. Use of the CONCEPT-T3 model tool may or may not be as useful as the standard use of MOBILE6 with separately generated traffic data. The CONCEPT model also uses the MOBILE6 model to estimate the emission factors.

The Inventory Protocol for MSATs should be developed using the same approach used for developing PM, ozone, or other criteria pollutant inventories for mobile sources. This generally requires an area to determine its fleet composition, traffic characteristics and control strategies implemented over the region. Traffic data should be based on current data for the baseline case and projections for the future time horizons. All studies will be initiated by the summer of 2007 and completed within one year. Based on this schedule, the baseline inventory would be 2007 and the future year inventories would be developed for 2017 and 2027. In the case of the MSAT Proximity Study, only a subset of the data typically used in mobile source inventories is required since the analysis is limited to the area boundaries of the study being conducted, not a region.

### **Estimating Emission Factors Using MOBILE6.2**

The MOBILE6 model was designed to estimate regional emissions and not project emission such will be measured for this study. However, since only one site is being studied, careful selection of inputs specifically tailored to the site may provide reasonable estimates. It is essential to use the estimates calculated by the models (and traffic forecasts too) in a *relative comparison process*. Treating the calculations of either the emission factors or the traffic estimates as *absolute values* will be incorrect due to the “regional” design properties of the programs or estimate assumptions.

Other analysis approaches may be considered to achieve the specific goal – measurement of the emissions at the study site, not regionally. For the purposes of this study, the emission factors should be calculated with MOBILE6 and traffic activity from any standard traffic estimation approach. Whichever approach used, the forecasting must be tailored to the characteristics of the site itself to provide a better estimate of the emissions for that site.

The volatile organic compound fractions (VOCs) include acetaldehyde, acrolein, benzene, butadiene, and formaldehyde should be calculated using the same information as used when developing the ozone precursor emission factors since the MSAT factors are fractional portions of the HC/VOC emission rates. MOBILE does require specific information for these factors in addition to the data required for the precursor and this is defined in the MOBILE6 User Guide provided by EPA.

Estimating the diesel particulate matter (DPM;  $DPM = PM + \text{Diesel Exhaust Organic Gases} - \text{DEOG}$ ) emission factor using the MOBILE model requires running the model for particulate matter (PM) associated with the diesel fleet (i.e. LDDV, LDDT, HDDT) but only using the emission factors associated with elemental carbon, organic carbon, and sulfate). These emission factors should then be weighted by the each vehicle type contribution and summed to yield the DPM emission factor. Vehicle count estimates for the diesel vehicles passing through this site provide the “activity” value for the DPM calculation. Multiplying this activity level and the corresponding diesel emission factor will provide the total emission quantity of DPM generated by the diesel vehicles passing this site.

### **Estimating the Traffic Activity (VMT, AADT)**

For activity levels, the volume can be estimated from either traffic demand models or from records of current traffic volumes including HPMS data. The baseline traffic volume should use the average traffic volume measured over the sampling period at the sampling site. This activity level is usually expressed in terms of average annual daily traffic (AADT). Air quality planners typically use another term, the vehicle miles traveled (VMT) since they are estimating the volume for all highway facilities in a regional area rather than the volume of traffic associated with any one specific highway or highway link. Transportation planners use the AADT term since their work focuses on each facility and the links on those facilities. These two terms can be used interchangeably providing certain assumptions are made. For the MSAT Proximity Study being described here, a specific location along a highway or highway link is being investigated and the AADT for that highway can be equated to the VMT if it is assumed that the site is one mile long. Since AADT refers to the total number of vehicles passing a point over a 24-hour period of time, or the average annual *daily* traffic, this equals the VMT as long as it is referring to all vehicles traveling in all lanes over that one-mile segment. The VMT term defines all the miles of all facilities in a region, however, if the “region” is considered to the specific site of interest over a one mile segment (irregardless of whether the facility includes 2, 4, or more lanes of traffic) the number of vehicles traveling over this one mile segment is equal to the vehicle miles traveled over that segment (say, 150, 000 AADT X 1 mile = 150, 000 VMT/mile). Thus, unless estimates are being made for periods of time less than 24 hours (say one hour) or for only some of the lanes (say 2 lanes of a 4 lane facility) on the facility, the VMT for a specific stretch of highway can be assumed to correspond to the daily volume or the AADT.

