Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant

APPENDIX III
PART A
EXPOSURE ASSESSMENT

As Approved by the Scientific Review Panel
on April 22, 1998

California Environmental Protection Agency

Air Resources Board

Report to the Air Resources Board on the Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant

Part A

Exposure Assessment

As Approved by the Scientific Review Panel on April 22, 1998

Project Manager

Robert K. Krieger

Reviewed by

Janette M. Brooks, Manager
Substance Evaluation Section

Genevieve A. Shiroma, Chief
Air Quality Measures Branch

Donald J. Ames, Assistant Chief
Stationary Source Division

Peter D. Venturini, Chief
Stationary Source Division

ACKNOWLEDGMENTS

The following people helped prepare this draft report by providing information, writing sections of the report, comments, or review: Janey Arey and Roger Atkinson (Statewide Air Pollution Research Center, University of California, Riverside); Barbara Zeilinska (Desert Research Institute); Joan Denton (Office of Environmental Health Hazard Assessment); and Don Chernich, Steve Church, Joe De Vita, Andy Delao, Michele Houghton, Kelly Hughes, Steve Hui, Paul Jacobs, Peggy Jenkins, Jackie Johnson, Martin Johnson, Bill Lovelace, Susan Lum, Chris Nguyen, Elizabeth Parkhurst, Ralph Propper, Andy Ranzieri, Tony Servin, and Jeff Wright (ARB).

REPORT TO THE AIR RESOURCES BOARD ON DIESEL EXHAUST

Part A - Public Exposure To, Sources and Emissions of
Diesel Exhaust in California

Table of Contents

Page

V. EXPOSURE TO DIESEL EXHAUST

VI. ATMOSPHERIC PERSISTENCE AND FATE OF DIESEL EXHAUST

LIST OF APPENDICES

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF FIGURES

I.
SUMMARY

This document, prepared by staff of the Air Resources Board (ARB), contains the staff's evaluation of atmospheric exposure to diesel exhaust in California. It is Part A of the Technical Support Document Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant, and was developed under the authority of California's Toxic Air Contaminant (TAC) Program (Assembly Bill 1807: Health and Safety Code sections 39660-39662).

This report contains the staff evaluation of diesel exhaust PM_{10} and $PM_{2.5}$ (particulate matter equal to or less than 10 and 2.5 microns in diameter, respectively) emissions, outdoor ambient and indoor air concentrations, potential near source exposures, statewide population-weighted exposures including an estimate of total exposure, and atmospheric persistence and fate.

Diesel exhaust is a complex mixture of inorganic and organic compounds that exist in gaseous, liquid, and solid phases. As with other fuel combustion sources, the primary gaseous components are nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2), and water vapor (H_2O). Some of the exhaust components, like arsenic, benzene, and nickel, are known to cause cancer in humans. Over 40 components of the exhaust, including suspected human carcinogens benzo[a]pyrene, 1,3-butadiene, and formaldehyde, have been listed as TACs by the ARB, and as hazardous air pollutants by the U.S. EPA.

One of the main characteristics of diesel exhaust is the release of particles at a rate of about 20 times greater than from gasoline-fueled vehicles (WHO, 1996). Diesel exhaust particles carry many of the harmful organics and metals present in the exhaust. The particles are typically smaller than 1 micrometer [(μm) 1 millionth of a meter] in diameter, and are easily inhaled into the bronchial and alveolar regions of the lung.

The combustion of diesel fuel in an internal combustion engine produces diesel exhaust. Approximately 2.1 billion gallons of diesel fuel were burned in internal combustion engines in California during 1995. The future estimated diesel fuel consumption is predicted to increase in California from current levels up to 2.3 billion gallons in 2000 to 2.9 billion gallons in 2010.

Three major sources emit diesel exhaust in California: mobile sources (on-road vehicles and other mobile sources), stationary area sources (i.e. oil and gas production facilities, shipyards, repair yards), and stationary point sources (i.e., chemical manufacturing, electric utilities). Emissions of carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), reactive organic gases (ROG), PM_{10}, and $PM_{2.5}$ are estimated in this report. For 1995, emissions of diesel exhaust CO are estimated to be about 188,000 tons per year (tpy); NO_X to be about 415,000 tpy; SO_x to be about 28,000 tpy; and ROG to be about 41,000 tpy. Diesel exhaust PM_{10} and $PM_{2.5}$

emissions during 1995 were estimated to be about 27,000 tpy and 26,000 tpy, respectively. Statewide emission estimates for other substances found in diesel exhaust are not known (i.e. list of TACs in Table III-1). Further research is needed to estimate emissions from these substances.

In this report, California's population exposure to fine diesel exhaust particulate matter (PM_{10}) is discussed in more detail because more is known about the particulate fraction, and many researchers believe that the diesel exhaust particles contain many of the toxic components of the exhaust. However, the exposure actually experienced in most health studies, particularly the human studies, has been to the overall exhaust. Until more research is done to identify the specific causes of toxicity in diesel exhaust, the identification of whole diesel exhaust is consistent with the basis of health studies.

To estimate Californian's outdoor ambient exposures to diesel exhaust PM_{10}, ARB staff used receptor modeling techniques, which includes chemical mass balance model results from several studies, ambient 1990 PM_{10} monitoring network data, and 1990 PM_{10} emissions inventory data. The staff used the 1990 PM_{10} inventory and monitoring data as the basis for calculating the statewide exposure to diesel exhaust PM_{10} because it would best represent the emission sources in the years when the ambient data were collected for the studies used to estimate 1990 diesel exhaust PM_{10} outdoor concentrations. The staff estimated a population-weighted average outdoor diesel exhaust PM_{10} exposure concentration in California in 1990 to be 3.0 micrograms per cubic meter ($\mu g/m^3$). The staff have also estimated outdoor exposure concentrations for 1995 based on linear extrapolations from the base year 1990 to the 1995 emissions inventories. The estimated 1995 outdoor ambient concentration in California is 2.2 $\mu g/m^3$.

Near-source exposures to diesel exhaust may occur near busy roads and intersections where diesel vehicles are operating. In December 1993, the ARB conducted a study to determine diesel exhaust PM_{10} concentrations due to emissions of diesel exhaust particles near a freeway. Results indicate that diesel exhaust PM_{10} concentrations may be up to five times above 1995 average outdoor ambient concentrations of 2.2 $\mu g/m^3$ and about six times above the 1995 total air exposure concentration of 1.5 $\mu g/m^3$.

To estimate Californian's indoor and total air exposure to diesel exhaust particles, the staff used the 1990 population-weighted outdoor ambient concentration estimates in a model that can estimate indoor air concentrations and total air exposure. The exposure modeling results indicate that, in 1990, Californian's were exposed to average diesel exhaust particle concentrations of 2.0 $\mu g/m^3$ and 2.1 $\mu g/m^3$ for indoor and total air exposure scenarios, respectively. The staff have also estimated indoor and total air exposure concentrations for 1995. These estimates were not developed using the model used in calculating the 1990 indoor and total air exposure estimates. Instead, the staff used the ratios of indoor and total air exposure concentrations to outdoor ambient exposure concentrations and applied these to the 1995 outdoor ambient concentration estimate to calculate 1995 indoor and total air exposure concentrations. The estimated 1995 indoor and total air exposure concentrations are 1.47 $\mu g/m^3$ (rounded to 1.5 $\mu g/m^3$) and 1.54 $\mu g/m^3$ (rounded to 1.5 $\mu g/m^3$), respectively.

As mentioned above, diesel exhaust is a complex mixture of substances, and each substance will remain in the air or react with other substances according to the substance's individual chemical properties. The diesel particles are typically smaller than 1 micron and are expected to remain in the air for about 10 days.

Over the past 20 years, several advances in engine design and fuel formulation have been made in reducing diesel exhaust emissions as a result of control measures that have been adopted by the ARB and U.S. EPA. For example, as part of California's overall program to reduce harmful exposures to particulate matter, current and in the future, the ARB and the U.S. EPA have adopted a series of mobile source standards and regulations to reduce diesel exhaust PM_{10} emissions (see Chapter IV). As a measure of the effectiveness of these standards and regulations, statewide diesel exhaust PM_{10} emissions from on-road mobile sources are expected to be reduced by approximately 80 percent between 1990 and 2010 or about 60 percent from 1995 to 2010.

The U.S. EPA has also adopted a National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ (particulate matter equal to or less than 2.5 microns in diameter). The federal Clean Air Act requires that the U.S. EPA establish NAAQS' and reassess, at least every five years, whether adopted standards are adequate to protect public health based on current scientific evidence. After review, the U.S. EPA's Clean Air Scientific Advisory Committee (CASAC) found that current PM_{10} standards do not adequately protect public health. For this reason, on July 18, 1997, the U.S. EPA adopted an annual $PM_{2.5}$ federal standard of 15 micrograms per cubic meter ($\mu g/m^3$) and a 24-hour federal standard of 65 $\mu g/m^3$. The addition of the $PM_{2.5}$ standards will result in substantially more health protection than the current federal PM_{10} standards alone. We are looking at how this standard may affect the need for further diesel engine exhaust particle controls, realizing that a larger percentage of the fine $PM_{2.5}$ inventory (as compared to PM_{10} inventory) is due to petroleum-based fuel combustion sources.

Diesel exhaust is in the identification (risk assessment) phase of our air toxics program. While no new control measures specific to the toxicity of diesel exhaust are being proposed at this time, a number of existing sources of diesel engine exhaust are already subject to California regulations requiring reductions of criteria air pollutants contained in diesel exhaust. If diesel exhaust is identified as a TAC, the ARB will begin a full, open public process to evaluate the need, feasibility, and cost of control to determine if any regulatory action is necessary to reduce the risk of exposure to diesel exhaust.

II.
INTRODUCTION

This report (Part A) consists of the ARB staff evaluation of the public exposures to, sources and emissions of diesel exhaust in California. It provides the exposure assessment portion of the evaluation of diesel exhaust as a toxic air contaminant (TAC), pursuant to California's Toxic Air Contaminant Program (Health and Safety Code section 39660). The Office of Environmental Health Hazard Assessment (OEHHA) has developed a comprehensive health evaluation of diesel exhaust (Part B report). Together, these documents serve as the basis for ARB's proposed identification of diesel exhaust as a TAC.

Diesel exhaust entered into the identification program in October 1989. In March 1990, the ARB sponsored a conference on the risk assessment of diesel exhaust. On June 17, 1994, the first draft report was released to the public for a six month comment period. On September 14, 1994, a public workshop was held to discuss the report. On January 29-30, 1996, the OEHHA, ARB, Health Effects Institute, National Institute for Occupational Safety and Health, World Health Organization, and the U.S. EPA sponsored a scientific workshop to discuss the application of human health study data in developing quantitative cancer risk estimates for diesel exhaust. A second version of the draft report was released for public comment in May 1997. On July 1, 1997, a third public workshop was held to discuss the second draft of the report.

This version of the report reflects the public comments received on the exposure assessment during the first and second public comment periods and at the September 1994, January 1996, and July 1997 workshops. Currently, the SRP is planning to hold a special public meeting in early March 1998 to hear from invited scientists, with expertise in the study of diesel exhaust, to hear their research and perspectives on diesel exhaust health effects. It is the SRP's view that the material presented and discussed at this meeting will assist in a better understanding of the science regarding the health effects of diesel exhaust. After this meeting, and the end of the third comment period, the report, along with the comments received and any revisions resulting from the comments, will be formally discussed with the SRP at a duly noticed meeting. We anticipate that this meeting will occur in late April 1998. If the SRP approves the report, the report, and a proposal to formally list diesel exhaust as a TAC, will be presented to the ARB at a public hearing, after a 45-day comment period.

III.
CHEMICAL AND PHYSICAL PROPERTIES OF DIESEL EXHAUST

Diesel exhaust is a complex mixture that contains thousands of inorganic and organic substances (IARC, 1989) which occur in the form of gases and fine particles (composed of liquid and solid materials). The composition of this mixture will vary depending on engine type, operating conditions, fuel, lubricating oil, and whether an emission control system is present. Many of the individual exhaust constituents remain unidentified. Appendix A contains a list of substances and substance groups that have been either positively identified in diesel exhaust, detected (but not quantified in the exhaust), found in the fuel and/or lubricating oil and expected to be emitted in the exhaust, or theorized to be present in the exhaust based on known chemical reactions. Further research is needed to estimate many of these components contribution to whole diesel exhaust and the resulting atmospheric concentrations.

A. Diesel Exhaust's Primary Component Groups

Diesel engines operate with excess air (around 25-30 parts air to 1 part fuel: Lassiter and Milby, 1978). Consequently, the primary gaseous components of whole diesel exhaust are nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2), and water vapor (H_2O).

Diesel exhaust also contains substances such as carbon monoxide, oxides of nitrogen, sulfur dioxide, hydrocarbons, particulate matter, aldehydes, ketones, sulfates, cyanides, phenols, metals, and ammonia (Volkswagen, 1989). These substances are unburned fuel and lubricant components, products of incomplete combustion, or are a result of engine wear or trace contaminants in the fuel and lubricating oil.

Emissions from diesel engines have and continue to be regulated to reduce emissions of carbon monoxide, nitrogen oxides, sulfur oxides, hydrocarbons, and particulate matter (see Chapter IV, section D) as part of the effort to control emissions of criteria pollutants in California. Emissions of many toxic species in diesel exhaust are correspondingly being reduced as the existing criteria pollutant standards and regulations are implemented.

B. Toxic Air Contaminants in Diesel Exhaust

Diesel exhaust contains substances formally listed as toxic air contaminants (TACs) by the State of California and as hazardous air pollutants by the U.S. EPA. Section 39655 of California's Health and Safety Code defines a TAC as an air pollutant which "may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health."

Table III-1 is a list of TACs that have either been identified in diesel exhaust, or are predicted to be in diesel exhaust based on observed chemical reactions and/or their presence in the fuel or lubricating oil. Further research is needed to determine the contribution of many of these substances to atmospheric diesel exhaust exposures. The exhaust constituents arsenic, benzene, and nickel are known to cause cancer in humans (IARC, 1987). These three constituents, in addition to 1,3-butadiene, cadmium, dioxins/dibenzofurans, and formaldehyde, have been listed by the ARB as TACs under California's air toxics identification program (Health and Safety Code section 39660). At least 35 other diesel exhaust components and component groups were identified by the ARB as TACs in April 1993, under Assembly Bill (AB) 2728 (Tanner, 1992; Health and Safety Code section 39656). AB 2728 required all federally-listed hazardous air pollutants to be identified as TACs by the ARB.

C. Gas Phase Components

The composition of diesel exhaust gases is similar to that of gasoline engine gases, but because of the relatively higher air to fuel ratio which causes engines to have more complete combustion at increased temperatures, carbon monoxide (CO) and hydrocarbons (HC) occur in lower concentrations in diesel exhaust. However, the emissions of oxides of nitrogen (NO_x), PM, and sulfur compounds is higher (the latter due to the higher sulfur content of the fuels).

As mentioned above, diesel exhaust is composed of both gaseous and particle phase compounds. The gas, or vapor phase, contains typical combustion gases N_2, O_2, CO_2, and volatile hydrocarbon species (Zaebst, 1991). They include classes of compounds such as aldehydes (e.g. formaldehyde, acetaldehyde), alkanes, alkenes, and aromatic compounds (e.g. benzene, toluene, 1,3-butadiene), many of which are known or potential carcinogens.

These gas phase compounds primarily originate from the unburned fuel and lubricating oil, although some may be formed during the combustion process and by reaction with catalysts (Johnson, et al. 1994). The emissions of some of the individual organic components and classes of compounds, summarized as total hydrocarbons, have been measured by a number of researchers for the individual gaseous substances such as 1,3-butadiene, formaldehyde, acetaldehyde, acrolein, benzene, toluene, ethylbenzene, and xylenes (Volkswagen, 1989; Egeback & Bertilsson, 1983; Hamerle et al., 1994).

Other gas phase components of diesel exhaust, as well as other fuel combustion sources, are low-relative molecular mass PAH and nitro-PAH derivatives (volatile 2- to 4-ring PAH and 2-ring nitro-PAH). Atmospheric reactions of these gas phase PAH and nitro-PAH derivatives may lead to the formation of several mutagenic nitro-PAH, and nitro-PAH compounds, including nitrodibenzopyranones, 2-nitroflouranthene and 2-nitropyrene (Atkinson and Arey, 1994;

Table III-1
Substances in Diesel Exhaust Listed by the ARB as Toxic Air Contaminants*

TACs identified under Health and Safety Code section 39660

arsenic	dioxins and dibenzofurans
benzene	formaldehyde
1,3-butadiene	nickel
cadmium	inorganic lead

TACs identified under Health and Safety Code section 39656

acetaldehyde	mercury compounds
acrolein	methanol
aniline	methyl ethyl ketone
antimony compounds	naphthalene
beryllium compounds	4-nitrobiphenyl
biphenyl	phenol
bis[2-ethylhexyl]phthalate	phosphorus
chlorine	***POM, including PAHs
chlorobenzene	and their derivatives
**chromium compounds	propionaldehyde
cobalt compounds	selenium compounds
cresol isomers	styrene
cyanide compounds	toluene
dibutylphthalate	xylene isomers and mixtures
ethyl benzene	o-xylenes
hexane	m-xylenes
manganese compounds	p-xylenes

---

* Further research is needed to quantify the concentrations of many of these substances before one can assess the contribution of each of these substances to atmospheric diesel exhaust exposures.

** The valence state of exhaust chromium is unknown, but a portion of total chromium emitted may be in the +VI valence state. Chromium VI is a known human carcinogen and has been identified by the ARB as a TAC.

*** POM (polycyclic organic matter) represents a large group of compounds having at least two benzene rings and a boiling point greater than or equal to 100 degrees Celsius. The PAHs (polycyclic aromatic hydrocarbons) are a subset of POM, and also represent a large number of compounds. Several PAHs can be converted to more potent substances in the exhaust stream or in the atmosphere. For example, benzo[a]pyrene can be converted to 3-nitro-benzo[a]pyrene, a potentially powerful mutagen (Finlayson-Pitts and Pitts, 1986; IARC, 1989).

Arey et al., 1987; Atkinson et al., 1988). It is also believed that the majority of the ambient nitro-PAH are now thought to be formed in the atmosphere from gas phase reactions of PAH of four or less rings (Atkinson and Arey, 1994).

Although the above studies provided some quantitative estimates on the compounds mentioned, further research is needed to quantify the gaseous components of diesel exhaust from a variety of engines and test conditions before quantitative estimates of many of the gas phase components can be made.

D. Particulate Matter

Diesel exhaust is characterized by a significantly higher content of particulate matter than that of a gasoline-fueled vehicle (Volkswagon, 1989; Williams, 1989; WHO, 1996). The amount and composition of particles emitted from various diesel engines varies greatly, depending on factors like engine design, load, operating speed, fuel composition, and engine emission controls. In general, newer heavy-duty trucks emit about 20 times more particulate than catalyst-equipped gasoline- fueled vehicles (WHO, 1996). However, depending on operating conditions, fuel composition, and engine control technology, light-duty diesel engines can emit 50 to 80 times and heavy-duty diesel engines 100 to 200 times more particulate mass than typical catalytically equipped gasoline engines (McClellan, 1986).

In urban areas, mobile sources are major contributors to ambient PM_{10} concentrations. Several studies have demonstrated the importance of these sources (Watson et al., 1988; Chow et al., 1991; Wittorff et al., 1994; Gertler et al., 1995; Chow et al., 1996). Chow et al. (1991) looked at PM_{10} and $PM_{2.5}$ source contributions in Phoenix in the winter of 1989-1990. Chemical characteristics of source emissions and ambient concentrations were used as input data to the chemical mass balance (CMB) receptor model which calculates the contributions to the atmospheric PM_{10}. Results indicated that primary motor vehicles contributed up to 52 percent of the observed ambient PM_{10} concentrations, of which, at least 50 percent was derived from diesel engine exhaust. In a similar study done in Bullhead City, Arizona during 1988-1989, Gertler et al. (1995) estimated that primary motor vehicle emissions contribute a yearly average of 17 percent of the measured ambient PM_{10} concentrations. In another study, Wittorf et al. (1994) used the CMB receptor model to apportion the sources of ambient PM_{10} observed at a site heavily impacted by diesel emissions. Results showed that primary diesel exhaust emissions contributed an average of about 53 percent of the ambient PM_{10} mass observed. In a study done by Chow et al., (1996) in Santa Barbara, California, aerosol samples were analyzed chemically using standard methods, and source contributions to PM_{10} were determined using the CMB model. Results showed that primary motor vehicle emissions were responsible for up to 42 percent of the PM_{10} mass.

1. Particle Formation

Studies have shown that the primary soot particles in diesel exhaust are formed in the combustion chamber by nucleation of heavy relative molecular weight PAH (Johnson et al., 1994), with a large percentage of these being oxidized during the expansion stroke (Luo et al., 1989). The particles that survive oxidation typically agglomerate together to form the long chain aggregates or clusters associated with diesel particles (Kittleson et al. 1985). The final particle processes occur in the atmosphere. These are mainly photochemical reactions and to a lesser extent particle surface reactions. It is also possible to have gas-to-particle conversion due to the nucleation of hydrocarbons, oxides of nitrogen, or oxides of sulfur (Baumgard and Johnson, 1996).

2. Particle Size Distribution

Studies have shown that the particle size distribution of diesel exhaust is bi-modal with a nuclei mode (0.0075 to 0.042 μm in diameter) and an accumulation mode (0.042 to 1.0 μm in diameter) (Baumgard and Johnson, 1996), most of which occur in aerodynamic diameters ranging from 0.1 to 0.25 μm (Groblicki and Begeman, 1979; Dolan et al., 1980; National Research Council, 1982; Williams, 1982). Approximately 98 percent of the particles emitted from diesel engines are less than 10 microns in diameter, 94 percent less than 2.5 microns in diameter, and 92 percent less than 1.0 microns in diameter (see Table III-2) (ARB, 1997). The light absorbing black portion of these particles, commonly referred to as elemental carbon (EC), is determined to be a major contributor to reduced visibility in urban areas (Gray, 1986; Trijonis et al., 1990).

Table III-2
Diesel Exhaust Particle Size Distribution*

$\leq$ 1.0 *um*	$\leq$ 2.5 *um*	$\leq$ 10 *um*
92%	94%	98%

* Based on ARB 1995 emission inventory (ARB, 1997)

3. Particle Composition

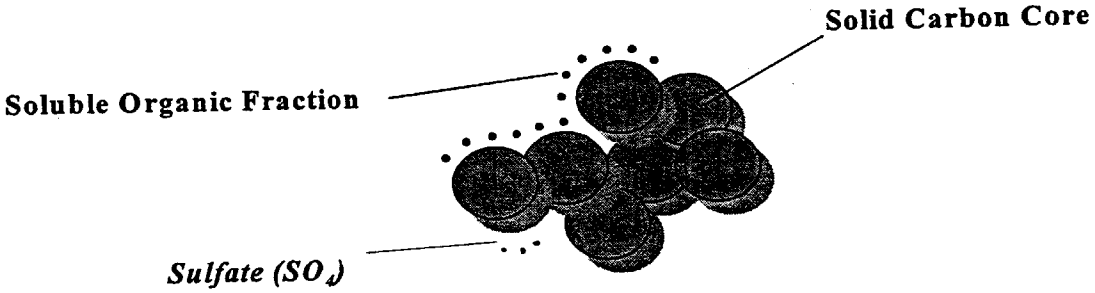
The particles emitted from diesel engines are mainly aggregates of spherical carbon particles coated with organic and inorganic substances (Figure III-1) with the composition of the particles being predominantly, 80 to 90 percent, organic and inorganic carbon (Lowenthal et al., 1994). The inorganic fraction consists of small solid carbon particles, ranging from 0.01 to 0.08 micrograms (McClellan, 1986), and sulfur, oxygen, carbon, sulfate (SO_4), CO and NO_x (Johnson et al., 1994). The amount of the solid carbon, or EC, in the average particle will typically range from approximately 64 percent (Gray, 1986) to 71 percent (Volkswagen, 1989).

The fine EC aerosol is formed during the combustion process, and is not found in the atmosphere by reactions involving gaseous hydrocarbon precursors. Therefore, the entire concentration of EC observed in the atmosphere is from primary emission sources.

The characteristic sponge-like structure and large surface area (50 to 200 m^2/gram of soot: Volkswagen, 1989) of particles emitted from diesel engines make it an excellent carrier for organic compounds of low volatility. These compounds reside on the particle surface (as a liquid) or are included inside the particle, or both. Organic compounds present inside the particles may be protected against photolysis and chemical reaction, while organic compounds present on the surface of the particles can volatilize or react with other compounds from the particle surface (described in more detail in Chapter VI).

The organic fraction of the diesel particle contains compounds such as aldehydes, alkanes and alkenes, aliphatic hydrocarbons, and PAH and PAH-derivatives (Zielinska, 1990; Johnson et al., 1994). The organic fraction comes from the unburned fuel and lubricating oil (see section F), and from partially oxidized fuel and oil (Williams et al., 1987). The majority of the organic fraction is adsorbed onto the surface of the solid carbon core. This fraction is called the soluble organic fraction (SOF) because of its solubility in solvents such as dichloromethane (Bagely et al., 1993). Also associated with the total particle mass (TPM) of the particulate matter may be droplets of liquid, condensed hydrocarbons, and SO_4 particles (Johnson et al., 1994). These hydrocarbons collected with the TPM are not volatile enough to exist in the vapor phase and may not be adsorbed onto the solid fraction due to low solid levels, but will also be removed by an organic solvent as the SOF (Johnson et al., 1994). The National Research Council (1983) has shown that approximately 25 percent of the particle mass may be extracted using organic solvents but, depending on the engine conditions and testing cycle, the contribution of organics to the TPM is between 10 and 90 percent (Williams et al., 1989).

Figure III-1
Diesel Exhaust Particles are Mainly Aggregates of Carbon Particles



The SO_4 fraction of diesel exhaust TPM is composed primarily of the sulfuric acid formed when sulfur trioxide (SO_3) reacts with water vapor (Truex et al., 1980). SO_3 is formed from the oxidation of SO_2, which is produced during the combustion process by the oxidation of sulfur in

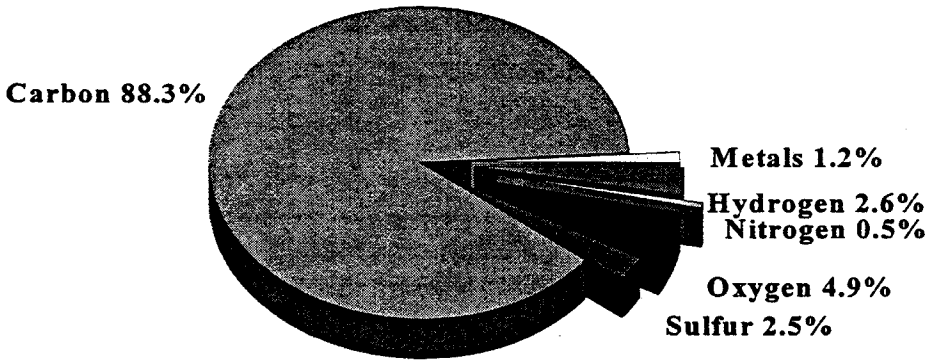
the fuel (Bagely et al., 1993). This portion can contribute up to 14 percent of the diesel exhaust particle (Lowenthal et al., 1994).

Recently, a study conducted by Bagely et al. (1996), characterized the physical and chemical composition of emissions from a 1988 heavy-duty diesel engine equipped with a ceramic particulate trap, and a 1991 heavy-duty diesel engine equipped with an oxidation catalytic converter. The investigators determined the number and size of particles within the exhaust of the two engines tested. The results show that, despite a substantial reduction in the weight of the total particulate matter, the total number of particles from the more advanced 1991-model engine was 15 to 35 times greater than the number of particles from the 1988 engine when both engines were operated without emission control devices. This suggests that more fine particles, a potential health concern, could be formed as a result of new technologies. Further study is needed since the extent of these findings only measured exhaust from two engines and engine technologies.

Finally, diesel vehicle exhaust particles yield an average composition (by weight) of carbon (88.3 percent), oxygen (4.9 percent), hydrogen (2.6 percent), sulfur (2.5 percent), metals (1.2 percent) and nitrogen (0.5 percent) (Volkswagen, 1989). Figure III-2 depicts this information.

Engines running under low load typically produce fewer particles with a higher proportion of organic compounds associated with the available particle mass. Conversely, engines under high load typically produce more particulate matter with a lower proportion of organic

Figure III-2
Carbon is the Primary Element in a Diesel Exhaust Particle
(adapted from Volkswagen, 1989)



compounds associated with the available particles. Kishi et al. (1992) found that exhaust gas temperature was an important determinant for particle composition; low exhaust gas

temperatures produced particulate matter with more adsorbed soluble organics than did particulate matter produced in a high exhaust gas temperature environment.

Inorganic exhaust components are products of engine and component wear, or are trace contaminants of the fuel and/or lubricant oil. The inorganic compounds associated with the particles are primarily trace fuel contaminants such as antimony, arsenic, barium, beryllium, cobalt, and strontium. These substances usually vaporize in the combustion chamber and then "plate" themselves to particles in the exhaust stream. Inorganic exhaust particles can also act as condensation nuclei for vapor-phase exhaust components.

E. PAH and PAH-derivatives

Over that last 10-15 years, several researchers have investigated the health effects of PAH emissions and their atmospheric transformation products. The focus for this attention arose from observed mutagenic and carcinogenic effects of this important class of compounds and their nitro-derivatives. Diesel engine emissions are one of several sources of PAH and nitro-PAH emissions found in the ambient atmosphere. This section focuses on the PAH and PAH-derivatives found in diesel exhaust.

