

# **THE 1999 BROWN CLOUD PROJECT FOR THE MARICOPA COUNTY AREA**

**Draft Final Report**

**October 1999**

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## **EXECUTIVE SUMMARY**

### **ES.1 INTRODUCTION**

Many residents of Maricopa County are attracted to the area by the warm winters and the clear air typical of deserts in the western United States. Most of the year, the air is much clearer in Maricopa County than in the eastern United States. However, on calm fall and winter mornings, dark-colored hazes are often observed over the urban parts of Maricopa County. These hazes have come to be known as brown clouds and are of concern among local residents.

The complaints about brown clouds by residents are mostly based on aesthetics. Residents also tend to use the visual quality of the air as a yardstick by which air pollution is measured. They are concerned that brown clouds are unhealthy.

Consequently, the Maricopa Association of Governments (MAG) conducted this study to recommend feasible measures to abate the brown clouds that occur in Maricopa County. The study topics include: 1) background information on brown clouds in western urban areas; 2) brown clouds in Maricopa County; 3) sources of emissions in Maricopa County primarily responsible for brown clouds; and, 4) recommendation of six potential control measures available to decrease the emissions from these sources.

The study was expanded to include the application of source emission profiles measured in a recent study in the Denver area to Maricopa County air quality data. The purpose was to determine if these profiles could reasonably account for air quality conditions in Maricopa County. It was found that these

source profiles could explain the Maricopa County air quality data reasonably well. In addition, these applications indicated that the relative importance of emission sources was similar to the ranking for the Denver area.

Six control measures are recommended by this study to decrease emissions contributing to the brown cloud. Many control measures implemented to comply with Federal air quality regulations for carbon monoxide, ozone, and particulate matter will also reduce emissions that contribute to brown clouds. The six recommended measures were chosen because they were not being implemented by other programs, and would directly control those pollution sources most responsible for the brown cloud. The six recommended measures would need to be further evaluated for feasibility by the respective implementing entities.

It is important to note that the 1999 Brown Cloud Project is not intended as a State Implementation Plan revision for any air pollutant including PM<sub>10</sub> and PM<sub>2.5</sub>.

### **ES.2 BACKGROUND INFORMATION ON URBAN BROWN CLOUDS**

Brown clouds occur over most urban areas in the western United States. Brown clouds are hazes with a brown appearance. Haze is a suspension in the atmosphere of minute particles that are not individually seen but, nevertheless, impair visibility. These particles are called particulate matter, or PM. The dominant cause of haze in urban areas is light scattering by particles with a diameter less than 2.5 micrometers. These particles are called fine particles or PM<sub>2.5</sub>.

The hazes appear brown because of light absorption by elemental carbon, which has a chemical form similar to the graphite used in pencil leads. The days when brown clouds occur are determined by the weather. Brown clouds occur on calm mornings during fall and winter when the cool air near the ground forms a stable layer that traps emissions near the surface.

The dominant source of PM<sub>2.5</sub> is combustion sources, primarily gasoline and diesel engine exhaust. Decreasing the amount of elemental carbon in brown clouds will decrease the dark or brown appearance of the haze and may be visually rewarding. Because elemental carbon absorbs light very efficiently and contributes to the dark appearance of brown clouds, the control strategies recommended place greatest emphasis on decreasing the emissions of elemental carbon.

The new PM standards were published by the EPA Administrator in July 1997. These standards place limits on the concentrations of both PM<sub>2.5</sub> and PM<sub>10</sub>. However, on May 14, 1999, a three-judge panel of the U.S. Court of Appeals for the District of Columbia Circuit issued a split opinion regarding the final national air quality standards for ozone and particulate matter that the Environmental Protection Agency promulgated in July 1997. With respect to the particulate matter standards, the Court vacated the revised coarse particle (PM<sub>10</sub>) standards, and the pre-existing PM<sub>10</sub> standard continues to apply.

Regarding the PM-2.5 standard, the Court upheld EPA's decision to rely on the regional haze program to mitigate some of the adverse visibility effects caused by PM-2.5. The Court also asked for further briefing on several issues. On June 18, 1999, the Court ruled that the PM<sub>2.5</sub> standard should remain in place. However, the Court will allow parties to

apply for the standard to be vacated if "the presence of this standard threatens a more imminent harm." Presumably, the "harm" refers to the burden on sources complying with the regulations.

On June 28, 1999, EPA and the Department of Justice filed a petition for rehearing en banc with the D.C. Circuit. EPA continues to support the need for the health protections that these revised standards provide as well as the science backing them. In general, EPA was encouraged that the panel of judges did not question the scientific basis of the standards; rather the panel questioned the constitutionality of the primary public health provisions of the Clean Air Act.

### **ES.3 URBAN BROWN CLOUDS IN MARICOPA COUNTY**

Airport visibility observations provide an indication of a decrease in regional haze in Maricopa County, but for reasons discussed in the report, do not provide information about trends in brown clouds in Maricopa County.

Starting in December 1993, the Arizona Department of Environmental Quality (ADEQ) began measuring light extinction over a 3-mile sight path in Phoenix. The data provide a measure of the severity of the brown clouds and indicate that the haze in Phoenix is highly variable. Severe hazes mostly occur from late September through February and rarely occur during the spring or summer. During the fall and winter, the weather may cause the air to be clear or very hazy at any time of day.

Soil dust is mostly composed of particles too large to scatter light efficiently. About half of the PM in Maricopa County is soil dust, but this dust is typically responsible for less than 10

percent of the light scattering that causes brown clouds. Elemental carbon absorbs light very efficiently. Light absorption by elemental carbon is primarily responsible for the dark or brown appearance of most urban hazes.

#### **ES.4 IMPORTANT SOURCES**

Information on the emission sources in Maricopa County that make the largest contributions to brown clouds was derived from chemical mass balance (CMB) calculations performed during this study and as part of the 1989-1990 Phoenix PM<sub>10</sub> Study and the 1989-1990 Phoenix Urban Haze Study. Briefly, CMB is a mathematical method that finds the combination of emission sources that best accounts for the pollutant concentrations measured in the atmosphere at the time and location where a pollution sample was collected. The emission inventory information contained in the MAG 1999 Serious Area Particulate Plan for PM<sub>10</sub> for the Maricopa County Nonattainment Area was also used. These two types of information on emission sources were used to identify sources that make the largest contribution to brown clouds.

In addition, a series of sensitivity tests and reasonableness checks were performed on the CMB data. In general, the sensitivity tests indicated that the source apportionments are highly sensitive to changes in source profile selection and that other source attributions with acceptable statistics may be obtained from the same data set using different combinations of source profiles. Accordingly, the source apportionments derived from a CMB analysis should be thought of as representing the general level of contribution from a source and not an absolute number.

As shown in Figure ES-1, combustion sources emissions constitute the majority of PM<sub>2.5</sub>. Gasoline engine exhaust accounts for about half of the ambient PM<sub>2.5</sub> and diesel engine exhaust accounts for about 15 percent. In addition, gasoline and diesel exhaust account for nearly all of the carbonaceous fraction of the fine particles (organic carbon and elemental carbon).

When interpreting the results from the CMB analysis, it is important to keep in mind the limitations of the model and view the results as the general level of contributions from a source.

The results presented have different levels of confidence associated with them. For example, there is a relatively high level of confidence in estimates for the contribution of total mobile source exhaust, ammonium nitrate, ammonium sulfate, and geological material. There is a lower level of confidence associated with the split in mobile source exhaust between diesel-powered engines and gasoline-powered engines. There is low confidence that the CMB attribution of gasoline-powered engines emissions to cold start, high emitter, and hot stabilized is accurate.

#### **ES.5 CONTROL MEASURES TO REDUCE THE BROWN CLOUD**

Based on literature reviews, interviews, and research done to complete the Serious Area PM<sub>10</sub> Plan, the study team identified over 40 candidate brown cloud control measures. The candidate measures were screened using factors such as technical feasibility, ability to augment existing programs, and applicability to important brown cloud sources. In addition, the committed control measures from the State and local governments in the MAG 1999

Serious Area Particulate Plan for PM<sub>10</sub> were applied to the appropriate source categories to identify where additional control measures were needed. Six measures were recommended for consideration because they were not being implemented by other programs and would directly control those pollution sources most responsible for the brown cloud. These recommended measures would need to be further evaluated for feasibility by the respective implementing entities.

One of the steps in the control measure identification and screening process involved identifying existing Maricopa County control measures that will mitigate the brown cloud. The effort focused on reviewing committed measures from the State and local governments in the MAG 1999 Serious Area Particulate Plan for PM<sub>10</sub> and previous plans. **Tables ES-1 and ES-2** summarize both Federal actions and State and local government measures by source category. Table ES-1 addresses the most important brown cloud combustion sources, which include: nonroad mobile diesel exhaust and onroad mobile diesel and gasoline exhaust. Table ES-2 lists several control measures that offer only minor brown cloud control benefits. They are included in this report to illustrate particulate matter air quality control efforts already underway in the Maricopa County area.

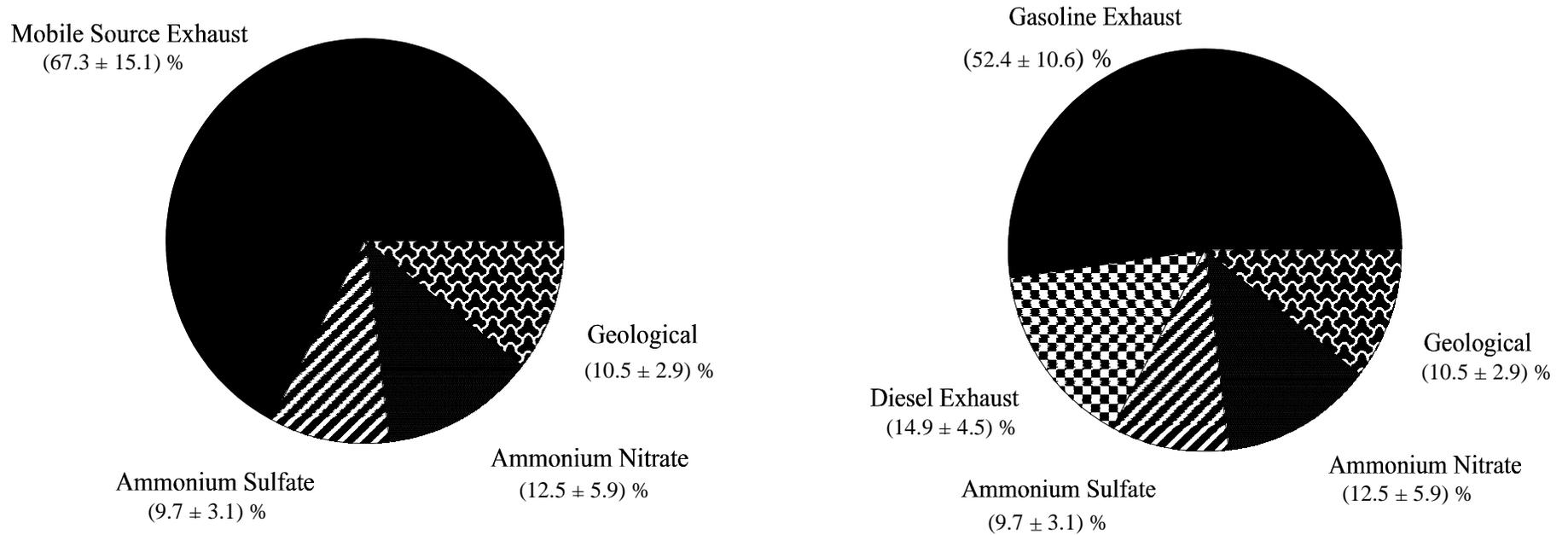
Table ES-2 addresses sources of dust. As detailed in the Serious Areas PM<sub>10</sub> Plan, dust is the single most important component of the Maricopa County PM<sub>10</sub> problem. Although dust is not a major contributor to brown clouds, dust controls do provide some modest brown cloud mitigation benefits. The dust control measures are presented in this report to illustrate particulate matter air quality control efforts already underway in the Maricopa County area.

The overall control strategy focused on reducing nonroad and onroad diesel emissions, and reducing emissions from high PM-emitting onroad gasoline powered vehicles. Mobile source control measures fall into four categories: establishing more stringent new-vehicle standards; retrofitting and replacing older vehicles; reformulating the fuels used; and restricting or changing the use of the vehicle or engine. These four control measure approaches directly reflect the parameters controlling the amount of pollution produced by mobile sources. Table ES-3 briefly highlights how these parameters and control measure approaches relate to the important sources contributing to the brown cloud. The table identifies important sources, important pollution parameters for each source, and how the recommended measures relate to the parameters responsible for pollution to create the brown cloud.

In addition to the six recommended measures, two additional measures are suggested for further study. These measures include:

- Implementing the use of remote sensing devices (RSDs) capable of detecting smoking vehicles.
- Implementing an IM program enhancement to detect or test for smoking vehicles or particulate matter high emitters.

Figure ES-1. PM-2.5 source contributions from the CMB analysis of samples from the Phoenix Super Site.



The data in the parenthesis represent the mean percentage and standard deviation with 95% confidence.

Note: The lack of source profiles in the CMB analysis for wood burning and meat cooking likely results in an overestimate of the emissions from diesel and gasoline-powered engines. The contribution from gasoline-powered engines is likely to be overestimated to a greater extent than the contribution from diesel-powered engines.

Table ES-2. Minor brown cloud sources, state and local government measures.

Source Category and Sources	State and Local Government Measures
I. Nonroad Mobile Sources – gasoline	<p><u>Exhaust Standards</u>: Off Road Vehicle Engine Standards</p> <p><u>Fuel</u>: Winter Fuel Reformulation: California Phase 2 Reformulated Gasoline with 3.5 Percent Oxygen Content November 1 through March 31</p> <p><u>I/M</u>: none.</p> <p><u>Use Management</u>: Encourage the Use of Temporary Electrical Power Lines Rather than Portable Generators at Construction Sites</p> <p>Voluntary Lawn Mower Emissions Reduction Program</p> <p>Restrictions on the Use of Gasoline-Powered Blowers for Landscaping Maintenance</p>
Area Sources	<p>Restaurant Charbroiler Controls</p> <p>PM-10 Episode Thresholds</p> <p>Clean Burning fireplace Ordinance</p> <p>Public Information Program on Wood Stoves and Wood Heat</p>
Point Sources	<p>PM-10 Best Available Control Technology (BACT) Determinations for Stationary Sources</p>

Table ES-2. Minor brown cloud sources, state and local government measures.

Source Category	State and Local Government Measures
Fine Soil Dust - Fugitive/Windblown	PM-10 Efficient Street Sweepers  Curbing, Paving, or Stabilizing Shoulders on Paved Roads (Includes Painting Stripe on Outside of Travel Lane)  Paving, Vegetating and Chemically Stabilizing Unpaved Access Points Onto Paved Roads (Especially Adjacent to Construction/Industrial Sites)  Reduce Particulate Emissions from Unpaved Shoulders on Targeted Arterials  Crack Seal Equipment  Frequent Routine Sweeping or Cleaning of Paved Roads  Strengthening and Better Enforcement of Fugitive Dust Control Rules*  Reduce Particulate Emissions from Unpaved Roads and Alleys  Low Speed Limit for Unpaved Roads  Use of Petroleum Products for Public Road and Street Maintenance  Agricultural Best Management Practices  Additional Dust Control Measures (City of Tempe)  Additional Dust Control Measures (City of Phoenix)

\* Includes:

2. Reduce Particulate Emissions from Unpaved Parking Lots
3. Reduce Particulate Emissions from Vacant Disturbed Lots
4. Dust Control Plans for Construction/Land Clearing and Industrial Sites (Including Active landfills), with Elements Addressing Trackout Prevention, Site and Material Maintenance, Construction Staging, and High Wind Operating Restrictions
5. Dust Abatement and Management Plans for State Lands.

# 1. INTRODUCTION

Many residents of Maricopa County are attracted to the area by the warm winters and the clear air typical of deserts in the western United States. Most of the year, the air is much clearer in Maricopa County than in the eastern United States. However, on calm fall and winter mornings, dark-colored hazes are often observed over the urban parts of Maricopa County. These hazes have come to be known as brown clouds and are of concern among local residents.

Nearly all major urban areas in the inland portions of the western United States experience wintertime brown clouds. Air quality studies have been performed in many of these areas, including Maricopa County, to understand the composition of brown clouds and the emission sources that make the most important contributions. These studies have shown that brown clouds in western cities have more similarities than differences.

The complaints about brown clouds by residents are mostly based on aesthetics. Residents also tend to use the visual quality of the air as a yardstick by which air pollution is measured. They are concerned that brown clouds are unhealthy.

Consequently, the Maricopa Association of Governments (MAG) conducted this study to recommend feasible measures to abate the brown clouds that occur in Maricopa County. The study topics include: 1) background information on brown clouds in western urban areas, 2) brown clouds in Maricopa County, 3) sources of emissions in Maricopa County primarily responsible for brown clouds, and 4) recommendation of six potential control

measures available to decrease the emissions from these sources.

The study was expanded to include the application of source emission profiles measured in a recent study in the Denver area to Maricopa County air quality data. The purpose was to determine if these profiles could reasonably account for air quality conditions in Maricopa County. It was found that these source profiles could explain the Maricopa County air quality data reasonably well. In addition, these applications indicated that the relative importance of emission sources was similar to the ranking for the Denver area.

This Final Report is divided into six chapters. The four chapters that follow this introduction summarize the key results for each study topic listed above. The final chapter contains the references for the report.

Detailed information is presented in eight appendices. Appendix A is a Glossary that defines many of the terms used in this report that may be unfamiliar to many readers. Appendix B contains a discussion of the light-extinction coefficient. This coefficient is universally used to quantify the severity of haze, including brown clouds. It is useful for the reader of this report to understand the parameter research workers use to measure brown clouds. The remaining appendices provide detailed information supporting the discussions in Chapters 2 through 5.

An effort was made to present the information in Chapter 2 on urban hazes in the western United States in an easily readable style. This chapter could be used as a stand-alone introduction to brown clouds.

Chapter 5 presents six control measures recommended by this study to decrease emissions contributing to the brown cloud. As noted in the chapter, many control measures implemented to comply with Federal air quality regulations for carbon monoxide, ozone, and particulate matter will also reduce emissions that contribute to brown clouds. The six recommended measures were chosen because they were not being implemented by other programs, and would directly control those pollution sources most responsible for the Brown Cloud. The six recommended measures would need to be further evaluated for feasibility by the respective implementing entities.

## 2. BACKGROUND INFORMATION ON URBAN BROWN CLOUDS

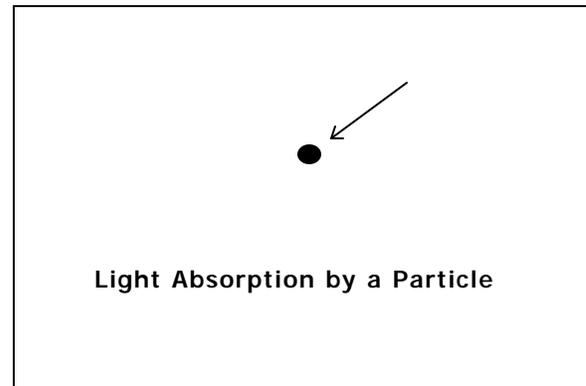
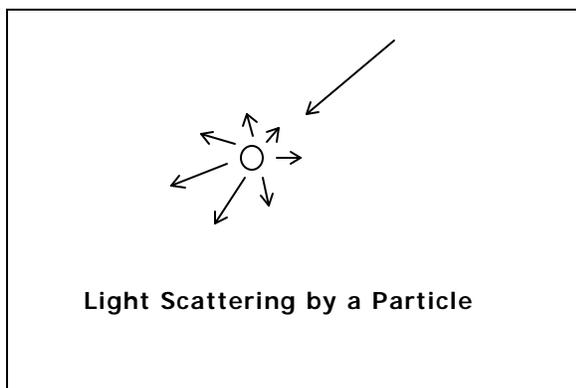
### 2.1 INTRODUCTION

The following description of the brown clouds that occur over most urban areas in the western United States is intended to provide a general understanding of the properties and causes of these urban hazes. Because there are more similarities than differences between the brown clouds in western cities, the description here is general and applies to most western cities. The properties and causes of the brown clouds in Maricopa County are discussed in Chapters 3 and 4.

### 2.2 WHAT ARE BROWN CLOUDS?

Brown clouds are hazes with a brown appearance that occur over urban areas. Haze is a suspension in the atmosphere of minute particles that are not individually seen but nevertheless impair visibility.

Haze particles cause visibility impairment by scattering and absorbing light. When particles scatter light, they change the direction of travel of the light. A dense fog or water clouds in the sky are examples of strong light scattering.



When particles absorb light, the light is removed from the atmosphere and turned into heat. Increasing the light absorption in a haze makes the haze appear darker. The darkening of a haze by light absorption also tends to give it a brown appearance. This is caused in part by the properties of human vision described in Section 2.10.

Only one gas, nitrogen dioxide, contributes to brown clouds. Nitrogen dioxide is formed in the atmosphere from the nitrogen oxides emitted by combustion sources, such as engines in motor vehicles. Nitrogen dioxide has a brown appearance and contributes to the brown color of urban hazes. All other pollutant gases (e.g., carbon monoxide and ozone) are invisible.

The dominant cause of the brown appearance of the haze is light absorption by elemental carbon. Elemental carbon is the component of the haze most responsible for light absorption. Other chemical species do absorb light, but their contribution is negligible compared to that of elemental carbon. Elemental carbon has a chemical form similar to that of graphite, which is the black pigment used in pencil leads.

The main cause of the visibility impairment in urban areas is light scattering by particles. This visibility impairment makes it difficult or impossible to see objects at a distance and also causes the sky to have a color different from blue. The haze particles in western urban areas are, in decreasing order of importance, composed of organic compounds, ammonium nitrate, elemental carbon, fine soil dust particles, and ammonium sulfate. The relative amounts of these chemical species vary from day to day, and may vary substantially. For example, ammonium sulfate may be the dominant component of a brown cloud downwind from sulfur dioxide gas emissions. Soil dust makes a larger contribution in cities in the desert than in forested areas. Both the mix of emission sources in and near an urban area and the weather determine the relative amounts of these chemical species in urban hazes.

In summary, brown clouds are primarily caused by light scattering by minute particles in the atmosphere. The dark, or brown, color of the haze is primarily caused by light absorption by elemental carbon particles, but light absorption by nitrogen dioxide gas also contributes to the brown color. Pollutant gases other than nitrogen dioxide do not contribute to brown clouds.

### **2.3 WHERE DO BROWN CLOUDS OCCUR?**

Almost all urban areas in the western United States experience brown cloud events. There are more similarities than differences among these urban brown clouds. Therefore, most results from research studies of brown clouds in one city are applicable to all western cities. However, the details of the meteorology

and the relative proportion of the various categories of emissions do vary from one area to another. For example, wood smoke tends to be more prevalent in the Pacific Northwest than in the southwestern deserts, and the contribution of sulfates depends on the amount of sulfur dioxide emitted in the surrounding area.

Urban brown clouds are of less concern in the eastern United States because the regional haze is denser than in the west. Regional haze covers multistate regions and is typically transported long distances. Regional haze makes it more difficult to perceive urban hazes, which occur above urban areas. For example, the sum of light scattering and absorption by regional haze is three to four times greater in the national parks in the Appalachian mountains than in northern Arizona. The urban haze level above Phoenix during the 1989-1990 Phoenix Urban Haze Study was more than five times greater than in the surrounding parts of Arizona. This difference makes it much easier to observe the urban haze over the Phoenix area. By comparison, the urban haze over a city in the mid-Atlantic states typically may be only twice as dense as the regional haze over the surrounding areas. The high levels of regional haze in the east make it more difficult to observe urban hazes from a distance.

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*The dominant cause of haze in urban areas is light scattering by fine particles.*

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### **2.4 WHERE DO HAZE PARTICLES COME FROM?**

The dominant sources of haze particles in urban areas are combustion sources and dust from roadways, construction, and agricultural activities. Combustion sources include gasoline and diesel engines in onroad and nonroad mobile sources, residential wood burning, industrial boilers, incinerators, charcoal broilers,

space and water heaters, etc. Nonroad mobile sources include engines for lawnmowers, construction equipment, forklifts, and farm equipment, etc.

Combustion may cause particles in the atmosphere in two ways. One way is for particles to be directly emitted by the combustion source. If the particle emissions are great enough, they may be seen as smoke. These particles are known as primary particles. The other way is for gases emitted by the combustion source to be converted in the atmosphere to particles. The gases from combustion sources that contribute most to particle formation are nitrogen oxides, sulfur dioxide, and volatile organic compounds. Information on particle formation in the atmosphere is presented in Section 2.12.

## 2.5 EFFECT OF METEOROLOGY

The emissions in most urban areas tend to be much the same every weekday, and the days on which brown clouds occur are determined by the weather. Brown clouds are worst when the atmosphere is stagnant and emissions remain close to their sources. On these occasions, a low-level haze will form over the parts of the urban area with the greatest combustion sources (e.g., onroad and nonroad gasoline and diesel engines). It is not uncommon for a haze layer to be thin enough that downtown buildings rise above the worst of the haze.

Stagnant conditions with limited atmospheric mixing occur on calm, clear nights. Heat from the surface of the Earth is radiated into space. This radiative cooling is retarded by clouds or water vapor in the atmosphere, and is

most efficient on clear, dry nights, which often occur in the desert. When the surface of the Earth is cooled, the air next to it is also cooled. The cool air does not mix upward because it is more dense than the warmer air aloft. The only mixing in this cool air layer is caused by air flowing around trees, buildings, and rough terrain. At night, the airflows at the surface are decoupled from the airflows aloft; each airflow is unaffected by the other.

During the daytime, the sun heats the surface of the Earth and thereby warms the air next to the surface. This warm air rises and is replaced by cooler air from aloft. This vertical mixing disperses pollutants. It also couples the airflows near the surface with the airflows aloft, causing the surface flows to be influenced by the regional airflows aloft. During the daytime, brown clouds are dissipated and transported away from the urban area both by the vertical mixing caused by the solar heating and by the winds that result from coupling the surface airflows with the airflows aloft.

Air stagnations tend to be more severe in the winter than in the summer. The nights are longer and heating by the sun is weaker in the morning. Also, more of the morning commute and the start of business activity take place before the solar heating has an opportunity to generate atmospheric mixing. Therefore, the most dense and long-lasting brown clouds occur in the winter.

Cold air near the surface of the Earth tends to flow downhill. Therefore, nighttime airflows tend to be down-valley flows; and these flows tend to transport brown clouds down valley during the night and early morning. In the early morning, urban hazes tend to be worst in low areas and downstream from the urban areas.

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*The days on which brown clouds occur are determined by the weather.*

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As the day progresses and the mixing deepens, the haze tends to be transported in a direction determined by the regional air flows aloft. It is possible for these flows to bring the haze back over the urban area, with the result that the haze persists into the day longer than normal.

It is also possible for meteorology to affect chemical reactions in the atmosphere. High temperatures and strong sunlight accelerate the reactions that form photochemical smog. As a result, the formation of ozone and smog is most severe in the summer. The photochemical smog reactions tend to produce haze during summer afternoons.

The atmospheric chemical reactions that form sulfates and nitrates may be accelerated by moisture in the atmosphere because the reactions take place most readily inside cloud and fog drops. Sulfate and nitrate formation may also be enhanced by cold, foggy conditions that sometimes follow rainstorms. This sulfate and nitrate formation contributes to brown clouds in the winter season.

## 2.6 HOW DOES THE BROWN CLOUD RELATE TO AIR POLLUTION?

The six trace constituents of the atmosphere listed in **Table 2-1** are regulated by the National Ambient Air Quality Standards (NAAQS) and are known as criteria pollutants. The allowable concentrations of these six

species were set to protect the public health with an adequate margin of safety. Three of these six pollutants are invisible gases. Therefore, the appearance of the atmosphere does not provide a direct indication of the concentrations of these pollutants.

Three of the trace constituents in Table 2-1 could cause visible effects. Lead is the least important of the three because the use of unleaded gasoline has made the typical lead concentrations in the air too low to cause visible effects. Nitrogen dioxide is a brown gas and may affect the appearance of the atmosphere, as described above. Finally, because the brown cloud is primarily caused by particulate matter (PM), there is a close linkage between the concentration of this pollutant and the severity of brown clouds. More information on this topic appears in Sections 2.8 and 2.9.

There is a tendency for the concentrations of all air pollutants to be correlated. On a clear, breezy day, all emissions are rapidly transported away from an urban area and are diluted by the winds and the turbulence. Under these conditions, all pollutants have low concentrations. On stagnant days, all pollutants accumulate and tend to have higher concentrations. Therefore, variations in atmospheric transport and dispersion tend to make all pollutant concentrations increase or decrease together.

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*Most air pollutants are invisible.*

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Table 2-1. U.S. criteria pollutants.

Pollutant	Health Effect	Visual Effect
Carbon monoxide	Reduced blood oxygen, angina aggravation	Invisible gas
Lead	Neurological impairments	Negligible
Nitrogen dioxide	Lung irritant, respiratory disease	Brown gas
Ozone	Decreased lung function, lung damage	Invisible gas
Particulate matter	Premature mortality, disease aggravation	Haze particulates
Sulfur dioxide	Respiratory illness	Invisible gas

Source: Pope, Dockery, and Schwartz (1995)

In addition, some processes produce more than one pollutant. The photochemical reactions that produce ozone also produce particles, which contribute to haze. Motor vehicles are the major cause of high carbon monoxide concentrations, but these vehicles also emit particles in their exhaust and stir up road dust.

In summary, three of the six criteria pollutants are invisible gases, hence the appearance of the atmosphere does not provide a reliable indication of the concentrations of these pollutants. Haze is caused by PM, and as a result, haziness is directly related to PM concentrations. The

concentrations of all pollutants tend to vary together; therefore, high concentrations of any of the criteria pollutants is often accompanied by haze caused by elevated concentrations of PM. Consequently, the atmosphere is often hazy and somewhat brown when concentrations of any of the criteria pollutants are elevated.

## 2.7 PUBLIC HEALTH

There is considerable justification for the public to equate the visual appearance of haze to its health effects. Haze is caused by PM, which also causes adverse health effects. These health effects have recently been reviewed by the U.S. Environmental Protection Agency (EPA) as part of the process of revising the National Ambient Air Quality Standards for PM.

**Table 2-2** shows the results from a review of the health effects of PM<sub>10</sub>, which are

Table 2-2. Health effects of particles (effect per 10 µg/m<sup>3</sup> increase in PM<sub>10</sub>).

Observed Effect	Magnitude
Mortality	+1.0%
Morbidity	
• Asthma	+3.0%
• Hospital admissions for respiratory disease	+1.2%
• Emergency room visits	+1.0%
• FEV-1 (lung function)	-0.3%

Source: Pope, Dockery, and Schwartz (1995).

***Haze particles cause adverse health effects.***

the particles in the air smaller than 10 micrometers (µm) diameter. Before the recent revision of the PM standards, only the PM<sub>10</sub> concentrations were regulated. Therefore, only PM<sub>10</sub> was routinely monitored. It was found that when PM<sub>10</sub> concentrations increased by 10 µg/m<sup>3</sup>, the rate at which people died during one day increased by 1 percent. This increase in PM<sub>10</sub> also caused the indicated percentage increases in asthma complaints, hospital admissions for respiratory disease, and emergency room visits indicated in Table 2-2. The process of revising the PM standards generated a national debate on the certainty of current knowledge regarding the health effects of PM and the economic costs of additional air pollution controls. It is a weakness of the current understanding of the health effects of PM that the relative health effects of either the different particle sizes or the different chemical constituents of PM are not known. This lack of understanding is due in part to a lack of monitoring data for different particle sizes and chemical constituents. The new PM regulations contain provisions for additional PM monitoring and research on the health effects of PM.

The new PM standards were published by the EPA Administrator in July 1997. These standards place limits on the concentrations of both PM<sub>2.5</sub> and PM<sub>10</sub>. PM<sub>2.5</sub> are particles with a diameter smaller than 2.5 µm and are often called fine particles.

However, on May 14, 1999, a three-judge panel of the U.S. Court of Appeals for the District of Columbia Circuit issued a split

opinion regarding the final national air quality standards for ozone and particulate matter that the Environmental Protection Agency promulgated in July 1997. With respect to the particulate matter standards, the Court vacated the revised coarse particle (PM-10) standards, and the pre-existing PM-10 standard continues to apply.

Regarding the PM-2.5 standard, the Court upheld EPA's decision to rely on the regional haze program to mitigate some of the adverse visibility effects caused by PM-2.5. The Court also asked for further briefing on several issues. On June 18, 1999, the Court ruled that the PM-2.5 standard should remain in place. However, the Court will allow parties to apply for the standard to be vacated if "the presence of this standard threatens a more imminent harm." Presumably, the "harm" refers to the burden on sources complying with the regulations.

On June 28, 1999, EPA and the Department of Justice filed a petition for rehearing en banc with the D.C. Circuit. EPA continues to support the need for the health protections that these revised standards provide as well as the science backing them. In general, EPA was encouraged that the panel of judges did not question the scientific basis of the standards; rather the panel questioned the constitutionality of the primary public health provisions of the Clean Air Act.

Because PM<sub>2.5</sub> concentrations were not regulated, few monitoring programs measured the concentration of this PM size fraction. Much of the PM<sub>2.5</sub> data that do exist for western urban areas were obtained from studies of a few weeks or months duration designed to support

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*Reduction in fine particles due to the new PM 2.5 standard and regional haze regulations will also reduce the brown cloud problem.*

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*Particles cause haze because they scatter and absorb light.*

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special studies of brown clouds and PM<sub>10</sub> control strategies.

On July 1, 1999, the EPA Administrator published new regulations for regional haze designed to protect visual air quality in national parks and wilderness areas. Because regional haze is transported over multi-state regions, all states will need to develop an implementation plan describing long-term strategies designed to address regional haze. Any future reductions in fine particle concentrations in Maricopa County as a result of the new PM<sub>2.5</sub> standard and regional haze regulations would directly benefit the brown cloud problem because PM<sub>2.5</sub> is the pollutant primarily responsible for brown clouds.

As indicated in the previous section, not all air pollutants with adverse health effects cause haze. There is an association between hazy air and adverse health effects, but clear air does not necessarily mean healthy air.

## 2.8 OPTICAL PROPERTIES OF PARTICLES

The atmosphere contains a great variety of particle types, and each has different optical properties. The study of the properties of haze particles is an active area of research; information on this topic is continually evolving. This section presents a few generalizations that summarize current knowledge. Additional information is included in Section 2.11.

Particles cause haze because they scatter and absorb light. As indicated above, when particles scatter light, they change the direction of travel of the light. A dense fog or water clouds in the sky are examples of strong light scattering.

The amount of light scattered by a particle is primarily controlled by its size, and is affected to a lesser degree by its chemical composition.

When particles absorb light, the light is removed from the atmosphere and turned into heat. Increasing the light absorption in a haze makes the haze appear darker.

The amount of light absorbed by a particle is primarily controlled by its chemical composition, and is affected to a lesser degree by its size.

Light absorption by particles is less complicated than light scattering, and is overwhelmingly due to elemental carbon. The fact that soil dust has a brown, reddish, or black appearance indicates that these particles do absorb light, but in the absence of a dust storm, this absorption is negligible compared to the light absorption by elemental carbon. The elemental carbon in the atmosphere is nearly all in fine particles, i.e., in particles with a diameter less than 2.5  $\mu\text{m}$ .

Light absorption by particles is typically measured by collecting ambient particles on a filter and using an optical instrument to measure the darkening of the filter. Monitoring data from urban areas typically show a good correlation between light absorption by particles and the amount of elemental carbon as determined by chemical analysis. The strength of the light absorption by elemental carbon may be quantified by an efficiency factor that has dimensions of area per mass. This factor specifies the area that would intercept the same amount of light as absorbed by unit mass of particles. The light-absorption efficiency of elemental carbon in ambient particles is typically 9 or 10  $\text{m}^2/\text{g}$  (square meters per gram). In English units, this efficiency is 2900  $\text{ft}^2/\text{oz}$

(square feet per ounce). Thus, one ounce of elemental carbon dispersed in atmospheric particles absorbs an amount of light equal to that passing through an area of 2900 square feet, which is the area of a square about 54 ft on a side.

The efficiency of light scattering by particles is primarily controlled by the particle size. As with absorption, it is measured by an efficiency factor, except the area is equal to the amount of light scattered by a unit mass of particles. When the atmosphere is dry, the light-scattering efficiency of fine particles is approximately 3  $\text{m}^2/\text{g}$ . This efficiency has been measured in urban and in pristine areas and, for dry particles, has a value that is relatively independent of the measurement location. The size distribution of coarse particles, i.e., particles with diameters between 2.5  $\mu\text{m}$  and 10 to 15  $\mu\text{m}$ , is more variable, with the result that the scattering efficiency is also variable.

Values near 0.4  $\text{m}^2/\text{g}$  have been reported. These extinction efficiencies for fine and coarse particles represent averages over all particles in each size range.

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*When an urban haze is dense enough to obscure objects completely, the visual benefits from decreasing the amount of haze will be small.*

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The light-scattering efficiencies of single particles vary dramatically with size. The smallest particles emitted by combustion sources are too small compared to the wavelength of light to scatter much light. Particles with a diameter approximately equal to the wavelength of light, or approximately 0.5  $\mu\text{m}$ , are the most efficient light scatterers. As particles become larger than about 0.5  $\mu\text{m}$ , their light-scattering efficiency decreases, and becomes quite small for the largest dust particles. The greatest mass concentration of fine particles is typically in the range of 0.2 to 0.3  $\mu\text{m}$ ; most fine particles are slightly smaller than the optimum for light scattering. Processes

that increase the size of fine particles will increase their light-scattering efficiency.

One process that increases the size of fine particles is the absorption of water at high humidities. As described in more detail in Section 2.11, some constituents of ambient particles absorb water at high humidities, and these constituents may dissolve completely to form liquid particles at very high humidities. The absorption of water by ambient particles is typically small at relative humidities below 50 percent, is quite measurable at relative humidities near 60 percent, becomes important at relative humidities near 70 percent, and is a dominant factor determining particle size at relative humidities above 90 percent. High humidities increase light scattering by particles, and therefore increase haze.

Coarse particles are typically composed of soil dust and other species that do not absorb water effectively. Therefore, the effect of humidity on light scattering by coarse particles is much smaller than for fine particles.

Sulfates and nitrates are atmospheric species that absorb water. If the light-scattering efficiency is stated in terms of the light scattering by the wet particle per mass of dry sulfate or nitrate, the light-scattering efficiencies of these species may exceed 10 or 15 m<sup>2</sup>/g at humidities above 90 percent. Part of the reason light-scattering efficiencies are sometimes stated this way is that the amount of sulfate or nitrate in the atmosphere is measured by collecting particles on a filter, drying them to a standard relative humidity near 50 percent, and determining the mass of sulfate or nitrate present. There are no good methods for determining the amount of water in ambient particles because water is

gained or lost from the particles during collection.

In summary, elemental carbon is very efficient at absorbing light, and has an efficiency of 9 or 10 m<sup>2</sup>/g. Dry fine particles scatter light with an efficiency of about 3m<sup>2</sup>/g and coarse particles have an efficiency of roughly 0.4 m<sup>2</sup>/g. At high humidities, fine particles absorb water and their light-scattering efficiency increases. This increase may become very large at relative humidities above 90 percent. Light-scattering and light-absorption efficiencies measure the relative effectiveness of various types of particles in causing haze.

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*The appearance of haze depends on the angle of view.*

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## **2.9 OPTICAL PROPERTIES OF HAZES**

The previous section presented information on the optical properties of individual particles or classes of particles, and this section addresses the combined optical properties of particles in a cloud of haze. When sunlight enters a hazy region of the atmosphere, a portion of it is scattered. This light is deflected from the direct solar ray and travels in a different direction. Some of the scattered light is scattered again, and in dense hazes, may be scattered many times. This multiple scattering of light creates the diffuse illumination observed in a very dense haze or fog.

Light absorption occurs throughout this process. Multiple scattering increases the path length of light through haze, and thus increases the amount of light absorbed.

To see an object through haze, it is necessary for some light reflected or emitted from the object to pass through the haze to the eye of the observer. The appearance of such an object is determined by the competition between the light that comes directly from the object without being scattered or absorbed and the diffused light from the haze that has been

scattered. If most of the light entering the eye of an observer from a region of a scene comes from the object being viewed, this object may be seen clearly. If most of the light has been diffused by the haze, the object is indistinctly seen. When the fraction of light coming from the object becomes small enough, the object may not be seen at all.

Urban hazes sometimes obscure distant objects, especially when the view is nearly horizontal through a long distance. Hills on the other side of an urban area or tall buildings may disappear from view. It is very difficult to improve the visibility in these cases. It is possible that implementing control measures that decrease the amount of haze by 30 percent, for example, would still leave enough haze to obscure distant objects completely. During these worst haze events, citizens would see little benefit from their efforts to reduce haze.

The appearance of hazes depends on the angle of view compared to the angle of the sun's rays. All particles tend to scatter light in the forward direction, and this is especially true of large particles. Therefore, a haze will appear brighter when viewed looking toward the sun than when looking away from it. Both large particles and light-absorbing particles will cause the haze to have a dark appearance when the sun is behind the observer.

## 2.10 HUMAN PERCEPTION OF HAZE

Human perception is a large and complex field of study. The complexity of this topic is illustrated by the many optical illusions with which we entertain ourselves. In this document, there is space to describe only a few attributes of human vision related to the perception of hazes.

There are well developed mathematical procedures for predicting which colors will

appear to be the same, or match. When two colors do not match, these mathematical procedures predict whether one color will appear more blue or more green or more red than the other. Thus, it is possible to describe colors by mathematical formulas.

Human color vision is three dimensional. This may be demonstrated by examining a computer monitor or television screen with a magnifier. All images on these display devices are composed of red, green, and blue dots. It is possible to specify any displayed color by numbers that indicate the intensity of the red, green, and blue light from the phosphors. Colors that match have the same three numbers.

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*Decreasing the brown appearance of the haze may be visually rewarding.*

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The eye tends to perceive the lightest and brightest element of a scene as being white. For example, a white picket fence appears to be white when viewed during a colorful sunset even though it will appear yellow or orange in a photograph. Because of this property of vision, water clouds in the sky appear to be white even though instrumental measurements show that they reflect much more blue light than red light. By comparison, a darker cloud with a more nearly neutral spectrum will be perceived as yellowish or brownish, depending on its darkness. (Brown is dark yellow.) Because of this property of human vision, the relatively neutral absorption of light by elemental carbon may cause an urban haze to appear as a "brown cloud." Of course, absorption of light by nitrogen dioxide, which absorbs blue light much more strongly than green or red light, adds to the brown appearance of urban hazes.

The brown appearance of an urban haze is one of its least appealing attributes. Decreasing the amount of elemental carbon in hazes will decrease their brown appearance. It is quite possible that such a change in the color of the haze would be more easily perceived, and

hence more rewarding to local residents, than would a reduction in the amount of haze. For this reason, this study emphasizes control measures that decrease the emissions of elemental carbon.

## 2.11 CHARACTERISTICS OF ATMOSPHERIC PARTICLES

Ambient particles are classified as being coarse or fine according to their diameter. This classification is useful because particles in these two size ranges have different origins and different chemical and optical properties.

Coarse particles have diameters larger than 2.5  $\mu\text{m}$ . For comparison, the diameter of a human hair is approximately 80  $\mu\text{m}$ . Most coarse particles are soil dust and are due to dust kicked up by vehicles on paved and unpaved roads, construction activities, agricultural activities, and dust picked up by the winds from desert surfaces that have been disturbed. Ash from combustion sources is a small contributor to coarse particles in the atmosphere.

Particles larger than 10  $\mu\text{m}$  do occur in the atmosphere, especially near dust sources. They receive little attention in this report because their mass concentrations are usually small, and these particles are large enough that they do not scatter light efficiently. Except in dust storms, their contribution to urban hazes is negligible.

Fine particles are smaller than 2.5  $\mu\text{m}$  diameter. Most fine particles are either emitted by combustion sources or are formed in the atmosphere from gases. Some dust particles are small enough to be fine particles.

It is useful to classify the chemical species in fine particles into primary species and

secondary species. Secondary species are formed in the atmosphere from gases. Examples are ammonium sulfate and ammonium nitrate, which are further discussed below. Primary species are emitted from sources and remain in the atmosphere unchanged by subsequent chemical processes. Coarse particles are mostly composed of primary species.

The most important secondary species in fine particles in western cities are the ammonium salts, ammonium sulfate and ammonium nitrate. Chemical compounds of ammonium and sulfate may exist in several forms, such as ammonium bisulfate and letovicite, which represent various

stages in the reaction between ammonia gas and sulfuric acid. Sulfates are not volatile. Ammonium nitrate is volatile; it may decompose into ammonia gas and nitric acid gas, which are invisible. The

equilibrium in this reaction shifts toward the gas phase as the atmosphere becomes hotter and drier. The processes that lead to the formation of these secondary species in the atmosphere are discussed in Section 2.12.

Hundreds of organic compounds have been identified in atmospheric particles. Some of these compounds are volatile and exist partly in the gas and partly in the particle phases. These organic compounds are a poorly understood mixture of species emitted from sources (primary species) and species formed in the atmosphere (secondary species). Also, there is considerable uncertainty about the relative importance of the emissions of organic compounds from plants and animals versus the emissions from combustion sources, industrial processes, and paints.

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*Mobile sources are the dominant source of particles and nitrogen oxides that contribute to brown clouds.*

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As discussed in Section 2.8, some chemical species absorb water at high relative humidities. These species include all ammonium salts and some organic compounds. Pure ammonium salts absorb enough water to dissolve and form a liquid solution when the relative humidity is above about 70 percent. Most particles in the atmosphere are a mixture of soluble and insoluble species, and it is believed these particles are composed of a liquid solution surrounding a solid core at high humidities.

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*Fine particles (smaller than 2.5  $\mu\text{m}$  diameter) are mostly emitted by combustion sources or formed from gases in the atmosphere.*

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## 2.12 DOMINANT SOURCES OF PARTICLES

This section contains information applicable to most western cities on the sources of ambient particles and of gases that cause particle formation in the atmosphere. More specific information on sources in Maricopa County is presented in Chapter 4.

In most urban areas, onroad and nonroad motor vehicles are a major source of fine particles and nitrogen oxides that contribute to brown clouds. Thus, every citizen who travels in a vehicle contributes to this pollution. Because of the desire of citizens to drive automobiles, effective solutions to the brown cloud problem are difficult to find.

The elemental carbon particles emitted during the morning commute hours are a major contributor to haze. Diesel engines emit black particles that are obvious at the tailpipe, and are often blamed for much of the elemental carbon in urban areas. However, gasoline engines also emit elemental carbon, and this is sometimes apparent in the black smoke from a defective vehicle. An air quality study recently completed in the Denver area showed that particles emitted by gasoline engines are a major contributor to the Denver brown cloud.

Emissions from gasoline engines when they are first started and from the relatively small fraction of gasoline vehicles that emit more particles than most vehicles were shown to be the dominant contributors to the particle emissions from gasoline engines. Studies of the Maricopa County area have also shown that exhaust emissions from mobile sources are the single greatest contributor to brown clouds. Mobile sources, which include onroad and nonroad motor vehicles, account for more than 50 percent of the constituents of

the brown cloud.

Mobile sources also emit nitrogen oxides, which are converted in the atmosphere to the brown gas, nitrogen dioxide. Nitrogen dioxide is oxidized in the atmosphere to form nitrates. Initially, this nitrate is in the form of nitric acid, which is an invisible gas, but nitric acid may combine with ammonia emitted by agricultural operations to form particulate ammonium nitrate, which is a significant contributor to haze in many western urban areas.

Mobile sources also emit particulate organic compounds as well as organic gases that may be oxidized in the atmosphere to form particles. An example of particulate organic compounds is the white oil smoke emitted from a vehicle in which engine wear permits loss of oil.

Changes in engine fuels designed to address high concentrations of ozone and carbon monoxide have resulted in much lower concentrations of sulfur in fuel. This has caused engine exhaust emissions of sulfur dioxide to decline. Sulfur dioxide may be oxidized in the atmosphere to form sulfate particles, which contribute to haze.

Next to engine exhaust, the emission sources which contribute most to haze in western urban areas vary depending upon other considerations. In areas such as the Pacific Northwest, wood smoke and industrial emissions are more important sources. In desert areas, soil dust emissions are second in importance to engine exhaust in contributing to brown clouds. Because soil dust is mostly composed of particles too large to scatter light efficiently, dust makes a much smaller contribution to haze than engine exhaust.

Industrial emissions are generally well controlled in major urban areas and make a smaller contribution to haze than other sources. The relative emissions contribution of various types of industries varies from one urban area to the next.

Emissions from plants and animals are poorly understood in most urban areas. These emissions tend to contribute more to elevated ozone concentrations than to elevated haze levels. In coastal cities, sea salt is a measurable component of atmospheric particles.

In summary, studies in western urban areas have confirmed that gasoline and diesel engine exhaust are a primary source of the particulate emissions contributing to brown clouds. Other minor sources contributing to haze in western cities include wood smoke or soil dust, depending on other characteristics of the area.

## 3. URBAN BROWN CLOUDS IN MARICOPA COUNTY

### 3.1 INTRODUCTION

Chapter 2 presented general information on the urban brown clouds in the western United States. This chapter presents specific information about the properties of urban brown clouds in Maricopa County. The three main sources of local data are light extinction monitoring by the Arizona Department of Environmental Quality (ADEQ) beginning mid-December 1993; airport visibility observations, which have continued for decades and were replaced by an instrumental visibility measurement in March 1994; and intensive studies of PM<sub>10</sub> and the urban haze during the fall and winter of 1989-1990.

Historical data for the clarity of the air in Maricopa County are presented first. The most quantitative data are from an instrument that has a light detector about 3 miles from a light source. This instrument measures the extinction (weakening) of the 3-mile light beam by haze, rain, or fog. This light extinction monitoring began in December 1993, with the result that only five complete years of data are available. The results from these measurements are presented in Section 3.2.1 and Appendix C.

Data with the longest period of record are human observations of the visibility at Sky Harbor Airport. Data for 1961 through 1993 are presented in Section 3.2.2 and Appendix D. These data indicate a general improvement in visibility in Maricopa County. For reasons described below, these data do not provide a useful indication of the long-term trends in the severity of brown clouds in Maricopa County.

Section 3.3 summarizes the key findings of the 1989-1990 Phoenix PM<sub>10</sub> Study and the

1989-1990 Phoenix Urban Haze Study for the spatial and temporal distributions of light extinction and PM concentrations, the effects of meteorology, and the composition of the PM in brown clouds in Maricopa County. Section 3.3 also presents data for the light-extinction efficiencies of the major chemical components of fine particles. These data are used in Chapter 4 in the calculation of the relative contribution of different sources to brown clouds in Maricopa County. Many technical terms used in this chapter are defined in the Glossary in Appendix A.

### 3.2 HISTORICAL VISIBILITY DATA

The data currently available for visibility and brown clouds in Maricopa County are not sufficient to establish historical trends for the frequency and severity of the brown cloud problem. The reasons for this are described along with the results of the visibility measurements in Sections 3.2.1 and 3.2.2.

The discussion in Sections 2.8 and 3.3.7 indicate that light extinction is mainly caused by fine particles, i.e., ambient particles with a diameter less than 2.5  $\mu\text{m}$ . If long-term measurements of fine particles had been made, these data could be analyzed to obtain information on trends in brown clouds. The available fine-particle data do not cover a long enough time period to determine long-term trends. Most fine-particle measurements in Maricopa County were made during special studies conducted during four months in the winter of 1989-1990 as described in Section 3.3 and during a study in 1985 (Solomon and Moyers, 1986). It is not possible to determine trends from data that have been collected only for brief time periods.

The historical record for PM in Maricopa County contains data only for total suspended particles (TSP), which includes all particles smaller than roughly 15 or 20  $\mu\text{m}$  in diameter, as well as  $\text{PM}_{10}$ , which includes ambient particles with a diameter less than 10  $\mu\text{m}$ . The data in Sections 2.8 and 3.3.7 show that particles larger than 2.5  $\mu\text{m}$  diameter do not scatter light efficiently, with the result that the concentrations of particles in these size fractions have only a small effect on light extinction. Therefore, trends in TSP or  $\text{PM}_{10}$  concentrations would not provide reliable information on trends in the frequency and severity of brown cloud events.

### 3.2.1 Light Extinction

The monitoring data in Maricopa County that most directly measure the severity of brown cloud events are from a transmissometer operated for the ADEQ by Air Resource Specialists, Inc. of Fort Collins, Colorado. A more complete description of this instrument and the data obtained is presented in Appendix C. The transmissometer measures the amount of green light transmitted through a sight path with a length of 4.76 km (2.96 miles) in north-central Phoenix (see map in Appendix C). The transmittance data are used to calculate the light-extinction coefficient, which is a property of the atmosphere in the sight path that provides a quantitative measure of air quality related to visibility. More complete definitions of these terms appear in the glossary in Appendix A. A discussion of the light-extinction coefficient also appears in Appendix B of this report.

The first full month of transmissometer measurements occurred in January 1994. Data for January 1994 through May 1999 were obtained for analysis as part of this study. The data for December 1989 through May 1999 are subject to recalibration when the annual maintenance of the transmissometer is performed in December 1999.

Statistical summaries of the data are reported in Appendix C, and key results are presented in **Figures 3-1 and 3-2**. The filled

symbols in Figure 3-1 show the median values of the light-extinction coefficient for each month of the year. For example, the median value for January was determined by sorting all January readings from 1994 through 1999 in order of decreasing value and selecting the reading in the middle. Half of the

January readings were higher than the median and half were lower. The median values shown by the open symbols were calculated in the same way, except that only readings made at 8:00 a.m. MST were included in the calculations for each month. This hour was

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*The data currently available for visibility and brown clouds in Maricopa County are not sufficient to establish historical trends for the frequency and severity of the brown cloud problem.*

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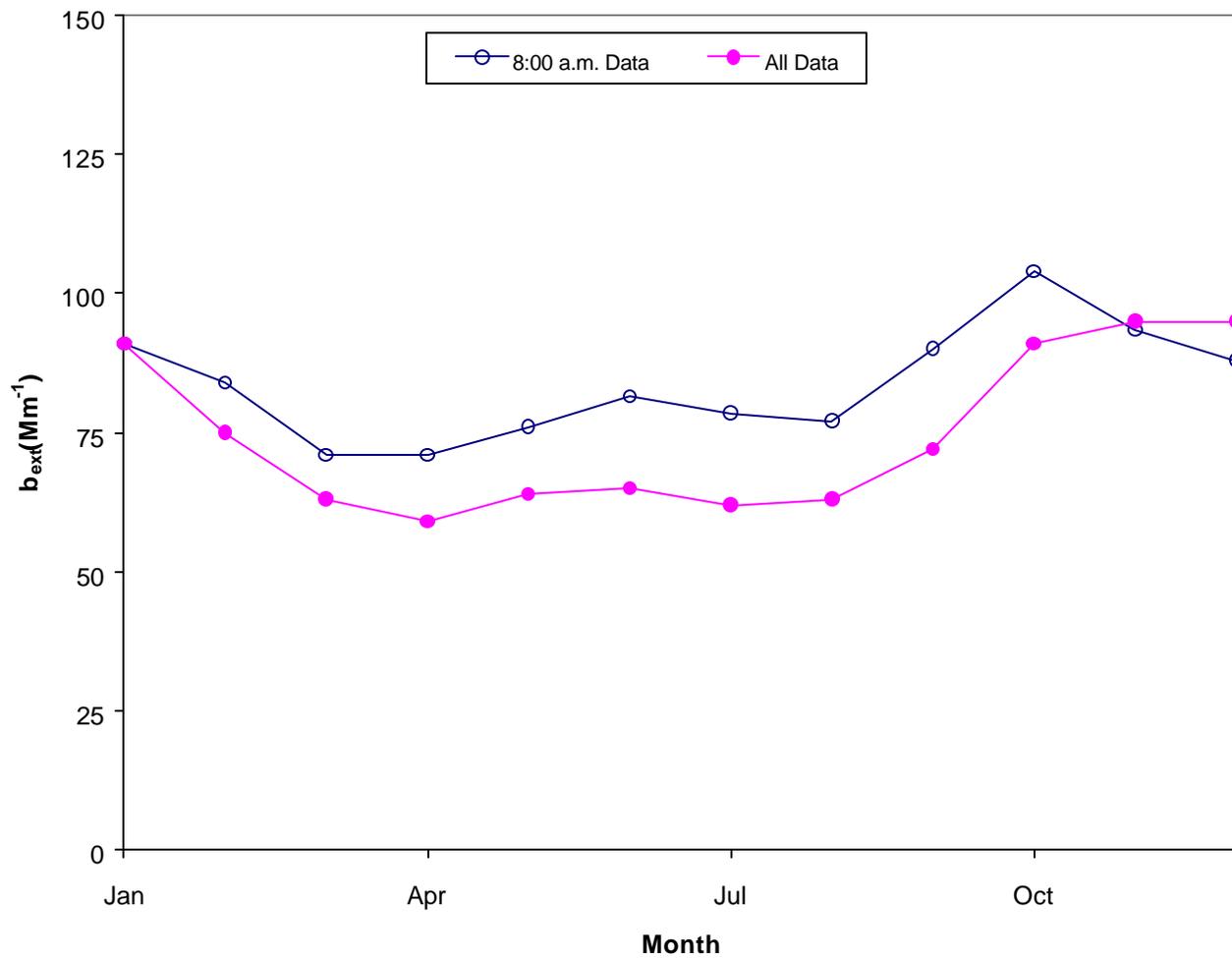


Figure 3-1. Seasonal dependence of median monthly values of the hourly light-extinction coefficient measured from January 1994 through April 1999. The filled symbols show the medians for all data and open symbols the medians for 8:00 a.m. MST measurements.

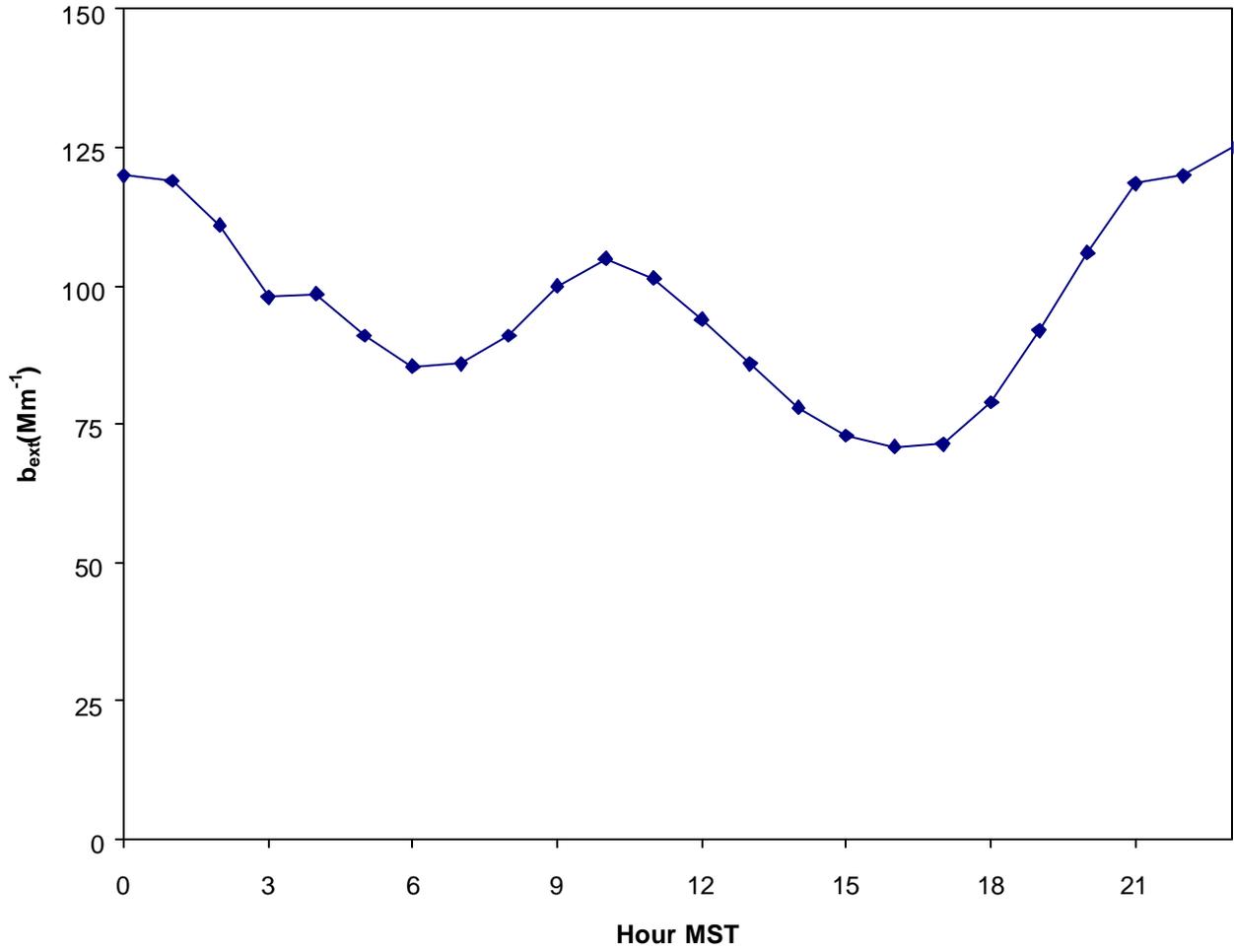


Figure 3-2. Dependence on the time of day of the median values of the November, December, and January hourly light-extinction coefficients measured from January 1994 through January 1999.

selected because the largest morning median light extinction readings occur at this hour during most of the year, and brown clouds are most noticeable in the morning.

The line for the median of all data shows a seasonal dependence. The lowest median light-extinction values occur in the spring and summer and the highest occur in the late fall and winter. The median light extinction in October is significantly higher than in September. This indicates a relatively rapid transition from summertime to fall conditions.

Figure 3-2 shows the dependence of the median light extinction values on the time of day during November, December, and January. The lowest medians, which correspond to the best visibility, occur in the afternoon, and the highest medians, which correspond to the greatest visibility impairment, at night. The morning peak in the median occurs at 10:00 a.m. Additional plots of the light-extinction coefficient data appear in Appendix C. Those plots show that during the summer, the morning peak in the median light extinction occurs at about 8:00 a.m.

The median values of the 8:00 a.m. data in Figure 3-1 show less seasonal variation than for all data. This is because during the warm season, when the light extinction values are low most of the day, the highest medians are observed at 8:00 a.m. Also, during the cold seasons the 8:00 a.m. light extinction values are less than the morning peak values, which occur later in the day. Additional information on these data appear in Appendix C.

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*The highest media light extinction values occur in the late fall and winter.*

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The median value of all light-extinction coefficients having the same hour of the day, month, and year were calculated for all hours, months, and years to explore the possibility of a year-to-year trend in light extinction. **Figure 3-3** shows the median values calculated for 8:00 a.m. MST in the upper panel and 10:00 a.m. MST in the lower panel. The 8:00 a.m. medians show a trend of increasing light extinction during the years 1994 through 1998.

The medians at 10:00 a.m. have larger values than at 8:00 a.m. for October through January, and there is no apparent trend in the data for these months. The 10:00 a.m. medians for April through September do show an upward trend during the years shown.

Plots of data for 9:00 a.m. MST and 4:00 p.m. MST showed trends similar in appearance to the trend in the 8:00 a.m. data. These plots are not shown.

The data in Figure 3.3 indicate an increase in haze in the transmissometer sight path in Phoenix during the years 1994 through 1998. These data alone do not provide enough information to determine the cause of the increase in light extinction.

The airport visibility data presented in Section 3.2.2 and Appendix D cover a period of 33 consecutive years. The summary of the trends in Figure D-4 in Appendix D indicates a variability in the

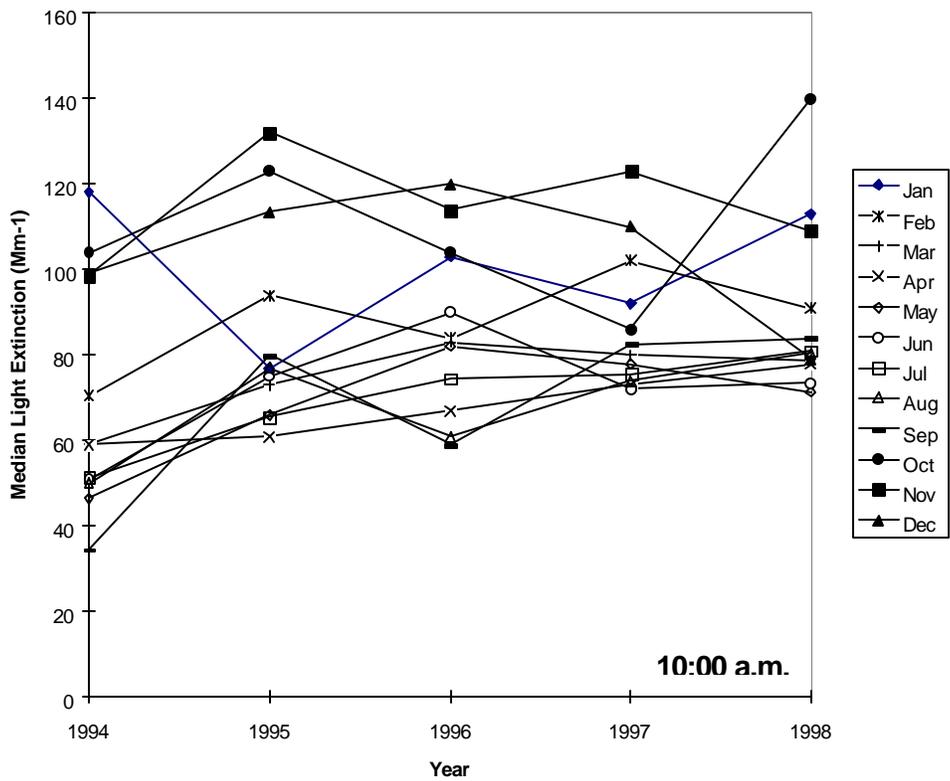
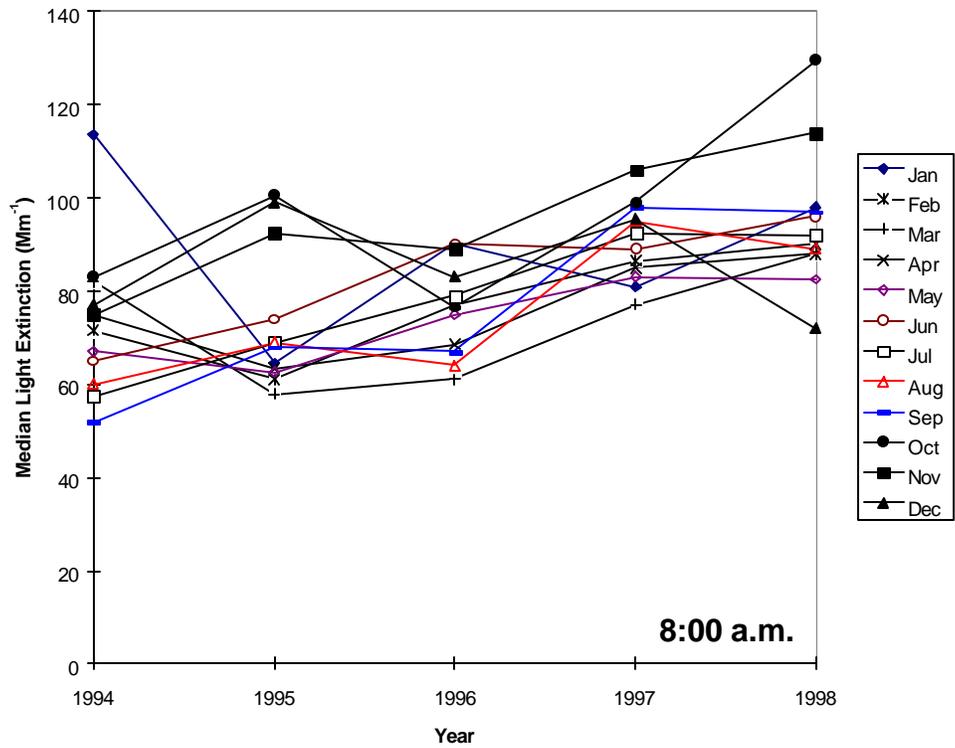


Figure 3-3. Five-year trends in monthly median light extinction in Phoenix at 8:00 a.m. (upper panel) and 10:00 a.m. (lower panel). Higher values of light extinction correspond to greater visibility impairment.

data that is large compared to the 33-year trend. The years 1971 through 1977 (7 years), 1979 through 1983 (5 years) and 1986 through 1993 (8 years) showed strong trends of improved visibility, which were reversed in the intervening years. These data indicate that the 5 years of transmissometer measurements cover too short a time period to draw conclusions about long-term trends in brown clouds in Maricopa County.

The transmissometer data do indicate that the urban haze in Phoenix has increased during the last 5 years. Because of the short time period these data cover, it is not known how much of the increase is due to changes in emissions and how much is due to year-to-year variability in the weather. The analyses performed during this study did not include an examination of the meteorological records to see if stagnant weather conditions were more common in recent years than in 1994.

### **3.2.1 Airport Visibility**

#### **Introduction**

Human observations of visibility at Sky Harbor Airport in Phoenix provide the longest-duration historical record of haze in the vicinity of Maricopa County. Visibility observations were made every hour by determining the greatest distance dark targets could be seen on the horizon in half or more of the full circle of view. Because visibility targets were available only at certain distances, the visibility at the time of the observation was equal to or better than the recorded value. The observations were archived by the National Climatic Data Center, and data for 1961 and later years were obtained and analyzed as described in

Appendix D. Human observations of visibility at Sky Harbor Airport ended during March 1994 and were replaced by instrumental readings.

It has long been recognized that airport visibility observations have shortcomings. Human observers who make airport visibility observations introduce variability into the data due to differences in training and judgment (Middleton, 1952). Therefore, airport visibility data need to be reviewed for anomalies and used with caution (Trijonis, 1979, 1982).

#### **Data analysis methods**

The visibility data used in these analyses were screened to remove unwanted meteorological effects. All hours that precipitation of any type or fog were reported were flagged and not used in the analyses. Also, observations made when the relative humidity was 95 percent or greater were not used. The screening criteria were used to focus the analyses on the effects of air quality on visibility and to minimize the effects of weather.

The transmissometer data in Section 3.2.1 and Appendix C show that the effects of brown clouds are greatest on fall and winter mornings. Therefore, 8:00 a.m. MST observations for the months of October through February were selected for analysis. This hour was selected because, for some years, airport visibility data were available only every three hours and were not available for 6:00, 7:00, 9:00, and 10:00 a.m.

***Human observers who make airport visibility observations introduce variability into the data due to differences in training and judgment.***

## Results

The 8:00 a.m. MST October through February airport visibility observations for 1961 through 1993 indicate a slight improvement in visibility during this time period. The discussion near the end of Section 3.2.1 indicates that there was a substantial year-to-year variability in visibility. These short-term variations are about twice as large as the change in visibility due to the long-term trend during this time period.

The long-term trend indicates that the median visual range increased from about 36 miles in 1961 to about 42 miles in 1993. This 6-mile increase is approximately twice the smallest change in visual range that is detectable by an experienced observer (Pitchford et al., 1990). The median visual range for each calendar year during this time period ranged from approximately 32 to 44 miles.

It is also possible to summarize the airport visibility observations by indicating the fraction of the time a target at a given distance is perceptible. For example, a target at a distance of 40 miles could be seen in 24 percent of the readings in 1961. The frequency of a 40-mile visibility increased to 56 percent of the readings in 1967, 58 percent of the readings in 1968, then decreased to 30 percent of the readings in 1972, and increased to 67 percent of the readings in 1983. The long-term trend indicates that the frequency of a visual range of 40 miles or more increased from about 33 percent of the observations in 1961 to 60 percent in 1993.

Visual ranges of 60 miles or better were rarely observed in the 1960s, and were

increasingly observed until 1987 and 1988, when they occurred in 7 percent of the observations. The frequency of 60 miles or better visibility in 1992 appears to be anomalously high. The data for short visual ranges indicate that the frequency of visibility observations of 20 miles or better has been increasing throughout the time period shown. In

other words, the frequency of visual ranges less than 20 miles has been decreasing during this time period. Additional information on the analysis

of the airport visibility data is presented in Appendix D.

Some of the variability in the airport visibility data is due to changes in emissions. An industrywide copper strike took place from July 1967 to March 1968. Trijonis (1979) showed that the decreased emissions of sulfur dioxide in Arizona and adjacent states caused by the strike resulted in decreased concentrations of sulfate particles in the atmosphere and increased visibility. The visibility observations indicate that generally improved visibility was observed at Sky Harbor Airport during 1967 and 1968.

Sulfur dioxide emissions from smelters in Arizona and surrounding states have decreased greatly since 1961. It is likely this decrease in emissions contributed to the general improvement in visibility at Sky Harbor Airport during this time period. This study did not include any analyses designed to evaluate the relative importance of brown clouds, regional haze, or other factors in contributing to the observed trends in visibility.

## Comment

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*Airport observations for 1961 through 1993 indicate a slight improvement in visibility.*

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Some Maricopa County residents may believe that a general improvement in the wintertime 8:00 a.m. airport visibility data is contrary to the perception that the brown clouds are becoming worse. There are simple reasons why both of these apparently contradictory observations may be valid.

The first reason is that the visual range at the airport is typically greater than the dimensions of the brown cloud, with the result that much, if not most, of the sight paths for the visual range observations are outside the brown cloud. The airport observations are affected by both the brown cloud and the regional haze. One possible explanation of the trends in the airport visibility data is that the amount of regional haze has decreased, and that this decrease had a greater effect on the airport visibility observations than any changes that may have occurred in the frequency and severity of brown clouds.

The second reason is that a decrease in the regional haze would make the urban brown cloud more apparent. Observers outside the brown cloud would have a clearer view of the urban haze and could more easily compare the haze over the populated areas with the clear air nearby. Observers near the edges of the brown cloud would see more visibility degradation in some directions than in others. Any decrease in regional haze would increase the contrast between the brown cloud and the surrounding air and would make the brown cloud appear worse.

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*Any decrease in regional haze would increase the contrast between the brown cloud and the surrounding air and would make the brown cloud appear worse.*

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The work reported in this section and Appendix D did not include any analyses designed to determine the relative contributions of brown clouds and regional haze to the airport visibility observations. The airport visibility data analyzed here provide no information on whether or not brown clouds have become worse in recent decades. These data do indicate that visibility at the Sky Harbor Airport has improved during this time period.

### **3.3 1989-1990 PHOENIX URBAN HAZE AND PM<sub>10</sub> STUDIES**

#### **3.3.1 Introduction**

A pair of major air quality studies were conducted in the fall and winter of 1989-1990 in Maricopa County to characterize brown clouds and particulate matter in the atmosphere and to determine the relative contribution of emission sources to PM concentrations and light extinction. These studies were the 1989-1990 Phoenix PM<sub>10</sub> Study (Watson et al., 1990a; Chow et al., 1991a, 1991b) and the 1989-1990 Phoenix Urban Haze Study (Watson et al., 1990b, 1991a, 1991b). Both of these studies were receptor oriented, i.e., air quality measurements were made at a number of monitoring sites (receptor sites) and the contribution of emission sources was inferred from the measured composition of the atmosphere. Field measurements were conducted from September 25, 1989 to January 22, 1990.

This section contains a summary of the information on brown clouds in Maricopa County presented in two reports from the

1989-1990 studies (Chow et al., 1991a; Watson et al., 1991a) and appendices (Chow et al., 1991b; Watson et al., 1991b). Information from these reports on the emission sources that contribute to brown clouds is presented in Chapter 4. Since all of this information has been publicly available for eight years, the objective of this section is to provide a brief overview of the results from these studies.

### 3.3.2 Monitoring Sites and Measurement Methods

Fifteen monitoring sites were used in the 1989-1990 Phoenix Urban Haze and PM<sub>10</sub> studies. The greatest concentration of sites was in the central portion of the urban area. The east-west gradients in haze and PM were monitored by sites in South Scottsdale and West Phoenix. The vertical gradients were monitored by the site on the roof of the Valley National Bank 175 m (meters) above ground level (agl) (575 ft agl) in downtown Phoenix and at nonurban elevated sites at South Mountain and Pinnacle Peak. The background site at the General Motors (GM) Proving Ground monitored air entering Maricopa County from the southeast.