For daily inventories, the number of lanes is not important since the AADT counts refer to the total capacity (vehicles using all lanes) of the facility at a specific point, whether there are two lanes, four lanes or some other number of lanes. If however, an hourly volume is desired, the number of lanes may be important since estimates may be made based on the capacity of each lane. A facility with four lanes would have a capacity of 2300 vehicles per lane per hour or  $4 \times 2300 = 9200$  vehicles (9200 VMT) and a facility with six lanes would have a capacity of 2300 vehicles per lane per hour or  $6 \times 2300 = 13,800$  vehicles (13,800 VMT). The capacity per lane (2300 in the example) will vary due to several factors. None of this should be relevant to this study, but may be useful if some optional issues wish to be studied.

For traffic activity, forecasting programs must be used for the future scenarios since traffic counts for the future are unavailable. Many models exist that can be used for these estimates. The recommendation would be to use the model currently used in the area or contact the State DOT or MPO and request the estimates for the traffic segment where the study is being conducted. Simpler approximations are possible by using the currently measured traffic volume for the base year and multiplying it by a growth factor. Equation 2 can be used for this estimate.

$$\text{Future Traffic Volume} = \text{Present Traffic Volume} \times (1 + \text{Growth Rate})^{\text{time}} \quad (2)$$

Future Traffic Volume = Volume in 10 years, 20 years

Present Traffic Volume = Volume measure at site for baseline

Growth rate = historical growth rates for the area (generally 3 % per year)

Time = number of years in future (10 years, 20 years)

An example may be useful to illustrate the possible traffic volume for the 10 year time horizon using a growth rate of 3%, time horizon of 10 years, and current AADT of 150, 000:

$$10 \text{ Years Traffic Volume} = \text{Baseline Traffic Volume} \times (1 + 0.03)^{10}$$

$$10 \text{ Years Traffic Volume} = 150, 000 \times (1 + 0.03)^{10}$$

$$10 \text{ Years Traffic Volume} = 201, 587$$

In either case (models or simple calculation methods), both yield approximations since forecasting for the future is difficult and contains considerable inaccuracy. Growth rates of traffic assume population changes dependent on community growth, job growth, economic activity, and personal driving habits among other items. As in the case of the emission factors, travel activity for the inventories must be adjusted for this future growth when projections are made for future years.

An example below is provided to define the requirements of developing the inventory.

#### Example

The inventory should be developed as illustrated in the example below and summarized in Table 1. MOBILE6 was used to generate the emission factors for the base year only. Future estimated emission factors were assumed to be fractions of this, 50% reduction of the base year for 10 year horizon, and for the 20 year horizon year, an additional 40% reduction from base year over the 50% already reduced for the 10 year horizon year (50% + 40% = 90% reduction over the base year). Traffic volume projections for the 10 and 20 year horizon years used the equation (2) to generate the projected increases over the baseline year. It is possible that some loadings will remain the same or even increase due to additional traffic volume. It must also be noted, however, that additional reductions not accounted for by the model would likely reduce any increases as can be seen looking back 20 years from today.

An inventory of the emissions from vehicles along a stretch of Highway 50 as it passes through Sootville is desired. Highway 50 stretches between Emitsburg to the south and Sickton to the north. Highway 50 is a six-lane road through Sootville, three lanes north and three lanes south. The one-mile stretch of Highway 50 through Sootville is the section of the highway that is of interest and will be monitored. The emissions generated along this stretch of highway need to be calculated for the inventory. Each linear mile of the Highway 50 roadway is equivalent to six

miles of traffic and the average annual daily traffic (AADT) volume has been measured as 150,000 vehicles is based on all six lanes of traffic. This measured volume of these vehicles is over the same one mile segment of highway over a 24 hour (one day) time frame and therefore is equivalent to 150,000 VMT (or AADT). With this information, the emission inventory can be calculated as:

$$\text{Emissions} = \text{Emission Factor} \times \text{Activity level}$$

$$\text{Emissions} = \text{Emission Factor} \times 150,000 \text{ AADT/mile}$$

The emissions factor is dependent on the types of vehicles traveling along Highway 50 – small cars, large trucks, gasoline vehicles, and diesel vehicles among other types of vehicles. Each of these emit different amounts of each of the MSAT compounds. The MOBILE model calculates the individual emission rates for each compound and each different vehicle type. MOBILE also calculates a “composite” emission rate for all vehicle classes if just one rate for all vehicles is desired. For this inventory, only one composite rate is needed since the inventory is intended to be general and is not trying to establish the emissions of specific vehicle types. In this example, a composite emission rate is selected for benzene. The emission rate is 45.46 milligrams/mile (as calculated by the MOBILE6.2 model) and the inventory is then computed as:

$$\text{Emissions} = \text{Emission Factor} \times \text{Activity level}$$

$$\text{Emissions} = \text{Emission Factor} \times 150,000 \text{ AADT/mile}$$

$$\text{Emissions} = 45.46 \text{ milligrams/mile} \quad \times 150,000 \text{ miles}$$

$$\text{Emissions} = 6,819,000 \text{ milligrams}$$

$$\text{Emissions} = 6,819,000 \text{ milligrams} \times 0.0000000102 \text{ tons/milligram}$$

$$\text{Emissions} = 0.007 \text{ tons/day}$$

So the inventory for this one compound, for this location, for the baseline condition, is 0.007 tons per day. This same process must be completed for 10 years and 20 years in the future.

### **Future Version of MOBILE6 (MOVES)**

Appendix A of the Settlement Agreement suggest the use of the MOBILE6.2 replacement model, MOVES. It is unclear the viability of this suggestion since the MOVES model is not available and may not be officially released before this study is completed. The uncertainty in its release date and its accuracy when released will complicate the terms of this requirement. The MSAT Proximity Study is likely to be completed in the 2008 or 2009 calendar year which may be before the model is officially released and endorsed. Should MOVES be released later than 2007, the timeliness for using the model is questionable. FHWA should be consulted when developing the inventories requiring the use of MOVES.

### **Results**

The inventories developed as discussed above now must be compared to determine the impact of vehicles on mobile source contributions.

**References**

- 1) Technical Description of the Toxics Module for MOBILE6.2 and Guidance on its Use for Emission Inventory Preparation, EPA, EPA420-R-02-029, November 2002.

**Table 1. Emission Projections for Study Site.**

Pollutant	Baseline (2007)			10 Year Horizon (2017)			20 Year Horizon (2027)		
	EF (mg/mi)	Traffic Volume	Loading (tons/day)	EF (mg/mi)	Traffic Volume	Loading (tons/day)	EF (mg/mi)	Traffic Volume	Loading (tons/day)
Acetaldehyde	6.36	150,000	0.001	3.18	201,587	0.0006	0.64	270,917	0.0001
Acrolein	0.46	150,000	0.0001	0.23	201,587	0.00005	0.05	270,917	0.00001
Benzene	45.46	150,000	0.007	22.73	201,587	0.005	4.55	270,917	0.0012
1,3-Butadiene	5.09	150,000	0.0008	2.54	201,587	0.0005	0.51	270,917	0.0001
DPM	0.90	15,000	0.00001	0.45	20,159	0.00001	0.09	27,092	0.00003
Formaldehyde	11.55	150,000	0.002	5.78	201,587	0.0012	1.16	270,917	0.0003

**Notes:** This table is only meant to serve as an example. Emission Factors (EF) were calculated using the MOBILE6.2 Emission Factor Model and generic input data. Emission model input data for the specific site should be used to calculate the EF. This example assumes 150,000 AADT for the base year. This number will vary according to site and needs to be adjusted for each site. The loading in this table is expressed in tons/day. Tons are calculated by multiplying the EF X Traffic Volume X (0.000 000 00102 tons/milligram). Since the traffic volume is a daily average, the resulting emission loading is expressed as tons per day. Note DPM uses a lower traffic volume based on the estimated diesel fleet (in this case 10 % of AADT).

Conversion factor from milligrams to tons = multiply milligrams by 0.000 000 001 02  
 405, 000 milligrams = 452 grams = 1 lb; 2000 pounds = 1 ton; 1 / (405,000 milligrams/lb X 2000lb/ ton) = 0.000 000 00102 tons/mg

Example (benzene): 45.46 milligrams/vehicle-mile X 150, 000 vehicle-mile/day X 0.000 000 00102 tons/milligram = 0.007 tons/day