PAH and PAH-derivatives present in the atmosphere are distributed between the gas and particle phases mainly due to their liquid-phase vapor pressure (Bidleman, 1988). They are most likely to be formed by incomplete combustion of hydrocarbons at high temperatures (Kittleson et al., 1985; Tokiwa and Ohnishi, 1986). They are also formed from the reaction of parent hydrocarbons with nitrogen oxides in ambient air. Possible sources of PAH in diesel exhaust are unburnt PAH from the fuel, electrophylic nitration of PAH during combustion, crankcase oils, and engine or systems deposits.

A wide spectrum of gas- and particle-phase PAH and PAH-derivatives are emitted in diesel exhaust (National Research Council, 1983; Jensen and Hites, 1983; Barbella et al., 1988). Many of the PAH that can be extracted from the exhaust particle mass are unburned fuel and/or lubricant oil components (Obuchi et al., 1987; Barbella et al., 1989) like the fuel components naphthalene, fluorene, phenanthrene and their alkyl derivatives (Williams et al., 1986). PAH may also be formed in the combustion chamber during the combustion of diesel fuel (Tancell et al., 1995).

Methylated PAH appear to be the most abundant PAH-derivatives in diesel exhaust. Schuetzle et al. (1981) identified over 100 oxy-PAH in the moderately polar fractions of a diesel exhaust extract. The extract also contained hydroxy-, ketone-, quinone-, acid anhydride-, nitro-, and carboxaldehyde-PAH-derivatives.

The nitro-PAH compounds are recognized mutagens and can be formed by the nitration of PAH by NO_2 in an acid environment (Pitts et al., 1979). More than 50 nitro-PAH have been identified in diesel exhaust, including mononitro-PAH, mononitro-alkyl-PAH, di- and trinitro-PAH, and oxygenated nitro-PAH (Schuetzle et al., 1982; Paputa-Peck et al., 1983;

Robbat et al., 1986). The major nitro-PAH observed in diesel exhaust are isomers of the parent PAH derivatives, formed by electrophilic nitration (Schuetzle, 1983; Nielsen, 1984). The most abundant nitro-PAH in diesel exhaust are 1-nitropyrene and 2-nitrofluorene (Schuetzle and Perez, 1983; Beje and Moller, 1988). Henderson et al. (1984) suggested that the active nitrogen oxide species in the exhaust stream could be a limiting factor in nitro-PAH formation.

Kittelson et al. (1985) measured concentrations of select PAH and 1-nitropyrene in the cylinder and exhaust manifold of an operating diesel engine. They observed that the PAH concentrations were higher in the cylinder than in the exhaust manifold, but the 1-nitropyrene concentrations were higher in the exhaust manifold than in the cylinder. This suggests that most of the nitro-PAH in the exhaust are probably formed during the expansion/exhaust process rather than during combustion.

Nitro-PAH can also be formed during transport through the atmosphere by reactions of adsorbed PAH with nitric acid, by gas-phase radical-initiated reactions in the presence of oxides of nitrogen (Atkinson and Arey, 1994; Pitts, 1983), and the artifactual formation of nitro-PAH during high volume sampling of ambient air (Arey et al., 1988).

In a recent study, researchers detected a new class of compounds that have direct mutagenic activity in organic extracts of both diesel exhaust and airborne particles. Specifically, 3-nitrobenzanthrone was isolated and studied. Its mutagenicity compares with that of 1,8-dinitropyrene, which is one of the strongest direct acting mutagens by Ames assay. 3-nitrobenzanthrone is formed during the combustion process of fossil fuels and from reaction between benzanthrone and lower oxides of nitrogen (Enya and Suziki, 1997).

F. Contribution of Lubricating Oil to Diesel Exhaust Particulate Matter

The contribution of lubricating oil to diesel exhaust PM emissions can be substantial. Researchers have reported that from 2 to 48 percent of the diesel exhaust PM mass, depending on speed and load, consisted of material from lubricating oil. Of this material, lubricating oil can contribute up to 88 percent of the SOF of a diesel exhaust particle (Mayer, et al., 1980; Cartillieri and Tritthart, 1984; Williams, et al, 1989; Rogge, et al., 1992). This contribution is important since several studies show that portions of the SOF of the diesel exhaust particle contains substances which are mutagenic, carcinogenic, or both (Pierson et al., 1983; Dorie et al., 1987; Rasmussen, 1988; NIOSH, 1988; Hsieh et al., 1993).

G. Current Research on Diesel Exhaust Emissions

The 1988 ARB diesel fuel regulation which became effective October 1, 1993, mandated reformulated diesel fuel that limited the maximum sulfur content to 0.05 percent, the minimum cetane index to 40, and the maximum aromatic content to 10 percent. Since lowering the aromatic content to levels under 10 percent would dramatically increase the production costs, ARB decided to allow alternative fuels with a higher aromatic content as long as equivalent

emissions reductions could be demonstrated. The diesel fuel regulation was adopted for the purpose of reducing particulate matter (PM) and oxides of nitrogen (NO_x) (criteria pollutants), and was not specific to toxic components of diesel exhaust.

To investigate the effects that diesel fuel composition may have on the toxic exhaust constituents from diesel engines, ARB funded a study by the College of Engineering, Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside. The primary purpose of this study was to obtain a preliminary assessment of the potential impact of diesel fuel formulation on toxic components and on the speciation of hydrocarbons in diesel exhaust. The test was conducted on a Cummins L10 engine (represented the most-used heavy-duty diesel engine in California) operating on pre-October 1993 California diesel fuel, on fuel with lower than the 10 percent aromatic content requirement, and on a mix of alternative fuels with higher aromatic content that comply with ARB's regulation. Testing was conducted from December 1996 to January 1997 and results became available in spring of 1998.

The results from the CE-CERT draft final report show comparable criteria pollutant reductions to those estimated in the ARB staff report for the 1988 diesel fuel regulation. The low aromatic and typical in-use fuels produced particulate matter and NO_x exhaust emissions that met the diesel fuel regulation requirements. For more deatiled information on these and other measured substances, see *Evaluation of Factors that Affect Diesel Exhaust Toxicity* (draft final report), ARB Contract No. 94-312 (CE-CERT, 1998).

The contract was planned as a scoping study. It should be emphasized that the study design did not allow the resulting data to be used to obtain statistically robust conclusions (due to use of one engine and the limited number of data points for each target analyte/fuel combination). In particular, additional data would need to be collected from other types of engines and driving conditions. Rather, the data collected was intended to be used to characterize the influence of diesel fuel formulation on the emissions of toxic species and to assist in the design of more comprehensive studies.

Total Hydrocarbons (THC), NO_x, and Carbon Monoxide (CO)

Emissions of THC and NO_x show the following order of emissions rate with fuel type: pre-1993 > alternative > low aromatic. The emissions rate for THC and NOx from the use of the alternative fuel was approximately six and three percent lower, respectively, than from use of the pre-1993 fuel.

The use of the low aromatic fuel resulted in an increase, and the alternative fuel in a decrease, in the CO emission rates compared to use of the pre-1993 fuel.

PM_{10} and $PM_{2.5}$

The use of low aromatic and alternative formulation fuels resulted in reductions in PM emission rates of approximately 20 percent compared to use of the pre-1993 fuel, comparable to what ARB staff predicted from implementation of our 1988 reformulated diesel fuel regulation.

More than 99 percent of the particulate mass measured fell within the PM_{10} (particulate matter 10 microns or less) range and greater than 95 percent in the $PM_{2.5}$ (particulate matter 2.5 microns or less) range. These estimates are similar to previous estimates as already indicated in Table III-2. The ARB emissions inventory for 1995 estimates that 98 percent of diesel exhaust PM is less than 10 microns and 94 percent is less than 2.5 microns.

The size distribution of PM_{10} and $PM_{2.5}$ emissions were found to be similar among the three different fuels used.

Elemental and Organic Carbon, Ion, and Elemental Analysis

The low aromatic and alternative fuels exhibited lower total carbon emission rates than the pre-1993 fuel. Elemental and organic carbon dominated the composition of the particulate matter for all fuels, representing more than 97 percent of the total identified mass. Organic carbon as a percent of total carbon is relatively constant for all three fuels and ranged from 33 to 40 percent. These numbers agree fairly well with previous estimates as discussed in section D.

Carbonyls

The use of alternative fuel resulted in similar emissions rates for the targeted carbonyls (formaldehyde, acetaldehyde, acrolein, and propionaldehyde) as from use of the pre-1993 fuel.

Speciated Hydrocarbons

Differences in emission rates among the speciated hydrocarbons were small between the pre-1993 and alternative fuel for 1,3-butadiene, benzene, toluene, ethylbenzene, o-xylene, m- & p-xylene, styrene, and naphthalene.

Particle-Phase PAHs

Many of the PAHs analyzed showed little difference in emissions rates with fuel type. However, four PAHs that ARB has identified as TACs did exhibit significant reductions in the alternative formulation blend and low-aromatic fuel compared to the pre-1993 fuel. These four PAHs were: anthracene, benz[a]anthracene, chrysene (co-eluted with triphenylene), and dibenzo[a,h]pyrene.

Nitro-PAHs

1-Nitropyrene, 6-nitrobenzo[a]pyrene, 9-nitroanthracene, and 1- and 2-nitronaphthalene were measured in the emissions from all three fuel types. 1-Nitropyrene was the most abundant nitro-PAH measured and the emission rate was similar among the three fuel types.

Vapor-Phase PAHs

Of all vapor phase PAHs analyzed, naphthalene emission rates were the highest for all three fuels. A comparison of the emission profiles using three different fuels showed a similar distribution of volatile alkyl-PAHs but at significantly different emission rates. Individual alkyl-PAH emission rates showed the following order with fuel type: pre-1993 > alternative > low aromatic. Lower emissions of volatile alkyl-PAHs may lead to a decreased potential for the atmospheric formation of highly mutagenic nitro-PAHs and nitro-PAH lactones.

Nitrosamines

The pre-1993 fuel emission rate for N-nitrosodimethylamine was similar to the alternative formulation fuel (the low aromatic fuel was not analyzed for nitrosamines). One pre-1993 fuel emission sample and one alternative formulation fuel emission sample contained measurable levels of N-nitrosodipropylamine. No other nitrosamines, such as N-nitrosomorpholine, were detected in any of the samples.

Previous studies have reported nitrosamine emissions from diesel and gasoline powered vehicles. Most of these studies have centered on emissions from catalyst equipped vehicles. N-nitrosodimethylamine has been detected from malfunctioning catalyst equipped vehicles.

Dioxins

Standardized testing procedures are not available for polychlorinated dibenzo-p-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in engine emissions. A major objective of this study was to develop improved methods to collect, identify, and quantify dioxins from engines. However, the results are qualitative only and indicate the need for further method development. Hence, results are not presented in Table III-3.

Isomers of PCDD and PCDF were detected in the emissions from the alternative formulation blend and pre-1993 fuel. The most toxic isomers, 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), 1,2,3,7,8-PCDD, and 2,3,4,7,8-PCDF were not detected in the emissions from the pre-1993 nor the alternative formulation fuels.

Bioassay

Mutagenic activity was detected in the particle- and vapor-phase emissions from all fuels tested. Higher mutagenic activity was observed in both the particle phase and vapor phase

samples collected from pre-1993 fuel than from the low aromatic and alternative formulation fuel. However, the differences are not statistically significant. The calculated emission rate for particle and vapor-phase sample mutagenic activity (reported as revertants per brake horsepower per hour) was higher in the pre-1993 fuel than the low aromatic and alternative formulated fuels. Emission samples were chemically fractionated using high performance liquid chromotography (HPLC). Nine individual fractions were collected from each fuel and these fractions were tested in the bioassay. The most mutagenic fraction for the particulate matter is in a fraction (with unidentified constituents) that differs from (is more polar than) the fractions containing the PAHs and nitro-PAHs.

Table III-3
Average Emission Rates[1]
(mg/bhp-hr)

Substance(s)	Pre-1993	Alt. Formulation	Low-Aromatic
Formaldehyde	57.12	59.83	58.75
Acetaldehyde	18.15	19.93	19.10
Acrolein	2.14	2.42	5.79
Propionaldehyde	3.69	4.13	3.92
1,3-Butadiene	1.80	1.84	2.46
Benzene	5.90	5.81	8.03
Toluene	1.93	1.86	2.26
Ethylbenzene	1.22	1.18	0.67
o-Xylene	0.78	0.88	0.61
m- & p-Xylene	2.09	2.14	1.24
Styrene	1.27	1.45	1.58
Naphthalene	2.41	1.95	1.45
Emissions in μg/bhp-hr			
Anthracene	38.89	26.16	18.54
Benz[a]anthracene	16.42	10.96	10.57
Chrysene + Triphenylene	17.36	12.20	10.38
Benzo[b+j+k]fluoranthene	31.05	29.18	23.17
Benzo[a]pyrene	20.46	20.59	16.48
Dibenz[a,h + a,c]anthracene	1.54	1.48	0.87
Dibenzo[a,l]pyrene	2.84	2.31	1.25
Dibenzo[a,e]pyrene	1.10	1.13	0.61
Dibenzo[a,i]pyrene	0.91	0.71	0.27
Dibenzo[a,h]pyrene	1.33	0.84	0.75
5-Nitroacenaphthene	<0.5	<0.5	<0.5
2-Nitrofluorene	<0.3	<0.3	<0.3
1-Nitropyrene	1.95	1.64	2.07
4-Nitropyrene	<0.06	<0.06	<0.06
6-Nitrochrysene	<0.1	<0.1	<0.1
Biphenyl	410	333	90
N-Nitrosodimethylamine	6.41	7.92	
N-Nitrosomorpholine	<7.8	<7.8	

[1] The emission rate among the individual substances may reflect averages from multiple test cycles (two hot starts) or the complete test matrix [1/7(cold start) + 6/7(hot start)].

H. References for Chapter III

Air Resources Board, 1997. Emission Inventory 1995, Technical Support Division, October 1997.

Arey, J., Zielinska, B., Atkinson, R., Winer, A.M. 1987. Polycyclic Aromatic Hydrocarbon and Nitroarene Concentrations in Ambient Air During a Winter-time High NOx Episode in the Los Angeles Basin. Atmospheric Environment, 21:1437-1444.

Arey J., Zeilinska, B., Atkinson, R. and A.M. Winer, 1988. Formation of Nitroarenes During Ambient High-Volume Sampling. *Environ. Sci. Technol.*, 22, 457-462.

Atkinson, R., Arey, J., Winer, A.M., Zielinska, B., Harger, W.P., and McElroy, P.A. 1988. A Survey of Ambient Concentrations of Selected Polycyclic Aromatic Hydrocarbons (PAH) at Various Locations in California. Final Report. California Air Resources Board, Sacramento, CA.

Atkinson R. and Arey J., 1994. Atmospheric Chemistry of Gas-Phase Polycyclic Aromatic Hydrocarbons; Formation of Atmospheric Mutagens. *Environ. Health Perspect.*, 102, 117-126.

Bagely S.T., Gratz L.D., Leddy D.G., and J.H. Johnson, 1993. Characterization of Particle- and Vapor-Phase Organic Fraction Emissions from a Heavy-Duty Diesel Engine Equipped with a particle Trap and Regeneration Controls. Research Report No. 56. July 1993. Health Effects Institute, Cambridge, MA..

Bagely S.T., Baumgard, K.J., Gratz, L.D., Johnson, J.H., and D.G. Leddy, 1996. Characterization of Fuel and Aftertreatment Device Effects on Diesel Emissions. Research Report No. 76. September 1996. Health Effects Institute, Cambridge , M.A..

Barbella R., Bertoli C., Ciajolo A. and A. D'Anna, 1988. Soot and Unburnt Liquid Hydrocarbon Emissions from Diesel Engines. *Combust. Sci. and Tech.*, 59, 183-198.

Barbella R., Ciajolo A., D'Anna A. and C. Bertoli, 1989. Effect of Fuel Aromaticity on Diesel Emissions. *Combust. and Flame*, 77, 267-277.

Baumgard, K.J. and Johnson, J.H. 1996. The Effect of Fuel and Engine Design on Diesel Exhaust Particle Size Distributions. *SAE Technical Paper Series, #960131.*

Beje B. and Moller L. 1988. 2-Nitrofluorene and Related Compounds: Prevalence and Biological Effects. *Mutat. Res.*, 196, 177-209.

Bidleman, T.F. 1988. Atmospheric Process. *Environmental Science & Technology*, 22:361-367.

Cartillieri W. and P. Tritthart, 1984. Particulate Analysis of Light Duty Diesel Engines (IDI & DI) with Particular Reference to the Lube Oil Particulate Fraction. *SAE Technical Paper No. 841395.*

References for Chapter III (continued)

CE-CERT, 1998. Evaluation of Factors That Affect Diesel Exhaust Toxicity. College of Engineering - Center for Environmental Research and Technology (CE-CERT), University of California at Riverside. ARB Contract No. 94-312.

Chow J.C., Watson J.G., Richards L.W., Haase D.L., McDada C., Dietrich D.L., Moon D., and Sloane C, 1991. The 1989-90 Phoenix Study. Volume II: Source Apportionment. DRI Document No. 8931.6F1, prepared for Arizona Department of Environmental Quality, Phoenix, AZ, by Desert Research Institute, Reno, NV.

Chow J.C., Watson J.G., Lowenthal D.H. and R.J. Countess, 1996. Sources and Chemistry of PM_{10} Aerosol in Santa Barbara County, CA. *Atmos. Environ.,* 30, No. 9., 1489-1499.

Dolan D.F., Kittelson D.B. and D.Y.H. Pui, 1980. Diesel Exhaust Particle Size Distribution Measurement Techniques. *SAE Technical Paper No. 800187*, SAE Trans.

Dorie D.D., Bagley S.T., Woon P.V., Leddy D.G., and J.H. Johnson, 1987. Collection and Characterization of Particulate and Gaseous-Phase Hydrocarbons in Diesel Exhaust Modified by Ceramic Particle Traps. *SAE Technical Paper No. 870254.*

Egeback, K.E. and Bertilsson, B.M. 1983. Chemical and Biological Characterization of ExhaustEmissions from Vehicles Fueld with Gasoline, Alcohol, LPG and Diesel. (Report No. SNV PM 1635). Solina, national Swedish Environmental Protection Board, 188 pp.

Enya, T. And Suzuki, H., 1997. 3_Nitrobenzanthron, a Powerful Bacterial Mutagen and Suspected Human Carcinogen Found in Diesel Exhaust and Airborne Particles. *Environmental Science and Technology*, Vol. 31, 2772-2776.

Finlayson-Pitts B.J. and J.N. Pitts Jr., 1986. Atmospheric Chemistry: Fundamentals and Experimental Techniques. John Wiley and Sons, Publisher. New York, New York.

Gertler A.W., Lowenthal D.H. and W.G. Coulombe, 1995. PM_{10} Source Apportionment Studyin Bullhead City, Arizona. *Journal of Air and Waste Management Association*, Vol. 45, 75-82.

Gray H.A., 1986. Control of Atmospheric Fine Primary Carbon Particle Concentrations. EQL Report 23, Environmental Quality Laboratory, California Institute of Technology, Pasadena CA.

Groblicki P.J. and C.R. Begeman, 1979. Particle Size Variation in Diesel Car Exhaust. *SAE Technical Paper No. 790421.*

References for Chapter III (continued)

Hammerle, R.H., Horrocks, R.W., Huthwohl, G. Ketcher, D.A., Lepperhoff, G., and Luers, B. 1994. Emissions from Current Diesel Vehicles. SAE Technical Paper Series. Society of Automotive Engineers, Warrendale, PA.

Henderson T.R., Sun J.D., Li A.P., Hanson R.L., Bechtold W.E., Harvey T.M., Shabanowitz J. and D.F. Hunt, 1984. GC/MS and MS/MS Studies of Diesel Exhaust Mutagenicity and Emissions from Chemically Defined Fuels. *Environ. Sci. Technol.*, 18, 428-434.

Hsieh D.P.H., Kado N.Y., Okamoto R., Kuzmicky P., Rathbun C. and J. Ito, 1993. Measurement and Chemical Characterization of Vapor-Phase Mutagens in Diesel Exhaust. Final Report Prepared for the California Air Resources Board, Contract No. A032-095.

International Agency for Research on Cancer (IARC), 1987. Letter from Dr. L. K. Shuker, IARC, World Health Organization, Lyon, France, to Dr. K. Hooper, California Department of Health Services, Berkeley, CA. IARC reference number CI/75/2-S4 (87). Dated 10 April 1987.

IARC, 1989. International Agency for Research on Cancer Monographs on the Evaluation of Carcinogenic Risks to Humans. Diesel and Gasoline Engine Exhausts and Some Nitroarenes, Monograph 46, pp. 41-57.

Jensen T.E. and R.A. Hites, 1983. Aromatic Diesel Emissions as a Function of Engine Condition. *Anal. Chem.*, 55, 594-599.

Johnson H.J., Bagley S.T., Gratz L.D. and D.G. Leddy, 1994. A Review of Diesel Particulate Control Technology and Emission Effects. *SAE Technical Paper No. 940233.*

Kishi Y., Tohno H. and M.Ara, 1992. Characteristics and Combustibility of Particulate Matter. Reducing Emissions from Diesel Combustion, Published by the Society of Automotive Engineers, Warrendale, PA. pp. 139-146. February.

Kittelson D.B., Du C.J. and R.B. Zweidinger, 1985. Measurements of Polycyclic Aromatic Compounds in the Cylinders of an Operating Diesel Engine. EPA-600/D-85/012, January.

Lassiter D.V. and T.H. Milby, 1978. Health Effects of Diesel Exhaust Emissions: A Comprehensive Literature Review, Evaluation and Research Gaps Analysis. US NTIS PB-282-795, Washington D.C., American Mining Congress.

Lowenthal D.H., Zielinska B., Chow J.C. and J.G. Watson, 1994. Characterization of Heavy-Duty Diesel Vehicle Emissions. *Atmos. Environ.*, 28, No. 4, 731-743.

References for Chapter III (continued)

Luo L., Pipho, M.J., Ambs, J.L., and Kittleson, D.B. 1989. Particle Growth and Oxidation in a direct-injection Diesel Engine. SAE Technical Paper No. 890580. Society of Automotive Engineers, Warrendale, PA.

Mayer J.M., Lechman D.E. and D.L. Hilden, 1980. The Contribution of Engine Oil to Diesel Exhaust Particulate Emissions. *SAE Technical Paper No. 800256.*

McClellan R.O., 1986. Health Effects of Diesel Exhaust: A Case Study in Risk Assessment. *Amer. Ind. Hyg. Assoc. J.*, 47(I):1-13, January.

National Institute of Occupational Safety and Health (NIOSH), 1988. Current Intelligence Bulletin No. 50: Carcinogenic Effects of Exposure to Diesel Exhaust. DHHS Pub. No. 88-116. Gov. Printing Office, Washington, D.C.

National Research Council (NRC), 1982. Diesel Cars: Benefits, Risks, and Public Policy. Diesel Impacts Study Committee, National Research Council, National Academy Press, Washington, D.C., pp. 142.

NRC, 1983. Polycyclic Aromatic Hydrocarbons: Evaluation Sources and Effects. The Committee on Pyrene and Selected Analogues, National Research Council, National Academy Press, Washington, D.C.

Nielsen T., 1984. Reactivity of Polycyclic Aromatic Hydrocarbons toward Nitrating Species. *Environ. Sci. Technol.*, 18, 157-163.

Obuchi A., Ohi A., Aoyama H. and H. Ohuchi, 1987. Evaluation of gaseous and particle emission characteristics of a single cylinder diesel engine. *Combustion and Flame*, 70, 215-224.

Paputa-Peck M.C., Marano R.S., Schuetzle D., Riley T.L., Hampton C.V., Prater T.J., Skewes L.M., Jensen T.E., Ruehle P.H., Bosch L.C. and W.P. Duncan, 1983. Determination of Nitrated Polynuclear Aromatic Hydrocarbons in Particulate Extracts by Capillary Column Gas Chromatography with Nitrogen Selective Detection. *Anal. Chem.*, 55, 1946-1954.

Pierson W.R., Gorse R.A. Jr., Szkariat A.C., Brachaczek W.W., Japar S.M., Lee F.S., Zweidinger R.B. and L.D. Claxton, 1983. Mutagenicity and Chemical Characteristics of Carbonaceous Particulate Matter from Vehicles on the Road. *Environ. Sci. Technol.*, 17, 31-44.

Pitts J.N., Jr., Van Cauwenberghe K.A., Grosjean D., Schmid J.P., Fitz D.R., Belser W.L., Krudson G.B. and Hynds P.M., 1979. Atmospheric Reactions of Polycyclic Aromatic Hydrocarbons: Facile Formations of Mutagenic Nitro Derivatives. *Science,* 202:515-519.

References for Chapter III (continued)

Pitts J.N., Jr., 1983. Formation and Fate of Gaseous and Particulate Mutagens and Carcinogens in Real and Simulated Atmospheres. *Environ. Health Perspect.*, 47, 115-140.

Rasmussen R.E., 1988. Genotoxicity of Diesel Exhaust Particles and Vapors Collected from Engines With and Without Particle Trap Oxidizers. Final Report, California Air Resources Board Contract No. A5-130-33.

Robbat A. Jr., Corso N.P., Doherty P.J. and M.H. Wolf, 1986. Gas Chromatographic Chemiluminescent Detection and Evaluation of Predictive Models for Identifying Nitrated Polycyclic Aromatic Hydrocarbons in a Diesel Fuel Particulate Extract. *Anal. Chem.*, 58, 2087-2084.

Rogge R.F., Hildemann L.M., Mazurek M.A. and G.R. Cass, 1992. Sources of Fine Organic Aerosol: 2. Noncatalyst and Catalyst-Equipped Automobiles and Heavy-Duty Diesel Trucks. California Institute of Technology.

Schuetzle D., Lee F.S., Prater T.J. and S.B. Tejada, 1981. The identification of polynuclear aromatic hydrocarbon (PAH) derivatives in mutagenic fractions of diesel particulate extracts. Intern. *J. Environ. Anal. Chem.*, 9, 93-144.

Schuetzle D., Riley T.L., Prater T.J., Harvey T.M. and D. F. Hunt, 1982. Analysis of Nitrated Polycyclic Aromatic Hydrocarbons in Diesel Particulates. *Anal. Chem.*, 54, 265-271.

Schuetzle D., 1983. Sampling of Vehicle Emissions for Chemical Analysis and Biological Testing. *Environ. Health Perspec.*, 47, 65-80.

Schuetzle D. and J.M. Perez, 1983. Factors Influencing the Emissions of Nitrated Polynuclear Aromatic Hydrocarbons (Nitro-PAH) from Diesel Engines. *Air Poll. Cont. Assoc. J.*, 33, 751-755.

Tancell P.J., Rhead M.M., Pemberton R.D. and J. Braven, 1995. Survival of Polycyclic Aromatic Hydrocarbons during Diesel Combustion. *Environ. Sci. Technol.*, 29, 2871-1876.

Tokiwa, H. And Ohnishi, Y. 1986. Mutagenicity and Carcinogenicity of Nitroarenes, and Their Sources in the Environment. *CRC Critical Review Toxicology*, 17:23-60.

Trijonis, J.C.; Malm, W.C.; Pitchford, M.; White, W.H.; Charlson, R. and Husar, R. 1990. Acid Deposition: State of Science and Technology. NAPAP report 24: Visibility Existing and Historical Conditions-Causes and Effects. National Acid Precipitation Assessment Program.

Truex, T.J., Pierson, W.R., and D.F. McKee, 1980. Sulfate in Diesel Exhaust. *Environ. Sci. Tech.* 14:1118.

References for Chapter III (continued)

Volkswagen, 1989. Unregulated Motor Vehicle Exhaust Gas Components. Volkswagen AG, Research and Development (Physico-Chemical Metrology). Project Coordinator: Dr. K.-H. Lies. 3180 Wolfsburg 1, F.R. Germany.

Watson J.G., Chow J.C., Richards L.W., Anderson S.R., Houck J.E. and D.L., Dietrich, 1988. The 1987-88 Metro Denver Brown Cloud Air Pollution Study, Volume III: Data Interpretation. Desert Research Institute Document No. 8819.1F3, prepared for the Greater Denver Chamber of Commerce, Denver, CO.

Williams R.L., 1982. Diesel Particulate Emissions. Toxicological Effects of Emissions from Diesel Engines. J. Lewtas (Ed.), Elsevier Science Publishing Co., Inc., New York, NY, pp. 15-32.

Williams P.T., Bartle K.D. and G.E. Andrews, 1986. The Relation between Polycyclic Aromatic Compounds in Diesel Fuels and Exhaust Particulates. *Fuel,* 65, 1150-1158.

Williams P.T., Andrews G.E. and K.D. Bartle, 1987. The Role of Lubricating Oil in Diesel Particulate and Particulate PAH Emissions. *SAE Technical Paper No. 87084.* Society of Automotive Engineers, Warrendale, PA.

Williams D.J., Milne J.W., Quigley S.M., Roberts D.B. and M.C. Kimberlee, 1989. Particulate Emissions from "In-Use" Motor Vehicles-II. Diesel Vehicles. *Atmos. Environ.*, 23, No. 12, 2647-2661.

Wittorff D.N., Gertler A.W., Chow J.C., Barnard W.R. and H.A. Jongedyk. 1994. The Impact of Diesel Particulate Emissions on Ambient Particulate Coatings. Desert Research Institute, Presented at the 87th Annual AWMA Meeting and Exhibition, Cincinnati, Ohio, June 19-24, 1994.

WHO, 1996. Diesel Fuel and Exhaust Emissions. International Program on Chemical Safety. World Health Organization, Geneva, 1996.

Zaebst D.D., Clapp D.E., Blade L.M., Marlow D.A., Steenland K., Hornung R.W., Scheutzle D. and J. Butler, 1991. "Quantitative Determination of Trucking Industry Workers' Exposures to Diesel Exhaust Particles." *Am. Ind. Hyg. Assoc. J.,* 52(12), 529-541, December.

Zielinska B., 1990. Private Correspondence. Risk Assessment of Diesel Exhaust: 1990 and Beyond, Los Angeles, California. Sponsored by the California Air Resources Board, Sacramento, CA.