Most of the study results summarized below were obtained from two types of measurements: the collection of filter samples of ambient particulate matter for subsequent laboratory analysis and continuous measurement of the optical properties of the atmosphere by monitoring instruments. Two strategies were used for the collection of filter samples. For the PM<sub>10</sub> Study, 24-hr filter samples were collected beginning at midnight, because this sampling period is specified by

Federal regulations. For the Urban Haze Study, filter samples were collected in the morning (6:00 a.m. to noon MST) and afternoon (1:00 to 7:00 p.m. MST) because it was known that morning PM concentrations were significantly higher than afternoon PM concentrations.

Both studies used filter samplers with 2.5 µm (micrometer) and 10 µm cutpoints on the air sample inlets. The sampler with the 2.5 µm cutpoint collected only fine particles and measured PM<sub>2.5</sub> (the concentration of ambient particles with a diameter less than 2.5 µm). The sampler with a 10 µm cutpoint measured PM<sub>10</sub> (the concentration of ambient particles with a diameter less than 10 µm). Filters from each of these samplers were subjected to a number of analyses to determine the chemical and physical properties of the collected particles (Chow et al., 1991a; Watson et al., 1990a, 1990b, 1991a). The difference between the data from collocated (i.e., side-by-side) PM<sub>10</sub> and PM<sub>2.5</sub> samplers gave a measure of the coarse particle concentration and chemical composition. Coarse particles have diameters between 2.5 and 10 µm.

Most data discussed below for the optical properties of the atmosphere were measured by three types of instruments (Watson et al., 1990b, 1991a). The transmissometer, which is described in Section 3.2.1 and Appendix C, measured the light transmittance of a sight path between the roof of the Industrial Commission of Arizona (ICA) building on Washington Street near Eighth Avenue and a Holiday Inn 4.4 km (2.6 miles) north of the ICA site. Integrating nephelometers drew ambient air through a

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*This section contains a summary of information in two reports from the 1989-1990 air quality studies.*

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scattering chamber and measured light scattering by particles at four sites: the ICA building, West Phoenix, South Scottsdale, and the roof of the Valley National Bank 175 m agl (575 ft agl) in downtown Phoenix. Most nephelometers had no particle-size fractionating device on the inlet and sampled particles smaller than roughly 15  $\mu\text{m}$  diameter. Light absorption by particles was measured by drawing ambient air through a filter and measuring the darkening of the filter caused by the absorption of light by the collected particles. Instruments in the field recorded

hourly light absorption measurements at the ICA and Monterey Park sites. In addition, light absorption was measured on all  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  filter samples that were returned to the laboratory.

PM samplers were operated at all sites where optical instruments were located as well as at a number of nonurban sites. Therefore, the PM data cover a greater geographic area than the optical measurements.

### 3.3.3 Spatial Distribution of Light Extinction and PM

Table 3-1 shows the average 24-hr  $\text{PM}_{10}$  concentrations measured in the  $\text{PM}_{10}$  study (Chow et al., 1991a). The standard deviations indicate the sample-to-sample

Table 3-1. Means and standard deviations of the 24-hr  $\text{PM}_{10}$  concentrations (Chow et al., 1991a).

Monitoring Site	Mean and Standard Deviation of the $\text{PM}_{10}$ Concentration ( $\mu\text{g}/\text{m}^3$ ) <sup>a</sup>	Number of Valid Samples
West Phoenix	46±21	59
Central Phoenix	50±21	40
South Scottsdale	37±15	58
Estrella Park	37±21	53
Gunnery Range	23±10	50
Pinnacle Peak	15±6	37
Valley National Bank	28±13	54
South Mountain	13±6	40

<sup>a</sup>  $\mu\text{g}/\text{m}^3$  is micrograms per cubic meter.

variability. The average PM<sub>10</sub> concentrations were highest at the Central Phoenix and West Phoenix sites. The next highest average concentration was observed at South Scottsdale. The average concentration on the roof of the Valley National Bank, 175 m agl (575 ft agl) in central Phoenix, was smaller than at the surface in South Scottsdale. The lowest average concentrations were measured at Pinnacle Peak and South Mountain, which are elevated nonurban sites.

**Table 3-2** shows the spatial distribution of the average PM<sub>2.5</sub> concentrations measured during the morning and afternoon sampling periods of the Urban Haze Study (Watson et al., 1991a). As with the 24-hr PM<sub>10</sub> concentrations, the highest morning fine-particle concentrations were measured at the surface sites in central and western Phoenix (ICA and West Phoenix). Lower morning fine-particle concentrations were measured at the surface site in South Scottsdale. The morning fine-particle concentrations measured on the roof of

the Valley National Bank, 175 m agl in central Phoenix, were comparable to those measured at the surface in South Scottsdale. The lowest morning fine-particle concentrations were measured at the GM Proving Ground southeast of central Phoenix. The afternoon fine particle concentrations were nearly the same at all sites, and were approximately equal to the morning concentrations in South Scottsdale and on the roof of the Valley National Bank.

The optical and PM measurements indicated that the ICA and West Phoenix sites experienced very poor visibility (light-extinction coefficient greater than 200 Mm<sup>-1</sup>) for more than 50 percent of the morning samples. (See Appendix B for a definition of Mm<sup>-1</sup>). With this amount of light extinction, an observer would not be able to see most hills or buildings that are more than 10 miles away. South Scottsdale experienced light extinctions greater than 200 Mm<sup>-1</sup> during less than 10 percent of the morning samples. Valley National Bank experienced

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*24-hr average PM<sub>10</sub> concentrations were highest at the Central Phoenix and West Phoenix sites and lower at nonurban sites.*

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Table 3-2. Means and standard deviations of morning (6:00 a.m. to noon MST) and afternoon (1:00 to 7:00 p.m. MST) fine-particle concentrations (Watson et al., 1991a).

Monitoring Site	Mean and Standard Deviation of the PM <sub>2.5</sub> Concentration (µg/m <sup>3</sup> )	
	Morning	Afternoon
ICA	27.9±11.5	15.4±8.9
West Phoenix	30.0±13.1	14.7±7.4
Valley National Bank	15.1±5.9	16.5±11.1
South Scottsdale	16.3±9.3	15.4±8.8
GM Proving Ground	10.2±4.7	Not Reported

morning extinctions exceeding this value for less than 2 percent of the samples. During the afternoon sampling period, less than 10 percent of the light extinctions exceeded  $200 \text{ Mm}^{-1}$  at any of the sites.

In summary, the light-extinction values and PM concentrations were highest in the morning near ground level in central Phoenix and in the residential areas to the west. PM concentrations and light extinction were roughly half as high in the morning in South Scottsdale, a residential area to the east of central Phoenix, and at the top of a tall building in central Phoenix. PM concentrations were lower at nonurban sites in Maricopa County than at urban sites.

### 3.3.4 Hourly Variation of Light Extinction and PM

The 1989-1990 study participants observed an hourly variation in light extinction and PM concentrations at ground level similar to the wintertime variations in recent transmissometer data, shown in Figure 3-2 and in Appendix C. As in the recent transmissometer data, the day-to-day variations in PM and light extinction observed in the 1989-1990 studies were large and did not follow a regular pattern. However, the means and median values of the 1989-1990 data show variations that are explained by hourly variations in emissions and meteorology.

**Figures 3-4 and 3-5** show the variation of the hourly median light scattering coefficient measured on the roof of the ICA building, and South Scottsdale, respectively. Figure 3-4 also shows the hourly variation of median light absorption by particles, and both plots show the hourly variation of median nitrogen dioxide

( $\text{NO}_2$ ) concentrations.  $\text{NO}_2$  is a brown gas which contributes to the color of urban brown clouds. Both of these figures report the hourly variations for weekdays and weekends separately.

Figure 3-4 shows a strong weekday morning peak in both light scattering and light absorption by particles at the ICA site. The morning peak is less pronounced on weekends. The weekday morning peak is due to a combination of morning emissions and the limited atmospheric mixing in the morning. A similar peak is not observed during the evening rush hour, when the onroad vehicle emissions are comparable, because atmospheric mixing is better in the evening than in the morning. Both light scattering and light absorption by particles increased between late afternoon and midnight. In this time period, atmospheric mixing decreases and pollutants are increasingly trapped near the surface. The decreases in light scattering and absorption after midnight are attributed to decreased emissions during those hours. The hourly patterns for West Phoenix are similar to those for the ICA site and these plots are not shown.

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*Light-extinction values and PM concentrations are greatest in the morning near ground level in central Phoenix and residential areas to the west.*

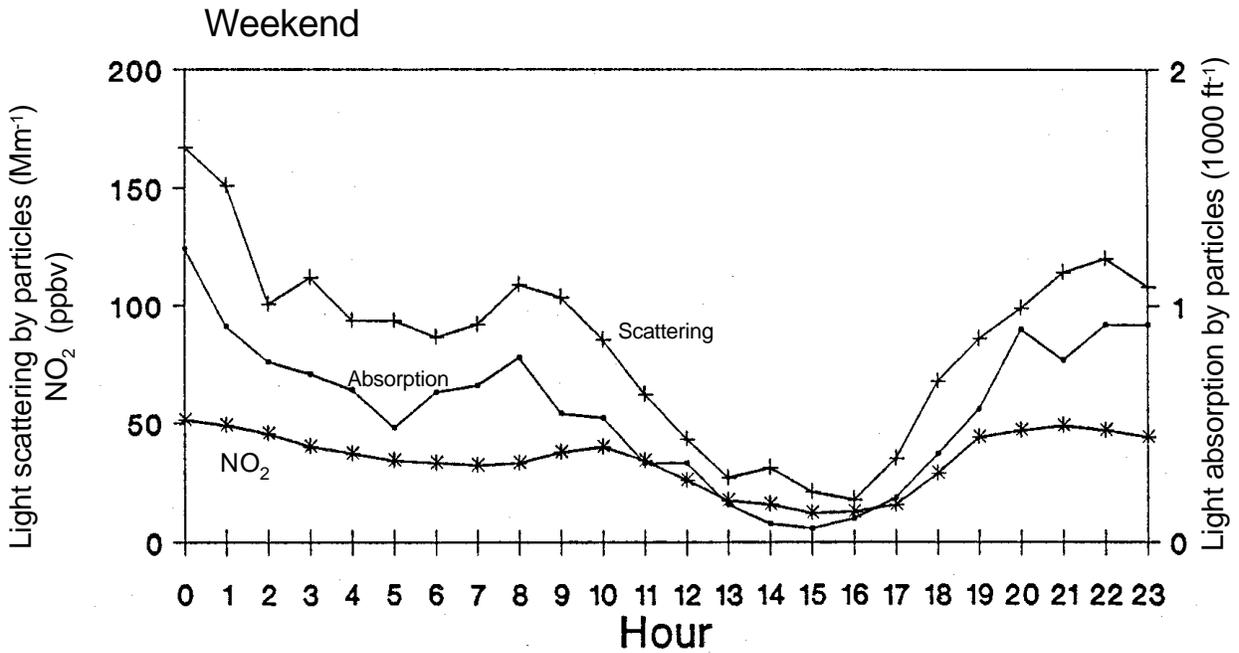
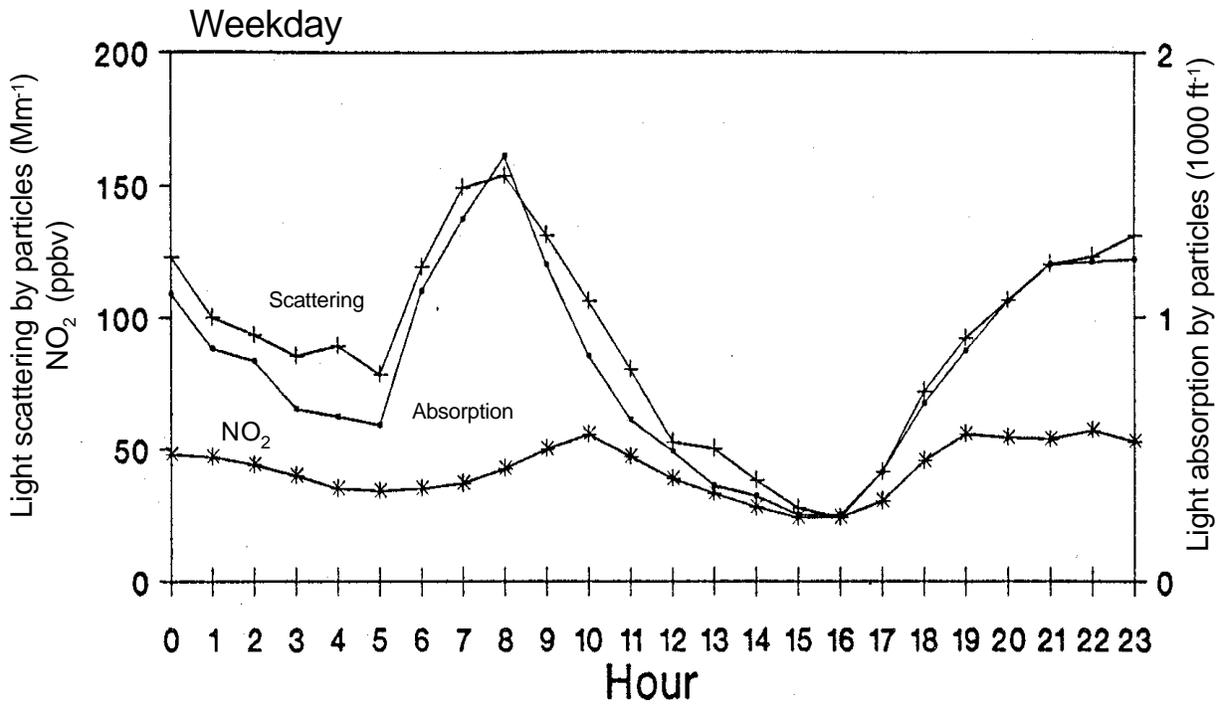


Figure 3-4. Daily variations of weekday and weekend hourly median light scattering and light absorption by particles and NO<sub>2</sub> concentration at the ICA site (Watson et al., 1991a).

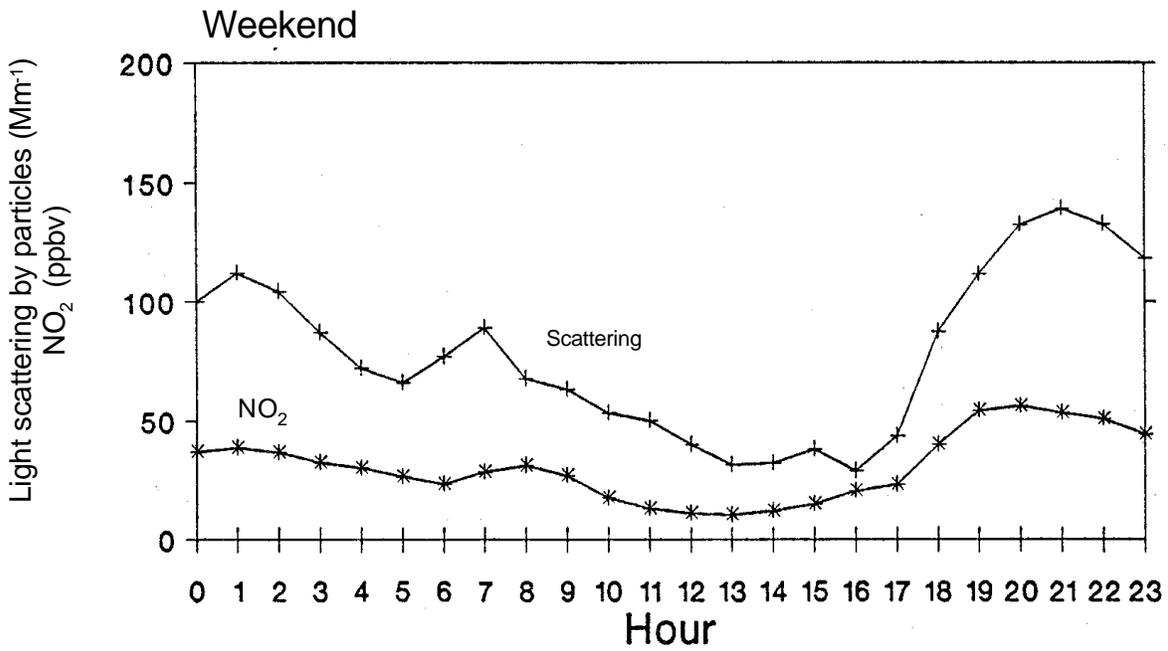
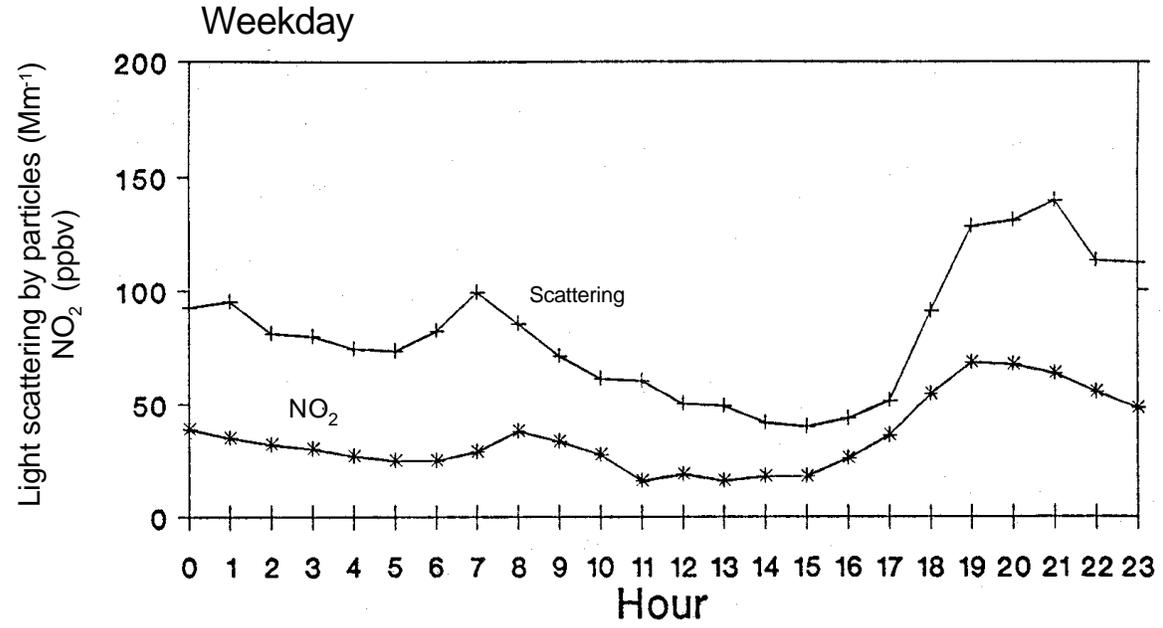


Figure 3-5. Daily variations of weekday and weekend hourly median light scattering by particles and NO<sub>2</sub> concentration at the South Scottsdale site (Watson et al., 1991a).

Figure 3-5 shows that the hourly pattern in South Scottsdale differs from that at the ICA building and West Phoenix. The morning peaks in light scattering by particles at the South Scottsdale site are similar on weekdays and weekends, and are much smaller than the weekday morning peaks at ICA and West Phoenix. However, the increase in light scattering by particles during the early part of the night is similar at all three sites.

The data in Table 3-2 show the patterns observed in the fine-particle mass concentrations during the morning and afternoon sampling periods at five sites. These data show trends similar to those in the optical data in Figures 3-4 and 3-5. The PM<sub>2.5</sub> concentrations were highest in the morning at the sites in central and western Phoenix (ICA and West Phoenix). The morning concentrations in South Scottsdale and on the roof of the Valley National Bank (175 m agl) were lower, were all about the same, and were all about the same as the afternoon concentrations. These data and photographs indicate that the brown clouds formed thin layers near the ground in the early mornings, then mixed upward each day as the solar heating increased the atmospheric mixing. The afternoon concentrations were approximately the same at all urban sites. PM<sub>2.5</sub> was measured at the General Motors Proving Ground only in the morning, and morning concentrations there were lower than either morning or afternoon concentrations at any site.

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*Afternoon average light extinction values and PM concentrations were approximately the same at all urban sites, and were about half the morning values at the surface in central Phoenix.*

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### 3.3.5 Effects Of Meteorology

Seasonal weather conditions and day-to-day weather changes largely determine the day-to-day variations of the brown cloud. An overview of the effects of meteorology appears in Chapter 2. This section presents meteorological information specific to Maricopa County.

Wind frequency distributions for the morning (6:00 a.m. MST) and afternoon (3:00 p.m. MST) observed at the Sky Harbor Airport in Phoenix for September 1989 through January 1990 are reported by Watson et al. (1991a). The data for 6:00 a.m. indicate that by far the most common observation was light winds from the east.

These winds were produced by cold air draining down the Salt River Valley. At night, the ground radiates heat into space, resulting in a layer of air at ground level that is colder than the air above it. Cool air is more dense than the warmer air aloft, and tends to flow downhill.

The afternoon winds were more variable in direction and sometimes stronger than in the morning. Winds from the west occurred more frequently than from other directions. Winds from the west return the air that was transported down the Salt River Valley in the morning back to the urban area. When this happens, the air over the urban area contains both morning and afternoon emissions, and the brown cloud tends to be more persistent than on days when this recirculation does not occur.

The most severe brown clouds occur on mornings when the air near the ground is cold and forms a relatively thin layer that does not mix with the air aloft. This layer often has a depth less than 100 m (330 ft) at the beginning of the day. During December, when daylight is of minimum duration, the surface layer that contains the fresh emissions does not attain a depth of 150 m (500 ft) until about 11:00 a.m. MST, and does not attain depths greater than 500 m (1650 ft) until 1:00 p.m. MST. As a result, sampling sites at the surface show a strong hourly variation in particle concentrations and light extinction, with the highest values in the morning. Elevated monitoring sites, such as on the roof of the Valley National Bank, are typically above the brown cloud in the morning, and show less difference between the morning and afternoon particle concentrations and light extinction values.

Brown clouds occur both under dry conditions and the wet conditions that follow rainstorms. The high humidity conditions following rainstorms result in two effects. As indicated in the following section, the high humidity changes the air chemistry and favors the formation of particulate ammonium nitrate. In addition, ambient particles absorb water at high humidities. This absorption increases both the particle mass concentration and, as described in Section 3.8, the light scattering efficiency of the particles. Some of the most severe brown clouds occur after rains, and ammonium nitrate is sometimes observed to account for 25 to 50 percent of the light

extinction during these events. Because the ground is damp during wet brown cloud events, soil dust sources are less important than during dry events.

### 3.3.6 Composition of PM

**Table 3-3** shows the mass concentration and average composition of the 24-hr PM<sub>2.5</sub> and PM<sub>10</sub> samples collected at West Phoenix,

Central Phoenix, and South Scottsdale during the 1989-1990 PM<sub>10</sub> Study (Chow et al., 1991a). The composition of the coarse particles was determined by the difference between the PM<sub>10</sub> and PM<sub>2.5</sub> data.

The concentration of soil dust was calculated as twice the sum of the measured concentrations of aluminum, silicon, calcium, titanium, manganese, and iron. The factor of two accounts for other elements in the soil particles, including oxygen, that were not measured. The concentration of organic compounds was assumed to be 1.2 times the concentration of organic carbon, to account for hydrogen and other elements present in organic compounds. The sums of the percentages indicate how well the calculated sums of the species concentrations agree with the measured mass concentrations. One-hundred percent indicates perfect agreement. **Figure 3-6** presents data from Table 3-3 for the composition of the fine particles at the West Phoenix site. Data from the other sites in Table 3-3 are similar enough that separate figures showing them were not prepared.

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*Coarse and fine particles contributed about equally to the PM<sub>10</sub> concentration in the central part of the urban area. Carbon species made up more than 70 percent of the fine particle mass and soil dust made up more than 70 percent of the coarse particle mass.*

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Table 3-3. Average mass and chemical composition of PM<sub>2.5</sub>, coarse particles, and PM<sub>10</sub> from 24-hour samples.

	Central Phoenix			West Phoenix			South Scottsdale		
	PM <sub>2.5</sub>	Coarse	PM <sub>10</sub>	PM <sub>2.5</sub>	Coarse	PM <sub>10</sub>	PM <sub>2.5</sub>	Coarse	PM <sub>10</sub>
Mass (mg/m <sup>3</sup> )	30.8	33.3	64.0	32.2	36.6	68.7	25.2	29.4	54.6
Percent Composition									
Nitrate	10.4	2.6	6.4	12.3	2.8	7.3	14.4	2.3	7.9
Sulfate	3.6	1.0	2.3	4.9	1.2	3.0	5.1	1.1	3.0
Ammonium	4.8	0.4	2.6	5.6	0.5	2.9	6.0	0.3	2.9
Organic Species	28.7	14.3	21.2	47.5	18.2	31.9	48.4	15.8	30.9
Elemental Carbon	19.2	2.2	10.4	29.0	2.4	14.8	28.8	3.1	14.9
Soil Dust	7.5	85.1	47.8	5.9	72.9	41.5	6.7	76.1	44.1
Sum	74.2	105.7	90.6	105.2	97.9	101.3	109.5	98.7	103.7

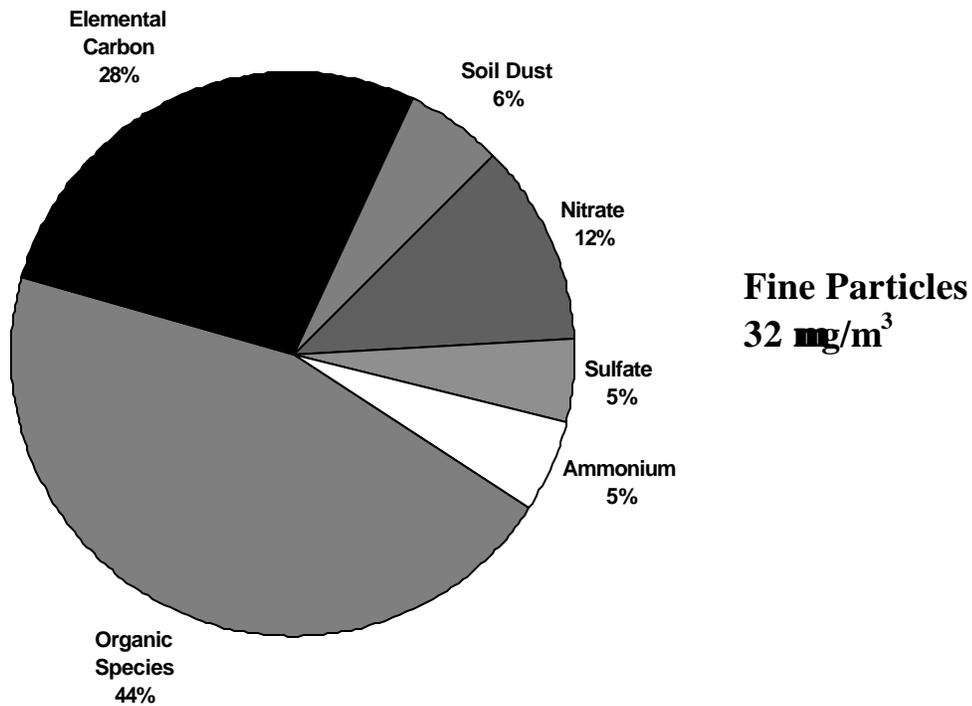


Figure 3-6. Average species composition of the 24-hr fine particles collected at the West Phoenix site during the 1989-90 Phoenix PM<sub>10</sub> Study (Chow et al., 1991a). The percentages have been adjusted to add to 100.

These data show that in the central part of the urban area, coarse and fine particles contributed about equally to the PM<sub>10</sub> concentration. Carbon species (elemental carbon plus organic compounds) made up more than 70 percent of the fine particle mass and nitrate accounted for 10 to 15 percent. Sulfate and ammonium accounted for about 5 percent each. Soil dust made up more than 70 percent of the coarse particle mass and organic compounds accounted for 15 to 20 percent. Sulfate, nitrate, and elemental carbon contributed less than 3 percent each to the coarse particle mass.

The data reported by Chow et al. (1991a) indicate that at the non-urban sites, fine particles contributed about half as much to PM<sub>10</sub> mass as the coarse particles. Much of the decrease in fine particle concentrations at the non-urban sites was due to smaller concentrations of organic compounds and elemental carbon.

**Table 3-4** shows the average mass and chemical composition of morning (6:00 a.m. to noon MST) and afternoon (1:00 to 7:00 p.m. MST) fine particle samples (Watson et al., 1991a). The mass data are the same as shown in Table 3-2. Differences in the mass and chemical composition data are to be expected because these data were measured on different days from those reported in Table 3-3. As in the data shown in Figure 3-6, carbon compounds (organic compounds and elemental carbon) are the dominant component of fine particles. The nitrate concentrations are higher in Table 3-4 than in Table 3-3. Part of the reason for the difference in nitrate concentrations is that the sampler used to collect the Urban Haze Study data in Table 3-4 had a backup filter to collect and measure nitrate volatilized during sample collection, while the samplers used in the PM<sub>10</sub> study did not. The Urban Haze Study made use of a sampling method that measured the particulate nitrate lost from the collection filter during sample collection. The Urban Haze Study data provide a better measure of the concentrations of nitrate particles that contribute

Table 3-4. Average mass and chemical composition of morning and afternoon PM<sub>2.5</sub> samples.

	ICA		Valley Bank		West Phoenix		South Scottsdale		GM Pr. Gnd.	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Mass ( <b>µg</b> /m <sup>3</sup> )	27.9	15.4	15.1	14.7	30.0	16.5	16.3	15.4	10.2	
Percent Composition										
Nitrate	14.3	28.9	19.7	28.8	14.3	27.7	13.1	24.0	2.0	
Sulfate	5.9	7.8	7.5	7.4	5.0	6.8	6.2	11.1	12.8	
Ammonium	4.3	6.2	5.8	6.4	3.8	5.2	4.2	5.7	5.1	
Organic Compounds	37.2	48.1	44.4	40.8	39.6	44.5	41.0	43.0	9.9	
Elemental Carbon	29.0	19.9	24.4	15.6	29.4	16.7	26.6	19.4	21.2	
Soil Dust	11.8	15.5	13.1	15.0	9.6	14.8	13.9	15.4	28.0	
Sum	102.5	126.5	114.9	114.0	101.7	115.7	105.0	118.6	78.9	

to brown clouds. The nitrate concentrations were variable, and accounted for a larger fraction of the PM on days with high PM concentrations. Nitrate concentrations were highest during the wet haze episodes described in Section 3.5. Particulate nitrate is mostly in the form of ammonium nitrate, which is volatile. When the weather is dry and hot, ammonium nitrate tends to dissociate into ammonia and nitric acid, which are invisible gases. Cool temperatures and high humidities shift the equilibrium toward ammonium nitrate particles, which contribute to light scattering in brown clouds.

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*The light scattering efficiency of coarse particles is approximately one-tenth the efficiency of fine particles. Soil dust is not a major contributor to light extinction.*

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### 3.3.7 Light Extinction Efficiencies

Data for the light-scattering and light-absorption efficiencies of haze particles is presented here because it is an important property of haze particles in Maricopa County. These data are used in Section 4.3.3, where the contributions of sources to brown clouds are estimated. A general discussion of the light-extinction efficiencies of particles in western urban areas is presented in Section 2.8.

The calculation of the contributions of sources to brown clouds is performed in two steps (Watson et al., 1991a). The first step is to calculate the source contributions to PM, and these analyses are presented in Section 4.2. The second step is to multiply these source contributions by the light-extinction efficiencies of the chemical species presented in this section. These calculations were performed for each filter sample collected in the 1989-1990 Phoenix Urban Haze Study, and the results are summarized in Section 4.2.3.

The light-scattering and absorption efficiencies used for these calculations are summarized in **Table 3-5**. Equations for the humidity-dependent light scattering efficiencies of ammonium sulfate, ammonium nitrate, and organic compounds were derived from measurements of the particle-size distribution of these species as a function of relative humidity as described by Watson et al. (1991a). The values in Table 3-5 were calculated from those equations. The scattering efficiencies of these species depend on relative humidity because ambient particles absorb water at high humidity.

An important feature of these data is that the light-scattering efficiency of coarse particles, which are primarily composed of soil dust, is roughly one-tenth the light-scattering efficiencies of the chemical species in fine particles. The data in Table 3-3 indicate that the PM is about one-half coarse particles and one-half fine particles. These data indicate that coarse particles contribute roughly 10 percent of the light scattering by PM in brown clouds.

As described in Chapter 2 and Appendix B, light extinction is the sum of light scattering and light absorption. The light absorption efficiencies of elemental carbon and nitrogen dioxide gas are also listed in Table 3-5. No other components of brown clouds make a significant contribution to light absorption.

Table 3-5. Light scattering and light absorption efficiency factors used to calculate source contributions to light extinction (Watson et al., 1991a).

	Light Absorption Efficiency (m <sup>2</sup> /g) <sup>a</sup>	Light Scattering Efficiency (m <sup>2</sup> /g) at the Indicated Relative Humidity (percent) (See Appendix B for explanation.)			
		30	60	80	90
Fine Particles					
Ammonium Sulfate	0	2.43	3.50	6.0	11.
Ammonium Nitrate	0	3.66	5.05	8.3	15
Organic Compounds	0	4.26	4.90	6.4	9.4
Elemental Carbon	8.3	1.6	1.6	1.6	1.6
Remaining Mass	0	1.0	1.0	1.0	1.0
Coarse Particles	0	0.4	0.4	0.4	0.4
Gas					
Nitrogen Dioxide	1.7	0	0	0	0

<sup>a</sup> m<sup>2</sup>/g is square meters per gram.

### 3.3.8 Discussion

The field measurements for the 1989-1990 Phoenix PM<sub>10</sub> Study and the 1989-1990 Phoenix Urban Haze Study were performed more than nine years ago. Since that time, changes in emissions are likely to have occurred that could affect the brown cloud.

These changes are expected to have been caused by factors such as increased population, increased motor vehicle use, expansion of the

freeway system, turnover of the motor vehicle fleet, reformulation of motor fuels, conversion of vehicles to alternative fuels, and implementation of emission control measures. It is expected that changes in the relative contribution of emission sources during the last seven years were small enough that the conclusions presented in this Chapter are still valid. This expectation is based in part on data for emissions and sources presented in Chapter 4.

## **4. EMISSION SOURCES THAT CONTRIBUTE TO BROWN CLOUDS**

### **4.1 INTRODUCTION**

This chapter presents information on the emission sources in Maricopa County that make the largest contributions to brown clouds. Section 4.2 presents information on sources of emissions derived from chemical mass balance (CMB) calculations performed during this study and as part of the 1989-1990 Phoenix PM<sub>10</sub> Study and the 1989-1990 Phoenix Urban Haze Study. Section 4.2 begins with an introduction to the methods used in CMB calculations. Briefly, CMB is a mathematical method that finds the combination of emission sources that best accounts for the pollutant concentrations measured in the atmosphere at the location where a pollution sample was collected during the time period the sample was collected. The information in Section 4.3 was obtained from emission inventories contained in the MAG 1999 Serious Area Particulate Plan for PM-10 for the Maricopa County Nonattainment Area. These two types of information on emission sources are combined in Section 4.4 to prepare a list of sources that make the largest contribution to brown clouds.

### **4.2 CHEMICAL MASS BALANCE SOURCE ATTRIBUTION OF PM<sub>2.5</sub>**

#### **4.2.1 Introduction**

CMB calculations were performed both during the 1989-1990 Phoenix PM<sub>10</sub> Study and the 1989-1990 Phoenix Urban Haze Study to estimate the relative contribution of various emission source categories to PM<sub>2.5</sub> and PM<sub>10</sub> in Maricopa County. At the time those calculations were performed, it was not possible to separate the contribution of gasoline

engine exhaust from the contribution of diesel engine exhaust to PM concentrations in the atmosphere.

Recently, the ability of CMB calculations to resolve the contributions of similar sources has been expanded by measuring the concentrations of an array of organic compounds both in the source emissions and in the ambient air. The Northern Front Range Air Quality Study (NFRAQS) was recently completed in the Denver area, and this study determined the composition of the emissions from an unusually large number of emission sources. Also, ADEQ conducted a hazardous air pollutants monitoring program in Maricopa County in 1994 to 1996 that provided data for the ambient concentrations of a number of organic compounds. The data from these two studies provided an opportunity to perform new CMB calculations that estimated the separate contributions of exhaust from gasoline and diesel engines to PM concentrations. Therefore, these CMB calculations were performed as part of this study. The results from the current study are presented first, followed by the results from the 1989-1990 studies.

#### **4.2.2 CMB Calculations Performed During This Study**

This section summarizes the results of the PM<sub>2.5</sub> source apportionments performed at Desert Research Institute (DRI) as part of this study. A CMB receptor model was applied to ambient PM<sub>2.5</sub> samples that were collected in the Maricopa County area by ADEQ from November 1994 to September 1995. An important new feature of these CMB calculations is that 12 organic compounds were included in the chemical species used in the

calculations. This improved the ability to apportion ambient PM to different categories of mobile source emissions. A more complete account of these CMB calculations and tabulations of the source profiles and detailed results may be found in Appendix E.

## **Methods and Approach**

CMB calculations are based on the fact that many chemical species do not participate in rapid chemical reactions in the atmosphere. Therefore, when collected, they have the same chemical form as when they were emitted. These chemical species may be used in a three-step procedure to perform a source apportionment, i.e., to apportion the ambient pollutants to the sources from which they were emitted. The first step is to measure the chemical composition of the emissions from the more important source categories (e.g., diesel engines, gasoline engines, meat cooking, wood combustion, coal-fired boilers, smelters, resuspended dust, etc.). Since gasoline engine emissions vary from one vehicle to the next, a composite or average composition may be calculated from measurements on a number of vehicles. These data for the composition of emissions are called source profiles. The second step is to collect and analyze samples of the chemical species in the ambient air.

The third step is to apply the CMB model to each ambient sample to estimate the relative amounts of emissions from each source category which, when mixed together, give the best agreement with the measured composition of the atmosphere. This result is called a source apportionment or source attribution. The application of the CMB model includes a choice by the operator of the source profiles to include in the calculations. If a source profile is included that is not needed to explain the

ambient concentrations, the CMB model will return the result that the contribution from this source category is not important. If an important source category is omitted from the CMB calculation, it is likely that the model will not be able to find a source attribution that accurately reproduces the measured ambient concentrations.

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*CMB calculates the combination of emissions that accounts for the composition of the air pollution.*

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An error analysis is a key component of CMB calculations. Each item of input data is accompanied by an estimate of its uncertainty. The CMB model combines these uncertainties to calculate the uncertainty in each output value that is attributable to the uncertainties in the input data. If a contribution from one source category is small compared to its uncertainty, the calculations do not show that this source is important. If the best fit ambient composition calculated by the CMB model differs from the measured ambient composition by more than the uncertainties, there is a problem with either the selection of source profiles used in the calculations or the accuracy of the input data. More detailed information about the assumptions underlying CMB calculations and the error analyses is presented in Appendix E.

In addition, a series of sensitivity tests and reasonableness checks were performed on the CMB data. The results of the effort are presented in Appendix E. In general, the sensitivity tests indicated that the source apportionments are highly sensitive to changes in source profile selection and that other source attributions with acceptable statistics may be obtained from the same data set using different combinations of source profiles. Accordingly, the source apportionments derived from a CMB analysis should be thought of as

representing the general level of contribution from a source and not an absolute number.

The ambient data used in this study consist of fine particle (PM<sub>2.5</sub>) samples collected at three locations in the Maricopa County area every sixth day from November 1994 to September 1995 by the ADEQ. Chemical analyses were performed on sets of filters collected on seven or eight days each calendar quarter. Measured components of PM<sub>2.5</sub> include nitrate, sulfate, chloride, soluble potassium, organic and elemental carbon, and elements from aluminum to uranium. These are the “conventional” species used in CMB calculations. The CMB model was applied to 28 and 22 sets of 6-hour and 24-hour samples, respectively, from Tempe and ASU West and 25 and 26 sets of 6-hour and 24-hour samples, respectively, from the Phoenix Super Site.

ADEQ also collected samples for semi-volatile and particulate polycyclic aromatic hydrocarbons (PAHs) in 1994 to 1996 as part of an ambient hazardous air pollutants (HAPs) monitoring program. Twelve of the 24-hour PAH samples were collected at the Phoenix Super Site concurrently with the PM<sub>2.5</sub> samples during the November 1994 to March 1995 period. The PAH data from these samples were added to the corresponding conventional PM speciation to obtain “extended speciation” data. The addition of PAHs allows the separate apportionment to gasoline and diesel engine exhaust. These species potentially make it possible to separately apportion gasoline engine emissions to cold starts, smoking engines, and properly operating hot stabilized (warmed up) engines in catalyst-equipped

vehicles. Meat cooking and wood combustion could not be quantitatively apportioned because organic compounds that are markers for these sources (methoxylated phenols, hopanes, steranes, lactones, and sterols) were not measured in the HAPs monitoring program.

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*New results were obtained by including organic compounds in the CMB.*

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The CMB analysis was performed using source profiles from NFRAQS (recently completed in the Denver area), from the 1989-

1990 Phoenix Urban Haze Study, and from the characterization of gasoline- and diesel-powered vehicles at a Phoenix Inspection and Maintenance (IM) facility. Sets of profiles consisting of conventional species and conventional species plus PAHs were considered for the NFRAQS and Phoenix IM profiles. The profiles from the Phoenix Urban Haze Study consist of conventional species only. Chemical abundances in each emission source are expressed as the fraction of emitted PM<sub>2.5</sub> mass. Both particle-phase and gas-phase emissions are normalized to the PM<sub>2.5</sub> mass. The IM profiles generally gave poor model performance and consistently resulted in underestimation of ambient elemental carbon. This result suggests that the test procedure used at the IM station does not produce exhaust compositions that are representative of on-road diesel and gasoline exhaust emissions or that profiles from an important source were not included in the CMB analysis. The absence of cold-starts and hard accelerations in the IM 240 test and constant rather than variable loads in the heavy-duty trucks test could be possible explanations for the poor performance obtained when using the IM station source profiles. In contrast, use of the NFRAQS exhaust profiles consistently resulted in good model performance.

## Summary of Findings

The present study focused on measurement of PM<sub>2.5</sub>, the fine particles that contribute to brown clouds. The ambient PM<sub>2.5</sub> data showed that in the urban areas of Maricopa County, particulate carbon species (organic compounds and elemental carbon) were the largest contributor, accounting for nearly two-thirds of the PM<sub>2.5</sub>. Particulate ammonium nitrate was the second most important species, with ammonium sulfate and dust next in abundance.

When interpreting the results from the CMB analysis, it is important to keep in mind the limitations of the model and view the results as the general level of contributions from a source. For example, since source profiles for wood burning and meat cooking were not included in the analysis, the attribution of mass to sources with similar emission compositions (i.e., other combustion sources such as diesel and gasoline engines) is likely to be overestimated. In the current analysis, the lack of source profiles for wood burning and meat cooking is likely to result in a greater overestimation of emissions from gasoline engines than from diesel engines since, similar to gasoline engine exhausts, both wood burning and meat cooking produce emissions with a high ratio of organic carbon to elemental carbon, whereas the opposite is true for diesel engines.

The results presented below have different levels of confidence associated with them. For

example, there is a relatively high level of confidence in estimates for the contribution of total mobile source exhaust, ammonium nitrate, ammonium sulfate, and geological material.

There is a lower level of confidence associated with the split in mobile source exhaust between diesel-powered engines and gasoline-powered engines. There is low confidence that the CMB attribution of gasoline-

powered engines emissions to cold start, high emitter, and hot stabilized is accurate.

The following are the main findings from the CMB analysis (with extended speciation) for the Phoenix Super Site during the November 1994 to March 1995 period. It is important to note that although the sampling period lasted five months, only 12 samples were used in the CMB analysis with extended species. Therefore, the results from that analysis are based on a relatively small number of samples from one location in the nonattainment area. As evidenced in the 1989-1990 studies, the source contributions may vary throughout the nonattainment area.

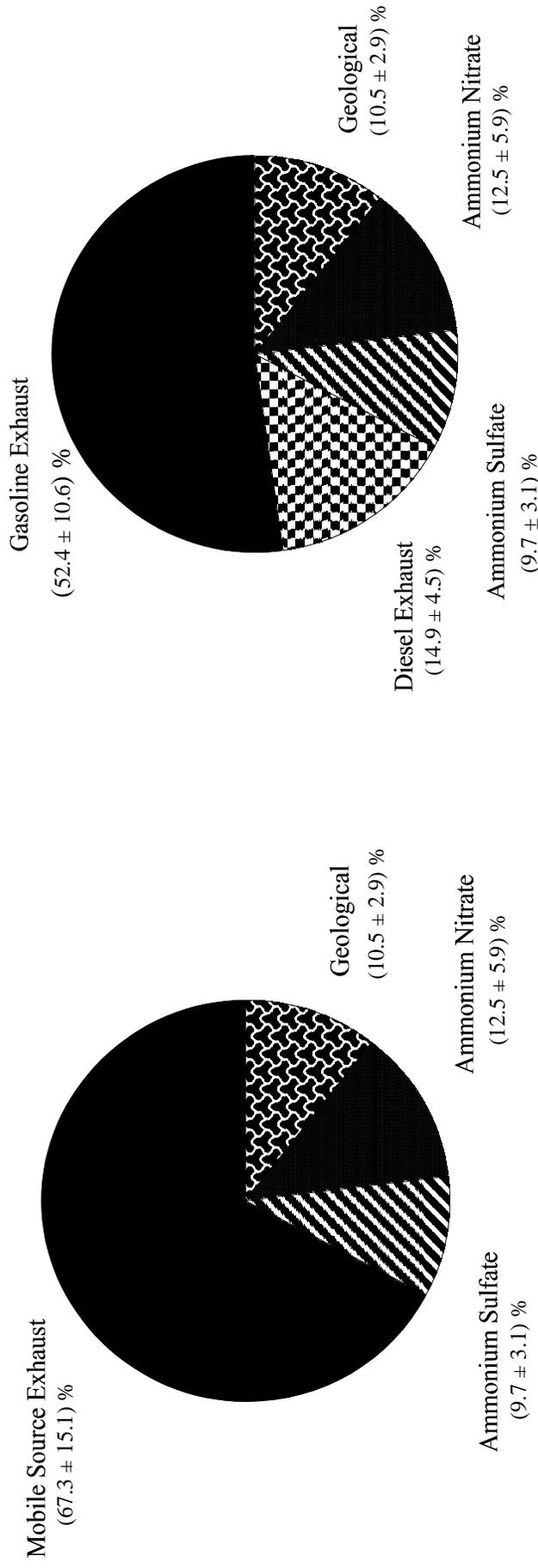
As shown in Figure 4-1, combustion sources emissions constitute the majority of PM-2.5. Gasoline engine exhaust accounts for about half of the ambient PM-2.5 and diesel engine exhaust accounts for about 15 percent. In addition, gasoline and diesel exhaust account for nearly all of the carbonaceous fraction of the fine particles (organic carbon and elemental carbon).

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*Gasoline and diesel engine exhaust account for most of the PM<sub>2.5</sub> and nearly all of the elemental carbon and organic carbon compounds.*

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Figure 4.1. PM-2.5 source contributions from the CMB analysis of samples from the Phoenix Super Site.



The data in the parenthesis represent the mean percentage and standard deviation with 95% confidence.

Note: The lack of source profiles in the CMB analysis for wood burning and meat cooking likely results in an overestimate of the emissions from diesel and gasoline-powered engines. The contribution from gasoline-powered engines is likely to be overestimated to a greater extent than the contribution from diesel-powered engines.

Gasoline exhaust accounts for nearly 90 percent of the carbon. It is important to note that diesel exhaust makes a slightly larger contribution to elemental carbon than does gasoline exhaust, and these two sources account for nearly all of the elemental carbon. As indicated earlier, elemental carbon causes most of the color of the brown cloud.

Diesel exhaust makes a slightly larger contribution to elemental carbon than does gasoline exhaust, and these two sources account for nearly all the elemental carbon.

The source contribution estimates for gasoline and diesel exhaust are based on source profiles for engines in vehicles, and may include emissions from off-road diesel engines (e.g., trains and construction equipment), diesel-powered equipment (e.g., generators), off-road gasoline mobile source (e.g., all-terrain vehicles), and gasoline-powered equipment (e.g., lawnmowers, leaf blower, chainsaws). The attribution for mobile sources should be considered the upper limit since the contributions of wood combustion and meat cooking could not be apportioned because suitable marker species were not measured. (See the discussion in the Conclusions section below.)

Road and geologic dust sources account for approximately 10 percent of the  $PM_{2.5}$ . These sources make a negligible contribution to elemental carbon and organic compounds. Ammonium nitrate accounts for slightly more than 10 percent and ammonium sulfate accounts for slightly less than 10 percent of the ambient  $PM_{2.5}$  at the Phoenix Super Site. CMB is not able to attribute these species to

sources because they are formed in the atmosphere. Only negligible amounts of these species are directly emitted by sources.

***An unexpectedly large fraction of  $PM_{2.5}$  from gasoline engine exhaust appears to come from high emitters and cold starts.***

The NFRAQS study determined that, in Denver, gasoline engine emissions from cold starts and high emitters both made contributions four times greater than emissions from gasoline engines operating in the hot stabilized mode. Similarly, the CMB analysis in the Maricopa County study indicated that the gasoline engine emissions were coming from cold starts and high emitters and that the contribution from the hot stabilized mode was negligible. Since these results were surprising, MAG conducted a reasonableness check on the relative distribution of onroad mobile gasoline engine emissions (see Appendix E). These reasonableness checks confirm that cold starts and high emitters contribute a disproportionate amount of the total gasoline engine exhaust. However, gasoline engine exhaust from the hot stabilized mode contributed a significant fraction of the total gasoline engine exhaust even if it was assumed that as much as ten percent of the vehicles were high emitters. Therefore, there is a low level of confidence associated with the CMB apportionment to specific modes of gasoline vehicle activity. However, the importance of controlling high emitters and cold starts was confirmed by the reasonableness check.

There is some uncertainty in the application of the NFRAQS vehicle emission source profiles measured near Denver to Maricopa County. There are differences in fuel composition, and Denver has a higher elevation

and lower temperatures. This makes the uncertainties in the results reported above larger than the reported mathematical uncertainties. Nevertheless, the CMB calculations using the NFRAQS source profiles resulted in excellent fits to the ambient concentrations measured in Maricopa County. Also, the differences between the source profiles of gasoline and diesel vehicles are much greater than the differences that might occur if all source profiles were measured in Maricopa County. Therefore, it is believed that the above results are substantially the same as would have been obtained from source profiles measured in Maricopa County.

The composition of gasoline exhaust appears to be nearly the same as diesel exhaust if only conventional species are used in the profiles, which leads to higher uncertainties in the apportionment. However, the combined contributions of gasoline and diesel exhaust to  $PM_{2.5}$  are about 60 to 65 percent at the Phoenix Super Site for both the conventional CMB and extended CMB. The following is a summary of the findings from the CMB analyses using conventional speciation.

The mobile source contributions to  $PM_{2.5}$  are about ten percent higher for the 6-hour morning samples at all three sites (i.e., Phoenix Super Site, Tempe, and ASU West) compared to the 24-hour samples from Phoenix Super Site. The contributions of fine dust ranged from 8 to 15 percent at the three sites. There are no apparent seasonal trends in apportionments.

In some cases, it was necessary to include an ambient background source with smelter emissions to account for excess arsenic, lead, and lanthanum. This contribution is not

strictly attributable to emissions from smelters. This background profile also contains secondary sulfate and nitrate in addition to other particulate matter found in regional background samples. It was not necessary to include source profiles from any other stationary source categories in the CMB calculations to fit the ambient data.

### Conclusions

The source apportionment analysis for the Maricopa County area shows that exhaust emissions from mobile sources produced about 65 percent of the  $PM_{2.5}$ . Including the road and geologic dust caused by mobile sources would make the total contribution of these sources even larger. The  $PM_{2.5}$  emissions from gasoline engines were three times greater than those from diesel engines. Fine particles produced by road dust, construction, and wind-blown sand contributed about 10 to 15 percent of the  $PM_{2.5}$ . Wood burning emissions and meat cooking could not be apportioned with the available data.

It is useful to compare the above results for Maricopa County with those found in the metropolitan Denver area during NFRAQS because a much larger number of trace organic compounds were measured and used in the CMB calculations during NFRAQS. Although the fraction of carbonaceous particles in  $PM_{2.5}$  is greater in Maricopa County than in Denver, the relative contributions of mobile sources to  $PM_{2.5}$  carbon are nearly identical in the two regions.  $PM_{2.5}$  emissions from gasoline-powered vehicles in Denver were three times the  $PM_{2.5}$  emissions produced by diesel-

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*A much more extensive CMB study for the Denver area gave essentially the same results.*

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powered vehicles, compared with current emission estimates for Denver in which diesel-powered vehicles are projected to produce more emissions than gasoline-powered vehicles. High-emitting or smoking vehicles, which comprise a small fraction of the in-use vehicle fleet in the Denver area, produced nearly one-half of the gasoline  $PM_{2.5}$  exhaust. The diesel  $PM_{2.5}$  exhaust comes from trucks, locomotives, construction equipment, and other sources. Fine particles from road debris and dust, construction activities, and wind-blown sand contributed 16 percent of the total  $PM_{2.5}$ , an amount much lower than current emission estimates for the Denver area. All of these conclusions, derived for Northern Front Range area, are also applicable to Maricopa County.

It was possible to include meat cooking and wood combustion in the NFRAQS source apportionments because a greater number of organic compounds was measured, including those specific to wood combustion (e.g., syringols and guaiacols). On average, the combined contribution of wood burning and meat cooking was nine percent of the  $PM_{2.5}$  in Denver. Omitting these species from the CMB calculations for Maricopa County introduces a small, but not negligible, error. The NFRAQS area has a number of coal-fired power plants, and primary particles (fly ash) from them contributed approximately two percent of the  $PM_{2.5}$ . There are no coal-fired power plants in Maricopa County.

An underestimation of particulate emissions from gasoline-powered vehicles in the emission inventories is plausible given the current development of motor vehicle emission factor

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*The new CMB results from this study agree with those from the 1989-1990 Phoenix Urban Haze and  $PM_{10}$  Studies.*

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models. The EPA particulate emission factors vary in the PART 5 computer model only by vehicle model year groups. Emission rates for pre-1981 noncatalyst and post-1980 catalyst vehicles are 30 and 4.3 mg/mile of carbon, respectively.

In contrast, the average particulate emission rates from the NFRAQS vehicle emissions tests were 82.6 mg/mile for pre-1980 light-duty gasoline vehicles and 24.9 to 48.2 mg/mile for post-1980 vehicles. The corresponding Phase 1 (“cold”) emission rates were 290 mg/mile for pre-1980 light-duty gasoline vehicles and 81.3 to 159 mg/mile for post-1980 vehicles. Smoking vehicles emitted an average of 1179 mg/mile in Phase 1 and 434 mg/mile in the composite source profile for the Federal Test Procedure (FTP). Because of substantially higher emission rates, smokers, marginal smokers/high emitters, and “puffers” (older vehicles in cold start mode) should account for a disproportionate fraction of particulate emissions relative to their numbers. Yet, current emission factor models used to calculate data for emission inventories do not adequately account for emissions from these vehicles. It is well established that in-use vehicle exhaust emissions are gamma distributed and that ten percent of the vehicles account for over 50 percent of the total CO and VOC emissions. There is no evidence to suggest that PM emissions are not similarly gamma distributed. The plausibility of ambient attributions of gasoline exhaust to subcategories of the vehicle fleet depends on assumptions regarding the contributions of a relatively small fraction of the vehicle fleet and the average particulate emission rates of normal emitters in hot stabilized operation.

### 4.2.3 CMB Calculations from the 1989-1990 Phoenix Studies

It was a key objective of both the 1989-1990 Phoenix  $PM_{10}$  Study and the 1989-1990 Phoenix Urban Haze Study to determine the relative contribution of various categories of emission sources to PM in Maricopa County. Both studies were receptor oriented, i.e., they measured the composition of the atmosphere at a number of monitoring sites (receptor sites), then used CMB to calculate the contribution of the more important source categories to air pollution during each sample collection time period. These results are reported in detail in the final reports and appendices from these studies (Chow et al., 1991a, 1991b; Watson et al., 1991b, 1991c). The following overview presents a representative sample of average results from one monitoring site and a brief summary of the findings from the two studies.

#### Source Contributions to PM

The data presented below are from the Urban Haze Study (Watson et al., 1991a), and were selected because they show the source contributions for morning (6:00 a.m. to noon MST) and afternoon (1:00 to 7:00 p.m. MST) samples for fine particles. The pie diagrams in **Figure 4-2** show the average source contributions calculated for the West Phoenix site. As was typical of all urban sites, primary particles from mobile source exhaust was the dominant contributor to fine particles. These CMB calculations, performed nearly a decade ago, used only the conventional chemical species. As was the case in the results reported from the current CMB analysis above, these

CMB calculations could not separate the contributions of onroad and nonroad mobile sources. Therefore, the total from these two source categories is reported. Also, as was the case for the current CMB analysis with conventional species reported above, the CMB analysis from the Urban

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*The dominant contributor to  $PM_{10}$  was soil dust. Coarse particles are mostly soil dust.*

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Haze Study could not separate the contributions of gasoline and diesel engines. Ammonium nitrate, which is formed in the atmosphere from the nitrogen oxides emitted by mobile sources, was the second most important contributor. Soil dust smaller than 2.5  $\mu m$  diameter was third in importance. The average contributions of ammonium sulfate and vegetative burning (e.g., wood combustion) to fine-particle concentrations were small. Soil dust was by far the dominant contributor to coarse particles, and primary particles from mobile source exhaust accounted for most of the remainder of the coarse particles.

Mobile source exhaust particles and soil dust are primary species. Primary species are emitted from sources, transported through the atmosphere without major chemical change, and collected on filters in much the same form as they were emitted. Ammonium, sulfate, and nitrate are secondary species; which are formed in the atmosphere from gases such as sulfur dioxide, nitrogen oxides, and ammonia. These secondary species have the same chemical form regardless of the emission source that released the gases from which they were formed. Consequently, it is not possible to determine the source of these gases from the chemical composition of the secondary species. The secondary species are included in the source contribution diagrams in Figure 4-2, but the source of these particles is not indicated.

Primary particles have a chemical composition characteristic of their source, and this information may be used to determine the relative contributions of different sources to the primary particle component of PM concentrations.

The contributions of ammonium nitrate and volatilized nitrate to fine-particle concentrations are shown separately in Figure 4-2. Volatilized nitrate is nitrate that was volatilized from the collection filter during sample collection and collected on a backup filter. Ammonium nitrate is nitrate that was collected and did not volatilize. Because of federal standards for PM<sub>10</sub> sampling, the nitrate that did not volatilize was the only nitrate included in the data from the PM<sub>10</sub> Study. The volatilized nitrate was measured in the

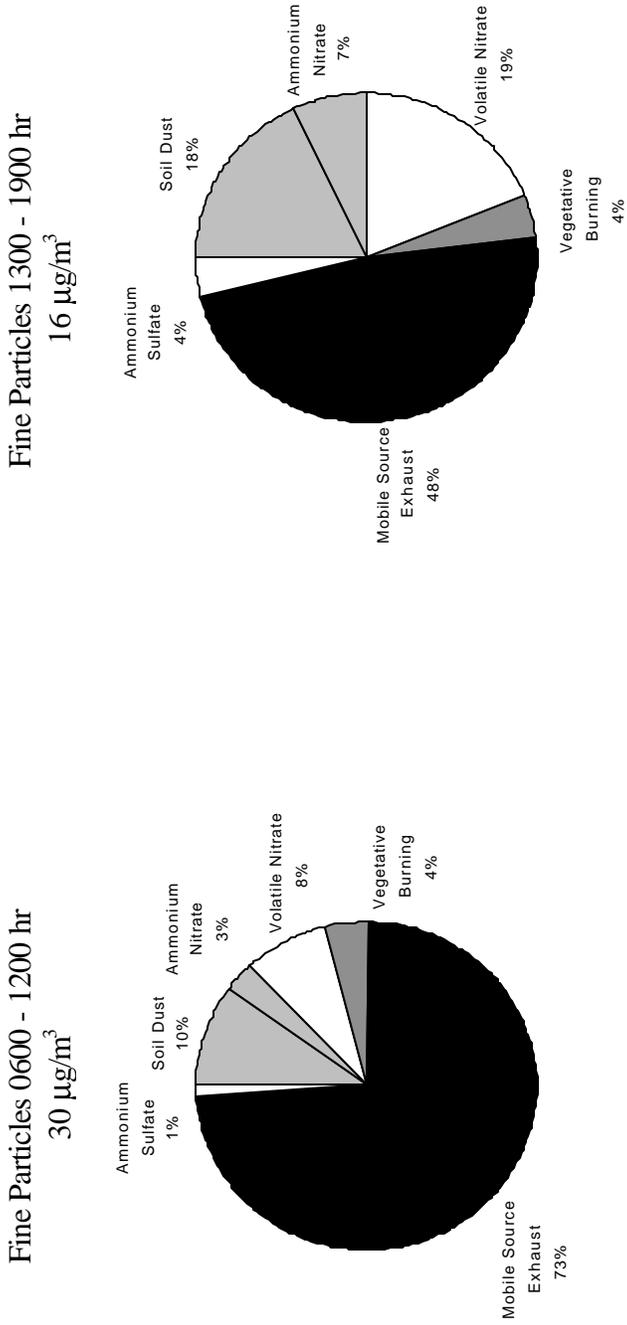


Figure 4-2. Average morning and afternoon source contributions to fine particle mass concentrations at the West Phoenix site (Watson et al., 1991b). Volatile Nitrate is volatilized ammonium nitrate collected on a nylon backup filter.

Urban Haze Study because the sum of the measured ammonium nitrate and volatilized nitrate provides a better measure of the nitrate in the atmosphere than does only the ammonium nitrate measurement.

Results similar to those in Figure 4-2 were obtained in the PM<sub>10</sub> Study (Chow et al., 1991a). Mobile sources were by far the dominant source contributing to fine-particle concentrations. The average fraction of the PM<sub>2.5</sub> attributed to mobile source emissions varied from 50 percent at the South Scottsdale monitoring site to 71 percent at the Central Phoenix site. The average fraction of PM<sub>2.5</sub> attributed to vegetative burning (e.g., wood burning) varied from 29 percent at the West Phoenix monitoring site to a value too small to report at the Gunnery Range site.

The dominant contributor to PM<sub>10</sub> was soil dust, which accounted for 43 to 76 percent of the measured PM<sub>10</sub>. Because PM<sub>10</sub> includes fine particles (PM<sub>2.5</sub>), and about half of the PM<sub>10</sub> mass is due to fine particles, it is apparent from these results that soil dust is by far the dominant contributor to coarse particles.

The highest fraction of mobile source emissions was observed at the Central Phoenix site, and the highest fractions of vegetative burning were observed at the West Phoenix and South Scottsdale sites, which are in residential areas. The sites at which soil dust was responsible for the highest fractions of fine particles were Estrella Park and Gunnery Range. Soil dust sources have a greater relative importance at these nonurban sites primarily

because of the lower concentrations of particulate elemental carbon and organic compounds attributed to mobile source emissions.

Mobile source emissions that contribute to PM and brown clouds include primary particles emitted from automobile exhaust pipes, particles from brake and tire wear, and dust resuspended from paved and unpaved roads. A fraction of the secondary ammonium sulfate and ammonium nitrate particles formed in the atmosphere are from the sulfur dioxide and nitrogen oxides emitted by mobile sources, but it is not possible to determine the relative contribution of mobile sources to these species from the measurements made during these studies. The particles attributed to mobile sources in Figure 4-2 are primary particles from

exhaust. Dust resuspended by vehicle traffic appears in these figures as soil dust. Particles resulting from tire wear and brake wear were not identified in the CMB calculations. A review

of data for fuel use, vehicle emission factors, and vehicle miles traveled performed in 1991 indicated that at least 50 percent of the ambient particles attributed to mobile source exhaust particulate emissions were due to diesel vehicles (Watson et al., 1991a). This estimate attributes a higher fraction of the mobile source exhaust emissions to diesel vehicles than does the CMB analysis from the current study using the extended chemical speciation.

The sources that are third and fourth in importance (after mobile source exhaust and soil dust) are vegetative burning and secondary ammonium nitrate. In urban areas, most

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*The light scattering efficiency of coarse particles is approximately one-tenth the efficiency of fine particles. Soil dust is not a major contributor to light extinction.*

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vegetative burning is due to residential wood combustion. This emission source is variable, and is highest during the holidays. The average secondary ammonium nitrate concentration is less than five percent of the PM<sub>10</sub>, but nitrate concentrations may be a larger fraction of the PM during wet haze events, as described in Sections 3.5 and 3.6.

### **Source contributions to light extinction**

The source contributions to light extinction were calculated in two steps (Watson et al., 1991b). The first step was to calculate the source contribution to PM to obtain the results above. These calculations were performed for each morning and afternoon sampling period for filter samples collected at each of the four Urban Haze Study monitoring sites. These sites were the ICA building, West Phoenix, South Scottsdale, and the roof of the Valley National Bank 175 m (575 ft) above ground level in downtown Phoenix. The second step was to multiply these source contributions by the light-scattering and light-absorption efficiencies in Table 3-5 to obtain the contribution of sources to light extinction. A key feature to note in the data in Table 3-5 is that the light-extinction efficiency of coarse particles, which are primarily composed of soil dust, is roughly one-tenth the light-extinction efficiency of the chemical species in fine particles. As described in Chapter 1 and in Appendix B, light extinction is the sum of light scattering and light absorption.

The results from these calculations of the contributions of different source categories to light extinction were similar to the PM source attribution results from the Urban Haze Study and, therefore, are not plotted separately. There was a large day-to-day variability in the light extinction. On almost all days, light

extinction was greater during the morning sampling period than during the afternoon. In nearly every sample, primary mobile source emissions were responsible for more than half the light extinction, and in the morning samples, it was common for primary mobile source emissions to account for more than 80 percent of the light extinction.

Similar results were obtained from the calculations of the source contributions to light extinction at the West Phoenix and ICA sites. At the South Scottsdale and Valley National Bank sites, the calculated light-extinction coefficients were typically smaller in the morning than at the ICA site and were more nearly equal to the afternoon values. The afternoon values of the light-extinction coefficient and calculated source contributions were comparable at all four sites.

The source contribution calculations indicate that mobile source exhaust is, by far, the dominant contributor to light extinction. Sources of soil dust rank second in importance, but their percentage contribution to light extinction is much smaller than their percentage contribution to particulate mass. Soil dust sources contributed mainly to the coarse particle-size fraction, which has a light-extinction efficiency approximately one-tenth the light-extinction efficiency of the fine-particle size fraction.

On days with high light extinction, secondary ammonium nitrate is often the second most important contributor to light extinction. As indicated in Section 3.5, ammonium nitrate concentrations are the greatest during wet haze events that occur after rains. The ground is wet during these events, hence the contribution of soil dust is less than during dry haze events.

Vegetative burning contributed 25 to 50 percent of the light extinction for some samples in residential areas (West Phoenix and South Scottsdale) during the holidays. In most samples, vegetative burning accounted for less than 10 percent of the light extinction. Secondary ammonium sulfate and nitrogen dioxide each contributed less than 10 percent of the light extinction in almost all samples.

#### 4.2.4 Discussion of CMB Results

The results reported above from the CMB analysis of air quality data collected at different times in different studies are remarkably similar. Essentially the same values are obtained from CMB analyses performed during the 1980-1990 studies and as part of this study. Also, the results from the CMB analyses with extended chemical species agree with those from the conventional chemical species.

All these CMB analyses suffer from the limitation that it was not possible to separately quantify the emissions from onroad and nonroad sources. In addition, the CMB analyses performed with the conventional chemical species could not separately determine the emissions from gasoline and diesel engines. Thus, the conventional CMB analyses estimated the combined contribution of the exhaust from all onroad and nonroad diesel and gasoline engines to  $PM_{2.5}$ . In addition, the lack of source profiles for wood burning and meat cooking likely resulted in an overestimation of emissions from onroad and nonroad sources.

It is a consensus of these CMB analyses that exhaust from gasoline and diesel engines contributed between 60 and 70 percent of the 24-hour average  $PM_{2.5}$  concentrations. During the morning hours, exhaust from these engines accounted for 70 percent or more of the  $PM_{2.5}$ .

Results from CMB calculations with extended species indicate that exhaust from these engines was responsible for more than 95 percent of the organic carbon and elemental carbon species in the atmosphere.

The CMB analysis with extended speciation provided new information concerning the importance of emissions from cold starts and high emitters. At the receptor location in Maricopa County, organic carbon was typically the largest component of  $PM_{2.5}$ . The CMB calculations with extended speciation indicated that most of the organic carbon compounds were emitted by gasoline vehicles during cold starts and by high emitting vehicles. Diesel engine and hot stabilized gasoline engine exhaust made a much smaller contribution to organic carbon compounds. The reasonableness checks performed indicated that emissions from gasoline vehicles during cold starts and from high emitting vehicles contributed a surprisingly large portion of gasoline engine emissions relative to their level of vehicle miles of travel. However, emissions from vehicles operating in the hot stabilized mode also contributed a significant portion of gasoline engine emissions.

The CMB calculations with extended speciation also indicated that gasoline and diesel engine exhaust contributed about equally to elemental carbon concentrations. It is important to note that the dark appearance of brown clouds is mostly caused by elemental carbon.

According to the emission inventories, gasoline and diesel engines are also responsible for most of the emissions of nitrogen oxides, which are partially converted in the atmosphere into particulate nitrate that contributes to brown clouds. Onroad and nonroad vehicles also cause dust to be resuspended, and as indicated

in Chapter 3, some of this dust is in the  $PM_{2.5}$  particle-size fraction. When all of these contributions are combined, gasoline and diesel engines and the vehicles powered by these engines account for the great majority of the emissions that contribute to  $PM_{2.5}$ . Since  $PM_{2.5}$  is the dominant cause of brown clouds, the CMB analyses indicate that the emissions from these engines and vehicles are the most important cause of brown clouds.

### 4.3 EMISSION INVENTORIES

Emission inventories are catalogs of individual emission sources or categories of sources. For example, an individual source might be a specific manufacturing plant, or a source category might be home water heaters. The inventory includes estimates of the types and amounts of pollutants emitted by each source or source category, the location or geographic distribution of the emissions, and when possible, information on how the emissions vary with the time of day, day of the week, and season of the year. Specific sources are called point sources because the emissions are typically released from one or a few stacks. Sources such as water heaters are called area sources because the emissions are released at a great many locations throughout the urban area. The location of area sources is usually estimated from some related parameter. For example, the geographical distribution of residential water heater emissions may be estimated from data for the geographical distribution of houses.

The two sources mentioned in the previous paragraph are examples of stationary sources. Mobile sources include both onroad vehicles that travel on roadways and nonroad engines that generate most of their emissions off roadways, such as construction equipment and farm equipment. Railroad locomotives are also

mobile sources. Onroad and nonroad vehicles include both gasoline-powered and diesel-powered vehicles. Some inventories separate these vehicles into light duty (e.g., automobiles and pickup trucks), medium duty (e.g., delivery vans), and heavy duty (e.g., large trucks).

The emission inventory most relevant to this study was prepared for the MAG 1999 Serious Area Particulate Plan for  $PM_{10}$  for the Maricopa County Nonattainment Area (Maricopa Association of Governments, 1999a). This plan, referred to in this report as the Serious Area  $PM_{10}$  Plan, describes the controls necessary for the Maricopa County Nonattainment Area to be brought into compliance with the National Ambient Air Quality Standards for  $PM_{10}$ . The plan is accompanied by a Technical Support Document (TSD) that addresses the emission and dispersion modeling aspects of the regional study required by the EPA (Maricopa Association of Governments, 1999b). The emission inventories prepared for the  $PM_{10}$  Plan present an overview of the  $PM_{10}$  emissions from major source categories.  $PM_{10}$  includes both coarse particles that make a large contribution to  $PM_{10}$  concentrations but only a small contribution to brown clouds, as well as fine particles, which are primarily responsible for brown clouds. The TSD presents information on the spatial and temporal distribution of these emissions, but that information is not reproduced here.

In decreasing order of importance, the largest emission sources for  $PM_{10}$  other than dust are nonroad engine exhaust, other area sources, and point sources. According to the inventory, onroad mobile exhaust will contribute only a few percent of the  $PM_{10}$  emissions in 2006. The combined onroad and nonroad

mobile exhaust will contribute about ten percent of the PM<sub>10</sub> emissions in 2006.

Part of the process of preparing the Serious Area PM<sub>10</sub> Plan (Maricopa Association of Governments, 1999a) included the preparation of a draft PM<sub>10</sub> inventory for 1994 (Maricopa Association of Governments, 1997). This inventory has been superseded, but it provides more detailed information about a much larger number of source categories that may be used in a qualitative way to guide the selection of the sources that make the largest contribution to brown clouds in Maricopa County. Since the majority of exhaust particles are in the PM<sub>2.5</sub> size range, the relative emissions assigned to various combustion sources in the PM<sub>10</sub> inventory may be inferred to represent the relative magnitude of PM<sub>2.5</sub> emissions from these sources. Therefore, the inventory data may be combined with the CMB data to estimate the relative contribution of diesel and gasoline combustion sources to total diesel and gasoline engine exhaust.

Based on the aforementioned assumptions, the sources that make the largest contribution to brown clouds in Maricopa County are listed below. Sources of dust are not listed because most dust is composed of large particles that do not scatter light efficiently and, therefore, make only a small contribution to brown clouds. The sources listed below are combustion sources identified in the draft 1994 inventory. Combustion sources emit mostly fine particulate matter, which contributes to the brown cloud, as opposed to dust sources which produce mostly coarse particles not important to the formation of the brown cloud. The 1994 inventory information, obtained from Table 3-1 on page 3-4 of the Serious Area PM<sub>10</sub> Plan (Maricopa Association of Governments, 1999a), identifies, in decreasing order of importance, the following combustion sources:

- Nonroad mobile industrial and commercial equipment exhaust
- Onroad diesel engine exhaust
- Stationary industrial processes
- Onroad gasoline engine exhaust

Based on the aforementioned assumption, the following sources also contribute to brown clouds, but to a lesser degree. They are also listed in decreasing order of importance.

- Residential wood combustion
- Nonroad mobile airport ground support equipment
- Railroad locomotives
- Lawn and garden equipment
- Stationary point source internal combustion engines
- Charbroiling and meat frying

The emission inventory information included in the PM<sub>10</sub> Plan indicates the most important combustion source category is nonroad mobile industrial and commercial equipment exhaust. The following are examples of industrial and commercial diesel equipment: fork lifts, pumps, generators, air compressors, sweepers/scrubbers, back hoes, concrete mixers, rock breakers, and other material handling equipment. The draft 1994 inventory indicates that virtually all of the industrial and commercial PM<sub>2.5</sub> emissions come from construction equipment (Maricopa Association of Governments, 1997). National data indicate that approximately two thirds of all construction equipment is diesel-powered (STAPPA and ALAPCO, 1996).

#### **4.4 MOST IMPORTANT SOURCES**

The CMB calculations reported in Section 4.2 were performed for the PM<sub>2.5</sub> particle-size fraction and the emission inventory data in Section 4.3 are for PM<sub>10</sub>. Therefore, these

sources of information are not directly comparable. Brown clouds are mostly caused by  $PM_{2.5}$ , and, therefore, the CMB calculations are more directly relevant to the determination of the sources that contribute to brown clouds than are the  $PM_{10}$  emission inventory data in Section 4.2. However, the inventory data specific to combustion sources, which produce mostly  $PM_{2.5}$ , help to qualitatively identify which combustion source categories are the most important contributors to the brown cloud. It is particularly useful to combine the findings from both the CMB analyses and inventory review since the CMB analysis is not able to differentiate among diesel exhaust source categories. The inventory information helps to clarify which diesel source categories are more important.

The following statements summarize key findings concerning the most important brown cloud sources:

- The dominant cause of haze is  $PM_{2.5}$ .
- $PM_{2.5}$  is composed of (in decreasing order of importance): organic compounds, ammonium nitrate, elemental carbon, soil dust, and sulfates.
- Mobile source exhaust contributes 60 to 70 percent of  $PM_{2.5}$ .
- Elemental carbon is responsible for the brown appearance of the haze in Maricopa County.
- Nearly all elemental carbon is due to mobile source exhaust emissions. Gasoline and diesel engines contribute approximately equally.
- Major contributors to  $PM_{2.5}$  carbon species (both organic and elemental carbon) are gasoline exhaust vehicles and diesel exhaust.

- The most important diesel sources are: nonroad industrial and commercial equipment and onroad diesel vehicles.
- Overall, the most important brown cloud sources include: nonroad industrial and commercial diesel equipment (construction equipment), onroad diesel vehicles, and light duty gasoline vehicles.
- Wood burning makes an important contribution to brown clouds only on winter holidays.
- It appears that cold starts and high emitting gasoline vehicles contribute a disproportionately large fraction of gasoline engine emissions relative to their vehicle miles of travel.

Based on the combination of the CMB analyses and the  $PM_{10}$  inventory, the most important contributors to the brown cloud have been identified. The next logical step is to identify the control measures that are currently being applied to these sources. The results of this assessment will facilitate the identification of both control measures that may be strengthened and new potential control measures that may reduce the brown cloud.

## 5. POTENTIAL CONTROL MEASURES TO REDUCE THE BROWN CLOUD

### 5.1 INTRODUCTION

This chapter identifies potential air pollution control opportunities to reduce the brown cloud. The information presented is the product of a research effort that involved interviewing representatives from other western United States communities, reviewing air pollution control literature, and evaluating the array of existing control measures already adopted for implementation in Maricopa County. Generally, these existing control measures are the committed measures from the State and local governments in the MAG 1999 Serious Area Particulate Plan. The research was motivated by two goals: (1) to identify air pollution controls that have already been committed to in Maricopa County that will help mitigate the brown cloud; and (2) to recommend additional brown cloud controls for consideration by agencies in the Maricopa County area.

#### 5.1.1 Brown Cloud Control Strategy

The main goal of the brown cloud control strategy is to reduce fall and winter diesel and gasoline engine emissions of elemental carbon. As described in Chapters 2 and 3, the brown cloud forms when a layer of cold air is trapped near the ground on cold mornings, and pollutants are emitted into and concentrated in this shallow air layer. The layer of cold air, capped by a temperature inversion, rises and is dispersed as the sun rises and heats the ground. On most days, the brown cloud dissipates by late morning or early afternoon. As

described in Chapter 3, elemental carbon is primarily responsible for the brown appearance of brown clouds. As described in Chapter 4, fine particles emitted by diesel and gasoline engine exhaust are responsible for the vast majority of all elemental carbon emissions in Maricopa County. Opportunities are available to control the brown cloud by further reducing diesel and gasoline engine exhaust emissions through new control measures and measures that augment existing control programs.

The State and local governments have worked for years to identify and implement air pollution control measures which those entities have determined are feasible for the Maricopa County area.

The same sources that contribute to brown clouds also contribute to ozone, carbon monoxide, and particulate matter problems. Each of these problems is being actively controlled by State Implementation Plans applicable to Maricopa County. Therefore it is not surprising that it is difficult to identify easily implemented, inexpensive, technologically feasible measures to reduce the brown cloud problem that have not already been attempted or evaluated in Maricopa County. Mobile source emissions are the major source of brown clouds, and it is difficult to find new mobile source controls that have not already been considered. The brown cloud controls recommended in this study include measures which have not been previously implemented, and measures which have may have already been implemented to a lesser degree than recommended here.

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*Six control measures are recommended in this chapter; all focus on diesel and gasoline exhaust.*

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### 5.1.2 Recommended Measures

The six recommended brown cloud control measures include:

1. Mandating the use of a clean burning diesel fuel.

Reformulating diesel fuel to reduce emissions from onroad vehicles and nonroad diesel-powered equipment.

2. Encouraging retrofits and replacements of nonroad diesel engines and equipment.

Retrofitting or replacing older, more polluting nonroad diesel equipment, especially construction equipment, to reduce exhaust emissions.

3. Strengthening the voluntary onroad diesel vehicle retirement program.

Strengthening existing programs to encourage early retirement of higher polluting onroad heavy-duty diesel vehicles.

4. Electrifying truck stops through a pilot program.

Implementing a pilot program to demonstrate the feasibility of reducing heavy-duty diesel vehicles idling through truck stop electrification.

5. Implementing a toll-free telephone number for smoking vehicle complaints.

Strengthening current Maricopa County programs by implementing a toll-free telephone number to help the public report smoking vehicles. The toll-free number could facilitate follow-up notifications to vehicle owners to have their vehicle inspected at an inspection and maintenance (IM) facility.

6. Implementing a smoking vehicle identification and citation program.

Operating a smoking vehicle identification program to identify and send written notices

to smoking vehicles, requiring the vehicle to be inspected at an IM facility.

In addition to the six recommended measures, two additional measures are suggested for further study. These two measures include:

- Implementing the use of remote sensing devices (RSDs) capable of detecting smoking vehicles.
- Implementing an IM program enhancement to detect or test for smoking vehicles or particulate matter high emitters.

There is currently great interest in advancing available RSD and IM technology to help identify and repair smoking vehicles. RSD units and IM 240 equipment have been used on an experimental and research basis to identify and test smoking vehicles. However, these applications have been conducted for a limited time and by skilled researchers. The applications are time consuming and not well adapted to high volume operations. For example, researchers have used IM 240 equipment to test motor vehicle PM emissions. The tests, including proper handling and evaluation of filters used to collect PM, may take as long as 12 hours (Lindner, 1999). As of August 1999 there are no RSD or IM equipment or testing protocols available that will enable metropolitan areas to accurately and quickly identify high PM-emitting vehicles. However, several organizations, including the Colorado Department of Public Health and Environment, the University of Denver, and private sector interests, are continuing to pursue IM and RSD advances. New control measure opportunities may become available for the MAG region over the next two to three years.

## **5.2 PM<sub>10</sub> MEASURES ALREADY ADOPTED OR COMMITTED TO IN MARICOPA COUNTY**

One of the steps in the control measure identification and screening process involved identifying existing Maricopa County control measures that will mitigate the brown cloud. The effort focused on reviewing committed measures from the State and local governments in the MAG 1999 Serious Area Particulate Plan for PM-10 and previous plans. In addition to identifying existing controls applicable to the brown cloud, the review also identified several other candidate brown cloud control measures.

**Tables 5-1 and 5-2** present summarize both Federal actions and State and local government measures by source category. The State and local government measures are included in the MAG 1999 Serious Area PM<sub>10</sub> Plan. Table 5-1 addresses the most important brown cloud combustion sources; whereas Table 5-2 addresses minor brown cloud sources. The important sources include: nonroad mobile diesel exhaust and onroad mobile diesel and gasoline exhaust.

Table 5-2 lists several control measures that offer only minor brown cloud control benefits. They are included in this report to illustrate particulate matter air quality control efforts already underway in the Maricopa County area.

Table 5-2 addresses sources of dust. As detailed in the Serious Areas PM<sub>10</sub> Plan, dust is the single most important component of the Maricopa County PM<sub>10</sub> problem. Although dust is not a major contributor to brown clouds, dust controls do provide some modest brown cloud mitigation benefits. The dust control measures are presented in this report to illustrate particulate matter air quality control efforts already underway in the Maricopa County area.

Table 5-1. Important brown cloud sources, major federal actions, state and local government measures and potential additional control measure opportunities. Information is organized to reflect the four major control strategies available to reduce mobile source emissions: exhaust standards for new engines and vehicles, fuel changes, vehicle inspection and maintenance (I/M), and use management.

Source Category and Sources	Federal Actions	State and Local Government Measures	Opportunities for Additional Control
<p>I. Nonroad Mobile Sources – diesel</p>	<ol style="list-style-type: none"> <li>1. <u>Exhaust Standards</u>: October 23, 1998: EPA final rulemaking to reduce emissions from nonroad diesel engines. Rule establishes standards (stds) for virtually all nonroad equipment; the new stds would phase in from 1999-2008, depending upon equipment types. Standards would achieve approximately a 34% reduction in PM emissions by 2010, and a 45% reduction by 2020 (Environmental Protection Agency, 1998; Preamble, Table 6).</li> <li>2. <u>Fuel</u>: none.</li> <li>3. <u>I/M</u>: none.</li> <li>4. <u>Use Management</u>: none</li> </ol>	<p><u>Exhaust Standards</u>: Off Road Vehicle Engine Standards</p> <p><u>Fuel</u>: Limit Sulfur Content of Diesel Fuel Oil to 500 ppm</p> <p>Diesel Fuel Sampling and Reporting</p> <p><u>I/M</u>: none.</p> <p><u>Use Management</u>: Encourage the Use of Temporary Electrical Power Lines Rather than Portable Generators at Construction Sites</p>	<ol style="list-style-type: none"> <li>1. <u>Exhaust Standards</u>: Encourage retrofits of existing equipment with more effective exhaust control technology.</li> <li>2. <u>Fuel</u>: (a) provide tax incentives, low interest loans, and/or rebates to retrofit diesel equipment with alternative fuel capability (CNG/LNG), or to purchase new alternative fueled or cleaner operating equipment; (b) explore potential fuel reformulations, such as: <ul style="list-style-type: none"> <li>• lowering sulfur content;</li> <li>• lowering aromatics, as with California diesel (may generate a 10% reduction in PM); lowering aromatics lowers soot emissions (STAPPA and ALAPCO, 1996; p. 105);</li> <li>• raising cetane level of fuel provides potential PM reductions of up to 12% (NESCAUM, 1997; p. IX-22);</li> <li>• adding oxygenates (e.g., water, alcohols, or ethers); a 2% oxygen content may generate 8 to 15% reductions in PM; 5% oxygen may reduce PM by 20% (NESCAUM,1997; p. VIII-5). Note: the only commercially available oxygenated diesel sold in the U.S. is biodiesel, sold in small volume in the northeast U.S., in part due to its higher cost (Oxy-Fuel News, 1997).</li> </ul> </li> <li>3. <u>I/M</u>: encourage EPA to develop in-use compliance testing program.</li> <li>4. <u>Use Management</u>: Encourage use of low-emitting equipment through (a) contractor award criteria for government-sponsored construction projects; and/or (b) emission budget and trading approach for nonroad sources.</li> </ol>

Table 5-1. Important brown cloud sources, major federal actions, state and local government measures and potential additional control measure opportunities. Information is organized to reflect the four major control strategies available to reduce mobile source emissions: exhaust standards for new engines and vehicles, fuel changes, vehicle inspection and maintenance (I/M), and use management.

Source Category	Federal Actions	State and Local Government Measures	Opportunities for Additional Control
Onroad Mobile Sources - diesel exhaust	<p>1. <u>Exhaust Standards:</u></p> <ul style="list-style-type: none"> <li>• May 13, 1999: EPA Notice of Proposed Rulemaking for Tier 2 Motor Vehicle Emission Standards included fuel-neutral Tier 2 standards for the <b>light-duty</b> market which applies the standards equally to gasoline and diesel powered vehicles. Tier 2 standards are proposed to be phased-in between 2004 and 2009.</li> <li>• October 6, 1999: EPA Regulatory Announcement for a Proposed Strategy to Reduce Emissions from Heavy Duty Vehicles with a gross vehicle weight rating greater than 8,500 pounds, including diesel and gasoline engines used in large commercial trucks, larger versions of full-size pickup trucks, passenger vans, and the largest sport utility vehicles. The first phase would require gasoline trucks to be 78 percent cleaner and diesel trucks to be 50 percent cleaner than today's models. The first phase would take effect starting with the 2004 model year. In late 1999, EPA anticipates proposing a second phase to propose even more stringent standards that could take effect as early as 2007 to reduce Nox emissions by between 75 and 90 percent beyond phase one. Emissions of particulate matter could be reduced by 80 to 90 percent.</li> <li>• New and retrofit trucks and urban bus standards phased-in 1991-1994; reduce PM emissions more than 80% in affected vehicles; reductions will continue to accrue as fleet turns over. [Note that in October 1997, EPA announced more stringent NO<sub>x</sub> and hydrocarbon (HC) emissions standards for diesel trucks and buses; the new standards do not affect directly emitted PM.]</li> </ul>	<p><u>Exhaust Standards:</u> Require Pre-1988 Heavy-Duty Diesel Commercial Vehicles Registered in the Nonattainment Area to Meet 1988 Federal Emission Standards; Provide Incentives to Encourage Voluntary Accelerated Vehicle Replacement by the Year 2004</p> <p><u>Fuel:</u> Limit Sulfur Content of Diesel Fuel Oil to 500 ppm</p> <p>Diesel Fuel Sampling and Reporting</p> <p>Alternative Fuel Vehicles for Local Governments and School Districts, and Federal Government/Low Emission Vehicle Requirements</p> <p><u>I/M:</u> Voluntary Vehicle Repair and Retrofit Program</p> <p>Random Roadside Testing of Diesel Vehicles</p> <p>Snap Acceleration Test for Heavy-Duty Diesel</p> <p>Oxidation Catalyst for Heavy Duty Diesel Vehicles</p> <p><u>Use Management:</u> Coordinate Traffic Signal Systems</p> <p>Develop Intelligent Transportation Systems</p>	<p>1. <u>Exhaust Standards:</u> (a) Implement voluntary low emission standards, with emission reduction credits as an incentive (based on SCAQMD program) (NESCAUM, 1997; p. X-11). (b) encourage retrofitting of existing vehicles.</p> <p>(continued)</p>

Source Category	Federal Actions	State and Local Government Measures	Opportunities for Additional Control
	<p>2. <u>Fuel</u>:</p> <ul style="list-style-type: none"> <li>• May 13, 1999: EPA Advance Notice of Proposed Rulemaking for Control of Diesel Fuel Quality indicated that new quality requirements for fuel used in diesel engines is being considered to bring about large environmental benefits through the enabling of a new generation of diesel emission control technologies. The most promising change would be desulfurization to enable the new engine and after treatment technologies that are currently sensitive to sulfur. These advanced sulfur-sensitive technologies have the potential to reduce diesel engine Nox emissions by up to 75 percent and PM emissions by 80 percent or more.</li> <li>• October 6, 1999: EPA Regulatory Announcement for a Proposed Strategy to Reduce Emissions from Heavy Duty Vehicles with a gross vehicle weight rating greater than 8,500 pounds, including diesel and gasoline engines, indicated that EPA intends to propose a second phase in late 1999 which would involve reducing the sulfur content of highway diesel fuel by 90 percent from its current level of 500 ppm. The second phase could take effect as early as 2007.</li> <li>• beginning in October 1993, diesel fuel had to be low sulfur (500 ppm), and have either a 35% maximum aromatics level or a minimum cetane index of 40; EPA estimates that PM emissions are reduced by 90% due to low sulfur fuel (NESCAUM, 1997; p. VIII-2).</li> </ul> <p>3. <u>I/M</u>: none.</p> <p>4. <u>Use Management</u>: none.</p>		<p>2. <u>Fuel</u>: (a) Continuing to promote the use of alternative fuels. (b) Reformulate diesel fuel to reduce elemental carbon emissions (see discussion above for off-road equipment).</p> <p>3. <u>I/M</u>: Supplementing the region's existing HDDV inspection and maintenance program, by either (a) expanding the program's geographic scope, (b) conducting random roadside testing, as is being implemented in California in 1998 (voluntary or mandatory; mandatory currently prohibited under SB 1002).</p> <p>4. <u>Use Management</u>: Limit vehicle idling</p>

Table 5-1. Important brown cloud sources, major federal actions, state and local government measures and potential additional control measure opportunities. Information is organized to reflect the four major control strategies available to reduce mobile source emissions: exhaust standards for new engines and vehicles, fuel changes, vehicle inspection and maintenance (I/M), and use management.

Source Category	Federal Actions	State and Local Government Measures	Opportunities for Additional Control
<p>Onroad Mobile Sources - gasoline exhaust</p>	<p><u>Exhaust Standards</u>: May 13, 1999: EPA Notice of Proposed Rulemaking for Tier 2 Motor Vehicle Emission Standards included fuel-neutral Tier 2 standards for the <b>light-duty</b> market which applies the standards equally to gasoline and diesel powered vehicles. Tier 2 standards are proposed to be phased-in between 2004 and 2009.</p> <p><u>Fuel</u>: May 13, 1999: EPA Notice of Proposed Rulemaking for Tier 2 Motor Vehicle Emission Standards also included reducing the sulfur in gasoline by establishing an average sulfur standard of 30 ppm and a cap of 80 ppm in 2004. In the notice, EPA indicates that reductions in gasoline sulfur levels would reduce PM emissions from gasoline vehicles.</p> <p><u>I/M</u>: No programs targeted to “gross” or high PM emitters. In general, enhanced I/M requirements applicable in the MAG area, along with fleet turnover, will contribute to vehicle retirement and maintenance.</p>	<p><u>Exhaust Standards</u>: National Low Emissions Vehicle Program</p> <p><u>Fuel</u>: Winter Fuel Reformulation: California Phase 2 Reformulated Gasoline with 3.5 Percent Oxygen Content November 1 through March 31</p> <p>Alternative Fuel Vehicles for Local Governments and School Districts, and Federal Government/Low Emission Vehicle Requirements</p> <p>Alternative Fuel Vehicles for State Government/Low Emission Vehicle Requirements</p> <p>Alternative Fuel Vehicle and Equipment Tax Incentives/Low Emission Vehicle Requirements</p> <p>Public Awareness Program for Alternative Fuels</p> <p>Alternative Fuels for Fleets</p> <p><u>I/M</u>: Tougher Enforcement of Vehicle Registration and Emission Tests</p> <p>Catalytic Converter Replacement Program</p> <p>One-Time Waiver from Vehicle Emissions Test</p> <p>Phased-In Emission Test Cutpoints</p> <p>Enhanced Emission Testing of Constant Four-Wheel Drive Vehicles</p> <p>Increased Waiver Repair Limit Options</p> <p>Gross Polluter Option for I/M Program Waivers</p> <p>Vehicle Repair Grant Program</p>	<ol style="list-style-type: none"> <li>1. <u>Exhaust Standards</u>: none.</li> <li>2. <u>Fuel</u>: none.</li> <li>3. <u>I/M</u>: (a) Expand the enhanced I/M program to include more stringent pass/fail standards and a broader geographic scope. (b) Explore with California officials the appropriateness of using the California HEP program. (c) Encourage early vehicle retirement by identifying gross emitters through the existing I/M and remote sensing programs.</li> <li>4. <u>Use Management</u>: Change the Smoking Vehicle Hotline to a toll free number, and link publicity about the new number to a public outreach campaign tied to forecasting Brown Cloud problems.</li> </ol>

Source Category	Federal Actions	State and Local Government Measures	Opportunities for Additional Control
		<p>Voluntary Vehicle Repair and Retrofit Program</p> <p>Voluntary Gasoline Vehicle Retirement Program/Maricopa County Travel Reduction Program</p> <p>Expansion of Area A Boundaries</p> <p>Remote Sensing</p> <p><u>Use Management</u>: Coordinate Traffic Signal Systems</p> <p>Mass Transit Alternatives</p> <p>Develop Intelligent Transportation Systems</p> <p>Special Event Controls - Required Implementation from List of Approved Strategies</p> <p>Encourage Limitations on Vehicle Idling</p> <p>Voluntary No-Drive Days</p> <p>Expansion of Public Transportation Programs</p> <p>Employer Rideshare Program Incentives</p> <p>Preferential Parking for Carpools and Vanpools</p> <p>Reduce Traffic Congestion at Major Intersections</p> <p>Site-Specific Transportation Control Measures</p> <p>Encouragement of Bicycle Travel</p> <p>Development of Bicycle Travel Facilities</p> <p>Alternative Work Schedules</p> <p>Land Use/Development Alternatives</p> <p>Encouragement of Pedestrian Travel</p>	

<b>Source Category</b>	<b>Federal Actions</b>	<b>State and Local Government Measures</b>	<b>Opportunities for Additional Control</b>
		<p>Areawide Public Awareness Programs</p> <p>Encouragement of Vanpooling</p> <p>Trip Reduction Program</p> <p>Park and Ride Lots</p> <p>Encouragement of Telecommuting, Teleworking, and Teleconferencing</p> <p>Promotion of High Occupancy Vehicle (HOV) Lanes and By-Pass Ramps</p>	

Table 5-2. Minor brown cloud sources, state and local government measures.

Source Category and Sources	State and Local Government Measures
I. Nonroad Mobile Sources – gasoline	<p><u>Exhaust Standards</u>: Off Road Vehicle Engine Standards</p> <p><u>Fuel</u>: Winter Fuel Reformulation: California Phase 2 Reformulated Gasoline with 3.5 Percent Oxygen Content November 1 through March 31</p> <p><u>I/M</u>: none.</p> <p><u>Use Management</u>: Encourage the Use of Temporary Electrical Power Lines Rather than Portable Generators at Construction Sites</p> <p>Voluntary Lawn Mower Emissions Reduction Program</p> <p>Restrictions on the Use of Gasoline-Powered Blowers for Landscaping Maintenance</p>
Area Sources	<p>Restaurant Charbroiler Controls</p> <p>PM-10 Episode Thresholds</p> <p>Clean Burning fireplace Ordinance</p> <p>Public Information Program on Wood Stoves and Wood Heat</p>
Point Sources	<p>PM-10 Best Available Control Technology (BACT) Determinations for Stationary Sources</p>

Table 5-2. Minor brown cloud sources, state and local government measures.

Source Category	State and Local Government Measures
Fine Soil Dust - Fugitive/Windblown	PM-10 Efficient Street Sweepers  Curbing, Paving, or Stabilizing Shoulders on Paved Roads (Includes Painting Stripe on Outside of Travel Lane)  Paving, Vegetating and Chemically Stabilizing Unpaved Access Points Onto Paved Roads (Especially Adjacent to Construction/Industrial Sites)  Reduce Particulate Emissions from Unpaved Shoulders on Targeted Arterials  Crack Seal Equipment  Frequent Routine Sweeping or Cleaning of Paved Roads  Strengthening and Better Enforcement of Fugitive Dust Control Rules*  Reduce Particulate Emissions from Unpaved Roads and Alleys  Low Speed Limit for Unpaved Roads  Use of Petroleum Products for Public Road and Street Maintenance  Agricultural Best Management Practices  Additional Dust Control Measures (City of Tempe)  Additional Dust Control Measures (City of Phoenix)

\* Includes:

2. Reduce Particulate Emissions from Unpaved Parking Lots
3. Reduce Particulate Emissions from Vacant Disturbed Lots
4. Dust Control Plans for Construction/Land Clearing and Industrial Sites (Including Active landfills), with Elements Addressing Trackout Prevention, Site and Material Maintenance, Construction Staging, and High Wind Operating Restrictions
5. Dust Abatement and Management Plans for State Lands.

### 5.3 OVERVIEW OF THE CONTROL MEASURE IDENTIFICATION AND SELECTION PROCESS

The brown cloud control measure selection process involved assembling a list of candidate controls, and then screening the candidates to select recommended measures. The most important factor in identifying candidate brown cloud control measures was identification of the sources of the brown cloud problem. As described in Chapter 4, gasoline and diesel engine exhaust sources are the most important contributors to the brown cloud. These include nonroad industrial and commercial diesel equipment (construction equipment), onroad diesel vehicles, and light-duty gasoline vehicles (high emitters and cold start emissions). Wood burning is also important on a limited number of days (usually holidays). Other sources are small contributors to the brown cloud, such as dust and relatively minor combustion sources such as point sources. The first step in the control measure selection process was to identify candidate controls, organized by the following important source categories:

- Onroad mobile sources (diesel exhaust)
- Onroad mobile sources (gasoline exhaust)
- Nonroad mobile sources (diesel exhaust)
- Area (residential wood burning)

There are four control methods for reducing emissions from mobile sources, and these approaches establish the context for identifying potential control measures that could mitigate the brown cloud. The four approaches include: (1) change or improve the emission characteristics of the fuel used; (2) improve vehicles and engines currently in-use, through better maintenance or retrofitting the vehicles and engines with newer emission control technology; (3) introduce cleaner vehicles and engines to decrease emissions as the fleet changes; and (4) control the use of the vehicle or engine to reduce or change driving or operating times

or to operate the vehicle or engine in a less polluting manner. These four control measure approaches are often divided into two broad categories:

- Technological controls, which include fuels changes, in-use vehicle and engine improvements through maintenance and retrofits, and new vehicle and equipment standards; and
- Behavioral controls, which include limiting or changing the use of the vehicle or engine through economic incentives or restrictions.

Wood burning controls may take the form of prohibitions or restrictions when burning occurs, restrictions on what is burned, and installation limitations and standards related to new or upgraded wood burning appliances and fireplaces. The investigation of candidate measures was organized to identify control measure opportunities corresponding to each of the control techniques applicable to mobile sources and wood burning.

Once the candidate measures had been identified, the measures were screened using several criteria. The criteria and their importance include:

1. Focusing on the most important brown cloud sources. The most important result from this criterion was screening out additional wood burning controls as less important than mobile source controls.
2. Focusing on technological, rather than behavioral controls. This ultimately resulted in screening out controls such as pollution charges. Technology measures were emphasized based on the greater likelihood of creating public and political support for implementation and their longer record of achievement in reducing air pollution.

3. Addressing specific emissions problems. This resulted in addressing specific problems such as heavy-duty diesel vehicle idling and high-emitting light-duty gasoline vehicles.

4. Avoiding overlap with existing federal, state, and regional control efforts. This resulted in eliminating measures from consideration that had recently been adopted or committed to by various government agencies. For example, heavy-duty vehicle random roadside inspections were identified earlier in this project as a candidate measure. Subsequent to that research, the Serious Area PM<sub>10</sub> Plan included a commitment to implement random roadside inspections for heavy-duty diesel vehicles. The candidate measure list was reviewed to eliminate the overlap between early research findings and the latest control measure commitments.

5. Considering the timing and coverage of the candidate measure. This resulted in identifying diesel fuels changes as the most important candidate measure. Fuels changes affect all sources that use the fuel, and produce emissions reduction benefits more quickly than other measures such as new-vehicle or new-engine emission standards. Other recommended measures will affect a more limited number of sources or accrue benefits over a longer time frame.

6. Considering the technological feasibility of the candidate measure. This resulted in separating out promising measures for further study (such as IM and RSD program enhancements) and recommending some measures be implemented on a pilot basis (such as electrifying truck stops).

7. Augmenting existing programs. This resulted in recommending measures that could build upon existing institutional relationships and infrastructure. For example, the recommendation to encourage retrofits for nonroad mobile sources builds upon the existing Voluntary Vehicle Repair and Retrofit Program created for onroad

vehicles. The recommendation to implement a smoking vehicle identification and citation program builds upon the existing Registration Compliance Program operated by the Motor Vehicle Division of the Arizona Department of Transportation.

Cost information is included, where possible, for the recommended measures. Virtually all of these measures have already been evaluated based on cost effectiveness as potential PM, ozone, and CO controls for Maricopa County. Much of the cost data provided in this study comes from the economic analyses prepared for the Serious Area PM<sub>10</sub> Plan. Additional cost information is provided where recent information helped to supplement information included in the PM<sub>10</sub> Plan.

#### **5.4 DEVELOPMENT OF A LIST OF CANDIDATE MEASURES FOR FURTHER SCREENING**

Four information sources were used to develop the candidate measures list:

##### The Serious Area PM<sub>10</sub> Plan

The PM<sub>10</sub> plan development process included a review of numerous potential control measures, some of which were not ultimately selected for implementation. This study reconsidered those control measures that had been reviewed but not committed to as part of the Serious Area PM<sub>10</sub> Plan. The control measures were reconsidered on the premise that although the measures may not have been feasible for the Serious Area PM<sub>10</sub> Plan, they may provide brown cloud control benefits if they target PM<sub>2.5</sub>.

##### Most Stringent Measures (MSM) Analysis

As part of the PM<sub>10</sub> plan development process, MAG commissioned Sierra Research to identify the “most stringent PM<sub>10</sub> control measures” currently employed throughout the United States. The resulting

report identified 14 potential PM<sub>10</sub> control measures, several of which were committed to in the PM<sub>10</sub> plan (Maricopa Association of Governments, 1999a; pp. 10-36 through 10-37). Remaining measures relevant to the brown cloud were included in the list of candidate control measures. The relevant measures relate to wood burning and diesel fuel properties.

### Literature Reviews

As part of this study, various published information was reviewed to identify potentially promising brown cloud controls. The literature review work proceeded in several stages throughout the project. The material is presented in tabular form in Appendix G, Table G-2. Appendix H presents a narrative discussion that integrates the findings of the literature review and interviews, and identifies opportunities to control nonroad and onroad mobile sources.

### Interviews

Interviews with Maricopa County officials and officials from other western U.S. metropolitan areas helped to further identify potential control measures. As with the literature reviews, interviews took place during several stages through the project. The information reviewed is presented in Appendix G, Table G-1. Appendix H both integrate findings from the interviews and the literature reviews.

**Table 5-3** lists the candidate measures for controlling brown clouds in Maricopa County.

Table 5-3. List of candidate brown cloud control measures.

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Onroad Mobile (Diesel Exhaust)

- California Air Resources Board (CARB) Diesel or other clean diesel fuel.
- Vehicle pollution charge.
- Voluntary diesel vehicle retirement.
- Truck stop electrification to reduce vehicle idling.

Onroad Mobile (Gasoline Exhaust)

- Vehicle pollution charge.
- Performance-based standards for motor vehicle fuel.
- Tighter limits on sulfur content in gasoline.
- Use of clean fuels on a statewide basis.
- Measures to encourage the construction and operation of fueling stations for alternative fuel vehicles.
- Adoption of the California Low-Emission Vehicle Program.
- High occupancy vehicle lane pricing.
- Fuel tax increase.
- Special event controls - required implementation from list of approved strategies.
- Limit excessive car dealership vehicle starts.
- Limit idling time to three minutes.
- Use the California High Emitting Profile (HEP) program to identify potential smoking vehicles, and require more frequent IM for those vehicles.
- Implement toll-free smoking vehicle hotline.
- Use remote sensing devices (RSD) to identify high emitting smoking vehicles.
- Expand the existing IM 240 inspection program to include PM and/or smoking vehicle testing.
- Implement a smoking vehicle observation and citation program.

Nonroad Mobile (Diesel Exhaust)

- CARB Diesel or other clean diesel fuel.
- Emission standards for heavy-duty construction equipment.
- Encourage retrofit of existing equipment.
- Promote voluntary purchase of cleaner operating equipment.
- Require railroads to accelerate deployment of cleaner operating locomotives (as opposed to the phase-in schedule contained in the EPA locomotive rulemaking).
- Require geographic movement of railroad switching yard activities to downwind of Maricopa County.
- Implement railroad yard idling restrictions.
- Encourage further electrification efforts for airport ground support equipment exhaust.
- Continue to support use of alternative fuels for airport ground support equipment exhaust.
- Encourage movement of aircraft ground support equipment (GSE) activities to the afternoon.

Area (Residential Wood Burning)

- Ban on solid fuel burning devices in new or modified construction.
- Limit emissions of new woodstoves & inserts to 60% of EPA Phase II standards.
- Retrofit of fireplaces and uncertified woodstoves.
- Curtailment of wood heating.
- Enforce opacity limit on residential wood smoke.
- Require change-out of uncertified wood stoves upon sale of home.
- Tradable permits for wood stoves.
- Improved performance/maintenance of wood burning devices, including weatherization programs.
- Inducements/requirements to eliminate or upgrade existing wood stoves and fireplaces.
- Restrict the number or design of new wood stoves and fireplaces.
- Ban on fireplace installation in new homes.

## 5.5 IDENTIFICATION OF TOP MEASURES FOR CONSIDERATION BY MARICOPA COUNTY AGENCIES

This discussion describes the candidate measures selected for further consideration by implementing agencies in Maricopa County. The discussion is organized around each major source category used to describe the candidate measures (see Table 5-3).

### 5.5.1 Discussion by Source Category

#### Onroad Mobile Diesel Exhaust

This category contained four candidate measures, three of which were selected to be included among the final six recommended measures. The first of these recommended measures is perhaps the single most effective control opportunity available to reduce brown cloud problems: mandating the use of clean burning diesel fuel. Clean burning diesel fuel has several important benefits. For example, changing fuel properties may affect all engines using that fuel regardless of whether they are onroad or nonroad engines. Changing fuels also has an immediate impact on the entire vehicle fleet, once the fuel is delivered to the market and existing fuel stocks turn over. Finally, regulators may introduce fuel changes without having to first identify individual higher polluting engines or vehicles.

Another recommended measure in this source category is strengthening the voluntary diesel vehicle retirement program. Retirements may be encouraged through emission reduction credits, tax incentive programs, low interest loans, and rebate (or “bounty”) programs. Onroad diesel vehicles

contribute significantly to the brown cloud; phasing out older, higher polluting vehicles will help reduce elemental carbon emissions.

The third recommended measure in this source category is electrifying truck stops. This control option addresses the large quantity of diesel emissions that originate from vehicle idling, since truck tractors may idle up to 60 percent of the time (NESCAUM, 1997).

Vehicle pollution charges were eliminated from further consideration. Pollution charges are an example of a behavioral control measure. This study focused on recommending technological control measures due to the longer history in the U.S. of successfully implementing technological rather than behavioral air quality controls.

#### Onroad Mobile Gasoline Exhaust

This source category includes 16 candidate measures, two of which were selected to be included among the final six recommended measures. Smoking vehicles are a small fraction (probably less than two percent) of the vehicle fleet that experience maintenance and operation problems resulting in excessive PM emissions. Control measures focus on identifying problem vehicles, and securing their repair or retirement.

The two recommended measures include: implementing a toll-free telephone number for smoking vehicle complaints, and implementing a smoking vehicle identification and citation program. The toll-free phone system could expand an existing Maricopa County control effort. Once a vehicle has been identified by a caller, the vehicle owner would receive a request to bring their vehicle to an IM facility. The smoking vehicle identification

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*Identifying and repairing smoking vehicles will help control brown clouds.*

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and citation program involves having human observers (as opposed to remote sensing devices) identify smoking vehicles, and then having the Motor Vehicle Division of the Arizona Department of Transportation send citations to vehicle owners directing them to take their smoking vehicles to an IM facility for a required inspection and subsequent repair.

Two additional measures had significant promise for identifying and reducing emissions from smoking vehicles. These included: implementing the use of RSDs capable of detecting smoking vehicles and implementing an IM program enhancement to detect or test for smoking vehicles or particulate matter high emitters. Discussions with staff from the EPA Office of Mobile Sources, the National Renewable Energy Laboratory, the University of Denver, General Motors, and the Colorado Department of Public Health and Environment, however, suggested that neither measure has advanced beyond the research stage. Given the difficulties of identifying smoking vehicle emissions, and the important role they play in brown cloud formation, it is recommended that future studies be conducted to determine whether RSD or IM program enhancements can be accomplished in the next two to three years to identify smoking vehicles.

During the screening process the remaining measures were eliminated from further consideration because they did not directly help identify and mitigate PM emissions from smoking vehicles. Fuel-based measures, for example, could affect the entire fleet, and could likely fail to address the maintenance problems associated with smoking vehicles. Pollution charges have not proven to be politically feasible. California has created a “high emitter profile” (HEP) program to identify potentially problematic vehicles based on

past IM history. Implementing the HEP program appeared promising, but further research identified a poor overlap between high PM-emitting vehicles, and the high hydrocarbon (HC) and carbon monoxide (CO) emitting vehicles targeted by the California HEP program (see, for example, the discussion in Cadle et al., 1998; p. ii).

#### Nonroad Mobile Diesel Exhaust

Ten candidate measures were identified to control nonroad mobile diesel exhaust emissions, two of which were selected to be included among the final six recommended measures. The two measures include mandating the use of clean burning diesel fuel (a repeat of the same measure identified for onroad diesel vehicles), and encouraging retrofits and replacements of nonroad diesel engines and equipment. Other measures were eliminated for a variety of reasons. For example, adoption of emissions standards for heavy-duty construction equipment was eliminated because the equipment is already covered by recently published EPA nonroad standards (U.S. Environmental Protection Agency, 1998). Other sources, such as airport ground service equipment, railroad locomotives, and agricultural equipment, are (combined) less important than onroad trucks and buses and nonroad industrial and commercial equipment emissions (see Maricopa Association of Governments, 1999a; Table 3-1, p. 3-4). In addition, the best available control measure (BACM) analysis prepared for the Serious Area PM<sub>10</sub> Plan indicated that some of these source categories, such as railroad emissions, are infeasible to control.

#### Area (Residential Wood Burning)

Eleven candidate measures were identified to reduce wood burning emissions. However, wood burning contributes most to brown clouds on a

limited number of days during the winter holiday season. In addition, the Serious Area PM<sub>10</sub> Plan includes a variety of wood burning control measures, including implementation of more stringent PM-10 thresholds for declaration of no-burn days. Given the ongoing regional efforts to reduce wood burning emissions and the restricted number of days when wood burning contributes significantly to the brown cloud, wood burning is not a recommended focus for further control. All of these measures were eliminated from further consideration.

### 5.5.2 Summary Discussion of Important Sources and Control Measure Considerations

**Table 5-4** presents additional information on the reasons for selecting the recommended measures identified in section 5.1.1. Each important source category, such as onroad mobile sources, produces pollutant emissions that contribute to brown clouds. The frequency and rate at which the sources emit pollutants is typically a function of one or more of the following four factors, which are the important parameters related to mobile source pollution:

1. Inherent design of the engine or vehicle: Newer vehicles and engines are designed to meet more stringent pollution standards. For example, heavy-duty diesel engines were not required to meet federal emission standards until 1974. EPA established heavy-duty diesel engine emission standards for particulate matter in 1988; the standards became more stringent in 1991 and again in 1994. One way to distinguish higher from lower polluting heavy-duty diesel vehicles is to determine the year they were manufactured, and to encourage the replacement of older engines and vehicles with newer, cleaner-operating

versions. In many cases, older equipment may be upgraded or retrofitted to meet more recent standards and to produce fewer pollutants.

2. Maintenance of the engine or vehicle: Properly maintained engines and vehicles will produce fewer pollutants. Improperly maintained engines, or engines with worn parts, increase pollution. For example, emission control equipment might fail; poorly tuned engines may use more fuel than is properly combusted to power the engine; and leaking valves and seals may introduce motor oil into the combustion process.

3. Characteristics of the fuel used: Engines and vehicles produce different pollutants and emit different volumes of pollutants depending upon the fuel used. For example, federal diesel fuel requirements now specify reduced sulfur content in comparison to fuels produced several years ago. Reduced fuel sulfur results in lower sulfur dioxide emissions and lower particulate emissions.

4. Engine and vehicle operation: As vehicles are driven more miles, or equipment is operated more hours, more pollution is produced. In addition, the manner in which the engine or vehicle is operated may increase pollution. For example, vehicles driven with aggressive accelerations and frequent starts and stops produce more pollutants than vehicles driven the same distance but at moderate, steady speeds. An additional example of vehicular pollution related to operations involves vehicle idling, where the vehicle produces emissions without transporting the occupants and contents—more idling equals more pollutant emissions.

Table 5-4. Important brown cloud sources, source parameters, and recommended controls.

Source Category and Sources	Source Parameters	Recommended Brown Cloud Controls	Brief Control Measure Comments
Nonroad Mobile Sources - diesel exhaust	Diesel engine design Diesel engine maintenance practices Diesel fuel specifications Hours of use (time of day and total hours)	<ul style="list-style-type: none"> <li>• Retrofit and replacement of nonroad equipment</li> <li>• Clean burning diesel fuel</li> </ul>	Recommended measures address engine design and maintenance and fuel specifications. Implementing a clean burning diesel fuel is an effective way to reduce emissions from both nonroad and onroad diesel-powered engines. Encouraging replacements complements new EPA standards for nonroad engines; the standards phase-in between 1999 and 2008. Use restrictions would be difficult to enforce given the broad array of equipment in the nonroad category.
Onroad Mobile Sources - diesel exhaust	Diesel engine design Diesel engine maintenance practices Diesel fuel specifications Vehicle miles traveled (VMT) Hours of use (including idling time)	<ul style="list-style-type: none"> <li>• Retirement of onroad diesel vehicles</li> <li>• Clean burning diesel fuel</li> <li>• Electrify truck stops</li> </ul>	Recommended measures address engine design and maintenance, fuel specifications, and hours of use. Implementing a clean burning diesel fuel is an effective way to reduce emissions from both nonroad and onroad diesel-powered engines. Encouraging replacements complements more stringent PM emissions standards, which began in 1991. Driving and idling restrictions are difficult to enforce. Programs to reduce idling may become more practical if the pilot program to electrify heavy-duty vehicle stops produces useful information.
Onroad Mobile Sources - gasoline exhaust	Engine oil consumption Vehicle maintenance practices Engine operation (rich or lean) VMT	<ul style="list-style-type: none"> <li>• Toll-free number for smoking vehicles</li> <li>• Smoking vehicle identification and citation program</li> </ul>	Recommended measures address oil consumption and vehicle maintenance/engine operation. Smoking vehicle identification programs identify high PM-emitting vehicles and encourage maintenance and repair work to reduce emissions. VMT restrictions are difficult to enforce, particularly since smoking vehicles are difficult to identify.

As mentioned in Section 5.3, mobile source control measures fall into four categories: establishing more stringent new-vehicle standards, retrofitting and replacing older vehicles, reformulating the fuels used, and restricting or changing the use of the vehicle or engine. These four control measure approaches directly reflect the parameters controlling the amount of pollution produced by mobile sources. Table 5-4 briefly highlights how these parameters and control measure approaches relate to the important sources contributing to the brown cloud. The table identifies important sources, important pollution parameters for each source, and how the recommended measures relate to the parameters responsible for pollution to create the brown cloud.

## **5.6 RECOMMENDED MEASURES**

The best opportunities for controlling brown clouds are to reduce exhaust emissions from nonroad and onroad diesel equipment and vehicles, and from high PM-emitting onroad gasoline vehicles. The following discussion includes brief descriptions of each of the six recommended measures, as well as further details on the two measures recommended for further study. Much of the discussion for several of these measures is drawn directly from the Serious Area PM<sub>10</sub> Plan (Maricopa Association of Governments, 1999a). Appendix G and Appendix H include background information collected during the research phase of the brown cloud study that is specific to controlling nonroad and onroad diesel exhaust, and onroad light-duty gasoline exhaust from high emitting vehicles.

### **5.6.1 Six Recommended Measures for Implementation**

#### **1. Mandating the Use of Clean Burning Diesel Fuel**

##### **EPA Proposed Regulatory Approach**

At the national level, the U.S. Environmental Protection Agency published an Advance Notice of Proposed Rulemaking for Control of Diesel Fuel Quality in the Federal Register on May 13, 1999. In the notice, EPA indicated that new quality requirements for fuel used in diesel engines is being considered in order to bring about large environmental benefits through the enabling of a new generation of diesel emission control technologies. The most promising change would be fuel desulfurization for the purpose of enabling new engine and after treatment technologies that are currently sensitive to sulfur. These advanced sulfur-sensitive technologies have the potential to reduce diesel engine NO<sub>x</sub> emissions by up to 75 percent and PM emissions by 80 percent or more.

According to the advance notice, the impetus for near-term action on diesel fuel quality comes from the EPA efforts to set fuel-neutral Tier 2 standards for the light-duty market, which applies the standards equally to gasoline and diesel powered vehicles. The Tier 2 standards are proposed to be phased-in between 2004 and 2009. Emissions control technologies that prove effective in light-duty diesel applications are likely to be effective with heavy-duty highway engines as well. Thus higher quality diesel fuel for heavy-duty applications, combined with more stringent heavy-duty engine emission standards that effectively introduce the new technologies, could provide large environmental benefits, on perhaps a different implementation schedule than that required for the light-duty program.

With a phased-in program, the higher quality diesel fuel could be focused initially on the light-duty diesel fuel and then the market penetration could be widened to fulfill the expanding need created by sales of new heavy-duty diesel vehicles that also employ the advanced technologies. Eventually, these advanced technologies could also find application in nonroad equipment.

In the notice, EPA indicated that there is a reasonable possibility that diesels will become more prevalent in the light-duty truck fleet. Vehicle and engine manufacturers have indicated their intent to sell more diesel-powered light-duty trucks and in some cases have made capital investments to implement these plans. The Partnership for a New Generation of Vehicles, a public-private research and development effort, has been pursuing several promising technologies such as improved diesel engines which may be able to deliver large fuel economy improvements in the near future.

In order to assess the potential impact of increased diesel sales penetration on PM-2.5 emissions, the Tier 2 PM standards were analyzed by EPA under a scenario in which diesel engines in light trucks increase rapidly by five percent per year from 2001 through 2010, when diesels would account for 50 percent of light-duty truck sales; beyond 2010, diesel sales were assumed to be stable at 50 percent of the light-truck market. If this scenario for increased diesel engines in light trucks were to occur, the May 13, 1999 proposal would reduce diesel PM-2.5 by over 90 percent in 2020.

On October 6, 1999, the U.S. Environmental Protection Agency announced a strategy to significantly reduce

emissions from on-highway heavy-duty vehicles (vehicles with a gross vehicle weight rating greater than 8,500 pounds), including diesel and gasoline engines used in large commercial trucks, large versions of full-size pickup trucks, passenger vans, and the largest sport utility vehicles. The first phase of the strategy to reduce emissions from heavy-duty trucks would take effect starting with the 2004 model year. The second phase could take effect as early as 2007. It is important to note that the lighter vehicles weighing up to 8,500 pounds would be covered under the tailpipe emission standards that EPA proposed in May 1999 (Tier 2 standards).

The first phase of this strategy for heavy-duty vehicles would require gasoline trucks to be 78 percent cleaner and diesel trucks to be 50 percent cleaner than today's models. The second phase is anticipated to be proposed by EPA late this year. The Agency is considering even more stringent standards that could take effect as early as 2007 to reduce NO<sub>x</sub> emissions by between 75 and 90 percent even beyond phase one. Emissions of particulate matter could be reduced by 80 to 90 percent.

As a part of this second phase, in order to enable new emissions-control technology on heavy trucks, EPA will be proposing the reduction of the sulfur content of highway diesel fuel by approximately 90 percent from its current level of 500 ppm. EPA already has proposed to significantly reduce sulfur levels in gasoline in the Tier 2 proposal.

### **New Clean Diesel Fuels in the Market Place**

In addition to the efforts at the national level, there are also new clean burning diesel fuels emerging in the market

place. These new clean burning diesel fuels include: A-55; Atlantic Richfield Company's (ARCO) clean diesel fuel; Biodiesel "B20"; PuriNO<sub>x</sub> Performance Systems diesel fuel; and California Air Resources Board diesel fuel (CARB Diesel).

#### A-55 /Clean Fuels

According to the A-55 Limited Partnership, the A-55 Clean Fuels can be used in all gasoline and diesel engines, as well as boilers, heating units and turbines. The fuels are a mixture of water and a petroleum-based hydrocarbon such as diesel fuel or heavy naphtha, a crude oil byproduct produced early in the oil refining process. The A-55 Clean Fuels can contain from 30 to 55 percent water, which is introduced into engine systems, boilers and heating units. A proprietary additive package binds the water and petroleum together, and contains elements that protect engines and other combustion units from rusting and freezing inherent with introducing water into those systems. The water in the A-55 Clean Fuels allows the fuel to burn cooler and more efficiently, producing the same power and less pollution.

The A-55 Clean Fuels reduce NO<sub>x</sub> emissions by more than 50 percent in diesel engines, with even lower NO<sub>x</sub> emissions as more water is added to the fuels. The fuels also significantly reduce particulate emissions (A-55 Limited Partnership, 1999).

#### Atlantic Richfield Company's (ARCO) Clean Diesel Fuel

In 1999, the Atlantic Richfield Company announced that it has developed a cleaner diesel fuel for trucks and other large vehicles. Anticipating further fuel actions by the State of California, ARCO developed the new fuel known as EC-D. In early

testing on a small number of vehicles, the fuel reduced particulates by 13 percent, nitrogen oxides by 3 percent and sulfates by 97 percent. According to ARCO, EC-D may reduce emissions more than the CARB Diesel formula.

ARCO is planning to produce approximately seven million gallons of fuel at Arco's refinery in Carson, California. It will be tested by a fleet of 150 trucks, school buses and other diesel-powered vehicles (Arizona Republic, 1999 and ARCO Products Company Fuels Development, 1999).

#### Biodiesel "B20"

Based upon information from the U.S. Department of Energy, Biodiesel is a cleaner-burning fuel for diesel engines that is made from renewable, domestic resources. Biodiesel is composed of fatty acid methyl esters that are formed when vegetable oil and animal fats are reacted with methanol. This process removes the glycerin that creates fouling and engine problems when pure vegetable oil is used as a diesel fuel. Biodiesel should meet the recently approved ASTM standard for biodiesel.

Biodiesel can be used as-is (100 percent pure) in conventional diesel applications (mobile, marine, and stationary) without modifications. It can also be blended with any diesel fuel in any percentage, and it will stay blended in storage. B20 was selected as the optimal blend that reduces power and fuel economy by only 1 percent while reducing most major air pollutants such as particulates, soot and visible smoke, sulfur dioxide, hydrocarbons, carbon monoxide, and air toxics. In general, B20 is a 20 percent blend of biodiesel with 80 percent diesel fuel. No new

infrastructure or new vehicles are required (U.S. Department of Energy, 1999).

### PuriNO<sub>x</sub> Performance Systems

According to the Lubrizol Corporation, Lubrizol and Caterpillar entered into a joint development agreement and a commercial agreement to combine chemical and system capabilities with diesel engine combustion and emissions knowledge in developing and marketing PuriNO<sub>x</sub> Performance Systems. PuriNO<sub>x</sub> fuel is a stable blend of additives, water and commercial diesel fuel. PuriNO<sub>x</sub> fuel is applicable to direct heavy-duty compression ignition engines. It requires no changes to engines or equipment. Use of the fuel is compatible with existing engines and complementary systems. PuriNO<sub>x</sub> fuel remains completely stable at room temperature for a minimum of two months.

PuriNO<sub>x</sub> fuel, when compared to commercial diesel fuel, reduced NO<sub>x</sub> emissions from compression ignition engines by 5 to 30 percent. Particulate emission reductions range from 20 to 50 percent. Test data indicates that levels of hydrocarbons remain constant or are reduced; carbon monoxide is also reduced. Carbon dioxide remains essentially the same (The Lubrizol Corporation, 1999).

### CARB Diesel

Required in California beginning in the fall of 1993, the regulation requiring CARB Diesel specifies an aromatic content of 10 percent (for large refiners) and a sulfur content of 0.05 percent. However, refiners may use alternative formulations if they demonstrate that the same emission reductions will be achieved with their

formulation (Maricopa Association of Governments, 1999a; pp. 5-38 through 5-40).

A. Suggested Implementing Entity. The federal government could require the use of a clean burning diesel fuel on a national basis. The Arizona Legislature could require the use of a clean burning diesel fuel for onroad and nonroad vehicles and engines in Maricopa County or on a statewide basis.

B. Cost. Cost information is provided for CARB Diesel since this fuel has been in the marketplace for several years. Other clean diesel fuels are relatively new. The differential for CARB Diesel has been estimated by the California Air Resources Board (CARB) to be \$0.06 per gallon relative to conventional Diesel #2. In the Draft Particulate Control Measure Feasibility Study prepared for MAG by Sierra Research in 1996 (Sierra Research, 1996), the cost effectiveness in reducing PM<sub>2.5</sub> by using CARB Diesel was estimated to be \$57.42 per pound in the year 2001. The cost data is from a 1996 report; costs are in 1994 dollars (Sierra Research, 1996).

C. Basis for Consideration. The use of a clean burning diesel fuel will reduce tailpipe PM emissions from diesel vehicles. What is particularly important with respect to the brown cloud, however, is the expected reduction in elemental carbon emissions from using clean burning diesel fuel. Reformulated diesel fuel that lowers aromatic content reduces elemental carbon emissions (STAPPA and ALAPCO, 1996; pp. 104-105). Adopting California reformulated diesel fuel requirements or other clean burning diesel fuel requirements could directly lower the allowable aromatic content and reduce elemental carbon emissions. In addition, Arizona Revised Statutes Section 49-571, passed in 1992,

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*Another control option is to expand the Voluntary Vehicle Repair and Retrofit program to include nonroad diesel engines.*

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requires newly purchased transit vehicles used in the MAG region to operate on clean-burning alternative fuels, which include reformulated diesel and gasoline.

D. Benefits and Other Considerations. The lower aromatic formulation in California results in approximately a 10 to 20 percent reduction in PM emissions beyond what is achieved with federal fuel requirements (Brasil, 1997; NESCAUM, 1997, pp. VIII-3 through VIII-4). California reformulated diesel fuel reduces aromatic hydrocarbons, limiting the aromatic hydrocarbon content to 10 percent for most refiners. Aromatic hydrocarbons have a greater tendency to form elemental carbon in burning than other hydrocarbon species.

One drawback to requiring CARB Diesel could be the controversy likely to surround its introduction due to problems encountered during the initial California introduction in 1993. The EPA, the California Trucking Association, and the Department of Defense all agreed that the lower aromatic content of California diesel fuel led to vehicle performance problems in the initial months following the introduction of the new fuel. However, these problems seemed to disappear with the replacement of some older rubber engine components on affected vehicles (STAPPA and ALAPCO, 1996). A final report prepared in March 1996 for the California Diesel Fuel Task Force found that the fuel manufacturing process, rather than the fuel itself, may have been responsible for the performance problems (NESCAUM, 1997). California continues to require the use of its lower aromatic fuel, and CARB staff indicate that the state has overcome the problems experienced during the first few months of using the reformulated fuel (Brasil, 1997).

Additional concerns were raised during the Serious Area PM<sub>10</sub> Plan development

process. The PM<sub>10</sub> Plan documents several reasons why CARB diesel was not determined to be feasible and therefore not selected as a PM<sub>10</sub> control measure (MAG, 1999a):

- Onroad diesel vehicles might refuel outside Maricopa County, and thus avoid using CARB diesel.
- There may be an inadequate supply of CARB diesel available since Arizona cannot compel California refiners to produce enough fuel for the Arizona market, and New Mexico and West Texas refiners currently do not produce CARB diesel. The supply concern becomes even more important if CARB diesel is required statewide instead of in Maricopa County. Supply concerns relate to the deadlines to implement PM<sub>10</sub> Plan control measures. The PM<sub>10</sub> Plan documented, for example, that refineries would have difficulty providing adequate CARB diesel supplies by the spring of 2001, an important milestone for the PM<sub>10</sub> planning process.
- Incremental costs associated with CARB diesel are uncertain. The PM<sub>10</sub> Plan documented concern that incremental costs could rise substantially if an inadequate supply is produced for the Maricopa County area.
- Benefits from using CARB diesel are uncertain. The PM<sub>10</sub> Plan stated that no approved method exists for equating PM<sub>10</sub> emissions reductions to particular diesel formulations.

Notwithstanding these concerns, the brown cloud strategy includes clean burning diesel fuel for several reasons:

- Nonroad diesel-powered mobile sources are important contributors to brown clouds. While some onroad diesel vehicles may refuel outside an

area serviced by a clean burning diesel fuel, it is less likely that nonroad engines and equipment will have an opportunity to use fuels other than by a clean burning diesel fuel.

- Officials in the Maricopa County area have the flexibility to design a diesel implementation program that considers the ability of out-of-state refiners to provide an adequate supply of diesel fuel. There are no deadlines for achieving brown cloud reductions. It may be possible to establish a longer lead-time for fuel production and delivery than was available to those developing the PM<sub>10</sub> Plan.
- A clean burning diesel fuel reduces PM, and the reduced aromatic levels in those fuels, including CARB diesel specifically reduce the elemental carbon portion of PM (Brasil 1997; NESCAUM 1997, pp. VIII-1 through VIII-4; STAPPA and ALAPCO 1996, pp. 104-105). The brown cloud control strategy does not need to be submitted to the EPA for approval. This report is not intended to be a State Implementation Plan Revision for any pollutant including PM<sub>10</sub> and PM<sub>2.5</sub>. The lack of an approved emission reduction estimation methodology is not of direct concern to developing a brown cloud control strategy.

## 2. Encouraging Retrofits and Replacements of Nonroad Diesel Engines and Equipment

This measure could enhance an existing program to encourage the retrofitting and replacement of older nonroad diesel-powered engines. The existing measure is a “voluntary vehicle repair and retrofit”

program that applies to onroad vehicles. This recommendation is to consider adopting a similar program for nonroad engines. In addition, this measure could create contracting incentives to replace older, higher emitting nonroad equipment with newer equipment that meets recent EPA nonroad equipment emissions standards (Maricopa Association of Governments 1999a, p. 9-50; Maricopa Association of Governments 1999b, p. V-65).

The existing onroad vehicle repair and retrofit program was passed by the Arizona Legislature in 1998, and detailed in S.B. 1427. S.B. 1427 requires Maricopa County to establish and coordinate a Voluntary Vehicle Repair and Retrofit Program. The County is required to coordinate the program with the ADEQ and the Arizona Department of Transportation (ADOT). The program is required to provide for quantifiable emissions reductions based on actual emissions testing performed on the vehicles before repair and retrofit.

The control measure recommended as part of the Brown Cloud study could establish program requirements that are similar to the onroad program, but target fleets of nonroad, diesel-powered construction equipment. A nonroad equipment owner would participate in the program if all of the following criteria were met: (1) The owner would be willing to participate in the program; (2) The nonroad equipment would be functionally operational; (3) The nonroad equipment has been titled in Arizona and registered in Maricopa County for at least 24 months; (4) The nonroad equipment would be at least ten years older than the current model year for similar equipment, or has at least 8,000 hours of use. 5. The vehicle fails an

***Maricopa County agencies should consider expanding the onroad diesel vehicle retirement program with greater financial incentives.***

opacity emissions test. The equipment must be tested to determine its emissions level before it is eligible to participate in the program.

The County Board of Supervisors could be required to appoint an advisory committee composed of representatives from the ADOT, the ADEQ, and the parties affected by the Voluntary Nonroad Equipment Repair and Retrofit Program, including contractors that operate fleets of construction equipment, and the after-market products industry. The role of the committee could be to advise and make recommendations on the development and implementation of the program, including opacity testing specifications.

A. Suggested Implementing Entity. The Arizona Legislature could require Maricopa County to coordinate the program with the ADEQ and the ADOT.

B. Cost. The County could be required to develop a Pilot Nonroad Emissions Control Repair and Retrofit Program in cooperation with the ADEQ that has the following provisions (patterned after the existing onroad program):

1. Equipment owners who qualify for the repair and retrofit program will pay the first \$100 as a co-payment.
2. Equipment owners that require more than \$500 in repair costs or \$650 in retrofit parts and labor costs are not eligible unless the equipment owner chooses to pay additional costs.

Diesel powered nonroad construction equipment that is operated at least 500 hours per year and is registered in Maricopa County could be eligible for up to \$1,000 in repair or retrofit costs from the program. Qualified owners will be responsible for one-half of the costs of the qualified repairs

and the other one-half of the costs will be funded from the program up to \$1,000. No more than 20 percent of the program funds in any year may be used for these purposes.

The program could also establish a Voluntary Nonroad Equipment Repair and Retrofit Program Fund consisting of monies appropriated by the Legislature and political subdivisions and gifts, grants, and donations. The program could be similar in nature to one described in S.B. 1427, which included an appropriation of \$800,000 from the State General Fund in fiscal year 1998-1999 for the Voluntary Vehicle Repair and Retrofit Program Fund.

C. Basis for Consideration: Diesel exhaust is one of the most important contributors to the brown cloud. Nonroad construction equipment exhaust is one of the most important categories of diesel exhaust. The EPA considers nonroad engines to have a useful life of 8,000 hours or 10 years (U.S. Environmental Protection Agency, 1998), although a useful life of 10,000 to 20,000 hours is not uncommon (NESCAUM, 1997; p. IV-37). On average, California nonroad equipment operates approximately 800 hours per year (NESCAUM, 1997; p. IV-43). Engines are likely to be rebuilt or change owners as they approach the end of their service intervals or useful life (NESCAUM, 1997; pp. IV-44 through IV-45). The period when rebuilds or change of ownership occurs is an opportune time to implement repairs and retrofits to reduce emissions.

D. Benefits and Other Considerations: By December 1 of each year, the County could be required to prepare a report on the Voluntary Nonroad Equipment Repair and Retrofit Program that includes the number of vehicles or pieces of equipment repaired or retrofitted by model year, the cost effectiveness of the program in terms of

dollars spent per ton of vehicle emissions reductions, any recommendations for improving the effectiveness of the program, and the administrative costs of the program.

The EPA has established a three-tiered regulatory program to reduce exhaust emissions from nonroad equipment. The program phases in between 1996 and 2006 (U.S. Environmental Protection Agency, 1998). EPA rulemakings affect new equipment only, and do not regulate existing equipment. A program designed to create incentives to retrofit or replace older equipment will target those pollution sources that are not covered by the federal nonroad regulatory program.

In addition to the retrofit program, this measure could institute incentives to encourage the early retirement of higher emitting construction equipment. Public agencies in the Maricopa County area could give hiring preference to construction contractors that utilize only nonroad diesel equipment manufactured in 1996 or later (federal emissions standards became more stringent in 1996). When public agencies release requests for bids to complete public construction projects, the bid instructions could inform potential contractors that the selection criteria include the age of the equipment fleet. The Maricopa Association of Governments could draft "boilerplate" contracting language to implement this program and could provide the language to public agencies throughout Maricopa County.

### 3. Strengthening the Voluntary Onroad Diesel Vehicle Retirement Program

This measure could strengthen the existing vehicle retirement a program to purchase and scrap onroad heavy-duty diesel vehicles. This measure is focused on older vehicles because they have the highest

emissions. A vehicle scrappage program could be implemented as an enhancement to the existing inspection and maintenance program; this could involve scrapping vehicles that fail the emissions test and require repairs more costly than the waiver limit. This measure could also be implemented as a separate, stand-alone program available to all owners of older heavy-duty diesel vehicles. Vehicle owners could be offered an incentive of up to \$10,000 to scrap each vehicle. Only pre-1991 model year vehicles would be eligible. The program could be assumed to operate for two years (Maricopa Association of Governments 1999a, pp. 5-43 through 5-44).

A. Suggested Implementing Entity. A vehicle scrappage program, whether enacted in a stand-alone fashion or as an enhancement to the existing vehicle inspection and maintenance program, could be implemented by action of the Arizona Legislature.

B. Cost. In the Draft Particulate Control Measure Feasibility Study prepared for MAG by Sierra Research in 1996, it was assumed that each scrapped heavy-duty diesel vehicle would cost \$10,000 in bounty plus administrative fees. This cost estimate has been used in previous studies of heavy-duty diesel vehicle scrappage programs (see, for example, STAPPA and ALAPCO, 1996; pp. 92-93).

C. Basis for Consideration. Removing older, high-emitting heavy-duty diesel vehicles from service could result in a net decrease in PM emissions, and reduce the elemental carbon emissions contributing to the brown cloud.

D. Benefits and Other Considerations. A vehicle scrappage program could effectively target older, high-emitting heavy-duty diesel vehicles, which produce a disproportionate

share of the total onroad emission inventory. Because of the logistics involved in shipping vehicles to scrap yards and ensuring they are permanently removed from service, administration of a large scrappage program may prove cumbersome. It has been suggested that scrapped vehicles could be sold overseas, thereby reducing the total cost of the program.

The program could require establishment of a Voluntary Onroad Retirement Program Fund. The fund could consist of monies appropriated by the Legislature and political subdivisions and gifts, grants, and donations. The fund could require state appropriations for a two-year period. The program could be similar in nature to one described in S.B. 1427, which included an appropriation of \$800,000 from the State General Fund in fiscal year 1998-1999 for the Voluntary Vehicle Repair and Retrofit Program Fund. The same advisory committee overseeing the Repair and Retrofit Program could also oversee this program, and program reporting and review could be combined for both the retrofit and retirement efforts. The role of the committee could be to advise and make recommendations on the development and implementation of the program, including which vehicles would be eligible to receive program "bounties." The committee could focus on offering financial incentives to the small percentage of heavy-duty onroad vehicles considered to be "high emitters," and could scale the bounty to vehicle age, with older, less valuable vehicles being offered less money.

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*Piloting a bus or truck stop electrification program will help develop a strategy to reduce idling emissions.*

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#### 4. Electrifying Truck Stops Through a Pilot Program

This control measure seeks to reduce idling emissions from heavy-duty trucks (HDTs). It is estimated that HDTs may idle up to 60 percent of engine running time (NESCAUM, 1997; p. VIII-13). Most engine idling occurs at truck stops. Engine idling takes place for various reasons, such as to provide continuous power to refrigerated truck trailers and to provide heating and cooling to truck cabs. As a result, idling emissions represent a large fraction of HDT emissions. The goal of this measure is to test the feasibility of introducing electrification equipment at truck stops to reduce truck idling (Maricopa Association of Governments, 1999a; p. 5-89).

Past MAG research has identified difficulties in implementing a truck stop electrification program (Maricopa Association of Governments, 1999a; p. 6-4). This measure could create a pilot program to test electrification on a limited basis and to determine how to best approach implementing a broader program in Maricopa County. The proposed method of control is to retrofit HDTs and install electric outlets at truck and bus stop locations. The truck equipment will replace the engine idling functions by connecting to ground-based electric power.

A. Suggested Implementing Entity. Ultimately, this control measure could be implemented regionwide through action by Maricopa County. On a pilot basis, County staff could work with the Regional Public Transportation Authority (RPTA) to electrify a bus facility.

B. Cost. Savings could result from less fuel consumption, but could be offset by the cost of electrification. It is assumed that any net cost increase incurred by truck stop operators and truckers ultimately could be reflected in the consumer cost of trucked goods.

C. Basis for Consideration. Section 108(f) of the Clean Air Act identifies “programs to control extended idling of vehicles” as a transportation control measure for consideration in air quality plans. Other agencies are evaluating this control measure with support from the electric power industry. For example, the Lone Star Energy Company (which provides electric power to the Dallas/Fort Worth, Texas area) has applied to the North Central Texas Council of Governments to receive Congestion Mitigation Air Quality (CMAQ) funding to establish a truck stop electrification effort (Hayes, 1999).

D. Benefits and Other Considerations. This measure could seek to reduce the need for idling by trucks and buses by installing on-board electrification packages and equipping truck stops to accommodate such electrified vehicles. To date there has been little research in the area of quantifying potential emission benefits from eliminating idling trucks and buses and methodologies to determine actual volatile organic compound (VOC), CO, and PM reductions. A detailed study would need to be completed as part of the pilot project to help quantify these potential emissions reductions.

RPTA staff are willing to consider participating in a bus facility electrification pilot program (Zwagerman, 1999). RPTA staff indicate that midday idling controls

would work best. Buses return to a service facility at midday, following morning transit runs. Buses then leave again at 2:00 p.m. to service the evening commute period. A pilot program could electrify a service facility to test how electrification works during the midday period. Note that midday emissions do not contribute to the brown cloud as much as very late evening and early morning emissions do. In addition, the truck stop electrification concept is focused on providing power to heating and air conditioning a truck cab, which has a smaller volume of space than a bus. However, the pilot program could be more concerned with testing the feasibility of electrification rather than achieving emissions reductions applicable to the brown cloud. If successful, the program could be adapted to trucks, and to those times of the day when the brown cloud would be most affected. Members of the American Trucking Association (ATA) could be invited to participate as pilot program observers. Assuming the pilot is successful, the ATA could provide advice about a follow-up pilot project involving a truck stop within Maricopa County.

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*A toll-free smoking vehicle hotline, together with onroad enforcement, could improve identification and repair of high emitting smoking vehicles.*

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Truck stop electrification has not yet been implemented in the

U.S. and there are many program uncertainties to resolve. The pilot effort could help address these uncertainties by identifying the number of truck stops in Maricopa County and the idling emissions at those truck stops; surveying truck operators to determine why the idling occurs (for example, to reduce diesel engine start-ups, to control temperature in the cab, to keep refrigerated trucks operating); establishing electrical power needs; identifying available electrification equipment; assessing the ease of implementation; and quantifying program

benefits, both in terms of emissions reductions and economic benefits to trucking organizations from reduced fuel use and reduced engine wear. The pilot project could study these program elements while working with RPTA on a bus electrification effort.

#### 5. Implementing a Toll-Free Number for Smoking Vehicle Complaints

This measure could establish and publicize a toll-free telephone number citizens may use to register complaints about smoking vehicles. The measure could enhance existing Maricopa County efforts. The ADEQ implemented a smoking vehicle hotline in October 1996, and Maricopa County assumed responsibility for the hotline in 1999. The program provides a local phone number for the public to use to provide information regarding vehicles that are observed emitting excessive tailpipe smoke. In response to a complaint, the County mails a letter to the registered vehicle owner recommending an emissions test for vehicles emitting excessive smoke. This control measure could change the existing hotline to a toll-free number, could publicize the new number through existing clean air promotion programs, and could establish a tracking system to estimate the number of vehicles that are identified and then emissions tested as a result of the program (Maricopa Association of Governments, 1999a; pp. 9-67 through 9-68; Maricopa Association of Governments, 1999b; p. V-83).

A. Suggested Implementing Entity. Maricopa County could implement the measure and could work through other agencies such as the RPTA to publicize the availability of the toll-free number.

B. Cost. Costs for promoting the toll-free number could be minimized by providing

information about the toll-free number in existing clean air promotions. Costs to operate a toll-free program may be recovered if the vehicle owner is assessed a fee provided tests confirm the complaint. The toll-free telephone system for the greater Los Angeles area, which contains more than six times the population of the Maricopa County area, costs approximately \$416,000 per year to operate; those costs include salaries and benefits for four office staff, two telephone operators, and two field staff (Redmond, 1999).

C. Basis for Consideration. The CMB analyses (see Chapter 4) have identified smoking light-duty gasoline vehicles as a significant contributor to the brown cloud. Studies estimate that anywhere from 0.6 to 2.5 percent of vehicles are smoking vehicles. (Cadle et al., 1998, say the number is between 0.6 to 1.1 percent; Durbin et al., 1999, say the number is between 1.1 to 1.8 percent; and Lawson, 1999, says the number is up to 2 or 2.5 percent.)

D. Benefits and Other Considerations. In the Los Angeles area, the South Coast Air Quality Management District (SCAQMD) operates a toll-free smoking vehicle hotline known as the "Cut Smog" program. The toll-free number is 1-800-CUT-SMOG. Over a 12-month period, from October 1994, through October 1995, the program collected approximately 138,000 records (Durbin et al., 1999). Durbin et al. (1999) estimate that 88 percent, or 121,000, light-duty vehicle records were collected.

A well publicized toll-free number in Maricopa County could expect to identify a large fraction of the light-duty smoking vehicles over a one-year period. During the 1994-1995 Los Angeles data collection effort, approximately 10 million vehicles, including automobiles, commercial vehicles, and motorcycles, were registered in the

greater Los Angeles area. (More vehicles operated in the area, since a fraction of the onroad vehicles were registered in other locations.) (Keynejad, 1999). Approximately 8.1 million of these vehicles were light-duty automobiles. Assuming that smoking vehicles represent approximately 2 percent of the light-duty vehicle population, there are about 162,000 light-duty smoking vehicles registered in the greater Los Angeles metropolitan region (2 percent of 8.1 million). Ignoring the fraction of vehicles operating in Los Angeles that are registered outside the Los Angeles area, the Cut Smog hotline identified 121,000 light-duty smoking vehicles, or a number equivalent to approximately 75 percent of all the light-duty smoking vehicles registered in the Los Angeles region. Even if 75 percent is approximate (due to some fraction of the identified vehicles coming from outside the region, due to overlapping records, due to an inaccurate assessment of the true number of smoking vehicles on the road, or for other reasons), it is still valid to note that an effective toll-free hot line system has the potential for identifying a large fraction of smoking light-duty vehicles.

The toll-free number may be publicized by adding awareness about the number to existing clean air promotion programs. For example, the RPTA is carrying out an area-wide public awareness program. The program is targeted at employers and employees affected by the Maricopa County Trip Reduction Program (TRP), employers not affected by the TRP, and the general public. The awareness program includes paid radio and television advertising for eight weeks during the winter pollution season (when the brown cloud occurs), promotional mailings to TRP participants up

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*RSD and IM program enhancements need further study to identify opportunities to reduce the population of smoking vehicles.*

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to four times per year, workshops to increase participation in Clean Air Campaign events, and events to increase awareness of alternative modes of transportation and work schedules. High Pollution Advisory faxes are also sent to over 700 Valley employers during the winter and summer high pollution season when air quality is “forecast” to exceed federal air quality standards. Promotion of a toll-free hotline could be included in the RPTA public awareness program, as well as other County clean air programs.

6. Implementing a Smoking Vehicle Identification and Citation Program

This control measure could deploy trained Motor Vehicle Division officers to identify and record the license plate numbers of smoking vehicles. Smoking vehicle owners could receive notification requiring that the vehicle be tested at an inspection facility or risk forfeiting their valid vehicle registration (Maricopa Association of Governments, 1999b; p. V-38).

A. Suggested Implementing Entity. The Motor Vehicle Division (MVD) of the ADOT could implement this measure. The measure could enhance already existing enforcement programs implemented by the MVD.

B. Cost. Additional costs for the program may be minimal if the program is attached to the existing “Registration Compliance Program” operated by the MVD.

C. Basis for Consideration. The CMB analyses (see Chapter 4) have identified smoking light-duty gasoline vehicles as a significant contributor to the brown cloud. Studies estimate that anywhere from 0.6 to 2.5 percent of vehicles are smoking vehicles.

(Cadle et al., 1998, say the number is between 0.6 to 1.1 percent; Durbin et al., 1999, say the number is between 1.1 to 1.8 percent; and Lawson, 1999, says the number is up to 2 or 2.5 percent.)

D. Benefits and Other Considerations. According to the December 1996 Report of the Governor's Air Quality Strategies Task Force, the MVD of ADOT has instituted a comprehensive enforcement program. Three key elements of the new program are a Registration Enforcement Team, a Registration Enforcement Tracking System, and a New Resident Tracking Program. Through public participation, consistent policy and procedure application, and new tracking methods, MVD enforces the Arizona registration laws to ensure vehicles in question are registered properly. This control measure could enhance the existing enforcement program by training enforcement personnel to identify smoking vehicles.

The Registration Compliance Program began in January 1994 with one full-time employee responding only to complaints. In April 1996, this program was enhanced with five MVD officers periodically conducting a statewide effort locating and issuing warning notices on vehicles suspected of being in violation of Arizona registration laws. This effort resulted in a substantial increase in the collection of the Vehicle Licenses Tax (VLT) for 1996. MVD officers, in a manner similar to the way registration compliance warning notices are issued, could issue smoking vehicle citations. The citations could require smoking vehicle owners to bring their vehicles to an IM 240 test facility. If the vehicle is not tested within 90 days, a second notice could be sent, warning that the vehicle registration will be suspended if the owner does not have the vehicle tested within 90 days of the second notice.

Implementation of the citation and testing part of the program could be coordinated with the existing RSD program. Smoking vehicle notices could be sent and subsequent vehicle testing could be tracked, in a manner similar to the way the RSD program notifies owners of high CO or HC-emitting vehicles.

Implementation of the Smoking Vehicle Identification and Citation Program could be added to the responsibilities of existing and future Compliance Program staff. Currently, the required staff time for the existing MVD enforcement program is equivalent to eight full-time employees. Additional staff requirements for the initial phase of the Registration Compliance Program are expected require a total of 12 full-time (active) employees and one supervisor. The funding allocated for implementation of the Registration Compliance Program is included as part of the overall MVD budget. A Smoking Vehicle Identification program evaluation following the first year of operation could determine whether the program operated effectively and whether staffing levels were adequate to service the Smoking Vehicle program.

### **5.6.2 Study Measures**

Two additional measures have potential for identifying and reducing emissions from smoking vehicles. These include: (1) implementing the use of RSDs capable of detecting smoking vehicles; and (2) implementing an IM program enhancement to detect or test for smoking vehicles or particulate matter high emitters. Unfortunately, neither measure has advanced beyond the research stage. This section briefly reviews what is known about these two options, and recommends that Maricopa County officials study both these

measures further and track when they might be appropriate for implementation.