IV.
PRODUCTION, USES, EMISSIONS, AND EMISSIONS PROJECTIONS

Diesel engines are used to power passenger cars, trucks, buses, ships, railway locomotives, in nonroad equipment used for farming and construction, and in almost every kind of industry.

A. Production

The combustion of diesel fuel in an internal combustion engine produces diesel exhaust. Approximately 2.1 billion gallons of diesel fuel were burned in internal combustion engines in California during 1995 (BOE, 1996). The State predicts that diesel fuel use will increase in California from current levels up to 2.3 billion gallons in 2000 and 2.9 billion gallons in 2010 (CEC, 1998).

B. Uses

The staff is not aware of any commercial or industrial use of diesel exhaust in California. Small amounts are used in research.

C. Emissions

Diesel engine emissions have changed dramatically over the last 20 years because of improvements in engine technology, emissions controls, and fuel formulation. Emissions of NO_x and PM_{10} are significantly lower than those from older uncontrolled engines. Emissions of reactive organic gases (ROG) and CO have also declined as a result of engine emissions standards.

In this report, diesel exhaust PM_{10} emissions and air concentration estimates are used to represent exposure to diesel exhaust. The total emissions of toxic diesel exhaust species have not been estimated because inadequate analytical methods, in conjunction with excessive costs, prevent the detection and quantification of the many individual toxic and potentially toxic species and their atmospheric contribution. Diesel exhaust particulate matter is extremely fine (over 90 percent of the particles are smaller than 1 micrometer [μm] in diameter), readily respirable, and is the primary carrier for many of the hydrocarbons and metals found in the exhaust, many of which are known or suspected mutagens and carcinogens. Because the 1990 year emissions inventory is used in our ambient concentrations analysis (see Chapter V), the primary focus will be on the 1990 emissions inventory. We have, however, included emissions estimates for 1995 to indicate the decrease in emissions that have occurred as a result of recent diesel regulations and estimates of the future trends in diesel engine emissions.

Three major source categories emit diesel exhaust in California: mobile sources (on-road vehicles and other mobile sources), stationary area sources, and stationary point sources. Table IV-1 through Table IV-6 breaks the three major source categories into individual emission groups, and lists the individual groups' emissions in tons per year (TPY), both for base year 1990 (inventory year used for ambient exposure analysis) and for year 1995 for diesel exhaust PM_{10}, $PM_{2.5}$, NO_x, SO_x, CO, and ROG.

Table IV-1
Diesel Exhaust PM_{10} Emitted into California's Air for Years 1990 & 1995 [1]

	PM_{10} Emissions in Tons/Year	
	1990	**1995**
Mobile Sources		
On-Road Vehicles (Diesel Only)		
Heavy-duty Trucks	25, 220	14,730
Light-duty Passenger Cars	1,230	540
Urban Buses	170	110
Light/Medium-duty Trucks	630	300
Total On-Road	**27,250**	**15,680**
Other Mobile (Diesel Only)		
Off-road Vehicles	640	440
Ships	1,030	1,080
Trains	1,440	1,090
Mobile Equipment	10,700	7,220
Total Other Mobile	**13,810**	**9,820**
Stationary Area Sources		
Total Area Sources	**1,360**	**1,370**
Stationary Point Sources		
Total Point Sources	**4**	**30**
TOTAL ALL SOURCES	**42,424**	**26,900**

Notes: 1) Data from California Emission Forecasting System, 1993 Base year trends (run date: 1/5/98).

Table IV-2
Diesel Exhaust $PM_{2.5}$ Emitted Into
California's Air for Years 1990 & 1995[1]

	$PM_{2.5}$ Emissions in Tons/Year	
	1990	**1995**
Mobile Sources		
On-Road Vehicle (Diesel Only)		
Heavy-duty Trucks	24,555	14,315
Light/Medium-duty Trucks	600	280
Light-duty Passenger Cars	1,170	510
Urban Buses	165	105
Total On-Road	**26,490**	**15,210**
Other Mobile (Diesel Only)		
Off-road Vehicles	610	425
Ships	1,005	1,040
Trains	1,220	1,065
Mobile Equipment	9,665	7,050
Total Other Mobile	**12,500**	**9,580**
Stationary Sources		
Total Stationary Sources	**1,330**	**1,360**
TOTAL ALL SOURCES	**40,320**	**26,150**

Notes: 1) Data from California Emission Forecasting System, 1993 Base year trends (run date: 4/29/98).

Table IV-3
Diesel Exhaust NO_x Emitted into
California's Air for Years 1990 & 1995 [1]

	NO_x Emissions in Tons/Year	
	1990	**1995**
Mobile Sources		
On-Road Vehicles (Diesel Only)		
Heavy-duty Trucks	221,600	174,900
Light-duty Passenger Cars	5,570	2,690
Urban Buses	6,610	6,370
Light/Medium-duty Trucks	2,530	1,310
Total On-Road	**236,310**	**185,270**
Other Mobile (Diesel Only)		
Off-road Vehicles	6,660	7,130
Ships	16,640	15,360
Trains	65,040	54,350
Mobile Equipment	177,030	136,560
Total Other Mobile	**265,370**	**213,400**
Stationary Area Sources		
Total Area Sources	**16,900**	**16,060**
Stationary Point Sources		
Total Point Sources	**60**	**380**
TOTAL ALL SOURCES	**518,640**	**415,110**

Notes: 1) Data from California Emission Forecasting System, 1993 Base year trends (run date: 1/2/98).

Table IV-4
Diesel Exhaust SO_x Emitted into
California's Air for Years 1990 & 1995 [1]

	SO_x Emissions in Tons/Year	
	1990	1995
Mobile Sources		
On-Road Vehicles (Diesel Only)		
Heavy-duty Trucks	22,300	8,060
Light-duty Passenger Cars	1,180	180
Urban Buses	580	190
Light/Medium-duty Trucks	620	90
Total On-Road	**24,680**	**8,520**
Other Mobile (Diesel Only)		
Off-road Vehicles	880	830
Ships	8,540	10,090
Trains	6,100	2,650
Mobile Equipment	27,550	5,070
Total Other Mobile	**43,070**	**18,640**
Stationary Area Sources		
Total Area Sources	**1,230**	**1,250**
Stationary Point Sources		
Total Point Sources	**7**	**30**
TOTAL ALL SOURCES	**68,987**	**28,440**

Notes: 1) Data from California Emission Forecasting System, 1993 Base year trends (run date: 1/2/98).

Table IV-5
Diesel Exhaust CO Emitted into
California's Air for Years 1990 & 1995 [1]

	CO Emissions in Tons/Year	
	1990	1995
Mobile Sources		
On-Road Vehicles (Diesel Only)		
Heavy-duty Trucks	111,440	106,480
Light-duty Passenger Cars	6,070	3,960
Urban Buses	780	700
Light/Medium-duty Trucks	2,780	1,900
Total On-Road	**121,070**	**113,040**
Other Mobile (Diesel Only)		
Off-road Vehicles	2,590	1,990
Ships	1,650	1,920
Trains	9,030	8,040
Mobile Equipment	53,700	58,000
Total Other Mobile	**66,970**	**69,950**
Stationary Area Sources		
Total Area Sources	**4,590**	**4,620**
Stationary Point Sources		
Total Point Sources	**10**	**100**
TOTAL ALL SOURCES	**192,640**	**187,710**

Notes: 1) Data from California Emission Forecasting System, 1993 Base year trends (run date: 1/2/98).

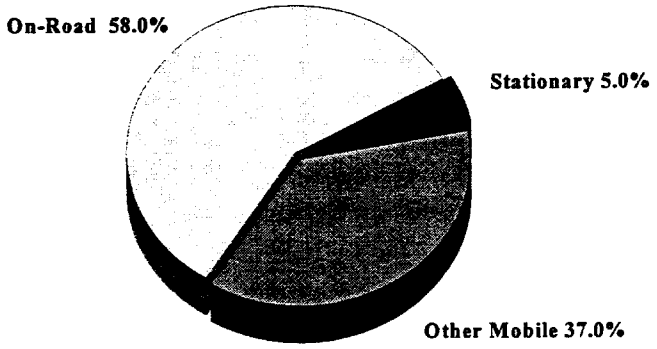
Table IV-6
Diesel Exhaust ROG Emitted into
California's Air for Years 1990 & 1995 [1]

	ROG Emissions in Tons/Year	
	1990	1995
Mobile Sources		
On-Road Vehicles (Diesel Only)		
Heavy-duty Trucks	27,190	21,780
Light-duty Passenger Cars	1,260	660
Urban Buses	600	630
Light/Medium-duty Trucks	590	350
Total On-Road	**29,640**	**23,420**
Other Mobile (Diesel Only)		
Off-road Vehicles	1,440	1,090
Ships	1,160	1,550
Trains	2,780	2,470
Mobile Equipment	16,680	12,190
Total Other Mobile	**22,060**	**17,300**
Stationary Area Sources		
Total Area Sources	**530**	**570**
Stationary Point Sources		
Total Point Sources	**4**	**50**
TOTAL ALL SOURCES	**52,234**	**41,340**

Notes: 1) Data from California Emission Forecasting System, 1993 Base year trends (run date: 1/2/98).

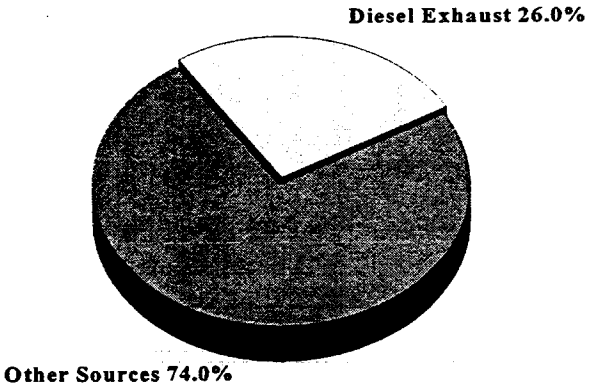
Figure IV-1 illustrates that on-road mobile sources (heavy-duty trucks, light-duty passenger cars and trucks, and urban buses) emit the majority, or about 58 percent of the diesel exhaust PM_{10} in California for 1995. Other mobile sources contribute about 37 percent, and stationary sources emit about 5 percent.

Figure IV-1
1995 Statewide Diesel Exhaust PM_{10} Emissions



Fuel combustion sources include those sources that use various fuels (e.g. solid-liquid combustion material, gasoline, diesel fuel, natural gas, jet fuel, wood and waste combustion) in their production or use. These sources include stationary sources such as oil and gas production facilities, electric utilities, and manufacturing/industrial plants, and mobile sources such as motor vehicles, ships, trains, and aircraft. Figure IV-2 illustrates that diesel exhaust PM_{10} contributes approximately 26 percent of the total statewide PM_{10} from fuel combustion sources. The remaining non-diesel fuel combustion sources contribute the remaining 74 percent (ARB, 1997a, 1998a).

Figure IV-2
1995 Statewide PM_{10} Emissions from Fuel Combustion Sources



The ARB staff also estimates that emissions from diesel exhaust contribute about 3 and 8 percent of the total PM_{10} and $PM_{2.5}$ inventories, respectively (ARB, 1997b). Diesel exhaust particulate matter is a larger percentage of the Statewide $PM_{2.5}$ inventory, primarily because the $PM_{2.5}$ inventory targets smaller particles emitted from combustion sources (see Figures IV-3 and IV-4). For both PM_{10} and $PM_{2.5}$ inventories, emissions from non-diesel mobile on-road sources include gasoline-powered vehicles, tire wear, and brake dust; non-diesel other mobile emissions include sources such as trains, ships, and mobile equipment; and non-diesel stationary (point and area) emissions include sources such as petroleum refining, mineral processes, residential fuel combustion, farming operations, construction and demolition, entrained road dust, and fugitive windblown dust (ARB, 1998a,b).

1. Mobile Sources

a. On-Road Vehicles

Heavy-duty trucks, urban buses, passenger cars, and light-duty trucks emitted an estimated 27,250 tons (approximately 64 percent of the total emissions) of diesel exhaust PM_{10} statewide during 1990 (ARB, 1998a). Emissions from on-road vehicles has declined to 15,680 tons (approximately 58 percent of the total emissions) in 1995 due to engine emission standards and the introduction of reformulated diesel fuel (see Table IV-1).

b. Other Mobile Sources

Other diesel-fueled mobile sources emitted an estimated 13,810 tons of engine exhaust PM_{10} (approximately 33 percent of the total) statewide during 1990 and 9,820 tons (approximately 37 percent of the total) in 1995. This category includes off-road transportation equipment and mobile industrial equipment such as construction and road equipment, mobile refrigeration units, ships, heavy-duty farm equipment, trains, and recreational and commercial boats (ARB, 1998a).

2. Stationary Sources

Stationary sources emitted an estimated 1,364 tons of diesel exhaust PM_{10} statewide during 1990 (approximately 3 percent of the total) and 1,400 tons (approximately 5 percent of the total) in 1995 (ARB, 1998a).

Most districts in California do not have a complete inventory of their stationary diesel engines. Consequently, the statewide emissions of diesel exhaust PM_{10} from stationary sources are likely higher than those reported here (which are based on available emission inventories).

a. Stationary Area Sources

Stationary area sources of diesel exhaust include shipyards, warehouses, heavy equipment repair yards, and oil and gas production operations where exhaust emissions are emitted from multiple locations within the site. Stationary area sources emitted an estimated 1,360 and 1,370 tons of diesel exhaust PM_{10} in California during 1990 and 1995, respectively (ARB, 1998a).

Figure IV-3
1995 Statewide PM_{10} Emissions

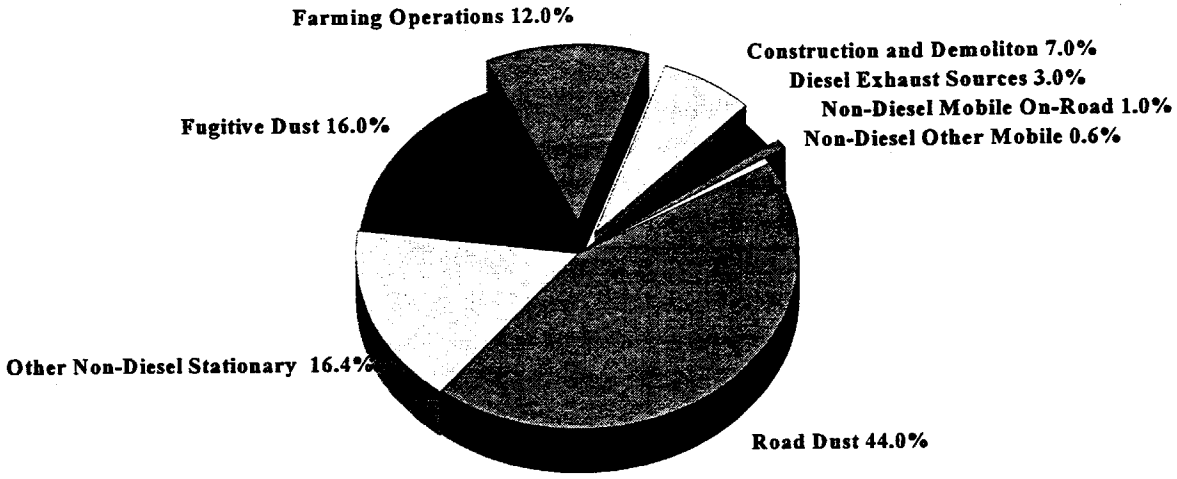
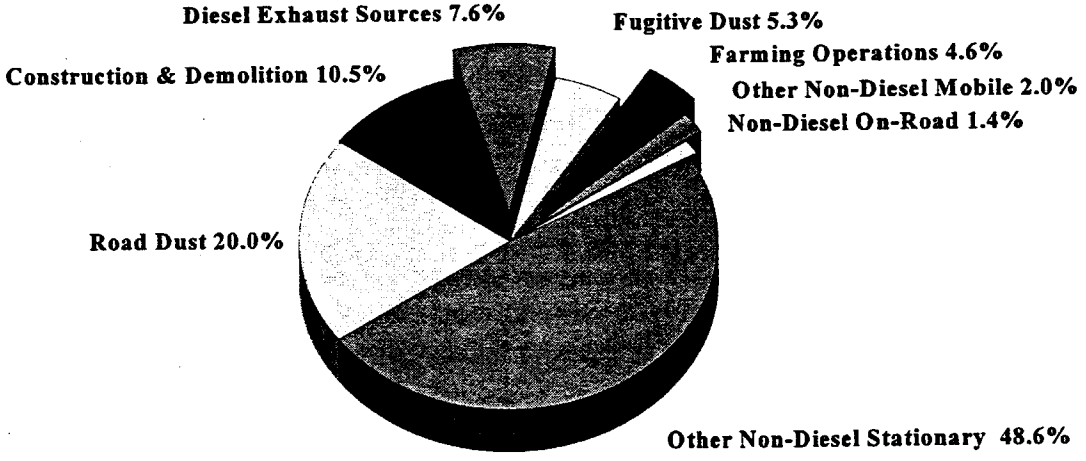


Figure IV-4
1995 Statewide $PM_{2.5}$ Emissions



b. Stationary Point Sources

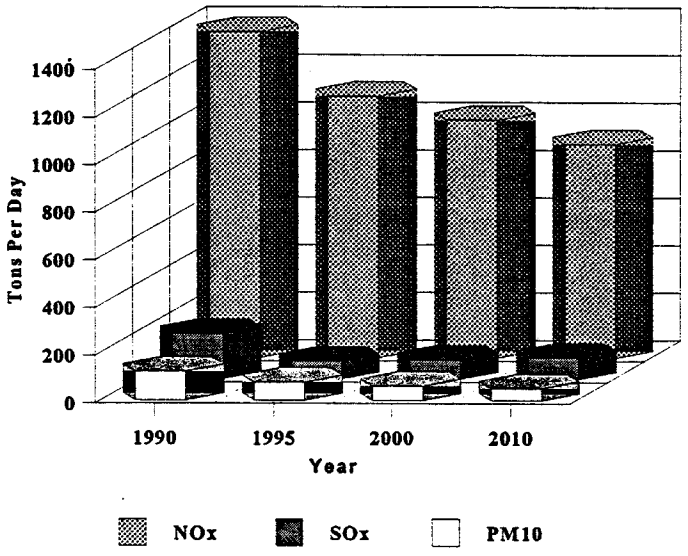
Stationary point sources generate diesel exhaust emissions from specific, fixed locations. These sources include chemical manufacturing, stone, clay, and glass manufacturing, mining, public administration, and utility and water services. Stationary point sources emitted an estimated 4 and 30 tons of diesel exhaust PM_{10} in California during 1990 and 1995, respectively (ARB, 1998a).

D. Emission Projections

1. Mobile Sources

There have been significant advances in the development of technology to control diesel particulate matter emissions. Some of these efforts included engine design modifications, the use of aftertreatment devices, and improvements in fuel formulations. All of these improved technologies were developed to comply with engine emission standards and fuel modifications adopted to date by ARB and the U.S. EPA. Figure IV-5 illustrates emission estimates for PM_{10}, NO_x, and SO_x for the years 1990 and 1995, and emissions projections for years 2000 and 2010.

Figure IV-5
Diesel Exhaust Mobile Source Emissions and Projections
(1990 - 2010)



Emissions of diesel exhaust PM_{10} from mobile sources in California are expected to decrease about 60 percent from 1990 to 2010 as a result of mobile source emission standards and regulations already adopted by the ARB and the U.S. EPA through 1997.

The use of low sulfur fuel (0.05% by mass) has led to additional reductions in total particulate matter levels of diesel exhaust. Since 1990, sulfur oxide (SO_x) emissions from diesel-fueled vehicles have decreased about 60 percent due to the use of this fuel (sold beginning October 1993). However, from now until 2010, SO_x emissions are expected to increase slowly due to increases in population, traffic congestion, and VMT.

Nitrogen oxides (NO_x) emissions from diesel powered mobile sources are expected to decrease from now until about 2010. The U.S. EPA is proposing a new NO_x heavy-duty engine emission standard to be implemented in 2004 which will cut emissions of NO_x from diesel engines statewide by about 18 percent each year thereafter.

a. Particulate Matter

In order to address particulate matter pollution, the U.S. EPA and the ARB have established ambient air quality standards for PM_{10} (U.S. EPA: 24-hr - 150 $\mu g/m^3$, annual arithmetic mean - 50 $\mu g/m^3$; ARB: 24-hr - 50 $\mu g/m^3$, annual geometric mean - 30 $\mu g/m^3$). The U.S. EPA has also adopted a new National Ambient Air Quality Standard for $PM_{2.5}$ to address concerns regarding the health effects of fine particles. On July 18, 1997, the U.S. EPA adopted an annual $PM_{2.5}$ standard of 15 $\mu g/m^3$ and a 24-hour standard of 65 $\mu g/m^3$. To assist in meeting these standards, the ARB and the U.S. EPA are addressing diesel exhaust PM_{10} emissions through a series of on-road and other mobile source emission standards and regulations. The diesel exhaust PM_{10} standards and regulations for on-road and other mobile sources adopted by the ARB and the U.S. EPA include:

On-Road Mobile Sources

- emission standards that limit the gram per mile (g/mi) of PM that can be emitted from 1982 and newer light- and medium-duty on-road diesel vehicles (1985: 0.4 g/mi; 1986-88: 0.2 g/mi; and 1989 and newer: 0.08 g/mi.);

- PM emission standards for 1988, 1991, and 1994 and newer diesel powered heavy-duty vehicles of 0.60, 0.25, and 0.10 grams per brake-horsepower-hour (g/bhp-hr), respectively, except for urban bases;

- PM emission standards that limit new 1991 through 1993 urban bus engines from emitting more than 0.10 g/bhp-hr. 1994-1995 model year urban bus engines are required to meet a 0.07 g/bhp-hr interim in-use standard. Beginning in 1996, new urban buses are restricted from emitting more than 0.05 g/bhp-hr;

- the roadside testing of heavy-duty on-road vehicles for excessive smoke opacity (1991);

- use of low sulfur/low aromatics diesel fuel (October 1993) that helps reduce PM emissions from mobile sources (excluding locomotives and marine vessels);

- continuation of the fleet inspection and maintenance program for heavy-duty vehicles (anticipated implementation in early 1998);

Other Mobile Sources

- PM emission standards for 1995 and newer utility diesel engines rated under 25 horsepower (1995-98: 0.9 g/bhp-hr; 1999 and newer: 0.25 g/bhp-hr);

- hydrocarbon (HC) + NO_x emission standards for 1995 and newer utility diesel engines rated under 25 horsepower (1995-98: 12.0 g/bhp-hr for engines less than 225 cubic centimeters (cc) and 10.0 g/bhp-hr for engines greater than or equal to 225 cc; 1999 and newer: 3.2 g/bhp-hr for all engines under 25 horsepower);

- PM emission standards for certain heavy-duty off-road diesel engines rated from 175 to 750 horsepower (1996-2000: 0.4 g/bhp-hr; 2001 and newer: 0.16 g/bhp-hr);

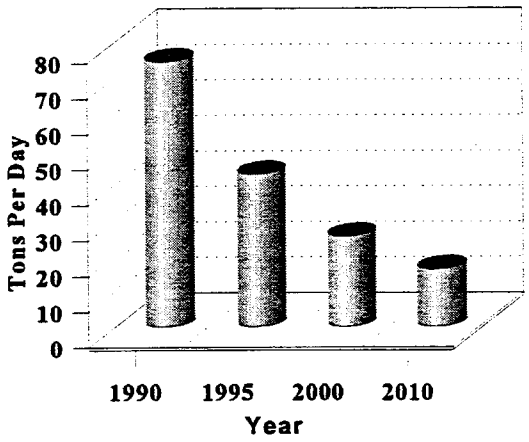
- NO_x emission standards for certain heavy-duty off-road diesel engines rated from 175 to 750 horsepower (1996-2000: 6.9 g/bhp-hr; 2001 and newer: 5.8 g/bhp-hr);

- PM emission standards for certain heavy-duty off-road diesel engines rated above 750 horsepower (2000 and newer: 0.4 g/bhp-hr); and

- NO_x emission standards for certain heavy-duty off-road diesel engines rated above 750 horsepower (2000 and newer: 6.9 g/bhp-hr).

As a result of these control measures, statewide diesel exhaust PM_{10} emissions from on-road diesel vehicles are expected to be reduced by approximately 80 percent over the period 1990-2010 (Figure IV-6). The expected reduction is due to adopted diesel vehicle emission and fuel regulations (listed above), even though both the number and VMT of heavy-duty trucks are expected to increase substantially during this period.

Figure IV-6
Diesel Exhaust On-Road Vehicle
PM_{10} Emissions Projections



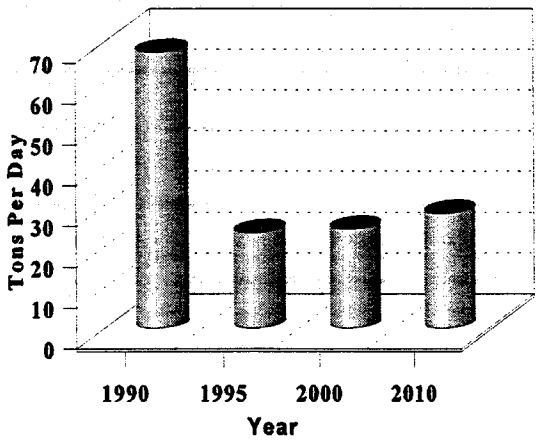
b. Sulfur Oxides

Sulfur is a component of diesel fuel, and is emitted in diesel exhaust as sulfur oxides. Approximately 98 percent of the sulfur is emitted as sulfur dioxide (SO_2) and 2 percent of particulate sulfate (Pierson et al., 1978; Truex et al., 1980). Sulfur oxide (SO_x) inhalation can cause bronchial tube constriction and exacerbation of preexisting respiratory or pulmonary disease (Blumenthal, 1985). Additionally, SO_x emissions from diesel-fueled engines, which may undergo chemical reactions in the atmosphere to form acidic sulfates, can contribute to acid deposition in California. The principle chemical transformation of SO_2 in the atmosphere is reaction with the OH radical followed by the formation of sulfuric acid (Stockwell and Calvert, 1983). SO_x may also react with other compounds in the atmosphere to form particles which contribute to PM emissions.

Since October 1993, diesel fuel sold in California for combustion in mobile sources (excluding locomotives and marine vessels) has been reformulated to be a low aromatic/low sulfur diesel fuel. Use of this reformulated fuel has resulted in lower emissions of SO_x, NO_x and PM, and lower ambient air concentrations of SO_x in areas impacted by diesel exhaust emissions. Low sulfur diesel fuel has been required in the South Coast Air Basin since 1985.

Statewide SO_x emissions from on-road diesel vehicles are expected to have decreased by about 64 percent from 1990 to 1995, and increase slowly after that due to growth in vehicles and VMT (see Figure IV-7).

Figure IV-7
Diesel Exhaust On-Road Vehicle
SO_x Emissions Projections



c. Nitrogen Oxides

Diesel engines produce nitrogen oxides (NO_x, primarily nitrogen monoxide) as a result of a high-temperature combustion process that uses large amounts of air. NO_x is the sum of nitric oxide (NO), nitrogen dioxide (NO_2), and other nitrogen oxide components. This makes controlling both NO_x and particulate matter emissions for a diesel engine difficult, because the decrease of one usually results in the production of the other. NO_x inhalation can cause constriction of the bronchial tubes, exacerbation of preexisting lung disease, and an increased susceptibility to respiratory infections (Blumenthal, 1985). Additionally, NO_x emissions from diesel-fueled engines contribute to acid deposition and tropospheric ozone formation.

Diesel exhaust contains mutagenic substances that are a result of NO_x radical reaction. For example, the major nitro-PAHs observed in diesel exhaust are formed by electrophilic reaction of the parent PAHs with NO_x radicals (see Chapter III). A reduction in the amount of NO_x in the exhaust stream should result in lower exhaust pipe/stack emissions of mutagenic nitro-compounds.

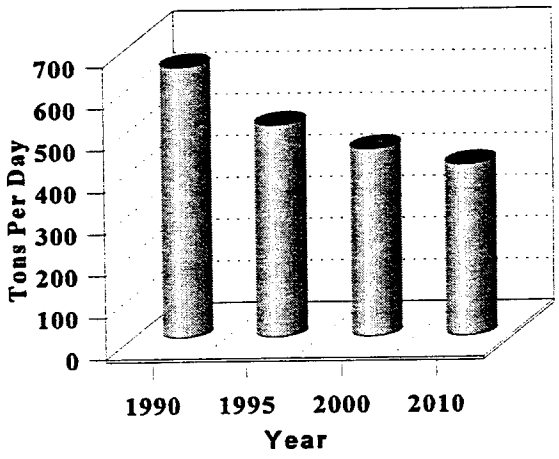
Since 1991, new heavy-duty diesel trucks and buses in California have been restricted from emitting more than 5.0 grams of NO_x per brake horsepower hour (g/bhp-h). As a result of the diesel fuel regulations adopted by the ARB in 1993, NO_x emissions from diesel-powered motor vehicles have reduced NO_x emissions by about 7 percent (70 tons per day). In 1996, the NO_x standard for new heavy-duty urban buses became 4.0 g/bhp-h. In 1998, new heavy-duty trucks will be required to meet the same standard. In addition, and as part of California's plan to address heavy-duty diesel vehicle pollutants, the U.S. EPA, ARB, and the leading manufacturers

of heavy-duty diesel engines signed a historical agreement to reduce emissions of NO_x and hydrocarbons. In this "Statement of Principles," signed on July 11, 1995, the signatories agreed to pursue new heavy-duty diesel engine standards from future trucks and buses on a nationwide basis by proposing a national non-methane hydrocarbon (NMHC) plus NO_x standard of 2.4 g/bhp-hr, or a combined NMHC plus NO_x standard of 2.5 g/bhp-hr with an NMHC cap of 0.5 g/bhp-hr. The U.S. EPA formally proposed these standards in a Notice of Proposed Rulemaking on June 2, 1996. The final rule was published in the Federal Register in October 1997. The new standards are proposed to be implemented beginning in 2004, and are predicted to decrease NO_x emissions by approximately 71 tons per year or about 18 percent. The ARB staff is proposing to adopt a similar emission standard at a ARB public hearing in April 1998.

Lower emissions of NO_x from affected sources will result in lower ambient air concentrations of NO_x in areas impacted by diesel exhaust emissions. Since NO_x is an ozone precursor, this would decrease the amount of ozone formed in the atmosphere.

As a result of the regulations mentioned above, the ARB projects that statewide NO_x emissions from on-road diesel vehicles will decrease by about 19 percent from now until 2010 (Figure IV-8).

Figure IV-8
Diesel Exhaust On-Road Vehicle
NO_x Emissions Projections



2. Stationary Sources

Diesel exhaust emissions from stationary sources are increasing with the increase in California's population. Emission regulations that will slow the increase in diesel exhaust PM and NO_x emissions from these types of sources have been addressed or may be addressed by the local air pollution control districts.

E. Indoor Sources of Diesel Exhaust

Indoor non-occupational environments will not typically have sources of indoor diesel exhaust. The presence of diesel exhaust indoors will normally result from infiltration of outdoor air contaminated with diesel exhaust. Industrial workplaces such as fire stations and loading docks are potential sources of indoor exposures. These environments may have occasional indoor sources such as diesel-powered tools, machinery, forklifts, and vehicles. Such sources may be used in enclosed work spaces near outdoor air intakes that draw the exhaust in and deliver it to indoor work spaces. Exposure to diesel exhaust indoors is discussed in more detail in Chapter V.

F. References for Chapter IV

ARB, 1997a. Emission Inventory. Run Date: 12/31/97. Technical Support Division, Air Resources Board.

ARB, 1997b. Emission Inventory. Run Date: 7/2/97. Technical Support Division, Air Resources Board.

ARB, 1998a. Emission Inventory. Run Date: 1/2/98. Technical Support Division, Air Resources Board

ARB, 1998b. Emission Inventory. Run Date: 4/29/98. Technical Support Division, Air Resources Board

ARB, 1998c. Emission Inventory. Run Date: 1/5/98. Technical Support Division, Air Resources Board

BOE, 1996. Data obtained from the California Board of Equalization. Use Fuel: Total Diesel Gallonage for Year 1995. Run Date: 10/29/96. Board of Equalization, Legislative Division, Sacramento, CA.

Blumenthal D.S., M.D., 1985. Introduction to Environmental Health. Springer Publishing Company, Inc., New York, New York. ISBN 0-8261-3900-0.

CEC, 1998. Data obtained from the California Energy Commission (CEC). Draft fuel consumption projections. Energy Information and Analysis Division, Sacramento, CA.

Pierson W.R., Brachaczek W.W., Hammerle R.H., McKee D.E. and J.W. Butler, 1978. Sulfate Emissions from Vehicles on the Road. *J. Air Pollut. Control Assoc.* 28, 123-132.

Stockwell, W.R. and Calvert, J.G., 1983. The Mechanisms of the HO-SO_2 Reaction. *Atmosheric Environment*, Vol. 28, 3,083-3,091.

Truex T.J., Pierson W.R., and D.F. McKee, 1980. Sulfate in Diesel Exhaust. *Environ. Sci. Tech.* 14:1118.

V.
EXPOSURE TO DIESEL EXHAUST

The main focus of this chapter is to provide an estimate of near source and total exposure to diesel exhaust PM_{10} in California. It also includes: a discussion of monitoring methods used by other researchers to predict ambient concentrations of diesel exhaust PM_{10}, a description of ARB's method for estimating outdoor ambient concentrations, ARB staff projections for future ambient diesel exhaust PM_{10} concentrations, an estimate of indoor exposures, and a discussion of other routes of exposure (multipathway).

A. Monitoring for Diesel Exhaust

Diesel exhaust is a complex mixture of thousands of gases and particles. Because of its complex mixture and that many of the individual constituents of diesel exhaust may be emitted from other combustion sources, whole diesel exhaust has not been directly monitored or quantified in the atmosphere.

The most common approach to monitoring diesel exhaust has been to select a surrogate measure or measures of exposure that are representative of the exhaust as a whole. Although diesel exhaust markers (substances unique to diesel exhaust that could be used to qualify and quantify its presence in the atmosphere) have not been found, fine particles and elemental carbon have been used as surrogates of exposure to diesel exhaust particulate matter. Consequently, ambient diesel exhaust PM concentrations are often used by researchers to represent the public's exposure to whole diesel exhaust.

The ARB staff estimated diesel exhaust concentrations using a PM-based exposure method. Although there are several diesel exhaust PM estimation methods (discussed on following pages), the staff of the ARB used a PM-based exposure estimation method for the following reasons:

- we have a comprehensive emissions inventory and ambient concentrations data base for diesel exhaust-derived PM in California;
- diesel exhaust PM contains many of the toxic components of the exhaust; and

- diesel exhaust PM has been shown to contribute a significant portion of the exposure to the whole exhaust. The PM has been associated with approximately 50 (Hsieh et al., 1993) to 90 (Schuetzle, 1983) percent of the mutagenic potency of whole diesel exhaust, (NIOSH, 1988)*.

Toxic gas-phase exhaust constituents like acetaldehyde, benzene, 1,3-butadiene, and formaldehyde are not directly included in a PM-based exposure estimation because they are not typically carried on or in the particles. The ARB and others have initiated research to improve and refine the estimates of exposure to the gas-phase portion of the exhaust.

Until more sophisticated estimation methods can be devised, PM-based estimation methods provide a useful tool to develop diesel exhaust exposure estimates.

Table V-1, adapted from Krieger et al. (1994), lists ambient diesel exhaust PM concentration estimates developed by a number of researchers using a variety of data bases and estimation methods. Most of the estimations presented in the Table are not California-specific, and represent only general diesel exhaust PM air concentrations (California-specific data are presented later in this Chapter). Based on the information shown in Table V-1, ambient diesel exhaust PM concentrations range from 0.2 to 23 $\mu g/m^3$.

As discussed, several diesel exhaust PM estimation methods have been developed. These include the use of the following:

- tracers;
- modeled exhaust emissions; and
- source apportionment.

1. Tracers

Although diesel exhaust may not contain markers that can be used to qualify and quantify its presence in the atmosphere, it does contain substances predominately emitted from diesel-fueled engines (tracers) which can be used to estimate its presence and concentrations. Tracer substances are consistently emitted from diesel-fueled engines, and can be consistently monitored in the air. Diesel exhaust tracers that have been suggested by various researchers include particle-associated diesel fuel additives, elemental carbon, PAH and PAH ratios, and lubricating oil combustion products. Known quantities of substances not normally found in the atmosphere can also be added to the fuel as artificial tracers.

In an effort to quantify atmospheric concentrations of diesel exhaust in Vienna, Austria, researchers added a small amount of the rare element dysprosium to the area's entire diesel fuel supply. Dysprosium is not normally detected in ambient air, and its quantifiable presence in Vienna's atmosphere during the 4-week study period allowed scientists to successfully qualify and quantify its carrier (diesel exhaust PM) in the atmosphere through PM sampling and analysis.

---

* The OEHHA's discussion and evaluation of diesel exhaust's toxicity is contained in the Part B *Health Risk Assessment for Diesel Exhaust*.

Table V-1
Estimates of Diesel Exhaust Ambient PM Concentrations by Selected Researchers

Conditions/Method	for Year	Concentrations ($\mu g/m^3$)	Reference
Ambient Concentration Estimates Using:			
Dysprosium Tracer - range	1988	5 - 23	Horvath, et al., 1988
- typical	1988	11	
Lead Surrogate - range	1995	0.7 - 3.9	U.S. EPA, 1983
Elemental Carbon - range	1982	3.4 - 5.7	Adapted from
Surrogate			Denton, et al., 1992
NAAQS Exposure Model - range	1995	3.1 - 3.7	U.S. EPA, 1983
NAAQS Exposure Model modified	1986	2.6	Ingalls, 1985
Source Apportionment -			
Urban Areas	1991	4 - 22	Chow et al. 1991
Ambient Concentration Estimates (considering only light-duty diesel vehicles) Using Various Dispersion Models:			
Urban residents - typical	1995	0.2	Cuddihy, et al., 1981
- near freeway	1995	2.0	& McClellan, 1986
Street Canyon - range	1989	3.9 - 8.8	Volkswagen, 1989
Expressway - range	1989	2.6 (100m) - 7.1 (4m)	Volkswagen, 1989

Horvath et al. (1988) found that from 12 to 33 percent of the PM suspended in Vienna's atmosphere was diesel exhaust PM, in concentrations that varied with the density and flow of traffic. The diesel exhaust PM mixed well in the atmosphere, and there were no dramatic differences in ambient concentrations between busy commercial areas and calm residential areas. Diesel exhaust PM concentrations during the study ranged between 5 and 23 $\mu g/m^3$, with typical concentrations around 11 $\mu g/m^3$. The researchers observed that the diesel exhaust PM concentrations increased 5.5 $\mu g/m^3$ above ambient levels for every 500 diesel-fueled vehicles passing near a monitoring site per hour.

2. Modeled Exhaust Emissions

Researchers at Volkswagen (1989) estimated air concentrations of vehicle exhaust PM in urban street canyons and near U.S. expressways. The researchers used emission factors for on-road gasoline- and diesel-fueled vehicles, estimates of the numbers and types of vehicles on the road, diurnal activity patterns, and mathematical simulation models of a typical U.S. street canyon and expressway. Emissions from heavy-duty on-road vehicles were not included in the researchers' calculations.

The researchers estimated that vehicle exhaust PM concentrations in the street canyon would range from 3.9 to 8.8 $\mu g/m^3$, while PM concentrations near the expressway would range from 7.14 $\mu g/m^3$ at 4 meters from the side of the road, to 2.57 $\mu g/m^3$ at 100 meters from the side of the road.

3. Source Apportionment

Source apportionment is a technique for identifying the sources and source emissions which contribute to the total ambient air concentrations of a pollutant in a specific area. PM source apportionment typically employs a chemical mass balance (CMB) model to match the chemical profiles of ambient PM samples with known chemical profiles of PM from specific types of sources. Source apportionment can be used to calculate diesel exhaust PM concentrations in a specific area for which adequate emissions inventory and PM ambient air data are available. With this information, future year diesel exhaust PM concentrations can be estimated from future year emission inventories (see section D).

a. PM_{10} Source Apportionment

Zielinska (1991) reported that a PM_{10} source apportionment study conducted by the Desert Research Institute during the winter of 1989-1990 (Chow et al., 1991) produced estimates of motor vehicle exhaust concentrations for West Phoenix, Central Phoenix, and South Scottsdale, Arizona. The results of this study indicated that primary motor vehicle exhaust is the second highest contributor to PM_{10} at all sampling sites, and that diesel-fueled motor vehicle exhaust was determined to be responsible for at least half of the motor vehicle-derived PM_{10}.

The calculated diesel exhaust PM_{10} concentrations for the winter study period ranged from approximately 4 $\mu g/m^3$ (at all three sites), to 14 $\mu g/m^3$ (in South Scottsdale) and 22 $\mu g/m^3$ (in Central Phoenix).

b. Elemental Carbon Source Apportionment

As previously mentioned, elemental carbon (EC) has been used by researchers to estimate ambient diesel exhaust PM concentrations. Gray (1986) used fine particulate EC ambient data (particle sizes below 2.1 in diameter) collected in the Los Angeles area in 1982 and emissions inventory data to determine source contributions from diesel engine emissions. Results indicated that diesel engine emissions were responsible for approximately 67 percent of the fine EC mass in the Los Angeles area atmosphere, and that the exhaust particles averaged about 64 percent EC. Average annual fine EC concentrations ranged from 3.03 to 5.04 $\mu g/m^3$. From this information, we derived approximate concentrations of fine PM attributed to diesel exhaust by multiplying the EC concentrations measured during the study by 67 percent and dividing the result by 64 percent. In addition, Gray estimates that the fine PM constitutes about 93 percent of the PM_{10} mass for diesel emissions. This percentage is then divided by the fine diesel exhaust PM concentration to determine total diesel exhaust PM_{10} concentrations. Therefore, diesel exhaust PM concentrations, calculated as described above, ranged from approximately 3.4 to 5.7 $\mu g/m^3$ (See Table V-1).

In another study, diesel exhaust PM_{10} concentrations were estimated in the South Coast from ambient PM_{10} measurements taken throughout 1986 and source apportioned using the CMB model (Gray et al., 1989; reported in 1991). The results of the study indicate the following: The average diesel exhaust PM concentrations due to light-duty diesel emissions ranged from 3.6 to 5.6 $\mu g/m^3$ across the eight sites in the study area (averaging 4.6 $\mu g/m^3$). The highest average 24-hour diesel exhaust PM concentrations in the study area ranged from 6.2 to 22.0 $\mu g/m^3$ (averaging 14.3 $\mu g/m^3$).

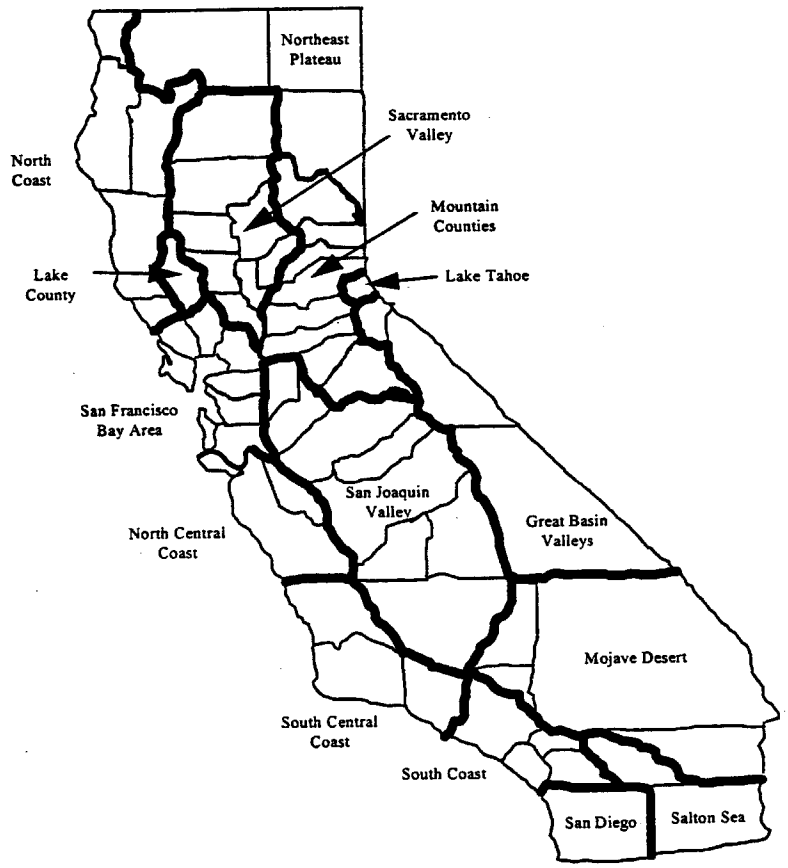
B. ARB Staff Method for Estimating Diesel Exhaust PM_{10} Outdoor Ambient Concentrations in California

Staff of the ARB estimated diesel exhaust PM_{10} concentrations for California's 15 air basins (see Figure V-1) using receptor modeling techniques, which include chemical mass balance model results from several studies. This method provides a means to apportion sources of primary PM_{10} on a site-by-site basis, and is used to estimate population-weighted annual averaged outdoor concentrations statewide. Studies from the San Joaquin Valley (1988-89), South Coast (1986), and San Jose (winters of 1991-1992 and 1992-1993) were used to obtain speciated PM_{10} ambient data. The ARB staff used these studies along with the ambient PM_{10} monitoring network data, and the 1990 PM_{10} emissions inventory, in a receptor model approach to estimate statewide outdoor concentrations of diesel exhaust PM_{10}.

In each of the studies used to estimate diesel exhaust PM_{10} concentrations, researchers used a chemical mass balance model to apportion primary sources of PM_{10} to diesel exhaust. Using their methods and results along with several assumptions, staff of the ARB were able to extract the diesel exhaust PM_{10} concentrations from the San Joaquin Valley, South Coast (including the Southeast Desert), and San Jose areas.

Calculations for the other 12 air basins in California were based on the DRI SJV source apportionment study results to estimate average fractions for rural and urban exposures (DRI, 1990). Air monitoring data for California were extracted from the 1988 through 1992 versions of the California Air Quality Data Summary, Air Quality Data Gaseous & Particulate Pollutants Report (CAQDS report), published by the ARB's Technical Support Division. The 1990 PM_{10} Emission Inventory for diesel exhaust analysis and the CAQDS report were used to extrapolate the PM_{10} concentrations from diesel exhaust in the San Joaquin Valley (SJV) to the other 12 air basins. The SJV is used as a surrogate because the chemical mass balance results are the most recent and inclusive of rural and urban areas. By using each basin's inventory, basin-specific results were obtained (see Appendix B of this report).

Figure V-1
California's 15 Air Basins



Using an interpolation model and population distribution model, staff calculated the population-weighted annual average diesel exhaust PM_{10} concentration for all the air basins using 1990 census data for California (Appendix B).

With the sources of data outlined above, a number of assumptions were made. Some of the assumptions include: 1) using diesel exhaust PM_{10} as a subset of the primary motor vehicle category of the chemical mass balance results, 2) the diesel exhaust subset may be determined from the motor vehicle emission inventory, and 3) the sampling sites within the SJV can be characterized as rural or urban and this characterization can be further extrapolated to other air basins where source apportionment data are not available (See Appendix B for a detailed discussion of the approach taken and the assumptions used). The results of our analysis have been extensively discussed at public workshops and have incorporated public comments. We believe our approach used to estimate Californians' outdoor ambient exposure to diesel exhaust PM_{10} reflects the best available science and methods.

C. Estimated Concentrations of Outdoor Ambient Diesel Exhaust PM_{10} in California

Table V-2 summarizes the ARB staff-estimated ambient concentrations of diesel exhaust PM_{10} in California. The statewide population-weighted annual outdoor average diesel exhaust PM_{10} concentration is 3.0 $\mu g/m^3$. The basin-wide average diesel exhaust PM_{10} concentrations range from 0.2 $\mu g/m^3$ (Great Basin Valleys Air Basin) to 3.6 $\mu g/m^3$ (South Coast Air Basin). These concentrations are within the range of estimates given by other researchers (see Table V-1). The statewide population-weighted annual outdoor average diesel exhaust PM_{10} concentration estimate represents, in general, what most Californians may be exposed to, although 14 out of the 15 air basins with less population have values below the statewide average.

The ARB staff have also estimated 1995 outdoor ambient exposure concentrations based on linear extrapolations from the 1990 to the 1995 emissions inventories using linear rollback techniques. Linear rollback techniques are used to estimate the projected ambient concentrations of primary sources with respect to the base year emissions inventory. For this technique, a one-to-one correspondence between basin-wide emissions and source contributions at a given site is assumed. It is assumed that the changes in a specific source category, due to growth or emission control, will not greatly alter the distribution of emissions from that source category, and thus affect the outdoor ambient concentration estimate. Using this technique, we estimated 1995 outdoor ambient concentration of diesel exhaust PM_{10} in California of 2.2 $\mu g/m^3$.

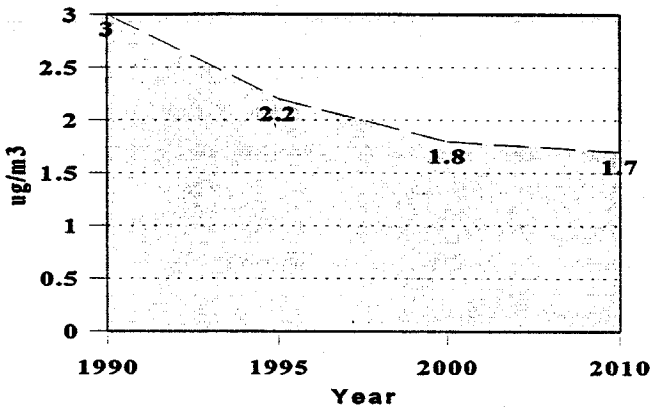
Table V-2
Average Ambient Outdoor Concentrations of Diesel Exhaust PM_{10} in California for 1990

Air Basin	Air Basin Population	Diesel Exhaust PM_{10} ($\mu g/m^3$)
Great Basin Valleys	29,000	0.2
Lake County	51,000	0.3
Lake Tahoe	21,000	1.0
Mojave Desert	557,000	0.8
Mountain Counties	485,000	0.6
North Central Coast	622,000	1.4
North Coast	564,000	1.2
Northeast Plateau	80,000	1.1
Sacramento Valley	2,219,000	2.5
Salton Sea	330,000	2.6
San Diego	2,504,000	2.9
San Francisco Bay Area	5,967,000	2.5
San Joaquin Valley	2,658,000	2.6
South Central Coast	1,232,000	1.8
South Coast	12,809,000	3.6
Statewide Population-Weighted Concentration	**30,131,000**	**3.0**

D. Diesel Exhaust PM_{10} Outdoor Ambient Air Concentration Projections

As with the 1995 estimated outdoor ambient exposure estimation, linear rollback techniques are used to project the ambient diesel exhaust PM_{10} concentration for the years 2000 and 2010. Figure V-2 shows the estimated and projected PM_{10} outdoor ambient concentrations based on the emissions inventory from diesel exhaust emissions for the base year, 1990 and 1995, and the projected years 2000, and 2010. Based on the emissions inventory projections, staff estimates that outdoor ambient diesel exhaust PM_{10} concentrations decreased from 3.0 $\mu g/m^3$ in 1990 to 2.2 $\mu g/m^3$ in 1995. By 2000 and 2010, concentrations are projected to be 1.8 $\mu g/m^3$ and 1.7 $\mu g/m^3$, respectively.

Figure V-2
Estimated PM_{10} Concentrations
Attributed to Emissions from Diesel Exhaust
for 1990, 1995, 2000, 2010



E. Near-source Emissions and Exposures

Approximately 60 percent of California's diesel exhaust PM_{10} is emitted on roadways by heavy-duty trucks, buses, and light-duty passenger vehicles. People living and/or working near busy roadways or intersections are exposed to higher-than-average concentrations of diesel exhaust.

The ARB staff conducted a study in 1993 to determine the PM_{10} concentrations due to the primary emissions from diesel engine exhaust near the Long Beach Freeway. Ambient carbon data was collected for three days in December 1993 on both sides of the freeway as well as on the roof of a school gymnasium located 1.5 miles away to obtain background concentrations. The measured carbon data, elemental and organic, were then used to estimate near-freeway diesel exhaust PM_{10} concentrations. In addition, information from other studies on motor vehicle EC/OC source profiles, ARB's emission estimates from its EMFAC7G model, and a system of equations were used to estimate the concentrations. Results indicate that near-roadway concentrations of diesel exhaust PM_{10} may be as high as 8 $\mu g/m^3$ above ambient concentrations for one 24-hour period (ARB, 1996; Appendix C of this report).

This estimate is similar to the result that researchers at Volkswagen (1989) obtained from dispersion models to estimate typical U.S. roadway exhaust PM concentrations that would result from light-duty vehicle emissions. PM emissions from heavy-duty diesel vehicles were not included in the models. The researchers estimated that the vehicle-derived PM concentrations near an expressway could be as high as 7.1 $\mu g/m^3$ (4 meters from the road), while PM concentrations in an urban street canyon could be as high as 8.8 $\mu g/m^3$ (1 meter from the curb).

Even without adding the contribution of heavy-duty vehicles, near-road PM concentrations estimated in this study for typical U.S. roadways are about twice the average ambient statewide population-weighted diesel exhaust PM_{10} concentration of 3.0 $\mu g/m^3$.

Diesel exhaust drifting away from stationary sources can significantly increase outdoor diesel exhaust concentrations (and the resulting public risk) in impacted areas. Higher-than-average exposures to diesel exhaust can occur near powerplants, oil production facilities, pumping stations, construction sites, shipping docks, railroad yards, truck parks, heavy equipment repair facilities, bus terminals, and other point or area emission sources where heavy-duty diesel engine operation is common.

1. Occupational Exposure

Occupational exposure studies have certain advantages over environmental studies conducted in outdoor ambient atmosphere. The diesel exhaust concentrations are generally higher, the exposed workplace population is better defined, duration of exposure more predictable, and sources of diesel exhaust are usually definable.

For example, Froines et al. (1987) reported PM concentrations (primarily diesel exhaust PM) inside urban fire stations from less than 100 $\mu g/m^3$ to as high as 480 $\mu g/m^3$, depending on the number of runs during the sampling period (8-hour). Personal sampling was used to measure total airborne particulate in several fire stations in New York, Boston, and Los Angeles. The authors sought the participation of nonsmokers to reduce the potential for elevated results due to the particles emitted from tobacco smoke. The fire stations acted as emission sources as the exhaust escaped from the buildings; the researchers reported outdoor PM concentrations ranging from 30 to 120 $\mu g/m^3$. The study also estimated a "worst-case" scenario. In a Los Angeles fire station, concentrations as high as 748 $\mu g/m^3$ were found. This represents an upper bound for the concentration of particles likely to be found in fire stations.

Recent industrial surveys of miners, forklift truck operators, truck drivers and railroad workers indicate a wide range of daily occupational exposures to PM in diesel exhaust (4 to 1,700 $\mu g/m^3$). Mine workers in enclosed spaces were exposed to the highest concentrations. NIOSH estimates that approximately 1.35 million people are exposed to diesel exhaust in the workplace. The 8-hour average measured concentrations of diesel particulate range from 100 to 1,000 $\mu g/m^3$ and levels in excess of 2,000 $\mu g/m^3$ have been reported (NIOSH, 1988).

In another study, and as part of a case control mortality study of trucking industry workers, exposures to diesel aerosol, via elemental carbon, were measured among four exposed job groups (road drivers, local drivers, dockworkers, and mechanics). In this study, eight industrial hygiene surveys were conducted at eight U.S. terminals and truck repair shops. A single-stage personal impactor was used to collect submicrometer-sized diesel particulates. All of the samples were taken over a full shift (approximately 8 hours) to maximize sensitivity. Results from these surveys indicated that overall average exposures to EC ranged from 5.1 $\mu g/m^3$ in road (long

distance) drivers to 26.6 $\mu g/m^3$ in mechanics. These were significantly higher than average background concentrations, measured at the same locations where workers were sampled, of 3.4 $\mu g/m^3$ on major highways and 1.4 $\mu g/m^3$ in residential areas (Zaebst, et al. 1991). By assuming that the percentage of diesel exhaust-derived EC in Los Angeles (approximately 67 percent) and that diesel exhaust particles are about 64 percent EC (Gray et al., 1986) applies to other urban areas, we calculated approximate concentrations of diesel exhaust PM to range from 5.3 to 27.8 $\mu g/m^3$.

As part of the epidemiology studies used to estimate exposures to railroad workers, measurements were made to characterize workers' exposure to diesel exhaust. Personal samples to respirable particulate matter for over 530 workers in 39 jobs in four U.S. railroads over a three-year period were made. The samples were adjusted to remove the fraction of cigarette smoke, or called the adjustable respirable particulate (ARP). The geometric mean exposures to the ARP ranged from 17 $\mu g/m^3$ for clerks to 134 $\mu g/m^3$ for locomotive shop workers (Woskie et al., 1988).

F. Indoor and Total Air Exposure

People spend a majority of their time indoors. To accurately estimate the population's exposure to toxic air pollutants, risk assessors must consider both the amount of time people spend in different environments and the concentrations of the pollutants of interest in those environments.

To estimate Californians' exposures to diesel exhaust particles, ARB staff used estimates of population-weighted ambient diesel exhaust particle concentrations (discussed in sections B and C of this Chapter and in detail in Appendix B) in a model that can estimate indoor air concentrations, population indoor air exposure, and total air exposure. The model, called the California Population Indoor Exposure Model (CPIEM), was recently developed under contract to the ARB to improve estimates of population exposures to toxic air pollutants (Koontz et al., 1995). The model generally uses distributions of data (rather than single values) as inputs, and a Monte Carlo (repeated random sampling) simulation approach. ARB's model estimates developed using CPIEM are summarized here and discussed in more detail in Appendix D.

Because representative data on indoor concentrations of diesel exhaust particles are not available, population-weighted outdoor concentrations of diesel exhaust particles plus other inputs (such as distributions of California building air exchange rates) were used in a mass-balance model (provided as one of two modules in CPIEM) to estimate indoor air concentrations of diesel exhaust particles for different indoor environments. Using these indoor air concentration distribution estimates, the second module of CPIEM that combines adults and children's activity pattern data and air concentration data was used to estimate Californians' exposures to diesel exhaust particles across all enclosed environments. In addition, CPIEM was used to provide estimates of the population's total air exposure to diesel exhaust particles by combining indoor and outdoor air exposure estimates.

In estimating indoor air concentrations for different indoor environments, input data and various assumed values for six parameters were entered into the mass balance model. The six parameters were: the outdoor concentration distributions of diesel exhaust particles; air exchange rates; penetration factor; volume of the indoor space; indoor source emissions rate (set to zero); and a net loss factor that accounts for removal of particles from the indoor space. The statewide population-weighted annual average outdoor diesel exhaust particle concentration estimate of 3.0 ± 1.1 $\mu g/m^3$ (standard deviation) was used as the outdoor concentration input distribution. The mass-balance module was used to estimate indoor diesel exhaust particle concentrations for the four indoor environments (residences, office buildings, schools, and stores/retail buildings) in CPIEM for which specific data for one or more of the input parameters are available. Estimated indoor concentrations for these environments are shown in Table V-3 and range from 1.6 ± 0.7 $\mu g/m^3$ to 2.1 ± 0.9 $\mu g/m^3$. These and other estimates developed using CPIEM are discussed further in Appendix D.