1. Implementing the Use of Remote Sensing Devices (RSDs) Capable of Detecting Smoking Vehicles

The Maricopa County area is one of the first in the nation to implement a remote sensing program to identify high emitting vehicles. The current program uses carbon monoxide and hydrocarbon readings to identify high emitters and notifies vehicle owners to have their vehicles tested at an IM facility. RSD units are also theoretically capable of being used as opacity detectors, i.e., to measure smoke emissions and the degree to which the smoke obscures the visible light seen when looking through a tailpipe exhaust. However, discussions with remote sensing experts, including one of the inventors of the RSD, Dr. Donald Stedman at the University of Denver, indicated that RSDs do not currently operate as accurate opacity measurement instruments (Stedman, 1999; Lawson, 1999). Staff from the Northeast States for Coordinated Air Use Management (NESCAUM) have identified at least one company (Aerodyne Research) working to develop an RSD unit capable of detecting PM (Cooper, 1999). RSD units are not yet commercially available, however, that could effectively measure either smoke or PM.

Given the growing interest in smoking vehicles, and growing experience with implementing RSD programs, it is possible that significant advances may occur during the next two to three years and that RSD units may become available that effectively detect PM and smoke. Maricopa County officials should actively study progress made in this area, and track the availability of RSD units that might assist in the identification of smoking vehicles.

2. Implementing an IM Program Enhancement to Detect or Test for Smoking Vehicles or Particulate Matter High Emitters

Maricopa County currently operates one of the most advanced IM 240 inspection programs in the country. Enhancing the IM 240 program to also test for PM, or to otherwise identify smoking vehicles, could help address the smoking vehicle problem that contributes to the brown cloud. Unfortunately, discussions with staff from the EPA Office of Mobile Sources, the National Renewable Energy Laboratory, the University of Denver, General Motors, and the Colorado Department of Public Health and Environment all indicate that IM for PM has not advanced beyond the research stage (Lindner, 1999; Lawson, 1999; Stedman, 1999; Cadle, 1999; Gallagher, 1999). Several obstacles are posed by PM testing, perhaps the most important of which are (a) how to properly handle and weigh PM filters used to conduct a test, and (b) how to analyze in a relatively short amount of time the PM sample obtained. For example, when PM filters are currently weighed during research efforts, the procedure requires a room with good temperature, humidity, and cleanliness controls. In addition, new equipment would need to be added to current IM facilities, including exhaust dilution tunnels. Protocols to “fast pass” or “fast fail” vehicles, which are current procedures used to speed up the IM test process, would probably not work well with PM testing since a minimum particulate sample needs to be collected (Cadle, 1999).

Notwithstanding the drawbacks to PM testing, there is interest in the air quality control field in finding a way to utilize IM facilities to identify smoking vehicles and high PM emitters. State of Colorado staff are currently exploring how to add a smoking vehicle identification process to the existing IM program. One approach they are considering is adding smoke detection equipment to the IM

lanes to identify smoking vehicles arriving for inspection (Gallagher, 1999). Given the broad interest in this problem, and the number of public agencies involved in IM, there are several opportunities for Maricopa County agencies to track and study the progress being made. In addition to simply tracking existing research in this area, Maricopa County might be able to jointly study program implementation options with other public agencies, thereby reducing the study costs and perhaps accelerating the availability of PM or smoke detection protocols. Potential partner agencies include the EPA Office of Mobile Sources, the National Renewable Energy Laboratory in Colorado, NESCAUM, and the Colorado Department of Public Health and Environment. In the near term, the most important study opportunity is to work with Colorado officials to track progress adding smoke detection capabilities to the Denver area IM program.

## 5.7 CONCLUSIONS

In general, the brown cloud forms on cold mornings when a layer of air is trapped near the ground and pollutants are emitted into and concentrated in this shallow air layer. The layer of cold air, capped by a temperature inversion, rises and is dispersed as the sun rises and heats the ground.

Elemental carbon is the pollutant most responsible for the brown appearance of brown clouds in Maricopa County. Fine particles emitted by diesel and gasoline engine exhaust are responsible for the majority of all elemental carbon emissions in Maricopa County. Reducing fine particle exhaust emissions from diesel and gasoline engines may mitigate the brown cloud.

MAG and other agencies at the county, state, and federal levels have committed to several State Implementation Plans (SIPs) designed to reduce ozone, CO, and PM air quality problems. Many of the control measures included in these SIPs will decrease diesel and gasoline engine

particulate emissions over the coming years. The control measures recommended by this study could provide additional measures and supplement existing control efforts already underway.

Recommended brown cloud control measures focus on two objectives: (1) reducing emissions from vehicles and equipment in use today, and (2) speeding the introduction of newer vehicles and equipment that will operate more efficiently and produce fewer elemental carbon emissions. Given the importance of diesel emissions, the recommended measures focus on reducing pollution from both nonroad and onroad diesel-powered mobile sources. Also important are recommendations to identify and repair high emitting gasoline vehicles. A small fraction, perhaps less than two percent, of onroad gasoline powered automobiles contribute a disproportionate share of the mobile source emissions. In addition to reducing diesel exhaust from nonroad and onroad mobile sources, an important component of the overall brown cloud control strategy should be to reduce the number of onroad high-emitting gasoline vehicles.

Two measures warrant further study: (1) implementing the use of RSDs capable of detecting smoking vehicles; and, (2) implementing an IM program enhancement to detect or test for smoking vehicles or particulate matter high emitters. RSD and IM have not yet advanced to a point where they assist in large-scale operations designed to identify smoking, high PM-emitting vehicles. However, various agencies, academic organizations, and private sector interests are working to advance the state of the practice for RSD and IM. For example, the Colorado Department of Public Health and Environment is actively exploring how to identify smoking vehicles as part of the Denver-area IM program. Continued study of RSD and IM may yield additional brown cloud control opportunities over the next several years.

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# **APPENDIX A**

## **BROWN CLOUD GLOSSARY**

## BROWN CLOUD GLOSSARY

Word	Abbreviation or Acronym	Definition Bold words are defined in this glossary
Aerosol		A mixture of <b>particles</b> suspended in a <b>gas</b> . The particles may be <b>liquid, solid</b> or a mixture of liquids and solids.
Ammonia	NH <sub>3</sub>	An invisible <b>gas</b> produced by all living animals. Agricultural activities, including fertilizer use, are the dominant source. (See <b>ammonium nitrate</b> and <b>ammonium sulfate</b> .)
Ammonium nitrate	NH <sub>4</sub> NO <sub>3</sub>	A <b>solid</b> chemical <b>species</b> formed in the atmosphere by the reaction of <b>ammonia</b> and <b>nitric acid</b> . This reaction is reversible; on hot days, ammonium nitrate particles may evaporate to produce <b>ammonia</b> and <b>nitric acid</b> , which are invisible gases.
Ammonium sulfate	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	A <b>solid</b> chemical <b>species</b> formed in the atmosphere by the reaction of <b>ammonia</b> and <b>sulfuric acid</b> . This reaction is not reversible; ammonium sulfate particles persist in the atmosphere once they are formed.
Black carbon		Chemical forms of carbon that efficiently absorb light, e.g., graphite. Black carbon is almost entirely made up of <b>elemental carbon</b> .
Brown cloud		An <b>urban haze</b> with a brown appearance.
Carbon monoxide	CO	An invisible <b>gas</b> emitted by combustion sources, especially motor vehicles. It is toxic and one of the six <b>criteria pollutants</b> .
Carbonaceous species		Chemical <b>species</b> that contain the chemical element, carbon. In this report, carbonaceous <b>species</b> include <b>organic compounds</b> and <b>elemental carbon</b> , but not carbonates.
Coarse particles		<b>Particles</b> in the atmosphere larger than 2.5 μm diameter. This term is sometimes used to indicate the fraction of <b>PM<sub>10</sub></b> larger than 2.5 μm (i.e., particles with diameters between 2.5 and 10 μm), but may also be used to indicate the concentration of all particles in the atmosphere larger than 2.5 μm.
Coupled		Airflows at the surface are coupled with airflows aloft when there is enough vertical mixing that the surface flows are mostly controlled by the flows aloft.
Criteria pollutants		Six air pollutants with adverse health effects that have been regulated by the Federal Government since the passage of the Clean Air Act in 1970 (See <b>CO, Lead, NO<sub>2</sub>, O<sub>3</sub>, PM, and SO<sub>2</sub></b> ).
Decoupled		Airflows at the surface are decoupled from airflows aloft when there is little vertical mixing and the two flows act independently.

Word	Abbreviation or Acronym	Definition Bold words are defined in this glossary
Elemental carbon	EC	Chemical forms of carbon in which concentrations of other elements are relatively small, e.g., graphitic carbon. Elemental carbon particles absorb light efficiently, have a black appearance, and are sometimes called <b>black carbon</b> .
Fine particles		<b>Particles</b> in the atmosphere smaller than 2.5 µm diameter (see PM <sub>2.5</sub> ).
Fugitive		Fugitive emissions are unintentional emissions. Emissions from an automobile tailpipe are not fugitive emissions because the tailpipe was designed to release emissions, while dust from tires on the road are fugitive emissions because tires were not intended to cause dust.
Gas		One of the three <b>states of matter</b> . A gas has neither a definite volume nor a definite shape. Like liquids, gases are fluids and assume the shape of their container. Unlike liquids, they will expand to fill any container, regardless of its size. Air is a gas.
Haze		Suspension in the atmosphere of minute particles that are not individually seen but nevertheless reduce visibility.
High emitting		The terms “high emitting” and “ <b>gross polluting</b> ” refer to vehicles that emit far more pollution than the average vehicle. In some contexts, the terms have legal connotations. For example, the Arizona <b>IM</b> program “Gross Polluter Option” defines gross polluting vehicles as those emitting more than twice the pollution amounts allowable by government standards. High emitting vehicles account for a large share of onroad vehicular pollution. A typical estimate is that 10 percent of <b>onroad</b> gasoline-powered automobiles cause 50 percent or more of onroad <b>CO</b> , <b>VOC</b> , and <b>NO<sub>x</sub></b> pollution. High <b>PM</b> emitting vehicles include visibly smoking vehicles, which represent approximately one to two percent of the onroad <b>light duty</b> fleet.
Gross polluting		See <b>high emitting</b>
Heavy duty		Heavier weight onroad motor vehicles, such as trucks and buses. Technically, “heavy duty” vehicles are defined as trucks or buses with a gross vehicle weight rating, or GVWR (i.e., vehicle weight plus rated cargo capacity) of at least 26,000 lbs. Smaller three and four-axle tractor-trailer trucks fall into this category. Lighter weight trucks are referred to as “medium” duty vehicles (e.g., delivery vans and postal vehicles); heavier trucks are referred to as “heavy-heavy” duty vehicles (e.g., multi-trailer trucks, concrete mixers, dump trucks).

Word	Abbreviation or Acronym	Definition Bold words are defined in this glossary
Inspection and Maintenance	IM	The name for government programs that require periodic inspection of vehicles and repair of vehicles that do not meet emission standards.
Inversion		A condition of the atmosphere in which the temperature increases with height above ground level. One cause of inversions is the cooling of the surface of the Earth at night by radiation into space and the resultant cooling of the air near the surface. The air within or under an inversion is <b>stable</b> , and will not spontaneously mix upwards.
Lead	Pb	A toxic chemical element. It was included among the six <b>criteria pollutants</b> because of its use as a gasoline additive, which caused lead concentrations in the atmosphere high enough to be of concern.
Light absorption		A process that absorbs light when it interacts with matter and converts the energy into heat.
Light duty		Smaller, lighter weight onroad motor vehicles, including passenger cars, usually seating 12 passengers or less. All vehicles and trucks under 8,500 pounds gross vehicle weight rating, or GVWR (i.e., vehicle weight plus rated cargo capacity) are included. Small pick-up trucks and vans may be included.
Light extinction		The sum of <b>light scattering</b> and <b>light absorption</b> . A beam of light passing through matter is weakened by light extinction.
Light scattering		A process that changes the direction of travel of light when it interacts with matter.
Liquid		One of the three <b>states of matter</b> . A liquid has a definite volume but no definite shape; it is a fluid and flows to the shape of the containing vessel. Liquid <b>particles</b> suspended in a <b>gas</b> assume a spherical shape.
Micrometer	$\mu\text{m}$	One millionth of a meter. A human hair has a diameter of approximately 80 $\mu\text{m}$ . The wavelength of green light is 0.55 $\mu\text{m}$ .
Mobile sources		Emission sources that move about, such as vehicles, construction equipment, forklifts, farm equipment, etc.
Nitric acid	$\text{HNO}_3$	An invisible gas formed in the atmosphere by the oxidation of $\text{NO}_2$ . It reacts reversibly with <b>ammonia</b> to form <b>ammonium nitrate</b> particles, which contribute to <b>haze</b> .
Nitric oxide	NO	An invisible <b>gas</b> emitted by all combustion sources. It reacts rapidly in the atmosphere with <b>ozone</b> to form $\text{NO}_2$ .
Nitrogen dioxide	$\text{NO}_2$	A toxic, brown <b>gas</b> that is one of the six <b>criteria pollutants</b> . It is formed in the atmosphere by the reaction of <b>NO</b> and <b>ozone</b> .

Word	Abbreviation or Acronym	Definition Bold words are defined in this glossary
Nitrogen oxides	NO <sub>x</sub>	The sum of <b>NO</b> and <b>NO<sub>2</sub></b> . In emission inventories, <b>NO<sub>x</sub></b> emissions are reported (in units such as pounds per hour or tons per year) as if all <b>NO</b> were converted to <b>NO<sub>2</sub></b> . In fact, nearly all <b>NO<sub>x</sub></b> emissions are in the form of <b>NO</b> .
Onroad		Adjective that identifies <b>mobile sources</b> (vehicles) that typically operate on roadways.
Nonroad		Adjective that identifies <b>mobile sources</b> (vehicles) that typically operate off roadways. Examples include construction and farm equipment.
Organic compounds		Chemical compounds that contain carbon as well as other elements. Most organic compounds are predominantly composed of carbon and hydrogen atoms. The next most common atoms are oxygen and nitrogen, in that order. <b>Particulate</b> organic compounds are a major contributor to <b>haze</b> throughout the United States, including western urban areas. Carbonates are not included in organic compounds.
Ozone	O <sub>3</sub>	An invisible, toxic <b>gas</b> formed in the atmosphere by photochemical reactions. It is one of the six <b>criteria pollutants</b> . It is natural, and exists in pristine environments at concentrations approximately equal to 1/3 of the Federal standard. In polluted atmospheres, it is formed from <b>NO<sub>x</sub></b> and <b>VOC</b> emissions by the chemical reactions that form <b>smog</b> .
Particle		A minute portion of matter. Particles may be <b>liquid</b> , <b>solid</b> , or a combination of liquids and solids.
Particulate		An adjective indicating that a substance is in the form of <b>particles</b> . Careful linguists discourage the use of this word (or its plural) as a noun.
Particulate Matter	PM	<b>Particles</b> in the atmosphere; one of the six <b>criteria pollutants</b> .
	PM <sub>2.5</sub>	<b>Particulate matter</b> in particles smaller than 2.5 μm diameter. Beginning in 1997, the federal standard for <b>PM</b> was modified to regulate PM <sub>2.5</sub> concentrations as well as <b>PM<sub>10</sub></b> .
	PM <sub>10</sub>	<b>Particulate matter</b> in particles smaller than 10 μm diameter. Beginning in 1987, the federal standard for <b>PM</b> was modified to regulate PM <sub>10</sub> concentrations.
Phase		<b>State of matter</b> . Chemical <b>species</b> may exist in the <b>gas</b> , <b>liquid</b> , or <b>solid</b> phases.
Plume		An identifiable region of pollution generated by an identifiable source, such as a smokestack or the tailpipe of one vehicle. Plumes may be identified either visually or photographically (when they contain particles) or by instrumental measurements.

Word	Abbreviation or Acronym	Definition Bold words are defined in this glossary
Primary particles		<b>Particles</b> whose chemical form has not been significantly altered while in the atmosphere; their chemical properties are much the same as when they were emitted.
Regional haze		<b>Haze</b> from many sources that has been mixed with the result that the effects of individual sources are no longer identifiable. Regional haze covers multistate regions and is typically transported long distances. If the haze is localized to an urban area, it is called an <b>urban haze</b> instead of a regional haze.
Relative Humidity	RH	A measure of the amount of water vapor in the atmosphere. It is equal to the fraction or percentage of the amount of water vapor the atmosphere would contain at that temperature if it were saturated, i.e., in equilibrium with liquid water.
Secondary particles		<b>Particles</b> formed in the atmosphere from gases. Examples are <b>ammonium sulfate</b> and <b>ammonium nitrate</b> particles.
Smog		A popular name used to indicate photochemical air pollution. It is derived from the words, smoke and fog. However, smog is a combination of <b>particulate</b> and gaseous pollutants formed in the atmosphere from <b>NO<sub>x</sub></b> and <b>VOC</b> emissions. Prominent components of smog are <b>fine particles</b> and <b>ozone</b> , which are regulated, and other toxic gases (such as <b>nitric acid</b> and peroxyacetyl nitrate or PAN), whose concentrations are not regulated.
Solid		One of the three <b>states of matter</b> . Solids have both a definite volume and a definite shape.
Soot (This term not used)		Black emissions from incomplete combustion. Soot is not a precisely defined technical term, and may be used, for example, as a name for the mixture of <b>elemental carbon</b> , tars, uncombusted oils and other organic compounds, etc. emitted by diesel engines or woodburning fireplaces.
Species		Chemical species include both chemical elements and chemical compounds.
Stable		When the atmosphere is stable, vertical mixing is limited and pollutants emitted near the ground tend to remain near the ground. Temperature <b>inversions</b> may cause the atmosphere to be stable.
State of matter		Chemical <b>species</b> may exist in three states or <b>phases</b> , <b>gas</b> , <b>liquid</b> , or <b>solid</b> .
Sulfur dioxide	SO <sub>2</sub>	A toxic, invisible gas that is one of the six <b>criteria pollutants</b> . It reacts in the atmosphere to form sulfate particles that are a major contributor to <b>haze</b> in the eastern United States or in western areas downwind of <b>SO<sub>2</sub></b> sources.

Word	Abbreviation or Acronym	Definition Bold words are defined in this glossary
Sulfuric acid	H <sub>2</sub> SO <sub>4</sub>	Formed in the atmosphere by the oxidation of <b>SO<sub>2</sub></b> . It rapidly reacts with <b>ammonia</b> to form particulate <b>ammonium sulfate</b> , which is a major component of <b>haze</b> in the United States. Ammonium sulfate is less important in western urban areas because of a lack of SO <sub>2</sub> emissions.
Urban haze		<b>Haze</b> in an urban area due to multiple sources.
Urban plume		<b>Urban haze</b> transported downwind to form a <b>plume</b> that may be shown to have its origins in an identifiable urban area.
Vehicle miles traveled	VMT	The number of miles driven by a single vehicle, or by a fleet of vehicles, over a set period of time such as a day, week, month, or year.
Volatile organic compounds	VOC	<b>Organic compounds</b> in the <b>gas</b> phase.

## **APPENDIX B**

### **THE LIGHT-EXTINCTION COEFFICIENT**

## THE LIGHT-EXTINCTION COEFFICIENT

The light-extinction coefficient indicates the strength of the attenuation of light by the atmosphere. When this coefficient has large values, light rays are strongly weakened as they pass through the atmosphere and visibility is impaired. Small values of this coefficient indicate good visibility. Light extinction is the most important optical property of the atmosphere, and the light-extinction coefficient is universally used by scientists in descriptions of atmospheric optics and visibility. However, most people are not familiar with this coefficient. Therefore, this appendix provides a brief introduction to the concept of light extinction and the parameter used to measure it.

When a ray of light passes through the atmosphere, it is weakened by light scattering and light absorption. Light scattering causes light to change its direction of travel, causing it to be lost from the original light beam and to travel in a different direction. Light absorption causes light to disappear and to be turned into heat. Dense fogs provide an example of strong light scattering. It is not possible to see objects at a distance through a fog because light coming from distant objects toward the eyes of the observer is scattered into other directions by the fog droplets. Very little light from distant objects traverses the fog without being scattered, with the result that it is not possible to perceive distant objects. Light that has been scattered no longer conveys information about its source, and gives fogs their featureless appearance. Light absorption is easily observed when ink or a dye is added to a glass of water.

The weakening of a beam of light by scattering and absorption is called light

extinction, and it is measured by the light-extinction coefficient. The technical definition of the light-extinction coefficient is given in the following paragraph, because it is more easily understood after considering a specific example. A beam of light passing through very clear air is attenuated by light scattering by air molecules. (It is this light scattering which makes the sky blue.) Scattering by air molecules weakens a beam of green light by 1 percent per kilometer, or about 1.6 percent per mile. The strength of this light extinction caused by scattering may be indicated by translating the 1 percent per kilometer to 1 per hundred per kilometer, or 1/100 per kilometer, or 0.01 per kilometer, which may be written as  $0.01 \text{ km}^{-1}$ . This is approximately the value of the light-extinction coefficient (and also the light-scattering coefficient) for particle free air at elevations typical of most of the United States.

The rate at which a beam of light loses energy due to light extinction is proportional to the energy of the beam. If the beam is twice as intense, it loses twice as much energy in a given distance. The proportionality constant that specifies the distance-rate of energy loss is the light-extinction coefficient. As in the example above, it has units of  $1/\text{length}$  or  $\text{length}^{-1}$ . The value of the light-extinction coefficient does not depend on the strength of the illumination. For a given air parcel, it has the same value if the air is illuminated by strong sunlight or only starlight. The value of the light-extinction coefficient does depend on the wavelength (i.e., color) of the light. In visibility studies, it is customary to give the value of the light-extinction coefficient for green light, which is in the middle of the range of visible wavelengths and is the wavelength to which the eye is most sensitive.

The strength of light scattering and absorption are indicated by the light-scattering coefficient and the light-absorption coefficient, which may be defined in the same way as the light-extinction coefficient. The light-extinction coefficient is equal to the sum of the light-scattering coefficient and the light-absorption coefficient.

As indicated above, visibility impairment due to light scattering and light absorption increase as the values of these coefficients increase. In Maricopa County, much of the light absorption in the atmosphere is caused by elemental carbon emitted by gasoline and diesel engines (Watson et al., 1991b). As the elemental carbon concentration increases, the light-absorption coefficient increases.

Many optical calculations are simplified if these coefficients are measured

in units of  $\text{Mm}^{-1}$  instead of  $\text{km}^{-1}$ .  $\text{Mm}$  is the abbreviation for a megameter, which is one thousand kilometers (km) or a million meters (m). An example of a simplified calculation uses data from Table 3-5 for light-scattering and light-absorption efficiency factors in units of  $\text{m}^2/\text{g}$ . For any chemical species listed in that table, multiplying the light-scattering efficiency in units of  $\text{m}^2/\text{g}$  by the ambient concentration of that species in units of  $\mu\text{g}/\text{m}^3$  gives the contribution of that species to the light-extinction coefficient in units of  $\text{Mm}^{-1}$ . When these units are used, this calculation may be performed without applying any additional factors to convert units.

Converting the light-extinction coefficient for very clear air from units of 1/kilometers to units of 1/megameters changes  $0.01 \text{ km}^{-1}$  to  $10 \text{ Mm}^{-1}$ . During the summer, the light-extinction coefficient measured in central Phoenix is often between 40 and  $70 \text{ Mm}^{-1}$ . During these times, the total light extinction is 4 to 7 times as great as the light extinction due to pollution-free air. During winter brown cloud events, the light-extinction coefficient frequently exceeds  $200 \text{ Mm}^{-1}$ , which is 20 times the light extinction in clean air.

## **APPENDIX C**

### **TRANSMISSOMETER MEASUREMENTS OF LIGHT EXTINCTION**

## TRANSMISSOMETER MEASUREMENTS OF LIGHT EXTINCTION

The monitoring data in Maricopa County that most directly measure the severity of the brown clouds were obtained by a transmissometer operated for the Arizona Department of Environmental Quality (ADEQ) by Air Resource Specialists, Inc. (ARS) of Fort Collins, Colorado. The location of the transmissometer is shown in **Figure C-1**. A transmitter at the Phoenix Baptist Hospital near Bethany Road and Interstate 17 directed a beam of light of controlled intensity toward the receiver at the Quality Hotel, which is 4.76 km (2.96 miles) to the south southeast. The receiver measured the amount of light that traversed the sight path. The measured amount of light was subtracted from the amount that would be observed if the sight path were in a vacuum to determine the light extinction due to light scattering and light absorption in the sight path. The measured light extinction and the length of the sight path were used to calculate the light-extinction coefficient, which is a property of the atmosphere in the sight path. More complete definitions of these terms appear in the glossary in Appendix A, and a discussion of the light-extinction coefficient is presented in Appendix B.

The Optec Transmissometer used to make the light transmittance measurements has been described by Molenaar et al. (1992). This instrument is used in the Interagency Monitoring of Protected Visual Environments (IMPROVE) program to monitor haze in national parks and wilderness areas in the United States. The procedures for the instrument operation, data reduction, and data archiving are described in a standard operating procedure prepared for the IMPROVE program (Blandford, 1994; Mercer, 1994). These procedures flag data

influenced by meteorological effects, such as fog or precipitation. The meteorological effects may be very large, and, if left in the data, would tend to obscure the effects of air pollution on light extinction. All flagged data were omitted from the data summaries presented below. The light extinction measurements are made with green light with a wavelength range centered at 550 nm, which is the wavelength of light to which the human eye is most sensitive.

Light scattering by air molecules causes the sky to be blue and also causes some light extinction in the transmissometer sight path. Pure air weakens the transmissometer light beam by approximately 1 percent per kilometer. This corresponds to a light extinction coefficient of  $0.01 \text{ km}^{-1}$ . Many optical calculations for the Earth's atmosphere are simplified if distances are measured in millions of meters (megameters or Mm) instead of thousands of meters (kilometers or km). In these units, the light extinction coefficient for particle-free air is  $10 \text{ Mm}^{-1}$ . This is the value the transmissometer would measure if Maricopa County were completely free of both natural and manmade air pollution.

**Figure C-2** presents a time-series plot of the hourly light-extinction coefficient data for the months of October 1995 through February 1996. As will be shown below, these are the months with the highest levels of light extinction. The vertical dividing lines in the plot are at midnight, and the labels indicate the day of

Figure

C-1

here

Figure

C-2

here

the month. It is apparent that the readings are highly irregular, and vary by roughly a factor of two on most days. Strong peaks in the data may occur at any time of day, but have a tendency to occur at night or early morning. The lowest readings tend to occur in the afternoon. These trends show clearly in the statistical summaries presented below. The purpose of Figure C-2 is to show that while the trends presented below are simple, the underlying data are highly variable.

The first full month of transmissometer measurements occurred in January 1994. The latest data available at the time the transmissometer data were obtained were for the month of May 1999. The data for December 1998 through May 1999 are subject to recalibration when the transmissometer is returned to the manufacturer in December 1999 for annual maintenance. **Figures C-3 through C-13** present statistical summaries of the transmissometer data for all months for which data are available. The data are grouped by month to show the seasonal trends, and within each month by the hour of the day to show the daily trends. Each box-and-whisker symbol provides an easy method for viewing the statistical properties of the data. The box encloses the middle half of the data. One quarter of the light-extinction readings are greater than the top of the box and one quarter are smaller than the bottom of the box. When the boxes are relatively long, as in the hours late in the day in January 1994, the measured values of light extinction have a broad range. When the boxes are relatively short, as in the May 1994 data, most light-extinction readings fall in a narrow range.

The whiskers provide information about the high and low readings. The whiskers always end on a data point; when the plots show no data points beyond the end of a whisker, the whisker shows the value of the highest or lowest data point. The whiskers have a maximum length equal to 1.5 times the length of the box. If there are data outside this range, the points are shown on the plot and the whisker ends on the highest or lowest data point within the range of the whisker.

The line through the box shows the median; half the data points are above this line and half below. The average of the data is shown by the symbol within the box.

A visual range scale appears at the upper right of each figure to help in the interpretation of the data. The visual range is the greatest distance at which it is possible to see a dark target against the horizon sky. If it is assumed that the atmosphere and its illumination are uniform throughout a sight path that extends well beyond the dark target, then it is possible to show that the visual range (VR) and the light-extinction coefficient  $b_{\text{ext}}$  are related by the formula (Koschmeider, 1924),

$$VR = 4/b_{\text{ext}} \quad (\text{C-1})$$

Distances in megameters calculated from this formula have been converted to miles in the scales in the figures.

The assumptions used in the derivation of this formula are important, and are often overlooked. Contrary to the assumption, haze in the atmosphere is almost never uniform. This is especially true of brown

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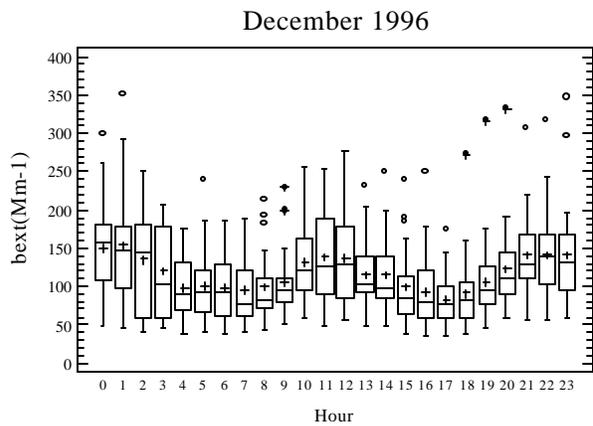
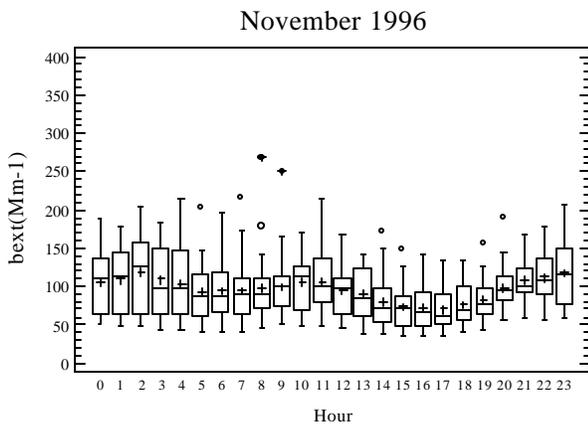
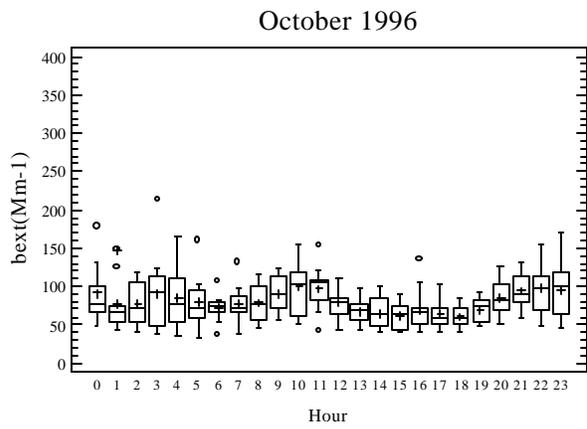
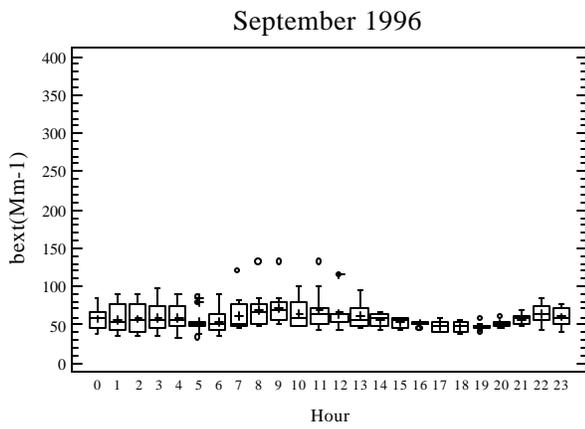
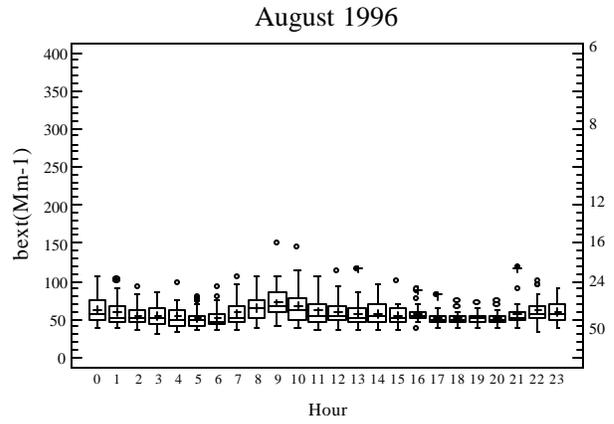
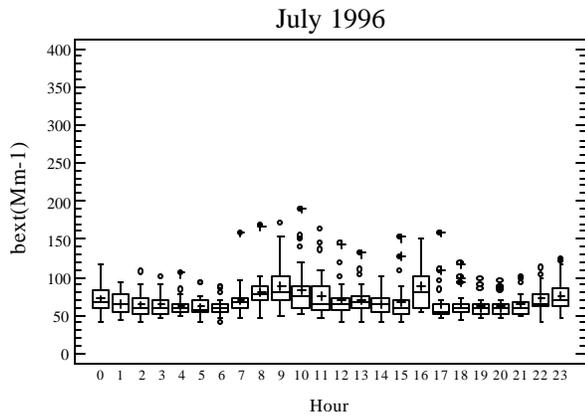


Figure C-8. Box whisker plots of hourly light extinction in Phoenix during July-December 1996. The top right plot includes a scale of visual range in miles.

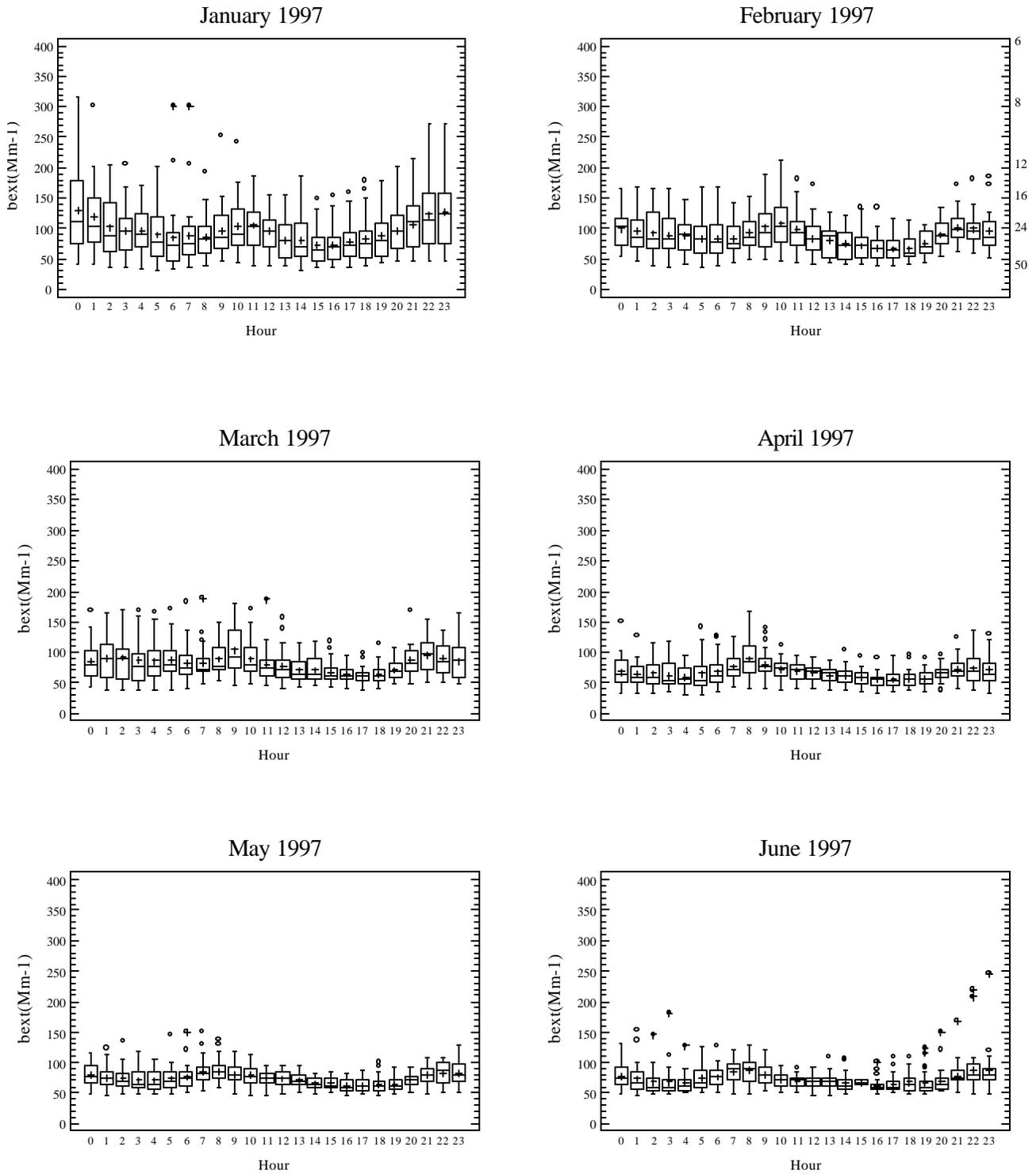


Figure C-9. Box whisker plots of hourly light extinction in Phoenix during January-June 1997. The top right plot includes a scale of visual range in miles.

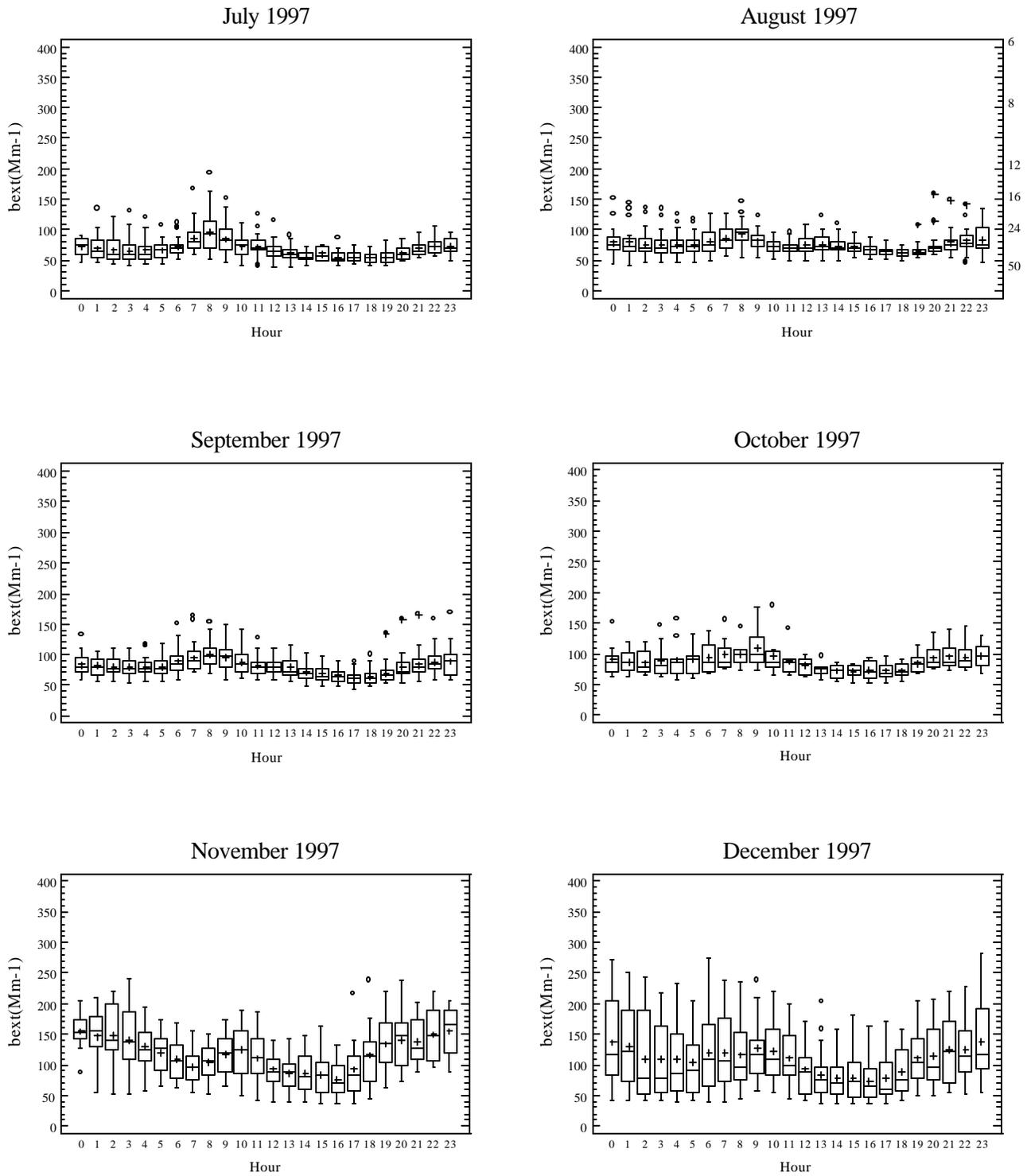


Figure C-10. Box whisker plots of hourly light extinction in Phoenix during July-December 1997. The top right plot includes a scale of visual range in miles.

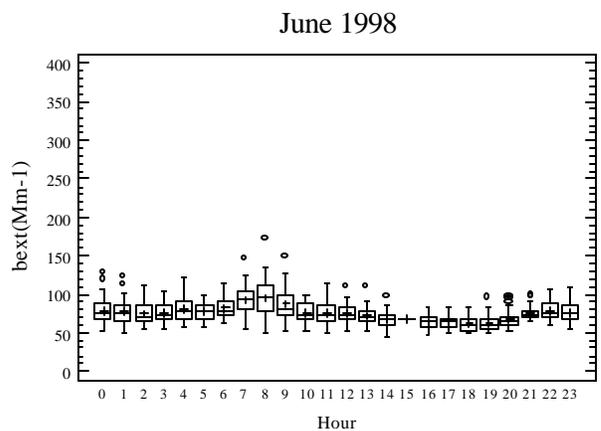
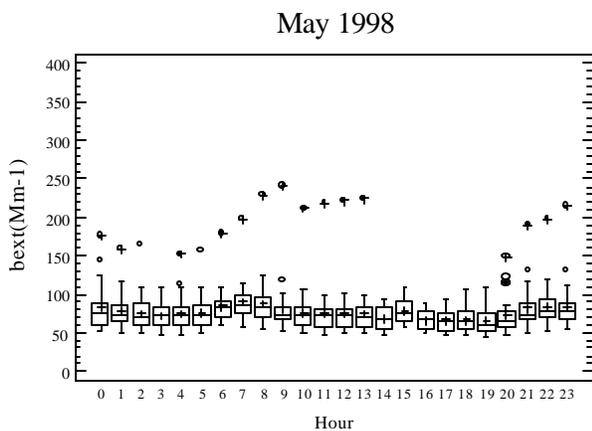
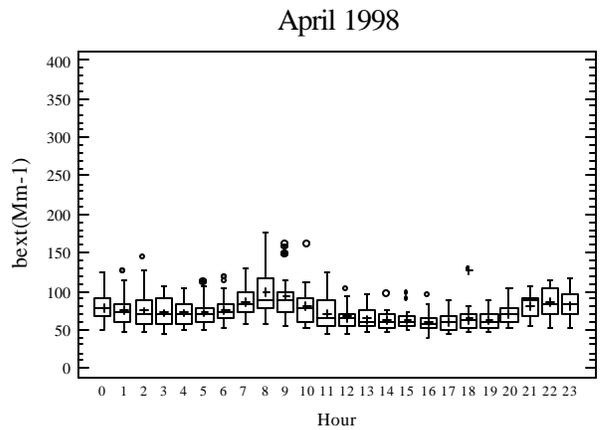
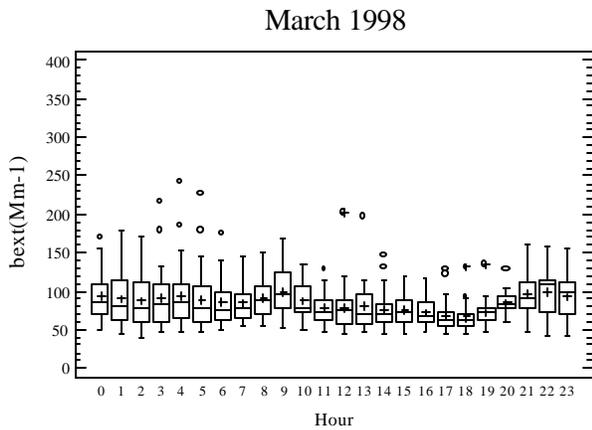
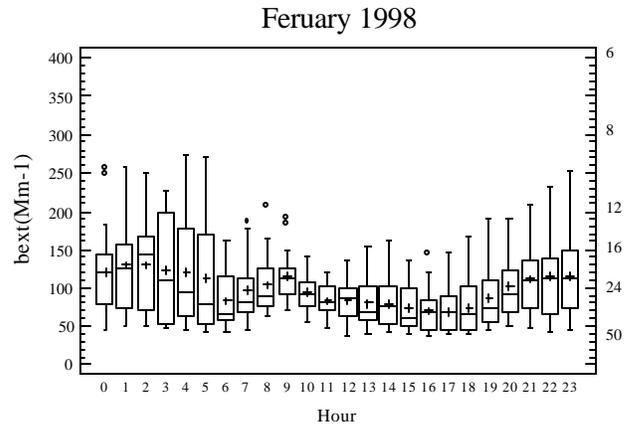
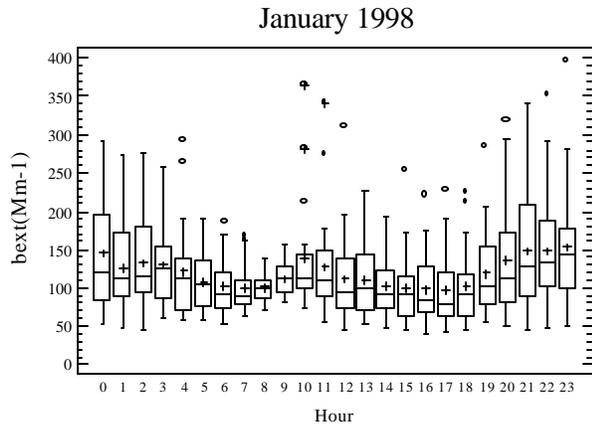


Figure C-11. Box whisker plots of hourly light extinction in Phoenix during January-June 1998. The top right plot includes a scale of visual range in miles.

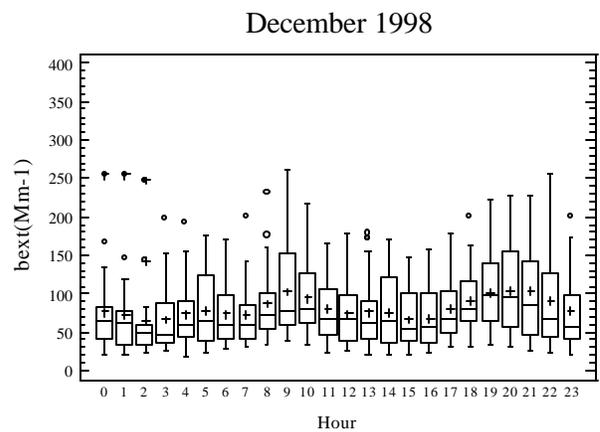
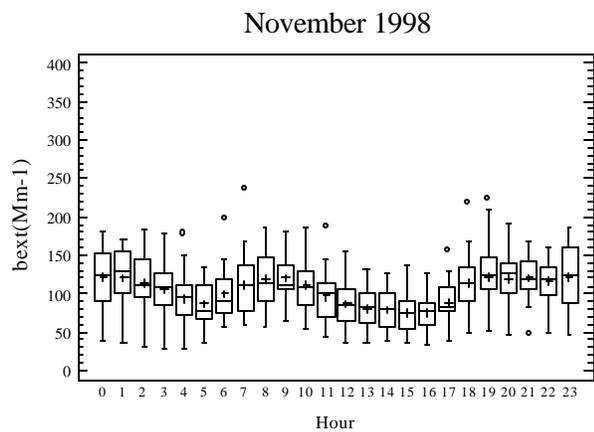
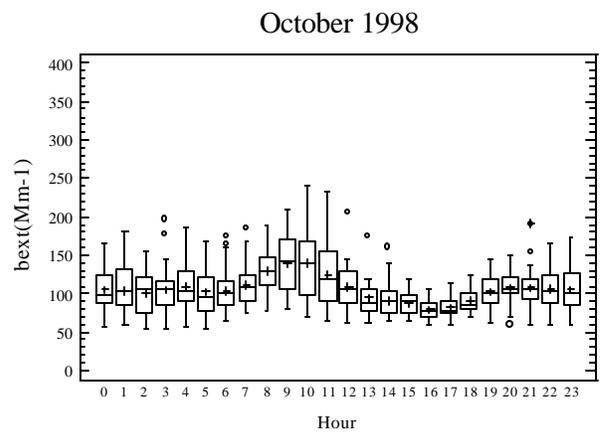
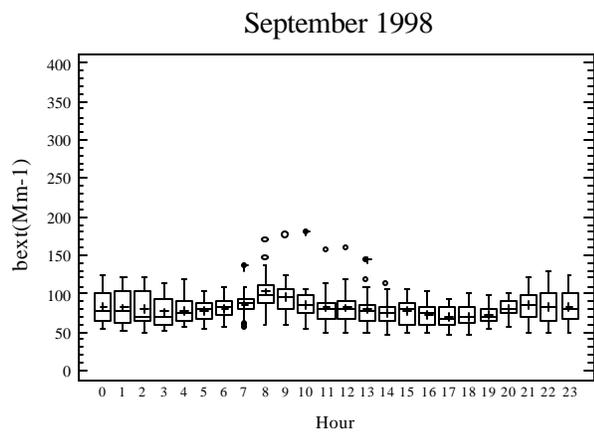
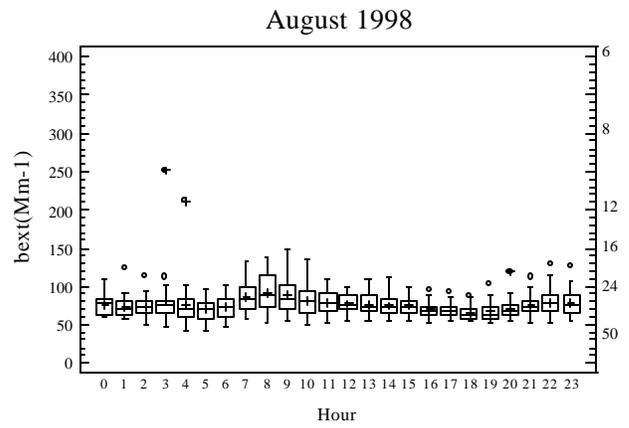
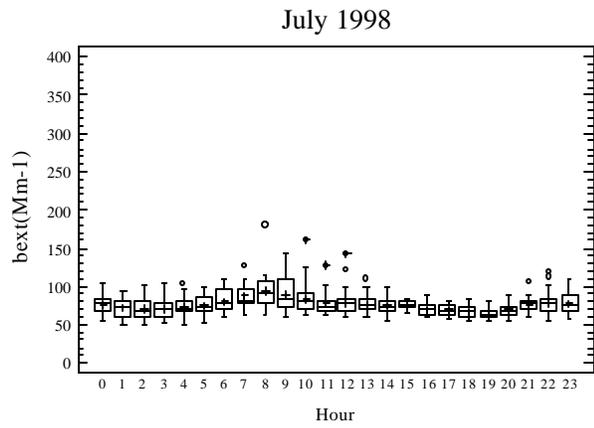


Figure C-12. Box whisker plots of hourly light extinction in Phoenix during July-December 1998. The top right plot includes a scale of visual range in miles.

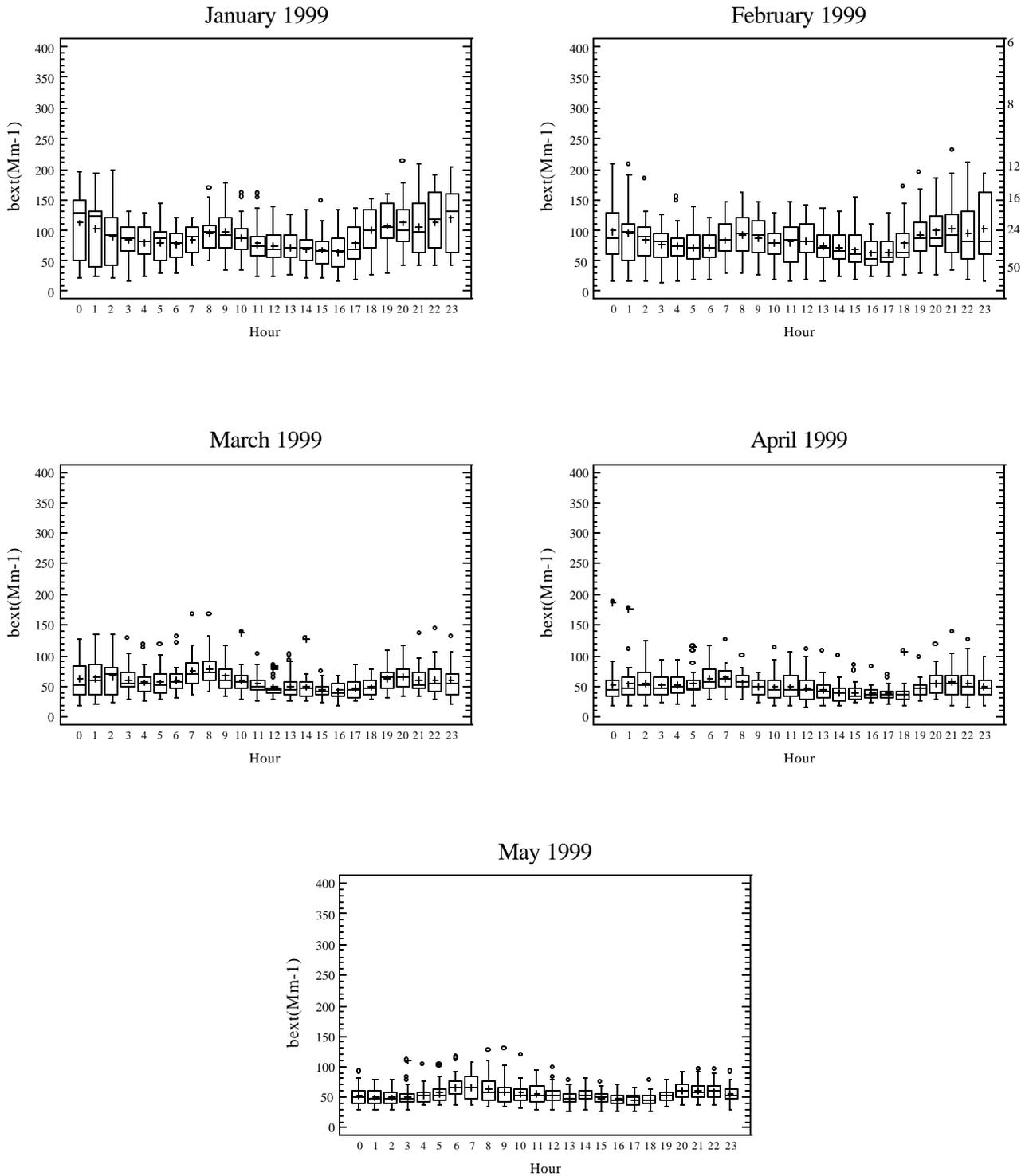


Figure C-13. Box whisker plots of hourly light extinction in Phoenix during January-May 1999. The top right plot includes a scale of visual range in miles.

clouds, which are formed in the most densely populated areas and drift with the winds. For example, the transmissometer might be measuring a local haze that would limit the visual range to 20 miles if the haze were uniform, while a human observer near the transmissometer could see much farther because the haze may be this intense only in the nearby portion of the sight path to a distant target.

The data in Figures C-3 through C-13 show a definite seasonal trend. Light extinction is greatest during October through January and the least during April. They also show a daily trend, with a minimum in the afternoon and higher values at night and during or after the morning rush hours. These trends are primarily caused by trends in the meteorology, as described in Sections 2.5

and 3.3.5. The maximum in the light extinction in the late morning is caused by a combination of the increased emissions during the morning rush hour and the lack of atmospheric dispersion early in the day. The low values in the afternoon are caused by the greater atmospheric mixing and transport during this time of day. These latter processes both dilute the urban emissions and transport them away from the urban area.

The data in Figures C-3 through C-13 indicate that high values of light extinction, which are an indicator of brown clouds, occur most frequently during October through February, and that quite high values occur occasionally in March and April. Control measures that are implemented seasonally should focus on these months.

## **APPENDIX D**

### **TRENDS IN AIRPORT VISIBILITY OBSERVATIONS**

## TRENDS IN AIRPORT VISIBILITY OBSERVATIONS

### INTRODUCTION

Human observations of visibility at Sky Harbor Airport (PHX) in Phoenix provide the longest-duration historical record of haze in the Maricopa County area. These observations are recorded hourly and archived by the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) in Asheville, North Carolina. Data from these observations were obtained from two sources. Solar and Meteorological Surface Observational Network (SAMSON) data were purchased from NCDC on CD-ROM. This database contains hourly observations from 237 sites in the United States, including Phoenix, for the years 1961 through 1990. National Weather Service (NWS) Surface Airways hourly observations for the years 1991 through 1995 were obtained from the Western Regional Climate Center (WRCC) operated for the NWS by Desert Research Institute (DRI), Reno, Nevada.

### EXPERIMENTAL METHODS

Visibility observations are made every hour by determining the greatest distance at which it is possible to see dark targets on the horizon in half or more of the full circle of view. The visibility targets used in Phoenix after 1990 are shown in **Figure D-1**. According to Mike Bruce of the Phoenix office of the National Weather Service, essentially the same targets were used before 1990. Because visibility targets are available only at certain distances, a recorded visibility of 45 miles indicates that it was possible to see the target at a distance of 45 miles, and the visibility is 45 miles or better.

The human observers who record visibility observations introduce variability into the data as a result of differences in training and judgment (Middleton, 1952). Therefore, airport visibility data need to be reviewed for anomalies and used with caution (Trijonis, 1979, 1982).

The visibility data used in the following analyses were screened to remove meteorological effects. All hours that precipitation of any type or fog were reported were flagged and not used in the analyses. Also, observations made when the relative humidity was 95 percent or greater were not used. The purpose of this data flagging was to focus the analyses on the effects of air quality on visibility.

### RESULTS

The analyses of the airport visibility data began by examining the frequency distributions of data recorded at 8:00 a.m. MST for the months of October through February. This time of day was selected for two reasons: it is near the time of maximum light extinction due to the brown cloud, and data were available for this time for all years. For some years, data were available only every three hours and were not available for 6:00, 7:00, 9:00, and 10:00 a.m. Data for October through February were selected for analysis because the 8:00 a.m. light extinction due to the brown cloud is greatest during these months. This data selection maximizes the chance that statistical analysis of the airport visibility might show trends caused by trends in the frequency and severity of brown clouds. The mechanics of manipulating the data were greatly simplified

Figure

D-1

here

by grouping the data by calendar year. For example, the 1975 data include January, February, and October through December 1975.

The 8:00 AM wintertime airport visibility data for the 33-year time period from 1961 to 1993 are shown as cumulative frequency distributions in **Figure D-2**. Each line shows the fraction of the 8:00 AM readings with visibility as good as or better than the value indicated on the label for the line. For example, the visibility was 40 miles or better in 24 percent of the readings in 1961. The frequency of a 40-miles visibility increased to 56 percent of the readings in 1967, 58 percent of the readings in 1968, then decreased to 30 percent of the readings in 1972 and increased to 67 percent of the readings in 1983. During this time period, the long-term trend was for the frequency of occurrence of readings of 40 miles or better to increase.

Other lines in Figure D-2 are similarly interpreted. Readings of 60 miles or better were rarely observed in the 1960s, and were increasingly observed until 1987 and 1988, when they occurred in 7 percent of the observations. The frequency of 60 miles or better visibility in 1992 appears to be anomalously high. The lines showing data for short visual ranges indicate that the frequency of visibility observations of 20 miles or better has been increasing throughout the time period shown. In other words, the frequency of visual ranges less than 20 miles has been decreasing during this time period. The overall trend in these data is a general improvement in visibility.

The variability in the visibility data is readily apparent. The visibility during 1967 and 1968, and again during 1982 and 1983, was better than in other years. Decreased visibility

occurred during 1972 and 1973 and again during 1985 and 1986. This variability is due in part to natural variability, i.e., the year-to-year variability in the weather. It is also likely that some of the variability is due to differences in the training and judgment of the human observers (Middleton, 1952; Trijonis, 1979 and 1982).

Some of the variability is also due to changes in emissions. An industry-wide copper strike took place from July 1967 to March 1968. Trijonis (1979) showed that the decreased emissions of sulfur dioxide in Arizona and adjacent states caused by the strike resulted in decreased concentrations of sulfate particles in the atmosphere and increased visibility during the strike. These effects contributed to the improved visibility in 1967 and 1968 in Figure D-2.

## TRENDS IN AIRPORT VISIBILITY

The lines in **Figure D-3** show the trends in the visibility data. These lines were obtained from least-squares fits of a quadratic equation to the data. Most lines show a general improvement in visibility during the data period. The lines for 50 and 55 miles visibility do not follow the trends in the surrounding data. It is likely that this anomaly is due to the uncertainties in human observations of targets at fixed locations and distances.

The frequency of occurrence of a visibility less than 10 miles was little changed during this time period. This result should be interpreted with caution, because most observations less than 10 miles are caused by meteorological effects such as fog, precipitation, or very

WRCC Data

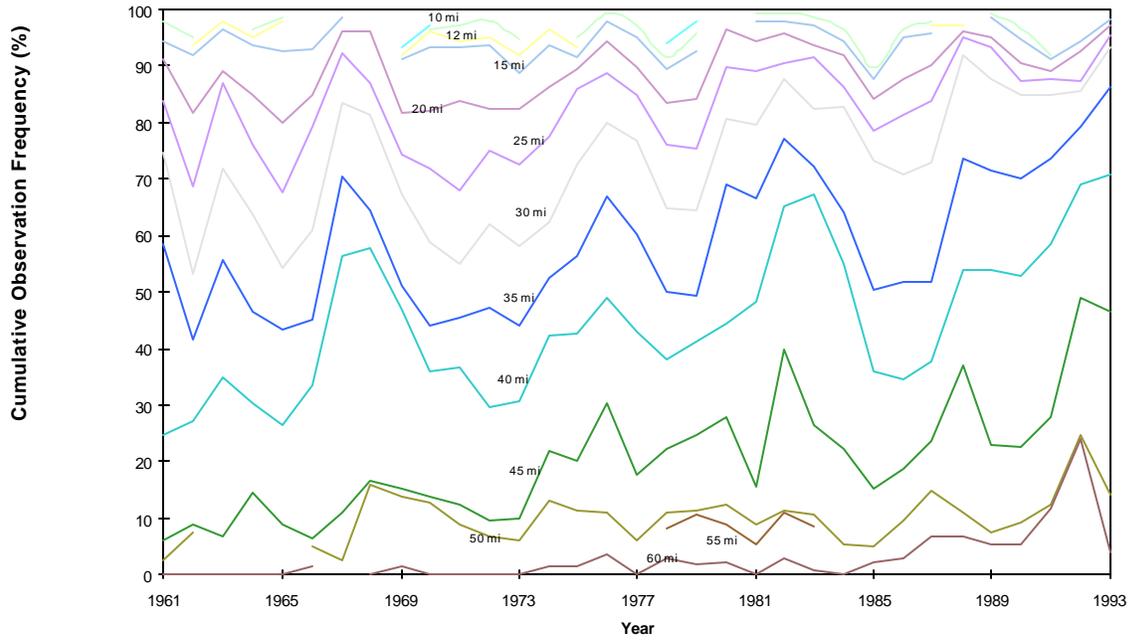


Figure D-2. Frequency of occurrence of 8:00 a.m. October-February Phoenix visibility observations equal to or greater than the values indicated by the labels on the lines. The 1961 through 1990 observations are from SAMSON and 1991 through 1993 from WRCC.

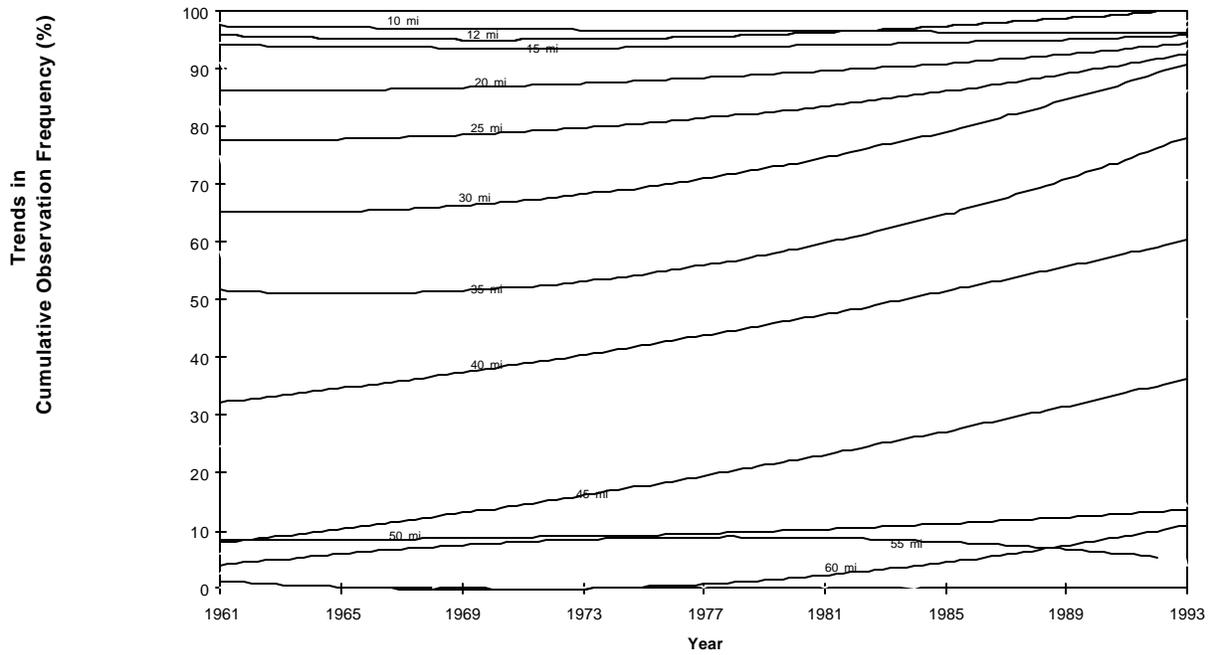


Figure D-3. Visibility trends derived from least-squares fits to the 8:00 a.m. October-February Phoenix visibility observations in Figure D-2.

high relative humidity. The observations due to weather effects were flagged and not used in the analyses, as described above. Few observations less than 10 miles remained in the data. The procedures for flagging and removing data are not reliable enough to be sure that trends in the few remaining observations of limited visibility are meaningful.

If the lines in Figure D-3 were exactly correct, they would not cross each other. The cases where the lines do cross are caused by simplifications in the calculations.

**Figure D-4** presents these same airport visibility data in a simpler form. The solid line shows the median visual range each year. (Half the visibility observations are

greater than the median and half are less each year.) The dotted line shows the trend in the median visual ranges. According to this trend line, the median visual range increased from about 35 miles in 1961 to more than 42 miles in 1993.

Sulfur dioxide emissions from smelters in Arizona and surrounding states decreased greatly during the time period included in the trend lines in Figures D-3 and D-4. It is likely this decrease in emissions contributed to the general improvement in visibility during this time period. The analyses reported here did not include any attempt to evaluate the relative importance of changes in smelter emissions compared to other factors that could have contributed to the trends shown in Figures D-3 and D-4.

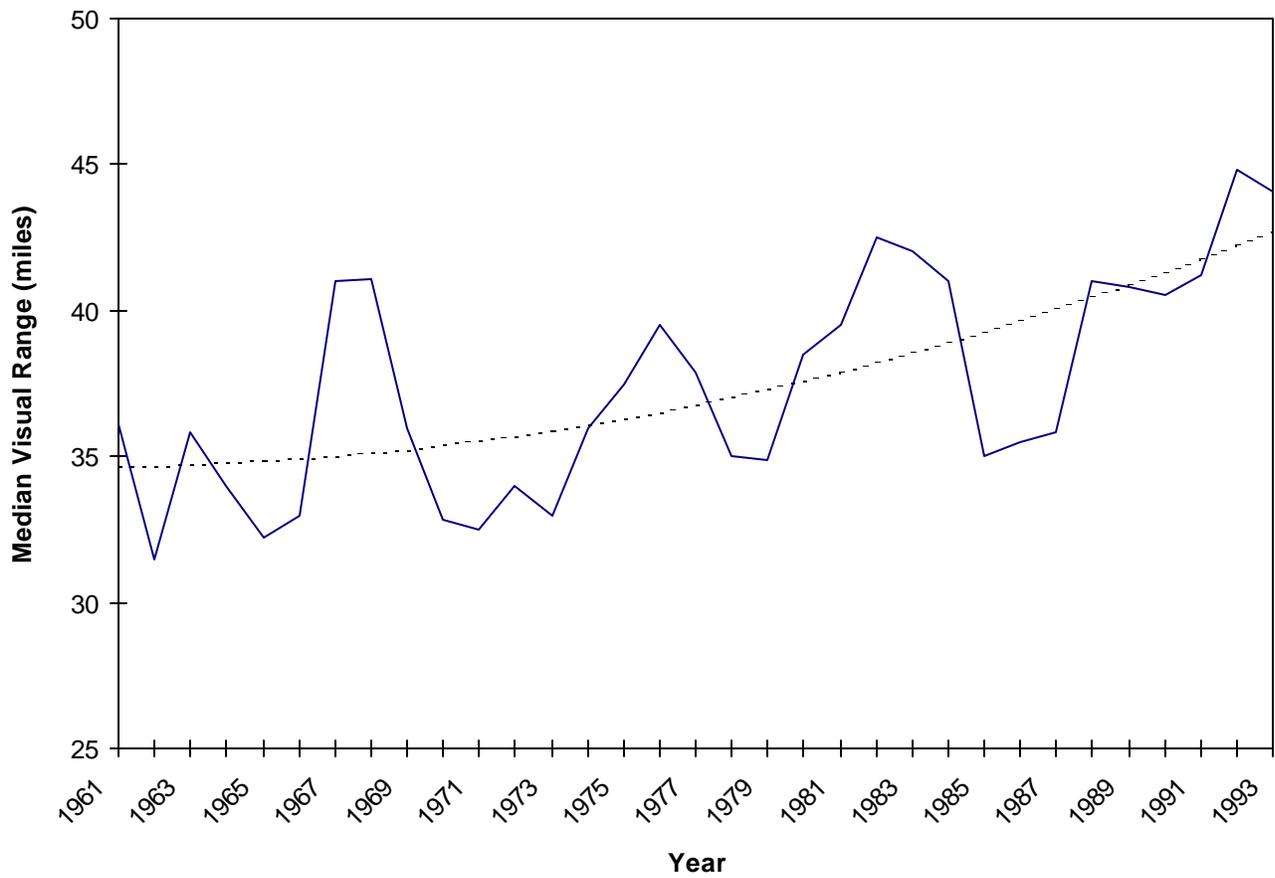


Figure D-4. Median values of the 8:00 a.m. airport visibility observations during January, February, and October through December each year. The dotted line shows the trend.

## **APPENDIX E**

**EXHIBIT 1: CHEMICAL MASS BALANCE CALCULATIONS WITH EXTENDED CHEMICAL SPECIATION DATA**

**EXHIBIT 2: SENSITIVITY ANALYSIS OF THE DATA PRESENTED IN THE MAG BROWN CLOUD STUDY SOURCE ATTRIBUTION OF PM 2.5**

## **EXHIBIT 1**

### **CHEMICAL MASS BALANCE CALCULATIONS WITH EXTENDED CHEMICAL SPECIATION DATA**

## **EXHIBIT 2**

### **SENSITIVITY ANALYSIS OF THE DATA PRESENTED IN THE MAG BROWN CLOUD STUDY SOURCE ATTRIBUTION OF PM 2.5**

## CHEMICAL MASS BALANCE CALCULATIONS WITH EXTENDED CHEMICAL SPECIATION DATA

### INTRODUCTION

This appendix provides backup information for the PM<sub>2.5</sub> source apportionments described in Section 4.2.2 that were performed as part of this study. These calculations were performed by Eric Fujita at Desert Research Institute (DRI).

Version 8 of the Chemical Mass Balance (CMB) receptor model was applied to a total of 101 ambient PM<sub>2.5</sub> samples that were collected in the Maricopa County area by the Arizona Department of Environmental Quality (ADEQ) from November 1994 to September 1995. The CMB analysis was performed using source profiles from NFRAQS recently completed in the Denver area (Watson et al., 1998; Zielinska et al., 1998b; and Fujita et al., 1998), from the 1989-1990 Phoenix Urban Haze Study (Watson et al., 1991b, 1991c), and from a characterization of gasoline- and diesel-powered vehicles at a Phoenix Inspection and Maintenance (I&M) facility (Zielinska et al., 1997).

The CMB uses the chemical and physical characteristics of gases and particles measured at sources and receptors to both identify the presence of and to quantify source contributions to receptor concentrations. Sources that typically contribute to ambient PM<sub>2.5</sub> levels in urban areas are: 1) onroad and nonroad mobile source exhaust, 2) residential wood combustion, 3) paved road dust and entrained geological material, 4) coal-fired boilers at power plants, and 5) restaurant grills and residential cooking. Inorganic constituents including trace elements, sulfate, nitrate, and ammonium; total particulate organic carbon (OC); and

elemental carbon (EC) are typically measured in PM source apportionment studies. However, source contributions of carbonaceous particles (elemental carbon plus organic compounds), which account for the majority of fine particulate mass, are difficult to distinguish on the basis of these kinds of constituents. For example, soluble potassium, which is widely used as a wood-smoke tracer, is also found in paved road dust. Elemental and organic carbon are present in gasoline and diesel engine exhaust, wood-smoke, and other combustion-related emissions in varying proportions within the same source type. Lead and bromine additives to gasoline have served as useful tracers for gasoline engine emissions but due to the phase-out of leaded gasoline in many parts of the United States in 1990, they have become obsolete as gasoline engine emission tracers. Although the CMB analyses performed during the 1989-1990 Phoenix Urban Haze Study attributed a major fraction of the pollutants that cause brown clouds to mobile sources, the contributions of the exhaust from gasoline- and diesel-fueled engines could not be distinguished using traditionally-measured chemical species (Lowenthal et al., 1992).

Source profiles that include both particulate and gaseous organic compounds in combination with traditionally-measured inorganic species have been successfully used to distinguish contributions of diesel-fueled engines, gasoline-fueled engines, and other particulate pollutant sources. Polycyclic aromatic hydrocarbons (PAH) are useful tracers of various types of combustion emissions because they are present in emissions from all combustion sources and the relative proportions of

different PAH compounds in emissions from a given source may vary over several orders of magnitude. In addition, good sampling and analytical methods exist for this class of compounds. PAHs exhibit a wide range of volatility, and the factor of about  $10^7$  in the range of their vapor pressure is reflected in the fact that, at ambient temperature, naphthalene exists almost entirely in the gas phase, while BaP, other five-ring PAHs, and higher ring PAHs are predominantly adsorbed on particles. The intermediate three- and four-ring PAHs (semi-volatile PAHs) are distributed between the two phases. The two- to four- ring PAHs, which exist partially in the gas phase, react readily with OH radicals and  $N_2O_5$  (Zielinska et al., 1989a, 1989b, 1990; Arey et al., 1989; Atkinson et al., 1988, 1990). Their atmospheric lifetimes have been estimated to range from about 2 hours for anthracene to about 9 hours for naphthalene. Although the reactivity of semi-volatile PAHs complicates their use in CMB modeling, appropriate rate constants for these and other volatile organic compounds may be used to modify organic tracer concentrations in CMB source profiles. PAH atmospheric reaction rates are substantially less during the winter, and the need to adjust the profiles is correspondingly diminished. Alternatively, it is possible to circumvent the effects of reactivity by selecting nonreactive fitting species in the CMB calculation.