No data for input parameters were found for the other enclosed environments used in the exposure module of CPIEM; consequently, those environments were assigned surrogate diesel exhaust particle distributions equal to the distributions estimated for similar types of buildings or environments. As shown in Table V-3, industrial plants and enclosed vehicles were assigned the population-weighted average outdoor concentration values, restaurants and lounges were assumed to have levels similar to those found in stores and retail buildings, and "other indoor places" were assumed to have levels similar to those in office buildings.

The distributions of indoor concentration estimates shown in Table V-3 were used as inputs in the exposure module of CPIEM, which combines concentration data and data on Californians' activity patterns to develop time-weighted population exposure estimates. The results, shown in Table V-4, indicate that Californians were are exposed to average diesel exhaust particle concentrations of $2.0 + 0.7$ $\mu g/m^3$ in indoor environments in 1990. The population time-weighted average total air exposure concentration across all environments (including outdoor) is $2.1 + 0.8$ $\mu g/m^3$. This is about two-thirds of the population-weighted ambient average concentration. The integrated exposure estimates in Table V-4 predict the average exposure to diesel exhaust particles experienced by Californians indoors and across all environments. Both the integrated exposure estimates and the average air exposure concentration estimates take into account the differences in air concentrations in different environments and the time spent by Californians in those environments.

Table V-3
Estimated Statewide Air Concentrations of Diesel Exhaust Particles used as Exposure Module Inputs ($\mu g/m^3$)*

Environment	Estimated Mean (+ std dev)	Surrogate Mean (+ std dev)
Residences	1.9 ± 0.9	
Offices	1.6 ± 0.7	
Schools	1.9 ± 0.8	
Stores/Public/Retail Bldgs.	2.1 ± 0.9	
Outdoor Places	3.0 ± 1.1	
Industrial Plants		3.0 ± 1.1 (outdoors)
Restaurant/Lounges		2.1 ± 0.9 (retail)
Other Indoor Places		1.6 ± 0.7 (office)
Enclosed Vehicles		3.0 ± 1.1 (outdoors)

* Values significant to one digit (whole micrograms); calculated values shown here are rounded to two digits for informational purposes.

Similar indoor concentration and exposure calculations were conducted for the South Coast Air Basin and the San Francisco Bay Area. For the South Coast, the population-weighted outdoor concentration input distribution was 3.6 + 1.4 $\mu g/m^3$; the resulting estimated population average indoor exposure concentration was 2.4 + 0.9 $\mu g/m^3$, and the population average total exposure concentration was 2.5 + 0.9 $\mu g/m^3$. The input population-weighted outdoor concentration distribution use for the San Francisco Bay Area was 2.5 + 1.6 $\mu g/m^3$; the resulting estimated population average indoor exposure concentration was 1.7 + 0.9 $\mu g/m^3$, and the population average total exposure concentration was 1.7 + 0.9 $\mu g/m^3$.

Table V-4
Estimated Exposure of Californians to Diesel Exhaust Particles for 1990

	Time in Environment (Mean hours)	Integrated Daily Exposure (μg-hr/m^3)	Average Air Exposure Conc. ($\mu g/m^3$)*
Total Indoor (Enclosed) Exposure	22.5	48 ± 18	2.0 ± 0.7
Total Air Exposure	24	53 ± 18	2.1 ± 0.8

* Values significant to one digit (whole numbers); calculated values shown here are rounded to two digits for informational purposes.

It is important to note that these estimates are population estimates based on very limited input data and a number of assumptions. These estimates are "improved" over previous estimates because they incorporate into the exposure calculation both Californians' activity patterns and the reduced air concentrations of diesel exhaust particles in indoor environments relative to levels measured at ambient monitoring stations. However, they include notable uncertainty and do not adequately reflect the great variability of exposures that Californians are likely to experience over time. Of particular concern is the fact that higher exposures (the upper tail of the distribution) are likely to be underestimated and are not fully identified in this type of analysis, largely because the primary input (the annual average outdoor concentration calculated from ambient station data) does not necessarily reflect elevated diesel exhaust particle levels in "hot spot" locations and data are not available for environments such as inside vehicles where levels typically would be elevated. Individuals whose occupation or leisure activities keep them in close proximity to diesel exhaust for extended periods would be exposed to much higher levels of diesel exhaust particles than are reflected by the average estimated levels (and the distributions) shown in Tables V-3 and V-4.

1. Indoor and Total Air Exposure Estimates for 1995, 2000, and 2010

The estimated average indoor air exposure concentration associated with the 1995, 2000, and 2010 estimated outdoor average population-weighted exposure concentrations of 2.2 $\mu g/m^3$, 1.8 $\mu g/m^3$, and 1.7$\mu g/m^3$, respectively, is estimated to be approximately 1.47 $\mu g/m^3$ for 1995, 1.2 $\mu g/m^3$ for 2000, and 1.13 $\mu g/m^3$ for 2010. The average total air exposure concentration for the years 1995, 2000, and 2010 is estimated to be about 1.54 $\mu g/m^3$, 1.26 $\mu g/m^3$, and 1.19 $\mu g/m^3$, respectively (see Table V-5). The discussion below demonstrates how these estimates were made using the method for calculating 1995 estimates as an example.

These estimates were not developed by using the CPIEM model as were the earlier estimates for the 1990 baseline year. Because of the uncertainties associated with the outdoor ambient population-weighted average exposure concentrations for 1995, 2000, and 2010, and the lack of distributional information (such as a standard deviation) for these estimates, it is not appropriate to use the CPIEM to develop detailed indoor and total air exposure concentration estimates. Instead, to provide parallel average indoor and total air exposure estimates for 1995, 2000, and 2010, the ratios of the 1990 average indoor and total air exposure estimates to the 1990 population-weighted average outdoor concentration estimate were calculated and applied to the corresponding 1995, 2000, and 2010 outdoor estimates. The ratio of the 1990 estimated average indoor air exposure concentration to the 1990 population-weighted outdoor average concentration is 2.0/3.0. Using this ratio, we calculated the time-weighted average indoor exposure concentrations for 1995, 2000, and 2010. Two-thirds of 2.2 $\mu g/m^3$ (the 1995 outdoor population-weighted average estimate), 1.8 $\mu g/m^3$ (2000) and 1.7 $\mu g/m^3$ (2010) equals 1.47 $\mu g/m^3$, 1.2 $\mu g/m^3$ and 1.13 $\mu g/m^3$, respectively. The ratio of the 1990 baseline total air exposure to the population-weighted outdoor average concentration is 2.1/3.0. Taking 2.1/3 times the corresponding population-weighted outdoor levels for 1995, 2000, and 2010, we estimate average total air exposure concentrations to be 1.54 $\mu g/m^3$ for 1995, 1.26 $\mu g/m^3$ for 2000, and 1.19 $\mu g/m^3$ for 2010. These calculations assume that the ratios of the indoor and total

air exposure concentrations relative to the estimated population-weighted ambient levels do not change over time, which may or may not be true due to changes in activity patterns and other factors. These estimates are approximations only, and are provided to allow some comparison to the 1990 baseline estimates.

These total exposure estimates are believed to underestimate, to an unknown extent, Californians' actual exposures to diesel exhaust particles. This is because insufficient data are available for concentrations inside vehicles and along roadways to allow such near-source, elevated exposures to be estimated for the population. Instead, in estimating total exposure, in-vehicle and roadway concentrations were assumed to equal the ambient outdoor population-weighted concentration. The few roadside data available indicate that in-vehicle and roadside levels would typically be several times higher than those measured at nearby ambient stations. Thus, because adult Californians spend an average of seven percent of their time inside vehicles, and at least one percent of their time walking or biking along roadways, elevated concentrations in those environments would increase the population's total exposure.

Table V-5
Estimated Exposure of Californians to Diesel Exhaust Particles for 1995, 2000, 2010

	Estimated Average Air Exposure Concentration - 1990 $\mu g/m^3$ (std. dev.)	1990 Ratio	Estimated Average Air Exposure Concentration $\mu g/m^3$		
			1995	2000	2010
Ambient Estimate	3.0 (1.1)		2.2	1.8	1.7
Total Indoor Exposure Estimate	2.0 (0.7)	2.0/3.0	2/3 x 2.2 = 1.47*	2/3 x 1.8 = 1.20*	2/3 x 1.7 = 1.13*
Total Air Exposure Estimate	2.1 (0.8)	2.1/3.0	2.1/3 x 2.2 = 1.54*	2.1/3 x 1.8 = 1.26*	2.1/3 x 1.7 = 1.19*

* Significant to two figures

G. Relevant Indoor Air Quality Studies

Data from a variety of studies were reviewed by ARB staff to develop the inputs to CPIEM to estimate diesel exhaust particle concentrations in indoor environments for use in exposure modeling. Except for indoor elemental carbon data collected for one study of southern California museums, there are no data available that can be used to directly estimate diesel exhaust particle concentrations inside enclosed environments. However, there is a small but

increasing number of studies on building air exchange rates, particle penetration factors, indoor particle deposition and sink effects, and other factors that can be used, in combination with outdoor diesel exhaust particle concentration estimates, to estimate concentrations of diesel exhaust particles in indoor environments. Some of those studies were conducted in California and provide California-specific data. The major studies used in the modeling work described in the previous section are discussed briefly below. All of the studies reviewed for the modeling work and the specific data from those studies used to develop the model inputs are discussed in Appendix D of this report.

1. Residential Studies

The Particle Total Exposure Assessment Methodology (PTEAM) Study provided important input data for residential air exchange rates, particle outdoor-to-indoor penetration factors, and indoor particle removal rates for modeling residential concentrations of diesel particles. In the PTEAM study, investigators measured PM_{10} and $PM_{2.5}$, metals, and other pollutants in 178 homes in southern California in the summer and fall of 1990 (Clayton et al., 1993). The air exchange rates (number of air changes of the volume of air in the house with outdoor air per hour) measured in those homes averaged 1.25 with a standard deviation of 1.02, and thus covered a broad range of air exchange situations that would be expected (Ozkaynak et al., 1994). The penetration factor calculated by the investigators for $PM_{2.5}$ was estimated to equal one, meaning that essentially all of the fine particles present in the outdoor air that entered the homes made it past the building shell. The indoor particle removal rate (due to indoor deposition and sink effects) was estimated to be about 0.4 per hour.

These PTEAM estimates were relied upon more heavily than estimates from other studies in modeling residential indoor concentrations of diesel exhaust particles for several reasons. The PTEAM data were collected from California homes, they are fairly recent, and they are based on a reasonable sample size. Most important, the investigators examined the relationships among air exchange rate, penetration factor, and indoor removal rate and provided estimates for all of these variables. Because these factors are inter-related, a data set such as that provided by PTEAM is somewhat more reliable for modeling purposes than data sets that provide information on only one of these factors.

In addition to the PTEAM study, a number of other California studies have included measurements of air exchange rates in homes in various regions of the state and during different seasons. Together, they provide a useful body of data for estimating annual air exchange rates for California homes. Air exchange rate measurements obtained during winter or from newer, more air-tight, California homes were available for over 1000 California homes; the average rates ranged from about 0.5 to 0.9 (Sheldon et al., 1993; BSG, 1990; Wilson et al., 1993; Wilson et al., 1986; Pellizzari et al., 1989). The average air exchange rates measured in a total of about 500 California homes during the summer ranged from about 0.7 to 2.8 (BSG, 1990; Wilson et al., 1986; ADM, 1990; Pellizarri et al., 1989). Data for fall and spring values, which fall somewhere in between the summer and winter values, were available from more than 700 California homes (BSG, 1990; Wilson et al., 1993; Wilson et al., 1986). The use of the data from these studies to

develop a distribution of air exchange rates is described in Appendix D.

Penetration factor estimates for residences were based on a review of studies that provide modeled penetration factors based on various measured values. In the major California study discussed above, PTEAM investigators estimated a penetration factor of one for $PM_{2.5}$ and nearly one for PM_{10} (Ozkaynak et al., 1994). Other field study investigators have estimated penetration factors of less than one in residences. In a large field study of 394 homes, Koutrakis et al., (1992) estimated a penetration factor of about 0.84 for particles smaller than 2.5 microns. Results from smaller studies of 68 and 47 homes indicated penetration factors of 0.7 to 0.85 (Suh et al., 1994; Dockery and Spengler, 1981). In a winter study of 10 homes in Boise, Idaho conducted for the U.S. EPA's Integrated Air Cancer Project, investigators estimated an infiltration factor of about 0.5 for fine particles and 1.0 for VOCs, based on indoor/outdoor ratios of pollutants in homes with very low air exchange rates (0.2 - 0.8).

In a single, two-story California home, Thatcher and Layton (1995) investigated in detail the relationships among penetration, deposition, resuspension, and airborne particle concentrations indoors. The deposition velocities for particles were measured by raising the particle concentration indoors and simultaneously measuring air infiltration rates and particle concentration decay rates. Based on sampling results on different days, the indoor deposition rate for particles from 1 to 3 μm in diameter ranged from about 0.25 to 0.75 per hour, and deposition rates for particles 3 to 10 μm in diameter ranged from about 0.75 to 1.78 per hour. The investigators estimated the penetration factor for both particle fractions based on the experimentally determined deposition velocities and indoor/outdoor particle concentration ratios. For both particle fractions, the penetration factor was calculated to be nearly one; the investigators indicated that this shows that the building shell is not effective at removing particles as air enters the building. These test home results are consistent with the field study estimates obtained by Ozkaynak et al. (1994). Because Thatcher and Layton and Ozkaynak et al. both accounted for indoor deposition in their calculation of penetration factor, results from these studies were weighed more heavily in developing estimates of penetration factor and net indoor removal for the model, as discussed in Appendix D to this report.

2. Studies of Commercial and Public Buildings

Air exchange rate data for commercial and public buildings are provided by three studies, only one of which is a California study. Grot (1995) measured air exchange rates in 49 non-residential buildings located throughout the State of California. These buildings included 14 schools, 22 office buildings and 13 retail buildings. The measurements were taken for the buildings when their air handling systems were purposely set at minimum damper settings. Therefore, the data represent the natural infiltration rates of the buildings with a minimum influence from the air handling systems, and thus provide conservative (low) estimates of the typical in-use air exchange rates. The school buildings had the highest mean air exchange rate at 2.45 air changes per hour. The mean rate for retail buildings was 2.22, and the mean rate for office buildings was 1.35. For both office and retail buildings, large buildings were shown to have lower air exchange rates than small buildings.

In a second study, the National Institute of Standards and Technology conducted over 3000 measurements of air exchange rates in 14 U.S. office buildings (Persily, 1989). These included 2- to 15-story buildings which were mechanically ventilated by different types of heating, ventilating, and air conditioning (HVAC) systems. Investigators monitored each building for about a year under a range of weather and building operation conditions. The mean air exchange rate of all the measurements was 0.94 air changes per hour. The mean air exchange rate of individual buildings ranged from 0.29 to 1.73 (medians ranged from 0.25 to 1.65). In a third study, Turk et al. (1987) obtained air exchange measurements ranging from 0.3 to 4.1 in 38 buildings in the Pacific Northwest. The mean air exchange rate was 1.5.

Penetration factor data were not available for common public and commercial buildings. Because many public and commercial buildings have central HVAC systems that actively bring in outdoor air and filter the outdoor air, re-circulated indoor air, or both, distributions of penetration factors were estimated for different types of buildings. A single study provided information on the percent of different types of buildings that have active air filtration. BSG (1993) conducted a telephone survey to gather information about HVAC systems of non-residential buildings in California. Participants were specifically asked whether a filtration system was used in their air handling units. Complete information was provided on 88 buildings. These included 26 office buildings, 28 retail buildings and 34 schools. About 76% of school buildings, 64% of retail buildings and 73% of office buildings in the survey had filtered air. Approximately 20% of the buildings surveyed had only unfiltered air.

Data from several studies on filter efficiencies and the fraction of air filtered (Sinclair et al., 1990 and 1992; Weschler et al., 1983 and 1995; Ligocki et al., 1993) were used in combination with the BSG (1993) data to estimate distributions of penetration factors for different types of buildings. These data are very limited, but cover a range of building types including museums, telecommunications buildings, and manufacturing plants. The use of these studies to estimate particle penetration for public and commercial buildings is described in Appendix D and in Tables C4 and C5 of Appendix D.

In one of these studies, the investigators examined elemental carbon levels indoors in museums. Their results showed that indoor concentrations of elemental carbon vary with the air exchange rate and with the type of HVAC system used and the extent of particle filtration. Ligocki, et al. (1993) measured elemental carbon concentrations in and around five museums in Southern California during the summer of 1987 and the winter of 1987-1988. The five museums were the Getty Museum in Malibu, the Norton Simon Museum in Pasadena, the Scott Gallery in San Marino, the Southwest Museum in Los Angeles, and the Sepulveda House in downtown Los Angeles. The first three museums are modern buildings with custom heating, ventilation, and air conditioning (HVAC) systems with particle filtration. The Southwest Museum has a HVAC system in the hall, but no particle filtration system. The Sepulveda House is a historical museum with no HVAC system--when the weather is warm it is often operated with the doors and windows open. Seasonal averages for elemental carbon in the museums ranged from approximately 0.14 $\mu g/m^3$ at the Getty Museum during the summer, to 7.4 $\mu g/m^3$ at the Sepulveda House during the winter. The ratios of indoor to outdoor air concentrations of fine

particles ranged from approximately 1:5 at the Norton Simon Museum (with the best HVAC system) to approximately 1:1 at the Sepulveda House (Nazaroff et al., 1990; Ligocki, et al., 1993).

As reported earlier in this Chapter (see 3.b. Elemental Carbon Source Apportionment), Gray (1986) determined that diesel exhaust contributes 67 percent of the Los Angeles area's airborne EC, and that an average diesel exhaust particle is about 64 percent EC. If this is the case, then the indoor diesel exhaust PM concentrations in the museums may have ranged from approximately 0.15 $\mu g/m^3$ (in the buildings with modern HVAC systems) to 7.7 $\mu g/m^3$ (in the Sepulveda House with no HVAC). Corresponding outdoor diesel exhaust particulate matter concentrations may have ranged from approximately 0.03 to 7.7 $\mu g/m^3$.

H. Other Routes of Diesel Exhaust Exposure (Multipathway)

Exposure assessment also involves determining concentrations of the various pollutants in media by which humans are exposed. Air emissions contaminate not only the air, but deposit onto water, soil, and vegetation. These media represent the additional possible pathways of exposure to ambient diesel exhaust concentrations. In order to estimate long-term exposures resulting from ambient concentrations, the risk assessment must address both inhalation and non-inhalation pathways of exposure.

Multiple exposure pathways may contribute to the total exposure to a pollutant. For humans, the primary pollutant exposure pathways are inhalation, ingestion of dirt and contaminated food products, water ingestion, and dermal absorption of pollutants or contaminated dirt deposited on the skin. The secondary pathways are a result of the assimilation of the pollutant into a food source.

In order to assess non-inhalation pathways, substance and site-specific data are needed. Since the specific parameters for diesel exhaust are not known for these pathways, a multi-pathway assessment for diesel exhaust exposure was not done. More research is needed in this area for diesel exhaust.

J. References for Chapter V

ADM (1990), "Pilot Residential Air Exchange Survey, Task 2: Pilot Infiltration Study, Indoor Air Quality Assessment Project," Report to the California Energy Commission prepared by ADM Associates, Inc., Sacramento, CA, Contract No. 400-88-020.

ARB, 1996. Evaluation of Carbon Samples Collected Near a Freeway to Determine the Above Ambient Levels of PM_{10} due to Diesel Emissions from Diesel Engine Exhaust. Report requested from the Stationary Source Division, prepared by the Technical Support Division. 19 July 1996.

BSG (1990), "Occupancy Patterns and Energy Consumption in New California Houses (1984-1988)," California Energy Commission Consultant Report (P400-90-009), prepared by Berkeley Solar Group and Xenergy, Oakland, CA.

BSG (1993) "Outdoor Air Exchange Rates in Nonresidential Buildings, Task 2: Survey Instrument Selected Sample Pilot Study," Report to the California Energy Commission prepared by the Berkeley Solar Group, Oakland, CA, Contract No. 400-90-028.

Chow J.C., Watson J.G., Richards L.W., Haase D.L., McDade C., Dietrich D.L., Moon D. and C. Sloane, 1991. "The 1989-90 Phoenix PM_{10} Study. Volume II: Source Apportionment. Final Report." DRI Document No. 8931.6F1, prepared for Arizona Department of Environmental Air Quality, Phoenix, AZ, by Desert Research Institute, Reno, NV.

Clayton, C.A., R.L. Perritt, E.D. Pellizzari, K.W. Thomas, R.W. Whitmore, L.A.Wallace, H. Ozkaynak, and J.D. Spengler, (1993), "Particle Total Exposure Assessment Methodology (PTEAM) Study: Distributions of Aerosol and Elemental Concentrations in Personal, Indoor, and Outdoor Air Samples in a Southern California Community," Journal of Exposure Analysis and Environmental Epidemiology 3(2): 227-250.

Cuddihy R.G., Griffith W.C., Clark C.R. and R.O. McClellan, 1981. Potential Health and Environmental Effects of Light Duty Diesel Vehicles II, Inhalation Toxicology Research Institute, Lovelace Biomedical and Environmental Research Institute, prepared for the U.S. Department of Energy, LMF-89, UC-48, October.

Denton J.E., Hughes K.V., Ranzieri A.J., Servin A., Dawson S.V., Alexeeff G.V., Smith A.H., Bates M.N. and H.M. Goeden, 1992. Development of Exposure and Toxicity Data for Diesel Exhaust in California. ARB Technical report ARB/SS-92-01, October.

References for Chapter V (continued)

Desert Research Institute, 1990. San Joaquin Valley Air Quality Study Phase 2: PM-10 Modeling and Analysis, Volume I: Receptor Modeling Source Apportionment, DRI Document No. 8929.1F, October 11.

Dockery, D.W. and J.D. Spengler (1981), "Indoor-Outdoor Relationships of Respirable Sulfates and Particles," Atmospheric Environment 15: 335-343.

Froines J.R., Hinds W.C., Duffy R.M., Lafuente E.J. and W.C.V. Liu, 1987. Exposure of Firefighters to Diesel Emissions in Fire Stations. *Am. Ind. Hyg. Assoc. J.*, 48 (3), 202-207.

Gray H.A., 1986. Control of Atmospheric Fine Primary Carbon Particle Concentrations. EQL Report No. 23, Environmental Quality Laboratory, California Institute of Technology, Pasadena, CA.

Gray H.A., Landry B., Liu C.S., Henry R.C., Cooper J.A., and J.R. Sherman, 1989. Receptor Modeling for PM_{10} Source Apportionment in the South Coast Air Basin of California. Air Quality Management Plan, 1989 Revision, Appendix V-K. South Coast Air Quality Management District.

Grot, R.A. (1995) "Air Change Rates in Non-residential Buildings in California," California Energy Commission Consultant Report P400-91-034BCN.

Horvath H., Kreiner I., Norek C. and O. Preining, 1988. Diesel Emissions in Vienna. *Atmos. Environ.*, 22(7), 1255-1269.

Hsieh D.P.H., Kado N.Y., Okamoto R., Kuzmicky P., Rathbun C. and J. Ito, 1993. Measurement and Chemical Characterization of Vapor-Phase Mutagens in Diesel Exhaust. Final Report Prepared for the California Air Resources Board, Contract No. A032-095.

Ingalls M.N., 1985. Improved Mobile Source Exposure Estimation, Southwest Research Institute, EPA-460/3-85-002, March 1985.

Koontz M.D., W.C. Evans and C.R. Wilkes, 1995. Development of a Model for Assessing Indoor Exposure to Air Pollutants. Draft Final Report to the California Air Resources Board, Contract No. A933-157.

Koutrakis, P., S.L.K. Briggs and B.P. Leaderer (1992), "Source Apportionment of Indoor Aerosols in Suffolk and Onondaga Counties, New York," Environ. Sci. Technol. 26:521-527.

References for Chapter V (continued)

Krieger R.K., Denton J.E., Dawson S.V. and G.V. Alexeeff, 1994. Presented at the Proceedings of the 5th Annual West Coast Regional Conference of the Air & Waste Management Association Meeting, November 9-10, 1994. Publication "Current Issues in Air Toxics."

Ligocki M.P., Salmon L.G., Fall T., Jones M.C., Nazaroff W.W. and G.R. Cass, 1993. Characteristics of Airborne Particles Inside Southern California Museums. *Atmos. Environ.*, 27A(5), 697-711.

McClellan R.O., 1986. Health Effects of Diesel Exhaust: A Case Study in Risk Assessment, *Am. Ind. Hyg. Assoc. J.*, 47(1):1-13, 154.

National Institute for Occupational Safety and Health (NIOSH), 1988. Current Intelligence Bulletin No. 50: Carcinogenic Effects of Exposure to Diesel Exhaust. Publication No. 88-116. NIOSH, Cincinnati, Ohio.

Nazaroff W., Salmon L. and G.R. Cass, 1990. Concentration and Fate of Airborne Particles in Museums. *Environ. Sci. Technol.*, 24(1), 66-76.

Ozkaynak, H., J. Xue, R. Weker, D. Butler, P. Koutrakis and J. Spengler (1994), "The Particle TEAM (PTEAM) Study: Analysis of the Data," May 1994 report to the U.S. EPA., Volume III of Final Report.

Pellizzari, E.D., L.C. Michael, K. Perritt, D.J. Smith, T.D. Hartwell and J. Sebestik (1989), "Development and Implementation of Exposure Assessment Procedures for Toxic Air Pollutants in Several Los Angeles County, California Communities," Final Report to the California Air Resources Board, Contract No. A5-174-33.

Persily, A (1989), "Ventilation Rates in Office Buildings," in *The Human Equation: Health and Comfort*, Proceedings of the ASHRAE/SOEH Conference, IAQ 89. April 17-20, 1989, San Diego, CA pp. 128-136.

Schuetzle D., 1983. Sampling of Vehicle Emissions for Chemical Analysis and Biological Testing. *Environ. Health Perspect.*, 47, 65-80.

Sheldon, L., A. Clayton, J. Keever, R. Perritt and D. Whitaker (1993), "Indoor Concentrations of Polycyclic Aromatic Hydrocarbons in California Residences," Draft Final Report to the Air Resources Board, Contract No. A033-132.

References for Chapter V (continued)

Sinclair, J.D., L.A. Psota-Kelty, C.J. Weschler and H.C. Shields (1990), "Measurements and Modeling of Airborne Concentrations and Indoor Surface Accumulation Rates of Ionic Substances at Neenah, Wisconsin," Atmospheric Environment 24A(3): 627-638.

Sinclair, J.D., L.A. Psota-Kelty and G.A. Peins (1992), "Indoor/Outdoor Relationships of Airborne Ionic Substances: Comparison of Electronic Equipment Room and Factory Environments," Atmospheric Environment 26A(5), pp. 871-882.

Suh, H.H., P. Koutrakis and J.D. Spengler (1994), "The Relationship between Airborne Acidity and Ammonia in Indoor Environments," Journal of Exposure Analysis and Environmental Epidemiology 4(1): 1-22.

Thatcher, T.L. and D.W. Layton (1995) "Deposition, Resuspension, and Penetration of Particles within a Residence," Atmospheric Environment, 29(13): 1487-1497.

Turk, B.H., J.T. Brown, K. Geisling-Sobotka, D.A. Froehlich, D.T. Grimsrud, J. Harrison, J.F. Koonce, R.J. Prill and K.L. Revzan (1987), "Indoor Air Quality and Ventilation Measurements in 38 Pacific Northwest Commercial Buildings," Volume 1, LBL-22315 ½, Lawrence Berkeley Laboratory.

U.S. Environmental Protection Agency (EPA), 1983. Diesel Particulate Study, Office of Mobile Sources, Office of Air and Radiation, October.

Volkswagen, 1989. Unregulated Motor Vehicle Exhaust Gas Components. Volkswagen AG, Research and Development (Physico-Chemical Metrology). Project Coordinator: Dr. K.-H. Lies. 3180 Wolfsburg 1, F.R. Germany.

Weschler, C.J., S.P. Kelty and J.E. Lingousky (1983), "The Effect of Building Fan Operation on Indoor-Outdoor Dust Relationships," Journal of the Air Pollution Control Association 33:624-629

Weschler, C.J., H.C. Shields and B. Shah (1995), "Understanding and Controlling the Indoor Concentration of Sub-Micron Particles at a Commercial Building in Southern California," Presented at the 88th Annual Meeting of Air and Waste Management Association, June 18-23, 1995, Paper No. 95-MP4.01.

Wilson, A.L., S.D. Colome and Y. Tian (1993) "California Residential Indoor Air Quality Study, Volume 1: Methodology and Descriptive Statistics," Prepared for Gas Research Institute, Pacific Gas and Electric Company and Southern California Gas Company by Integrated Environmental Services, Irvine, CA.

References for Chapter V (continued)

Wilson A.L., S.D. Colome, P.E. Baker and E.W. Becker (1986), "Residential Indoor Air Quality Characterization Study of Nitrogen Dioxide," Phase I Final Report for Southern California Gas Company.

Woskie, S.R., Smith, T.J., Hammond, S.K., Schenker, M.B., Garshick, E. And F.E. Speizer. 1988. Estimation of the Diesel Exhaust Exposures of Railroad Workers: I. Current Exposures. *Am. J. Ind. Med.*, 13, 381-394.

Zaebst D.D., Clapp D.E., Blake L.M., Marlow D.A., Steenland K., Hornung R.W., Scheutzle D. and J. Butler, 1991. Quantitative Determination of Trucking Industry Workers Exposures to Diesel Exhaust Particles. *Am. Ind. Hyg. Assoc. J.*, 52(12), 529-541.

Zielinska B., 1991. Diesel Emissions: New Technology, Health Effects and Emission Control Programs. Final Report. DRI Document No. 8201.FR, Prepared for the Arizona Department of Environmental Quality. Desert Research Institute, Reno, Nevada.