The utility of particulate and gaseous organic compounds in distinguishing sources of fine particles by CMB modeling was evaluated during 1996-1997 as part of NFRAQS (Fujita et al., 1998). One of the major objectives of NFRAQS was to apportion the carbonaceous material in airborne particles along Colorado's Northern Front Range to emission sources. In order to address this objective, the list of typically-measured chemical species was extended to

include selected particulate and semi-volatile PAHs, methoxylated phenols, hopanes, steranes, lactones, and sterols. Methoxylated phenols are tracers for wood combustion, and lactones and sterols are emitted during charbroiling of meat. Hopanes and steranes are found in motor oils and are emitted with the exhaust from mobile sources. The addition of speciated organic compounds to conventional species ("extended" CMB) allowed carbonaceous particles to be apportioned to diesel exhaust, three categories of light-duty gasoline vehicle (LDGV) exhaust (cold starts, hot stabilized operation, and high particle emitters), meat cooking, and two categories of wood combustion (softwoods and hardwoods). These profiles were also applied to ambient NFRAQS samples with traditionally-measured species ("conventional" CMB) by combining the three LDGV profiles into one composite profile and by combining meat cooking with wood combustion.

Sulfates and nitrates are the most common secondary particles, though a fraction of organic carbon may also result from volatile organic compounds (VOCs) via atmospheric reactions. Sulfates and nitrates are almost entirely secondary because there are few primary emitters of these species. Secondary organic particles are more difficult to distinguish from primary organic compounds because only organic carbon, and not its chemical constituents, is usually measured and there are many primary emitters of organic material. Secondary organic compounds in particulate matter include aliphatic acids, aromatic acids, nitro aromatics, carbonyls, esters, phenols, and aliphatic nitrates (Grosjean, 1992; Grosjean and Seinfeld, 1989). However, these compounds are also present in primary emissions (see, for example, Rogge et al., 1993a, 1993b), thus they are not unique tracers for atmospheric

transformation processes. Because secondary organic particles may not be apportioned by receptor modeling, the importance of secondary aerosol formed by the photochemical processes (specifically, OH radical reactions) was assessed in NFRAQS by measuring the concentrations of nitroarenes.

## CHEMICAL MASS BALANCE

The CMB (Friedlander, 1973; Cooper and Watson, 1980; Gordon, 1980, 1988; Watson, 1984; Watson et al., 1984, 1990c, 1991a; Hidy and Venkataraman, 1996) consists of a solution to linear equations that express each receptor chemical concentration as a linear sum of products of source profile abundances and source contributions. The source profile abundances (i.e., the mass fraction of a chemical or other property in the emissions from each source type) and the receptor concentrations, with appropriate uncertainty estimates, serve as inputs to the CMB. The CMB calculates values for the contributions from each source and the uncertainties of those values.

The CMB is implicit in all factor analysis and multiple linear regression models that intend to quantitatively estimate source contributions (Watson, 1979). These models attempt to derive source profiles from the covariation in space and/or time of many different samples of atmospheric constituents that originate in different sources. These profiles are then used in a CMB to quantify source contributions to each ambient sample. The CMB is applicable to multi-species data sets, the most common of which are chemically-characterized PM<sub>10</sub> (suspended particles with aerodynamic diameters less than 10 μm), PM<sub>2.5</sub> (suspended particles

with aerodynamic diameters less than 2.5 μm), and VOCs.

The CMB procedure requires: 1) identification of the contributing sources types, 2) selection of chemical species or other properties to be included in the calculation, 3) estimation of the fraction of each of the chemical species which is contained in each source type (source profiles), 4) estimation of the uncertainty in both ambient concentrations and source profiles, and 5) solution of the chemical mass balance equations. CMB model assumptions are: 1) compositions of source emissions are constant over the period of ambient and source sampling; 2) chemical species do not react with each other (i.e., they add linearly); 3) all sources with a potential for contributing to the receptor have been identified and have had their emissions characterized; 4) the number of sources or source categories is less than or equal to the number of species; 5) the source profiles are linearly independent of each other; and 6) measurement uncertainties are random, uncorrelated, and normally distributed.

The degree to which these assumptions are met in applications depends to a large extent on the particle and gas properties measured at the sources and receptors. CMB model performance is examined generically, by applying analytical and randomized testing methods, and specifically for each application by following an applications and validation protocol (Pace and Watson, 1987). The six assumptions are fairly restrictive and they will never be totally complied with in actual practice. Fortunately, the CMB model will tolerate reasonable deviations from these assumptions, though these deviations increase the stated uncertainties of the source contribution estimates (Cheng and Hopke, 1989; Currie et al., 1984; deCesar et

al., 1985; Dzubay et al., 1984; Henry, 1982, 1992; Javitz and Watson, 1986; Javitz et al., 1988a, 1988b; Kim and Henry, 1989; Lowenthal et al., 1987, 1988, 1992, 1994; Lowenthal and Rahn, 1988a, 1988b; Watson, 1979).

The CMB calculates source contribution estimates for each individual ambient sample. The combination of source profiles that best explains the ambient measurements may differ from one sample to the next owing to differences in emission rates (e.g., some days may have wood-stove burning bans in effect and others will not), wind directions (e.g., a downwind point source would not be expected to be contributing at an upwind sampling site), and changes in emissions compositions (e.g., different gasoline characteristics and engine performance in winter and summer may result in different profiles). It is not known *a priori* which profile best represents emissions from a source type for a specific sample. The profiles selected for a particular sample are inferred from performance measures that reflect how well the ambient concentrations are reproduced. For this reason, it is important to quantify the magnitude of biases that might result from judgements about profile selection.

Ambient samples were apportioned to source using CMB Version 8. CMB8 (Watson et al., 1997) replaces CMB7 (Watson et al., 1990c) as a more convenient method of estimating contributions from different sources to ambient chemical concentrations. CMB8 returns the same results as CMB7, but it operates in a Windows-based environment and accepts inputs and creates outputs in a wider variety of formats than does CMB7. Each of the CMB results includes values for performance measures that are used to evaluate the goodness of the solution, following the regulatory guidance of Pace

and Watson (1987). The most useful performance measures are:

- Source Contribution Estimate (SCE): This is the contribution of each source type to the pollutant being apportioned, which is usually the mass concentration. Each of the SCEs should be greater than zero and none should exceed the total mass concentration.
- Standard Error (STDERR): This is an indicator of the precision or certainty of each SCE. The STDERR is estimated by propagating the precisions of the receptor data and source profiles through the effective variance least-squares calculations. Its magnitude is a function of the uncertainties in the input data and the amount of collinearity (i.e., degree of similarity) among source profiles. It is desirable to have this value be much less than the source contribution estimate. When the SCE is less than the STDERR, the STDERR is interpreted as an upper limit of the source contribution.
- t-Statistic (TSTAT): This is the ratio of the source contribution estimate to the standard error. A high value for TSTAT ( $>2.0$ ), shows that the relative precision of the source contribution estimate is high and that the contribution is significant. A low TSTAT value ( $<2.0$ ) means that a source contribution is not present at a level which exceeds two times the STDERR. Twice the STDERR is a reasonable estimate of the upper limit for a source contribution when TSTAT  $<2.0$ .
- R-Square (R SQUARE) and Chi-Square (CHI SQUARE): The R

SQUARE measures the variance in the receptor concentrations which is explained by the calculated species concentrations. The CHI SQUARE statistic is the weighted sum of the squares of differences between calculated and measured species concentrations divided by the effective variance and the degrees of freedom (DF). A low R SQUARE (<0.8) indicates that the selected source profiles have not accounted for the variance in the selected receptor concentrations. A large CHI SQUARE (>4.0) means that one or more of the calculated species concentrations differs from the measured concentrations by several uncertainty intervals. The values for these statistics exceed their targets when: 1) contributing sources have been omitted from the CMB calculation, 2) one or more source profiles have been selected which do not represent the contributing source types, 3) precisions of receptor or source profile data are underestimated, and/or 4) source or receptor data are inaccurate.

- Percent of Mass Accounted For (PERCENT MASS): This is the ratio of the sum of the source contributions to the reconstructed mass for particulate samples. The target value is 100 percent, with a reasonable range of 80 to 120 percent. Percent mass values which are outside of this range result when: 1) source profiles have been incorrectly specified, 2) contributing source types have been omitted from the calculation, 3) mass or chemical species measurements are inaccurate, and/or 4) mass measurements are less than  $10 \mu\text{g}/\text{m}^3$  and within a few

precision intervals of the measurements.

- Max. Src. Unc. and Min. Src. Proj. – Replaces U/S CLUSTERS and SUM OF CLUSTER SOURCES: These are used in Henry's (1992) eligible space treatment of collinearity. This treatment uses two parameters, maximum source uncertainty and minimum source projection on the eligible space. These are set to default values of 1.0 and 0.95, respectively, in CMB8. Briefly, the maximum source uncertainty determines the eligible space to be spanned by the eigenvectors whose inverse singular values are less than or equal to the maximum source uncertainty. Estimable sources are defined to be those projections on the eligible space that are at least the minimum source projections. Inestimable sources are sources that are not estimable. To modify these values click in the edit boxes and edit with keyboard entry.
- Ratio of Residual to Its Standard Error (RATIO R/U): This is the ratio of the signed difference between the calculated and measured concentration (the residual) divided by the uncertainty of that residual (square root of the sum of the squares of the uncertainty in the calculated and measured concentrations). The RATIO R/U specifies the number of uncertainty intervals by which the calculated and measured concentrations differ. When the absolute value of the RATIO R/U exceeds 2, the residual is significant. If it is positive, then one or more of the profiles is contributing too much to that species. If it is negative, then there

is an insufficient contribution to that species and a source may be missing. The sum of the squared  $RATIO R/U$  for fitting species divided by the degrees of freedom yields the  $CHI SQUARE$ . The highest  $RATIO R/U$  values for fitting species are the cause of high  $CHI SQUARE$  values.

- Ratio of Calculated to Measured Species ( $RATIO C/M$ ): The column labeled  $RATIO C/M$  shows the ratio of calculated to measured concentration and the standard error of that ratio for every chemical species with measured data. The ratios should be near 1.00 if the model has accurately explained the measured concentrations. Ratios which deviate from unity by more than two uncertainty intervals indicate that an incorrect set of profiles is being used to explain the measured concentrations. The  $RATIO C/M$  for most species is within the target range for each example.

## **AMBIENT DATA**

The Arizona Department of Environmental Quality has maintained a particle sampling network in Maricopa County for many years. The collection of fine particle ( $PM_{2.5}$ ) samples began in October 1994. Currently, 24-hour  $PM_{2.5}$  samples are collected on Teflon filters every sixth day at five sites. All filters are weighed to determine the  $PM_{2.5}$  mass concentrations and an optical measurement is used to determine light absorption ( $b_{ab}$ ) by fine particles. At three sites, both Teflon and quartz  $PM_{2.5}$  filter samples are collected every sixth day from 0500 to 1100 MST and 24-hour quartz filter samples are also collected. The  $PM_{2.5}$  mass and  $b_{ab}$  are

measured for all Teflon filters. Chemical analyses are performed on sets of filters collected on seven or eight days each calendar quarter. None of the filter samples collected during October 1994 were chemically analyzed. The chemical data processed by Hurwitt and Richards (1998) for the period November 1994 through September 1995 were used in the CMB analysis for the MAG Brown Cloud Study. Data supplied by ADEQ were used by Hurwitt and Richards to calculate filter sample air volumes, and these were combined with laboratory analytical results provided by DRI to calculate ambient concentrations. Quartz filters were analyzed by ion chromatography for nitrate, sulfate, and chloride; by colorimetry for ammonium ion; by atomic absorption spectroscopy for soluble potassium; and by Thermo Optical Reflectance (TOR) for organic and elemental carbon. Teflon filters were analyzed by x-ray fluorescence for elements. The CMB model was applied to 28 and 22 sets of 6-hour Teflon and quartz filters from Tempe and ASU West, respectively, and 25 and 26 sets of 6-hour and 24-hour Teflon and quartz filters, respectively, from the Phoenix Super Site.

During 1994-1996, ADEQ also conducted ambient air monitoring for hazardous air pollutants in several representative urban and rural areas of Arizona (Zielinska et al., 1998a). As part of this monitoring, semi-volatile and particulate PAHs were collected on a sampling train consisting of a Teflon-impregnated glass fiber filter followed by a PUF/XAD cartridge. Following extraction, samples were analyzed by capillary gas chromatograph with mass spectrometric detection (GC-MS). Sampling media were prepared and analyzed at the Desert Research Institute using the same procedures utilized in NFRAQS. Twelve of the 24-hour PAH samples were collected at

the Phoenix Super Site concurrently with the PM<sub>2.5</sub> samples during the period November 1994 to March 1995. The PAH data from these samples were added to the corresponding conventional PM speciation. Methoxylated phenols, hopanes, steranes, lactones, and sterols were not measured in the HAPS monitoring program.

## SOURCE PROFILES

Source profiles from NFRAQS, Phoenix Urban Haze Study, and the Phoenix I&M study were evaluated for use in this study. The NFRAQS and Phoenix I&M profiles included both profiles with only conventional species and with conventional plus PAH species. The profiles from the Phoenix Urban Haze Study consist of conventional species only. Chemical abundances in each emissions source are expressed as the fraction of emitted PM<sub>2.5</sub> mass. Both particle-phase and gas-phase emissions are normalized to the PM<sub>2.5</sub> mass. The chemical species that were measured and used in the source composition profiles are listed in **Table 1** along with their measurement methods and species mnemonics used in the CMB model. **Table 2** provides a brief description of the source profiles. Tables 2a and 2b contain a complete listing of the fractional abundances for individual and composite profiles with conventional species plus PAHs and conventional species only, respectively.

Reconstructed PM<sub>2.5</sub> mass was used for normalization (i.e., geological [1.89×aluminum + 2.14×silicon + 1.4×calcium + 1.43×iron] + sum of particulate speciated organic compounds + unspciated organics [(1.2×organic carbon) – sum of particulate speciated organic compounds] + elemental carbon + sulfate + nitrate + ammonium + road salt [1.65×chlorine]) with one-sigma analytical

errors for individual profiles (Chow et al., 1998). These adjustments account for unmeasured oxygen and hydrogen in geological and organic carbon compounds. The numerators in the source profiles are the measured values without adjustments. Uncertainties in the composite profiles are the larger of either the one-sigma variation in fractional abundances among members of the composite or the propagated root mean squares of the analytical one-sigma uncertainties. Reconstructed mass was used because it often differed significantly from measured mass in source samples.

Semi-volatile organic compounds are distributed in both gas and particle phases by varying amounts, and the actual phase distributions depend on environmental conditions, especially temperature. Particle-phase organic compounds include PAHs and other organic compounds with gas chromatographic retention times equal to or greater than that of phenanthrene. Changing this particle/gas division has little effect on reconstructed mass over a fairly large range of volatility because the sum of quantified organic compounds is typically a small fraction of the total organic carbon. Abundances of gas-phase organics, carbon monoxide, hydrocarbons, and nitrogen oxides are included in the profiles and are also expressed as weight fractions of reconstructed PM<sub>2.5</sub> mass.

### Profiles From NFRAQS

Source characterization studies that were conducted as part of NFRAQS include sampling by the Colorado Department of Public Health and Environment (CDPHE) for light-duty vehicles (including smokers, normal and high PM emitters, and diesels) and by the Colorado School of Mines (CSM) Colorado Institute for Fuels and High Altitude Engine Research (CIFER) for

heavy-duty diesel vehicles (Graboski et al., 1998). The CDPHE and the U.S. Environmental Protection Agency (EPA) tested (FTP and IM-240 test cycles) approximately 190 in-use light-duty vehicles in the Denver area with the assistance of General Motors R&D Center (GMR&D) and Colorado State University (Cadle et al., 1997). Testing was conducted in August-September 1996 and in January-February 1997 to examine the impact of temperature on PM<sub>2.5</sub> mass emissions and chemical source profiles. CSM tested (State I&M idle test, EPA heavy-duty transient cycle, New York arterial cycle, and central business cycle for buses) 16 vehicles in March-June 1997. Samples collected by GMR&D and CSM were analyzed at DRI in accordance with the analytical methods that were used for the NFRAQS ambient samples and source characterization tests performed by DRI for residential wood combustion and for commercial meat cooking (Zielinska et al., 1998b).

Individual samples were grouped to form composite profiles appropriate for CMB source apportionment. Correlations of chemical groups and individual species with total PM<sub>2.5</sub> mass, organic carbon, elemental carbon, carbon monoxide, hydrocarbons, and nitrogen oxides (if available) were examined to identify which species varied within and between source categories. Species showing high correlation within a category, and poor correlations between categories were considered potential “markers” for a category. Fractional abundances for potential marker species were compared among individual source profiles to determine if the abundances were similar for a particular source type. Individual samples were grouped based on the similarity and differences of abundances for these markers. Composite profiles were determined for subsets of samples by calculating average and standard deviations

for species groups and individual marker species. Variations in source attributions that result from the use of each individual NFRAQS profile within composite groups were evaluated in a series of CMB sensitivity tests, and are summarized in Fujita et al. (1998).

### **Source Profiles From the Phoenix Urban Haze Study**

Composite source profiles for receptor modeling were constructed from samples taken at the S. Seventh St. Inspection and Maintenance (I&M) facility and from the roadside samples. The I&M samples were grouped into two categories: 1) diesel-powered vehicles (sampled from the exhaust of Lane 5 of the I&M facility) and 2) gasoline-powered vehicles (sampled from the exhaust of Lanes 1 to 4 of the I&M facility). A pure heavy-duty diesel profile (PHDIES) was constructed from the species averages and standard deviations of eight samples taken from Lane 5 (Sample IDs PDYD01, PDYD02, PDYD03, PDYD05, PDYD07, PDYD06, PDYD15, PDYD16, PDYD19) which were evaluated to be representative of the overall set of tests. A pure gasoline-powered vehicle profile (PHAUTO) was constructed from the species averages and standard deviations of nine samples taken from Lanes 1 to 4 (Sample IDs PDMX02, PDMX03, PDMX04, PDMX05, PDMX06, PDMX07, PDMX09, PDMX10, PDMX12). Other combinations of individual samples might be constructed on these or future samples based on the similarities of vehicle type mixtures contributing to each sample.

Forty-five soil and road dust samples were collected during the Phoenix Urban Haze Study. Thirty-six of these samples were resuspended into PM<sub>2.5</sub> and PM<sub>10</sub> size fractions and chemically analyzed, and 32 of

these were used to derive composite source profiles for geological material. The final composites were intended to represent: 1) construction, 2) paved road dust, 3) unpaved road dust, 4) bare agricultural soil, 5) overgrown agricultural soil, and 6) exposed desert soil.

It was suspected that pollutants could be transported into the urban area from distant sources such as coal-fired power plants and nonferrous copper smelters. The three non-urban sampling sites were selected to evaluate the non-urban source contributions. In addition to these sites, ambient PM<sub>2.5</sub> samples were collected at the General Motors (GM) Proving Grounds, which is normally upwind of the Phoenix urban area, from 0600 to 1200 MST for six days every week during the study. This period almost always experiences easterly to southeasterly transport winds. Wind speed and direction measured at the GM site and at the South Mountain site were examined for periods which might be associated with extensive transport times. Forty-six samples from the GM site were analyzed for all chemical species, and these species concentrations were submitted to the Principal Components Analysis (PCA) receptor model. PCA is often used with a time series of PM<sub>2.5</sub> or PM<sub>10</sub> chemical concentrations to aid in the identification of contributing pollution sources. In order to test whether or not this background aerosol could be detected at the urban sampling sites, two background profiles were constructed from sub-sets of the GM Proving Grounds data. The "smelter" background profile was determined by averaging the fractional compositions of the four samples identified above in which a smelter contribution had been detected. For comparison, a "nonsmelter" background profile was constructed by averaging the individual profiles of 28 samples which exhibited concentrations less than 0.003

µg/m<sup>3</sup>, the typical detection limit for this species. Nitrate, sulfate, sulfur dioxide, ammonium, organic carbon, and elemental carbon concentrations are similar in the smelter and nonsmelter background profiles. In contrast, arsenic (As) and lead (Pb) are 25 and 3 times higher, respectively, in the smelter background profile as compared to the nonsmelter background profile. Lanthanum (La) is also a factor of 2 higher in the smelter background profile as compared to the nonsmelter background profile.

### **Source Profiles From the Phoenix Inspection & Maintenance Station Study**

Arizona is one of the few states that tests heavy-duty diesel vehicles in the framework of their I&M program. An I&M station in Phoenix was used by Zielinska et al. (1997) to identify and quantify organic and inorganic components in the exhaust of diesel- and gasoline- powered vehicles from a representative population of gasoline-powered and diesel-powered vehicles. Sampling was carried out on December 4-6, 1995 from 0800 to 2000 MST. The I&M test for diesel vehicles measured steady-state exhaust opacity while operating under load. Single-axle diesel vehicles less than 26,000 lbs gross vehicle weight (GVW) were operated on a dynamometer at a constant speed. Tandem-axle vehicles and those with GVW over 26,000 lbs were operated at wide-open throttle at 80 percent of the maximum rpm (revolutions per minute) and then lugged down to 20 percent of the maximum rpm in the same gear. All gasoline-powered vehicles less than 8500 lbs GVW were tested using a loaded-mode dynamometer test. Vehicles of model year 1981 or newer were given the IM240 test. Since this test requires hot stabilized operation, the vehicles were run at a steady

state for about 2 min prior to the test. The IM240 test includes starting up the warm engine, accelerating up to the maximum 50 mph, two stops without stopping the engine and one final stop with stopping the engine. The average speed is 30 mph and 2.0 miles are driven during the test. Vehicles 1980 or older are given the loaded dynamometer test plus an idle test.

Each diesel- and gasoline-engine emission sample is a composite of exhaust from approximately 15 heavy-duty diesel trucks and about 20 gasoline-powered automobiles, respectively. Each set included a canister sample for volatile C2 to C11 hydrocarbons; a Tenax sample for C8 to C20 hydrocarbons; PM<sub>2.5</sub> particulate samples on Teflon and quartz filters for ions, elements, and organic and elemental carbon; and a PM<sub>2.5</sub> Teflon-impregnated glass fiber filter followed by a PUF/XAD cartridge for particulate and semi-volatile PAHs. The sampling and analytical procedures used are comparable to those used in NFRAQS. Individual and composite profiles were derived from the original raw data according to the mass normalization procedure used in NFRAQS. CMB8 was applied to the twelve ambient samples from the Phoenix Super Site with data for both conventional species and PAHs using the profiles derived from the Phoenix I&M test data. These profiles generally gave poor model performance and consistently resulted in underestimation of ambient elemental carbon. This result suggests that the test procedure used at the I&M station does not produce exhaust compositions that are representative of on-road diesel and gasoline exhaust emissions. The absence of cold-starts and hard accelerations in the IM240 test and variable loads in the heavy-duty trucks test could be possible explanations.

## CMB RESULTS

Apportionment of the ambient data included 12 apportionments using the “extended” data sets that include the PAHs measured at the Phoenix Super Site. The CMB was also applied to 101 24-hour average “conventional” data sets from three sites that included the elemental, ionic, and elemental/organic carbon concentrations that are most commonly measured on source and receptor samples. This allowed for comparison of source contribution estimates derived from the “extended” and “conventional” CMB calculations for the data from the Phoenix Super Site. The default source profiles used for the “extended” CMB are NVNSP (gasoline exhaust – cold start), NVNSP2 (gasoline exhaust – hot stabilized), NVSM (gasoline exhaust – high particle emitter), NWHD (diesel exhaust), AMSUL (ammonium sulfate), AMNIT (ammonium nitrate), and PHPVRD (fine – Phoenix paved road dust). The default source profiles for the “conventional” CMB are NWLD\_W (composite of NVNSP, NVNSP2, and NVSM), NWHD (diesel exhaust), AMSUL (ammonium sulfate), AMNIT (ammonium nitrate), and PHPVRD (fine – Phoenix paved road dust).

**Tables 3 and 4** show the average source contributions to PM<sub>2.5</sub> mass, total carbon, organic carbon, and elemental carbon for the “extended” and “conventional” CMB, respectively. Source contribution estimates (SCE) are undetectable when the SCE is less than its standard error. Two or three times the standard error may be taken as the upper limit of the SCE in this case. The chi square ( $\chi^2$ ), R<sup>2</sup>, and percent mass are goodness of fit measures for the least square calculation. For these apportionments, R<sup>2</sup> typically exceeded 0.9 and  $\chi^2$  values were mostly between 0.3 and 0.5. The CMBs were run with the automatic source elimination option

turned off. Percent of mass attributed was generally within one standard error of 100 percent. The unexplained source contributions are derived from the difference between reconstructed mass and sum of the absolute source contributions; and the percent contributions are normalized to the sum of source contributions including non-negative unexplained contributions. The average percent unexplained includes only non-negative unexplained contributions.

Of the 104 valid samples, three samples with  $\chi^2$  values greater than 2.0 were removed from the average contributions. These samples generally have low concentrations, which result in more collinearity among similar source profiles. The average absolute contributions in  $\mu\text{g}/\text{m}^3$  include zero values for samples in which a particular source was not detected. Uncertainty estimates for average absolute source contributions and relative source contributions (i.e., percentage contributions) are root mean squares of the individual one-sigma error propagation from the CMB model and reflect random measurement errors in both ambient and source data. Uncertainty estimates for average relative source contributions are also given in standard errors of the mean percent contributions, which reflect the sample-to-sample variations in source contributions.

The standard errors of the mean contributions are given first in the following discussion along with the propagated source and ambient measurement errors in parentheses. The results of the extended CMB in Table 3 show that, on average, light-duty gasoline vehicle exhaust accounts for  $51.5 \pm 2.3$  percent (19.2 percent) of the ambient  $\text{PM}_{2.5}$ ,  $74.5 \pm 3.2$  percent (2.3 percent) of TC,  $88.5 \pm 1.0$  percent (6.8 percent) of OC, and  $53.8 \pm 6.1$  percent (10.4

percent) of EC at the Phoenix Super Site during the period November 1994 to March 1995. Diesel exhaust contributes  $15.1 \pm 2.3$  percent (15.6 percent) of  $\text{PM}_{2.5}$ ,  $23.2 \pm 3.4$  percent (1.0 percent) of TC,  $8.0 \pm 1.2$  percent (3.7 percent) of OC, and  $45.6 \pm 6.2$  percent (6.8 percent) of EC. Contributions of wood combustion and meat cooking could not be apportioned because suitable marker species were not measured. Consequently, the attribution for vehicle exhaust should be considered upper limits. The corresponding contributions of road and geologic dust are  $10.6 \pm 1.5$  percent (1.9 percent),  $2.3 \pm 0.3$  percent (1.0 percent),  $3.5 \pm 0.5$  percent (1.6 percent), and  $0.5 \pm 0.1$  percent (0.3 percent). Ammonium nitrate and ammonium sulfate account for  $12.7 \pm 3.0$  percent (1.5 percent), and  $9.8 \pm 1.6$  percent (1.2 percent), respectively, of the ambient  $\text{PM}_{2.5}$  at the Phoenix Super Site. The sums of these contributions leaves essentially zero residual mass.

The 24-hour average ambient concentrations of carbonaceous particles account for 67 percent of  $\text{PM}_{2.5}$  at the Phoenix Super Site during November 1994 to March 1995. The results of the extended CMB in Table 3 show that the major contributors to  $\text{PM}_{2.5}$  carbon are LDGV high emitters, LDGV cold start emissions, and diesel exhaust. The profile for LDGV cold start is derived from the difference between Phase 1 of the Federal Test Procedure (FTP) cycle (i.e., 505-second, 3.6 mile drive from a cold start) and Phase 3 (i.e., same as Phase 1 after a 10-min shutdown). Based upon the relative emission rates, contributions within the vehicle fleet to cold start emissions are likely skewed with older vehicles contributing a disproportionate fraction of the emissions from this source. Motor vehicle exhaust accounts for about 98 percent of the  $\text{PM}_{2.5}$  carbon (in elemental carbon and organic compounds) at Phoenix Super Site. LDGV cold start emissions,

high particle emitters, and diesel exhaust are the largest components of the mobile source contribution, with average 24-hour contributions of  $39.5 \pm 4.9$  percent,  $36.9 \pm 2.7$  percent, and  $23.2 \pm 3.4$  percent, respectively. Non-smoking, LDGV hot stabilized emissions were undetectable. Attachment I includes a table with more detailed information from the extended CMB analysis.

Tables 4a through 4d show the apportionments obtained from the conventional CMB analysis for  $PM_{2.5}$ , TC, OC, and EC, respectively. In the conventional approach, apportionments of carbon sources are limited to two or three broad categories. LDGV cold starts, non-smoking LDGV hot stabilized exhaust, and LDGV high particle emitters were combined into one composite category called LDGV exhaust. The results of the extended CMB were used in NFRAQS to apply weighting factors to the three individual profiles in the composite profile. Meat cooking, softwood combustion, and hardwood combustion were similarly combined in composite profiles called meat and wood combustion. The same diesel profile was used in both CMB analyses. The mobile source contributions to  $PM_{2.5}$  are about 10 percent higher for the 6-hour morning samples at all three sites (i.e., Phoenix Super Site, Tempe, and ASU West) compared to the 24-hour samples from Phoenix Super Site. The contributions of fine dust ranged from 8 to 15 percent at the three sites.

It is clear from Tables 4a through 4d that gasoline exhaust and diesel exhaust are collinear with one another (i.e., have nearly the same composition) if only conventional species are used in the profiles. This causes the relative apportionments to gasoline and diesel exhaust from the conventional CMB to be unreliable, but does not degrade the

sum of the apportionments from these two sources. The combined contributions of gasoline and diesel exhaust to  $PM_{2.5}$  are about 60-65 percent at Phoenix Super Site for both conventional CMB and extended CMB. There are no apparent seasonal trends in apportionments. In some cases, it was necessary to include the ambient background with smelter to account for excess arsenic, lead, and Lanthanum. This contribution is not strictly attributable to emissions from smelters. This background profile also contains secondary sulfate and nitrate in addition to other particulate matter found in regional background samples. Attachment II includes a table with more detailed information from the conventional CMB analysis.

## DISCUSSION

The present study focused on measurement of  $PM_{2.5}$  (fine particles), which contribute to “brown clouds.” The data showed that in the urban areas of Maricopa County, particulate carbon species (elemental carbon plus organic compounds) were the largest contributor, accounting for nearly two-thirds of the  $PM_{2.5}$ . Particulate ammonium nitrate was the second-most important species, with ammonium sulfate and dust next in abundance.

The source apportionment analysis for the Maricopa County area shows that exhaust emissions from mobile sources (cars, trucks, construction equipment, and locomotives) produced about 65 percent of the  $PM_{2.5}$ . Including road and geologic dust with the exhaust contributions increases the mobile source-related contribution to as much as 75 percent of the  $PM_{2.5}$ . Moreover,  $PM_{2.5}$  emissions from gasoline-fueled engines were three times more important than those coming from diesel-fueled engines. Fine particles produced by road

dust, construction, and wind-blown sand, contributed about 10 to 15 percent of the  $PM_{2.5}$ . Wood burning emissions and meat cooking could not be apportioned with the data available.

It is useful to compare the above results for Maricopa County with those found in the metropolitan Denver area during NFRAQS because many more trace organic compounds were measured during NFRAQS and were used in the CMB calculations. Although the fraction of carbonaceous particles in  $PM_{2.5}$  is greater in Maricopa County, the relative contributions of mobile sources to  $PM_{2.5}$  carbon are nearly identical in the two regions.  $PM_{2.5}$  emissions from gasoline-fueled engines in Denver were three times the  $PM_{2.5}$  emissions produced by diesel-fueled engines, compared with current emission estimates for the Denver area in which diesel engines are projected to produce more emissions than gasoline engines. High-emitting or smoking vehicles, which comprise a small fraction of the in-use vehicle fleet, produced nearly one-half of the gasoline engine  $PM_{2.5}$  exhaust. The diesel engine  $PM_{2.5}$  exhaust comes from trucks, locomotives, construction equipment, and other sources. Fine particles from road debris and dust, construction activities, and wind-blown sand contributed only 16 percent of the total  $PM_{2.5}$ , an amount much lower than current emission estimates for the Denver area. All of these conclusions, derived for Northern Front Range area, are also applicable to Maricopa County.

It was possible to include meat cooking and wood combustion in the NFRAQS source apportionments because a greater number of organic compounds was measured. It was found that these sources were typically minor contributors to  $PM_{2.5}$ , but there were some samples for which their contribution exceeded 10 percent of the

$PM_{2.5}$ . Omitting these species from the CMB calculations for Maricopa County introduces a small, but not negligible, error. The NFRAQS area has a number of coal-fired power plants, and primary particles (fly ash) from them contributed approximately 2 percent of the  $PM_{2.5}$ . There are no coal-fired power plants in Maricopa County.

An underestimation of particulate emissions from gasoline-fueled engines in the emission inventories is plausible given the current development of motor vehicle emission factor models. Particulate emission factors vary in PART 5 only by vehicle model year groups. Emission rates for pre-1981 noncatalyst and post-1980 catalyst vehicles are 30 and 4.3 mg/mile of carbon, respectively. In contrast, the average particulate emission rates from the NFRAQS vehicle emissions tests were 82.6 mg/mile for pre-1980 light-duty gasoline vehicles and 24.9 to 48.2 mg/mile for post-1980 vehicles. The corresponding phase 1 (“cold”) emission rates were 290 mg/mile for pre-1980 light-duty gasoline vehicles and 81.3 to 159 mg/mile for post-1980 vehicles. Smoking vehicles emitted an average of 1179 mg/mile in phase 1 and 434 mg/mile in the composite source profile for the Federal Test Procedure (FTP). Because of their substantially higher emission rates, smokers, marginal smokers/high emitters, and “puffers” (older vehicles in cold start mode) should account for a disproportionate fraction of particulate emissions relative to their numbers. Yet, current emission factor models used to calculate data for emission inventories do not include their contributions. The plausibility of ambient attributions of gasoline exhaust to subcategories of the vehicle fleet depends on one’s assumptions regarding the contributions of a relatively small fraction of the vehicle fleet and the average particulate emission rates of normal emitters in hot stabilized operation.

Table 1  
CMB Species Selections

Species	Method	Mnemonic	CMB Input
Mass	Grav	MSGC	
chloride	IC	CLIC	*
nitrate	IC	N3IC	*
sulfate	IC	S4IC	*
ammonium	AC	N4CC	*
soluble potassium	AA	KPAC	*
total carbon	TOR	TCTC	
organic carbon	TOR	OCTC	*
elemental carbon	TOR	ECTC	*
Sodium	XRF	NAXC	*
Magnesium	XRF	MGXC	*
Aluminum	XRF	ALXC	*
Silicon	XRF	SIXC	*
Phosphorus	XRF	PHXC	*
Sulfur	XRF	SUXC	
Chlorine	XRF	CLXC	*
Potassium	XRF	KPXC	
Calcium	XRF	CAXC	*
Titanium	XRF	TIXC	*
Vanadium	XRF	VAXC	*
Chromium	XRF	CRXC	*
Manganese	XRF	MNXC	*
Iron	XRF	FEXC	*
Cobalt	XRF	COXC	
Nickel	XRF	NIXC	*
Copper	XRF	CUXC	*
Zinc	XRF	ZNXC	
Gallium	XRF	GAXC	
Arsenic	XRF	ASXC	*
Selenium	XRF	SEXC	*
Bromine	XRF	BRXC	*
Rubidium	XRF	RBXC	*
Strontium	XRF	SRXC	*
Yttrium	XRF	YTXC	
Zirconium	XRF	ZRXC	*
Molybdenum	XRF	MOXC	
Palladium	XRF	PDXC	
Silver	XRF	AGXC	
Cadmium	XRF	CDXC	
Indium	XRF	INXC	
Tin	XRF	SNXC	
Antimony	XRF	SBXC	
Barium	XRF	BAXC	
Lanthanum	XRF	LAXC	
Gold	XRF	AUXC	
Mercury	XRF	HGXC	*
Thallium	XRF	TLXC	
Lead	XRF	PBXC	*
Uranium	XRF	URXC	
Naphthalene	GC/MS	NAPHTH	
2-menaphthalene	GC/MS	MNAPH2	
1-menaphthalene	GC/MS	MNAPH1	
2,6+2,7-dimenaphthalene	GC/MS	DMN267	
1,7+1,3+1,6-dimenaphthalene	GC/MS	DM1367	
2.3+1.4+1.5-dimenaphthalene	GC/MS	D14523	

Table 1 (continued)  
NFRAQS CMB Species Selections

Species	Method	Mnemonic	CMB Input
1,2-dimenaphthalene	GC/MS	DMN12	
1,8-dimenaphthalene	GC/MS	DMN18	
Biphenyl	GC/MS	BIPHEN	
2-Methylbiphenyl	GC/MS	M_2BPH	
3-Methylbiphenyl	GC/MS	M_3BPH	
4-Methylbiphenyl	GC/MS	M_4BPH	
A-Trimethylnaphthalene	GC/MS	ATMNAP	
1-Ethyl-2-methylnaphthalene	GC/MS	EM_12N	
B-Trimethylnaphthalene	GC/MS	BTMNAP	
C-Trimethylnaphthalene	GC/MS	CTMNAP	
2-Ethyl-1-methylnaphthalene	GC/MS	EM_21N	
E-Trimethylnaphthalene	GC/MS	ETMNAP	
F-Trimethylnaphthalene	GC/MS	FTMNAP	
G-Trimethylnaphthalene	GC/MS	GTMNAP	
H-Trimethylnaphthalene	GC/MS	HTMNAP	
1,2,8-Trimethylnaphthalene	GC/MS	TM128N	
Acenaphthylene	GC/MS	ACNAPY	
Acenaphthene	GC/MS	ACNAPE	
Phenanthrene	GC/MS	PHENAN	*
Fluorene	GC/MS	FLUORE	*
A-Methylfluorene	GC/MS	A_MFLU	*
1-Methylfluorene	GC/MS	M_1FLU	*
B-Methylfluorene	GC/MS	B_MFLU	*
C-Methylfluorene	GC/MS	C_MFLU	*
A-Methylphenanthrene	GC/MS	A_MPHT	*
2-Methylphenanthrene	GC/MS	M_2PHT	*
B-Methylphenanthrene	GC/MS	B_MPHT	*
C-Methylphenanthrene	GC/MS	C_MPHT	*
1-Methylphenanthrene	GC/MS	M_1PHT	*
3,6-Dimethylphenanthrene	GC/MS	DM36PH	*
A-Dimethylphenanthrene	GC/MS	A_DMPH	*
B-Dimethylphenanthrene	GC/MS	B_DMPH	*
C-Dimethylphenanthrene	GC/MS	C_DMPH	*
1,7-Dimethylphenanthrene	GC/MS	DM17PH	*
D-Dimethylphenanthrene	GC/MS	D_DMPH	*
E-Dimethylphenanthrene	GC/MS	E_DMPH	*
Anthracene	GC/MS	ANTHRA	*
9-Methylanthracene	GC/MS	M_9ANT	*
Fluoranthene	GC/MS	FLUORA	*
Pyrene	GC/MS	PYRENE	*
A-Methylpyrene	GC/MS	A_MPYR	*
B-Methylpyrene	GC/MS	B_MPYR	*
C-Methylpyrene	GC/MS	C_MPYR	*
D-Methylpyrene	GC/MS	D_MPYR	*
E-Methylpyrene	GC/MS	E_MPYR	*
F-Methylpyrene	GC/MS	F_MPYR	*
Retene	GC/MS	RETENE	*
Benzonaphthothiophene	GC/MS	BNTIOP	*
Benz(a)anthracene	GC/MS	BAANTH	*
7-Methylbenz[a]anthracene	GC/MS	M_7BAA	*
Chrysene	GC/MS	CHRYSN	*
Benzo(b+j+k)FL	GC/MS	BBJKFL	*
BeP	GC/MS	BEPYRN	*
BaP	GC/MS	BAPYRN	*

Table 1 (continued)  
 NFRAQS CMB Species Selections

Species	Method	Mnemonic	CMB Input
7-Methylbenzo[a]pyrene	GC/MS	M_7BPY	*
Indeno[123-cd]Pyrene	GC/MS	INCDPY	*
Dibenz(ah+ac)anthracene	GC/MS	DBANTH	*
Benzo(b)chrysene	GC/MS	BBCHRN	*
Benzo(ghi)Perylene	GC/MS	BGHIPE	*
Coronene	GC/MS	CORONE	*

Table 2  
Descriptions of Source Composition Profiles

Mnemonic	Size	Project	Source Type	Species	Description
NVNSP	F	NFRAQS	Motor Vehicle	Conv & PAH	winter, light-duty, gasoline, 1-3 "cold start", L2, ML1, M1,M2,M3,H1
NVNSP2	F	NFRAQS	Motor Vehicle	Conv & PAH	winter, light-duty, gasoline, 2, L1P2,L2P2, ML1P2, M1P2,M2P2,M3P2,H1P2,H2P2
NVSM	F	NFRAQS	Motor Vehicle	Conv & PAH	winter, light-duty, gasoline, 1, 2, and 3, S2P1,S2P2,S2P3,S3P1,S3P2,S3P3
NWLD_W	F	NFRAQS	Motor Vehicle	Conventional	Composite of NVNSP, NVNSP2, and NVSM
NWHD	F	NFRAQS	Motor Vehicle	Conv & PAH	winter, heavy-duty, diesel, all, Runs 2-15
NMc	F	NFRAQS	Meat Cooking	Conv & PAH	composite of NMAHA, NMCH, NMCCa, and NMCK
NWFSc	F	NFRAQS	Vegetative Burning	Conv & PAH	Fireplace burning soft woods
NWSHc2	F	NFRAQS	Vegetative Burning	Conv & PAH	Fireplace burning hard woods
NWW_W	F	NFRAQS	Vegetative Burning	Conventional	Composite of NWFSc and NWSHc2
NWMW_W	F	NFRAQS	Veg Burn & Meat Cooking	Conventional	Composite of NWFSc, NWSHc3, and NMc
NRDC	F	NFRAQS	Geological	Conv & PAH	Composite roaddust, NRD01 to 05
AMSUL	F	Scenic Denver	Calculated	Conv & PAH	Secondary ammonium sulfate
AMNIT	F	Scenic Denver	Calculated	Conv & PAH	Secondary ammonium nitrate
PCHCLC1	F	Scenic Denver	Power Station	Conv & PAH	Composite, PCHKC03 & PCHKC04, boilers burning coal.
phautoc	F	Phoenix I&M	Motor vehicle, auto	Conv & PAH	Composite of Auto Runs # 5, 6, and 7
phdiesc	F	Phoenix I&M	Motor vehicle, diesel	Conv & PAH	Composite of Diesel Runs # 3, 5, and 6
phauto3	F	Phoenix I&M	Motor vehicle, auto	Conv & PAH	Auto Run 3 - Model year 1972 to 1995; 2 high HC emitters; all pass, 19 vehicles
phauto4	F	Phoenix I&M	Motor vehicle, auto	Conv & PAH	Auto Run 4 - Model year 1967 to 1995; no high HC (>100 ppm) emitters, 2 cars ~ 50 ppm HC; all pass, 26 vehicles
phauto5	F	Phoenix I&M	Motor vehicle, auto	Conv & PAH	Auto Run 5 - Model year 1976 to 1995; 1 high HC (> 100 ppm) emitter, 3 cars >50 ppm; 1 fail, 17 vehicles
phauto6	F	Phoenix I&M	Motor vehicle, auto	Conv & PAH	Auto Run 6 - Model year 1968 to 1993; 2 high HC (> 100 ppm) emitters, 2 cars>50 ppm; 2 fail, 15 vehicles
phauto7	F	Phoenix I&M	Motor vehicle, auto	Conv & PAH	Auto Run 7 - Model year 1969 to 1995; 2 high HC (> 100 ppm) emitters, 3 cars>50 ppm ; all pass, 26 vehicles
phdies2	F	Phoenix I&M	Motor vehicle, diesel	Conv & PAH	Diesel Run 2 - All pass; two (1978 and 1983) 6% opacity, 15 vehicles
phdies3	F	Phoenix I&M	Motor vehicle, diesel	Conv & PAH	Diesel Run 3 - All pass; one (1989) 4.3% opacity, 12 vehicles
phdies4	F	Phoenix I&M	Motor vehicle, diesel	Conv & PAH	Diesel Run 4 - All pass; one (1984) 7.2%, one (1986) 6.5% opacity, 13 vehicles
phdies5	F	Phoenix I&M	Motor vehicle, diesel	Conv & PAH	Diesel Run 5 - All pass; one (1989) 8.2%, heavy white smoke; one (1977) 8.1% and one (1994) 15% opacity, 15 vehicles
phdies6	F	Phoenix I&M	Motor vehicle, diesel	Conv & PAH	Diesel Run 6 - One fails (1978) 29% opacity; one (1990) 7.8% opacity, 17 vehicles
phdies7	F	Phoenix I&M	Motor vehicle, diesel	Conv & PAH	Diesel Run 7 - All pass; two (1982 & 1986) 11%; one (1993) 10% opacity, 12 vehicles
phdies8	F	Phoenix I&M	Motor vehicle, diesel	Conv & PAH	Diesel Run 8
phdies9	F	Phoenix I&M	Motor vehicle, diesel	Conv & PAH	Diesel Run 9 - All pass; one (1989) 13.4% opacity, 15 vehicles
PHCONSTR	F	PHOENIX	GEOLOGICAL	Conventional	Phoenix Construction Area Soil; Composite, 2 bulk samples collected on 1/19/90
PHCONSTR	T	PHOENIX	GEOLOGICAL	Conventional	Phoenix Construction Area Soil; Composite, 2 bulk samples collected on 1/19/90
PHPVRDCB	F	PHOENIX	GEOLOGICAL	Conventional	Phoenix Paved Road Dust; Composite, 2 vacumm samples collected on 1/19/90
PHPVRDCB	T	PHOENIX	GEOLOGICAL	Conventional	Phoenix Paved Road Dust; Composite, 2 vacumm samples collected on 1/19/90
PHPVRD	F	PHOENIX	GEOLOGICAL	Conventional	Phoenix paved road dust; Composite, 8 vacumm samples collected between 1/20/90 to 1/26/90
PHPVRD	T	PHOENIX	GEOLOGICAL	Conventional	Phoenix paved road dust; Composite, 8 vacumm samples collected between 1/20/90 to 1/26/90
PHUPRD1	F	PHOENIX	GEOLOGICAL	Conventional	Phoenix unpaved road dust W/Hi Calcium; Composite, 2 bulk samples collected on 1/20/90
PHUPRD1	T	PHOENIX	GEOLOGICAL	Conventional	Phoenix unpaved road dust W/Hi Calcium; Composite, 2 bulk samples collected on 1/20/90
PHUPRD2	F	PHOENIX	GEOLOGICAL	Conventional	Phoenix unpaved road dust W/Lo Calcium; Composite, 2 bulk samples collected on 1/24/90
PHUPRD2	T	PHOENIX	GEOLOGICAL	Conventional	Phoenix unpaved road dust W/Lo Calcium; Composite, 2 bulk samples collected on 1/24/90
PHBAREAG	F	PHOENIX	GEOLOGICAL	Conventional	Phoenix agricultural soil from bare field; Composite, 9 bulk samples collected on 1/21/90
PHBAREAG	T	PHOENIX	GEOLOGICAL	Conventional	Phoenix agricultural soil from bare field; Composite, 9 bulk samples collected on 1/21/90
PHDSSOIL	F	PHOENIX	GEOLOGICAL	Conventional	Phoenix desert soil; Composite, 4 bulk samples collected between 1/20/90 to 1/26/90
PHDSSOIL	T	PHOENIX	GEOLOGICAL	Conventional	Phoenix desert soil; Composite, 4 bulk samples collected between 1/20/90 to 1/26/90
PHAUTO	F	PHOENIX	MOTOR VEHICLE	Conventional	Phoenix motor vehicle: 100% gasoline; Composite, 9 samples collected on 1/03 to 1/05/90
PHDIES	F	PHOENIX	MOTOR VEHICLE	Conventional	Phoenix motor vehicle: 100% diesel; Composite, 8 samples collected on 12/28 to 12/29/90
PHRD	F	PHOENIX	MOTOR VEHICLE	Conventional	Phoenix motor vehicle; composite, 10 roadside samples average after background corrections

**Table 2a**  
**Source Composition Profiles Consisting of Conventional Species and PAHs**

Profile	NVNSP		NVNSP2		NVSM		NWHd		NM <sub>c</sub>		NWFS <sub>c</sub>	
clie	0.000325	± 0.000726	0.001406	± 0.001421	0.000271	± 0.000464	0.000414	± 0.000994	0.000461	± 0.000620	0.001247	± 0.000579
n3ic	0.001626	± 0.001539	0.001404	± 0.001666	0.002816	± 0.002457	0.001658	± 0.001438	0.000164	± 0.000672	0.001038	± 0.000680
s4ic	0.003645	± 0.014763	0.009419	± 0.006596	0.002379	± 0.001089	0.004167	± 0.004468	0.000598	± 0.000691	0.001846	± 0.000602
n4cc	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000077	± 0.000636	0.000995	± 0.000356
kpac	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.002082	± 0.002039	0.003436	± 0.000876
tctc	0.883925	± 0.076782	0.818314	± 0.053333	0.832597	± 0.033825	0.939272	± 0.037229	0.986644	± 0.078102	0.953217	± 0.314281
octc	0.459194	± 0.142555	0.567217	± 0.109640	0.770420	± 0.033579	0.189289	± 0.078860	0.964142	± 0.076978	0.617248	± 0.216149
ectc	0.424731	± 0.142284	0.251097	± 0.145596	0.062178	± 0.030366	0.749983	± 0.102669	0.022503	± 0.013199	0.335969	± 0.228149
naxc	0.000550	± 0.006767	0.001720	± 0.004236	0.000000	± 0.010000	0.001403	± 0.002203	0.000654	± 0.000887	0.000176	± 0.000469
mgxc	0.000000	± 0.001605	0.001761	± 0.001470	0.000000	± 0.010000	0.000882	± 0.000891	0.000007	± 0.000242	0.000114	± 0.000153
alxc	0.000687	± 0.001734	0.002563	± 0.002950	0.000000	± 0.010000	0.000401	± 0.000958	0.000131	± 0.000220	0.000108	± 0.000096
sixc	0.002570	± 0.004256	0.007841	± 0.005521	0.000000	± 0.010000	0.005102	± 0.001285	0.000195	± 0.000204	0.000657	± 0.000911
phxc	0.000171	± 0.003438	0.002355	± 0.001663	0.000000	± 0.010000	0.000344	± 0.000349	0.000298	± 0.000241	0.000025	± 0.000059
suxc	0.003420	± 0.009457	0.006906	± 0.004397	0.002504	± 0.000642	0.002968	± 0.001861	0.001428	± 0.000353	0.000847	± 0.000078
clxc	0.000537	± 0.001197	0.002320	± 0.002345	0.000448	± 0.000765	0.000683	± 0.001639	0.000878	± 0.000591	0.001045	± 0.000641
kpxc	0.000144	± 0.000482	0.000537	± 0.000547	0.000230	± 0.001577	0.000060	± 0.000294	0.001900	± 0.001669	0.003534	± 0.000309
caxc	0.000982	± 0.003096	0.003869	± 0.002679	0.001573	± 0.000896	0.000598	± 0.000466	0.000019	± 0.000097	0.000027	± 0.000136
tixc	0.000000	± 0.002864	0.000166	± 0.003021	0.000000	± 0.003474	0.000005	± 0.001150	0.000002	± 0.000523	0.000001	± 0.000256
vaxc	0.000000	± 0.001250	0.000112	± 0.001271	0.000000	± 0.001586	0.000012	± 0.000460	0.000002	± 0.000213	0.000000	± 0.000136
crxc	0.000119	± 0.000342	0.000529	± 0.000412	0.000004	± 0.000280	0.000000	± 0.000121	0.000001	± 0.000052	0.000000	± 0.000040
mnxc	0.000000	± 0.000288	0.000136	± 0.000357	0.000001	± 0.000196	0.000004	± 0.000090	0.000002	± 0.000040	0.000000	± 0.000022
fexc	0.005015	± 0.031091	0.010178	± 0.007952	0.000853	± 0.000245	0.000201	± 0.000226	0.000203	± 0.000393	0.000000	± 0.000041
nixc	0.000068	± 0.000190	0.000087	± 0.000229	0.000004	± 0.000070	0.000003	± 0.000058	0.000001	± 0.000027	0.000000	± 0.000013
cuxc	0.000000	± 0.000387	0.000262	± 0.000229	0.000098	± 0.000081	0.000001	± 0.000063	0.000008	± 0.000017	0.000000	± 0.000020
znxc	0.000507	± 0.004759	0.003939	± 0.003170	0.000561	± 0.001119	0.000593	± 0.000807	0.000255	± 0.000509	0.000349	± 0.000227
asxc	0.000008	± 0.000970	0.000004	± 0.000322	0.000016	± 0.000112	0.000004	± 0.000107	0.000000	± 0.000051	0.000002	± 0.000024
sexc	0.000001	± 0.000143	0.000011	± 0.000143	0.000003	± 0.000049	0.000003	± 0.000057	0.000000	± 0.000026	0.000000	± 0.000012
brxc	0.000245	± 0.000959	0.000213	± 0.000293	0.000008	± 0.000050	0.000013	± 0.000052	0.000007	± 0.000019	0.000024	± 0.000008
rbxc	0.000009	± 0.000127	0.000005	± 0.000111	0.000000	± 0.000077	0.000009	± 0.000048	0.000003	± 0.000023	0.000000	± 0.000011
srxc	0.000003	± 0.000120	0.000013	± 0.000123	0.000000	± 0.000137	0.000002	± 0.000053	0.000000	± 0.000025	0.000001	± 0.000012
zrxc	0.000015	± 0.000171	0.000003	± 0.000170	0.000006	± 0.000111	0.000000	± 0.000076	0.000000	± 0.000036	0.000000	± 0.000017
hgxc	0.000000	± 0.000328	0.000003	± 0.000330	0.000007	± 0.000142	0.000000	± 0.000128	0.000001	± 0.000059	0.000000	± 0.000027
pbxc	0.000690	± 0.003330	0.000796	± 0.000654	0.000226	± 0.000224	0.000003	± 0.000154	0.000002	± 0.000074	0.000006	± 0.000034
naphth	0.220095	± 0.206870	0.132500	± 0.133730	0.031074	± 0.007956	0.001401	± 0.001344	0.002764	± 0.002091	0.004235	± 0.001138
mnaph2	0.091002	± 0.070428	0.066444	± 0.051795	0.014145	± 0.002366	0.001640	± 0.001103	0.000203	± 0.000166	0.000895	± 0.000183
mnaph1	0.046672	± 0.034842	0.034283	± 0.029502	0.008026	± 0.001145	0.001157	± 0.000761	0.000206	± 0.000176	0.000759	± 0.000151
dmn267	0.009507	± 0.006760	0.008452	± 0.006671	0.002069	± 0.000224	0.000644	± 0.000500	0.000016	± 0.000012	0.000149	± 0.000026
dm1367	0.013677	± 0.009748	0.012329	± 0.010670	0.003408	± 0.000297	0.001106	± 0.000849	0.000035	± 0.000021	0.000513	± 0.000265
d14523	0.004379	± 0.003216	0.003933	± 0.003298	0.001257	± 0.000141	0.000335	± 0.000253	0.000030	± 0.000021	0.000116	± 0.000013
dmn12	0.001668	± 0.001279	0.001672	± 0.001329	0.000662	± 0.000071	0.000115	± 0.000094	0.000014	± 0.000015	0.000055	± 0.000022
biphen	0.003151	± 0.002476	0.003105	± 0.001963	0.000595	± 0.000188	0.000371	± 0.000229	0.000283	± 0.000224	0.000245	± 0.000066
m_2bph	0.000309	± 0.000326	0.000370	± 0.000415	0.000056	± 0.000050	0.000033	± 0.000066	0.000027	± 0.000037	0.000000	± 0.000013
m_3bph	0.002216	± 0.001708	0.002059	± 0.001271	0.000472	± 0.000129	0.000312	± 0.000266	0.000045	± 0.000022	0.000069	± 0.000024
m_4bph	0.001117	± 0.000864	0.001112	± 0.000632	0.000226	± 0.000066	0.000112	± 0.000100	0.000026	± 0.000020	0.000045	± 0.000019
atmnap	0.003236	± 0.002366	0.002928	± 0.001980	0.000852	± 0.000132	0.000281	± 0.000209	0.000013	± 0.000004	0.000099	± 0.000013

**Table 2a**  
**Source Composition Profiles Consisting of Conventional Species and PAHs (Continued)**

Profile	AMSUL	AMNIT	PCHCLC1	phautoc	phdiesc	phauto3
clie	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.003899 ± 0.004150	0.000855 ± 0.000721	0.003379 ± 0.004240
n3ic	0.000000 ± 0.000100	0.775000 ± 0.077500	0.000000 ± 0.002116	0.017786 ± 0.006751	0.002939 ± 0.002418	0.020608 ± 0.004161
s4ic	0.727000 ± 0.072700	0.000000 ± 0.000100	0.101716 ± 0.089405	0.026729 ± 0.007932	0.004316 ± 0.003643	0.020270 ± 0.004113
n4cc	0.273000 ± 0.027300	0.225500 ± 0.022550	0.003476 ± 0.001352	0.012099 ± 0.004441	0.001891 ± 0.001706	0.010583 ± 0.004447
kpac	0.000000 ± 0.000100	0.000000 ± 0.000100	0.001109 ± 0.000571	0.000792 ± 0.000426	0.000312 ± 0.000452	0.001059 ± 0.000445
tctc	0.000000 ± 0.000141	0.000000 ± 0.000141	0.042763 ± 0.042580	0.748839 ± 0.081423	0.844800 ± 0.052484	0.767735 ± 0.061446
octc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.029263	0.534771 ± 0.073987	0.618903 ± 0.062321	0.422297 ± 0.042218
ectc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.042763 ± 0.030931	0.214067 ± 0.092457	0.225896 ± 0.048967	0.345438 ± 0.044645
naxc	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000	0.001370 ± 0.007830	0.000000 ± 0.001138	0.002616 ± 0.007641
mgxc	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000	0.002927 ± 0.002740	0.000233 ± 0.000504	0.003563 ± 0.001950
alxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.059680 ± 0.005247	0.004532 ± 0.003061	0.000632 ± 0.000503	0.003693 ± 0.001334
sixc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.090112 ± 0.005675	0.018509 ± 0.004544	0.003538 ± 0.002644	0.021538 ± 0.002357
phxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.009372 ± 0.006322	0.001579 ± 0.000471	0.000242 ± 0.000064	0.001634 ± 0.000483
suxc	0.242700 ± 0.024270	0.000000 ± 0.000100	0.029480 ± 0.027290	0.009006 ± 0.003232	0.003036 ± 0.001425	0.007252 ± 0.000525
clxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000629 ± 0.000221	0.000825 ± 0.000780	0.000234 ± 0.000195	0.000646 ± 0.000999
kpxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.004644 ± 0.000602	0.002865 ± 0.001036	0.000580 ± 0.000572	0.002682 ± 0.000774
caxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.034536 ± 0.010411	0.008390 ± 0.001592	0.002632 ± 0.002830	0.007641 ± 0.000919
tixc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.004315 ± 0.000651	0.000587 ± 0.003682	0.000198 ± 0.000433	0.000948 ± 0.003777
vaxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000734	0.000248 ± 0.001493	0.000041 ± 0.000176	0.000133 ± 0.001530
crxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000176 ± 0.000041	0.000055 ± 0.000328	0.000011 ± 0.000041	0.000273 ± 0.000252
mnxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000284 ± 0.000139	0.000183 ± 0.000230	0.000052 ± 0.000058	0.000358 ± 0.000189
fexc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.029160 ± 0.003827	0.007792 ± 0.002024	0.002990 ± 0.003215	0.010025 ± 0.000722
nixc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000072 ± 0.000019	0.000055 ± 0.000165	0.000007 ± 0.000021	0.000146 ± 0.000127
cuxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000179 ± 0.000112	0.001100 ± 0.000216	0.002788 ± 0.004092	0.002140 ± 0.000176
znxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000797 ± 0.000341	0.002266 ± 0.000606	0.000608 ± 0.000270	0.001887 ± 0.000170
asxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000164	0.000039 ± 0.000390	0.000004 ± 0.000046	0.000036 ± 0.000413
sexc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000406 ± 0.000407	0.000047 ± 0.000181	0.000010 ± 0.000021	0.000057 ± 0.000180
brxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000147 ± 0.000154	0.000096 ± 0.000146	0.000013 ± 0.000019	0.000139 ± 0.000120
rbxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000053 ± 0.000043	0.000022 ± 0.000155	0.000006 ± 0.000018	0.000000 ± 0.000153
srxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.001964 ± 0.000686	0.000044 ± 0.000174	0.000014 ± 0.000019	0.000047 ± 0.000173
zrxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000247 ± 0.000043	0.000000 ± 0.000254	0.000002 ± 0.000030	0.000000 ± 0.000252
hgxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000154	0.000010 ± 0.000401	0.000000 ± 0.000047	0.000075 ± 0.000402
pbxc	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000680 ± 0.000336	0.000896 ± 0.000373	0.000098 ± 0.000048	0.001179 ± 0.000392
naphth	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.139681 ± 0.078670	0.009270 ± 0.002201	0.273785 ± 0.013798
mnaph2	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.122359 ± 0.065385	0.005701 ± 0.001361	0.200869 ± 0.010069
mnaph1	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.051686 ± 0.026624	0.002928 ± 0.000732	0.085476 ± 0.004285
dmn267	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.019570 ± 0.008867	0.002222 ± 0.000568	0.030619 ± 0.001535
dm1367	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.027599 ± 0.012230	0.003322 ± 0.001559	0.043847 ± 0.002198
d14523	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.010122 ± 0.004381	0.001541 ± 0.000352	0.016645 ± 0.000834
dmn12	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.004188 ± 0.001837	0.000558 ± 0.000170	0.006665 ± 0.000334
biphen	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.005631 ± 0.002551	0.001364 ± 0.000396	0.009188 ± 0.000461
m_2bph	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.001094 ± 0.000536	0.000395 ± 0.000141	0.001778 ± 0.000089
m_3bph	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.005176 ± 0.002803	0.002573 ± 0.000716	0.009525 ± 0.000477
m_4bph	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.002392 ± 0.001316	0.001039 ± 0.000291	0.004249 ± 0.000213
atmnap	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.008335 ± 0.004081	0.002007 ± 0.000445	0.013996 ± 0.000702

**Table 2a**  
**Source Composition Profiles Consisting of Conventional Species and PAHs (Continued)**

Profile	phauto6		phauto7		phdies2		phdies3		phdies4		phdies5	
clie	0.004722	± 0.004515	0.003465	± 0.003680	0.001870	± 0.000908	0.001687	± 0.000860	0.001258	± 0.000611	0.000468	± 0.000338
n3ic	0.024309	± 0.004360	0.010829	± 0.003461	0.003462	± 0.000693	0.005730	± 0.000735	0.003267	± 0.000485	0.001620	± 0.000315
s4ic	0.034103	± 0.004470	0.018336	± 0.003529	0.007999	± 0.000778	0.008516	± 0.000784	0.004712	± 0.000506	0.002430	± 0.000324
n4cc	0.016115	± 0.004974	0.007486	± 0.003708	0.002961	± 0.000790	0.003838	± 0.000858	0.002429	± 0.000568	0.001181	± 0.000345
kpac	0.000423	± 0.000455	0.000905	± 0.000379	0.000473	± 0.000080	0.000833	± 0.000093	0.000115	± 0.000050	0.000077	± 0.000033
tctc	0.720815	± 0.085908	0.758731	± 0.075423	0.871535	± 0.055263	0.825281	± 0.050557	0.882881	± 0.057386	0.849545	± 0.053794
octc	0.613260	± 0.081360	0.485126	± 0.066125	0.459115	± 0.034780	0.550711	± 0.041672	0.426089	± 0.032162	0.672904	± 0.050551
ectc	0.107554	± 0.027581	0.273605	± 0.036277	0.412420	± 0.042946	0.274570	± 0.028627	0.456792	± 0.047526	0.176641	± 0.018397
naxc	0.001715	± 0.008388	0.000000	± 0.007273	0.000000	± 0.001531	0.000000	± 0.001718	0.000000	± 0.001066	0.000000	± 0.000751
mgxc	0.004225	± 0.002037	0.002094	± 0.002898	0.000219	± 0.000594	0.000482	± 0.000751	0.000222	± 0.000473	0.000090	± 0.000352
alxc	0.001267	± 0.002249	0.007336	± 0.001189	0.000743	± 0.000125	0.001208	± 0.000172	0.000732	± 0.000112	0.000410	± 0.000072
sixc	0.017853	± 0.002327	0.023345	± 0.002128	0.003275	± 0.000201	0.006583	± 0.000366	0.004518	± 0.000250	0.001833	± 0.000110
phxc	0.001731	± 0.000511	0.001213	± 0.000412	0.000248	± 0.000056	0.000306	± 0.000069	0.000169	± 0.000045	0.000242	± 0.000035
suxc	0.012380	± 0.000755	0.005938	± 0.000447	0.002660	± 0.000152	0.004681	± 0.000250	0.002642	± 0.000145	0.002202	± 0.000118
clxc	0.000988	± 0.000730	0.001102	± 0.000603	0.000237	± 0.000064	0.000456	± 0.000078	0.000227	± 0.000049	0.000150	± 0.000034
kpxc	0.003000	± 0.000798	0.003827	± 0.000677	0.000481	± 0.000060	0.001239	± 0.000092	0.000461	± 0.000046	0.000270	± 0.000030
caxc	0.007593	± 0.000938	0.010223	± 0.000884	0.002075	± 0.000132	0.005897	± 0.000315	0.001812	± 0.000108	0.001107	± 0.000068
tixc	0.000514	± 0.003928	0.000780	± 0.003361	0.000181	± 0.000632	0.000463	± 0.000634	0.000159	± 0.000450	0.000077	± 0.000314
vaxc	0.000173	± 0.001591	0.000302	± 0.001364	0.000048	± 0.000256	0.000081	± 0.000258	0.000009	± 0.000182	0.000023	± 0.000128
rxrc	0.000043	± 0.000348	0.000003	± 0.000301	0.000027	± 0.000058	0.000021	± 0.000060	0.000010	± 0.000041	0.000007	± 0.000029
nxrc	0.000161	± 0.000266	0.000154	± 0.000232	0.000054	± 0.000016	0.000118	± 0.000018	0.000032	± 0.000033	0.000029	± 0.000008
hexc	0.008453	± 0.000677	0.009402	± 0.000642	0.002652	± 0.000138	0.006691	± 0.000340	0.002169	± 0.000112	0.001385	± 0.000072
nixc	0.000060	± 0.000176	0.000035	± 0.000152	0.000005	± 0.000029	0.000014	± 0.000031	0.000000	± 0.000021	0.000001	± 0.000015
cuxc	0.001112	± 0.000150	0.001310	± 0.000134	0.004326	± 0.000219	0.007512	± 0.000379	0.002270	± 0.000116	0.000379	± 0.000021
znxc	0.002663	± 0.000200	0.001568	± 0.000144	0.000372	± 0.000024	0.000915	± 0.000050	0.000526	± 0.000029	0.000495	± 0.000026
asxc	0.000000	± 0.000423	0.000117	± 0.000351	0.000019	± 0.000082	0.000013	± 0.000064	0.000009	± 0.000045	0.000000	± 0.000041
sexc	0.000076	± 0.000193	0.000022	± 0.000169	0.000021	± 0.000032	0.000018	± 0.000031	0.000006	± 0.000022	0.000009	± 0.000016
brxc	0.000171	± 0.000125	0.000050	± 0.000151	0.000033	± 0.000010	0.000028	± 0.000028	0.000017	± 0.000020	0.000006	± 0.000014
rbxc	0.000012	± 0.000165	0.000026	± 0.000146	0.000002	± 0.000027	0.000012	± 0.000027	0.000004	± 0.000019	0.000006	± 0.000014
srxc	0.000053	± 0.000186	0.000011	± 0.000163	0.000000	± 0.000030	0.000035	± 0.000010	0.000008	± 0.000022	0.000006	± 0.000016
zrxc	0.000000	± 0.000271	0.000000	± 0.000239	0.000000	± 0.000044	0.000002	± 0.000043	0.000004	± 0.000032	0.000005	± 0.000023
hgxc	0.000029	± 0.000430	0.000000	± 0.000375	0.000019	± 0.000071	0.000000	± 0.000067	0.000000	± 0.000049	0.000000	± 0.000036
pbxc	0.001057	± 0.000403	0.000617	± 0.000332	0.000284	± 0.000036	0.000102	± 0.000030	0.000057	± 0.000065	0.000145	± 0.000018
napth	0.058179	± 0.003108	0.215173	± 0.010910	0.010158	± 0.000592	0.011787	± 0.000676	0.009382	± 0.000517	0.007708	± 0.000414
mnaph2	0.055217	± 0.002759	0.185832	± 0.009317	0.004330	± 0.000218	0.006493	± 0.000326	0.004658	± 0.000231	0.004129	± 0.000207
mnaph1	0.023995	± 0.001199	0.077097	± 0.003866	0.002264	± 0.000114	0.003379	± 0.000170	0.002527	± 0.000125	0.002083	± 0.000105
dmn267	0.010814	± 0.000542	0.028544	± 0.001432	0.002292	± 0.000115	0.002803	± 0.000141	0.002541	± 0.000126	0.001668	± 0.000084
dm1367	0.015448	± 0.000773	0.039906	± 0.002002	0.004138	± 0.000208	0.005023	± 0.000252	0.004669	± 0.000231	0.002982	± 0.000150
d14523	0.006018	± 0.000308	0.014735	± 0.000745	0.001564	± 0.000079	0.001880	± 0.000094	0.001867	± 0.000093	0.001178	± 0.000059
dmn12	0.002498	± 0.000132	0.006144	± 0.000314	0.000617	± 0.000031	0.000751	± 0.000038	0.000735	± 0.000036	0.000428	± 0.000022
biphen	0.002968	± 0.000149	0.008053	± 0.000404	0.001457	± 0.000073	0.001758	± 0.000088	0.001715	± 0.000085	0.000966	± 0.000049
m_2bph	0.000530	± 0.000026	0.001596	± 0.000080	0.000352	± 0.000018	0.000418	± 0.000021	0.000430	± 0.000021	0.000244	± 0.000012
m_3bph	0.002555	± 0.000128	0.008131	± 0.000408	0.002420	± 0.000122	0.003158	± 0.000159	0.002771	± 0.000137	0.001774	± 0.000089
m_4bph	0.001173	± 0.000059	0.003787	± 0.000190	0.000978	± 0.000049	0.001278	± 0.000064	0.001080	± 0.000054	0.000715	± 0.000036
atmnap	0.004669	± 0.000233	0.012733	± 0.000638	0.001967	± 0.000099	0.002465	± 0.000124	0.002339	± 0.000116	0.001576	± 0.000079

Table 2a

## Source Composition Profiles Consisting of Conventional Species and PAHs (Continued)

Profile	phdies8		phdies9		PHCONSTR		PHPVRDCB		PHPVRD		PHUPRD1	
clie	0.001753	± 0.000882	0.000522	± 0.000449	0.000126	± 0.000254	0.001061	± 0.000841	0.001410	± 0.002264	0.000273	± 0.000354
n3ic	0.003427	± 0.000694	0.002906	± 0.000447	0.000365	± 0.000773	0.000427	± 0.001860	0.001132	± 0.002042	0.000860	± 0.001040
s4ic	0.005738	± 0.000725	0.003477	± 0.000450	0.001134	± 0.000938	0.003880	± 0.003315	0.002075	± 0.001907	0.003176	± 0.002762
n4cc	0.003514	± 0.000837	0.002036	± 0.000508	0.000672	± 0.000355	0.000413	± 0.000425	0.000706	± 0.000462	0.000369	± 0.000303
kpac	0.000302	± 0.000015	0.000106	± 0.000046	0.002657	± 0.000677	0.001383	± 0.001025	0.002147	± 0.001204	0.002426	± 0.000245
tctc	0.873773	± 0.054127	0.847026	± 0.053541	0.046167	± 0.017301	0.239449	± 0.022414	0.128440	± 0.049099	0.089465	± 0.046260
octc	0.509203	± 0.038552	0.666147	± 0.050106	0.046167	± 0.015767	0.217272	± 0.020782	0.118661	± 0.048698	0.089465	± 0.045528
ectc	0.364570	± 0.037993	0.180879	± 0.018868	0.000000	± 0.007122	0.022177	± 0.008395	0.009779	± 0.006266	0.000000	± 0.008199
naxc	0.000526	± 0.001451	0.000000	± 0.000870	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
mgxc	0.000000	± 0.000609	0.000340	± 0.000368	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
alxc	0.000388	± 0.000126	0.000726	± 0.000084	0.036848	± 0.002762	0.040178	± 0.003104	0.042470	± 0.005194	0.037034	± 0.002809
sixc	0.002649	± 0.000173	0.001916	± 0.000121	0.115005	± 0.013446	0.132720	± 0.009572	0.136932	± 0.015685	0.121216	± 0.008656
phxc	0.000171	± 0.000175	0.000176	± 0.000041	0.000286	± 0.000108	0.000899	± 0.000151	0.000782	± 0.000201	0.000297	± 0.000079
suxc	0.003171	± 0.000176	0.002481	± 0.000135	0.001073	± 0.000554	0.006693	± 0.000544	0.002593	± 0.000969	0.001357	± 0.000569
clxc	0.000038	± 0.000176	0.000098	± 0.000119	0.000620	± 0.000116	0.002094	± 0.000518	0.002159	± 0.001857	0.001007	± 0.000359
kpxc	0.000345	± 0.000057	0.000268	± 0.000036	0.014865	± 0.001237	0.014248	± 0.001067	0.018549	± 0.001965	0.015120	± 0.002285
caxc	0.001079	± 0.000092	0.000886	± 0.000064	0.091029	± 0.016756	0.060567	± 0.012806	0.046724	± 0.010890	0.103772	± 0.026776
tixc	0.000036	± 0.000665	0.000070	± 0.000393	0.003546	± 0.000374	0.004077	± 0.000484	0.004447	± 0.000435	0.003161	± 0.000345
vaxc	0.000000	± 0.000269	0.000010	± 0.000159	0.000238	± 0.000090	0.000365	± 0.000173	0.000261	± 0.000172	0.000211	± 0.000109
crxc	0.000005	± 0.000059	0.000000	± 0.000035	0.000186	± 0.000025	0.000478	± 0.000248	0.000248	± 0.000035	0.000176	± 0.000035
mnxc	0.000014	± 0.000045	0.000016	± 0.000027	0.001047	± 0.000132	0.001035	± 0.000106	0.001065	± 0.000140	0.000888	± 0.000122
fexc	0.001265	± 0.000070	0.001385	± 0.000073	0.035051	± 0.002494	0.047128	± 0.003399	0.044195	± 0.003630	0.034066	± 0.002763
nixc	0.000003	± 0.000030	0.000003	± 0.000018	0.000054	± 0.000008	0.000183	± 0.000025	0.000093	± 0.000018	0.000055	± 0.000010
cuxc	0.000659	± 0.000037	0.000635	± 0.000034	0.000109	± 0.000055	0.000340	± 0.000044	0.000257	± 0.000086	0.000079	± 0.000044
znxc	0.000395	± 0.000025	0.000395	± 0.000022	0.000335	± 0.000260	0.001296	± 0.000438	0.001202	± 0.000260	0.000880	± 0.000624
asxc	0.000027	± 0.000063	0.000000	± 0.000041	0.000016	± 0.000055	0.000000	± 0.000162	0.000013	± 0.000168	0.000017	± 0.000091
sexc	0.000000	± 0.000032	0.000009	± 0.000019	0.000000	± 0.000022	0.000000	± 0.000040	0.000011	± 0.000028	0.000013	± 0.000025
brxc	0.000013	± 0.000029	0.000014	± 0.000018	0.000018	± 0.000008	0.000013	± 0.000040	0.000042	± 0.000044	0.000017	± 0.000023
rbxc	0.000006	± 0.000028	0.000000	± 0.000016	0.000101	± 0.000016	0.000091	± 0.000041	0.000129	± 0.000023	0.000106	± 0.000018
srxc	0.000006	± 0.000032	0.000009	± 0.000019	0.000461	± 0.000109	0.000626	± 0.000109	0.000968	± 0.000633	0.000503	± 0.000042
zrxc	0.000003	± 0.000046	0.000000	± 0.000027	0.000156	± 0.000025	0.000158	± 0.000041	0.000155	± 0.000039	0.000111	± 0.000036
hgxc	0.000000	± 0.000073	0.000000	± 0.000043	0.000018	± 0.000045	0.000000	± 0.000081	0.000016	± 0.000066	0.000020	± 0.000056
pbxc	0.000019	± 0.000092	0.000080	± 0.000020	0.000165	± 0.000160	0.000710	± 0.000345	0.000811	± 0.000436	0.000417	± 0.000086
naphth	0.004893	± 0.000347	0.006090	± 0.000465	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
mnaph2	0.003157	± 0.000158	0.005351	± 0.000265	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
mnaph1	0.001698	± 0.000085	0.003534	± 0.000175	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
dmn267	0.001531	± 0.000077	0.002596	± 0.000129	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
dm1367	0.002642	± 0.000132	0.004517	± 0.000224	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
d14523	0.001063	± 0.000055	0.001790	± 0.000091	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
dmn12	0.000432	± 0.000023	0.000706	± 0.000037	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
biphen	0.001014	± 0.000051	0.001490	± 0.000074	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
m_2bph	0.000243	± 0.000012	0.000369	± 0.000018	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
m_3bph	0.001697	± 0.000085	0.002811	± 0.000139	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
m_4bph	0.000685	± 0.000034	0.001124	± 0.000056	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
atmnap	0.001260	± 0.000063	0.002433	± 0.000120	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000