VI.
ATMOSPHERIC PERSISTENCE AND FATE OF DIESEL EXHAUST

Diesel exhaust contains thousands of gas, particle, and particle- associated constituents, including carbon dioxide, carbon monoxide, water vapor, oxides of nitrogen, saturated and unsaturated aldehydes and ketones, alkanes, alkenes, monocyclic aromatic hydrocarbons, carbon-core particles, gas- and particle-phase polycyclic aromatic hydrocarbons (PAH) and PAH-derivatives, and metals (see Chapter III). This wide range of substances has an even wider range of atmospheric fates. For example, diesel exhaust contains the atmospherically-reactive animal carcinogen benzo[a]pyrene (BaP). Van Cauwenberghe et al. (1979) tentatively identified at least nine BaP derivatives after reaction with tropospheric ozone. Many of these derivatives are direct-acting mutagens (Finlayson-Pitts and Pitts, 1986).

Diesel exhaust's constituents can react with atmospheric radicals to form new species, combine with other substances to form more complex species, and/or be deposited onto surfaces. In this chapter, we provide a general discussion of what is known about the atmospheric lifetimes and fates of diesel exhaust's major component groups: particles, particle-associated organic compounds, gas and particle-associated PAH and PAH-derivatives, and gaseous species.

Diesel exhaust contributes to global warming because it contains substances such as methane and carbon dioxide. Diesel exhaust also contributes to acid deposition because it contains nitric and sulfuric acids, as well as other substances which can be transformed to acidic PM in the atmosphere. Diesel exhaust is not known to contribute to stratospheric ozone depletion.

A. Atmospheric Fate of Diesel Exhaust Particles

The two most important processes affecting diesel exhaust particles in the atmosphere are:

- dry and wet deposition (physical removal) of the particles, and
- atmospheric transformations of species adsorbed to the particles.

1. Physical Removal

Physical removal of diesel exhaust PM from the atmosphere is usually accomplished through accretion of the particles, atmospheric fall-out (dry deposition), and atmospheric removal by rain (wet deposition).

A particle's atmospheric lifetime due to dry deposition is a function of the particle's diameter (Graedel and Weschler, 1981). Diesel exhaust particles, generally smaller than 1 μm (Pierson et al., 1983), are expected to remain in the atmosphere from 5 to 15 days.

Rain events result in almost complete wash-out of particles 0.1 to 10 μm in diameter from

the atmosphere (Leuenberger et al., 1985; Ligocki et al., 1985a,b). Since diesel exhaust particles are in this size range, they are expected to be efficiently washed from the atmosphere when it rains.

2. Atmospheric Reactions of Particle-Associated Organic Compounds

Organic compounds absorbed by the particles in the exhaust stream may be protected from photolysis and/or chemical reaction. Organic species coating the surface of the particles may be expected to primarily react with sunlight (through photolysis), ozone (O_3), gaseous nitric acid (HNO_3) and nitrogen dioxide (NO_2). Organic compounds coating the surface of the particles can also volatilize from the particle and become more susceptible to photolysis and/or chemical reaction.

B. Atmospheric Transformations of PAH and PAH-derivatives

This section describes the reactions to PAH in general, keeping in mind that PAH are a product of incomplete combustion from a number of sources. Both gas- and particle-phase PAH are found in the atmosphere. Naphthalene and other 2-ring PAH are present in the gas phase in ambient air, while the 5- or more-ring PAH (such as the 5-ring benzo[a]pyrene) are particle-associated (Coutant et al., 1988; Arey et al., 1987, 1989a; Atkinson et al., 1988). A similar distribution between gas and particle phase occurs for the PAH-derivatives, with, for example, nitro-PAH with 4- or more-rings being particle-associated.

In contrast to the PAH (with no atmospheric formation pathways), PAH-derivatives can be formed in the atmosphere from the gas- and adsorbed-phase reactions of the parent PAH. Some of the PAH-derivatives studied in the laboratory have been found to be highly mutagenic (Arey et al., 1986; Atkinson et al., 1990; Atkinson and Arey, 1994).

PAH adsorbed to particles can be transformed into PAH-derivatives by a number of atmospheric reaction processes, including photolysis and reaction with O_3, NO_2 and/or HNO_3, sulphur dioxide (SO_2), and dinitrogen pentoxide (N_2O_5) (Pitts et al., 1978, 1980). For example, particle-associated PAH may photolyze in ambient atmospheres. The extent to which this occurs depends on the properties of the absorbent. Researchers investigating photooxidation and photolysis of PAH on various surfaces (Korfmacher et al., 1980a,b; Blau and Gusten, 1981; Behymer and Hites, 1985, 1988; Kamens et al., 1985a,b, 1986; Yokley et al., 1986; Valerio et al., 1987) have concluded that photolysis rates are highly substrate dependent, with darker substrates leading to lower photolysis rates (presumably due to stabilization of the PAH incorporated in the particles). Cope and Kalkwarf (1987) investigated the photooxidation of certain adsorbed oxy-PAH and found them to be generally stable in sunlight, but to decay under the influence of light and O_3.

Gas-phase PAH appear to dominate over particle-phase PAH in the formation of nitro-PAH and other PAH-derivatives in the atmosphere (Arey et al., 1987, 1989a, 1990a; Atkinson et al., 1988; Zielinska et al., 1989b, Atkinson and Arey, 1994). Most of the atmospheric transformation

products of the gas-phase PAH remain unidentified.

1. Loss Processes for the Gas-phase PAH and PAH-derivatives

Gas-phase PAH and PAH-derivatives undergo wet and dry deposition, photolysis, and reaction with OH radicals, NO_3 radicals, and O_3.

a. Wet and Dry Deposition

Gas-phase PAH have washout ratios ranging from 10^2 to 10^4, while particle-associated PAH generally have washout ratios around $10^{5\pm1}$ (Ligocki et al., 1985a; Bidleman, 1988). Comparison of the washout ratios for gas-phase PAH with the time-scale of gas-phase chemical reactions suggest that rain will not effectively remove them from the atmosphere. Dry deposition is also expected to be of minor importance (Eisenreich et al., 1981).

b. Reaction with the OH Radical

OH radical reactions with the PAH and PAH-derivatives proceed by OH radical addition to the aromatic ring (forming an initially energy-rich hydroxycyclohexadienyl-type radical), or by OH radical interaction with the substituent groups (either through H atom abstraction from C-H or O-H bonds or OH radical addition to >C=C< bonds: Atkinson, 1986; Atkinson, 1989).

The observed products of OH radical-initiated reactions (in the presence of NO_x) with PAH and PAH-derivatives are hydroxy- and nitro-arenes (Atkinson et al., 1987). The available (and limited) data indicate that yields of the hydroxyarenes are significantly higher than those of the nitroarenes.

c. NO_3 Radical Reactions

Reactions involving the initial addition of a NO_3 radical to the aromatic ring of a PAH lead to the formation of nitroarenes (Pitts et al., 1985a; Sweetman et al., 1986; Atkinson et al., 1987, 1990; Zielinska et al., 1989a; Arey et al., 1989b). Reactions involving NO_3 radical interaction with the substituent group(s) do not lead to the formation of nitroarenes (Atkinson, 1990). The other products of this type of reaction are not known with any certainty, although they may include hydroxynitro-PAH.

d. O_3 Reactions

For the gas-phase PAH studied to date, only acenaphthylene has been observed to react with O_3 (Atkinson and Aschmann, 1988), but reaction is also expected to occur for acephenanthrylene (Zielinska et al., 1988). These PAHs react with O_3 by addition of O_3 at the cylcopenta-fused ring >C=C< bond (Atkinson and Aschmann, 1988).

e. Photolysis

No evidence has been observed for the gas-phase photolysis of the 2- to 4-ring PAH (Atkinson et al., 1984; Biermann et al., 1985; Atkinson and Aschmann, 1986, 1988). However, photolysis of 1- and 2-nitronaphthalene and 2-methyl-1-nitronaphthalene has been observed under ambient outdoor sunlight conditions (Atkinson et al., 1989; Arey et al., 1990b).

C. Atmospheric Lifetimes of Gas-phase PAH and PAH-derivatives

Photolysis and reaction rate data have been combined with the ambient radiation flux and ambient concentrations of OH and NO_3 radicals, NO_2 and O_3 to estimate the lifetimes for some of the PAH and PAH-derivatives. These lifetime data are given in Table VI-1.

The ambient concentrations of NO_3 radicals in the lower troposphere over continental areas vary widely, in contrast to O_3 and OH radical concentrations which stay at reasonably consistent day-to-day ambient levels (Logan, 1985; Prinn et al., 1987; Arey et al., 1989a).

For the PAH that don't contain cyclopenta-fused rings, the dominant tropospheric loss process is by reaction with the OH radical, with calculated lifetimes of 1 day or less (the OH radical reaction only occurs during daylight hours).

The PAH containing cyclopenta-fused rings (such as acenaphthene, acenaphthylene, and acephenanthrylene) are expected to react with NO_3 radicals at a significant rate. NO_3 radical addition to the fused rings of the PAH is not significant as a tropospheric loss process for the PAH. PAH like acenaphthylene, having unsaturated cyclopenta-fused rings, are also expected to react with O_3 at a significant rate.

The dominant tropospheric removal process for the gas-phase PAH appears to be by daytime reaction with the OH radical, leading to lifetimes of about 1 day or less.

Many of the nitroarenes observed in ambient air are only formed in the atmosphere through the gas-phase reactions of the 2- 3- and 4-ring PAH (Pitts et al., 1985b; Nielsen and Ramdahl, 1986; Sweetman et al., 1986; Arey et al., 1986, 1987, 1989a,b, 1990a; Ramdahl et al, 1986; Zielinska et al., 1988, 1989a,b; and Atkinson et al., 1988).

The presence of the nitro-substituent group in the nitroarenes leads to a marked decrease in their reactivity towards the OH radical. Photolysis may be the dominant tropospheric removal process for these compounds, with calculated lifetimes of about 2 hours.

Table VI-1
The Atmospheric Lifetimes of Selected PAH and PAH-derivatives due to Photolysis and Gas-phase Reaction with OH and NO_3 Radicals, and O_3

PAHs	Lifetime due to reaction with OH[a]	NO_3[b]	O_3[c]	Photolysis[d]
Naphthalene	8.6 hrs	100 days	>80 days	
1-Methylnaphthalene	3.5 hrs	50 days	>125 days	
2-Methylnaphthalene	3.6 hrs	40 days	>40 days	
2,3-Dimethylnaphthalene	2.4 hrs	25 days	>40 days	
Biphenyl	2.1 days	>20 yrs	>80 days	
Acenaphthene	1.8 hrs	2.5 hrs	>30 days	
Acenaphthylene	1.7 hrs	13 mins	~43 mins	
Phenanthrene	6.0 hrs			
Anthracene	1.4 hrs			
Fluoranthene	~3.7 hrs[e]	~85 days		
Pyrene	~3.7 hrs[e]	~30 days		
1-Nitronaphthalene	2.9 days	3.6 yrs	>28 days	1.7 hrs
2-Nitronaphthalene	2.8 days	4.0 yrs	>28 days	2.2 hrs
1,4-naphthoquinone	5.0 days	100 days	>80 days	~2.6 hrs
2-Methyl-1-nitro-naphthalene	1.8 days	4.0 yrs	>55 days	2.1 hrs

[a] For a 12-hr daytime average OH radical concentration of 1.5×10^6 molecule cm^{-3} (Prinn et al., 1987).

[b] For a 12-hr average nighttime NO_3 radical concentration of 2.4×10^8 molecule cm^{-3} and an NO_2 concentration of 2.4×10^{12} molecule cm^{-3} (Atkinson et al., 1986).

[c] For a 24-hr average O_3 concentration of 7×10^{11} molecule cm^{-3} (Logan, 1985).

[d] For an average 12-hr daytime NO_2 photolysis rate of $J_{NO2} = 5.2. \times 10^{-3}\ s^{-1}$.

[e] Using estimated OH radical reaction rate constant correlation with ionization potential (Biermann et al., 1985; Arey et al., 1990b; Atkinson et al., 1990).

D. Atmospheric Reactions of Gaseous Species

Gaseous diesel exhaust species (such as benzene or formaldehyde) can react in the atmosphere with other pollutants and/or sunlight to form new species. For example, 1,3-butadiene can react in the atmosphere with OH radicals and O_3 to form formaldehyde, acrolein, and/or radicals (ARB, 1992). Gaseous diesel exhaust species will primarily react with the following:

- sunlight (through photolysis),
- O_3,
- the OH radical (during the daylight hours),
- the NO_3 radical (during the nighttime hours),
- gaseous HNO_3,
- NO_2, and
- the HO_2 radical (mainly during afternoon/evening hours).

The important reaction processes for most of the gas-phase organics are photolysis and reaction with O_3 and the OH and NO_3 radicals. For a limited number of compounds, one or more of the other reactive chemical species (HO_2, NO_2, and/or HNO_3) may react with them at significant rates. For example, HO_2 radicals react with formaldehyde, acetaldehyde, and glyoxal; NO_2 reacts with conjugated dienes; and gaseous HNO_3 reacts with the amines.

Gaseous species absorbed by particles may be unavailable for further chemical reaction. Gaseous species adsorbed to particles may be degraded by photolysis and reaction with tropospheric O_3, N_2O_5, NO_2, HNO_3, nitrous acid (HONO), sulfuric acid (H_2SO_4), and hydrogen peroxide (H_2O_2).

E. References for Chapter VI

ARB (Air Resources Board), 1992. Proposed Identification of 1,3-Butadiene as a Toxic Air Contaminant. Technical Support Document, Part A, May. Stationary Source Division.

Arey J., Zielinska B., Atkinson R., Winer A.M., Ramdahl T. and J.N. Pitts, Jr., 1986. The formation of nitro-PAHs from the gas-phase reactions of fluoranthene and pyrene with the OH radical in the presence of NO_x. *Atmos. Environ.*, 20, 2339-2345.

Arey J., Zielinska B., Atkinson R. and A.M. Winer, 1987. Polycyclic aromatic hydrocarbon and nitroarene concentrations in ambient air during a winter-time high-NO_x episode in the Los Angeles basin. *Atmos. Environ.*, 21, 1437-1444.

Arey J., Atkinson R., Zielinska B. and P.A. McElroy, 1989a. Diurnal concentrations of volatile polycyclic aromatic hydrocarbons and nitroarenes during a photochemical air pollution episode in Glendora, California. *Environ. Sci. Technol.*, 23, 321-327.

Arey J., Zielinska B., Atkinson R. and S.M. Aschmann, 1989b. Nitro-arene products from the gas-phase reactions of volatile polycyclic aromatic hydrocarbons with the OH radical and N_2O_5. *Int. J. Chem. Kinet.*, 21, 775-799.

Arey J., Zielinska B., Atkinson R. and P.A. McElroy, 1990a. Experimental Investigation of the Atmospheric Chemistry of Aromatic Hydrocarbons and Long-Chain Alkanes. UC Riverside. Under ARB Contract No. A032-067.

Arey J., Atkinson R., Aschmann S.M. and D. Schuetzle, 1990b. Experimental Investigation of the Atmospheric Chemistry of 2-Methyl-1-nitronaphthalene and a Comparison of Predicted Nitroarene Concentrations with Ambient Air Data. *Polycyclic Aromat. Compounds*, 1, 33-50.

Atkinson R., 1986. Kinetics and Mechanisms of the Gas-phase Reactions of the Hydroxyl Radical with Organic Compounds under Atmospheric Conditions. *Chem. Rev.*, 86, 69-201.

Atkinson R., 1989. Kinetics and Mechanisms of the Gas-phase Reactions of the Hydroxyl Radical with Organic Compounds. *J. Phys. Chem. Ref. Data*, Monograph. 1, 1-246.

Atkinson R., 1990. Gas-phase Tropospheric Chemistry of Organic Compounds: a Review. *Atmos.Environ.*, 24A, 1-41.

References for Chapter VI (continued)

Atkinson R. and J. Arey, 1994. Atmospheric chemistry of gas-phase PAH: formation of atmospheric mutagens. *Environ. Health Persp.*

Atkinson R. and S.M. Aschmann, 1986. Kinetics of the reactions of naphthalene, 2-methylnaphthalene, and 2,3-dimethylnaphthalene with OH radicals with O_3 at 295 + 1K. *Int. J. Chem. Kinet.*, 18, 569-573.

Atkinson R. and S.M. Aschmann, 1988. Kinetics of the reactions of acenapthene and acenaphthylene and structurally-related aromatic compounds with OH and NO_2 radicals, N_2O_5 and O_3 at 296 + 2K. *Int. J. Chem. Kinet.*, 20, 513-539.

Atkinson R., Aschmann S.M. and J.N. Pitts, Jr., 1984. Kinetics of the reactions of naphthalene and biphenyl with OH radicals and with O_3 at 294 + 1 K. *Environ. Sci. Technol.*, 18, 110-113.

Atkinson R., Winer A.M. and J.N. Pitts, Jr., 1986. Estimation of night-time N_2O_5 concentrations from ambient NO_2 and NO_3 radical concentrations and the role of N_2O_5 in night-time chemistry. *Atmos. Environ.*, 20, 331-339.

Atkinson R., Arey J., Zielinska B. and S.M. Aschmann, 1987. Kinetics and products of the gas-phase reactions of OH radicals and N_2O_5 with naphthalene and biphenyl. *Environ. Sci. Technol.*, 21, 1014-1022.

Atkinson R., Arey J., Winer A.M., Zielinska B., Dinoff T.M., Harger W.P. and P.A. McElroy, 1988. A Survey of Ambient Concentrations of Selected Polycyclic Aromatic Hydrocarbons (PAH) at Various Locations in California. Final Report, California Air Resources Board Contract No. A5-185-32, May.

Atkinson R., Aschmann S.M., Arey J., Zielinska B. and D. Schuetzle, 1989. Gas-phase Atmospheric Chemistry of 1- and 2-nitronaphthalene and 1,4-naphthoquinone. *Atmos. Environ.*, 23, 2679-2690.

Atkinson R., Arey J., Zielinska B. and S.M. Aschmann, 1990. Kinetics and Nitro-Products of the Gas-Phase OH and NO_3 Radical-Initiated Reactions of Naphthalene-d_8, Fluoranthene-d_{10}, and Pyrene. *Int. J. Chem. Kinet.*, Vol. 22, 999-1014.

Behymer T.D. and R.A. Hites, 1985. Photolysis of polycyclic aromatic hydrocarbons adsorbed on simulated atmospheric particulates. *Environ. Sci. Technol.*, 19, 1004-1006.

References for Chapter VI (continued)

Behymer T.D. and R.A. Hites, 1988. Photolysis of polycyclic aromatic hydrocarbons adsorbed on fly ash. *Environ. Sci. Technol.*, 22, 1311-1319.

Bidleman T.F., 1988. Atmospheric processes. *Environ. Sci. Technol.*, 22, 361-367.

Biermann H.W., Mac Leod H., Atkinson R., Winer A.M. and J.N. Pitts, Jr., 1985. Kinetics of the gas-phase reactions of the hydroxyl radical with naphthalene, phenanthrene, and anthracene. *Environ. Sci. Technol.*, 19, 244-248.

Blau, L. and H. Gusten, 1981. Quantum yields of the photodecomposition of polynuclear aromatic hydrocarbons adsorbed on silica gel. In: Aromatic Hydrocarbons, M. Cooke, A. J. Dennis and G. L. Fisher (Eds.), Battelle Press, Columbus, OH, pp. 133-144.

Cope, V. W. and D. R. Kalkwarf, 1987. Photooxidation of selected polycyclic aromatic hydrocarbons and pyrenequinones coated on glass surfaces. *Environ. Sci. Technol.*, 21, 643-648.

Coutant, R. W., Brown, L., Chuang, J. C., Riggin, R. M. and R. G. Lewis, 1988. Phase distribution and artifact formation in ambient air sampling for polynuclear aromatic hydrocarbons. *Atmos. Environ.*, 22, 403-409.

Eisenreich, S. J., Looney, B. B. and J. D. Thornton, 1981. Airborne organic contamination in the Great Lakes ecosystem. *Environ. Sci. Technol.*, 15, 30-38.

Finlayson-Pitts, B. J. and J. N. Pitts Jr., 1986. Atmospheric Chemistry: Fundamentals and Experimental Techniques. John Wiley and Sons, Publisher. New York, New York.

Graedel, T. E., and C. J. Weschler, 1981. Chemistry within aqueous atmospheric aerosols and raindrops. *J. Geophys. Res.*, 19, 505-539.

Kamens, R. M., Perry, J. M., Saucy, D. A., Bell, D. A., Newton, D. L., and B. Brand, 1985a. Factors which influence polycyclic aromatic hydrocarbon decomposition on wood smoke particles. *Environ. Int.*, 11, 131-136.

Kamens, R., Bell, D., Dietrich, A., Perry, J. Goodman, R., Claxton, L., and S. Tejada, 1985b. Mutagenic transformations of dilute wood smoke systems in the presence of ozone and nitrogen dioxide. Analysis of selected high-pressure liquid chromatography fractions from wood smoke particle extracts. *Environ. Sci. Technol.*, 19, 63-69.

References for Chapter VI (continued)

Kamens, R. M., Fulcher, J. N. and G. Zhishi, 1986. Effects of temperature on wood soot PAHs decay in atmospheres with sunlight and low NOx. *Atmos. Environ.*, 20, 1579-1587.

Korfmacher, W. A., Natusch, D. F. S., Taylor, D. R., Mamantov, G. and E. L. Wehry, 1980a. Oxidative transformations of polycyclic aromatic hydrocarbons adsorbed on coal fly ash. *Science*, 207, 763-765.

Korfmacher, W. A., Wehry, E. L., Mamantov, G. and D. F. S. Natusch, 1980b. Resistance to photochemical decomposition of polycyclic aromatic hydrocarbons vapor-adsorbed on coal fly ash. *Environ. Sci. Technol.*, 14, 1094-1099.

Leuenberger, C., Ligocki, M. P., and J. F. Pankow, 1985. Trace organic compounds in rain. 4. Identities, concentrations and scavenging mechanisms for phenols in urban air and rain. *Environ. Sci. Technol.*, 19, 1053-1058.

Ligocki M. P., Leuenberger C. and J.F. Pankow, 1985a. Trace organic compounds in rain - III. Particle scavenging of neutral organic compounds. *Atmos. Environ.*, 19, 1619-1626.

Ligocki M.P., Leuenberger C. and J.F. Pankow, 1985b. Trace organic compounds in rain - II. Gas scavenging of neutral organic compounds. *Atmos. Environ.*, 19, 1609-1617.

Logan J.A., 1985. Tropospheric ozone: seasonal behavior, trends, and anthropogenic influence. *J. Geophys. Res.*, 90, 10463-10482.

Nielsen T., 1984. Reactivity of polycyclic aromatic hydrocarbons toward nitrating species. *Environ. Sci. Technol.*, 18, 157-163.

Nielsen T. and T. Ramdahl, 1986. Discussion on "Determination of 2-nitrofluoranthene and 2-nitropyrene in ambient particulate matter: evidence for atmospheric reactions". *Atmos. Environ.*, 20, 1507.

Pierson W.R., Gorse R.A., Jr., Szkariate A.C., Brachaczek W.W., Japar S.M., Lee F.S.C., Zweidinger R.B. and L.D. Claxton, 1983. Mutagenicity and chemical characteristics of carbonaceous particulate matter from vehicles on the road. *Environ. Sci. Technol.*, 17, 31-44.

Pitts J.N., Jr., Van Cauwenberghe K.A., Grosjean D., Schmid J.P., Fitz D.R., Belser W.L., Jr., Knudson G.B. and P.M. Hynds, 1978. Atmospheric reactions of polycyclic aromatic hydrocarbons: facile formation of mutagenic nitro derivatives. *Science*, 202, 515-519.

References for Chapter VI (continued)

Pitts J.N., Jr., Lokensgard D.M., Ripley P.S., Van Cauwenberghe K.A., Van Vaeck L., Shaffer S.D., Thill A.J. and W.L. Belser, Jr., 1980. "Atmospheric" epoxidation of benzo[a]pyrene by ozone: formation of the metabolite benzo[a]pyrene-4,5-oxide. *Science,* 210, 1347-1349.

Pitts J.N., Jr., Atkinson R., Sweetman J.A. and B. Zielinska, 1985a. The gas-phase reaction of naphthalene with N O to form nitronaphthalenes. *Atmos. Environ.*, 19, 701-705.

Pitts J.N., Jr., Sweetman J.A., Zielinska B., Winer A.M. and R. Atkinson, 1985b. Determination of 2-nitrofluoranthene and 2-nitropyrene in ambient particulate matter: Evidence for atmospheric reaction. *Atmos. Environ.*, 19, 1601-1608.

Prinn R., Cummold D., Rassmussen R., Simmonds P., Alyea F., Crawford A., Fraser P. and R. Rosen, 1987. Atmospheric trends in methylchloroform and the global average for the hydroxyl radical. *Science*, 238, 945-950.

Ramdahl T., Zielinska B., Arey J., Atkinson R., Winer A.M. and J.N. Pitts, Jr., 1986. Ubiquitous occurrence of 2-nitrofluoranthene and 2-nitropyrene in air. *Nature*, 321, 425-427.

Sweetman J.A., Zielinska B., Atkinson R., Ramdahl T., Winer A.M. and J.N. Pitts, Jr., 1986. A possible formation pathway for the 2-nitrofluoranthene observed in ambient particulate organic matter. *Atmos. Environ.*, 20, 235-238.

Valerio F., Antolini E. and A. Lazzarotto, 1987. A model to evaluate half- lives of PAHs naturally occurring on airborne particulate. *Intern. J. Environ. Anal. Chem.*, 28, 185-196.

Van Cauwenberghe K., Van Vaeck L., and J.N. Pitts, Jr., 1979. Physical and Chemical Transformations of Organic Pollutants During Aerosol Sampling. *Adv. Mass Spectrom.*, 8, 1499.

Yokley R.A., Garrison A.A., Wehry E.L. and G. Mamantov, 1986. Photochemical transformation of pyrene and benzo[a]pyrene vapor-deposited on eight coal stack ashes. *Environ. Sci. Technol.*, 20, 86-90.

Zielinska B., Arey J., Atkinson R. and P.A. McElroy, 1988. Nitration of acephenanthrylene under simulated atmospheric conditions and in solution and the presence of nitroacephenanthrylene(s) in ambient air. *Environ. Sci. Technol.*, 22, 1044-1048.

References for Chapter VI (continued)

Zielinska B., Arey J., Atkinson R. and P.A. McElroy, 1989a. Formation of methylnitronaphthalenes from the gas-phase reactions of 1- and 2-methylnaphthalene with OH radicals and N_2O_5 and their occurrence in ambient air. *Environ. Sci. Technol.*, 23, 723-729.

Zielinska B., Arey J., Atkinson R., and A.M. Winer, 1989b. The nitroarenes of molecular weight 247 in ambient particulate samples collected in Southern California. *Atmos. Environ.*, 23, 223-229.

APPENDIX A

SPECIES/SPECIES GROUPS IDENTIFIED OR TENTATIVELY IDENTIFIED IN DIESEL EXHAUST

Appendix A

Species/Species Groups Identified or Tentatively Identified in Diesel Exhaust

The substances below have either been detected in diesel exhaust or presumed to be in diesel exhaust based on observed chemical reactions and/or their presence in the fuel or lubricating oil. Further research is needed to estimate their contribution to diesel exhaust as a whole, and to diesel exhaust related atmospheric exposures.