**Table 2a**  
**Source Composition Profiles Consisting of Conventional Species and PAHs (Continued)**

Profile	PHDSSOIL		PHAUTO		PHDIES		PHRD	
cllc	0.000118 ±	0.0000324	0.006400 ±	0.006554	0.016204 ±	0.043981	0.011573 ±	0.007545
n3lc	0.000720 ±	0.0001015	0.038949 ±	0.028743	0.003095 ±	0.003995	0.110254 ±	0.104066
s4lc	0.000147 ±	0.0000272	0.022885 ±	0.013188	0.024448 ±	0.010048	0.060125 ±	0.020920
n4cc	0.000994 ±	0.0000520	0.016722 ±	0.010236	0.008661 ±	0.001261	0.041064 ±	0.027397
kpac	0.003401 ±	0.0001440	0.003861 ±	0.009616	0.003876 ±	0.009574	0.007588 ±	0.023147
tctc	0.036610 ±	0.015840	0.435773 ±	0.146806	0.730145 ±	0.103475	0.754677 ±	0.216194
octc	0.036610 ±	0.012785	0.300752 ±	0.122989	0.400956 ±	0.066018	0.390031 ±	0.186177
ectc	0.000000 ±	0.009352	0.135021 ±	0.080161	0.329189 ±	0.079679	0.364646 ±	0.109899
naxc	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
mgxc	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
alxc	0.049811 ±	0.005476	0.004118 ±	0.002046	0.001735 ±	0.001211	0.000723 ±	0.005250
sixc	0.140039 ±	0.017430	0.016443 ±	0.008785	0.004627 ±	0.001838	0.000828 ±	0.011319
phxc	0.000828 ±	0.000403	0.001147 ±	0.000653	0.000609 ±	0.000583	0.000837 ±	0.001327
suxc	0.000598 ±	0.000087	0.010111 ±	0.004806	0.012395 ±	0.002824	0.020156 ±	0.006026
clxc	0.000415 ±	0.000127	0.003376 ±	0.003217	0.000282 ±	0.000613	0.005624 ±	0.004085
kpxc	0.018894 ±	0.003333	0.002493 ±	0.001414	0.000421 ±	0.000332	0.002150 ±	0.002294
caxc	0.034550 ±	0.013424	0.007071 ±	0.004068	0.001586 ±	0.000631	0.001253 ±	0.009805
tixc	0.005013 ±	0.000899	0.000654 ±	0.001256	0.000015 ±	0.001530	0.000872 ±	0.004008
vaxc	0.000300 ±	0.000115	0.000047 ±	0.000538	0.000008 ±	0.000621	0.000233 ±	0.002011
crxc	0.000241 ±	0.000098	0.000151 ±	0.000104	0.000039 ±	0.000147	0.000187 ±	0.000402
mnxc	0.001365 ±	0.000288	0.001048 ±	0.000359	0.000082 ±	0.000113	0.001782 ±	0.001142
fexc	0.044803 ±	0.005147	0.006849 ±	0.004231	0.001588 ±	0.000652	0.009341 ±	0.005294
nixc	0.000064 ±	0.000015	0.000094 ±	0.000093	0.000026 ±	0.000054	0.000189 ±	0.000149
cuxc	0.000111 ±	0.000026	0.000739 ±	0.000642	0.000132 ±	0.000082	0.003558 ±	0.001351
znxc	0.000288 ±	0.000123	0.002727 ±	0.002250	0.000699 ±	0.000190	0.005054 ±	0.003873
asxc	0.000008 ±	0.000052	0.000021 ±	0.000351	0.000009 ±	0.000208	0.000057 ±	0.000942
sexc	0.000000 ±	0.000030	0.000010 ±	0.000090	0.000009 ±	0.000103	0.000042 ±	0.000335
brxc	0.000007 ±	0.000029	0.000294 ±	0.000163	0.000023 ±	0.000089	0.000580 ±	0.000339
rbxc	0.000126 ±	0.000018	0.000014 ±	0.000090	0.000015 ±	0.000102	0.000019 ±	0.000331
srxc	0.000335 ±	0.000047	0.000070 ±	0.000106	0.000018 ±	0.000132	0.000042 ±	0.000476
zrxc	0.000181 ±	0.000036	0.000038 ±	0.000173	0.000019 ±	0.000198	0.000100 ±	0.000631
hgxc	0.000021 ±	0.000046	0.000018 ±	0.000216	0.000014 ±	0.000248	0.000035 ±	0.000798
pbxc	0.000166 ±	0.000087	0.001553 ±	0.000723	0.000147 ±	0.000294	0.002700 ±	0.001261
naphth	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
mnaph2	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
mnaph1	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
dmn267	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
dm1367	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
d14523	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
dmn12	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
biphen	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
m_2bph	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
m_3bph	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
m_4bph	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000
atmnap	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000	0.000000 ±	0.010000

**Table 2a**  
**Source Composition Profiles Consisting of Conventional Species and PAHs (Continued)**

Profile	NVNSP		NVNSP2		NVSM		NWHD		NMc		NWFS <sub>c</sub>	
em_12n	0.000919 ±	0.000709	0.000939 ±	0.000696	0.000338 ±	0.000068	0.000063 ±	0.000049	0.000043 ±	0.000024	0.000102 ±	0.000033
btmnap	0.003255 ±	0.002171	0.003245 ±	0.002266	0.000914 ±	0.000155	0.000265 ±	0.000206	0.000014 ±	0.000007	0.000137 ±	0.000042
ctmnap	0.003153 ±	0.002010	0.003300 ±	0.002219	0.000912 ±	0.000173	0.000318 ±	0.000216	0.000015 ±	0.000005	0.000075 ±	0.000013
em_21n	0.000180 ±	0.000141	0.000182 ±	0.000141	0.000086 ±	0.000024	0.000013 ±	0.000015	0.000012 ±	0.000008	0.000016 ±	0.000010
etmnap	0.002122 ±	0.001339	0.002179 ±	0.001553	0.000650 ±	0.000096	0.000222 ±	0.000158	0.000012 ±	0.000004	0.000079 ±	0.000019
ftmnap	0.002306 ±	0.001378	0.002606 ±	0.001682	0.000597 ±	0.000129	0.000193 ±	0.000124	0.000006 ±	0.000005	0.000053 ±	0.000018
gtmnap	0.001181 ±	0.000683	0.001415 ±	0.001020	0.000351 ±	0.000087	0.000099 ±	0.000059	0.000010 ±	0.000003	0.000048 ±	0.000008
htmnap	0.000435 ±	0.000277	0.000584 ±	0.000398	0.000274 ±	0.000056	0.000019 ±	0.000015	0.000006 ±	0.000003	0.000043 ±	0.000022
tml28n	0.000030 ±	0.000034	0.000130 ±	0.000066	0.000112 ±	0.000044	0.000005 ±	0.000014	0.000017 ±	0.000027	0.000044 ±	0.000019
acnapy	0.016914 ±	0.012669	0.009947 ±	0.014274	0.002760 ±	0.001142	0.000037 ±	0.000092	0.000641 ±	0.000425	0.001373 ±	0.000519
acnape	0.005074 ±	0.006087	0.000868 ±	0.000493	0.000216 ±	0.000060	0.000024 ±	0.000042	0.000030 ±	0.000027	0.000082 ±	0.000013
phenan	0.010780 ±	0.007887	0.042251 ±	0.020849	0.002238 ±	0.000880	0.000056 ±	0.000037	0.000756 ±	0.000380	0.002530 ±	0.000728
fluore	0.005255 ±	0.003700	0.004917 ±	0.002291	0.001094 ±	0.000278	0.000049 ±	0.000036	0.000169 ±	0.000082	0.000466 ±	0.000077
a_mflu	0.001416 ±	0.000899	0.003431 ±	0.002163	0.000511 ±	0.000188	0.000011 ±	0.000014	0.000032 ±	0.000101	0.000216 ±	0.000623
m_1flu	0.000634 ±	0.000405	0.001655 ±	0.001068	0.000216 ±	0.000077	0.000012 ±	0.000014	0.000012 ±	0.000013	0.000111 ±	0.000119
b_mflu	0.000297 ±	0.000210	0.000778 ±	0.000492	0.000122 ±	0.000047	0.000012 ±	0.000014	0.000008 ±	0.000009	0.000086 ±	0.000082
c_mflu	0.001255 ±	0.000803	0.010033 ±	0.003842	0.000734 ±	0.000409	0.000024 ±	0.000020	0.000181 ±	0.000507	0.000673 ±	0.001647
a_mpht	0.000754 ±	0.000590	0.005263 ±	0.003285	0.000264 ±	0.000145	0.000026 ±	0.000014	0.000022 ±	0.000009	0.000289 ±	0.000215
m_2pht	0.000890 ±	0.000725	0.005724 ±	0.003442	0.000278 ±	0.000136	0.000022 ±	0.000014	0.000030 ±	0.000011	0.000342 ±	0.000127
b_mpht	0.000457 ±	0.000449	0.000926 ±	0.001251	0.000096 ±	0.000049	0.000003 ±	0.000014	0.000010 ±	0.000008	0.000076 ±	0.000013
c_mpht	0.000514 ±	0.000448	0.003418 ±	0.002166	0.000200 ±	0.000104	0.000022 ±	0.000014	0.000023 ±	0.000010	0.000132 ±	0.000050
m_1pht	0.000574 ±	0.000518	0.003590 ±	0.002224	0.000179 ±	0.000083	0.000013 ±	0.000014	0.000024 ±	0.000009	0.000533 ±	0.000086
dm36ph	0.000110 ±	0.000082	0.001340 ±	0.000851	0.000052 ±	0.000028	0.000004 ±	0.000014	0.000004 ±	0.000002	0.000049 ±	0.000014
a_dmph	0.000156 ±	0.000116	0.001782 ±	0.001229	0.000056 ±	0.000032	0.000014 ±	0.000014	0.000003 ±	0.000003	0.000000 ±	0.000100
b_dmph	0.000060 ±	0.000049	0.000897 ±	0.000609	0.000028 ±	0.000016	0.000010 ±	0.000014	0.000003 ±	0.000002	0.000032 ±	0.000023
c_dmph	0.000252 ±	0.000216	0.002731 ±	0.001862	0.000104 ±	0.000056	0.000013 ±	0.000014	0.000007 ±	0.000005	0.000060 ±	0.000010
dm17ph	0.000139 ±	0.000111	0.001317 ±	0.000872	0.000046 ±	0.000020	0.000005 ±	0.000014	0.000003 ±	0.000002	0.000045 ±	0.000023
d_dmph	0.000048 ±	0.000052	0.000720 ±	0.000469	0.000022 ±	0.000012	0.000002 ±	0.000014	0.000008 ±	0.000004	0.000753 ±	0.000531
e_dmph	0.000092 ±	0.000078	0.001164 ±	0.000785	0.000039 ±	0.000020	0.000006 ±	0.000014	0.000060 ±	0.000035	0.000036 ±	0.000007
anthra	0.002237 ±	0.001330	0.011460 ±	0.007136	0.000645 ±	0.000270	0.000037 ±	0.000019	0.000153 ±	0.000067	0.000536 ±	0.000080
fluora	0.002342 ±	0.001593	0.021152 ±	0.011392	0.000555 ±	0.000307	0.000022 ±	0.000027	0.000186 ±	0.000060	0.000505 ±	0.000174
pyrene	0.002831 ±	0.001880	0.027608 ±	0.014800	0.000630 ±	0.000350	0.000039 ±	0.000033	0.000246 ±	0.000100	0.000434 ±	0.000150
b_mpyr	0.000025 ±	0.000031	0.000479 ±	0.000297	0.000015 ±	0.000008	0.000002 ±	0.000014	0.000011 ±	0.000005	0.000034 ±	0.000009
d_mpyr	0.000072 ±	0.000034	0.000482 ±	0.000287	0.000021 ±	0.000012	0.000001 ±	0.000014	0.000022 ±	0.000011	0.000053 ±	0.000020
f_mpyr	0.000025 ±	0.000040	0.000501 ±	0.000329	0.000014 ±	0.000005	0.000002 ±	0.000014	0.000016 ±	0.000008	0.000022 ±	0.000013
retene	0.000000 ±	0.000041	0.000000 ±	0.000055	0.000000 ±	0.000003	0.000001 ±	0.000020	0.000003 ±	0.000003	0.000386 ±	0.000075
baanth	0.000071 ±	0.000088	0.000220 ±	0.000147	0.000013 ±	0.000007	0.000040 ±	0.000043	0.000037 ±	0.000038	0.000236 ±	0.000240
chrysn	0.000091 ±	0.000057	0.000211 ±	0.000128	0.000013 ±	0.000004	0.000007 ±	0.000022	0.000038 ±	0.000022	0.000032 ±	0.000035
bbjkfl	0.000246 ±	0.000196	0.000190 ±	0.000287	0.000025 ±	0.000011	0.000003 ±	0.000023	0.000049 ±	0.000037	0.000218 ±	0.000161
bepyrn	0.000108 ±	0.000113	0.000099 ±	0.000101	0.000008 ±	0.000003	0.000006 ±	0.000014	0.000015 ±	0.000014	0.000041 ±	0.000030
bapyrn	0.000122 ±	0.000147	0.000096 ±	0.000127	0.000010 ±	0.000007	0.000013 ±	0.000046	0.000020 ±	0.000016	0.000065 ±	0.000049
incdpy	0.000093 ±	0.000098	0.000038 ±	0.000106	0.000008 ±	0.000006	0.000001 ±	0.000039	0.000013 ±	0.000009	0.000036 ±	0.000031
dbanth	0.000003 ±	0.000114	0.000004 ±	0.000153	0.000002 ±	0.000009	0.000000 ±	0.000056	0.000002 ±	0.000008	0.000009 ±	0.000009
bghipe	0.000357 ±	0.000415	0.000143 ±	0.000192	0.000021 ±	0.000009	0.000009 ±	0.000050	0.000020 ±	0.000013	0.000036 ±	0.000032
corone	0.000294 ±	0.000345	0.000096 ±	0.000275	0.000013 ±	0.000015	0.000001 ±	0.000101	0.000011 ±	0.000014	0.000012 ±	0.000010

**Table 2a**  
**Source Composition Profiles Consisting of Conventional Species and PAHs (Continued)**

Profile	AMSUL	AMNIT	PCHCLC1	phautoc	phdiesc	phauto3
em_12n	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.001943 ± 0.000894	0.000462 ± 0.000149	0.003482 ± 0.000175
btmnap	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.008180 ± 0.004227	0.003016 ± 0.000659	0.014631 ± 0.000733
ctmnap	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.008831 ± 0.004601	0.004152 ± 0.000888	0.016605 ± 0.000832
em_21n	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.005586 ± 0.002871	0.002959 ± 0.000762	0.010653 ± 0.000534
etmnap	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.005608 ± 0.002981	0.002515 ± 0.000677	0.010678 ± 0.000535
ftmnap	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.004119 ± 0.002092	0.002469 ± 0.000705	0.008162 ± 0.000409
gtmnap	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000796 ± 0.000414	0.000339 ± 0.000106	0.001713 ± 0.000086
htmnap	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.001088 ± 0.000501	0.000921 ± 0.000264	0.002352 ± 0.000118
tml28n	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000182 ± 0.000034	0.000260 ± 0.000139	0.002135 ± 0.000107
acnapy	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.013644 ± 0.003520	0.001251 ± 0.000228	0.027236 ± 0.001365
acnape	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.003314 ± 0.001016	0.000258 ± 0.000041	0.004175 ± 0.000209
phenan	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.007257 ± 0.002967	0.001774 ± 0.000512	0.013318 ± 0.000668
fluore	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.005335 ± 0.002236	0.000898 ± 0.000258	0.009358 ± 0.000469
a_mflu	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.004651 ± 0.002433	0.001782 ± 0.000345	0.008291 ± 0.000416
m_1flu	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.002398 ± 0.001213	0.001635 ± 0.000316	0.004523 ± 0.000227
b_mflu	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.001140 ± 0.000608	0.000341 ± 0.000073	0.001731 ± 0.000087
c_mflu	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.005209 ± 0.003016	0.001063 ± 0.000158	0.009409 ± 0.000472
a_mpht	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.002822 ± 0.001231	0.001172 ± 0.000105	0.004628 ± 0.000232
m_2pht	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.003138 ± 0.001380	0.001311 ± 0.000107	0.005180 ± 0.000260
b_mpht	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000358 ± 0.000246	0.000086 ± 0.000013	0.001081 ± 0.000054
c_mpht	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.001365 ± 0.000563	0.000947 ± 0.000107	0.002496 ± 0.000125
m_1pht	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.001284 ± 0.000520	0.000646 ± 0.000032	0.002270 ± 0.000114
dm36ph	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000627 ± 0.000237	0.000294 ± 0.000015	0.000995 ± 0.000050
a_dmph	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000745 ± 0.000313	0.000309 ± 0.000018	0.001129 ± 0.000057
b_dmph	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000404 ± 0.000173	0.000201 ± 0.000013	0.000679 ± 0.000034
c_dmph	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.001191 ± 0.000504	0.000913 ± 0.000110	0.002016 ± 0.000101
dm17ph	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000387 ± 0.000156	0.000268 ± 0.000023	0.000659 ± 0.000033
d_dmph	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000296 ± 0.000124	0.000239 ± 0.000017	0.000445 ± 0.000022
e_dmph	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000473 ± 0.000203	0.000243 ± 0.000031	0.000733 ± 0.000037
anthra	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.002185 ± 0.000991	0.000381 ± 0.000076	0.003881 ± 0.000195
fluora	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.002544 ± 0.000918	0.000348 ± 0.000056	0.004900 ± 0.000246
pyrene	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.003178 ± 0.001164	0.000463 ± 0.000053	0.006099 ± 0.000306
b_mpyr	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000196 ± 0.000079	0.000022 ± 0.000001	0.000275 ± 0.000014
d_mpyr	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000154 ± 0.000061	0.000023 ± 0.000002	0.000222 ± 0.000011
f_mpyr	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000113 ± 0.000046	0.000041 ± 0.000005	0.000186 ± 0.000009
retene	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000015 ± 0.000013	0.000017 ± 0.000010	0.000034 ± 0.000002
baanth	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000073 ± 0.000035	0.000027 ± 0.000009	0.000091 ± 0.000005
chrysn	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000089 ± 0.000048	0.000040 ± 0.000010	0.000136 ± 0.000007
bbjkfl	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000021	0.000032 ± 0.000019	0.000113 ± 0.000007
bepyrn	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000062 ± 0.000040	0.000020 ± 0.000007	0.000079 ± 0.000004
bapyrn	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000034 ± 0.000033	0.000017 ± 0.000013	0.000053 ± 0.000003
incdpy	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000044 ± 0.000036	0.000015 ± 0.000010	0.000091 ± 0.000005
dbanth	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000035	0.000001 ± 0.000002	0.000000 ± 0.000009
bghipe	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000162 ± 0.000113	0.000023 ± 0.000010	0.000328 ± 0.000016
corone	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000000 ± 0.000100	0.000127 ± 0.000080	0.000009 ± 0.000005	0.000283 ± 0.000014

Table 2a

## Source Composition Profiles Consisting of Conventional Species and PAHs (Continued)

Profile	phauto6		phauto7		phdies2		phdies3		phdies4		phdies5	
em_12n	0.001187	± 0.000059	0.002929	± 0.000147	0.000493	± 0.000025	0.000633	± 0.000032	0.000560	± 0.000028	0.000391	± 0.000020
btmnap	0.004407	± 0.000220	0.012748	± 0.000639	0.002646	± 0.000133	0.003516	± 0.000177	0.003200	± 0.000159	0.002269	± 0.000114
ctmnap	0.004660	± 0.000233	0.013767	± 0.000690	0.003781	± 0.000190	0.004942	± 0.000248	0.004453	± 0.000221	0.003191	± 0.000160
em_21n	0.003025	± 0.000151	0.008690	± 0.000436	0.002532	± 0.000127	0.003442	± 0.000173	0.003018	± 0.000150	0.002081	± 0.000105
etmnap	0.002919	± 0.000146	0.008812	± 0.000442	0.002474	± 0.000125	0.003297	± 0.000165	0.002739	± 0.000136	0.002094	± 0.000105
ftmnap	0.002205	± 0.000110	0.006353	± 0.000319	0.002177	± 0.000110	0.003198	± 0.000161	0.002347	± 0.000116	0.001791	± 0.000090
gtmnap	0.000515	± 0.000026	0.001272	± 0.000064	0.000310	± 0.000016	0.000415	± 0.000021	0.000358	± 0.000018	0.000218	± 0.000011
htmnap	0.000589	± 0.000029	0.001591	± 0.000080	0.000881	± 0.000044	0.001224	± 0.000061	0.000985	± 0.000049	0.000741	± 0.000037
tm128n	0.000147	± 0.000007	0.000215	± 0.000011	0.000213	± 0.000011	0.000239	± 0.000012	0.000139	± 0.000007	0.000133	± 0.000007
acnapy	0.009750	± 0.000489	0.016598	± 0.000834	0.001222	± 0.000061	0.001442	± 0.000072	0.002074	± 0.000103	0.000998	± 0.000050
acnape	0.002680	± 0.000135	0.004485	± 0.000227	0.000237	± 0.000012	0.000299	± 0.000015	0.000337	± 0.000017	0.000216	± 0.000011
phenan	0.004095	± 0.000205	0.009981	± 0.000500	0.001958	± 0.000099	0.002361	± 0.000119	0.001943	± 0.000096	0.001539	± 0.000077
fluore	0.003244	± 0.000162	0.007692	± 0.000386	0.000968	± 0.000049	0.001192	± 0.000060	0.000987	± 0.000049	0.000711	± 0.000036
a_mflu	0.002374	± 0.000119	0.007214	± 0.000362	0.001493	± 0.000075	0.002070	± 0.000104	0.001627	± 0.000081	0.001400	± 0.000070
m_1flu	0.001082	± 0.000054	0.003472	± 0.000174	0.001411	± 0.000071	0.001909	± 0.000090	0.001455	± 0.000072	0.001289	± 0.000065
b_mflu	0.000532	± 0.000027	0.001748	± 0.000088	0.000357	± 0.000018	0.000423	± 0.000021	0.000342	± 0.000017	0.000283	± 0.000014
c_mflu	0.002410	± 0.000120	0.008403	± 0.000421	0.001034	± 0.000052	0.001245	± 0.000063	0.001043	± 0.000052	0.000970	± 0.000049
a_mpht	0.001490	± 0.000074	0.003920	± 0.000196	0.000968	± 0.000049	0.001241	± 0.000062	0.000907	± 0.000045	0.001052	± 0.000053
m_2pht	0.001630	± 0.000081	0.004338	± 0.000218	0.001116	± 0.000056	0.001434	± 0.000072	0.001020	± 0.000051	0.001242	± 0.000062
b_mpht	0.000128	± 0.000006	0.000616	± 0.000031	0.000081	± 0.000004	0.000100	± 0.000005	0.000044	± 0.000002	0.000075	± 0.000004
c_mpht	0.000735	± 0.000037	0.001821	± 0.000091	0.000786	± 0.000040	0.001057	± 0.000053	0.000706	± 0.000035	0.000843	± 0.000042
m_1pht	0.000707	± 0.000035	0.001715	± 0.000086	0.000528	± 0.000027	0.000671	± 0.000034	0.000481	± 0.000024	0.000614	± 0.000031
dm36ph	0.000356	± 0.000018	0.000793	± 0.000040	0.000217	± 0.000011	0.000305	± 0.000015	0.000196	± 0.000010	0.000277	± 0.000014
a_dmph	0.000390	± 0.000019	0.000982	± 0.000049	0.000281	± 0.000014	0.000317	± 0.000016	0.000178	± 0.000009	0.000289	± 0.000015
b_dmph	0.000213	± 0.000011	0.000551	± 0.000028	0.000154	± 0.000008	0.000191	± 0.000010	0.000126	± 0.000006	0.000197	± 0.000010
c_dmph	0.000614	± 0.000031	0.001544	± 0.000077	0.000688	± 0.000035	0.000899	± 0.000045	0.000573	± 0.000028	0.000811	± 0.000041
dm17ph	0.000209	± 0.000010	0.000499	± 0.000025	0.000208	± 0.000010	0.000295	± 0.000015	0.000169	± 0.000008	0.000254	± 0.000013
d_dmph	0.000158	± 0.000008	0.000398	± 0.000020	0.000187	± 0.000009	0.000259	± 0.000013	0.000162	± 0.000008	0.000229	± 0.000011
e_dmph	0.000250	± 0.000013	0.000648	± 0.000032	0.000189	± 0.000010	0.000257	± 0.000013	0.000131	± 0.000006	0.000208	± 0.000010
anthra	0.001240	± 0.000062	0.003216	± 0.000161	0.000361	± 0.000018	0.000468	± 0.000023	0.000392	± 0.000019	0.000325	± 0.000016
fluora	0.001553	± 0.000079	0.002715	± 0.000137	0.000351	± 0.000018	0.000410	± 0.000021	0.000348	± 0.000017	0.000301	± 0.000015
pyrene	0.001991	± 0.000100	0.003225	± 0.000162	0.000453	± 0.000023	0.000517	± 0.000026	0.000403	± 0.000020	0.000411	± 0.000021
b_mpyr	0.000106	± 0.000005	0.000226	± 0.000011	0.000019	± 0.000001	0.000023	± 0.000001	0.000022	± 0.000001	0.000022	± 0.000001
d_mpyr	0.000091	± 0.000005	0.000159	± 0.000008	0.000016	± 0.000001	0.000022	± 0.000001	0.000022	± 0.000001	0.000022	± 0.000001
f_mpyr	0.000066	± 0.000003	0.000115	± 0.000006	0.000033	± 0.000002	0.000037	± 0.000002	0.000037	± 0.000002	0.000039	± 0.000002
retene	0.000006	± 0.000009	0.000019	± 0.000013	0.000014	± 0.000001	0.000029	± 0.000001	0.000009	± 0.000000	0.000013	± 0.000001
baanth	0.000038	± 0.000018	0.000074	± 0.000027	0.000012	± 0.000001	0.000018	± 0.000001	0.000029	± 0.000001	0.000027	± 0.000001
chrysn	0.000044	± 0.000010	0.000083	± 0.000015	0.000028	± 0.000001	0.000031	± 0.000002	0.000050	± 0.000002	0.000038	± 0.000002
bbjkfl	0.000000	± 0.000014	0.000000	± 0.000021	0.000019	± 0.000001	0.000018	± 0.000001	0.000039	± 0.000002	0.000024	± 0.000001
bepyrn	0.000031	± 0.000006	0.000046	± 0.000010	0.000014	± 0.000001	0.000013	± 0.000001	0.000022	± 0.000001	0.000019	± 0.000001
bapyrn	0.000013	± 0.000015	0.000019	± 0.000022	0.000008	± 0.000001	0.000005	± 0.000001	0.000019	± 0.000001	0.000016	± 0.000001
incdpy	0.000019	± 0.000017	0.000028	± 0.000025	0.000007	± 0.000000	0.000008	± 0.000000	0.000014	± 0.000001	0.000012	± 0.000001
dbanth	0.000000	± 0.000024	0.000000	± 0.000036	0.000000	± 0.000001	0.000000	± 0.000001	0.000000	± 0.000002	0.000000	± 0.000001
bghipe	0.000075	± 0.000022	0.000120	± 0.000033	0.000024	± 0.000001	0.000016	± 0.000001	0.000018	± 0.000001	0.000019	± 0.000001
corone	0.000056	± 0.000044	0.000111	± 0.000065	0.000009	± 0.000000	0.000005	± 0.000000	0.000005	± 0.000000	0.000008	± 0.000000

Table 2a

Source Composition Profiles Consisting of Conventional Species and PAHs (Continued)

Profile	phdies8		phdies9		PHCONSTR		PHPVRDCB		PHPVRD		PHUPRD1	
em_12n	0.000309	± 0.000015	0.000602	± 0.000030	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
btmnap	0.001859	± 0.000093	0.003482	± 0.000172	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
ctmnap	0.002565	± 0.000128	0.004681	± 0.000232	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
em_21n	0.001674	± 0.000083	0.003328	± 0.000165	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
etmnap	0.001620	± 0.000081	0.002928	± 0.000145	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
ftmnap	0.001560	± 0.000078	0.002919	± 0.000144	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
gtmnap	0.000193	± 0.000010	0.000316	± 0.000016	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
htmnap	0.000566	± 0.000028	0.000993	± 0.000049	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
tm128n	0.000089	± 0.000004	0.000178	± 0.000009	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
acnapy	0.000949	± 0.000048	0.001615	± 0.000081	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
acnape	0.000190	± 0.000010	0.000327	± 0.000017	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
phenan	0.001322	± 0.000066	0.001895	± 0.000094	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
fluore	0.000656	± 0.000033	0.000926	± 0.000046	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
a_mflu	0.001135	± 0.000057	0.001606	± 0.000079	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
m_1flu	0.001208	± 0.000060	0.001645	± 0.000081	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
b_mflu	0.000247	± 0.000012	0.000356	± 0.000018	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
c_mflu	0.000914	± 0.000046	0.001277	± 0.000063	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
a_mpht	0.000692	± 0.000035	0.000975	± 0.000048	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
m_2pht	0.000812	± 0.000040	0.001136	± 0.000056	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
b_mpht	0.000026	± 0.000001	0.000062	± 0.000003	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
c_mpht	0.000567	± 0.000028	0.000743	± 0.000037	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
m_1pht	0.000409	± 0.000020	0.000532	± 0.000026	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
dm36ph	0.000156	± 0.000008	0.000239	± 0.000012	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
a_dmph	0.000153	± 0.000008	0.000219	± 0.000011	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
b_dmph	0.000107	± 0.000005	0.000139	± 0.000007	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
c_dmph	0.000442	± 0.000022	0.000595	± 0.000029	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
dm17ph	0.000148	± 0.000007	0.000186	± 0.000009	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
d_dmph	0.000134	± 0.000007	0.000168	± 0.000008	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
e_dmph	0.000124	± 0.000006	0.000173	± 0.000009	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
anthra	0.000299	± 0.000015	0.000353	± 0.000018	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
fluora	0.000246	± 0.000013	0.000262	± 0.000014	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
pyrene	0.000306	± 0.000015	0.000355	± 0.000018	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
b_mpyr	0.000016	± 0.000001	0.000017	± 0.000001	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
d_mpyr	0.000013	± 0.000001	0.000018	± 0.000001	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
f_mpyr	0.000024	± 0.000001	0.000032	± 0.000002	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
retene	0.000007	± 0.000002	0.000008	± 0.000003	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
baanth	0.000020	± 0.000004	0.000016	± 0.000006	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
chrysn	0.000030	± 0.000003	0.000028	± 0.000003	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
bbjkfl	0.000006	± 0.000003	0.000000	± 0.000005	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
bepyrn	0.000013	± 0.000002	0.000018	± 0.000002	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
bapyrn	0.000010	± 0.000003	0.000011	± 0.000005	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
incdpy	0.000008	± 0.000004	0.000012	± 0.000005	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
dbanth	0.000000	± 0.000005	0.000000	± 0.000008	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
bghipe	0.000011	± 0.000005	0.000022	± 0.000007	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000
corone	0.000004	± 0.000010	0.000012	± 0.000014	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000	0.000000	± 0.010000



**Table 2b**  
**Source Composition Profiles Consisting of Conventional Species**

profil	NWLD_W	NWHDc	NWMW_W	NWW_W	NMc	NRDC	AMSUL	AMNIT
cllc	0.000633 ± 0.000569	0.000414 ± 0.000994	0.000759 ± 0.001460	0.001373 ± 0.002392	0.000461 ± 0.000620	0.028420 ± 0.026332	0.000000 ± 0.000100	0.000000 ± 0.000100
n3lc	0.002212 ± 0.001702	0.001658 ± 0.001438	0.000554 ± 0.002266	0.000954 ± 0.002424	0.000164 ± 0.000672	0.003170 ± 0.005028	0.000000 ± 0.000100	0.775000 ± 0.077500
s4lc	0.009626 ± 0.005395	0.004167 ± 0.004468	0.005403 ± 0.004303	0.006645 ± 0.004618	0.000598 ± 0.000691	0.009103 ± 0.009303	0.727000 ± 0.072700	0.000000 ± 0.000100
n4cc	0.000000 ± 0.010000	0.000000 ± 0.010000	0.002618 ± 0.005345	0.003374 ± 0.005737	0.000077 ± 0.000636	0.000769 ± 0.002733	0.273000 ± 0.027300	0.225500 ± 0.022550
kpac	0.000000 ± 0.010000	0.000000 ± 0.010000	0.007152 ± 0.010663	0.008477 ± 0.011388	0.002082 ± 0.002039	0.000991 ± 0.000449	0.000000 ± 0.000100	0.000000 ± 0.000100
tctc	0.830997 ± 0.036949	0.939272 ± 0.037229	0.923575 ± 0.158269	0.900673 ± 0.252791	0.986644 ± 0.078102	0.102711 ± 0.032674	0.000000 ± 0.000141	0.000000 ± 0.000141
octc	0.590272 ± 0.054108	0.189289 ± 0.078860	0.837839 ± 0.142934	0.683648 ± 0.196235	0.964142 ± 0.076978	0.095004 ± 0.038050	0.000000 ± 0.000100	0.000000 ± 0.000100
ectc	0.240726 ± 0.039747	0.749983 ± 0.102669	0.085737 ± 0.067962	0.217025 ± 0.159359	0.022503 ± 0.013199	0.007707 ± 0.008874	0.000000 ± 0.000100	0.000000 ± 0.000100
naxc	0.000703 ± 0.007182	0.000000 ± 0.010000	0.001855 ± 0.004523	0.001859 ± 0.004831	0.000654 ± 0.000887	0.015533 ± 0.012009	0.000000 ± 0.000100	0.000000 ± 0.000100
mgxc	0.000799 ± 0.006914	0.000000 ± 0.010000	0.000154 ± 0.001364	0.000218 ± 0.001460	0.000007 ± 0.000242	0.006916 ± 0.002676	0.000000 ± 0.000100	0.000000 ± 0.000100
alxc	0.001015 ± 0.006903	0.000000 ± 0.010000	0.000100 ± 0.000855	0.000087 ± 0.000908	0.000131 ± 0.000220	0.055334 ± 0.031319	0.000000 ± 0.000100	0.000000 ± 0.000100
sixc	0.003553 ± 0.007152	0.000000 ± 0.010000	0.000142 ± 0.000352	0.000312 ± 0.000665	0.000195 ± 0.000204	0.173543 ± 0.081030	0.000000 ± 0.000100	0.000000 ± 0.000100
phxc	0.001812 ± 0.006927	0.000000 ± 0.010000	0.000204 ± 0.000436	0.000083 ± 0.000436	0.000298 ± 0.000241	0.000292 ± 0.000689	0.000000 ± 0.000100	0.000000 ± 0.000100
suxc	0.006289 ± 0.002810	0.002968 ± 0.001861	0.004014 ± 0.005937	0.004198 ± 0.006384	0.001428 ± 0.000353	0.004384 ± 0.001882	0.242700 ± 0.024270	0.000000 ± 0.000100
clxc	0.001044 ± 0.000939	0.000683 ± 0.001639	0.001404 ± 0.001184	0.001552 ± 0.001262	0.000878 ± 0.000591	0.029973 ± 0.024970	0.000000 ± 0.000100	0.000000 ± 0.000100
kpxc	0.000339 ± 0.000893	0.000060 ± 0.000294	0.017052 ± 0.037951	0.020079 ± 0.040822	0.001900 ± 0.001669	0.023053 ± 0.010660	0.000000 ± 0.000100	0.000000 ± 0.000100
caxc	0.003308 ± 0.001356	0.000598 ± 0.000466	0.000010 ± 0.000842	0.000012 ± 0.000907	0.000019 ± 0.000097	0.025627 ± 0.017374	0.000000 ± 0.000100	0.000000 ± 0.000100
tixc	0.000029 ± 0.002310	0.000005 ± 0.001150	0.000007 ± 0.001965	0.000007 ± 0.002085	0.000002 ± 0.000523	0.002530 ± 0.004404	0.000000 ± 0.000100	0.000000 ± 0.000100
vaxc	0.000015 ± 0.001027	0.000012 ± 0.000460	0.000008 ± 0.000800	0.000008 ± 0.000851	0.000002 ± 0.000213	0.000118 ± 0.001734	0.000000 ± 0.000100	0.000000 ± 0.000100
crxc	0.000195 ± 0.000209	0.000000 ± 0.000121	0.000002 ± 0.000189	0.000002 ± 0.000201	0.000001 ± 0.000052	0.000099 ± 0.000419	0.000000 ± 0.000100	0.000000 ± 0.000100
mxrc	0.000079 ± 0.000180	0.000004 ± 0.000090	0.000002 ± 0.000148	0.000001 ± 0.000157	0.000002 ± 0.000040	0.000589 ± 0.000322	0.000000 ± 0.000100	0.000000 ± 0.000100
fexc	0.009408 ± 0.011846	0.000201 ± 0.000226	0.000133 ± 0.000296	0.000043 ± 0.000133	0.000203 ± 0.000393	0.033690 ± 0.015930	0.000000 ± 0.000100	0.000000 ± 0.000100
nixc	0.000076 ± 0.000119	0.000003 ± 0.000058	0.000000 ± 0.000099	0.000000 ± 0.000105	0.000001 ± 0.000027	0.000002 ± 0.000218	0.000000 ± 0.000100	0.000000 ± 0.000100
cuxc	0.000202 ± 0.000130	0.000001 ± 0.000063	0.000004 ± 0.000107	0.000001 ± 0.000115	0.000008 ± 0.000017	0.000729 ± 0.000732	0.000000 ± 0.000100	0.000000 ± 0.000100
znxc	0.003198 ± 0.001652	0.000593 ± 0.000807	0.000142 ± 0.000468	0.000161 ± 0.000363	0.000255 ± 0.000509	0.000862 ± 0.000483	0.000000 ± 0.000100	0.000000 ± 0.000100
asxc	0.000009 ± 0.000341	0.000004 ± 0.000107	0.000006 ± 0.000190	0.000008 ± 0.000202	0.000000 ± 0.000051	0.000005 ± 0.000431	0.000000 ± 0.000100	0.000000 ± 0.000100
sexc	0.000003 ± 0.000072	0.000003 ± 0.000057	0.000000 ± 0.000098	0.000000 ± 0.000104	0.000000 ± 0.000026	0.000001 ± 0.000235	0.000000 ± 0.000100	0.000000 ± 0.000100
brxc	0.000212 ± 0.000434	0.000013 ± 0.000052	0.000013 ± 0.000083	0.000021 ± 0.000088	0.000007 ± 0.000019	0.000039 ± 0.000212	0.000000 ± 0.000100	0.000000 ± 0.000100
rbxc	0.000004 ± 0.000070	0.000009 ± 0.000048	0.000018 ± 0.000086	0.000020 ± 0.000091	0.000003 ± 0.000023	0.000104 ± 0.000200	0.000000 ± 0.000100	0.000000 ± 0.000100
srxc	0.000006 ± 0.000093	0.000002 ± 0.000053	0.000000 ± 0.000092	0.000000 ± 0.000098	0.000000 ± 0.000025	0.000307 ± 0.000220	0.000000 ± 0.000100	0.000000 ± 0.000100
zrxc	0.000009 ± 0.000101	0.000000 ± 0.000076	0.000000 ± 0.000136	0.000000 ± 0.000144	0.000000 ± 0.000036	0.000119 ± 0.000320	0.000000 ± 0.000100	0.000000 ± 0.000100
hgxc	0.000005 ± 0.000170	0.000000 ± 0.000128	0.000004 ± 0.000223	0.000004 ± 0.000237	0.000001 ± 0.000059	0.000008 ± 0.000520	0.000000 ± 0.000100	0.000000 ± 0.000100
pbxc	0.001252 ± 0.001379	0.000003 ± 0.000154	0.000004 ± 0.000282	0.000005 ± 0.000299	0.000002 ± 0.000074	0.000217 ± 0.000627	0.000000 ± 0.000100	0.000000 ± 0.000100

**Table 2b (continued)**  
**Source Composition Profiles Consisting of Conventional Species**

Profil	PCHCLC1	phautoc	phdiesc	PHCONSTR	PHPVRDCB	PHPVRD	PHUPRD1	PHUPRD2
clic	0.000000 ± 0.000100	0.003899 ± 0.004150	0.000855 ± 0.000721	0.000126 ± 0.000254	0.001061 ± 0.000841	0.001410 ± 0.002264	0.000273 ± 0.000354	0.001248 ± 0.000373
n3ic	0.000000 ± 0.002116	0.017786 ± 0.006751	0.002939 ± 0.002418	0.000365 ± 0.000773	0.000427 ± 0.001860	0.001132 ± 0.002042	0.000860 ± 0.001040	0.002952 ± 0.001153
s4ic	0.101716 ± 0.089405	0.026729 ± 0.007932	0.004316 ± 0.003643	0.001134 ± 0.000938	0.003880 ± 0.003315	0.002075 ± 0.001907	0.003176 ± 0.002762	0.001117 ± 0.000564
n4cc	0.003476 ± 0.001352	0.012099 ± 0.004441	0.001891 ± 0.001706	0.000672 ± 0.000355	0.000413 ± 0.000425	0.000706 ± 0.000462	0.000369 ± 0.000303	0.000664 ± 0.000425
kpac	0.001109 ± 0.000571	0.000792 ± 0.000426	0.000312 ± 0.000452	0.002657 ± 0.000677	0.001383 ± 0.001025	0.002147 ± 0.001204	0.002426 ± 0.000245	0.003469 ± 0.001337
tctc	0.042763 ± 0.042580	0.748839 ± 0.081423	0.844800 ± 0.052484	0.046167 ± 0.017301	0.239449 ± 0.022414	0.128440 ± 0.049099	0.089465 ± 0.046260	0.060544 ± 0.017508
octc	0.000000 ± 0.029263	0.534771 ± 0.073987	0.618903 ± 0.062321	0.046167 ± 0.015767	0.217272 ± 0.020782	0.118661 ± 0.048698	0.089465 ± 0.045528	0.060544 ± 0.014134
ectc	0.042763 ± 0.030931	0.214067 ± 0.092457	0.225896 ± 0.048967	0.000000 ± 0.007122	0.022177 ± 0.008395	0.009779 ± 0.006266	0.000000 ± 0.008199	0.000000 ± 0.010332
naxc	0.000000 ± 0.000100	0.001370 ± 0.007830	0.000000 ± 0.001138	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000
mpxc	0.000000 ± 0.000100	0.002927 ± 0.002740	0.000233 ± 0.000504	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000
alxc	0.059680 ± 0.005247	0.004532 ± 0.003061	0.000632 ± 0.000503	0.036848 ± 0.002762	0.040178 ± 0.003104	0.042470 ± 0.005194	0.037034 ± 0.002809	0.046176 ± 0.006027
sixc	0.090112 ± 0.005675	0.018509 ± 0.004544	0.003538 ± 0.002644	0.115005 ± 0.013446	0.132720 ± 0.009572	0.136932 ± 0.015685	0.121216 ± 0.008656	0.134416 ± 0.013629
phxc	0.009372 ± 0.006322	0.001579 ± 0.000471	0.000242 ± 0.000064	0.000286 ± 0.000108	0.000899 ± 0.000151	0.000782 ± 0.000201	0.000297 ± 0.000079	0.000638 ± 0.000113
suxc	0.029480 ± 0.027290	0.009006 ± 0.003232	0.003036 ± 0.001425	0.001073 ± 0.000554	0.006693 ± 0.000544	0.002593 ± 0.000969	0.001357 ± 0.000569	0.000629 ± 0.000088
clxc	0.000629 ± 0.000221	0.000825 ± 0.000780	0.000234 ± 0.000195	0.000620 ± 0.000116	0.002094 ± 0.000518	0.002159 ± 0.001857	0.001007 ± 0.000359	0.001298 ± 0.000556
kpxc	0.004644 ± 0.000602	0.002865 ± 0.001036	0.000580 ± 0.000572	0.014865 ± 0.001237	0.014248 ± 0.001067	0.018549 ± 0.001965	0.015120 ± 0.002285	0.016740 ± 0.001519
caxc	0.034536 ± 0.010411	0.008390 ± 0.001592	0.002632 ± 0.002830	0.091029 ± 0.016756	0.060567 ± 0.012806	0.046724 ± 0.010890	0.103772 ± 0.026776	0.036432 ± 0.003338
tixc	0.004315 ± 0.000651	0.000587 ± 0.003682	0.000198 ± 0.000433	0.003546 ± 0.000374	0.004077 ± 0.000484	0.004447 ± 0.000435	0.003161 ± 0.000345	0.005233 ± 0.001587
vaxc	0.000000 ± 0.000734	0.000248 ± 0.001493	0.000041 ± 0.000176	0.000238 ± 0.000090	0.000365 ± 0.000173	0.000261 ± 0.000172	0.000211 ± 0.000109	0.000317 ± 0.000132
crxc	0.000176 ± 0.000041	0.000055 ± 0.000328	0.000011 ± 0.000041	0.000186 ± 0.000025	0.000478 ± 0.000248	0.000248 ± 0.000035	0.000176 ± 0.000035	0.000242 ± 0.000035
mxc	0.000284 ± 0.000139	0.000183 ± 0.000230	0.000052 ± 0.000058	0.001047 ± 0.000132	0.001035 ± 0.000106	0.001065 ± 0.000140	0.000888 ± 0.000122	0.001502 ± 0.000734
fexc	0.029160 ± 0.003827	0.007792 ± 0.002024	0.002990 ± 0.003215	0.035051 ± 0.002494	0.047128 ± 0.003399	0.044195 ± 0.003630	0.034066 ± 0.002763	0.043395 ± 0.003098
nixc	0.000072 ± 0.000019	0.000055 ± 0.000165	0.000007 ± 0.000021	0.000054 ± 0.000008	0.000183 ± 0.000025	0.000093 ± 0.000018	0.000055 ± 0.000010	0.000060 ± 0.000009
cuxc	0.000179 ± 0.000112	0.001100 ± 0.000216	0.002788 ± 0.004092	0.000109 ± 0.000055	0.000340 ± 0.000044	0.000257 ± 0.000086	0.000079 ± 0.000044	0.000142 ± 0.000021
znxc	0.000797 ± 0.000341	0.002266 ± 0.000606	0.000608 ± 0.000270	0.000335 ± 0.000260	0.001296 ± 0.000438	0.001202 ± 0.000260	0.000880 ± 0.000624	0.000556 ± 0.000296
asxc	0.000000 ± 0.000164	0.000039 ± 0.000390	0.000004 ± 0.000046	0.000016 ± 0.000055	0.000000 ± 0.000162	0.000013 ± 0.000168	0.000017 ± 0.000091	0.000013 ± 0.000133
sexc	0.000406 ± 0.000407	0.000047 ± 0.000181	0.000010 ± 0.000021	0.000000 ± 0.000022	0.000000 ± 0.000040	0.000011 ± 0.000028	0.000013 ± 0.000025	0.000018 ± 0.000023
brxc	0.000147 ± 0.000154	0.000096 ± 0.000146	0.000013 ± 0.000019	0.000018 ± 0.000008	0.000013 ± 0.000040	0.000042 ± 0.000044	0.000017 ± 0.000023	0.000037 ± 0.000020
rbxc	0.000053 ± 0.000043	0.000022 ± 0.000155	0.000006 ± 0.000018	0.000101 ± 0.000016	0.000091 ± 0.000041	0.000129 ± 0.000023	0.000106 ± 0.000018	0.000123 ± 0.000021
srxc	0.001964 ± 0.000686	0.000044 ± 0.000174	0.000014 ± 0.000019	0.000461 ± 0.000109	0.000626 ± 0.000109	0.000968 ± 0.000633	0.000503 ± 0.000042	0.000552 ± 0.000141
zrxc	0.000247 ± 0.000043	0.000000 ± 0.000254	0.000002 ± 0.000030	0.000156 ± 0.000025	0.000158 ± 0.000041	0.000155 ± 0.000039	0.000111 ± 0.000036	0.000164 ± 0.000043
hgxc	0.000000 ± 0.000154	0.000010 ± 0.000401	0.000000 ± 0.000047	0.000018 ± 0.000045	0.000000 ± 0.000081	0.000016 ± 0.000066	0.000020 ± 0.000056	0.000005 ± 0.000066
pbxc	0.000680 ± 0.000336	0.000896 ± 0.000373	0.000098 ± 0.000048	0.000165 ± 0.000160	0.000710 ± 0.000345	0.000811 ± 0.000436	0.000417 ± 0.000086	0.000584 ± 0.000524

**Table 2b (continued)**  
**Source Composition Profiles Consisting of Conventional Species**

Profile	PHBAREAG	PHDSSOIL	PHAUTO	PHDIES	PHRD
clic	0.000222 ± 0.000322	0.000118 ± 0.000324	0.006400 ± 0.006554	0.016204 ± 0.043981	0.011573 ± 0.007545
n3ic	0.000732 ± 0.001062	0.000720 ± 0.001015	0.038949 ± 0.028743	0.003095 ± 0.003995	0.110254 ± 0.104066
s4ic	0.000572 ± 0.000297	0.000147 ± 0.000272	0.022885 ± 0.013188	0.024448 ± 0.010048	0.060125 ± 0.020920
n4cc	0.001089 ± 0.000558	0.000994 ± 0.000520	0.016722 ± 0.010236	0.008661 ± 0.001261	0.041064 ± 0.027397
kpac	0.003685 ± 0.001213	0.003401 ± 0.001440	0.003861 ± 0.009616	0.003876 ± 0.009574	0.007588 ± 0.023147
tctc	0.042965 ± 0.020598	0.036610 ± 0.015840	0.435773 ± 0.146806	0.730145 ± 0.103475	0.754677 ± 0.216194
octc	0.042965 ± 0.018395	0.036610 ± 0.012785	0.300752 ± 0.122989	0.400956 ± 0.066018	0.390031 ± 0.186177
ectc	0.000000 ± 0.009269	0.000000 ± 0.009352	0.135021 ± 0.080161	0.329189 ± 0.079679	0.364646 ± 0.109899
naxc	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000
mgxc	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000	0.000000 ± 0.010000
alxc	0.050197 ± 0.007979	0.049811 ± 0.005476	0.004118 ± 0.002046	0.001735 ± 0.001211	0.000723 ± 0.005250
sixc	0.143490 ± 0.014780	0.140039 ± 0.017430	0.016443 ± 0.008785	0.004627 ± 0.001838	0.000828 ± 0.011319
phxc	0.000552 ± 0.000175	0.000828 ± 0.000403	0.001147 ± 0.000653	0.000609 ± 0.000583	0.000837 ± 0.001327
suxc	0.000912 ± 0.000128	0.000598 ± 0.000087	0.010111 ± 0.004806	0.012395 ± 0.002824	0.020156 ± 0.006026
clxc	0.000773 ± 0.000171	0.000415 ± 0.000127	0.003376 ± 0.003217	0.000282 ± 0.000613	0.005624 ± 0.004085
kpxc	0.019801 ± 0.003200	0.018894 ± 0.003333	0.002493 ± 0.001414	0.000421 ± 0.000332	0.002150 ± 0.002294
caxc	0.051507 ± 0.023243	0.034550 ± 0.013424	0.007071 ± 0.004068	0.001586 ± 0.000631	0.001253 ± 0.009805
tixc	0.004428 ± 0.000550	0.005013 ± 0.000899	0.000654 ± 0.001256	0.000015 ± 0.001530	0.000872 ± 0.004008
vaxc	0.000255 ± 0.000116	0.000300 ± 0.000115	0.000047 ± 0.000538	0.000008 ± 0.000621	0.000233 ± 0.002011
crxc	0.000234 ± 0.000037	0.000241 ± 0.000098	0.000151 ± 0.000104	0.000039 ± 0.000147	0.000187 ± 0.000402
mnxc	0.001363 ± 0.000255	0.001365 ± 0.000288	0.001048 ± 0.000359	0.000082 ± 0.000113	0.001782 ± 0.001142
fexc	0.047648 ± 0.008737	0.044803 ± 0.005147	0.006849 ± 0.004231	0.001588 ± 0.000652	0.009341 ± 0.005294
nixc	0.000065 ± 0.000015	0.000064 ± 0.000015	0.000094 ± 0.000093	0.000026 ± 0.000054	0.000189 ± 0.000149
cuxc	0.000140 ± 0.000065	0.000111 ± 0.000026	0.000739 ± 0.000642	0.000132 ± 0.000082	0.003558 ± 0.001351
znxc	0.000232 ± 0.000058	0.000288 ± 0.000123	0.002727 ± 0.002250	0.000699 ± 0.000190	0.005054 ± 0.003873
asxc	0.000017 ± 0.000059	0.000008 ± 0.000052	0.000021 ± 0.000351	0.000009 ± 0.000208	0.000057 ± 0.000942
sexc	0.000009 ± 0.000027	0.000000 ± 0.000030	0.000010 ± 0.000090	0.000009 ± 0.000103	0.000042 ± 0.000335
brxc	0.000021 ± 0.000016	0.000007 ± 0.000029	0.000294 ± 0.000163	0.000023 ± 0.000089	0.000580 ± 0.000339
rbxc	0.000136 ± 0.000027	0.000126 ± 0.000018	0.000014 ± 0.000090	0.000015 ± 0.000102	0.000019 ± 0.000331
srxc	0.000387 ± 0.000056	0.000335 ± 0.000047	0.000070 ± 0.000106	0.000018 ± 0.000132	0.000042 ± 0.000476
zrxc	0.000184 ± 0.000033	0.000181 ± 0.000036	0.000038 ± 0.000173	0.000019 ± 0.000198	0.000100 ± 0.000631
hgxc	0.000007 ± 0.000057	0.000021 ± 0.000046	0.000018 ± 0.000216	0.000014 ± 0.000248	0.000035 ± 0.000798
pbxc	0.000130 ± 0.000051	0.000166 ± 0.000087	0.001553 ± 0.000723	0.000147 ± 0.000294	0.002700 ± 0.001261

**Table 3**  
**Source Contributions to PM<sub>2.5</sub> at the Phoenix Super Site by Extended Species CMB (11/94 to 3/95)**

Site	PM <sub>2.5</sub> Mass	PM <sub>2.5</sub> Total Carbon	PM <sub>2.5</sub> Organic Carbon	PM <sub>2.5</sub> Elemental Carbon
Start Hour (MST)				
Duration	24	24	24	24
Observations	12	12	12	12
Concentration (ug/m3) ± RMS	15.2 ± 1.7	8.9 ± 0.7	5.3 ± 0.4	3.6 ± 0.4
R-square ± SD	0.95 ± 0.03			
Chi-square ± SD	0.36 ± 0.30			
Percent Mass Attributed ± SD	100.8 ± 1.7	100.3 ± 0.5	100.5 ± 0.5	100.2 ± 0.7
Mean Contributions (ug/m3) ± RMS <sup>a, b</sup>				
Gasoline Exhaust, cold start	3.8 ± 4.2	3.3 ± 0.3	1.7 ± 0.6	1.6 ± 0.6
Gasoline Exhaust, hot stabilized	-0.2 ± 1.2	-0.2 ± 0.0	-0.1 ± 0.0	-0.1 ± 0.1
Gasoline Exhaust, high emitter	4.1 ± 1.8	3.4 ± 0.2	3.1 ± 0.2	0.3 ± 0.1
Diesel Exhaust	2.4 ± 2.2	2.3 ± 0.1	0.5 ± 0.2	1.8 ± 0.3
Ammonium Sulfate	1.3 ± 0.2			
Ammonium Nitrate	2.5 ± 0.4			
Geological	1.4 ± 0.3	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0
Unexplained	-0.1	0.0	0.0	0.0
Mean Contributions (%) ± RMS <sup>c, d</sup>				
Gasoline Exhaust, cold start	26.4 ± 29.8	39.5 ± 3.7	34.1 ± 11.4	48.3 ± 17.7
Gasoline Exhaust, hot stabilized	-1.5 ± 8.2	-1.9 ± 0.2	-2.2 ± 0.6	-1.5 ± 1.3
Gasoline Exhaust, high emitter	26.6 ± 12.9	36.9 ± 1.5	56.5 ± 2.5	7.1 ± 3.6
Diesel Exhaust	15.1 ± 15.6	23.2 ± 1.0	8.0 ± 3.7	45.6 ± 6.8
Ammonium Sulfate	9.8 ± 1.2			
Ammonium Nitrate	12.7 ± 1.5			
Geological	10.6 ± 1.9	2.3 ± 1.0	3.5 ± 1.6	0.5 ± 0.3
Unexplained	0.2	0.0	0.0	0.1
Mean Contributions (%) ± Std Err <sup>c, e</sup>				
Gasoline Exhaust, cold start	26.4 ± 3.0	39.5 ± 4.9	34.1 ± 4.2	48.3 ± 6.5
Gasoline Exhaust, hot stabilized	-1.5 ± 0.4	-1.9 ± 0.5	-2.2 ± 0.6	-1.5 ± 0.4
Gasoline Exhaust, high emitter	26.6 ± 2.4	36.9 ± 2.7	56.5 ± 3.7	7.1 ± 0.7
Diesel Exhaust	15.1 ± 2.3	23.2 ± 3.4	8.0 ± 1.2	45.6 ± 6.2
Ammonium Sulfate	9.8 ± 1.6			
Ammonium Nitrate	12.7 ± 3.0			
Geological	10.6 ± 1.5	2.3 ± 0.3	3.5 ± 0.5	0.5 ± 0.1
Unexplained	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0

a Uncertainties are root mean squares of the individual 1-sigma error propagations from CMB. Zero uncertainties are excluded from RMS.

b Samples with percent mass attribution > 120 percent are removed from average source contributions.

c Contributions are normalized to sum of contributions including non-negative unexplained contributions.

d Uncertainties are root mean squares of the individual 1-sigma error in percent of normalized sum. Zero uncertainties are excluded from RM

e Uncertainties are standard errors of the mean.

**Table 4a**  
**Contributions to PM<sub>2.5</sub> Mass in Phoenix, AZ in 1994/95, Conventional Species CMB**

Site	ADEQ Super Site	ADEQ Super Site	Tempe	ASU West
Start Hour (MST)				
Duration	6	24	6	6
Observations	25	26	28	22
Concentration (ug/m3) ± RMS	19.6 ± 2.1	12.4 ± 1.4	13.8 ± 1.4	13.6 ± 1.5
R-square ± SD	0.97 ± 0.03	0.97 ± 0.02	0.98 ± 0.01	0.98 ± 0.01
Chi-square ± SD	0.36 ± 0.36	0.46 ± 0.40	0.18 ± 0.13	0.21 ± 0.15
Percent Mass Attributed ± SD	101.7 ± 4.6	103.5 ± 2.7	104.7 ± 4.6	103.6 ± 4.0
Mean Contributions (ug/m3) ± RMS <sup>a, b</sup>				
Gasoline Exhaust	13.7 ± 2.2	6.8 ± 1.2	8.9 ± 1.8	9.7 ± 1.5
Diesel Exhaust	-0.1 ± 1.5	0.8 ± 0.8	0.3 ± 1.3	-0.4 ± 1.0
Ammonium Sulfate	1.6 ± 0.3	1.6 ± 0.2	1.3 ± 0.4	1.4 ± 0.2
Ammonium Nitrate	2.6 ± 0.4	1.8 ± 0.4	1.3 ± 0.3	1.3 ± 0.3
Geological	1.6 ± 0.6	1.2 ± 0.4	1.7 ± 0.6	1.9 ± 0.4
Ambient Bkgrd w/Smelter	0.5 ± 2.8	0.4 ± 1.2	1.0 ± 2.4	0.1 ± 1.9
Unexplained	-0.2	-0.3	-0.7	-0.5
Mean Contributions (%) ± RMS <sup>c, d</sup>				
Gasoline Exhaust	74.1 ± 12.3	55.5 ± 8.9	64.4 ± 12.1	73.0 ± 11.1
Diesel Exhaust	-5.3 ± 8.1	4.6 ± 6.2	0.4 ± 8.3	-5.6 ± 7.0
Ammonium Sulfate	9.0 ± 2.1	15.2 ± 2.1	9.7 ± 2.4	9.6 ± 1.7
Ammonium Nitrate	10.0 ± 1.8	9.2 ± 1.5	7.9 ± 1.7	7.4 ± 1.5
Geological	8.4 ± 3.5	12.3 ± 2.9	11.8 ± 3.9	14.7 ± 3.1
Ambient Bkgrd w/Smelter	3.2 ± 18.6	3.0 ± 8.9	5.7 ± 13.9	0.6 ± 9.1
Unexplained	0.6	0.1	0.1	0.3
Mean Contributions (%) ± Std Err <sup>c, e</sup>				
Gasoline Exhaust	74.1 ± 3.8	55.5 ± 1.7	64.4 ± 3.2	73.0 ± 3.7
Diesel Exhaust	-5.3 ± 2.9	4.6 ± 1.9	0.4 ± 2.5	-5.6 ± 2.7
Ammonium Sulfate	9.0 ± 1.1	15.2 ± 1.8	9.7 ± 1.1	9.6 ± 1.1
Ammonium Nitrate	10.0 ± 2.4	9.2 ± 2.3	7.9 ± 1.6	7.4 ± 2.0
Geological	8.4 ± 2.1	12.3 ± 1.6	11.8 ± 2.2	14.7 ± 2.3
Ambient Bkgrd w/Smelter	3.2 ± 2.4	3.0 ± 1.5	5.7 ± 2.6	0.6 ± 0.6
Unexplained	0.6 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.2

- a Uncertainties are root mean squares of the individual 1-sigma error propagations from CMB. Zero uncertainties are excluded from RMS.
- b Samples with percent mass attribution > 120 percent are removed from average source contributions.
- c Contributions are normalized to sum of contributions including non-negative unexplained contributions.
- d Uncertainties are root mean squares of the individual 1-sigma error in percent of normalized sum. Zero uncertainties are excluded from RMS.
- e Uncertainties are standard errors of the mean.

**Table 4b**  
**Contributions to PM<sub>2.5</sub> Total Carbon in Phoenix, AZ in 1994/95, Conventional Species CMB**

Site	ADEQ Super Site	ADEQ Super Site	Tempe	ASU West
Start Hour (MST)				
Duration	6	24	6	6
Observations	25	26	28	22
Concentration (ug/m3) ± RMS	11.7 ± 1.0	6.7 ± 0.6	8.2 ± 0.7	8.0 ± 0.7
R-square ± SD				
Chi-square ± SD				
Percent Mass Attributed ± SD	99.1 ± 1.4	100.5 ± 1.0	99.9 ± 1.7	99.5 ± 1.2
Mean Contributions (ug/m3) ± RMS <sup>a, b</sup>				
Gasoline Exhaust	11.4 ± 0.5	5.7 ± 0.3	7.4 ± 0.3	8.0 ± 0.4
Diesel Exhaust	-0.1 ± 0.1	0.8 ± 0.1	0.3 ± 0.1	-0.4 ± 0.1
Geological	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.3 ± 0.1
Ambient Bkgrd w/Smelter	0.1 ± 1.4	0.1 ± 0.5	0.3 ± 1.2	0.0 ± 0.6
Unexplained	0.1	0.0	0.0	0.0
Mean Contributions (%) ± RMS <sup>c, d</sup>				
Gasoline Exhaust	103.9 ± 4.7	88.5 ± 4.0	93.2 ± 4.2	104.7 ± 4.7
Diesel Exhaust	-8.7 ± 0.9	6.4 ± 0.7	0.1 ± 0.8	-9.3 ± 0.9
Geological	2.0 ± 1.4	3.1 ± 1.5	2.9 ± 1.8	3.5 ± 1.9
Ambient Bkgrd w/Smelter	1.8 ± 17.4	1.8 ± 7.7	3.2 ± 13.0	0.4 ± 6.1
Unexplained	1.1	0.2	0.7	0.8
Mean Contributions (%) ± Std Err <sup>c, e</sup>				
Gasoline Exhaust	103.9 ± 4.1	88.5 ± 2.8	93.2 ± 3.9	104.7 ± 4.1
Diesel Exhaust	-8.7 ± 4.5	6.4 ± 3.1	0.1 ± 4.0	-9.3 ± 4.3
Geological	2.0 ± 0.7	3.1 ± 0.4	2.9 ± 0.7	3.5 ± 0.8
Ambient Bkgrd w/Smelter	1.8 ± 1.3	1.8 ± 0.8	3.2 ± 1.4	0.4 ± 0.4
Unexplained	1.1 ± 0.2	0.2 ± 0.1	0.7 ± 0.2	0.8 ± 0.2

a Uncertainties are root mean squares of the individual 1-sigma error propagations from CMB. Zero uncertainties are excluded from RMS.

b Samples with percent mass attribution > 120 percent are removed from average source contributions.

c Contributions are normalized to sum of contributions including non-negative unexplained contributions.

d Uncertainties are root mean squares of the individual 1-sigma error in percent of normalized sum. Zero uncertainties are excluded from RMS.

e Uncertainties are standard errors of the mean.

**Table 4c**  
**Contributions to PM<sub>2.5</sub> Organic Carbon in Phoenix, AZ in 1994/95, Conventional Species CMB**

Site	ADEQ Super Site	ADEQ Super Site	Tempe	ASU West
Start Hour (MST)				
Duration	6	24	6	6
Observations	25	26	28	22
Concentration (ug/m3) ± RMS	8.4 ± 0.7	4.3 ± 0.4	5.5 ± 0.5	5.9 ± 0.5
R-square ± SD				
Chi-square ± SD				
Percent Mass Attributed ± SD	99.0 ± 2.5	101.0 ± 2.1	100.4 ± 2.9	99.5 ± 1.8
Mean Contributions (ug/m3) ± RMS <sup>a, b</sup>				
Gasoline Exhaust	8.1 ± 0.8	4.0 ± 0.4	5.2 ± 0.5	5.7 ± 0.5
Diesel Exhaust	0.0 ± 0.3	0.2 ± 0.1	0.1 ± 0.2	-0.1 ± 0.1
Geological	0.2 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.1
Ambient Bkgrd w/Smelter	0.0 ± 1.5	0.0 ± 0.6	0.0 ± 1.3	0.0 ± 0.7
Unexplained	0.1	0.0	0.0	0.0
Mean Contributions (%) ± RMS <sup>c, d</sup>				
Gasoline Exhaust	97.3 ± 8.9	92.8 ± 8.5	93.8 ± 8.6	96.6 ± 8.9
Diesel Exhaust	-1.5 ± 2.7	2.5 ± 2.3	1.0 ± 2.7	-1.7 ± 2.4
Geological	2.3 ± 1.7	4.1 ± 2.0	3.6 ± 2.2	4.1 ± 2.2
Ambient Bkgrd w/Smelter	0.4 ± 26.8	0.4 ± 13.6	0.7 ± 23.4	0.1 ± 10.7
Unexplained	1.5	0.3	0.9	1.0
Mean Contributions (%) ± Std Err <sup>c, e</sup>				
Gasoline Exhaust	97.3 ± 1.3	92.8 ± 0.9	93.8 ± 1.3	96.6 ± 1.2
Diesel Exhaust	-1.5 ± 1.3	2.5 ± 1.0	1.0 ± 1.2	-1.7 ± 1.2
Geological	2.3 ± 0.7	4.1 ± 0.6	3.6 ± 0.8	4.1 ± 0.8
Ambient Bkgrd w/Smelter	0.4 ± 0.3	0.4 ± 0.2	0.7 ± 0.3	0.1 ± 0.1
Unexplained	1.5 ± 0.2	0.3 ± 0.1	0.9 ± 0.2	1.0 ± 0.2

a Uncertainties are root mean squares of the individual 1-sigma error propagations from CMB. Zero uncertainties are excluded from RMS.

b Samples with percent mass attribution > 120 percent are removed from average source contributions.

c Contributions are normalized to sum of contributions including non-negative unexplained contributions.

d Uncertainties are root mean squares of the individual 1-sigma error in percent of normalized sum. Zero uncertainties are excluded from RM!

e Uncertainties are standard errors of the mean.

**Table 4d**  
**Contributions to PM<sub>2.5</sub> Elemental Carbon in Phoenix, AZ in 1994/95, Conventional Species CMB**

Site	ADEQ Super Site	ADEQ Super Site	Tempe	ASU West
Start Hour (MST)				
Duration	6	24	6	6
Observations	25	26	28	22
Concentration (ug/m3) ± RMS	3.3 ± 0.5	2.4 ± 0.3	2.6 ± 0.4	2.1 ± 0.3
R-square ± SD				
Chi-square ± SD				
Percent Mass Attributed ± SD	100.8 ± 1.3	100.0 ± 0.6	100.3 ± 0.9	100.7 ± 0.9
Mean Contributions (ug/m3) ± RMS <sup>a, b</sup>				
Gasoline Exhaust	3.3 ± 0.6	1.6 ± 0.3	2.1 ± 0.4	2.3 ± 0.4
Diesel Exhaust	-0.1 ± 0.3	0.6 ± 0.2	0.3 ± 0.2	-0.3 ± 0.2
Geological	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ambient Bkgrd w/Smelter	0.1 ± 1.2	0.1 ± 0.5	0.2 ± 1.1	0.0 ± 0.5
Unexplained	0.0	0.0	0.0	0.0
Mean Contributions (%) ± RMS <sup>c, d</sup>				
Gasoline Exhaust	175.5 ± 37.7	89.0 ± 16.3	123.2 ± 26.1	176.5 ± 34.7
Diesel Exhaust	-81.9 ± 22.9	5.5 ± 5.9	-32.0 ± 14.1	-79.3 ± 19.2
Geological	0.9 ± 1.3	0.9 ± 0.7	1.1 ± 1.7	1.9 ± 2.6
Ambient Bkgrd w/Smelter	5.3 ± 54.5	4.3 ± 18.6	7.5 ± 32.1	0.9 ± 14.4
Unexplained	0.1	0.2	0.2	0.1
Mean Contributions (%) ± Std Err <sup>c, e</sup>				
Gasoline Exhaust	175.5 ± 29.9	89.0 ± 8.4	123.2 ± 19.0	176.5 ± 25.0
Diesel Exhaust	-81.9 ± 29.7	5.5 ± 8.5	-32.0 ± 18.9	-79.3 ± 25.3
Geological	0.9 ± 0.4	0.9 ± 0.2	1.1 ± 0.4	1.9 ± 0.8
Ambient Bkgrd w/Smelter	5.3 ± 4.0	4.3 ± 2.0	7.5 ± 3.5	0.9 ± 0.9
Unexplained	0.1 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.1 ± 0.0

a Uncertainties are root mean squares of the individual 1-sigma error propagations from CMB. Zero uncertainties are excluded from RMS.

b Samples with percent mass attribution > 120 percent are removed from average source contributions.

c Contributions are normalized to sum of contributions including non-negative unexplained contributions.

d Uncertainties are root mean squares of the individual 1-sigma error in percent of normalized sum. Zero uncertainties are excluded from RI

e Uncertainties are standard errors of the mean.

# **ATTACHMENT I**

## **EXTENDED SPECIES CMB RESULTS FOR INDIVIDUAL 24-HOUR SAMPLES AT PHOENIX SUPER SITE**

**Attachment I**  
**Extended Species CMB Results for Individual 24-Hour Samples at Phoenix Super Site**

Species	Date	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust, cold start (ug/m3)	Gasoline Exhaust, hot stabilized (ug/m3)	Gasoline Exhaust, high emitter (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Unexplained (ug/m3)
PM2.5	11/10/94	8.7 ± 0.9	0.92	0.58	99.8	3.8 ± 4.6	-0.1 ± 1.2	1.3 ± 1.8	0.0 ± 2.3	1.1 ± 0.1	0.8 ± 0.1	1.8 ± 0.2	0.0
PM2.5	11/2/94	9.1 ± 0.9	0.97	0.22	102.2	1.9 ± 1.5	0.0 ± 0.0	2.6 ± 0.9	1.6 ± 1.0	1.4 ± 0.1	0.7 ± 0.1	1.2 ± 0.2	-0.2
PM2.5	11/22/94	34.6 ± 3.5	0.98	0.26	99.2	6.5 ± 6.5	-0.7 ± 1.7	8.1 ± 2.9	5.3 ± 3.5	1.7 ± 0.2	11.4 ± 1.0	2.0 ± 0.5	0.3
PM2.5	11/28/94	16.8 ± 1.7	0.98	0.13	101.0	4.2 ± 4.5	-0.6 ± 1.2	5.5 ± 2.0	3.8 ± 2.4	0.4 ± 0.1	2.1 ± 0.2	1.5 ± 0.3	-0.2
PM2.5	12/04/94	19.3 ± 1.9	0.97	0.26	98.8	4.8 ± 4.9	-0.3 ± 1.3	5.8 ± 2.1	1.6 ± 2.6	2.3 ± 0.3	3.2 ± 0.3	1.6 ± 0.3	0.2
PM2.5	12/10/94	13.8 ± 1.4	0.97	0.18	100.7	2.9 ± 3.2	-0.5 ± 0.8	6.0 ± 1.5	2.8 ± 1.7	0.7 ± 0.1	0.9 ± 0.1	1.1 ± 0.3	-0.1
PM2.5	12/22/94	13.7 ± 1.4	0.97	0.23	100.9	4.7 ± 5.8	-0.1 ± 1.5	2.4 ± 2.3	2.8 ± 2.9	1.1 ± 0.1	0.6 ± 0.1	2.2 ± 0.3	-0.1
PM2.5	01/03/95	18.5 ± 1.8	0.89	1.12	99.8	1.7 ± 2.0	0.1 ± 0.5	4.3 ± 1.1	3.5 ± 1.2	2.2 ± 0.2	6.0 ± 0.5	0.7 ± 0.2	0.0
PM2.5	01/09/95	16.2 ± 1.6	0.97	0.16	100.2	4.7 ± 3.8	-0.4 ± 0.9	4.6 ± 2.0	4.4 ± 2.2	1.1 ± 0.2	0.8 ± 0.1	0.9 ± 0.3	0.0
PM2.5	02/02/95	16.8 ± 1.7	0.97	0.22	100.4	5.3 ± 4.8	-0.3 ± 1.2	4.4 ± 2.2	1.6 ± 2.5	1.5 ± 0.2	3.0 ± 0.3	1.3 ± 0.3	-0.1
PM2.5	02/08/95	8.7 ± 0.9	0.89	0.69	102.0	3.8 ± 3.7	-0.1 ± 0.9	1.4 ± 1.6	0.3 ± 1.9	2.1 ± 0.2	0.2 ± 0.0	1.2 ± 0.2	-0.2
PM2.5	03/22/95	6.2 ± 0.6	0.94	0.38	105.1	1.1 ± 1.2	0.0 ± 0.0	2.3 ± 0.7	1.1 ± 0.7	0.4 ± 0.1	0.4 ± 0.1	1.2 ± 0.2	-0.3
TC	11/10/94	4.5 ± 0.3	0.92	0.58	101.8	3.4 ± 0.3	-0.1 ± 0.0	1.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	-0.1
TC	11/2/94	5.5 ± 0.4	0.97	0.22	100.1	1.7 ± 0.1	0.0 ± 0.0	2.1 ± 0.1	1.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0
TC	11/22/94	17.1 ± 1.2	0.98	0.26	100.1	5.7 ± 0.5	-0.6 ± 0.0	6.7 ± 0.3	5.0 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0
TC	11/28/94	11.6 ± 0.8	0.98	0.13	100.2	3.7 ± 0.3	-0.5 ± 0.0	4.6 ± 0.2	3.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0
TC	12/04/94	10.5 ± 0.7	0.97	0.26	100.3	4.3 ± 0.4	-0.2 ± 0.0	4.8 ± 0.2	1.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0
TC	12/10/94	9.9 ± 0.7	0.97	0.18	100.0	2.5 ± 0.2	-0.4 ± 0.0	5.0 ± 0.2	2.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0
TC	12/22/94	9.0 ± 0.6	0.97	0.23	100.7	4.2 ± 0.4	-0.1 ± 0.0	2.0 ± 0.1	2.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	-0.1
TC	01/03/95	8.5 ± 0.7	0.89	1.12	100.2	1.5 ± 0.1	0.1 ± 0.0	3.6 ± 0.1	3.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0
TC	01/09/95	11.9 ± 1.0	0.97	0.16	100.3	4.2 ± 0.4	-0.3 ± 0.0	3.8 ± 0.2	4.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0
TC	02/02/95	9.8 ± 0.8	0.97	0.22	100.1	4.7 ± 0.4	-0.2 ± 0.0	3.7 ± 0.1	1.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0
TC	02/08/95	4.9 ± 0.4	0.89	0.69	100.4	3.3 ± 0.3	-0.1 ± 0.0	1.2 ± 0.0	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0
TC	03/22/95	4.1 ± 0.3	0.94	0.38	99.8	1.0 ± 0.1	0.0 ± 0.0	1.9 ± 0.1	1.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0

Species	Date	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust, cold start (ug/m3)	Gasoline Exhaust, hot stabilized (ug/m3)	Gasoline Exhaust, high emitter (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Unexplained (ug/m3)
OC	11/10/94	2.9 ± 0.2	0.92	0.58	101.7	1.8 ± 0.5	-0.1 ± 0.0	1.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0
OC	11/2/94	3.3 ± 0.2	0.97	0.22	100.0	0.9 ± 0.3	0.0 ± 0.0	2.0 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0
OC	11/22/94	10.0 ± 0.7	0.98	0.26	100.3	3.0 ± 0.9	-0.4 ± 0.1	6.2 ± 0.3	1.0 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0
OC	11/28/94	6.7 ± 0.4	0.98	0.13	100.6	1.9 ± 0.6	-0.3 ± 0.1	4.3 ± 0.2	0.7 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0
OC	12/04/94	7.0 ± 0.5	0.97	0.26	100.4	2.2 ± 0.7	-0.2 ± 0.0	4.5 ± 0.2	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0
OC	12/10/94	6.3 ± 0.4	0.97	0.18	100.0	1.3 ± 0.4	-0.3 ± 0.1	4.6 ± 0.2	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0
OC	12/22/94	4.7 ± 0.3	0.97	0.23	101.1	2.2 ± 0.7	0.0 ± 0.0	1.8 ± 0.1	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	-0.1
OC	01/03/95	4.9 ± 0.4	0.89	1.12	100.6	0.8 ± 0.2	0.1 ± 0.0	3.3 ± 0.1	0.7 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0
OC	01/09/95	6.4 ± 0.6	0.97	0.16	100.5	2.2 ± 0.7	-0.2 ± 0.0	3.5 ± 0.2	0.8 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0
OC	02/02/95	6.1 ± 0.5	0.97	0.22	100.2	2.4 ± 0.8	-0.2 ± 0.0	3.4 ± 0.1	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0
OC	02/08/95	2.9 ± 0.3	0.89	0.69	100.9	1.7 ± 0.5	-0.1 ± 0.0	1.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0
OC	03/22/95	2.6 ± 0.2	0.94	0.38	100.0	0.5 ± 0.2	0.0 ± 0.0	1.8 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0
EC	11/10/94	1.7 ± 0.2	0.92	0.58	102.1	1.6 ± 0.5	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
EC	11/2/94	2.2 ± 0.2	0.97	0.22	100.6	0.8 ± 0.3	0.0 ± 0.0	0.2 ± 0.1	1.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
EC	11/22/94	7.1 ± 0.7	0.98	0.26	99.8	2.7 ± 0.9	-0.2 ± 0.1	0.5 ± 0.2	4.0 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
EC	11/28/94	4.9 ± 0.5	0.98	0.13	99.7	1.8 ± 0.6	-0.1 ± 0.1	0.3 ± 0.2	2.9 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
EC	12/04/94	3.5 ± 0.3	0.97	0.26	100.4	2.1 ± 0.7	-0.1 ± 0.0	0.4 ± 0.2	1.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
EC	12/10/94	3.6 ± 0.4	0.97	0.18	100.1	1.2 ± 0.4	-0.1 ± 0.1	0.4 ± 0.2	2.1 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
EC	12/22/94	4.3 ± 0.4	0.97	0.23	100.2	2.0 ± 0.7	0.0 ± 0.0	0.1 ± 0.1	2.1 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
EC	01/03/95	3.7 ± 0.2	0.89	1.12	99.6	0.7 ± 0.2	0.0 ± 0.0	0.3 ± 0.1	2.6 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
EC	01/09/95	5.5 ± 0.4	0.97	0.16	100.0	2.0 ± 0.7	-0.1 ± 0.1	0.3 ± 0.1	3.3 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
EC	02/02/95	3.7 ± 0.2	0.97	0.22	99.9	2.2 ± 0.8	-0.1 ± 0.0	0.3 ± 0.1	1.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
EC	02/08/95	1.9 ± 0.1	0.89	0.69	99.6	1.6 ± 0.5	0.0 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
EC	03/22/95	1.4 ± 0.1	0.94	0.38	99.8	0.5 ± 0.2	0.0 ± 0.0	0.1 ± 0.1	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0

## **ATTACHMENT II**

### **CONVENTIONAL CMB RESULTS FOR INDIVIDUAL SAMPLES**

**Attachment II**  
**Conventional CMB Results for Individual Samples**

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
pm25	SS1-3	11/16/94	6	19.8 ± 2.0	0.98	0.26	100.7	13.0 ± 2.1	2.1 ± 1.3	1.6 ± 0.2	2.2 ± 0.3	1.1 ± 0.4	0.0 ± 0.0	-0.1
pm25	SS1-3	11/22/94	6	44.8 ± 4.5	0.99	0.21	99.3	21.1 ± 3.0	7.3 ± 2.5	1.9 ± 0.3	12.5 ± 1.1	1.7 ± 0.6	0.0 ± 0.0	0.3
pm25	SS1-3	11/28/94	6	39.6 ± 4.0	0.98	0.25	98.6	25.5 ± 3.5	6.3 ± 2.6	1.1 ± 0.3	6.1 ± 0.6	0.1 ± 0.7	0.0 ± 0.0	0.6
pm25	SS1-3	12/04/94	6	19.2 ± 1.9	0.97	0.46	99.5	13.2 ± 2.1	-0.1 ± 1.1	2.5 ± 0.3	2.5 ± 0.3	0.9 ± 0.4	0.0 ± 0.0	0.1
pm25	SS1-3	12/10/94	6	26.7 ± 2.7	0.98	0.28	99.7	17.3 ± 2.4	3.9 ± 1.7	0.8 ± 0.2	3.7 ± 0.4	0.9 ± 0.5	0.0 ± 0.0	0.1
pm25	SS1-3	12/22/94	6	28.6 ± 2.9	0.96	0.66	104.8	15.3 ± 2.4	7.9 ± 2.2	1.2 ± 0.2	1.5 ± 0.2	4.1 ± 0.7	0.0 ± 0.0	-1.4
pm25	SS1-3	12/28/94	6	28.3 ± 2.8	0.95	0.98	97.0	9.6 ± 1.6	0.4 ± 0.8	2.5 ± 0.3	14.5 ± 1.2	0.4 ± 0.3	0.0 ± 0.0	0.8
pm25	SS1-3	01/03/95	6	16.3 ± 1.6	0.96	0.36	103.8	11.0 ± 2.4	-1.5 ± 1.7	1.0 ± 0.6	2.6 ± 0.4	-0.2 ± 0.9	4.0 ± 2.0	-0.6
pm25	SS1-3	01/09/95	6	22.1 ± 2.2	0.91	1.42	97.6	13.7 ± 2.1	3.1 ± 1.3	0.9 ± 0.2	1.9 ± 0.2	1.9 ± 0.5	0.0 ± 0.0	0.5
pm25	SS1-3	02/02/95	6	25.0 ± 2.5	0.99	0.25	100.1	14.2 ± 2.0	-0.4 ± 1.1	1.6 ± 0.2	8.7 ± 0.8	1.0 ± 0.4	0.0 ± 0.0	0.0
pm25	SS1-3	02/08/95	6	12.6 ± 1.3	0.96	0.09	115.4	10.0 ± 3.9	-3.0 ± 2.9	-0.3 ± 1.0	0.5 ± 0.5	-0.8 ± 1.6	8.1 ± 3.4	-1.9
pm25	SS1-3	03/04/95	6	11.1 ± 1.1	0.98	0.18	98.9	10.6 ± 1.5	-1.5 ± 1.0	1.3 ± 0.2	0.5 ± 0.1	0.1 ± 0.3	0.0 ± 0.0	0.1
pm25	SS1-3	03/22/95	6	10.0 ± 1.0	0.99	0.05	99.0	8.8 ± 1.3	-0.8 ± 0.9	0.5 ± 0.1	0.6 ± 0.1	0.8 ± 0.3	0.0 ± 0.0	0.1
pm25	SS1-3	04/09/95	6	16.3 ± 1.6	0.97	0.45	114.8	8.9 ± 1.6	-1.6 ± 0.8	1.2 ± 0.2	0.7 ± 0.1	9.5 ± 0.9	0.0 ± 0.0	-2.4
pm25	SS1-3	04/21/95	6	12.3 ± 1.2	0.98	0.18	101.0	11.2 ± 1.6	-1.5 ± 1.0	1.1 ± 0.2	0.7 ± 0.1	1.0 ± 0.4	0.0 ± 0.0	-0.1
pm25	SS1-3	04/27/95	6	16.1 ± 1.6	0.99	0.12	102.3	15.1 ± 2.1	-2.7 ± 1.3	1.6 ± 0.2	0.4 ± 0.1	2.1 ± 0.5	0.0 ± 0.0	-0.4
pm25	SS1-3	05/09/95	6	14.8 ± 1.5	0.98	0.19	103.0	11.4 ± 1.6	0.1 ± 1.1	1.3 ± 0.2	1.0 ± 0.2	1.6 ± 0.4	0.0 ± 0.0	-0.4
pm25	SS1-3	05/21/95	6	12.2 ± 1.2	0.98	0.24	100.3	10.4 ± 1.5	-2.5 ± 0.9	2.5 ± 0.3	0.4 ± 0.1	1.4 ± 0.4	0.0 ± 0.0	0.0
pm25	SS1-3	06/20/95	6	13.6 ± 1.4	0.98	0.23	104.1	11.9 ± 1.7	-2.0 ± 1.0	1.0 ± 0.2	0.4 ± 0.1	2.8 ± 0.5	0.0 ± 0.0	-0.6
pm25	SS1-3	06/26/95	6	16.9 ± 1.7	0.98	0.17	103.3	15.9 ± 2.2	-2.9 ± 1.3	1.6 ± 0.2	0.4 ± 0.1	2.5 ± 0.6	0.0 ± 0.0	-0.6
pm25	SS1-3	07/08/95	6	15.4 ± 1.5	0.98	0.15	100.7	15.2 ± 2.2	-3.8 ± 1.3	2.0 ± 0.3	0.3 ± 0.1	1.9 ± 0.5	0.0 ± 0.0	-0.1
pm25	SS1-3	08/13/95	6	15.0 ± 1.5	0.98	0.17	97.2	16.4 ± 2.3	-4.5 ± 1.4	1.9 ± 0.3	0.5 ± 0.1	0.3 ± 0.4	0.0 ± 0.0	0.4
pm25	SS1-3	08/19/95	6	16.4 ± 1.6	0.88	1.25	99.3	15.0 ± 2.1	-2.2 ± 1.3	2.6 ± 0.3	0.4 ± 0.2	0.5 ± 0.4	0.0 ± 0.0	0.1
pm25	SS1-3	08/31/95	6	21.0 ± 2.1	0.99	0.15	103.6	14.4 ± 2.0	-0.3 ± 1.4	4.5 ± 0.5	0.4 ± 0.1	2.8 ± 0.6	0.0 ± 0.0	-0.8
pm25	SS1-3	09/06/95	6	15.1 ± 1.5	0.98	0.16	99.3	13.9 ± 1.9	-2.8 ± 1.2	2.7 ± 0.3	0.7 ± 0.2	0.6 ± 0.4	0.0 ± 0.0	0.1
pm25	SS2-4	11/16/94	24	9.1 ± 0.9	0.98	0.36	103.0	5.1 ± 0.7	1.3 ± 0.5	1.4 ± 0.1	0.7 ± 0.1	1.0 ± 0.2	0.0 ± 0.0	-0.3

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
pm25	SS2-4	11/22/94	24	34.6 ± 3.5	0.99	0.23	99.6	15.3 ± 2.1	4.5 ± 1.7	1.5 ± 0.2	11.5 ± 1.0	1.5 ± 0.5	0.0 ± 0.0	0.1
pm25	SS2-4	11/28/94	24	16.8 ± 1.7	0.98	0.31	101.8	10.2 ± 1.4	3.2 ± 1.1	0.3 ± 0.1	2.1 ± 0.2	1.2 ± 0.3	0.0 ± 0.0	-0.3
pm25	SS2-4	12/04/94	24	19.3 ± 1.9	0.90	1.99	103.2	11.2 ± 1.8	0.3 ± 1.3	1.7 ± 0.4	3.2 ± 0.4	1.1 ± 0.6	2.4 ± 1.4	-0.6
pm25	SS2-4	12/10/94	24	13.8 ± 1.4	0.98	0.27	100.4	10.0 ± 1.3	1.6 ± 0.9	0.6 ± 0.1	1.0 ± 0.1	0.7 ± 0.3	0.0 ± 0.0	-0.1
pm25	SS2-4	12/22/94	24	13.7 ± 1.4	0.97	0.57	104.9	7.1 ± 1.1	3.3 ± 1.0	1.1 ± 0.1	0.6 ± 0.1	2.2 ± 0.4	0.0 ± 0.0	-0.7
pm25	SS2-4	12/28/94	24	29.4 ± 2.9	0.99	0.22	97.5	11.4 ± 1.5	0.6 ± 0.9	2.6 ± 0.3	14.3 ± 1.2	-0.2 ± 0.3	0.0 ± 0.0	0.7
pm25	SS2-4	01/03/95	24	18.5 ± 1.8	0.99	0.14	103.6	7.9 ± 1.7	1.4 ± 1.3	1.4 ± 0.4	5.9 ± 0.6	-0.3 ± 0.6	2.9 ± 1.4	-0.7
pm25	SS2-4	01/09/95	24	16.2 ± 1.6	0.98	0.30	101.8	9.7 ± 1.6	4.2 ± 1.1	1.1 ± 0.1	0.9 ± 0.1	0.6 ± 0.3	0.0 ± 0.0	-0.3
pm25	SS2-4	02/02/95	24	16.8 ± 1.7	0.99	0.17	103.3	9.9 ± 1.7	1.0 ± 1.1	1.0 ± 0.3	3.0 ± 0.3	0.5 ± 0.5	1.9 ± 1.2	-0.6
pm25	SS2-4	02/08/95	24	8.7 ± 0.9	0.98	0.13	110.8	5.0 ± 1.6	-0.2 ± 1.2	1.3 ± 0.4	0.1 ± 0.2	0.2 ± 0.6	3.1 ± 1.4	-0.9
pm25	SS2-4	03/04/95	24	5.3 ± 0.5	0.99	0.22	101.5	3.6 ± 0.5	0.3 ± 0.3	1.0 ± 0.1	0.2 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	-0.1
pm25	SS2-4	03/22/95	24	6.2 ± 0.6	0.99	0.12	104.1	4.1 ± 0.6	0.6 ± 0.4	0.4 ± 0.1	0.4 ± 0.1	0.9 ± 0.2	0.0 ± 0.0	-0.3
pm25	SS2-4	04/21/95	24	4.7 ± 0.5	0.97	0.58	104.6	2.4 ± 0.4	-0.2 ± 0.2	1.1 ± 0.1	0.4 ± 0.1	1.1 ± 0.1	0.0 ± 0.0	-0.2
pm25	SS2-4	04/27/95	24	8.3 ± 0.8	0.96	0.68	106.7	4.9 ± 0.7	0.0 ± 0.5	1.6 ± 0.2	0.3 ± 0.0	2.1 ± 0.3	0.0 ± 0.0	-0.6
pm25	SS2-4	05/09/95	24	7.8 ± 0.8	0.98	0.41	104.8	4.7 ± 0.7	0.6 ± 0.6	1.1 ± 0.1	0.5 ± 0.1	1.4 ± 0.2	0.0 ± 0.0	-0.4
pm25	SS2-4	05/21/95	24	6.9 ± 0.7	0.97	0.45	103.8	4.4 ± 0.6	-0.7 ± 0.4	1.9 ± 0.2	0.3 ± 0.0	1.3 ± 0.2	0.0 ± 0.0	-0.3
pm25	SS2-4	06/20/95	24	7.3 ± 0.7	0.97	0.56	106.8	4.5 ± 0.7	0.0 ± 0.4	1.0 ± 0.1	0.3 ± 0.0	2.1 ± 0.3	0.0 ± 0.0	-0.5
pm25	SS2-4	06/26/95	24	8.8 ± 0.9	0.97	0.58	106.1	5.2 ± 0.8	-0.2 ± 0.5	1.7 ± 0.2	0.2 ± 0.0	2.4 ± 0.3	0.0 ± 0.0	-0.5
pm25	SS2-4	07/08/95	24	13.7 ± 1.4	0.93	1.26	101.7	9.5 ± 1.3	-1.1 ± 0.8	2.7 ± 0.3	0.6 ± 0.1	2.3 ± 0.4	0.0 ± 0.0	-0.2
pm25	SS2-4	07/26/95	24	10.9 ± 1.1	0.98	0.30	106.5	6.4 ± 1.0	0.6 ± 0.7	1.8 ± 0.2	0.2 ± 0.0	2.6 ± 0.4	0.0 ± 0.0	-0.7
pm25	SS2-4	08/13/95	24	8.2 ± 0.8	0.98	0.29	101.9	5.7 ± 0.8	-0.7 ± 0.5	2.0 ± 0.2	0.4 ± 0.1	1.1 ± 0.2	0.0 ± 0.0	-0.2
pm25	SS2-4	08/19/95	24	7.6 ± 0.8	0.95	0.79	101.1	4.8 ± 0.7	-0.8 ± 0.5	2.1 ± 0.2	0.2 ± 0.1	0.7 ± 0.2	0.6 ± 0.5	-0.1
pm25	SS2-4	08/31/95	24	13.4 ± 1.3	0.98	0.43	103.9	6.0 ± 0.9	1.1 ± 0.8	4.5 ± 0.4	0.2 ± 0.0	2.1 ± 0.3	0.0 ± 0.0	-0.5
pm25	SS2-4	09/06/95	24	7.6 ± 0.8	0.98	0.31	102.9	3.8 ± 0.5	-0.4 ± 0.3	3.0 ± 0.3	0.3 ± 0.0	1.2 ± 0.2	0.0 ± 0.0	-0.2
pm25	SS2-4	09/12/95	24	9.7 ± 1.0	0.99	0.21	104.4	5.0 ± 0.8	1.2 ± 0.7	1.9 ± 0.2	0.3 ± 0.0	1.7 ± 0.3	0.0 ± 0.0	-0.4
pm25	TM1-3	11/04/94	6	10.7 ± 1.1	0.95	0.66	100.6	6.1 ± 1.0	1.4 ± 0.6	0.7 ± 0.1	1.8 ± 0.2	0.8 ± 0.2	0.0 ± 0.0	-0.1
pm25	TM1-3	11/16/94	6	15.9 ± 1.6	0.98	0.26	106.4	8.1 ± 1.8	3.5 ± 1.4	1.3 ± 0.4	1.1 ± 0.2	1.0 ± 0.5	2.0 ± 1.3	-1.0
pm25	TM1-3	11/22/94	6	21.6 ± 2.2	0.99	0.22	102.9	10.6 ± 2.0	5.2 ± 1.5	1.3 ± 0.2	3.1 ± 0.3	2.0 ± 0.5	0.0 ± 0.0	-0.6

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
pm25	TM1-3	11/28/94	6	12.8 ± 1.3	0.98	0.21	103.6	6.4 ± 1.2	3.2 ± 0.9	0.5 ± 0.1	1.9 ± 0.2	1.4 ± 0.3	0.0 ± 0.0	-0.5
pm25	TM1-3	12/04/94	6	10.3 ± 1.0	0.98	0.14	106.1	7.6 ± 1.7	-1.8 ± 1.2	1.3 ± 0.4	0.9 ± 0.2	0.1 ± 0.6	2.7 ± 1.4	-0.6
pm25	TM1-3	12/10/94	6	5.0 ± 0.5	0.99	0.06	102.4	4.3 ± 0.8	-0.6 ± 0.4	0.5 ± 0.1	0.3 ± 0.1	0.6 ± 0.2	0.0 ± 0.0	-0.1
pm25	TM1-3	12/22/94	6	14.4 ± 1.4	0.98	0.31	109.1	8.9 ± 1.6	2.5 ± 1.0	1.0 ± 0.2	0.7 ± 0.1	2.7 ± 0.4	0.0 ± 0.0	-1.3
pm25	TM1-3	12/28/94	6	23.0 ± 2.3	1.00	0.07	100.0	8.9 ± 1.5	2.7 ± 1.0	2.3 ± 0.3	8.6 ± 0.8	0.5 ± 0.3	0.0 ± 0.0	0.0
pm25	TM1-3	01/03/95	6	15.3 ± 1.5	0.99	0.11	108.3	8.9 ± 2.3	0.9 ± 1.6	0.8 ± 0.6	1.9 ± 0.3	-0.1 ± 0.9	4.1 ± 1.9	-1.3
pm25	TM1-3	01/09/95	6	13.5 ± 1.3	0.99	0.09	104.2	7.6 ± 1.4	2.8 ± 1.0	0.6 ± 0.3	1.0 ± 0.2	0.3 ± 0.4	1.6 ± 1.1	-0.6
pm25	TM1-3	02/02/95	6	22.1 ± 2.2	0.99	0.10	107.6	9.0 ± 2.9	1.2 ± 2.1	0.6 ± 0.7	7.2 ± 0.8	0.2 ± 1.1	5.7 ± 2.5	-1.7
pm25	TM1-3	02/08/95	6	14.9 ± 1.5	0.96	0.07	118.7	9.8 ± 5.1	-1.9 ± 3.8	-0.5 ± 1.3	0.4 ± 0.7	-1.0 ± 2.0	10.9 ± 4.4	-2.8
pm25	TM1-3	03/04/95	6	7.8 ± 0.8	0.98	0.12	99.1	6.4 ± 1.0	-0.5 ± 0.7	1.1 ± 0.2	0.4 ± 0.1	0.3 ± 0.2	0.0 ± 0.0	0.1
pm25	TM1-3	03/22/95	6	9.9 ± 1.0	0.99	0.06	99.9	8.8 ± 1.3	-0.9 ± 0.9	0.5 ± 0.1	0.4 ± 0.1	1.1 ± 0.3	0.0 ± 0.0	0.0
pm25	TM1-3	03/28/95	6	9.3 ± 0.9	0.99	0.07	105.5	6.6 ± 1.0	0.0 ± 0.8	0.8 ± 0.2	0.5 ± 0.1	2.0 ± 0.3	0.0 ± 0.0	-0.5
pm25	TM1-3	04/09/95	6	13.2 ± 1.3	0.98	0.35	115.2	6.8 ± 1.3	-1.5 ± 0.6	1.2 ± 0.2	0.8 ± 0.1	8.0 ± 0.8	0.0 ± 0.0	-2.0
pm25	TM1-3	04/27/95	6	15.5 ± 1.6	0.99	0.15	105.8	10.5 ± 1.5	0.5 ± 1.1	1.6 ± 0.2	0.6 ± 0.1	3.2 ± 0.5	0.0 ± 0.0	-0.9
pm25	TM1-3	05/09/95	6	13.0 ± 1.3	0.99	0.08	104.1	10.0 ± 1.4	-0.2 ± 1.0	1.1 ± 0.2	0.8 ± 0.2	1.9 ± 0.4	0.0 ± 0.0	-0.5
pm25	TM1-3	05/21/95	6	10.1 ± 1.0	0.98	0.22	103.9	7.0 ± 1.0	-0.8 ± 0.6	2.0 ± 0.2	0.4 ± 0.1	1.9 ± 0.3	0.0 ± 0.0	-0.4
pm25	TM1-3	06/20/95	6	12.9 ± 1.3	0.98	0.19	110.2	8.0 ± 1.3	-0.1 ± 0.8	0.9 ± 0.2	0.6 ± 0.1	4.7 ± 0.6	0.0 ± 0.0	-1.3
pm25	TM1-3	06/26/95	6	13.8 ± 1.4	0.97	0.36	103.9	9.4 ± 1.4	0.1 ± 1.0	1.8 ± 0.2	0.5 ± 0.1	2.6 ± 0.4	0.0 ± 0.0	-0.5
pm25	TM1-3	07/08/95	6	11.3 ± 1.1	0.98	0.23	102.4	9.1 ± 1.3	-2.0 ± 0.8	2.1 ± 0.3	0.3 ± 0.1	2.1 ± 0.4	0.0 ± 0.0	-0.3
pm25	TM1-3	07/26/95	6	17.3 ± 1.7	0.99	0.09	104.2	12.0 ± 1.8	1.1 ± 1.4	1.6 ± 0.2	0.4 ± 0.1	3.0 ± 0.5	0.0 ± 0.0	-0.7
pm25	TM1-3	08/13/95	6	13.1 ± 1.3	0.98	0.12	98.3	14.1 ± 2.0	-3.5 ± 1.2	1.5 ± 0.2	0.6 ± 0.1	0.2 ± 0.4	0.0 ± 0.0	0.2
pm25	TM1-3	08/19/95	6	10.6 ± 1.1	0.97	0.25	99.2	10.2 ± 1.4	-2.2 ± 0.9	1.9 ± 0.2	0.3 ± 0.1	0.3 ± 0.3	0.0 ± 0.0	0.1
pm25	TM1-3	08/31/95	6	22.3 ± 2.2	0.99	0.11	103.8	14.3 ± 2.1	0.4 ± 1.5	4.4 ± 0.5	0.5 ± 0.1	3.6 ± 0.6	0.0 ± 0.0	-0.8
pm25	TM1-3	09/06/95	6	14.4 ± 1.4	0.99	0.14	102.8	9.9 ± 1.4	-0.3 ± 0.9	2.8 ± 0.3	0.8 ± 0.2	1.7 ± 0.4	0.0 ± 0.0	-0.4
pm25	TM1-3	09/12/95	6	12.6 ± 1.3	0.99	0.07	102.3	8.6 ± 1.2	0.4 ± 0.9	2.0 ± 0.2	0.4 ± 0.1	1.6 ± 0.3	0.0 ± 0.0	-0.3
pm25	WP1-3	12/10/94	6	12.8 ± 1.3	0.99	0.18	103.8	8.1 ± 1.4	1.6 ± 0.8	0.6 ± 0.1	0.8 ± 0.1	2.2 ± 0.4	0.0 ± 0.0	-0.5
pm25	WP1-3	12/22/94	6	17.8 ± 1.8	0.98	0.28	106.6	10.1 ± 1.9	4.2 ± 1.3	1.2 ± 0.2	0.7 ± 0.1	2.8 ± 0.5	0.0 ± 0.0	-1.2
pm25	WP1-3	12/28/94	6	28.8 ± 2.9	0.99	0.23	96.3	10.2 ± 1.8	2.8 ± 1.1	2.0 ± 0.3	12.5 ± 1.1	0.2 ± 0.3	0.0 ± 0.0	1.1

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgd w/Smelter (ug/m3)	Unexplained (ug/m3)
pm25	WP1-3	01/03/95	6	20.0 ± 2.0	0.98	0.27	101.6	10.0 ± 1.9	0.7 ± 1.4	1.8 ± 0.5	5.3 ± 0.6	-0.1 ± 0.7	2.7 ± 1.9	-0.3
pm25	WP1-3	01/09/95	6	17.5 ± 1.8	0.98	0.23	102.4	12.3 ± 1.8	2.4 ± 1.1	1.0 ± 0.2	1.1 ± 0.2	1.1 ± 0.4	0.0 ± 0.0	-0.4
pm25	WP1-3	03/04/95	6	7.9 ± 0.8	0.99	0.12	100.2	6.9 ± 1.0	-1.3 ± 0.6	1.2 ± 0.2	0.7 ± 0.1	0.5 ± 0.2	0.0 ± 0.0	0.0
pm25	WP1-3	03/22/95	6	7.8 ± 0.8	0.98	0.16	98.8	6.6 ± 1.0	-0.7 ± 0.7	0.5 ± 0.1	0.5 ± 0.1	0.7 ± 0.2	0.0 ± 0.0	0.1
pm25	WP1-3	03/28/95	6	10.5 ± 1.1	0.99	0.10	105.6	7.5 ± 1.1	-0.1 ± 0.9	0.8 ± 0.2	0.6 ± 0.1	2.2 ± 0.4	0.0 ± 0.0	-0.6
pm25	WP1-3	04/09/95	6	12.7 ± 1.3	0.97	0.49	114.4	7.1 ± 1.3	-1.9 ± 0.7	1.5 ± 0.2	1.1 ± 0.2	6.6 ± 0.7	0.0 ± 0.0	-1.8
pm25	WP1-3	04/21/95	6	11.9 ± 1.2	0.98	0.22	102.8	11.3 ± 1.6	-1.9 ± 0.9	1.0 ± 0.2	0.9 ± 0.2	0.9 ± 0.3	0.0 ± 0.0	-0.3
pm25	WP1-3	04/27/95	6	12.4 ± 1.2	0.99	0.15	104.9	9.5 ± 1.4	-1.1 ± 0.8	1.6 ± 0.2	0.5 ± 0.1	2.5 ± 0.4	0.0 ± 0.0	-0.6
pm25	WP1-3	05/09/95	6	11.9 ± 1.2	0.99	0.15	101.6	9.5 ± 1.3	-0.5 ± 0.9	1.0 ± 0.2	0.8 ± 0.2	1.3 ± 0.3	0.0 ± 0.0	-0.2
pm25	WP1-3	05/21/95	6	12.2 ± 1.2	0.99	0.14	103.5	11.0 ± 1.6	-2.5 ± 0.9	2.0 ± 0.3	0.5 ± 0.1	1.8 ± 0.4	0.0 ± 0.0	-0.4
pm25	WP1-3	06/20/95	6	8.8 ± 0.9	0.97	0.29	109.8	6.3 ± 1.0	-0.9 ± 0.5	0.4 ± 0.1	0.3 ± 0.1	3.6 ± 0.4	0.0 ± 0.0	-0.9
pm25	WP1-3	06/26/95	6	8.8 ± 0.9	0.99	0.07	107.1	8.8 ± 1.3	-2.1 ± 0.7	0.4 ± 0.2	0.3 ± 0.1	2.1 ± 0.4	0.0 ± 0.0	-0.6
pm25	WP1-3	07/08/95	6	18.5 ± 1.8	0.94	0.75	101.0	15.2 ± 2.1	-2.2 ± 1.3	2.5 ± 0.3	0.7 ± 0.2	2.6 ± 0.6	0.0 ± 0.0	-0.2
pm25	WP1-3	07/26/95	6	17.1 ± 1.7	0.99	0.16	107.2	12.8 ± 1.9	0.0 ± 1.3	1.2 ± 0.2	0.3 ± 0.1	4.0 ± 0.6	0.0 ± 0.0	-1.2
pm25	WP1-3	08/13/95	6	8.5 ± 0.9	0.98	0.12	102.3	8.6 ± 1.2	-2.0 ± 0.7	0.5 ± 0.2	0.3 ± 0.1	1.3 ± 0.3	0.0 ± 0.0	-0.2
pm25	WP1-3	08/19/95	6	8.6 ± 0.9	0.98	0.15	99.1	8.9 ± 1.2	-1.5 ± 0.7	0.7 ± 0.2	0.2 ± 0.1	0.3 ± 0.3	0.0 ± 0.0	0.1
pm25	WP1-3	08/31/95	6	18.0 ± 1.8	0.99	0.12	103.9	11.7 ± 1.7	-0.2 ± 1.1	4.0 ± 0.4	0.4 ± 0.1	2.8 ± 0.5	0.0 ± 0.0	-0.7
pm25	WP1-3	09/06/95	6	12.5 ± 1.2	0.98	0.21	100.4	10.7 ± 1.5	-2.1 ± 0.9	2.5 ± 0.3	0.6 ± 0.1	0.8 ± 0.3	0.0 ± 0.0	0.0
pm25	WP1-3	09/12/95	6	14.5 ± 1.4	0.99	0.10	106.1	9.8 ± 1.4	0.8 ± 1.1	1.8 ± 0.2	0.4 ± 0.1	2.5 ± 0.4	0.0 ± 0.0	-0.9
TCTC	SS1-3	11/16/94	6	12.8 ± 0.9	0.98	0.26	100.7	10.8 ± 0.5	1.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	-0.1
TCTC	SS1-3	11/22/94	6	24.6 ± 1.7	0.99	0.21	100.3	17.5 ± 0.8	6.9 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.1
TCTC	SS1-3	11/28/94	6	27.3 ± 1.9	0.98	0.25	99.2	21.2 ± 0.9	5.9 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2
TCTC	SS1-3	12/04/94	6	11.0 ± 0.8	0.97	0.46	100.0	11.0 ± 0.5	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
TCTC	SS1-3	12/10/94	6	18.2 ± 1.3	0.98	0.28	99.7	14.4 ± 0.6	3.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
TCTC	SS1-3	12/22/94	6	20.0 ± 1.4	0.96	0.66	103.2	12.7 ± 0.6	7.4 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.2	0.0 ± 0.0	-0.6
TCTC	SS1-3	12/28/94	6	8.5 ± 0.6	0.95	0.98	98.5	8.0 ± 0.4	0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
TCTC	SS1-3	01/03/95	6	8.9 ± 0.7	0.96	0.36	99.2	9.2 ± 0.4	-1.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.9	0.1

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
TCTC	SS1-3	01/09/95	6	14.6 ± 1.2	0.91	1.42	99.1	11.4 ± 0.5	2.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
TCTC	SS1-3	02/02/95	6	11.6 ± 0.9	0.99	0.25	99.4	11.8 ± 0.5	-0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
TCTC	SS1-3	02/08/95	6	7.7 ± 0.6	0.96	0.09	101.6	8.3 ± 0.4	-2.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	-0.1 ± 0.0	2.4 ± 1.8	-0.1
TCTC	SS1-3	03/04/95	6	7.5 ± 0.6	0.98	0.18	98.7	8.8 ± 0.4	-1.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
TCTC	SS1-3	03/22/95	6	6.7 ± 0.5	0.99	0.05	99.4	7.4 ± 0.3	-0.8 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
TCTC	SS1-3	04/09/95	6	7.4 ± 0.6	0.97	0.45	96.3	7.4 ± 0.3	-1.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.5	0.0 ± 0.0	0.3
TCTC	SS1-3	04/21/95	6	8.1 ± 0.7	0.98	0.18	98.6	9.3 ± 0.4	-1.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
TCTC	SS1-3	04/27/95	6	10.5 ± 0.9	0.99	0.12	98.6	12.5 ± 0.6	-2.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.2
TCTC	SS1-3	05/09/95	6	9.7 ± 0.8	0.98	0.19	100.0	9.4 ± 0.4	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS1-3	05/21/95	6	6.6 ± 0.6	0.98	0.24	97.9	8.7 ± 0.4	-2.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
TCTC	SS1-3	06/20/95	6	8.5 ± 0.7	0.98	0.23	98.6	9.9 ± 0.4	-1.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.1
TCTC	SS1-3	06/26/95	6	11.0 ± 0.9	0.98	0.17	98.4	13.2 ± 0.6	-2.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.2
TCTC	SS1-3	07/08/95	6	9.5 ± 0.8	0.98	0.15	98.0	12.6 ± 0.6	-3.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.2
TCTC	SS1-3	08/13/95	6	9.7 ± 0.8	0.98	0.17	97.2	13.6 ± 0.6	-4.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3
TCTC	SS1-3	08/19/95	6	10.7 ± 0.9	0.88	1.25	97.5	12.5 ± 0.6	-2.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.3
TCTC	SS1-3	08/31/95	6	12.1 ± 1.0	0.99	0.15	99.7	11.9 ± 0.5	-0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS1-3	09/06/95	6	9.2 ± 0.8	0.98	0.16	97.8	11.6 ± 0.5	-2.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.2
TCTC	SS2-4	11/16/94	24	5.5 ± 0.4	0.98	0.36	100.9	4.2 ± 0.2	1.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS2-4	11/22/94	24	17.1 ± 1.2	0.99	0.23	100.3	12.7 ± 0.6	4.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.1
TCTC	SS2-4	11/28/94	24	11.6 ± 0.8	0.98	0.31	100.3	8.5 ± 0.4	3.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS2-4	12/04/94	24	10.5 ± 0.7	0.90	1.99	99.2	9.3 ± 0.4	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.7 ± 0.5	0.1
TCTC	SS2-4	12/10/94	24	9.9 ± 0.7	0.98	0.27	99.7	8.3 ± 0.4	1.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
TCTC	SS2-4	12/22/94	24	9.0 ± 0.6	0.97	0.57	102.9	5.9 ± 0.3	3.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	-0.3
TCTC	SS2-4	12/28/94	24	10.0 ± 0.7	0.99	0.22	99.4	9.4 ± 0.4	0.5 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
TCTC	SS2-4	01/03/95	24	8.5 ± 0.7	0.99	0.14	101.4	6.5 ± 0.3	1.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.6	-0.1
TCTC	SS2-4	01/09/95	24	11.9 ± 1.0	0.98	0.30	101.6	8.1 ± 0.4	3.9 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	-0.2
TCTC	SS2-4	02/02/95	24	9.8 ± 0.8	0.99	0.17	100.7	8.2 ± 0.4	1.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.6 ± 0.4	-0.1
TCTC	SS2-4	02/08/95	24	4.9 ± 0.4	0.98	0.13	103.1	4.2 ± 0.2	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.7	-0.1

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
TCTC	SS2-4	03/04/95	24	3.3 ± 0.3	0.99	0.22	100.7	3.0 ± 0.1	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
TCTC	SS2-4	03/22/95	24	4.1 ± 0.3	0.99	0.12	100.4	3.4 ± 0.2	0.5 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
TCTC	SS2-4	04/21/95	24	2.0 ± 0.2	0.97	0.58	99.0	2.0 ± 0.1	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS2-4	04/27/95	24	4.3 ± 0.4	0.96	0.68	100.9	4.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS2-4	05/09/95	24	4.5 ± 0.4	0.98	0.41	101.2	3.9 ± 0.2	0.5 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.1
TCTC	SS2-4	05/21/95	24	3.1 ± 0.3	0.97	0.45	99.9	3.6 ± 0.2	-0.7 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS2-4	06/20/95	24	3.9 ± 0.3	0.97	0.56	100.9	3.7 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS2-4	06/26/95	24	4.5 ± 0.4	0.97	0.58	100.1	4.4 ± 0.2	-0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS2-4	07/08/95	24	7.1 ± 0.6	0.93	1.26	100.0	7.9 ± 0.4	-1.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS2-4	07/26/95	24	6.1 ± 0.5	0.98	0.30	100.7	5.3 ± 0.2	0.5 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS2-4	08/13/95	24	4.2 ± 0.4	0.98	0.29	99.2	4.7 ± 0.2	-0.7 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS2-4	08/19/95	24	3.6 ± 0.3	0.95	0.79	99.6	4.0 ± 0.2	-0.7 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.2 ± 0.1	0.0
TCTC	SS2-4	08/31/95	24	6.2 ± 0.5	0.98	0.43	100.9	5.0 ± 0.2	1.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	-0.1
TCTC	SS2-4	09/06/95	24	2.9 ± 0.2	0.98	0.31	99.5	3.1 ± 0.1	-0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
TCTC	SS2-4	09/12/95	24	5.5 ± 0.5	0.99	0.21	101.0	4.1 ± 0.2	1.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.1
TCTC	TM1-3	11/04/94	6	6.5 ± 0.5	0.95	0.66	99.9	5.0 ± 0.2	1.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
TCTC	TM1-3	11/16/94	6	10.5 ± 0.7	0.98	0.26	102.1	6.7 ± 0.3	3.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.6 ± 0.4	-0.2
TCTC	TM1-3	11/22/94	6	13.8 ± 1.0	0.99	0.22	101.7	8.8 ± 0.4	4.9 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	-0.2
TCTC	TM1-3	11/28/94	6	8.4 ± 0.6	0.98	0.21	101.1	5.3 ± 0.2	3.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.1
TCTC	TM1-3	12/04/94	6	5.4 ± 0.4	0.98	0.14	101.1	6.3 ± 0.3	-1.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.6	-0.1
TCTC	TM1-3	12/10/94	6	3.1 ± 0.4	0.99	0.06	99.6	3.6 ± 0.2	-0.6 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
TCTC	TM1-3	12/22/94	6	9.8 ± 0.7	0.98	0.31	102.2	7.4 ± 0.3	2.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	-0.2
TCTC	TM1-3	12/28/94	6	9.9 ± 0.7	1.00	0.07	101.0	7.4 ± 0.3	2.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	-0.1
TCTC	TM1-3	01/03/95	6	9.3 ± 0.7	0.99	0.11	101.5	7.4 ± 0.3	0.9 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.2 ± 0.9	-0.1
TCTC	TM1-3	01/09/95	6	9.4 ± 0.8	0.99	0.09	100.8	6.3 ± 0.3	2.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.3	-0.1
TCTC	TM1-3	02/02/95	6	10.0 ± 0.8	0.99	0.10	102.3	7.4 ± 0.3	1.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.7 ± 1.2	-0.2
TCTC	TM1-3	02/08/95	6	9.1 ± 0.7	0.96	0.07	104.1	8.2 ± 0.4	-1.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	-0.1 ± 0.0	3.2 ± 2.4	-0.4
TCTC	TM1-3	03/04/95	6	5.0 ± 0.9	0.98	0.12	98.6	5.3 ± 0.2	-0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgd w/Smelter (ug/m3)	Unexplained (ug/m3)
TCTC	TM1-3	03/22/95	6	6.7 ± 0.5	0.99	0.06	98.6	7.3 ± 0.3	-0.9 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.1
TCTC	TM1-3	03/28/95	6	5.7 ± 0.5	0.99	0.07	99.2	5.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
TCTC	TM1-3	04/09/95	6	5.5 ± 0.5	0.98	0.35	96.5	5.6 ± 0.2	-1.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.4	0.0 ± 0.0	0.2
TCTC	TM1-3	04/27/95	6	9.7 ± 0.8	0.99	0.15	99.8	8.7 ± 0.4	0.5 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2	0.0 ± 0.0	0.0
TCTC	TM1-3	05/09/95	6	8.4 ± 0.7	0.99	0.08	99.9	8.3 ± 0.4	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
TCTC	TM1-3	05/21/95	6	5.4 ± 0.5	0.98	0.22	98.7	5.8 ± 0.3	-0.7 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
TCTC	TM1-3	06/20/95	6	7.3 ± 0.6	0.98	0.19	99.0	6.7 ± 0.3	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.2	0.0 ± 0.0	0.1
TCTC	TM1-3	06/26/95	6	8.3 ± 0.7	0.97	0.36	99.0	7.8 ± 0.3	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.1
TCTC	TM1-3	07/08/95	6	6.1 ± 0.5	0.98	0.23	97.8	7.6 ± 0.3	-1.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.1
TCTC	TM1-3	07/26/95	6	11.4 ± 1.0	0.99	0.09	99.6	10.0 ± 0.4	1.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.0
TCTC	TM1-3	08/13/95	6	8.6 ± 0.7	0.98	0.12	97.9	11.7 ± 0.5	-3.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2
TCTC	TM1-3	08/19/95	6	6.6 ± 0.6	0.97	0.25	98.4	8.5 ± 0.4	-2.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
TCTC	TM1-3	08/31/95	6	12.8 ± 1.1	0.99	0.11	99.3	11.9 ± 0.5	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.2	0.0 ± 0.0	0.1
TCTC	TM1-3	09/06/95	6	8.2 ± 0.7	0.99	0.14	99.3	8.2 ± 0.4	-0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
TCTC	TM1-3	09/12/95	6	7.7 ± 0.7	0.99	0.07	99.5	7.1 ± 0.3	0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
TCTC	WP1-3	12/10/94	6	8.5 ± 0.6	0.99	0.18	100.0	6.7 ± 0.3	1.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
TCTC	WP1-3	12/22/94	6	12.3 ± 0.9	0.98	0.28	102.5	8.4 ± 0.4	3.9 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	-0.3
TCTC	WP1-3	12/28/94	6	11.2 ± 0.8	0.99	0.23	99.4	8.5 ± 0.4	2.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
TCTC	WP1-3	01/03/95	6	9.6 ± 0.8	0.98	0.27	101.5	8.3 ± 0.4	0.7 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.6	-0.1
TCTC	WP1-3	01/09/95	6	12.5 ± 1.0	0.98	0.23	101.0	10.2 ± 0.5	2.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	-0.1
TCTC	WP1-3	03/04/95	6	4.5 ± 0.8	0.99	0.12	99.2	5.7 ± 0.3	-1.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
TCTC	WP1-3	03/22/95	6	5.0 ± 0.9	0.98	0.16	97.7	5.5 ± 0.2	-0.6 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
TCTC	WP1-3	03/28/95	6	6.5 ± 0.5	0.99	0.10	99.6	6.3 ± 0.3	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
TCTC	WP1-3	04/09/95	6	5.1 ± 0.4	0.97	0.49	97.6	5.9 ± 0.3	-1.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.3	0.0 ± 0.0	0.1
TCTC	WP1-3	04/21/95	6	7.8 ± 0.7	0.98	0.22	98.9	9.4 ± 0.4	-1.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
TCTC	WP1-3	04/27/95	6	7.3 ± 0.6	0.99	0.15	99.2	7.9 ± 0.4	-1.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.1
TCTC	WP1-3	05/09/95	6	7.7 ± 0.6	0.99	0.15	99.5	7.9 ± 0.4	-0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
TCTC	WP1-3	05/21/95	6	7.1 ± 0.6	0.99	0.14	99.1	9.1 ± 0.4	-2.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
TCTC	WP1-3	06/20/95	6	4.7 ± 0.4	0.97	0.29	101.4	5.2 ± 0.2	-0.9 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.2	0.0 ± 0.0	-0.1
TCTC	WP1-3	06/26/95	6	5.6 ± 0.5	0.99	0.07	99.6	7.3 ± 0.3	-2.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
TCTC	WP1-3	07/08/95	6	11.0 ± 0.9	0.94	0.75	98.8	12.6 ± 0.6	-2.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.1
TCTC	WP1-3	07/26/95	6	11.2 ± 1.0	0.99	0.16	99.6	10.6 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.2	0.0 ± 0.0	0.0
TCTC	WP1-3	08/13/95	6	5.5 ± 0.5	0.98	0.12	98.9	7.1 ± 0.3	-1.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
TCTC	WP1-3	08/19/95	6	6.1 ± 0.5	0.98	0.15	98.6	7.4 ± 0.3	-1.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
TCTC	WP1-3	08/31/95	6	9.9 ± 0.8	0.99	0.12	99.8	9.7 ± 0.4	-0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.0
TCTC	WP1-3	09/06/95	6	7.2 ± 0.6	0.98	0.21	98.0	8.9 ± 0.4	-1.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
TCTC	WP1-3	09/12/95	6	9.2 ± 0.8	0.99	0.10	100.0	8.2 ± 0.4	0.7 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
OCTC	SS1-3	11/16/94	6	8.1 ± 0.9	0.98	0.26	101.2	7.7 ± 0.7	0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	-0.1
OCTC	SS1-3	11/22/94	6	14.0 ± 0.9	0.99	0.21	100.5	12.5 ± 1.1	1.4 ± 0.6	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.1
OCTC	SS1-3	11/28/94	6	16.5 ± 1.1	0.98	0.25	98.3	15.0 ± 1.4	1.2 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3
OCTC	SS1-3	12/04/94	6	7.9 ± 0.9	0.97	0.46	100.0	7.8 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
OCTC	SS1-3	12/10/94	6	11.1 ± 0.7	0.98	0.28	99.4	10.2 ± 0.9	0.7 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
OCTC	SS1-3	12/22/94	6	10.1 ± 0.7	0.96	0.66	108.6	9.1 ± 0.8	1.5 ± 0.6	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.2	0.0 ± 0.0	-0.9
OCTC	SS1-3	12/28/94	6	5.9 ± 0.6	0.95	0.98	97.8	5.7 ± 0.5	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
OCTC	SS1-3	01/03/95	6	6.4 ± 0.5	0.96	0.36	98.7	6.5 ± 0.6	-0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 1.0	0.1
OCTC	SS1-3	01/09/95	6	9.0 ± 0.8	0.91	1.42	98.6	8.1 ± 0.7	0.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
OCTC	SS1-3	02/02/95	6	8.5 ± 0.7	0.99	0.25	99.2	8.4 ± 0.8	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
OCTC	SS1-3	02/08/95	6	5.5 ± 0.5	0.96	0.09	102.4	5.9 ± 0.5	-0.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	-0.1 ± 0.0	0.3 ± 1.9	-0.1
OCTC	SS1-3	03/04/95	6	6.1 ± 0.5	0.98	0.18	98.2	6.3 ± 0.6	-0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
OCTC	SS1-3	03/22/95	6	5.2 ± 0.4	0.99	0.05	99.1	5.2 ± 0.5	-0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
OCTC	SS1-3	04/09/95	6	6.4 ± 0.5	0.97	0.45	95.3	5.3 ± 0.5	-0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.5	0.0 ± 0.0	0.3
OCTC	SS1-3	04/21/95	6	6.6 ± 0.5	0.98	0.18	98.0	6.6 ± 0.6	-0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
OCTC	SS1-3	04/27/95	6	8.8 ± 0.7	0.99	0.12	97.9	8.9 ± 0.8	-0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.2
OCTC	SS1-3	05/09/95	6	6.9 ± 0.6	0.98	0.19	99.9	6.7 ± 0.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
OCTC	SS1-3	05/21/95	6	6.0 ± 0.5	0.98	0.24	97.8	6.2 ± 0.6	-0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
OCTC	SS1-3	06/20/95	6	7.2 ± 0.6	0.98	0.23	97.8	7.1 ± 0.6	-0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.2
OCTC	SS1-3	06/26/95	6	9.3 ± 0.8	0.98	0.17	97.9	9.4 ± 0.9	-0.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.2
OCTC	SS1-3	07/08/95	6	8.7 ± 0.7	0.98	0.15	97.8	9.0 ± 0.8	-0.7 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.2
OCTC	SS1-3	08/13/95	6	9.2 ± 0.8	0.98	0.17	96.7	9.7 ± 0.9	-0.9 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3
OCTC	SS1-3	08/19/95	6	8.8 ± 0.7	0.88	1.25	96.6	8.9 ± 0.8	-0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.3
OCTC	SS1-3	08/31/95	6	8.8 ± 0.7	0.99	0.15	99.4	8.5 ± 0.8	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.1
OCTC	SS1-3	09/06/95	6	7.9 ± 0.7	0.98	0.16	97.4	8.2 ± 0.8	-0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.2
OCTC	SS2-4	11/16/94	24	3.3 ± 0.2	0.98	0.36	101.9	3.0 ± 0.3	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	-0.1
OCTC	SS2-4	11/22/94	24	10.0 ± 0.7	0.99	0.23	100.7	9.0 ± 0.8	0.9 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.1
OCTC	SS2-4	11/28/94	24	6.7 ± 0.4	0.98	0.31	100.5	6.0 ± 0.6	0.6 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0
OCTC	SS2-4	12/04/94	24	7.0 ± 0.5	0.90	1.99	98.7	6.6 ± 0.6	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.6	0.1
OCTC	SS2-4	12/10/94	24	6.3 ± 0.4	0.98	0.27	99.5	5.9 ± 0.5	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
OCTC	SS2-4	12/22/94	24	4.7 ± 0.3	0.97	0.57	107.2	4.2 ± 0.4	0.6 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	-0.3
OCTC	SS2-4	12/28/94	24	6.9 ± 0.5	0.99	0.22	99.1	6.7 ± 0.6	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
OCTC	SS2-4	01/03/95	24	4.9 ± 0.4	0.99	0.14	102.8	4.7 ± 0.4	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.7	-0.1
OCTC	SS2-4	01/09/95	24	6.4 ± 0.6	0.98	0.30	103.4	5.7 ± 0.5	0.8 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	-0.2
OCTC	SS2-4	02/02/95	24	6.1 ± 0.5	0.99	0.17	101.1	5.8 ± 0.5	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.5	-0.1
OCTC	SS2-4	02/08/95	24	2.9 ± 0.3	0.98	0.13	105.7	3.0 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.8	-0.2
OCTC	SS2-4	03/04/95	24	2.2 ± 0.2	0.99	0.22	101.1	2.1 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
OCTC	SS2-4	03/22/95	24	2.6 ± 0.2	0.99	0.12	100.8	2.4 ± 0.2	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
OCTC	SS2-4	04/21/95	24	1.6 ± 0.1	0.97	0.58	98.5	1.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0
OCTC	SS2-4	04/27/95	24	3.1 ± 0.3	0.96	0.68	101.0	2.9 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
OCTC	SS2-4	05/09/95	24	3.0 ± 0.2	0.98	0.41	102.0	2.8 ± 0.3	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.1
OCTC	SS2-4	05/21/95	24	2.6 ± 0.2	0.97	0.45	100.0	2.6 ± 0.2	-0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
OCTC	SS2-4	06/20/95	24	2.8 ± 0.2	0.97	0.56	101.2	2.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
OCTC	SS2-4	06/26/95	24	3.3 ± 0.3	0.97	0.58	100.0	3.1 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
OCTC	SS2-4	07/08/95	24	5.7 ± 0.5	0.93	1.26	99.7	5.6 ± 0.5	-0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
OCTC	SS2-4	07/26/95	24	4.2 ± 0.3	0.98	0.30	101.0	3.8 ± 0.3	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
OCTC	SS2-4	08/13/95	24	3.4 ± 0.3	0.98	0.29	98.8	3.3 ± 0.3	-0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0
OCTC	SS2-4	08/19/95	24	2.9 ± 0.2	0.95	0.79	99.1	2.9 ± 0.3	-0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.1	0.0
OCTC	SS2-4	08/31/95	24	3.9 ± 0.3	0.98	0.43	101.6	3.5 ± 0.3	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.1
OCTC	SS2-4	09/06/95	24	2.3 ± 0.2	0.98	0.31	99.3	2.2 ± 0.2	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0
OCTC	SS2-4	09/12/95	24	3.3 ± 0.3	0.99	0.21	101.8	2.9 ± 0.3	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.1
OCTC	TM1-3	11/04/94	6	4.0 ± 0.4	0.95	0.66	99.8	3.6 ± 0.3	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
OCTC	TM1-3	11/16/94	6	5.4 ± 0.6	0.98	0.26	104.8	4.8 ± 0.4	0.7 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.1 ± 0.5	-0.3
OCTC	TM1-3	11/22/94	6	7.2 ± 0.8	0.99	0.22	103.8	6.3 ± 0.6	1.0 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.3
OCTC	TM1-3	11/28/94	6	4.4 ± 0.5	0.98	0.21	103.0	3.8 ± 0.3	0.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	-0.1
OCTC	TM1-3	12/04/94	6	4.2 ± 0.5	0.98	0.14	101.5	4.5 ± 0.4	-0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.7	-0.1
OCTC	TM1-3	12/10/94	6	2.5 ± 0.3	0.99	0.06	99.4	2.6 ± 0.2	-0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
OCTC	TM1-3	12/22/94	6	5.8 ± 0.6	0.98	0.31	103.9	5.3 ± 0.5	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	-0.2
OCTC	TM1-3	12/28/94	6	5.7 ± 0.6	1.00	0.07	101.8	5.2 ± 0.5	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	-0.1
OCTC	TM1-3	01/03/95	6	5.4 ± 0.5	0.99	0.11	103.2	5.3 ± 0.5	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 1.0	-0.2
OCTC	TM1-3	01/09/95	6	5.0 ± 0.4	0.99	0.09	101.7	4.5 ± 0.4	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.4	-0.1
OCTC	TM1-3	02/02/95	6	5.5 ± 0.5	0.99	0.10	104.7	5.3 ± 0.5	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 1.4	-0.3
OCTC	TM1-3	02/08/95	6	5.3 ± 0.5	0.96	0.07	108.4	5.8 ± 0.5	-0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	-0.1 ± 0.0	0.5 ± 2.6	-0.4
OCTC	TM1-3	03/04/95	6	3.8 ± 0.4	0.98	0.12	98.5	3.8 ± 0.3	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
OCTC	TM1-3	03/22/95	6	5.2 ± 0.5	0.99	0.06	98.3	5.2 ± 0.5	-0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.1
OCTC	TM1-3	03/28/95	6	4.1 ± 0.4	0.99	0.07	99.3	3.9 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
OCTC	TM1-3	04/09/95	6	4.9 ± 0.4	0.98	0.35	95.7	4.0 ± 0.4	-0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.4	0.0 ± 0.0	0.2
OCTC	TM1-3	04/27/95	6	6.7 ± 0.5	0.99	0.15	99.2	6.2 ± 0.6	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2	0.0 ± 0.0	0.1
OCTC	TM1-3	05/09/95	6	6.1 ± 0.5	0.99	0.08	99.8	5.9 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
OCTC	TM1-3	05/21/95	6	4.3 ± 0.4	0.98	0.22	98.2	4.1 ± 0.4	-0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
OCTC	TM1-3	06/20/95	6	5.3 ± 0.4	0.98	0.19	98.8	4.7 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.2	0.0 ± 0.0	0.1
OCTC	TM1-3	06/26/95	6	6.0 ± 0.5	0.97	0.36	98.3	5.6 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.1
OCTC	TM1-3	07/08/95	6	5.4 ± 0.5	0.98	0.23	97.3	5.4 ± 0.5	-0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
OCTC	TM1-3	07/26/95	6	7.7 ± 0.6	0.99	0.09	99.3	7.1 ± 0.6	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.1	0.0 ± 0.0	0.1

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
OCTC	TM1-3	08/13/95	6	7.9 ± 0.7	0.98	0.12	97.2	8.3 ± 0.8	-0.7 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2
OCTC	TM1-3	08/19/95	6	5.8 ± 0.5	0.97	0.25	98.0	6.0 ± 0.6	-0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
OCTC	TM1-3	08/31/95	6	9.0 ± 0.8	0.99	0.11	98.8	8.4 ± 0.8	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2	0.0 ± 0.0	0.1
OCTC	TM1-3	09/06/95	6	6.1 ± 0.5	0.99	0.14	98.8	5.8 ± 0.5	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
OCTC	TM1-3	09/12/95	6	5.4 ± 0.4	0.99	0.07	99.2	5.1 ± 0.5	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.0
OCTC	WP1-3	12/10/94	6	5.3 ± 0.6	0.99	0.18	100.0	4.8 ± 0.4	0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
OCTC	WP1-3	12/22/94	6	6.7 ± 0.7	0.98	0.28	104.8	5.9 ± 0.5	0.8 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	-0.3
OCTC	WP1-3	12/28/94	6	6.7 ± 0.7	0.99	0.23	99.0	6.0 ± 0.6	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
OCTC	WP1-3	01/03/95	6	6.0 ± 0.5	0.98	0.27	102.3	5.9 ± 0.5	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.7	-0.1
OCTC	WP1-3	01/09/95	6	7.7 ± 0.7	0.98	0.23	101.8	7.3 ± 0.7	0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	-0.1
OCTC	WP1-3	03/04/95	6	3.9 ± 0.4	0.99	0.12	98.9	4.1 ± 0.4	-0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
OCTC	WP1-3	03/22/95	6	3.9 ± 0.4	0.98	0.16	97.3	3.9 ± 0.4	-0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
OCTC	WP1-3	03/28/95	6	4.7 ± 0.4	0.99	0.10	100.0	4.4 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
OCTC	WP1-3	04/09/95	6	4.8 ± 0.4	0.97	0.49	97.1	4.2 ± 0.4	-0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.3	0.0 ± 0.0	0.1
OCTC	WP1-3	04/21/95	6	6.5 ± 0.5	0.98	0.22	98.4	6.7 ± 0.6	-0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
OCTC	WP1-3	04/27/95	6	5.8 ± 0.5	0.99	0.15	99.2	5.6 ± 0.5	-0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
OCTC	WP1-3	05/09/95	6	5.7 ± 0.5	0.99	0.15	98.8	5.6 ± 0.5	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
OCTC	WP1-3	05/21/95	6	6.3 ± 0.5	0.99	0.14	98.8	6.5 ± 0.6	-0.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
OCTC	WP1-3	06/20/95	6	3.9 ± 0.3	0.97	0.29	101.8	3.7 ± 0.3	-0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.2	0.0 ± 0.0	-0.1
OCTC	WP1-3	06/26/95	6	5.1 ± 0.4	0.99	0.07	99.4	5.2 ± 0.5	-0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0
OCTC	WP1-3	07/08/95	6	9.0 ± 0.7	0.94	0.75	98.5	9.0 ± 0.8	-0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.1
OCTC	WP1-3	07/26/95	6	8.1 ± 0.7	0.99	0.16	99.3	7.5 ± 0.7	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.2	0.0 ± 0.0	0.1
OCTC	WP1-3	08/13/95	6	4.9 ± 0.4	0.98	0.12	98.6	5.1 ± 0.5	-0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0 ± 0.0	0.1
OCTC	WP1-3	08/19/95	6	5.1 ± 0.4	0.98	0.15	98.2	5.2 ± 0.5	-0.3 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
OCTC	WP1-3	08/31/95	6	7.3 ± 0.6	0.99	0.12	99.3	6.9 ± 0.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.1
OCTC	WP1-3	09/06/95	6	6.1 ± 0.5	0.98	0.21	97.7	6.3 ± 0.6	-0.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.1
OCTC	WP1-3	09/12/95	6	6.2 ± 0.5	0.99	0.10	100.1	5.8 ± 0.5	0.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	0.0 ± 0.0	0.0

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
ECTC	SS1-3	11/16/94	6	4.7 ± 0.5	0.98	0.26	99.8	3.1 ± 0.5	1.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	11/22/94	6	10.6 ± 1.0	0.99	0.21	99.8	5.1 ± 0.8	5.5 ± 0.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	11/28/94	6	10.8 ± 1.1	0.98	0.25	100.5	6.1 ± 1.0	4.7 ± 0.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	-0.1
ECTC	SS1-3	12/04/94	6	3.1 ± 0.3	0.97	0.46	100.0	3.2 ± 0.5	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	12/10/94	6	7.1 ± 0.7	0.98	0.28	100.1	4.2 ± 0.7	2.9 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	12/22/94	6	9.8 ± 1.0	0.96	0.66	97.7	3.7 ± 0.6	5.9 ± 0.8	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2
ECTC	SS1-3	12/28/94	6	2.6 ± 0.2	0.95	0.98	100.1	2.3 ± 0.4	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	01/03/95	6	2.5 ± 0.2	0.96	0.36	100.3	2.7 ± 0.4	-1.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.8	0.0
ECTC	SS1-3	01/09/95	6	5.6 ± 0.4	0.91	1.42	99.9	3.3 ± 0.5	2.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	02/02/95	6	3.1 ± 0.2	0.99	0.25	100.0	3.4 ± 0.6	-0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	02/08/95	6	2.2 ± 0.2	0.96	0.09	99.7	2.4 ± 0.4	-2.3 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.1 ± 1.6	0.0
ECTC	SS1-3	03/04/95	6	1.4 ± 0.4	0.98	0.18	100.8	2.6 ± 0.4	-1.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	03/22/95	6	1.5 ± 0.4	0.99	0.05	100.6	2.1 ± 0.4	-0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	04/09/95	6	1.0 ± 0.2	0.97	0.45	102.2	2.1 ± 0.4	-1.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.1	0.0 ± 0.0	0.0
ECTC	SS1-3	04/21/95	6	1.5 ± 0.3	0.98	0.18	101.1	2.7 ± 0.4	-1.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	04/27/95	6	1.6 ± 0.3	0.99	0.12	101.3	3.6 ± 0.6	-2.0 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	05/09/95	6	2.8 ± 0.5	0.98	0.19	100.3	2.7 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	05/21/95	6	0.6 ± 0.1	0.98	0.24	101.8	2.5 ± 0.4	-1.9 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	06/20/95	6	1.4 ± 0.2	0.98	0.23	101.1	2.9 ± 0.5	-1.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	06/26/95	6	1.6 ± 0.3	0.98	0.17	101.4	3.8 ± 0.6	-2.2 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	07/08/95	6	0.8 ± 0.1	0.98	0.15	102.4	3.7 ± 0.6	-2.9 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	08/13/95	6	0.5 ± 0.1	0.98	0.17	105.1	3.9 ± 0.7	-3.4 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	08/19/95	6	1.9 ± 0.4	0.88	1.25	101.9	3.6 ± 0.6	-1.7 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	08/31/95	6	3.2 ± 0.6	0.99	0.15	100.4	3.5 ± 0.6	-0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS1-3	09/06/95	6	1.2 ± 0.2	0.98	0.16	101.7	3.3 ± 0.6	-2.1 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	11/16/94	24	2.2 ± 0.2	0.98	0.36	99.5	1.2 ± 0.2	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	11/22/94	24	7.1 ± 0.7	0.99	0.23	99.8	3.7 ± 0.6	3.4 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	11/28/94	24	4.9 ± 0.5	0.98	0.31	100.1	2.4 ± 0.4	2.4 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
ECTC	SS2-4	12/04/94	24	3.5 ± 0.3	0.90	1.99	100.3	2.7 ± 0.4	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.5	0.0
ECTC	SS2-4	12/10/94	24	3.6 ± 0.4	0.98	0.27	100.2	2.4 ± 0.4	1.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	12/22/94	24	4.3 ± 0.4	0.97	0.57	98.1	1.7 ± 0.3	2.5 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.1
ECTC	SS2-4	12/28/94	24	3.2 ± 0.3	0.99	0.22	100.1	2.7 ± 0.5	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	01/03/95	24	3.7 ± 0.2	0.99	0.14	99.5	1.9 ± 0.3	1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.6	0.0
ECTC	SS2-4	01/09/95	24	5.5 ± 0.4	0.98	0.30	99.4	2.3 ± 0.4	3.1 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	02/02/95	24	3.7 ± 0.2	0.99	0.17	99.8	2.4 ± 0.4	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.4	0.0
ECTC	SS2-4	02/08/95	24	1.9 ± 0.1	0.98	0.13	99.0	1.2 ± 0.2	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.8 ± 0.6	0.0
ECTC	SS2-4	03/04/95	24	1.1 ± 0.1	0.99	0.22	99.9	0.9 ± 0.1	0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	03/22/95	24	1.4 ± 0.1	0.99	0.12	100.0	1.0 ± 0.2	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	04/21/95	24	0.5 ± 0.1	0.97	0.58	100.8	0.6 ± 0.1	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	04/27/95	24	1.2 ± 0.2	0.96	0.68	100.2	1.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	05/09/95	24	1.6 ± 0.3	0.98	0.41	99.8	1.1 ± 0.2	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	05/21/95	24	0.5 ± 0.1	0.97	0.45	100.4	1.0 ± 0.2	-0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	06/20/95	24	1.1 ± 0.2	0.97	0.56	100.0	1.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	06/26/95	24	1.1 ± 0.2	0.97	0.58	100.4	1.3 ± 0.2	-0.2 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	07/08/95	24	1.4 ± 0.3	0.93	1.26	100.8	2.3 ± 0.4	-0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	07/26/95	24	2.0 ± 0.4	0.98	0.30	100.0	1.5 ± 0.3	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	08/13/95	24	0.8 ± 0.2	0.98	0.29	100.9	1.4 ± 0.2	-0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	08/19/95	24	0.7 ± 0.1	0.95	0.79	101.1	1.2 ± 0.2	-0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1	0.0
ECTC	SS2-4	08/31/95	24	2.3 ± 0.4	0.98	0.43	99.6	1.4 ± 0.2	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	09/06/95	24	0.6 ± 0.1	0.98	0.31	100.6	0.9 ± 0.1	-0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	SS2-4	09/12/95	24	2.2 ± 0.4	0.99	0.21	99.5	1.2 ± 0.2	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	11/04/94	6	2.5 ± 0.2	0.95	0.66	100.1	1.5 ± 0.2	1.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	11/16/94	6	5.1 ± 0.5	0.98	0.26	99.3	1.9 ± 0.3	2.6 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.5 ± 0.4	0.0
ECTC	TM1-3	11/22/94	6	6.5 ± 0.6	0.99	0.22	99.3	2.6 ± 0.4	3.9 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	11/28/94	6	4.0 ± 0.4	0.98	0.21	99.4	1.5 ± 0.3	2.4 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	12/04/94	6	1.2 ± 0.1	0.98	0.14	99.6	1.8 ± 0.3	-1.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.5	0.0

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
ECTC	TM1-3	12/10/94	6	0.6 ± 0.1	0.99	0.06	100.3	1.0 ± 0.2	-0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	12/22/94	6	4.0 ± 0.4	0.98	0.31	99.7	2.1 ± 0.4	1.8 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	12/28/94	6	4.2 ± 0.4	1.00	0.07	99.8	2.1 ± 0.4	2.0 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	01/03/95	6	3.9 ± 0.3	0.99	0.11	99.6	2.2 ± 0.4	0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.8	0.0
ECTC	TM1-3	01/09/95	6	4.4 ± 0.3	0.99	0.09	99.8	1.8 ± 0.3	2.1 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.4 ± 0.3	0.0
ECTC	TM1-3	02/02/95	6	4.5 ± 0.3	0.99	0.10	99.4	2.2 ± 0.4	0.9 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.4 ± 1.1	0.0
ECTC	TM1-3	02/08/95	6	3.8 ± 0.3	0.96	0.07	98.4	2.4 ± 0.4	-1.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.8 ± 2.1	0.1
ECTC	TM1-3	03/04/95	6	1.2 ± 0.3	0.98	0.12	100.3	1.5 ± 0.3	-0.4 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	03/22/95	6	1.4 ± 0.4	0.99	0.06	101.0	2.1 ± 0.3	-0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	03/28/95	6	1.6 ± 0.4	0.99	0.07	100.3	1.6 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	04/09/95	6	0.6 ± 0.1	0.98	0.35	102.3	1.6 ± 0.3	-1.1 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	04/27/95	6	2.9 ± 0.5	0.99	0.15	100.6	2.5 ± 0.4	0.4 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	05/09/95	6	2.3 ± 0.4	0.99	0.08	100.2	2.4 ± 0.4	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	05/21/95	6	1.1 ± 0.2	0.98	0.22	100.7	1.7 ± 0.3	-0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	06/20/95	6	1.9 ± 0.4	0.98	0.19	100.6	1.9 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	06/26/95	6	2.3 ± 0.4	0.97	0.36	100.7	2.3 ± 0.4	0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	07/08/95	6	0.7 ± 0.1	0.98	0.23	101.8	2.2 ± 0.4	-1.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	07/26/95	6	3.7 ± 0.7	0.99	0.09	100.4	2.9 ± 0.5	0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	08/13/95	6	0.7 ± 0.1	0.98	0.12	102.8	3.4 ± 0.6	-2.7 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	08/19/95	6	0.8 ± 0.1	0.97	0.25	101.5	2.5 ± 0.4	-1.7 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	08/31/95	6	3.7 ± 0.7	0.99	0.11	100.4	3.4 ± 0.6	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	09/06/95	6	2.1 ± 0.4	0.99	0.14	100.7	2.4 ± 0.4	-0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	TM1-3	09/12/95	6	2.4 ± 0.4	0.99	0.07	100.2	2.1 ± 0.3	0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	12/10/94	6	3.2 ± 0.3	0.99	0.18	99.9	2.0 ± 0.3	1.2 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	12/22/94	6	5.6 ± 0.5	0.98	0.28	99.5	2.4 ± 0.4	3.1 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	12/28/94	6	4.5 ± 0.5	0.99	0.23	100.0	2.5 ± 0.4	2.1 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	01/03/95	6	3.7 ± 0.2	0.98	0.27	99.7	2.4 ± 0.4	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.5	0.0
ECTC	WP1-3	01/09/95	6	4.8 ± 0.3	0.98	0.23	99.8	3.0 ± 0.5	1.8 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0

Species	Site	Date	Duration (Hours)	Concentration (ug/m3)	R2	Chi- Squared	Percent Mass	Gasoline Exhaust (ug/m3)	Diesel Exhaust (ug/m3)	Ammonium Sulfate (ug/m3)	Ammonium Nitrate (ug/m3)	Geological (ug/m3)	Ambient Bkgrd w/Smelter (ug/m3)	Unexplained (ug/m3)
ECTC	WP1-3	03/04/95	6	0.6 ± 0.2	0.99	0.12	100.9	1.7 ± 0.3	-1.0 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	03/22/95	6	1.1 ± 0.3	0.98	0.16	100.9	1.6 ± 0.3	-0.5 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	03/28/95	6	1.7 ± 0.5	0.99	0.10	99.8	1.8 ± 0.3	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	04/09/95	6	0.4 ± 0.1	0.97	0.49	103.8	1.7 ± 0.3	-1.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	04/21/95	6	1.3 ± 0.2	0.98	0.22	101.3	2.7 ± 0.4	-1.4 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	04/27/95	6	1.5 ± 0.3	0.99	0.15	100.6	2.3 ± 0.4	-0.8 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	05/09/95	6	1.9 ± 0.4	0.99	0.15	100.6	2.3 ± 0.4	-0.3 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	05/21/95	6	0.8 ± 0.1	0.99	0.14	101.4	2.6 ± 0.4	-1.9 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	06/20/95	6	0.8 ± 0.1	0.97	0.29	99.6	1.5 ± 0.2	-0.7 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	06/26/95	6	0.5 ± 0.1	0.99	0.07	101.1	2.1 ± 0.3	-1.6 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	07/08/95	6	2.0 ± 0.4	0.94	0.75	101.0	3.7 ± 0.6	-1.7 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	07/26/95	6	3.1 ± 0.6	0.99	0.16	100.5	3.1 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	08/13/95	6	0.6 ± 0.1	0.98	0.12	101.3	2.1 ± 0.3	-1.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	08/19/95	6	1.0 ± 0.2	0.98	0.15	100.8	2.1 ± 0.4	-1.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	08/31/95	6	2.7 ± 0.5	0.99	0.12	100.5	2.8 ± 0.5	-0.1 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	09/06/95	6	1.0 ± 0.2	0.98	0.21	101.5	2.6 ± 0.4	-1.5 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0
ECTC	WP1-3	09/12/95	6	3.0 ± 0.5	0.99	0.10	100.3	2.4 ± 0.4	0.6 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0

# **SENSITIVITY ANALYSIS OF THE DATA PRESENTED IN THE MAG BROWN CLOUD STUDY SOURCE ATTRIBUTION OF PM-2.5**

## **INTRODUCTION**

MAG conducted a series of sensitivity tests using the ambient data collected at the Phoenix Super Site and the source profiles collected in North Front Range Air Quality Study (NFRAQS) and locally. The purposes of the sensitivity tests were to determine if the results presented for the Desert Research Institute (DRI) chemical mass balance (CMB) analysis could be replicated and how stable those results were. In addition, emission rate data collected in the NFRAQS were combined with assumptions about vehicle fleet characteristics to perform a reasonableness check on the attribution of gasoline exhaust to various modes of vehicle operation.

## **SENSITIVITY TEST ONE**

Since version 8 of the chemical mass balance receptor model had not been used extensively by MAG staff before, the first sensitivity test was to replicate the data from the DRI analysis. The results from the DRI analysis were replicated indicating that there were no errors in the analysis related to the operation of the CMB model.