Species/Species Groups Identified or Tentatively Identified in Diesel Exhaust

acenapthene (references: 1, 12)
acenaphthenequinone (11)
acenaphthylene (1, 4, 12)
acetaldehyde (1, 11)
acetone (11)
acetylene (11)
acrolein (1, 3, 4, 11)
aldehydes (11)
alkanes (3)
alkylanthraquinone (2)
alkylbenzenes (10)
alkyl-4H-cyclopenta[def]phenanthren-4-one isomers (6)
alkyl-9-fluorenones (2, 6)
alkyl-9-fluorenone isomers (6)
alkylnaphthaldehyde (2)
alkylnaphthaldehyde isomers (6)
alkylnaphthofuran carboxaldehyde (2)
C -alkylnitroanthracene isomer (6)
aluminum (7)
ammonia (4, 7, 11)
aniline (4)
anthanthrene (11)
anthracene (1, 4, 5, 6, 10, 12)
anthracene-x-aldehyde (11)
anthracene carboxaldehydes (5, 10)
anthracene-9-carboxaldehyde (2)
anthracene dicarboxylic acid anhydrides (10)
anthracene quinones (5, 10)
9,10-anthracenedione (13)
anthraldehyde isomer (6)

anthraquinone (2, 11)
9,10-anthraquinone (6)
anthrones(2, 5, 10)
antimony (7)
arsenic (1, 7)
barium (4, 7)
benzacenaphthylene (4)
benzacridines (4)
benzaldehyde (11)
benz[a]anthracene (1, 2, 4, 10, 11, 13)
benz[a]anthracene carboxaldehydes (10)
benz[a]anthracenedione (2)
benz[a]anthracene-7,12-dione (11)
7H-benz[de]anthracene-7-one (2, 11)
benz[de]anthracenone (2)
benzanthrone isomers (6, 10, 13)
7H-benz[de]anthrone-7-one (2, 11, 13)
benzene (1, 11)
benzo[c]cinnoline (12)
benzo[def]dibenzothiophene (4)
benzofluoranthene (12, 13)
benzo[b]fluoranthene (1, 4, 11)
benzo[ghi]fluoranthene (4, 10, 11, 12, 13)
benzo[j]fluoranthene (4)
benzo[k]fluoranthene (1, 4, 11)
benzofluorene isomer (6)
benzo[a]fluorene (4)
benzo[b]fluorene (4)
benzo[x]fluorene-y-one (11)
benzofluorenone (2)
benzo[a]fluorenone (2)
11-benzo[a]fluorenone (13)
benzoic acid (4)
benzonaphthothiophene (4)
benzo[b]naphtho[2,1-d]thiophene (4, 13)
benzo[b]naphtho[2,1-d]thiophene isomers (13)
benzo[ghi]perylene (1, 4, 11, 12)
benzo[c]phenanthrene (11)
1-benzopyran-2-one (12)
benzopyrenes (13)
benzopyrene ketones (2)
benzo[a]pyrene (1, 4, 8, 10, 11)
benzo[e]pyrene (4, 11)

benzo[xy]pyrene-z-one (11)
6H-benzo[cd]pyrenone isomers (6, 11)
benzo[cd]pyrenone (2)
6-H-benzo[cd]pyrene-6-one (11)
beryllium (1)
1,2-binaphthyl (4)
2,2-binaphthyl (4)
biphenyl (12)
biphenyl carboxaldehydes (5, 13)
biphenylene (12)
bis[ethylhexyl]phthalate isomer (6)
bromine (7)
1,3-butadiene (1, 3)
cadmium (1, 7)
calcium (7)
carbon dioxide (11)
carbon monoxide (1, 11)
carbonate ion (7)
chlorine (1, 7)
chlorobenzene (1)
chromium (1, 7)
chrysene (1, 4, 10, 11, 12, 13)
cobalt (7)
copper (1, 7)
coronene (4, 11)
cresols (4)
crotonaldehyde (11)
cyanides (11)
cyclopenta[cd]benzo[ghi]perylene (9)
cyclopenta[jk]naphtho[1,8,7-efg]pyrene (9)
cyclopentaphenanthrene-5-one (12)
4H-cyclopenta[def]phenanthrene (4)
4H-cyclopenta[def]phenanthren-4-one (2, 5, 6, 11)
cyclopenta[cd]pyrene (4, 9, 10, 11)
cyclopenteno[cd]pyrene (12)
dibenzacridines (4)
dibenz[a,c]anthracene (11)
dibenz[a,h]anthracene (1, 4, 11)
dibenz[a,j]anthracene (11)
dibenzofurans (12)
dibenzofuran carboxaldehydes (10)
dibenzopyrene or -[def,p]chrysene (4)
dibenzothiophene (4, 5, 13)

dibutyl phthalate (2)
2,3-dihydro-inden-1-one (12)
dihydroxyfluorenes (5)
1,3-dihydroxynitropyrene (4)
dihydroxyphenanthrenes (5)
dimethylanthracenes (4, 10)
dimethylanthracene carboxaldydes (1, 10)
dimethylanthrones (10)
dimethylbiphenyl (4)
1,9-dimethylfluorene (5)
dimethylfluorene quinones (10)
dimethylfluorenones (10)
dimethyhydroxyfluorene (10)
dimethylnaphthalene carboxaldehydes (10)
dimethylnaphthalene dicarboxylic acid anhydrides (10)
dimethylphenanthrene (4)
dimethylphenanthrenes (10)
dimethylphenanthrene carboxaldehydes (10)
dimethylphenanthrones (10)
4,4-dinitrobiphenyl (11)
2,5-dinitrofluorene (4)
2,7-dinitrofluorene (4)
2,7-dinitro-9-fluorenone (4)
dinitronaphthalene (4)
1,3-dinitropyrene (4)
1,6-dinitropyrene (4)
1,8-dinitropyrene (4)
dioxins (1)
elemental carbon (4, 7)
ethane (3, 11)
ethylbenzene (1)
ethyldibenzothiophene (4)
ethylene (3, 11)
ethylmethylphenanthrene (4)
2- or 9-ethylphenanthrene (4)
fluoranthene (1, 4, 5, 10, 11, 12, 13)
fluoranthene carboxaldehydes (10, 13)
fluoranthene quinones (10)
fluoranthones (10)
fluorene (1, 4, 5, 12)
fluorene carboxaldehydes (10)
fluorene quinones (5, 10, 12)
fluorenones (10, 13)

9-fluorenone (2, 11, 12)
fluoren-9-one (5)
9-fluorenone isomers (6)
formaldehyde (1, 11)
formic acid (4)
furans (1)
gallium (7)
heptane (3)
hexane (1, 3)
hexanaldehyde (11)
hydrogen (11)
hydrogen chloride (1)
hydrogen cyanide (11)
hydrogen sulfide (11)
hydroxyanthracenes (10)
hydroxychrysene/triphenylene (2)
hydroxydimethylanthracenes (10)
hydroxydimehtylphenanthrenes (10)
hydroxyfluoranthene (2)
hydroxyfluorene (10)
hydroxyfluorenone (10)
hydroxymethylanthracenes (10)
hydroxymethylphenanthrenes (10)
hydroxyphenanthrenes (5, 10)
hydroxypyrene (2)
hydroxyxanthene (10)
hydroxyxanthone (10)
indeno[1,2,3-cd]pyrene (1, 4, 11)
indium (7)
iron (4, 7, 11)
isobutyraldehyde (11)
lanthanum (7)
lead (1, 7)
manganese (1, 7, 11)
mercury (1, 7)
methane (3, 11)
methanol (4, 11)
methyl ethyl ketone (11)
methylanthracenes (10)
2-methylanthracene (4)
methylanthracene carboxaldehydes (2, 10)
methylanthracene-9-carboxaldehyde (2)
methylanthracene quinones (10)

methyl-9,10-anthracenedione (13)
methylanthraldehyde isomer (6)
methylanthraquinone (2)
x-methylanthraquinone (11)
methylanthrones (10)
methylbenz[a]anthracene (4)
7-methylbenzofuran (12)
methylbiphenyl carboxaldehydes (13)
9-methylcarbazole (4)
3-methylchrysene (4)
methyl-4H-cyclopenta[def]phenanthren-4-one isomer (6)
x-methyl-4-H-cyclopenta[def]phenanthrene-4-one (11)
methyldibenzothiophene (4)
methylfluoranthenes (4, 10, 13)
methylfluorenes (13)
9-methylfluorene (5)
methylfluorene carboxaldehydes (10)
methylfluorene quinones (10)
methylfluorenones (10, 13)
2-methylfluorenone (13)
methyl-9-fluorenone (2, 12)
methyl-9-fluorenone isomers (6, 11)
methylhydroxyfluorene (10)
methylnaphthaldehyde (2, 13)
methylnaphthaldehyde isomers (6)
6-methyl-2-naphthaldehyde (13)
methylnapthalene (12)
methylnaphthalene dicarboxylic acid anhydrides (10)
methylnitroanthracene isomer (6)
methylnitrofluoranthenes (10)
x-methyl-9-nitroanthracene (11)
x-methyl-1-nitronaphthalene (4)
methylnitropyrenes (6, 10)
methylphenanthrenes (10)
1-methylphenanthrene (5, 13)
2-methylphenanthrene (4, 5, 13)
3-methylphenanthrene (4, 13)
4-methylphenanthrene (13)
9-methylphenanthrene (5, 13)
methylphenanthrene carboxaldehydes (2, 10, 13)
methylphenanthrene-9-carboxaldehyde (2)
methylphenanthrene quinones (2, 10)
methylphenanthrones (10)

methylphenylnapthalenes (13)
methylpyrenes (4, 10, 12, 13)
1-methylpyrene (4)
methylthioxanthones (10)
methylxanthones (10)
molybdenum (7)
1-napthaldehyde (13)
2-napthaldehyde (13)
napthaldehyde isomers (6)
naphthalene (1, 5, 12)
naphthalene carboxaldehydes (5)
naphthalene dicarboxaldehydes (10)
naphthalene dicarboxylic acids (5)
1,8-naphthalene dicarboxylic acid (11)
naphthalene dicarboxylic acid anhydrides (5, 10)
naphthoic acid (4)
1-naphthol (4)
2-naphthol (4)
naphtho[1,8-cd]pyrene 1,3-dione (10, 12)
nickel (1, 7)
nitrates (7)
nitric acid (4)
nitric oxide (4)
nitro-PAHs (2)
1-nitro-3-acetoxypyrene (4)
nitroanthracenes (6, 10)
nitroanthracene isomer (6)
9-nitroanthracene (4, 8)
2-nitroanthracene (4)
(1 or 3)-nitrobenzo[a]pyrene (8)
(3 or 1)-nitrobenzo[a]pyrene (8)
6-nitrobenzo[a]pyrene (4, 8, 11)
x-nitrobenzoquinoline (4)
2-nitrobiphenyl (4)
3-nitrobiphenyl (4)
4-nitrobiphenyl (4)
1-nitrochrysene (4)
nitrochrysene isomer (6)
x-nitrodibenzothiophene isomers (4)
x-nitro-y,z-dimethylanthracene (4)
nitrofluoranthenes (10, 13)
nitrofluoranthene isomers (6)
1-nitrofluoranthene (4)

3-nitrofluoranthene (4, 11)
7-nitrofluoranthene (4)
8-nitrofluoranthene (4)
nitrofluorenes (10)
2-nitrofluorene (4, 11)
2-nitro-9-fluorene (4)
3-nitro-9-fluorene (4)
nitrogen (1, 11)
nitrogen oxides (1, 4, 11)
1-nitro-3-hydroxypyrene (4)
9-nitro-1-methylanthracene (4)
10-nitro-1-methylanthracene (4)
10-nitro-9-methylanthracene (4)
x-nitro-y-methylanthracene (4)
1-nitro-2-methylnaphthalene (4)
3-nitro-1-methylpyrene (4)
6-nitro-1-methylpyrene (4)
8-nitro-1-methylpyrene (4)
1-nitronaphthalene (4)
2-nitronaphthalene (4)
3-nitro-1,8-naphthalic acid anhydride (4)
2-nitrophenanthrene (4)
nitrophenanthrenes (6, 10)
nitropyrenes (5, 6, 10, 12, 13)
1-nitropyrene (4, 8, 11)
5-nitroquinoline (4)
8-nitroquinoline (4)
x-nitroterphenyl (4)
x-nitro-y,z,z'-trimethylanthracene [6 isomers] (4)
x-nitrotrimethylnaphthalene [3 isomers] (4)
nitrous acid (4)
octane (3)
organic Carbon (7)
4-oxapyrene-5-one(I) (8)
oxygen (11)
oxy-PAHs (2, 5)
PAHs (1, 2, 4, 5, 9, 10, 11)
PAH derivatives (2, 4, 5, 11)
PAH anhydrides (4, 5)
PAH carboxaldehydes (4, 5)
PAH coumarin (11)
PAH epoxides (2)
PAH esters (4)

PAH ketones (4, 5, 10)
PAH quinones (4)
PAH sulfonates (4)
palladium (7)
pentane (3)
perylene (11, 13)
1-H-phenalene-1-one (11)
phenanthrenes (1, 4, 5, 6, 7, 12, 13)
phenanthrene-x-aldehyde (11)
phenanthrene carboxaldehydes (5, 10, 13)
phenanthrene-9-carboxaldehyde (2)
2-phenanthrene carboxaldehyde (13)
phenanthrene dicarboxylic acid anhydrides (10)
phenanthrene quinones (5, 10, 12)
phenanthrene-9,10-quinone (11)
phenanthroic acid (4)
phenanthrones (2, 5, 10)
5H-phenanthro[4,5-bcd]pyran-5-one (8)
phenol (4, 11)
phenylbenzaldehyde isomers (6)
phenylnaphthalene (5, 13)
2-phenylnaphthalene (4)
1-phenylphenanthrene (4)
9-phenylphenanthrene (4)
phenylphenanthrene or -anthracene (4)
phosphorus (1, 7)
phthalate (11)
phthalate Anhydride (12)
phthalic acid (4)
platinum (4, 11)
POM [Polycyclic Organic Matter] (8)
potassium (7)
propane (1, 3)
propionaldehyde (11)
propylene (3)
pyrene (1, 4, 5, 6, 10, 11, 12, 13)
pyrene carboxaldehydes (10, 13)
1,12-pyrenedicarboxylic acid anhydride (11)
pyrene-3,4-dicarboxylic acid anhydride (2, 9)
pyrene quinones (10)
pyridine (4)
pyrones (10)
quercetin (8)

rhodium (11)
rubidium (7)
selenium (1, 7)
silicon (7)
siloxane (6)
silver (7)
sodium (7)
strontium (7)
styrene (3)
sulfates (7, 11)
sulfur (1, 7, 11)
sulfur dioxide (11)
sulfuric acid (4)
n-tetradecane (12)
tetramethylnaphthalene (4)
thioxanthen-9-one (5)
9H-thioxanthen-9-one (2)
thioxanthones (10)
tin (7)
titanium (7)
toluene (1, 11)
trimethylbiphenyl (4)
2,2,4-trimethyl-1,3-diol diisobutyrate (6)
trimethylnaphthalene (4)
trimethylnaphthalene carboxaldehydes (10)
2,4,7-trinitro-9-fluorenone (4)
triphenylene carboxaldehydes (10)
vanadium (7)
water vapor (11)
xanthene carboxaldehydes (10)
xanthen-9-one (5)
9H-xanthen-9-one (2)
xanthones (10)
xylenes (1)
yttrium (7)
zinc (1, 4, 7)
zirconium (7)

The following resources were used to develop this list:

1. ARB, 1993. Emissions profile information received under the AB 2588 Toxics Hot Spots reporting program, including information from the Ventura County Air Pollution Control District (1991), the Naval Energy and Environmental Support Activity (1982), and the

Halliburton Equipment Yard (1992).

2. Choudhury, D. R., 1982. Characterization of Polycyclic Ketones and Quinones in Diesel Emission Particulates by Gas Chromatography/Mass Spectrometry. Environmental Science and Technology, 16, pp. 102-106.

3. Diesel Exhaust Conference, March 19-20, 1990. Risk Assessment of Diesel Exhaust: 1990 and Beyond. Sponsored by Air Resources Board. Los Angeles, CA.

4. International Agency for Research on Cancer, 1989. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Diesel and Gasoline Engine Exhausts and Some Nitroarenes, Monograph 46, pp. 41-57.

5. Jensen, T. E., 1983. Aromatic Diesel Emissions as a Function of Engine Conditions. Analytical Chemistry, 55, pp. 594-599.

6. Newton, D. L., Erickson, M. D., Tomer, K. B., Pellizzari, E. D., and P. Gentry, 1982. Identification of Nitroaromatics in Diesel Exhaust Particulate Using Gas Chromatography/Negative Ion Chemical Ionization Mass Spectrometry and Other Techniques. Environmental Science and Technology, 16, pp. 206-213.

7. Omni Environmental Services Inc., 1989. Identification of Particulate Matter Species Profile. ARB Speciation Manual, June 30, V. 2, Table 3: PM Species Profile.

8. Pitts, J. N., Jr., Lokensgard, D. M., Harger, W., Fisher T. S., Mejia, V., Schuler, J. J., Scorziell, G. M., and Y. A. Kartzenstein, 1982. Mutagens in Diesel Exhaust Particulate. Identification and Direct Activities of 6-Nitrobenzo[a]pyrene, 9-Nitroanthracene, 1-Nitropyrene and 5H-Phenanthro[4,5-bcd]pyran-5-one. Muta. Research, 103, pp. 241- 249.

9. Rappaport, S. M., Wang, Y. Y., Wei, E. T., Sawyer, R., Watkins, B. E., and H. Rapoport, 1980. Isolation and Identification of a Direct-Acting Mutagen in Diesel-Exhaust Particulates. Environmental Science and Technology, 14, pp. 1505-1509.

10. Schuetzle, D., 1983. Sampling of Vehicle Emission for Chemical Analysis and Biological Testing. Environmental Health Perspective, 47, pp. 65-80.

11. Volkswagen, 1989. Unregulated Motor Vehicle Exhaust Gas Components. Volkswagen AG, Research and Development (Physico-Chemical Metrology). Project Coordinator: Dr. K. H. Lies. 3180 Wolfsburg 1, F. R. Germany.

12. Yergey, J. A., Risbey, T. H., and S. S. Lestz, 1982. Chemical Characterization of Organic Adsorbates on Diesel Particulate Matter. Analytical Chemistry, 54, pp. 354-357.

13. Yu, M., and R.A. Hites, 1981. Identification of Organic Compounds on Diesel Engine Soot. Analytical Chemistry, 53, pp. 951-954.

APPENDIX B

THE ARB STAFF'S METHODOLOGY FOR DETERMINING DIESEL EXHAUST CONCENTRATIONS IN CALIFORNIA'S AMBIENT AIR

ESTIMATE OF AMBIENT PM_{10} CONCENTRATIONS

FROM

DIRECTLY EMITTED EMISSIONS FROM DIESEL ENGINES

(REVISED 3/97)
(REVISED 7/96)
(REVISED 11/93)

Prepared by:

Modeling Support Section
Technical Support Division

March 19, 1997

State of California
Air Resources Board

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

APPENDICES

ACKNOWLEDGEMENT

This report, "Estimate of Ambient PM_{10} Concentrations from Directly Emitted Emissions from Diesel Engines (Revised 3/97)," was prepared by Anthony Servin, Associate Air Resources Engineer, under the general direction of Andrew Ranzieri, Manager of the Modeling Support Section, Technical Support Division.

I. INTRODUCTION

As part of the Toxic Air Contaminant Identification process, the Stationary Source Division requested the Technical Support Division to estimate the ambient PM_{10} concentration throughout the state due to the emissions from diesel exhaust. This analysis is part of the effort to evaluate diesel exhaust as a potential toxic air contaminant.

The results in this report are a first order estimate of the PM_{10} concentrations attributed to emissions from diesel exhaust. The estimates are the result of assumptions based on the best available data.

In this report, the ambient PM_{10} concentrations due to emissions from diesel exhaust are simply referred to as diesel exhaust PM_{10} concentrations. In each instance when the diesel exhaust PM_{10} concentration is referenced, the concentration is an annual average unless otherwise indicated. In addition, the units of measurement for the ambient concentration, micrograms per cubic meter, are abbreviated as $\mu g/m^3$.

This document was initially released in draft form, November 8, 1993, and subsequently for public comment in June 1994, as part of the toxic air contaminant identification process. As a result of public comments received, we have modified our approach to estimate state-wide ambient PM_{10} concentrations due to emissions from diesel exhaust. This report is an enhanced version of the document, written November 8, 1993, which includes a modified approach and results. Briefly, the changes to the document are as follows:

1) The 1990 base year motor vehicle emission estimates are based on the California Air Resources Board (CARB) EMFAC7G emissions model. Previously the motor vehicle emission estimates were based on the CARB EMFAC7E emissions model.

2) The 1990 base year stationary, area, and off road mobile source emissions are based on an inventory query of January 19, 1995. The development of an emission inventory is a dynamic process as other data become available. Therefore, emissions for the base year of 1990 queried at different dates may produce different results.

3) Chemical mass balance modeling results from the San Joaquin Valley, South Coast, and San Jose areas are used in this analysis. Previously, chemical mass balance results from the San Joaquin Valley alone were used. The results of a chemical mass balance model on speciated ambient PM_{10} data include the source apportionment to motor vehicle emissions.

4) Secondary PM_{10} are more closely evaluated. Previously, it was assumed that the rate of formation of secondary PM_{10} is the same as in the San Joaquin Valley. Currently, all analysis of PM_{10} due to diesel exhaust emissions are based on PM_{10} measurements which exclude secondary formations.

5) Microscale samplers are omitted from the analysis. Previously, all data collected from the state-wide ambient PM_{10} monitoring network were used in the analysis. Currently, those samplers which are identified as the microscale samplers are omitted from the analysis. Microscale samplers are designed to represent a spatial scale of several meters up to 100 meters. The monitoring objective of microscale samplers is to measure the highest concentrations or source impact.

6) Interpolation of the PM_{10} data is done on a once-in-every-six-day schedule. Previously, only the annual average PM_{10} data were evaluated for PM_{10} due to diesel exhaust emissions. As part of the micro-environment evaluation, it is necessary to determine the distribution of the annual data. Therefore the PM_{10} data are analyzed with every 24-hour measurement at a frequency sampling of every six days.

7) The ambient PM_{10} data from 1988 through 1992 are evaluated to obtain a 5-year average representing the 1990 base year. Previously data from 1987 through 1991 were used. More recent ambient data are available but are not used for a couple of reasons. The special studies (chemical mass balance analyses) are based on data collected spanning the years from 1986 through 1993 and more recent ambient data would not be representative of the data collected for the San Joaquin Valley and South Coast studies. The second reason is that the base year for our analysis is 1990 as supported by the 1990 emission inventory.

8) This analysis includes estimates for the newly designated Mojave Desert and Salton Sea Air Basins. Previously this terrain was included in the former Southeast Desert Air Basin. In addition, a variation in the South Coast Air Basin boundary is made to include ambient data collected at the Banning station.

9) The population distribution is based on the 1990 census data. Previously, the population distribution was based on the 1980 census data extrapolated to represent the 1990 census data.

10) Upper bound estimates based on PM_{10} emissions from diesel exhaust, which may be within the entrained road dust, are omitted. Previously an estimate was made for this subset of entrained road dust. The technical justification to calculate these upper bound estimates are limited.

The results from the new analyses are lower estimates of annual diesel exhaust PM_{10} concentrations.[1]

---

[1]An effort to retain and present results from our previous document, written November 8, 1993, for comparison purposes are not made. Where appropriate, the results and assumptions of our previous document are simply omitted.

II. BACKGROUND

A. Historical Modeling Approaches

The modeling of PM_{10} is still in being developed. No single approach can adequately treat all aspects of the PM_{10} problem, which include primary sources and secondary formations. Potential techniques for modeling annual concentrations of primary sources of PM_{10}, such as the case for diesel exhaust PM_{10}, are linear rollback modeling and receptor modeling.

Linear rollback modeling techniques are the most basic of all the methods. Linear rollback techniques are used to estimate the projected ambient concentrations of primary sources with respect to the base year emissions inventory. The only data requirement is an accurate emissions inventory for the base year. A one-to-one correspondence between county-wide emissions and source contributions at a given site is assumed.

Receptor modeling techniques provide a means to address source apportionment of primary PM_{10} on a site-by-site basis, and also provide upper bound estimates of the total contribution from secondary components. Receptor modeling techniques may be used wherever speciated ambient data and source profiles are available.

B. United States Environmental Protection Agency Recommended Approach

The United States Environmental Protection Agency has published limited guidance on modeling for PM_{10}. The current recommended methods include the use of a receptor model in conjunction with a dispersion model, or using two receptor modeling techniques such as the chemical mass balance model and principal components analysis. These approaches function well in areas with a limited number of sources of directly emitted PM_{10}.

C. Staff Approach to Estimate Diesel Exhaust PM_{10}

Given the available database, it is our opinion that receptor modeling is the best technique for evaluating ambient levels of diesel exhaust PM_{10} emissions. Receptor modeling techniques, which include chemical mass balance model results, to estimate diesel exhaust concentrations are used. (The technique is further described in this report.) It provides a means to apportion sources of primary PM_{10} on a site-by-site basis, and it is used to estimate population-weighted annual averaged concentrations statewide. The data requirements include speciated ambient data and source profiles. Special studies have been conducted by various scientist on speciated ambient data collected in the San Joaquin Valley (SJV) (1988-89), South Coast (SC) (1986), and San Jose (winters of 1991-1992 and 1992-1993). Making use of the special studies and the ambient PM_{10} monitoring network, the receptor model is used to estimate statewide concentrations of diesel exhaust PM_{10}.

D. Sources of Data

The following six sources of data are used to perform the analysis.

1) The Desert Research Institute San Joaquin Valley Air Quality Study Phase 2: PM-10 Modeling and Analysis Volume I: Receptor Modeling Source Apportionment, Chow, J. C., October 1990, is the kernel for our analysis. The study presents PM_{10} concentrations from primary motor vehicle emissions based on ambient data collect in 1988-89 for the San Joaquin Valley. The chemical mass balance model was used to determine the source apportionment. For simplicity, this study is referred to as the DRI SJV PM_{10} Analysis in this report.

2) The South Coast Air Quality Management District Air Quality Management Plan 1991 Revision, Technical Report V-F, PM_{10} Source Apportionment for the South Coast Air Basin, July 1991, include ambient primary PM_{10} concentrations due to motor vehicles

based on ambient data collected in 1986. Also included in this report is a special study on PM_{10} data gathered in Indio and Palm Springs during 1988-1989. The chemical mass balance model was used to determine source apportionment. Results from this study are used for estimating diesel exhaust PM_{10} in the South Coast and the Salton Sea Air Basins. For simplicity, this report is referred to as the SC PM_{10} Study.

3) The "Source Apportionment of Wintertime PM_{10} at San Jose, CA," May 18, 1994, Chow, J. C., prepared by the Desert Research Institute and the Bay Area Air Quality Management District, include ambient PM_{10} concentrations due to motor vehicles. The chemical mass balance model was used on ambient data collected in the winter of 1991-92. These results are used for estimating diesel exhaust PM_{10} in the San Francisco Bay Area (SFBA) Air Basin. For simplicity, this study is referred to as the San Jose PM_{10} Study.

4) The California Air Resources Board 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis is the result of a special request for this study. Included in the report are the 1990 PM_{10} emissions from the combustion of petroleum-based fuels in the SJV, from diesel exhaust for each air basin, and PM_{10} emissions from all sources for each air basin. The motor vehicle emissions are based on CARB's EMFAC7G emissions model. Also included are PM_{10} emissions for the years 1995, 2000, and 2010. The report is used to scale the PM_{10} concentrations attributed to primary motor vehicle emissions, calculated in the chemical mass balance analysis of the special studies above, to diesel exhaust PM_{10} concentrations in the SJV, SC, and San Jose. The 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis is also used to estimate the diesel exhaust PM_{10} concentrations in other air basins as well as to estimate future year concentrations.

5) The California Air Resources Board California Air Quality Data Summary of 1988 Air Quality Data Gaseous & Particulate Pollutants, Annual Summary and the reports for 1989 through 1992 are used to provide the total annual ambient PM_{10} concentrations statewide

which are used to estimate the diesel exhaust PM_{10} concentrations. For simplicity, these annual summaries are referred to as the Blue Sky Report for our analysis.

6) The 1990 census data are used to calculate a composite population-weighted annual average diesel exhaust PM_{10} concentration from estimates made with the above sources.

Another possible source of data is from Santa Barbara (1989). The "Sources and Chemistry of PM_{10} Aerosol in Santa Barbara County, CA, 1994," Chow, J. C., results are for a chemical mass balance analysis on data collected in 1989. The study results include PM_{10} concentrations from motor vehicle emissions. As indicated by Systems Applications International (SAI) (1994), the study does not include a source profile for wood burning and hence all ambient carbon was apportioned to the motor vehicle profile. This assumption will tend to overestimate motor vehicle concentrations. Therefore results from this study are not used in our analysis.

E. Assumptions

With the sources of data outlined above, a number of assumptions were made to proceed with the analysis. The results of our analysis may not represent actual ambient conditions because the estimated diesel exhaust PM_{10} concentrations may be biased by some of the assumptions in the modeling approach.

As noted above, the receptor modeling approach is used to evaluate annual average ambient diesel exhaust PM_{10} concentrations in air basins where chemical mass balance analyses results are available, the San Joaquin Valley, South Coast, Salton Sea, and San Francisco Bay Area Air Basins. The approach used for the SJV is extrapolated to the remaining air basins. The chemical mass balance model results from each of the studies are used to determine the source apportionment of speciated PM_{10} samples gathered in various locations in each of the three studies. In those reports, PM_{10} concentrations are apportioned to primary motor vehicle emissions.

It is assumed that the primary ambient PM_{10} concentrations due to diesel exhaust emissions are a subset of the PM_{10} concentrations apportioned as a result of primary motor vehicle emissions. The diesel exhaust concentration subset may be estimated based upon the emissions inventory.

Based upon these assumptions, the PM_{10} emission inventory of petroleum-based fuel combustion are used to linearly scale the PM_{10} concentrations attributed to primary motor vehicle emissions to represent PM_{10} concentrations due to emissions from diesel exhaust.

It is further assumed that the locations of the sampling sites in the DRI SJV PM_{10} Analysis can be characterized as rural or urban. A strict definition of rural and urban is not quantitatively defined. The location of a sampling site is classified as rural or urban based upon judgment. Crows Landing, Kern Refuge, and Fellows are classified as rural, while Stockton, Fresno, and Bakersfield are classified as urban.

The rural or urban characterization of the PM_{10} sampling location of the DRI SJV PM_{10} Analysis may be extrapolated to other locations listed in the Blue Sky Report. Based upon the relationship of diesel exhaust PM_{10} concentrations to the primary PM_{10} concentrations in rural or urban settings of the DRI SJV PM_{10} Analysis, the diesel exhaust PM_{10} concentrations are estimated from the primary PM_{10} concentrations retrieved from the Blue Sky Report.

The diesel exhaust PM_{10} concentrations, estimated from the Blue Sky Report, for 1988 through 1992, are used to interpolate concentrations in a uniform grid of receptors throughout an air basin. A distributed population field based upon census data is overlayed on the grid to determine a population-weighted average concentration for the air basin.

To estimate the diesel exhaust PM_{10} concentrations in other air basins that lack speciated ambient PM_{10} data, further assumptions are made. First it is assumed that the ratio of diesel exhaust PM_{10} concentration to the primary PM_{10} concentrations in the DRI SJV PM_{10} Analysis

can be extrapolated to other air basins. Secondly, to account for air basins which may have more or less diesel exhaust emissions relative to the SJV, it is assumed that the emission inventory of diesel exhaust and the primary PM_{10} for the air basins may be used to linearly scale estimated diesel exhaust PM_{10} concentrations with respect to the SJV.

III. ESTIMATING THE POPULATION-WEIGHTED AVERAGE AMBIENT DIESEL EXHAUST PM_{10} CONCENTRATION IN THE SAN JOAQUIN VALLEY

A. Method

As reported in the DRI SJV PM_{10} Analysis, speciated ambient PM_{10} measurements were collected for one year as part of the San Joaquin Valley Air Quality Study. PM_{10} samples were obtained at six sites in the SJV from June 9, 1988 through June 4, 1989, sampling every sixth day. The sites were selected to represent different portions of the San Joaquin Valley and different types of emission sources. The sites in Stockton, Fresno, and Bakersfield represent urban areas in the northern, central, and southern portions of the SJV. Samples at Crows Landing and Kern Wildlife Refuge represented non-urban particulate concentrations in the northern and southern portions of the SJV. Samples obtained at Fellows, in the midst of the west-side oil fields of Kern County, were intended to measure the effects of the oil extraction industry on PM_{10}.