## **SENSITIVITY TEST TWO**

As a second sensitivity test, the source profile for cold starts was removed and a CMB analysis was conducted with the remaining source profiles. As shown in Table 1, statistically acceptable results were obtained. However, these results indicate that hot stabilized gasoline exhaust is a significant contributor to PM-2.5 emissions. It is important to note that the chi-square and R-square statistics for the new analysis are not as good as for the original analysis. However, the standard errors associated with the source apportionments in the new analysis are less than those in the original analysis.

## **SENSITIVITY TEST THREE**

As a third sensitivity test, the source profiles for cold start and high emitter were removed. In addition, the source profile for hot stabilized gasoline exhaust was replaced with the Phoenix gasoline exhaust profile. Again, statistically acceptable results (Table 2) were obtained from the CMB analysis. It is important to note that the chi-square and R-square statistics for the new analysis are not as good as for the original analysis. However, the standard errors associated with the source apportionments in the new analysis are less than those in the original analysis. Interpretation of these results would lead to different conclusions about the relative contributions of sources than would be reached based on the DRI analysis.

**Table 1. PM-2.5 Source Contribution at the Phoenix Super Site by Extended Species CMB for Cases 1 and 2**

	Case 1				Case 2			
	PM2.5	Total Carbon	Organic Carbon	Elemental Carbon	PM2.5	Total Carbon	Organic Carbon	Elemental Carbon
Concentration (ug/m3) ± RMS	15.2 ± 1.7	8.9 ± 0.7	5.3 ± 0.4	3.6 ± 0.4	15.2 ± 1.7	8.9 ± 0.7	5.3 ± 0.4	3.6 ± 0.4
R-square ± SD	0.95 ± 0.03				0.82 ± 0.07			
Chi-square ± SD	0.36 ± 0.30				2.05 ± 1.07			
Percent Mass Attributed ± SD	100.8 ± 1.7	100.3 ± 0.5	100.5 ± 0.5	100.2 ± 0.7	103.6 ± 1.6	101.4 ± 0.6	104.0 ± 1.5	97.7 ± 1.2
Mean Contributions (ug/m3) ± RMS								
Gasoline Exhaust, cold start	3.8 ± 4.2	3.3 ± 0.3	1.7 ± 0.6	1.6 ± 0.6	-	Not	Used	-
Gasoline Exhaust, hot stabilized	-0.2 ± 1.2	-0.2 ± 0.0	-0.1 ± 0.0	-0.1 ± 0.1	2.9 ± 0.9	2.4 ± 0.2	1.7 ± 0.3	0.7 ± 0.5
Gasoline Exhaust, high emitter	4.1 ± 1.8	3.4 ± 0.2	3.1 ± 0.2	0.3 ± 0.1	3.9 ± 1.1	3.3 ± 0.2	3.0 ± 0.1	0.2 ± 0.1
Phoenix Gasoline Exhaust	-	Not	Used	-	-	Not	Used	-
Diesel Exhaust	2.4 ± 2.2	2.3 ± 0.1	0.5 ± 0.2	1.8 ± 0.3	3.4 ± 1.0	3.2 ± 0.1	0.6 ± 0.3	2.5 ± 0.4
Ammonium Sulfate	1.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ammonium Nitrate	2.5 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.5 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Geological	1.4 ± 0.3	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	1.6 ± 0.3	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0
Unexplained	-0.1	0	0	0	-0.4	-0.2	-0.2	0.2
Mean Contributions (%) ± RMS								
Gasoline Exhaust, cold start	26.4 ± 29.8	39.5 ± 3.7	34.1 ± 11.4	48.3 ± 17.7	-	Not	Used	-
Gasoline Exhaust, hot stabilized	-1.5 ± 8.2	-1.9 ± 0.2	-2.2 ± 0.6	-1.5 ± 1.3	21.1 ± 6.7	29.1 ± 2.0	33.7 ± 6.9	22.6 ± 14.0
Gasoline Exhaust, high emitter	26.6 ± 12.9	36.9 ± 1.5	56.5 ± 2.5	7.1 ± 3.6	25.9 ± 7.5	35.7 ± 1.5	54.7 ± 2.4	6.8 ± 3.5
Phoenix Gasoline Exhaust	-	Not	Used	-	-	Not	Used	-
Diesel Exhaust	15.1 ± 15.6	23.2 ± 1.0	8.0 ± 3.7	45.6 ± 6.8	22.0 ± 6.5	34.1 ± 1.4	11.6 ± 5.0	67.7 ± 9.3
Ammonium Sulfate	9.8 ± 1.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	9.9 ± 1.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ammonium Nitrate	12.7 ± 1.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	12.8 ± 1.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Geological	10.6 ± 1.9	2.3 ± 1.0	3.5 ± 1.6	0.5 ± 0.3	11.9 ± 1.8	2.5 ± 1.0	3.9 ± 1.7	0.5 ± 0.4
Unexplained	0.2	0	0	0.1	-3.6	-1.4	-3.9	2.4
Mean Contributions (%) ± Std Err								
Gasoline Exhaust, cold start	26.4 ± 3.0	39.5 ± 4.9	34.1 ± 4.2	48.3 ± 6.5	-	Not	Used	-
Gasoline Exhaust, hot stabilized	-1.5 ± 0.4	-1.9 ± 0.5	-2.2 ± 0.6	-1.5 ± 0.4	21.1 ± 0.6	29.1 ± 0.2	33.7 ± 0.7	22.6 ± 1.4
Gasoline Exhaust, high emitter	26.6 ± 2.4	36.9 ± 2.7	56.5 ± 3.7	7.1 ± 0.7	25.9 ± 0.4	35.7 ± 0.1	54.7 ± 0.2	6.8 ± 0.3
Phoenix Gasoline Exhaust	-	Not	Used	-	-	Not	Used	-
Diesel Exhaust	15.1 ± 2.3	23.2 ± 3.4	8.0 ± 1.2	45.6 ± 6.2	22.0 ± 0.4	34.1 ± 0.1	11.6 ± 0.4	67.7 ± 0.3
Ammonium Sulfate	9.8 ± 1.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	9.9 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ammonium Nitrate	12.7 ± 3.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	12.8 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Geological	10.6 ± 1.5	2.3 ± 0.3	3.5 ± 0.5	0.5 ± 0.1	11.9 ± 0.1	2.5 ± 0.1	3.9 ± 0.2	0.5 ± 0.1
Unexplained	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	-3.6 ± 0.5	-1.4 ± 0.2	-3.9 ± 0.4	2.4 ± 0.3

**Table 2. PM-2.5 Source Contribution at the Phoenix Super Site by Extended Species CMB for Cases 1 and 3**

	Case 1				Case 3			
	PM2.5	Total Carbon	Organic Carbon	Elemental Carbon	PM2.5	Total Carbon	Organic Carbon	Elemental Carbon
Concentration (ug/m3) ± RMS	15.2 ± 1.7	8.9 ± 0.7	5.3 ± 0.4	3.6 ± 0.4	15.2 ± 1.7	8.9 ± 0.7	5.3 ± 0.4	3.6 ± 0.4
R-square ± SD	0.95 ± 0.03				0.81 ± 0.06			
Chi-square ± SD	0.36 ± 0.30				2.27 ± 0.97			
Percent Mass Attributed ± SD	100.8 ± 1.7	100.3 ± 0.5	100.5 ± 0.5	100.2 ± 0.7	92.7 ± 6.3	89.2 ± 7.4	80.9 ± 15.7	102.0 ± 5.7
Mean Contributions (ug/m3) ± RMS								
Gasoline Exhaust, cold start	3.8 ± 4.2	3.3 ± 0.3	1.7 ± 0.6	1.6 ± 0.6	-	Not	Used	-
Gasoline Exhaust, hot stabilized	-0.2 ± 1.2	-0.2 ± 0.0	-0.1 ± 0.0	-0.1 ± 0.1	-	Not	Used	-
Gasoline Exhaust, high emitter	4.1 ± 1.8	3.4 ± 0.2	3.1 ± 0.2	0.3 ± 0.1	-	Not	Used	-
Phoenix Gasoline Exhaust	-	Not	Used	-	6.4 ± 0.9	4.8 ± 0.5	3.4 ± 0.5	1.4 ± 0.6
Diesel Exhaust	2.4 ± 2.2	2.3 ± 0.1	0.5 ± 0.2	1.8 ± 0.3	3.1 ± 1.1	2.9 ± 0.1	0.6 ± 0.3	2.3 ± 0.4
Ammonium Sulfate	1.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ammonium Nitrate	2.5 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.4 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Geological	1.4 ± 0.3	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	0.9 ± 0.2	0.1 ± 0.0	0.1 ± 0.0	0.0 ± 0.0
Unexplained	-0.1	0	0	0	1.3	1.1	1.2	-0.1
Mean Contributions (%) ± RMS								
Gasoline Exhaust, cold start	26.4 ± 29.8	39.5 ± 3.7	34.1 ± 11.4	48.3 ± 17.7	-	Not	Used	-
Gasoline Exhaust, hot stabilized	-1.5 ± 8.2	-1.9 ± 0.2	-2.2 ± 0.6	-1.5 ± 1.3	-	Not	Used	-
Gasoline Exhaust, high emitter	26.6 ± 12.9	36.9 ± 1.5	56.5 ± 2.5	7.1 ± 3.6	-	Not	Used	-
Phoenix Gasoline Exhaust	-	Not	Used	-	45.7 ± 6.6	57.5 ± 6.4	68.2 ± 9.7	41.9 ± 18.9
Diesel Exhaust	15.1 ± 15.6	23.2 ± 1.0	8.0 ± 3.7	45.6 ± 6.8	19.6 ± 7.4	30.2 ± 1.2	10.3 ± 4.5	59.8 ± 8.4
Ammonium Sulfate	9.8 ± 1.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	8.4 ± 1.1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ammonium Nitrate	12.7 ± 1.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	11.7 ± 1.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Geological	10.6 ± 1.9	2.3 ± 1.0	3.5 ± 1.6	0.5 ± 0.3	7.2 ± 1.6	1.5 ± 0.7	2.4 ± 1.2	0.3 ± 0.2
Unexplained	0.2	0	0	0.1	7.4	10.8	19.1	-2
Mean Contributions (%) ± Std Err								
Gasoline Exhaust, cold start	26.4 ± 3.0	39.5 ± 4.9	34.1 ± 4.2	48.3 ± 6.5	-	Not	Used	-
Gasoline Exhaust, hot stabilized	-1.5 ± 0.4	-1.9 ± 0.5	-2.2 ± 0.6	-1.5 ± 0.4	-	Not	Used	-
Gasoline Exhaust, high emitter	26.6 ± 2.4	36.9 ± 2.7	56.5 ± 3.7	7.1 ± 0.7	-	Not	Used	-
Phoenix Gasoline Exhaust	-	Not	Used	-	45.7 ± 0.5	57.5 ± 0.5	68.2 ± 0.7	41.9 ± 1.6
Diesel Exhaust	15.1 ± 2.3	23.2 ± 3.4	8.0 ± 1.2	45.6 ± 6.2	19.6 ± 0.4	30.2 ± 0.1	10.3 ± 0.5	59.8 ± 0.6

<b>Ammonium Sulfate</b>	<b>9.8 ± 1.6</b>	<b>0.0 ± 0.0</b>	<b>0.0 ± 0.0</b>	<b>0.0 ± 0.0</b>	<b>8.4 ± 0.1</b>	<b>0.0 ± 0.0</b>	<b>0.0 ± 0.0</b>	<b>0.0 ± 0.0</b>
<b>Ammonium Nitrate</b>	<b>12.7 ± 3.0</b>	<b>0.0 ± 0.0</b>	<b>0.0 ± 0.0</b>	<b>0.0 ± 0.0</b>	<b>11.7 ± 0.2</b>	<b>0.0 ± 0.0</b>	<b>0.0 ± 0.0</b>	<b>0.0 ± 0.0</b>
<b>Geological</b>	<b>10.6 ± 1.5</b>	<b>2.3 ± 0.3</b>	<b>3.5 ± 0.5</b>	<b>0.5 ± 0.1</b>	<b>7.2 ± 0.2</b>	<b>1.5 ± 0.1</b>	<b>2.4 ± 0.2</b>	<b>0.3 ± 0.1</b>
<b>Unexplained</b>	<b>0.2 ± 0.1</b>	<b>0.0 ± 0.0</b>	<b>0.0 ± 0.0</b>	<b>0.1 ± 0.0</b>	<b>7.4 ± 1.8</b>	<b>10.8 ± 2.1</b>	<b>19.1 ± 4.5</b>	<b>-2.0 ± 1.6</b>

## SENSITIVITY TEST FOUR

A fourth sensitivity run was done to test the effect of the inclusion of the profile from an insignificant source (hot stabilized gas exhaust) on the CMB analysis. In this run, the hot stabilized gasoline exhaust source profile was removed and a CMB analysis was conducted. The statistical fit of this test run appears nearly identical to the original DRI analysis with respect to chi-square and R-square (see Table 3). In addition, the standard errors associated with the source apportionments in the new analysis are less than those in the original analysis. Although the relative contributions allocated to cold start, high emitter, and diesel did change noticeably between the two runs, the change is not necessarily large compared to the uncertainties associated with the source attributions.

**Table 3. PM-2.5 Source Contribution at the Phoenix Super Site by Extended Species CMB for Cases 1 and 4**

	Case 1				Case 4			
	PM2.5	Total Carbon	Organic Carbon	Elemental Carbon	PM2.5	Total Carbon	Organic Carbon	Elemental Carbon
Concentration (ug/m3) ± RMS	15.2 ± 1.7	8.9 ± 0.7	5.3 ± 0.4	3.6 ± 0.4	15.2 ± 1.7	8.9 ± 0.7	5.3 ± 0.4	3.6 ± 0.4
R-square ± SD	0.95 ± 0.03				0.94 ± 0.04			
Chi-square ± SD	0.36 ± 0.30				0.45 ± 0.36			
Percent Mass Attributed ± SD	100.8 ± 1.7	100.3 ± 0.5	100.5 ± 0.5	100.2 ± 0.7	100.8 ± 1.2	100.2 ± 0.5	100.3 ± 0.6	100.1 ± 0.7
Mean Contributions (ug/m3) ± RMS								
Gasoline Exhaust, cold start	3.8 ± 4.2	3.3 ± 0.3	1.7 ± 0.6	1.6 ± 0.6	3.1 ± 2.2	2.7 ± 0.3	1.4 ± 0.5	1.3 ± 0.5
Gasoline Exhaust, hot stabilized	-0.2 ± 1.2	-0.2 ± 0.0	-0.1 ± 0.0	-0.1 ± 0.1	-	Not	Used	-
Gasoline Exhaust, high emitter	4.1 ± 1.8	3.4 ± 0.2	3.1 ± 0.2	0.3 ± 0.1	4.2 ± 1.5	3.5 ± 0.2	3.2 ± 0.2	0.3 ± 0.1
Diesel Exhaust	2.4 ± 2.2	2.3 ± 0.1	0.5 ± 0.2	1.8 ± 0.3	2.7 ± 1.5	2.5 ± 0.1	0.5 ± 0.3	2.0 ± 0.3
Ammonium Sulfate	1.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ammonium Nitrate	2.5 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	2.5 ± 0.4	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Geological	1.4 ± 0.3	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0	1.4 ± 0.3	0.2 ± 0.1	0.2 ± 0.1	0.0 ± 0.0
Unexplained	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean Contributions (%) ± RMS								
Gasoline Exhaust, cold start	26.4 ± 29.8	39.5 ± 3.7	34.1 ± 11.4	48.3 ± 17.7	22.7 ± 17.0	34.0 ± 3.3	29.5 ± 10.1	41.6 ± 15.6
Gasoline Exhaust, hot stabilized	-1.5 ± 8.2	-1.9 ± 0.2	-2.2 ± 0.6	-1.5 ± 1.3	-	Not	Used	-
Gasoline Exhaust, high emitter	26.6 ± 12.9	36.9 ± 1.5	56.5 ± 2.5	7.1 ± 3.6	27.6 ± 10.8	38.0 ± 1.6	58.4 ± 2.6	7.3 ± 3.7
Diesel Exhaust	15.1 ± 15.6	23.2 ± 1.0	8.0 ± 3.7	45.6 ± 6.8	16.9 ± 10.8	25.8 ± 1.1	8.9 ± 4.1	50.8 ± 7.5
Ammonium Sulfate	9.8 ± 1.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	9.9 ± 1.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ammonium Nitrate	12.7 ± 1.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	12.8 ± 1.5	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Geological	10.6 ± 1.9	2.3 ± 1.0	3.5 ± 1.6	0.5 ± 0.3	10.8 ± 1.8	2.3 ± 1.0	3.6 ± 1.6	0.5 ± 0.3

Unexplained	0.2	0.0	0.0	0.1	-0.7	-0.1	-0.4	-0.2
<b>Mean Contributions (%) ± Std Err</b>								
Gasoline Exhaust, cold start	26.4 ± 3.0	39.5 ± 4.9	34.1 ± 4.2	48.3 ± 6.5	22.7 ± 1.8	34.0 ± 0.4	29.5 ± 1.2	41.6 ± 2.1
Gasoline Exhaust, hot stabilized	-1.5 ± 0.4	-1.9 ± 0.5	-2.2 ± 0.6	-1.5 ± 0.4	-	Not Used	-	-
Gasoline Exhaust, high emitter	26.6 ± 2.4	36.9 ± 2.7	56.5 ± 3.7	7.1 ± 0.7	27.6 ± 0.9	38.0 ± 0.1	58.4 ± 0.2	7.3 ± 0.3
Diesel Exhaust	15.1 ± 2.3	23.2 ± 3.4	8.0 ± 1.2	45.6 ± 6.2	16.9 ± 1.0	25.8 ± 0.1	8.9 ± 0.5	50.8 ± 0.8
Ammonium Sulfate	9.8 ± 1.6	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	9.9 ± 0.2	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Ammonium Nitrate	12.7 ± 3.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	12.8 ± 0.3	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Geological	10.6 ± 1.5	2.3 ± 0.3	3.5 ± 0.5	0.5 ± 0.1	10.8 ± 0.1	2.3 ± 0.2	3.6 ± 0.2	0.5 ± 0.1
Unexplained	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.1 ± 0.0	-0.7 ± 0.4	-0.1 ± 0.2	-0.4 ± 0.2	-0.2 ± 0.2

## REASONABLENESS CHECKS

MAG also conducted a reasonableness check on the DRI source allocation with regards to the allocation of gasoline exhaust emissions among cold starts (approximately 49 percent of gasoline exhaust emissions in the DRI analysis), hot stabilized (approximately -3 percent of the gasoline exhaust emissions in the DRI analysis), and high emitters (approximately 53 percent of the gasoline exhaust emissions in the DRI analysis). The following assumptions regarding driving mode from the EPA MOBILE5a model were incorporated into the reasonableness check:

Driving in cold start mode accounts for 20.6 percent of annual vehicle miles traveled (VMT)

Driving in hot stabilized mode accounts for 52.1 percent of annual VMT

Driving in hot start mode accounts for 27.3 percent of annual VMT.

Emission factors measured for the NFRAQS were combined with the local vehicle age distribution to estimate a composite emission rate for each driving mode for normal emitters and high emitters. These mode and emitter specific emission factors were combined with the annual VMT per mode to estimate the emissions from each mode and emitter type. Three analyses were done using different assumptions about the fraction of the fleet that was high emitters: (1) 10% high emitter/90% normal emitter, (2) 1% high emitter/99% normal emitter, and (3) 0.1% high emitter/99.9% normal emitter. It is important to note that the data collected for the NFRAQS study, it was estimated that 0.13 percent of the fleet were high emitters.

The NFRAQS data contained measured emission factors for two data sets: data collected by Colorado Department of Public Health and Environment (CDPHE) and data collected by EPA. The analysis described above was carried out using each data set separately. The results of this analysis may not be directly comparable to the CMB results because a source profile was not included for the hot start mode in the CMB analysis.

The results from the reasonableness check using the EPA data are presented below. Table 4 contains the VMT fraction by vehicle age and the measured emission factors.

**Table 4. PM Emission Factors by Phases for Winter-EPA Measurement Data and MAG VMT Fractions by Vehicle Age.**

Period	VMT Fraction by Vehicle Age	Cold start (mg/mile)	Hot stabilized (mg/mile)	Hot start (mg/mile)
Pre-1981	0.049	290	26.1	37.9
1981-1985	0.056	159	19	21.4
1986-1990	0.156	70.6	16.9	18.7
1991-2000	0.739	81.3	13.4	6.3
Overall LDGV	1.000	94.21	14.88	10.63
High Emitter		1179	231	272

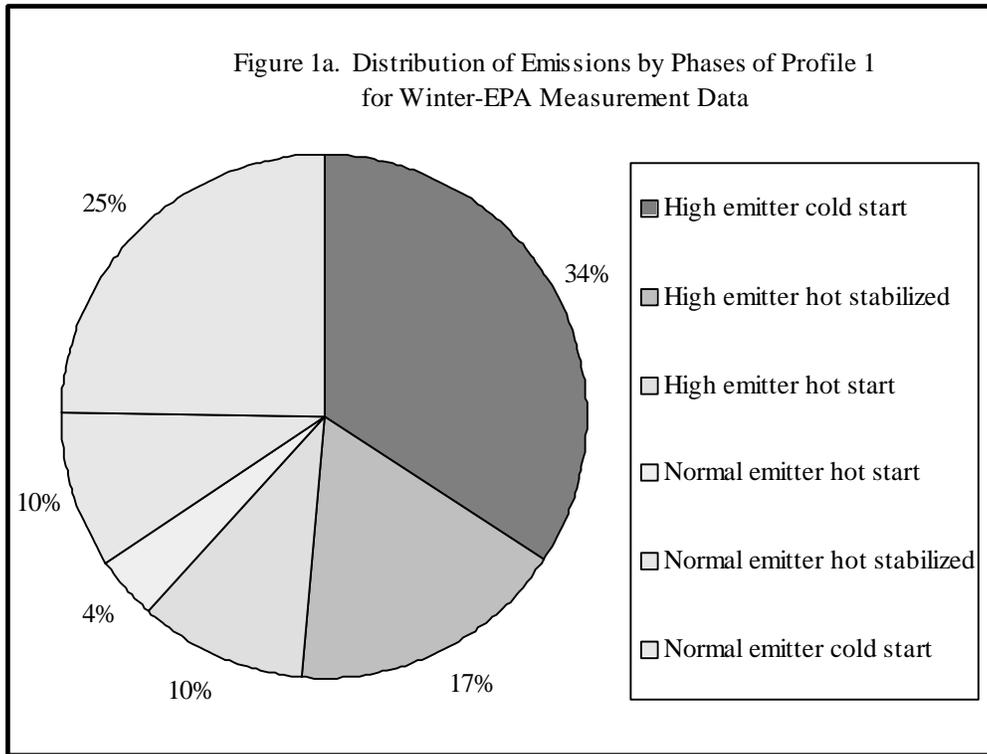
Table 5 contains the emissions and VMT fractions associated with each mode of operation for high emitters and normal emitters. The three scenarios for the fraction of the fleet that are high emitters are referred to as profile 1, profile 2, and profile 3 in Table 5.

**Table 5. Emissions and Distributions by Phases for Three Different Fleet Profiles Using Winter-EPA Measurement Data Set.**

<b>Profile 1</b>	Phase	VMT	Emission (mg)	Percent
10% high emitters	Cold start	0.0206	24.29	34.30
	Hot stabilized	0.0521	12.04	17.00
	Hot start	0.0273	7.43	10.49
	Subtotal	0.1000	43.75	61.79
90% normal emitters	Cold start	0.1854	17.47	24.67
	Hot stabilized	0.4689	6.98	9.86
	Hot start	0.2457	2.61	3.69
	Subtotal	0.9000	27.06	38.21
<b>Total</b>		<b>1.0000</b>	<b>70.80</b>	<b>100.00</b>
<b>Profile 2</b>				
1% high emitters	Cold start	0.00206	2.43	7.11
	Hot stabilized	0.00521	1.20	3.53
	Hot start	0.00273	0.74	2.18
	Subtotal	0.01000	4.37	12.82
99% normal emitters	Cold start	0.20394	19.21	56.28
	Hot stabilized	0.51579	7.68	22.49
	Hot start	0.27027	2.87	8.41
	Subtotal	0.99000	29.76	87.18
<b>Total</b>		<b>1.00000</b>	<b>34.14</b>	<b>100.00</b>
<b>Profile 3</b>				
	Cold start	0.000206	0.24	0.80

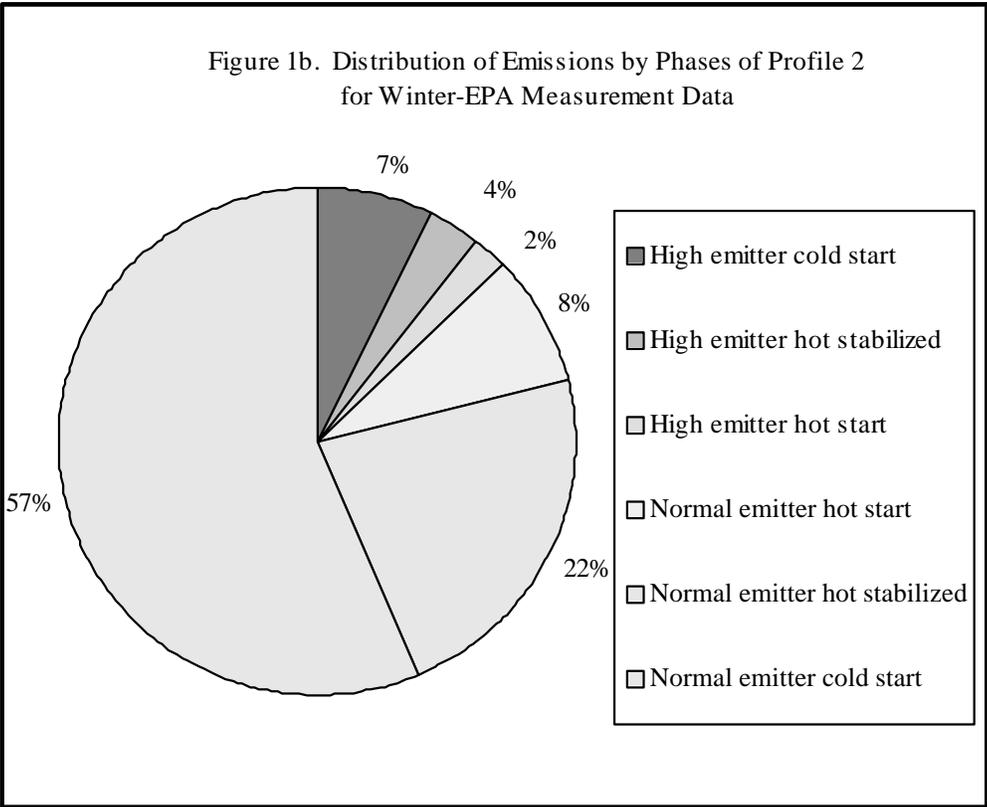
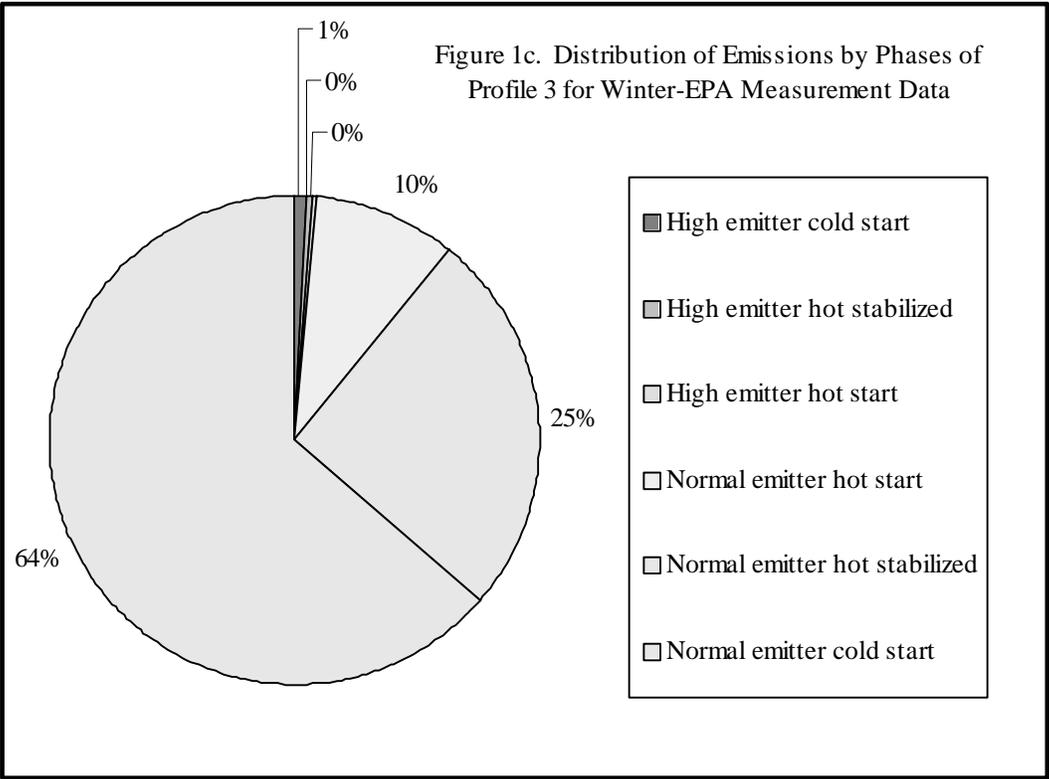
0.1%  
high  
emitters

0.40



	Hot stabilized	0.000521	0.12	
	Hot start	0.000273	0.07	0.24
	Subtotal	0.001000	0.44	1.44
	Cold start	0.205794	19.39	63.63
99.9% normal emitters	Hot stabilized	0.520479	7.75	25.42
	Hot start	0.272727	2.90	9.51
	Subtotal	0.999000	30.03	98.56
	Total	1.000000	30.47	100.00

The data from Table 5 are presented graphically in Figures 1a through 1c below. These data indicate that emissions from normal emitters operating in hot stabilized and hot start mode are estimated to contribute between 15 and 35 percent of the gasoline engine exhaust depending on the assumption of the number of high emitters.



The results from the reasonableness check using the CDPHE data are presented below. Table 6 contains the VMT fraction by vehicle age and the measured emission factors.

Table 6. PM Emission Factors by Phases for CDPHE Measurement Data and MAG  
VMT Fractions by Vehicle Age.

Period	VMT Fraction by Vehicle Age	Cold start (mg/mile)	Hot stabilized (mg/mile)	Hot start (mg/mile)
Pre-1981	0.049	143	27.8	41.2
1981-1985	0.056	82.6	20.3	30.2
1986-1990	0.156	27.9	7.3	8.2
1991-2000	0.739	9.1	1.8	2.9
Overall LDGV	1.000	22.71	4.97	7.13
High Emitter		742	298	315

Table 7. Emissions and Distributions by Phases for Three Different Fleet Profiles Using Winter-CDPHE Measurement Data.

<b>Profile 1</b>	Phases	VMT	Emission (mg)	Percent
10% high emitters	Cold start	0.0206	15.29	32.04
	Hot stabilized	0.0521	15.53	32.55
	Hot start	0.0273	8.60	18.03
	Subtotal	0.1000	39.41	82.62
90% normal emitters	Cold start	0.1854	4.21	8.83
	Hot stabilized	0.4689	2.33	4.88
	Hot start	0.2457	1.75	3.67
	Subtotal	0.9000	8.29	17.38
<b>Total</b>		<b>1.0000</b>	<b>47.70</b>	<b>100.00</b>
<b>Profile 2</b>				
1% high emitters	Cold start	0.00206	1.53	11.70
	Hot stabilized	0.00521	1.55	11.89
	Hot start	0.00273	0.86	6.58
	Subtotal	0.01000	3.94	30.17
99% normal emitters	Cold start	0.20394	4.63	35.46
	Hot stabilized	0.51579	2.56	19.62
	Hot start	0.27027	1.93	14.76
	Subtotal	0.99000	9.12	69.83
<b>Total</b>		<b>1.00000</b>	<b>13.06</b>	<b>100.00</b>
<b>Profile 3</b>				
0.1% high emitters	Cold start	0.000206	0.15	1.59
	Hot stabilized	0.000521	0.16	1.62
	Hot start	0.000273	0.09	0.90
	Subtotal	0.001000	0.39	4.11
99.9% normal emitters	Cold start	0.205794	4.67	48.69
	Hot stabilized	0.520479	2.59	26.94
	Hot start	0.272727	1.95	20.27
	Subtotal	99.900000	9.20	95.89
<b>Total</b>		<b>1.000000</b>	<b>9.60</b>	<b>100.00</b>

The data from Table 6 are presented graphically in Figures 2a through 2c below. These data indicate that emissions from normal emitters operating in hot stabilized and hot start mode are estimated to contribute between 9 and 47 percent of the gasoline engine exhaust depending on the assumption of the number of high emitters.

Figure 2a. Distribution of Emissions by Phases of Profile 1 for Winter-CDPHE Measurement Data

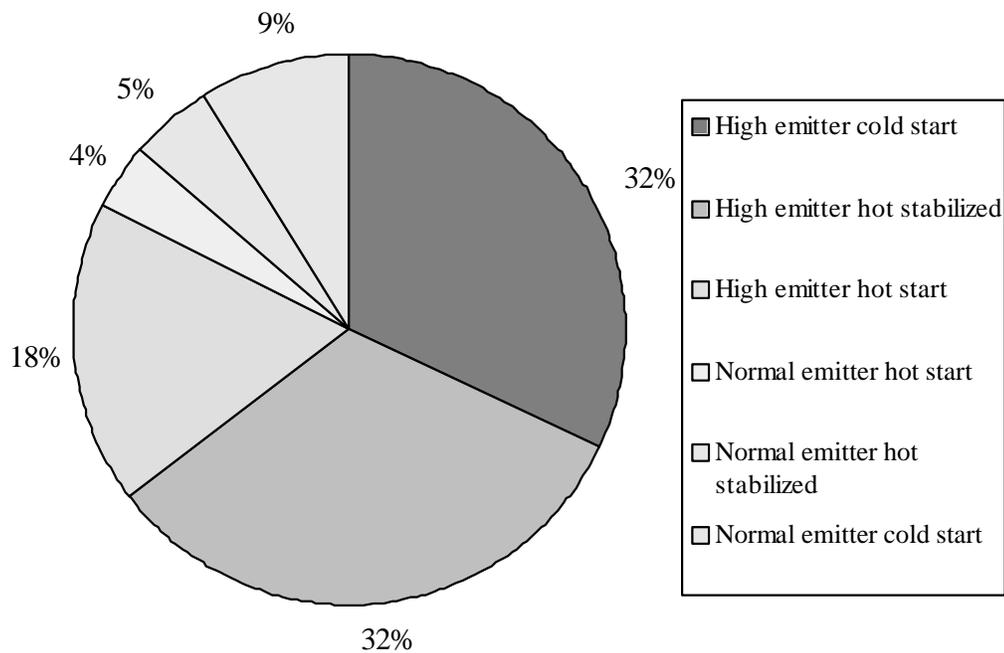
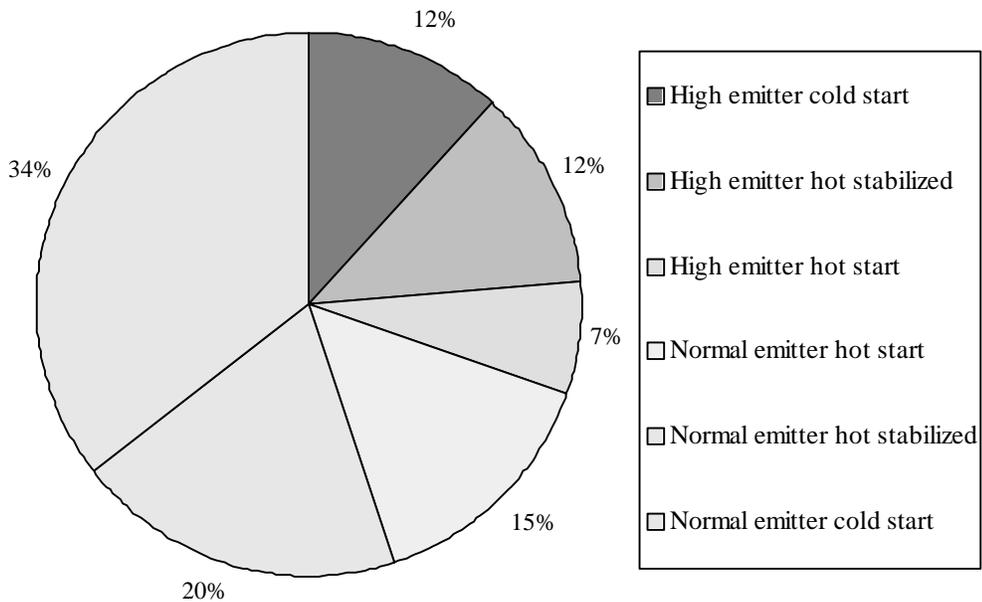
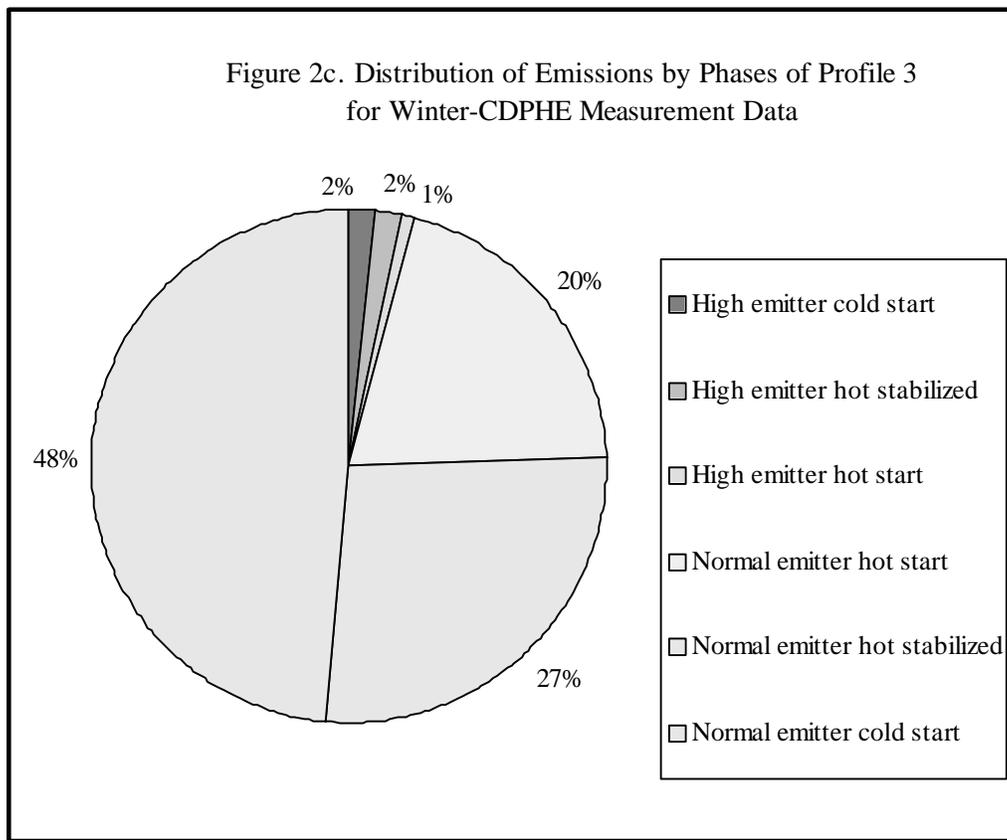


Figure 2b. Distribution of Emissions by Phases of Profile 2 for Winter-CDPHE Measurement Data





## CONCLUSIONS

Based on the results of the sensitivity tests and reasonableness checks, the results of the DRI CMB analysis should not be interpreted as absolute numbers. It is important to consider the uncertainty of the source attributions calculated by the model as well as the uncertainties introduced through source profile selection and missing source profiles. Through the sensitivity tests, it has been shown that different “acceptable” results may be obtained using the same ambient data and different source profiles. Therefore, it is important to examine the reasonableness of the source attributions with respect to physical reality.

Given that source profiles for meat cooking and wood burning were not included in the analysis, it is likely the contribution from mobile sources is overestimated since these two missing sources, produce mostly carbon emissions. The meat cooking profile is nearly all organic carbon and the wood burning

profile has a high organic to elemental carbon ratio. If meat cooking and wood burning contribute approximately nine percent of the PM-2.5 emissions in Phoenix, as in Denver, then the mobile source contribution is likely to be overestimated since nearly all of the carbon in the PM-2.5 is currently attributed to mobile sources. In particular since meat cooking and wood burning emissions are predominantly organic carbon and gasoline exhaust has significantly more organic carbon than does diesel exhaust, the overestimation of the mobile source contribution is likely to be mostly due to an overestimation of gasoline engine exhaust. If this is the case, then the ratio of gasoline engine exhaust to diesel engine exhaust would change significantly.

Based on the reasonableness checks, it appears that a scenario in which emissions from hot stabilized gasoline emissions are insignificant may be difficult to produce using the NFRAQS emission data. In fact, assuming that either one or 0.1 percent of the fleet are high emitters, emissions from the hot stabilized mode contribute at least 20 percent of the gasoline exhaust emissions. Although the reasonableness check does not agree with the CMB results in terms of the magnitude of emissions from various modes of gasoline-powered vehicles, the reasonableness check does agree with the CMB results in that emissions from cold starts and high emitters contribute a disproportionately large fraction of gasoline-powered vehicle emissions relative to their level of VMT.

## **APPENDIX G**

### **CONTROL MEASURE INFORMATION FROM INTERVIEWS AND LITERATURE REVIEW**

This appendix includes several tables summarizing information collected during the research phase of the Brown Cloud study. The tables are:

Table G-1: Control measure information derived from seven western U.S. geographic areas. Includes information from interviews and literature reviews specific to seven western U.S. geographic areas.

Table G-2: Control measure information derived from literature review.

Table G-1. Control measure information derived from seven western U.S. geographic areas (information gathered during mid- to late-1996).

Area	Controls/Programs	Reference	Comment
Albuquerque	<p><i>Area:</i></p> <ul style="list-style-type: none"> <li>• Wood burning limitations on calm days</li> </ul> <p><i>Mobile:</i></p> <ul style="list-style-type: none"> <li>• Oxygenated fuels program, vehicle I/M, ridesharing and transit promotion</li> </ul>	Dan Warren, City of Albuquerque Environmental Health Department, personal communication, August 22, 1996	Controls are focused on addressing carbon monoxide, although they have studied Brown Cloud
Clark County/Las Vegas	<p><i>Stationary:</i></p> <ul style="list-style-type: none"> <li>• Natural gas for some power plants</li> </ul> <p><i>Area:</i></p> <ul style="list-style-type: none"> <li>• Ban on wood burning in new residential</li> <li>• Construction dust controls</li> </ul> <p><i>Mobile:</i></p> <ul style="list-style-type: none"> <li>• Oxygenated fuel but no reformulated</li> <li>• Remote sensing coming</li> <li>• No central I&amp;M, buy back or TRO</li> <li>• Some CNG County public fleet, but not for transit or school buses</li> <li>• Paratransit all CNG</li> <li>• Will test A-55 (water based) in buses and street sweepers</li> </ul>	<i>Haze Apportionment</i> , Chester Environmental, 1993; <i>Fugitive Dust and Other Source Contributors in Nevada's Las Vegas Valley</i> , DRI, August, 1996.	Mike Naylor, Clark County Health District, indicated approximately two thirds of the haze problem is crustal (dust) versus combustion related (diesel followed by auto exhaust and wood smoke).
Denver	<p><i>Area:</i></p> <ul style="list-style-type: none"> <li>• Wood burning curtailment on forecasted high PM and poor visibility days, paved road sweeping and sanding requirements</li> </ul> <p><i>Mobile:</i></p> <ul style="list-style-type: none"> <li>• Oxygenated fuels use</li> <li>• Diesel I/M; national standards on heavy-duty vehicles and diesel fuel</li> <li>• Enhanced I/M; significant transit improvement program involving subsidized bus use, high-occupancy vehicle lanes, and plans for light rail</li> </ul> <p><i>Stationary:</i></p> <ul style="list-style-type: none"> <li>• NO<sub>x</sub> and SO<sub>x</sub> emission controls on major sources (e.g., Colorado Public Service Company), new PM<sub>10</sub> limits for major sources, restricted use of oil as a backup fuel</li> </ul>	<p>U.S. Environmental Protection Agency Region 8, Callie Videtich, personal communication September 3, December 10, 1996.</p> <p>Colorado SIP for Particulate Matter (PM-10), Regional Air Quality Council, Colorado Department of Health. October 20, 1994.</p>	Denver has a visibility regulation, but has not adopted controls specific to controlling visibility. Denver forecasts problem PM and visibility days, and prohibits wood burning on those days (mandatory control), and encourages reduced vehicle use (voluntary). The state is working to develop a comprehensive air quality plan which will encompass criteria pollutants and visibility; a near final draft of the plan is not likely to be complete until sometime in late 1997 or 1998.

Table G-1. Control measure information derived from seven western U.S. geographic areas (information gathered during mid- to late-1996).

Area	Controls/Programs	Reference	Comment
Portland	<p><i>Stationary:</i></p> <ul style="list-style-type: none"> <li>• RACT at industrial controls</li> <li>• VOC standards for paints and consumer products</li> <li>• No construction controls</li> <li>• Agriculture and forest burning not an issue</li> <li>• Certified wood stoves only in new construction</li> </ul> <p><i>Mobile:</i></p> <ul style="list-style-type: none"> <li>• Education to encourage electric yard tools, curtailed lawn mowing, vehicle trips</li> <li>• Winter oxygenated fuel program, I&amp;M, including testing of 1975+ models</li> <li>• Driving cycle I&amp;M proposed</li> <li>• New TRO for urban area employers over 50</li> <li>• Voluntary parking reduction in new non-residential development</li> <li>• Expanded transit, density bonuses</li> </ul>	Ozone Maintenance Plan, State of Oregon, Department of Environmental Quality, July, 1996.	Brian Finneran, Oregon Department of Environmental Quality indicates Portland does not have a haze problem and meets the PM <sub>10</sub> standard. Ozone Plan is impetus for most controls.

Seattle/Puget Sound

*Stationary:*

- Only certified stoves can be sold in King County
- Firewood moisture standard
- Outdoor burning ban
- wood burning education program
- Industrial and dust controls at ports
- Some CNG for airport tow vehicles, but not required
- Monitor CO and NO<sub>x</sub> at ends of runways
- Some power plant conversions from coal to gas

*Mobile:*

- Transit rejected liquid natural gas for clean diesel
- Some CNG for County fleet vehicles
- Will test remote sensing
- Oxygenated fuel a contingent measure (was required)
- I&M is biannual centralized
- Snap idle test for trucks not central, no test for interstate trucks
- Statewide TRO for urban areas

*Wood smoke Control in Puget Sound Region, Puget Sound APCA, 1992; Commute Trip Reduction, 1995 Report to the Washington State Legislature, Commute Trip Reduction Task Force, December 1, 1995; Analysis of Air-Quality Data in the Puget Sound Airshed, WYNDsoft Inc, September, 1994.*

Naydene Maykut, Puget Sound Air Pollution Control Agency indicated up to 75% of residential particulates are due to wood smoke, 18% sulfate, 15% mobile sources.

One report concludes Oxygenated fuel reduced winter CO up to 20%; burn bans reduced haze up to 35%.

Table G-1. Control measure information derived from seven western U.S. geographic areas (information gathered during mid- to late-1996).

Area	Controls/Programs	Reference	Comment
<p>South Coast Air Quality Management District</p>	<p><i>Mobile On-Road:</i></p> <ul style="list-style-type: none"> <li>• Accelerated refinement of light- and heavy-duty vehicles</li> <li>• Focus on reduction of NO<sub>x</sub> from heavy-duty engines</li> <li>• Phase II gasoline implemented encouraging use of cleaner burning fuels, with 10% new vehicle sales in 2003 being zero emission vehicles (ZEV)</li> <li>• Infrastructure for above being developed</li> </ul> <p><i>Off-Road:</i></p> <ul style="list-style-type: none"> <li>• Industrial equipment being encouraged to use natural gas and LPG with California or national standards</li> <li>• Most other sources — marine vessels, locomotives and pleasure craft controlled by national standards — support for stricter standards for these</li> <li>• Encouraging use of cleaner fuels including electric for lawn mowers, street sweepers and leaf blowers.</li> </ul>	<p>1997 Air Quality Management Plan, October 1996</p>	
<p>Washoe County/Reno</p>	<p><i>Area:</i></p> <ul style="list-style-type: none"> <li>• Ban on wood burning in new residential, change to certified stoves at sale</li> <li>• BACT requirements for food establishments</li> <li>• Episodic controls on all open, incinerator and stove burning</li> <li>• Construction, agriculture, livestock dust controls</li> </ul> <p><i>Stationary:</i></p> <ul style="list-style-type: none"> <li>• Concrete batch plant controls</li> <li>• HC vapor standards for fuel storage</li> </ul> <p><i>Mobile:</i></p> <ul style="list-style-type: none"> <li>• Restrict diesel idling</li> <li>• winter O<sub>x</sub> fuel</li> <li>• Reid vapor pressure standard</li> <li>• Gasoline transfer standards</li> <li>• No TRO</li> </ul>	<p><i>District Board of Health Regulations Governing Air Quality Management,</i> October, 1995.</p>	<p>Andy Goodrich, Air Quality Supervisor, County Health Department indicated that wood smoke and on and off road diesel are biggest contributors, though he has no studies in support and has limited 2.5 monitor data. Said idling rule is tough to enforce.</p>



Table G-2. Control measure information derived from literature review (information gathered during mid- to late-1996).

Literature	Controls	Pollution Target	Comments (especially regarding availability of measure cost-benefit information)
<p><i>Controlling Particulate Matter Under the Clean Air Act: A Menu of Options</i>, STAPPA/ALAPCO, July 1996 (Mobile Source Controls).</p>	<p><i>Mobile Diesel Exhaust Controls:</i></p> <ul style="list-style-type: none"> <li>• New engine standards for on-road HDVs by 2004-2007</li> <li>• Vehicle retrofit for HDVs, buses, and nonroad vehicles</li> <li>• HDV retirement program</li> <li>• HDV I/M</li> <li>• Reformulated diesel fuel for on and nonroad vehicles</li> </ul> <p><i>Small Non-road engine controls:</i></p> <ul style="list-style-type: none"> <li>• New standards for gasoline-powered engines</li> </ul> <p><i>Mobile Gasoline and Diesel Vehicles:</i></p> <ul style="list-style-type: none"> <li>• Alternative fuels use, transportation control measures</li> </ul>	<p>Particulate matter</p>	<p>Provides cost information such as cost per vehicle or engine unit, and overall cost benefit per ton of pollution reduced</p>
<p><i>Cost and Effectiveness of TCMs: A Review and Analysis of the Literature</i>, for National Association of Regional Councils, Apogee Research, January, 1994</p>	<ul style="list-style-type: none"> <li>• Employer trip reduction</li> <li>• Area-wide rideshare</li> <li>• Transit improvements</li> <li>• HOV lanes</li> <li>• Park and ride lots</li> <li>• Bike and walk facilities</li> <li>• Parking pricing</li> <li>• Congestion pricing</li> <li>• Compressed work week</li> <li>• Telecommuting</li> <li>• Land use</li> <li>• Signal timing</li> <li>• Incident management</li> <li>• Smog/VMT tax</li> <li>• Old vehicle buy-back</li> </ul>	<p>HC (on-highway, non-methane hydrocarbons)</p>	<p>Regional, daily HC emission reductions for the on-road vehicle fleet from each of the measures are below 5%, except for congestion pricing (8.2%). In terms of costs to governments and firms, cost per ton of HC reductions in 1997 dollars are:</p> <p>&gt;\$300,000: employer trip reduction; major rail improvements; bicycle facilities.</p> <p>\$100,000 to \$300,000: HOV lanes; park and ride.</p> <p>&lt;\$100,000: emissions/VMT tax; incident management; compressed work week; parking pricing; area-wide ridesharing.</p>

Table G-2. Control measure information derived from literature review (information gathered during mid- to late-1996).

Literature	Controls	Pollution Target	Comments (especially regarding availability of measure cost-benefit information)
<p><i>Draft Comprehensive List of Measures for Particulate Matter and Carbon Monoxide</i>, Maricopa Association of Governments, November 1996.</p>	<p><i>Mobile:</i></p> <ul style="list-style-type: none"> <li>• Vehicle emissions testing, clean fuels for conventional vehicles, cleaner vehicle technologies, reduced vehicle use and traffic congestion, reduced vehicle idling</li> </ul> <p><i>Area:</i></p> <ul style="list-style-type: none"> <li>• Reduced emissions from nonroad equipment, fugitive dust control, reduced emissions from agricultural activities, fireplace and other burning restrictions</li> </ul> <p><i>Stationary:</i></p> <ul style="list-style-type: none"> <li>• Reduced emissions from industrial sources</li> </ul>	<p>Particulate matter, carbon monoxide, ozone</p>	<p>This includes a comprehensive listing of measures divided into two categories: new measures, and existing measures which could be considered for strengthening. The report does not include cost-benefit information, however it does identify the potential implementing entity.</p>
<p><i>Feasibility and Cost Effectiveness of New Air Pollution Control Measures Pertaining to Mobile Sources</i>, for Maricopa Association of Governments, By Sierra Research, June 1993.</p>	<p><i>Mobile:</i></p> <ul style="list-style-type: none"> <li>• Telecommunications, emission-based vehicle registration charges, vehicle scrappage programs, alternative fuels programs, adoption of the California LEV program, land-use planning alternatives, off-peak goods movement, transit service improvements, I/M program enhancements, catalyst retrofit/replacement, control of nonresident motor vehicle emissions, freeway incident response, alternative work schedules</li> </ul>	<p>Ozone, carbon monoxide, particulate matter</p>	<p>Includes detailed cost-effectiveness information</p>

Table G-2. Control measure information derived from literature review (information gathered during mid- to late-1996).

Literature	Controls	Pollution Target	Comments (especially regarding availability of measure cost-benefit information)
<p><i>Particulate Control Measure Feasibility Study for Maricopa Association of Governments</i>, Sierra Research, September, 1996.</p>	<p>Road travel, construction, agriculture tilling, residential wood combustion, on-road and nonroad motor vehicle exhaust, particulate precursors, wind entrainment.</p>	<p>PM<sub>10</sub> and PM<sub>2.5</sub></p>	<p>In terms of 1994 dollars daily cost per pound of pollution reduced:</p> <p>&lt;\$10/lb: episodic curtailment of residential wood burning; restrict tilling in high winds; restrictions on blowers; traffic/speed reduction on unpaved roads; surface treatment on unpaved roads; material transport controls; street sweeping; construction controls; spill clean ups.</p> <p>\$10 - 50/lb: paving of unpaved roads; maintain wood burning devices; animal waste management; scrapping of heavy-duty diesel vehicles.</p> <p>&gt;\$50/lb: dust control on material storage; chemical stabilizing of unpaved access; limit of off-road use; heavy-duty diesel engine replacement; use "clean diesel;" enhanced diesel I&amp;M; dust control plan for grading; reduce agriculture ammonia emissions; windbreaks; fallow field treatment.</p>

Table G-2. Control measure information derived from literature review (information gathered during mid- to late-1996).

Literature	Controls	Pollution Target	Comments (especially regarding availability of measure cost-benefit information)
<p><i>Reducing Vehicular Emissions in Arizona: Reformulated Gasoline and Control of Particulate Emissions from Heavy Duty Diesel Vehicles</i>, DRI/McGraw-Hill, January 1993</p>	<p><i>Mobile:</i></p> <ul style="list-style-type: none"> <li>• Reformulated gasoline use</li> </ul>	<p>Ozone and particulate matter</p>	<p>Includes comprehensive cost-benefit information</p>
<p><i>Report of the Grand Canyon Visibility Transport Commission to the United States Environmental Protection Agency</i>, June 1996.</p>	<p><i>Mobile:</i></p> <ul style="list-style-type: none"> <li>• Capping emissions at lowest levels for fleet as a whole (around 2005)</li> <li>• National LEV program</li> <li>• National heavy-duty vehicle standards (for both on and off road engines)</li> <li>• National reductions in diesel and gasoline sulfur content</li> <li>• National standards for marine vessels, locomotives, aircraft, and federal vehicles</li> <li>• Evaporative emissions control for refueling</li> <li>• Establish clean fuel demonstration zones</li> <li>• Analyze heavy duty I/M and pricing measures to reduce VMT</li> <li>• Promote vehicle maintenance and scrappage of gross polluters</li> </ul>	<p>Visibility</p>	<p>Final report notes that the single most effective mobile source control measure (by the year 2020) is the implementation of a 49-state LEV program. Report provides little quantitative information on control costs (mainly for fire management strategies).</p>

*Transportation Control Measure Information Documents*, for U.S. Environmental Protection Agency, CSI, March, 1992.

- Trip reduction ordinances, employer-based programs, work schedule changes, area-wide ridesharing, improved public transit, HOV facilities, traffic flow improvements, parking management, park and ride, bicycle programs, special events, vehicle use restrictions, accelerated vehicle retirement, activity centers, vehicle idling and low temperature starts

All major pollutants

Generally information about costs but not c/e. Where there is c/e information it is not in terms of \$/pound or ton of pollution reduced. For example, employer programs cost employers up to \$3/vehicle trip reduced; rideshare programs cost 2.4 cents per vehicle mile reduced.

## **APPENDIX H**

### **BACKGROUND DISCUSSION ON IMPORTANT NONROAD AND ONROAD SOURCES**

## BACKGROUND DISCUSSION ON IMPORTANT NONROAD AND ONROAD SOURCES

As described in Chapter 5, nonroad and onroad mobile sources are the most important source categories contributing to the brown cloud. This appendix summarizes control strategy information collected during the research phase of the brown cloud project pertaining to these source categories. The information is organized by source category, and covers:

- (1) Nonroad industrial and commercial diesel equipment exhaust.
- (2) Onroad heavy- and light-duty vehicle diesel exhaust.
- (3) Onroad high emitting light-duty gasoline vehicles.

The information included in this appendix represents additional background information used to identify candidate brown cloud control measures. Virtually all of the information in this appendix was researched during the earlier phases of the brown cloud study, during 1996 and 1997.

### NONROAD INDUSTRIAL AND COMMERCIAL DIESEL EQUIPMENT EXHAUST

Definition: Industrial and commercial diesel equipment includes sources such as fork lifts, sweeper/scrubbers, pumps, generators, air compressors, welders, back-hoes, rock breakers, concrete mixers, pressure washers, and other material handling equipment. As indicated in the Serious Area PM<sub>10</sub> Plan, the largest fraction of nonroad exhaust emissions originates with industrial and commercial equipment (Maricopa Association of Governments, 1999a; Table 3-1, p. 3-4). Construction equipment is responsible for virtually all industrial and

commercial equipment PM emissions (Maricopa Association of Governments, 1997). Approximately two thirds of the construction equipment used in the United States is diesel-powered (STAPPA and ALAPCO, 1996).

Control Actions Already Taken or Considered: The U.S. EPA has finalized a rulemaking (October 23, 1998) to control virtually all of these and other nonroad equipment sources. These federal regulations will apply to new equipment and will be phased in during the 1999 to 2008 time period. U.S. EPA estimates that the new standards will result in approximately a 34 percent reduction in PM emissions by the year 2010, and a 45 percent reduction by the year 2020 (U.S. Environmental Protection Agency, 1998). In addition, the MAG area has already implemented, per S.B. 1002, diesel fuel requirements that limit the sulfur content of diesel fuel used in nonroad equipment to 500 ppm of sulfur. MAG area efforts enhance federal diesel fuel requirements, which only apply to onroad diesel engines. MAG, as part of its PM<sub>10</sub> state implementation plan (SIP) development, is also considering encouraging state and local government agencies to seasonally adjust their activity to minimize PM emissions during periods when the PM air quality standards might be exceeded.

Other communities have taken three types of actions to limit emissions from nonroad diesel mobile sources:

- Installing retrofit exhaust systems: Over 100,000 retrofit exhaust systems have been installed nationwide on nonroad equipment

produced by over 25 manufacturers (STAPPA and ALAPCO, 1996).

- Encouraging voluntary replacement of nonroad equipment with low or zero emission equipment: Rule 1620 (March, 1996) of the SCAQMD in southern California encourages voluntary replacement of nonroad equipment with low or zero-emission equipment (NESCAUM, 1997).
- Utilizing cleaner burning fuel formulations: Examples include:
  - (a) California diesel fuel requires lower aromatic content than federal requirements in place in Arizona. The California requirement to lower aromatic formulation results in approximately a 10 to 20 percent reduction in PM emissions beyond what is achieved with federal fuel requirements (Brasil, 1997; NESCAUM, 1997).
  - (b) French petroleum producer Elf-Aquitaine plans to introduce “Aquazole” fuel in spring of 1998; the fuel combines diesel and water and may reduce fine PM emissions up to 70 percent (with a catalytic converter); the target market is public transit fleets (Technology Report, 1997).
  - (c) Sacramento, California and Clark County, Nevada are testing “A-55,” a naphta/water fuel to replace diesel; it may cut emissions up to 40 percent (Platt, 1996).
  - (d) Since 1991, Sweden has had diesel sulfur restrictions of 10 ppm (for Class 1 diesel), and 50 ppm (for Class 2 diesel); Scandinavia in general has

combined lower sulfur (10 to 50 ppm) with cetane numbers in excess of 50 and has achieved greater PM reductions than is currently achieved in the U.S. (cetane numbers for diesel fuel are a measure of the ignition quality of the fuel) (NESCAUM, 1997; STAPPA and ALAPCO, 1996).

Opportunities for Additional Control: Three opportunities exist for agencies in Maricopa County to promote reduced nonroad emissions, beyond those reductions that will already be achieved by ongoing regulatory actions. These three options involve:

1. encouraging retrofits of existing equipment with more effective exhaust technology;
  2. requiring the use of cleaner burning fuels;
  3. promoting the voluntary purchase of cleaner operating equipment in advance of its normal introduction into the equipment fleet.
1. Encouraging retrofits may be done through incentive programs, such as the use of contract award criteria for government contracts that give contract award points to bids that commit to utilizing retrofit exhaust technology on all equipment used to carry out the work awarded. Local and state agencies could also provide tax incentives, low interest loans, and/or rebates to retrofit diesel equipment with alternative fuel capability (CNG/LNG), or to purchase new alternative fueled or cleaner operating equipment.

2. Cleaner burning fuel may be achieved by varying any one of four fuel components:

- Lowering sulfur content;
- Lowering aromatic content, as with California diesel (this may generate a 10 to 20 percent reduction in PM);
- Raising the cetane level of fuel; this provides potential PM reductions of up to 12 percent (NESCAUM, 1997); or
- Adding oxygenates (e.g., water, alcohols, or ethers); a 2 percent oxygen content may generate 8 to 15 percent reductions in PM; 5 percent oxygen may reduce PM by 20 percent (NESCAUM, 1997); note: the only commercially available oxygenated diesel sold in the U.S. is biodiesel, sold in small volume in the northeast U.S., in part due to its higher cost (Oxy-Fuel News, 1997).

Perhaps the most important of these fuel options relates to lowering the aromatic content, since aromatics form soot (STAPPA and ALAPCO, 1996). Adopting reformulated diesel fuel requirements similar to those in California would directly lower the allowable aromatic content.

3. Promoting voluntary purchase and use of cleaner operating equipment may be done in conjunction with U.S. EPA efforts to regulate nonroad engines. The U.S. EPA nonroad rulemaking includes a “Blue Sky Series Engines” program; this is a voluntary program to encourage very low emitting diesel engines (e.g., CNG or propane) (U.S. Environmental Protection Agency, 1998). Under the U.S. EPA rulemaking, engine manufacturers would generate credits under an averaging, banking, and trading program with Blue Sky Engines that were certified by

U.S. EPA to produce reduced emissions. It is the intent of U.S. EPA that the Blue Sky program continue through the 2004 model year. U.S. EPA will evaluate the program to determine if it should be continued for 2005 and later engines, and if so, whether any changes are needed. This evaluation would be considered as part of a year 2001 Feasibility Review built into the nonroad regulations. The U.S. EPA Blue Sky Program targets PM reductions of 35 to 65 percent beyond the Tier 2 exhaust standards built into the regulations. Local officials in the MAG region could offer contract award incentives, tax rebates and incentives, or low interest loans to encourage participation in the Blue Sky program.

### **ONROAD HEAVY- AND LIGHT-DUTY DIESEL EXHAUST**

Definition: More than 95 percent of these emissions are related to heavy-duty vehicle exhaust from trucks and buses. Remaining emissions originate from light-duty vehicles such as diesel cars.

Control Actions Already Taken or Considered: U.S. EPA promulgated new and retrofit truck and urban bus standards that were phased-in from 1991 to 1994. These standards reduce PM emissions more than 80 percent in affected vehicles, and the reductions will continue to accrue as truck and bus vehicle fleets turn over. Nationally, the average truck in 1994 was 8.4 years old, and the average transit bus was 8.9 years old (NESCAUM, 1997); there is a lag time between the introduction of new standards and fleet emissions reductions. [Note that in October 1997, U.S. EPA announced more stringent NO<sub>x</sub> and hydrocarbon (HC) emissions standards for diesel trucks and buses; the new standards do not affect directly emitted PM.]

There are a number of efforts underway in the MAG area to promote the use of alternative fuels and, in particular, to convert the regional transit bus fleet to alternative fueled vehicles. By 1999, approximately half of the Valley Metro bus fleet will be fueled by alternative fuels (Zwagerman, 1997). By the year 2000, all inter-terminal and parking buses at the Phoenix Skyharbor International Airport will be powered by compressed natural gas (CNG), instead of diesel (Crandall, 1997). The MAG Clean Cities Program was begun in 1995 and is promoting the conversion of vehicle fleets to alternative fuels. And, effective April 1997, per HB 2237, public agencies must have "fleet plans" to convert their vehicles to alternative fuels, or otherwise phase-in the retrofitting of pre-1993 model year heavy-duty diesel vehicles to reduce emissions.

Beginning in October 1993, diesel fuel in the MAG region had to be low sulfur (500 ppm), and have either a 35 percent maximum aromatics level or a minimum cetane index of 40; U.S. EPA estimates that PM emissions are reduced by 90 percent due to low sulfur fuel (NESCAUM, 1997). As noted in the nonroad industrial and commercial diesel equipment discussion, the MAG area has implemented these fuel requirements for both onroad and nonroad diesel engines.

The MAG area also has one of the more advanced and longest running heavy-duty diesel vehicle inspection programs. Heavy-duty diesel vehicles registered in the county undergo annual loaded mode testing. Per SB 1002, beginning in October 1998, vehicles greater than 8,500 lbs. switched to a new "snap acceleration" annual test (Maricopa Association of Governments, 1999a). The new test is considered safer to administer, since the vehicle is parked. A "snap acceleration" test measures the smoke opacity (or darkness) produced when an

engine is suddenly accelerated while the vehicle is parked. Starting from an idle position, the accelerator pedal is quickly depressed. This acceleration tends to produce a short "puff" of smoke. The peak smoke opacity produced during the test is recorded by an opacity meter, and compared to an established limit.

All vehicles tend to emit less when traveling at consistent speeds, rather than in stop-and-go traffic. HB 2001 required the synchronization of all traffic signals on roads carrying more than 15,000 vehicles per day (Maricopa Association of Governments, 1999a). As more traffic signals in the region are synchronized, per vehicle emissions reductions will occur from heavy-duty vehicles traveling affected streets.

As part of regional efforts to control PM, the MAG area recently committed to a broad range of control measures, including several measures which will help reduce PM from heavy-duty onroad vehicles. Examples of these control measures include:

- A voluntary vehicle repair and retrofit program
- Encouraged voluntary retirement of diesel vehicles by the year 2004
- Oxidation catalysts for heavy-duty diesel vehicles

Control actions taken by other communities help illustrate potential heavy-duty vehicle PM<sub>2.5</sub> control options. In December 1997, California announced a new HDDV I/M program with two key components: an annual self-inspection program for fleets of two or more vehicles (the "periodic smoke inspection" program), and a random roadside program using snap acceleration testing. The random roadside program began in 1998, and was based on a similar program in place from 1991-1993. British

Columbia has operated a successful roadside inspection pilot program since February 1996. [The Arizona Legislature passed S.B. 1427 in 1998 which requires ADEQ to implement a pilot random roadside emission testing program for heavy-duty diesel vehicles.]

Much as the MAG region has implemented alternative fuel programs for buses and trucks, similar efforts are underway throughout the country. Nearly one fifth of all transit buses ordered in the U.S. in 1996 were CNG fueled (Tri-State Transportation Campaign, 1997). In January 1997, New York and New Jersey announced the purchase of 500 clean fuel buses (15 percent of their entire fleet). In September 1997, the Metropolitan Transportation Authority (MTA) in Los Angeles agreed to purchase nearly 300 new CNG buses, for delivery beginning in February 1999, after which Los Angeles will have the largest alternative fueled bus fleet in the nation--over 800 CNG buses (PR Newswire, 1997). The U.S. Postal Service introduced 30 new CNG fueled 2-ton trucks into its New York fleet in September 1997, and plans to continue to introduce alternative fueled vehicles into its fleet in various places around the country including Texas, Colorado, and California; the Phoenix area was not cited as one of the cities slated to receive these vehicles (Business Wire, 1997).

In addition, a southern California based group, Gladstein and Associates, is working to create the Interstate Clean Transportation Corridor (ICTC). The ICTC is seeking to create natural gas refueling stations along the main travel corridors linking Los Angeles, Salt Lake City, and Las Vegas. Gladstein and Associates is working with public and private sector companies to encourage CNG use and infrastructure development (Williams, 1998). The same group is working to develop a pilot truck

stop electrification program along the major transportation corridors linking Mexico, the U.S., and Canada (Munger, 1999).

On a more experimental basis, the recent introduction of fuel cells by the Chicago Transit Agency (CTA) represents the use of new technology electric buses in the mass transit fleet. CTA fuel cell buses are powered by compressed hydrogen gas. The fuel cell bus will have the performance equivalent of other CTA diesel-powered vehicles. However, the fuel cell bus will create no pollution. Instead of the heavy exhaust often associated with diesel buses, the only by-product of a fuel cell bus is pure water vapor. The CTA buses feature a Ballard Fuel Cell Engine, and cost about \$1.4 million per bus (as opposed to the \$320,000 the MTA is spending per CNG powered bus in Los Angeles). CTA fuel cell buses were paid for with capital investment funds that were specifically embarked for environmental air quality improvement projects. Federal CMAQ grants from the Federal Transit Administration and the Regional Transportation Authority provided \$6.7 million for the project. The cost of the three Ballard fuel cell buses was \$1.4 million each. Spare parts, maintenance, training, and engineering are expected to cost \$1.6 million. Construction of the fueling station and the hydrogen fuel cost almost \$1 million. An additional \$2.9 million were provided by the FTA and the RTA to modify a Chicago Transit Authority bus garage that will house the fuel cell buses, and to pay for additional site work, labor costs by field forces and additional monitoring systems. In total, \$9.6 million were allocated for this project.

There are also examples of other communities restricting the use of HDDVs. Beginning in July 1996, three of the largest cities in Sweden prohibited the use of older heavy-duty vehicles in their central areas,

unless the trucks were retrofit with emissions controls (NESCAUM, 1997). In the U.S., both New York and Washington, D.C. have three minute idling restrictions for heavy-duty vehicles (NESCAUM, 1997).

Opportunities for Additional Control: Several opportunities exist for agencies in Maricopa County to achieve additional emission reductions from on-road HDDVs, beyond the efforts already underway or planned. These include:

1. Reformulating diesel fuels to produce fewer emissions.
2. Strengthening the existing program to encourage vehicle retirements and retrofits.
3. Limiting vehicle idling.

1. Reformulating diesel fuels to produce fewer emissions would be effective for on-road as well as nonroad sources. As described in the discussion for nonroad industrial and commercial sources, cleaner burning fuels that focus on lowering aromatic levels, as has been done in California, will reduce elemental carbon emissions that contribute to the brown cloud.

2. Encouraging vehicle retirements and retrofits may be achieved through emission reduction credits, tax incentive programs, low interest loans, rebate programs, and possible participation in the Interstate Clean Transportation Corridor program. Note that one of the methods to retrofit diesel vehicles is through the installation of oxidation catalysts; however, oxidation catalysts will not reduce black carbon emissions.

3. Controlling vehicle idling has the potential to be a significant emission reduction program. Truck tractors may idle up to 60 percent of the time (NESCAUM, 1997). The MAG Air Quality Technical Advisory Committee identified problems

with implementing truck stop electrification as a way to limit vehicle idling, due to a lack of facilities (Maricopa Association of Governments, 1999a). However, Maricopa County agencies may be able to pilot an electrification effort, and work with the American Trucking Association to determine suitable pilot opportunities.

## **ONROAD HIGH EMITTING LIGHT-DUTY GASOLINE VEHICLES**

Definition: A small fraction, perhaps approximately two percent, of light-duty automobiles emit much higher than average quantities of PM. For example, a study published in 1996 (Sagebiel et al., 1996) measured emissions from 23 vehicles identified as high emitters by remote sensing and roadside inspections. The average particle emission rate, as measured by advanced technology inspection equipment ("IM240" inspection equipment) showed that of the 23 vehicles, 17 were non-smoking vehicles that emitted approximately 51 mg of PM per mile. The remaining 6 vehicles emitted visible smoke and averaged 558 mg of PM per mile with a high of 1,342 mg per mile. In contrast, a "clean" vehicle typically emits 5 mg per mile. On average, most of the particulate mass was carbon with an average split of 75 percent organic carbon (OC) and 25 percent black carbon (EC), or soot.

Control Actions Already Taken or Considered: There are currently no programs specifically designed to identify and correct PM gross emitters. In general, enhanced I/M requirements applicable in the MAG area, along with fleet turnover, contribute to vehicle retirement and improved vehicle maintenance that will help reduce these PM emissions. Several actions recently committed to in the Serious Area PM<sub>10</sub> Plan for the MAG area will also help

identify and correct these gross emitting vehicles. Examples of these actions include (Maricopa Association of Governments, 1999a):

1. More stringent gross polluter requirements for vehicles seeking to waive out of the I/M 240 pass/fail standards (per S.B. 1427 in 1998).
2. Enhancements to the Vehicle Repair Grant program.
3. Tougher enforcement of vehicle registration and emissions test compliance.

In California, state officials have developed a computer program that identifies vehicle types most likely to be high emitting vehicles. The program, the “high emitter profile” (HEP) program, relies upon past and current I/M data, as well as remote sensing results.

Opportunities for Additional Control: Potential additional efforts include four program options:

1. Strengthening the enhanced IM program.
2. Implementing use of the California HEP program.
3. Changing the smoking vehicle hotline to a toll-free number.
4. Encouraging early vehicle retirement.

1. Strengthening the enhanced I/M program to include particulate matter or to identify smoking vehicles. The current I/M program is designed to address hydrocarbon, NO<sub>x</sub> and carbon monoxide, rather than PM emissions.

2. Implementing use of the California HEP program. The California vehicle fleet is different from the rest of the nation; however, the California HEP program may

have general applicability in identifying model years, engine families, and other indicators of potentially higher polluting vehicles. Arizona may be able to use the HEP program to identify gross PM emitting vehicles that contribute to the brown cloud. [Note: later research described in Chapter 5 determined that the California HEP program would not likely identify the smoking, high-PM emitting vehicles of primary concern to controlling the brown cloud.]

3. Changing the Smoking Vehicle Hotline to a toll-free number, and linking publicity about the new number to a public outreach campaign tied to forecasting brown cloud problems. Local officials in the MAG region may expand the Clean Air Campaign to include brown cloud forecasts and to

provide visual displays of air pollution formation to local weather forecasters. These outreach efforts may be linked to promoting a toll-free hotline number.

4. Encouraging early vehicle retirement by identifying gross emitters through the existing I/M and remote sensing programs. Once identified, owners of gross emitting vehicles could become eligible for low interest new vehicle purchase loans, vehicle scrappage payments, or other incentives or disincentives (such as the vehicle pollution charge) designed to promote early vehicle retirement.