The DRI SJV PM_{10} Analysis identified PM_{10} sources in nine different categories: 1) primary geological, 2) primary motor vehicle, 3) primary vegetative burning, 4) primary crude oil, 5) primary construction, 6) secondary ammonium sulfate, 7) secondary ammonium nitrate, 8) sodium chloride and sodium nitrate, and 9) secondary organic carbon. Even though all categories have some influence on this analysis, the category of most importance is the primary motor vehicle category.

Figures 1A and 1B show a schematic depiction of the procedure used to determine the PM_{10} mass fraction of an ambient air sample which is attributed to emissions from the exhaust of diesel engines. The ambient PM_{10} sample collected in a special study, Figure 1A, is speciated and then the motor vehicle fraction is apportioned (this is the chemical mass balance analysis). Next the diesel exhaust is evaluated as a subset of the motor vehicle category, which is similar

to the emission inventory (the last half of Figure 1A). In Figure 1B, the diesel exhaust mass from an ambient air sample is estimated, similar to the diesel exhaust mass in the special study air sample. Details on the specific procedures follow.

Figure 1A

Procedure for Estimating Ambient Diesel Exhaust PM_{10}

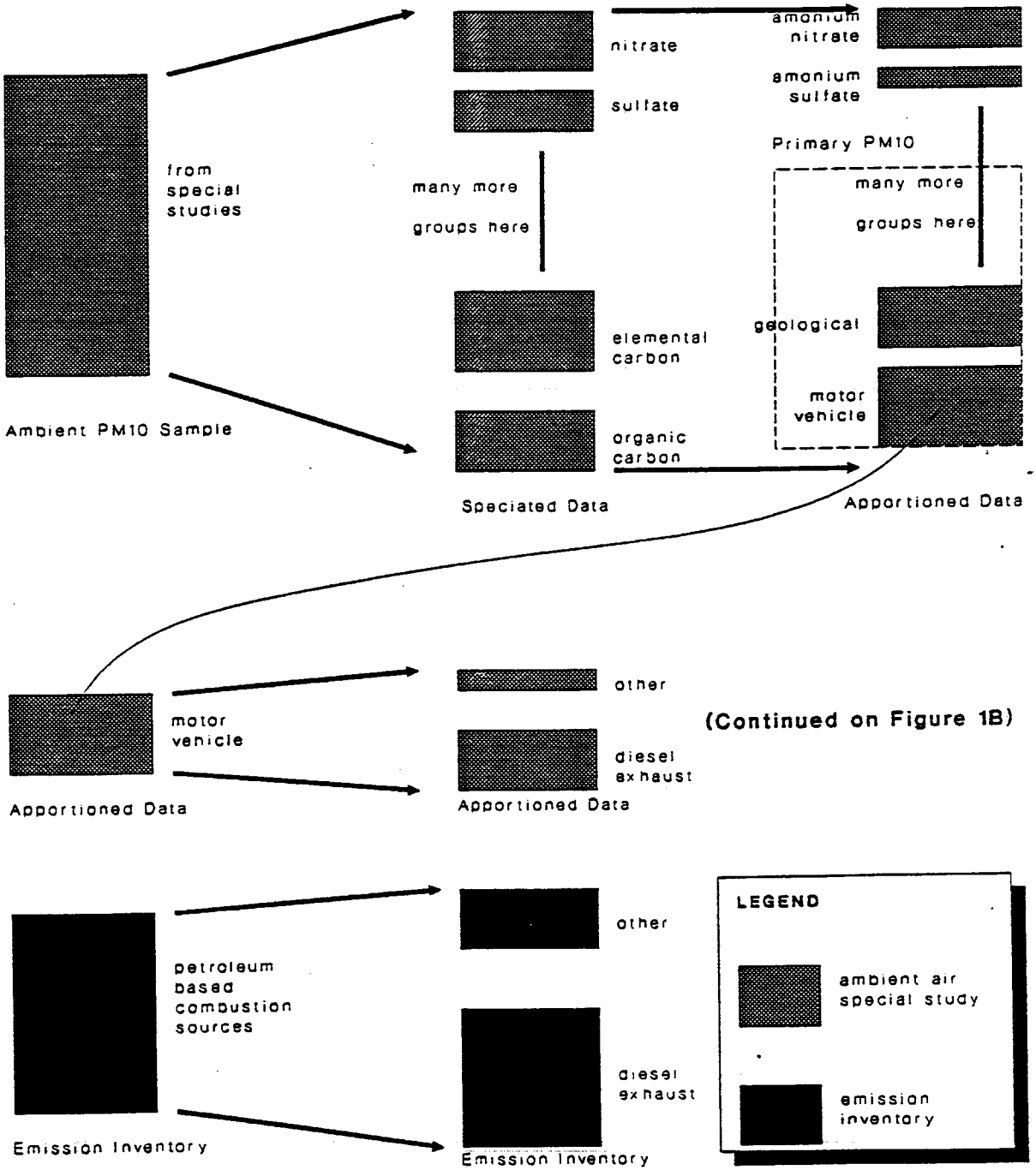
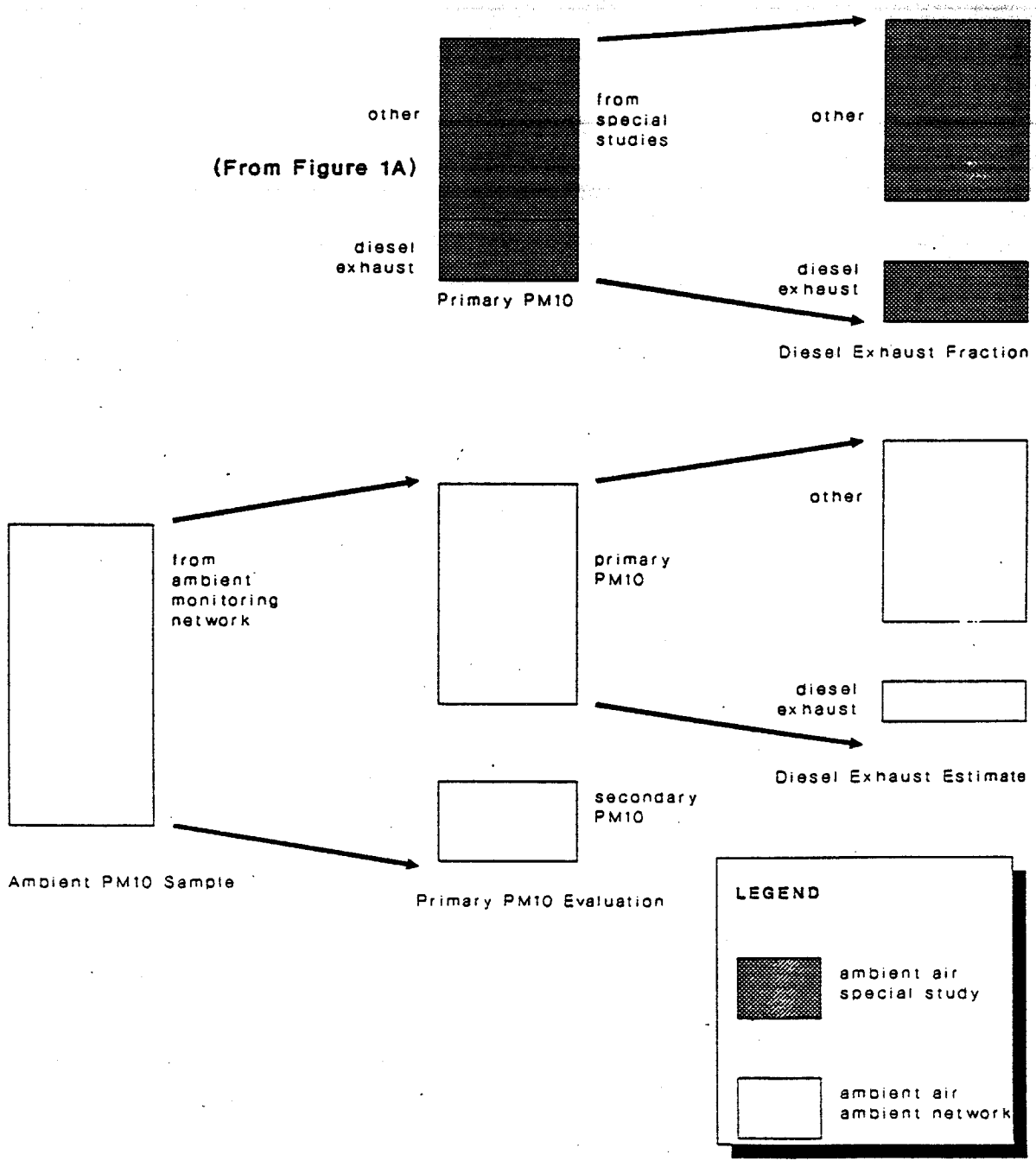


Figure 1B

Procedure for Estimating Ambient Diesel Exhaust PM_{10} (continued)



1. PM_{10} Emissions from Diesel Exhaust

The primary motor vehicle category is further defined in the DRI SJV PM_{10} Analysis as diesel and spark-ignition motor vehicles. Specifically, the chemical profile that characterizes the category is obtained for motor vehicle emissions from the South Coast Air Basin. For this study, PM_{10} concentrations of emissions from diesel exhaust are assumed to be a subset of the primary motor vehicle category.

The 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis provides PM_{10} emissions from petroleum-based fuel combustion, PM_{10} emissions from diesel exhaust, and total PM_{10} emissions for the San Joaquin Valley. This emission inventory for the San Joaquin Valley is used to estimate the subset of the "primary motor vehicle" category which is attributed to diesel exhaust emissions.

2. PM_{10} Emissions from Re-entrained Diesel Exhaust in Road Dust

Re-entrained road dust may also contain diesel exhaust emissions, which are included in the primary geological category of the DRI SJV PM_{10} Analysis. Re-entrained road dust is considered separately from the primary motor vehicle category. The primary geological category of the DRI SJV PM_{10} Analysis is based on the chemical profile of road dust. The chemical profile of Fresno road dust shows 2.69% elemental carbon, and for Taft unpaved road dust, it is 0.07% elemental carbon as per the DRI SJV PM_{10} Analysis.

Some of the elemental carbon in road dust is due to diesel exhaust. However, to continue this evaluation of entrained road dust requires in depth analysis with limited data. The error in the results are difficult to quantify. This analysis was carried out in our November 8, 1993 draft. However, this analysis is not carried out for this revision, and the estimated population-weighted diesel exhaust PM_{10} concentrations do not include any estimates for diesel exhaust as a subset of road dust.

3. Estimation of Diesel Exhaust PM_{10} Concentrations from the Blue Sky Report

The diesel exhaust PM_{10} concentrations are estimated from the ambient PM_{10} concentrations in the Blue Sky Report. This is done because the ambient monitoring network is larger than the DRI SJV PM_{10} Analysis network, twenty-two sites verses six sites, respectively. This provides superior coverage of the population database.

The Blue Sky Report monitoring sites are identified as an urban or rural area and located in the northern, central, or southern SJV. Therefore, it is assumed that data collected at a monitoring site located in an urban area in the northern SJV is similar to the data collected at a monitoring site of the DRI SJV PM_{10} Analysis located in Stockton. Detailed calculations will follow in section III. B.

4. Interpolation Algorithms

Drawing from the Blue Sky Report, diesel exhaust PM_{10} concentrations at various discrete locations are estimated. Using these as reference points, a spatial distribution of diesel exhaust PM_{10} concentrations is interpolated for the receptor field domain. The receptor field domain is defined as the geographical area of interest and is divided into equally spaced grid cells. A computer program is used to map the interpolated concentrations on a gridded domain using an inverse distance (1/R) interpolation algorithm.

The computer program interpolates concentrations between the measured discrete concentrations for all grid cells defined in the domain. The farther a cell is from a monitoring location, the less influence that monitoring location will have on the interpolated cell concentration. For grid cells distant from all monitoring locations, the interpolated cell concentration approaches the arithmetic mean of all measured discrete concentrations within the search radius. Concentrations are not computed for a cell if a monitoring location does not exist

within the search radius. The search radius is a user-defined distance to control the spatial range of interpolation. The weighting formula for this interpolation is given below:

$$weight=\frac{1}{d^n}, d \leq r,$$

$$weight=0, d>r.$$

where,

d: the distance from the grid cell to the monitoring location
n: the power factor
r: the user-defined search radius

If "d" is greater than the search radius, "r," then the measurement has no influence on the grid cell. If "d" is less than or equal to the search radius, "r," then the measurement influences the grid cell according to the weighting formula. The power factor "n" influences the strength of the weighting factor which is inversely proportional to the distance from the grid cell.

Typical values of "n" range from one to three. For this analysis, a value of two is used for "n." Air dispersion modeling of a single source typically requires a domain out to ten to fifty kilometers from the source. Therefore we arbitrarily select a search radius of thirty kilometers for the interpolation scheme. A sensitivity analysis for these two parameters, "n" and "r," are shown in the calculations to this report.

Barriers are placed in the domain when appropriate to prevent monitoring locations from influencing grid cells where a physical separation is evident. For example, mountain ridges over 1500 feet are input as barriers.

5. Population Distribution

The 1990 census data are used to obtain the population-weighted average ambient PM_{10} concentration from the spatial distribution of PM_{10} concentrations mapped over the domain. With the aid of a population distribution program, which combines census tract data with a specified domain and grid resolution, the 1990 population is mapped onto a grid matching the PM_{10} concentration domain. The distributed population grid is then superimposed on the interpolated concentration grid to compute a population-weighted average for the domain. The mathematical expression to calculate this parameter is given as:

$$C = \frac{\sum_{i=1}^{n} CiPi}{\sum_{i=1}^{n} Pi} \qquad (1)$$

where,

C: population-weighted average concentration,
C*i*: concentration for grid cell *i*, *i=1,2,3...n*,
P*i*: population for grid cell *i*, *i=1,2,3...n*,
n: the number of grid cells.

6. Future Estimates of Diesel Exhaust PM_{10} Concentrations

Linear rollback modeling is used to estimate the diesel exhaust PM_{10} concentrations for the years 1995, 2000, and 2010, based on the emission inventory. The method is similar for all air basins and is discussed in Section VIII. of this report.

B. Calculations

In this section, the calculations used to estimate ambient diesel exhaust PM_{10} concentrations for the entire SJV Air Basin are shown. Based on the following analysis, the population-weighted average concentration for diesel exhaust PM_{10} is estimated to be 2.6 $\mu g/m^3$ in the SJV.

Table III-1 shows measured ambient PM_{10} concentrations obtained from the DRI SJV PM_{10} Analysis which are used to calculate the directly emitted diesel exhaust PM_{10} for the SJV. Column one of Table III-1 is the sampling site and site identification number for the six sampling locations in the DRI SJV PM_{10} Analysis. Column two shows the number of samples used in the DRI SJV PM_{10} Analysis chemical mass balance analysis. Column three shows the measured total annual average PM_{10} concentration for each sampling site. Column four shows the calculated PM_{10} concentration for the primary motor vehicle category of the DRI SJV PM_{10} Analysis. Column five shows the estimated PM_{10} concentrations for the directly emitted diesel exhaust.

Columns three and four of Table III-1 are obtained directly from the DRI SJV PM_{10} Analysis. The values represent the seasonally stratified annual average concentrations for each respective category. The DRI SJV PM_{10} Analysis reports both the unweighted annual average and the seasonally stratified annual average concentrations. There are fewer measurements for the second quarter of 1989 than in the other quarters. Therefore to minimize any bias these unequal sampling numbers may have on an estimated annual average calculation, the seasonally stratified annual average concentrations, from the DRI SJV PM_{10} Analysis, are used in this analysis.

Table III-1
Ambient Annual Average PM_{10} Concentrations
June 1988 to June 1989, San Joaquin Valley,
Seasonally Stratified

(1) Sampling Site / Site ID No.	(2) Number of Samples	(3) Measured Total ($\mu g/m^3$)	(4) Primary Motor Vehicle ($\mu g/m^3$)	(5) Direct Diesel Exhaust ($\mu g/m^3$)
Stockton 3900252	49	59.37	4.85	2.79
Crows Landing 5000571	48	48.97	2.13	1.22
Fresno 1000234	49	68.87	6.53	3.75
Kern Refuge 1500205	50	45.92	2.18	1.25
Fellows 1501000	50	52.56	2.04	1.17
Bakersfield 1500203	48	77.34	7.40	4.26

Source: DRI SJV PM_{10} Analysis

(1) Sampling site identification.
(2) Number of samples obtained for period.
(3) Measured total mass from mass balance analysis.
(4) Calculated primary motor vehicle mass from mass balance analysis.
(5) Calculated direct diesel exhaust mass estimated as a subset of (4).

1. Calculations for Ambient PM_{10} Concentrations from Direct Diesel Exhaust Emissions in the San Joaquin Valley

The direct diesel exhaust PM_{10} concentration, column five, in Table III-1 is estimated by scaling the primary motor vehicle PM_{10} concentration, column four, by 0.575. This scale factor

is determined from the ratio of diesel exhaust PM_{10} inventory to the petroleum-based fuel sources PM_{10} inventory.

Table III-2 shows the inventory of PM_{10} emissions from the combustion of petroleum based fuels in the SJV, excluding crude oil combustion, based on the 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis, January 1995. Crude oil (residual oil) combustion in the SJV is speciated separately in the DRI SJV PM_{10} Analysis. Itemized in Table III-2 are the emissions from on-road motor vehicles burning diesel fuel, other internal combustion engines that burn numbers one and two distillate fuels, on-road motor vehicles that burn gasoline, and the combustion of other petroleum based fuels (excluding crude oil). Diesel exhaust emissions can be more generally described as emissions from internal combustion engines that use the heat of compression to ignite the fuel-air mixture. These engines generally burn numbers one and two fuel oil.

Table III-2
PM_{10} Emission Inventory
for Petroleum Based Fuels
in the San Joaquin Valley, 1990 Base Year

Emission Source	Emission (Tons per Year)
Motor Vehicle Diesel	3,567[a]
Other Distillate Fuels	1,639[b]
Motor Vehicle Gasoline	265[c]
Other Petroleum Based Fuels	3,588[d]
Total	9,059

Source: 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis

(a) On road motor vehicle diesel engines (EMFAC7G)
(b) Other engines combusting #1 and #2 distillate oil (1/19/95 EI query)
(c) On road motor vehicle gasoline engines (EMFAC7G)
(d) Other combustion of petroleum based fuels excluding crude oils (1/19/95 EI query)

To derive the 0.575 scaling factor, the numerator is 5,206 tons per year of PM_{10} emitted from engines burning numbers one and two fuel oil in the SJV Air Basin (5,206 = 3,567 + 1,639). The denominator becomes the emissions of all petroleum based fuels excluding crude oil, 9,059 tons per year. Therefore the diesel exhaust subset scaler is 0.575 (0.575 = 5,206 / 9,059).

2. Estimation of Diesel Exhaust PM_{10} Concentrations from the Blue Sky Report for the San Joaquin Valley

As discussed in section III. A. 3., diesel exhaust PM_{10} concentrations are estimated from the Blue Sky Report. The following section describes the calculations for estimating the diesel exhaust PM_{10} concentration.

Table III-3 shows the estimated diesel exhaust PM_{10} concentration for sites located in the SJV for the five-year average including 1988 - 1992. Table III-3 is estimated from data in the Blue Sky Report. Microscale samplers are omitted from the analysis. Microscale samplers are designed to represent a spatial scale of several meters up to 100 meters. The monitoring objective of microscale samplers is to measure the highest concentrations or impacts of nearby sources of emissions. This objective would bias our results toward overestimation. See Appendix A for a listing of all sample sites, including the ones that are omitted from the analysis.

As an example to derive the values in Table III-3, the detailed calculation for the data collected in 1990 for the sampling sites in Stockton and Modesto are used. A full summary of all calculations for all sites are included in Appendix A. It is assumed the composition of the data collected from the Blue Sky Report for the locations of Stockton and Modesto are similar to the data collected in the DRI SJV PM_{10} Analysis for Stockton, an urban northern SJV location. Thus, the mass fraction attributed to diesel exhaust is assumed to be similar.

Table III-3
Five Year Average, 1988 - 1992
Diesel Exhaust PM_{10} Concentration, San Joaquin Valley

Site	Site Number	Diesel Exhaust PM_{10} ($\mu g/m^3$)
Clovis-908 N	(1000248)	2.62
Five Points	(1000229)	1.29
Fresno-Cal St	(1000241)	2.92
Fresno-Olive	(1000234)	3.98
Fresno-3425	(1000246)	3.18
Fresno-4760 E	(1000244)	3.48
Bakersfield C	(1500203)	4.20
Kern Refuge	(1500205)	1.13
Taft College	(1500250)	1.19
Taft-N 10th S	(1500213)	1.37
Corcoran-Van	(1600715)	1.74
Hanford	(1600701)	3.22
Kettleman Cit	(1600714)	1.53
Madera-Librar	(2000002)	1.24
Los Banos	(2400522)	0.90
Merced	(2400521)	2.78
Stockton-Haze	(3900252)	2.19
Crows Landing	(5000571)	1.03
Modesto-Oakda	(5000558)	2.15
Modesto-1100	(5000567)	2.16
Porterville-C	(5400579)	3.21
Visalia-Churc	(5400568)	3.72

Table III-4 shows diesel exhaust PM_{10} as well as the total PM_{10} and primary PM_{10} concentrations for 1990 at these two locations, Stockton and Modesto. The total PM_{10} are directly from the Blue Sky Report. The diesel exhaust PM_{10} concentration is obtained by scaling the primary PM_{10} concentration by 0.0580. This scaler is the fraction of diesel exhaust PM_{10} concentration over primary PM_{10} concentration for the Stockton site in the DRI SJV PM_{10} Analysis and is discussed next.

Table III-4
1990 Annual Average PM_{10} Concentrations
Selected San Joaquin Valley Sites

Site	(1) Total PM_{10} ($\mu g/m^3$)	(2) Primary PM_{10} ($\mu g/m^3$)	(3) Diesel Exhaust PM_{10} ($\mu g/m^3$)
Stockton 3900521	51.4	38.8	2.25
Modesto 5000567	50.0	40.2	2.33

(1) Total PM_{10} from Blue Sky Report.
(2) Primary PM_{10} calculated as a subset of (1).
(3) Diesel Exhaust PM_{10} calculated as a subset of (2).

Table III-5 shows the fraction representing diesel exhaust PM_{10} over primary PM_{10} as well as the calculated diesel exhaust PM_{10} and the primary PM_{10} concentrations for each of the sites from the DRI SJV PM_{10} Analysis. The fraction for Stockton is 0.0580. The values of diesel exhaust PM_{10} concentration in Table III-5 are obtained from Table III-1. The primary PM_{10} concentrations in Table III-5 are calculated by subtracting the secondary PM_{10} from total PM_{10} concentrations in the DRI SJV PM_{10} Analysis.

Table III-5
Annual Average
Primary PM_{10} and Diesel Exhaust PM_{10} Concentrations
for the SJV Study Sites

Sampling Site	Primary ($\mu g/m^3$)	Diesel Exhaust ($\mu g/m^3$)	Fraction (Diesel Exhaust/Primary)
Stockton	48.1	2.79	0.0580
Crows Landing	38.5	1.22	0.0317
Fresno	54.6	3.75	0.0687
Kern Refuge	33.5	1.25	0.0373
Fellows	39.3	1.17	0.0298
Bakersfield	58.6	4.26	0.0727
RURAL AVERAGE			0.0329
URBAN AVERAGE			0.0665

Table III-6 shows the primary PM_{10} concentrations from the measurements made in the DRI SJV PM_{10} Analysis. Also shown are the results of the secondary PM_{10} concentrations calculated from data collected in DRI SJV PM_{10} Analysis. The primary PM_{10} concentrations are calculated by subtracting the secondary PM_{10} from the total measured PM_{10} concentrations. The primary PM_{10} concentration for Stockton in the DRI SJV PM_{10} Analysis is calculated as 48.1 $\mu g/m^3$ (48.1 = 59.37 - 3.01 - 6.37 - 1.87).

Table III-6
Ambient Annual Average PM_{10} Concentrations
SJV 6/88 to 6/89, Seasonally Stratified

Sampling Site	Number Samples	Measured Total ($\mu g/m^3$)	Secondary $(NH_4)_2SO_4$ ($\mu g/m^3$)	Secondary NH_4NO_3 ($\mu g/m^3$)	$NaNO_3$ + NaCl ($\mu g/m^3$)	Primary ($\mu g/m^3$)
Stockton	49	59.37	3.01	6.37	1.87	48.1
Crows Lnd	48	48.97	2.68	6.38	1.44	38.5
Fresno	49	68.87	3.48	9.83	0.95	54.6
Kern Rfg	50	45.92	3.20	7.79	1.48	33.5
Fellows	50	52.56	4.88	6.96	1.40	39.3
Bakersfld	48	77.34	5.41	11.88	1.50	58.6

To continue with the example, the primary PM_{10} concentrations for Stockton and Modesto, as shown in Table III-4, are obtained by subtracting the secondary PM_{10} concentration from the total PM_{10} concentration obtained from the Blue Sky Report, as shown in Table III-7. In the case for the SJV, the sulfates, nitrates and chlorides are scaled by 1.14, 1.28, and 1.65, respectively, to obtain secondary PM_{10}. (The basis for the scalers are described below.) Therefore the primary PM_{10} concentration for Stockton is 38.8 $\mu g/m^3$ (38.8 = 51.4 - 2.6(1.14) - 6.9(1.28) - 0.5(1.65)).

Table III-7
1990 Annual Average PM_{10} Concentrations, Selected San Joaquin Valley Sites
Total, Anions, and Primary

Site	Total PM_{10} ($\mu g/m^3$)	$SO_4^=$ ($\mu g/m^3$)	NO_3^- ($\mu g/m^3$)	Cl^- ($\mu g/m^3$)	Primary PM_{10} ($\mu g/m^3$)
Stockton 3900521	51.4	2.6	6.9	0.5	38.8
Modesto 5000567	50.0	2.1	5.4	0.3	40.2

The rate at which the anions combine with the various cations can vary. (Anions and cations are ions charge negatively and positively, respectively.) Table III-8 show the scalers used to estimate secondary PM_{10} concentrations from anions in the SJV. In addition, Systems Applications International (SAI 1994) performed an independent study. Their results of the anion scalers are presented in Table III-8. Lastly, in a CARB Technical Report, "Nature and Causes of the PM_{10} Problem in California," (ARB/TS-87-002, 1987) are suggested values for the scalers. As shown in Table III-8, (SAI 1994) did not include chloride anions in their evaluation. The effects of this are minimal because secondary chloride particulate formations are dwarfed when compared to sulphate and nitrate formations.

Table III-8
Anion Scalers to
Estimate Secondary PM_{10}

Source	$SO_4^=$	NO_3^-	Cl^-
SJV Diesel PM_{10} Analysis	1.14	1.28	1.65
SAI	1.29	1.23	-
ARB/TS-87-002	1.56	1.87	1.65

Anion-to-secondary-PM_{10} scalers are developed with recommendations in (ARB/TS-87-002, 1987) and results of the DRI SJV PM_{10} Analysis. The secondary ammonium sulphate concentration is scaled to the sulphate anion concentration to determine the sulphate scaler, 1.14, as shown in Table III-9. The scaler calculated, 1.14, is the mean of the scalers for all six sites in the DRI SJV PM_{10} Analysis.

Table III-9
Sulfates
from the SJV Study 6/88 to 6/89
Not Seasonally Stratified

Sampling Site	(1) $SO_4^=$ ($\mu g/m^3$)	(2) $(NH_4)_2SO_4$ ($\mu g/m^3$)	(3) $((NH_4)_2SO_4)/(SO_4^=)$
Stockton	2.69	3.07	1.14
Crows Lnd	2.34	2.76	1.18
Fresno	3.09	3.58	1.16
Kern Rfg	2.68	3.28	1.22
Fellows	5.17	5.07	0.98
Bakersfld	4.73	5.53	1.17
MEAN			1.14

(1) speciated data
(2) CMB results
(3) fraction = secondary PM_{10} / anion PM_{10}

It is further assumed the chloride scaler from (ARB/TS-87-002, 1987), 1.65, is applicable for the analysis. Data are not available to estimate the chloride scaler. Therefore, an appropriate scaler for the nitrates with the DRI SJV PM_{10} Analysis data can be estimated, as shown in Table III-10. For example the scaler for Stockton is 1.25 (1.25 = (6.94 + 1.78 - 0.55*1.65) / 6.25)). The nitrate scaler used, 1.28, is the mean of the scalers for the six sites in the DRI SJV PM_{10} Analysis.

Table III-10
Nitrates, and Chlorides
from the SJV Study 6/88 to 6/89
Not Seasonally Stratified

Sampling Site	(1) NO_3^- ($\mu g/m^3$)	(2) Cl^- ($\mu g/m^3$)	(3) NH_4NO_3 ($\mu g/m^3$)	(4) $NaNO_3$ + NaCl ($\mu g/m^3$)	(5) (NH_4NO_3 + $NaNO_3$) / (NO_3^-)
Stockton	6.25	0.55	6.94	1.78	1.25
Crows Landing	5.99	0.25	6.53	1.48	1.27
Fresno	8.49	0.27	10.39	0.96	1.28
Kern Refuge	7.37	0.21	8.32	1.48	1.28
Fellows	6.39	0.26	7.51	1.41	1.33
Bakersfield	10.71	0.34	12.72	1.52	1.28
MEAN					1.28

(1) and (2) speciated data
(3) and (4) CMB results
(5) fraction = secondary PM_{10} / anion PM_{10}

The above example is applicable for estimating the diesel exhaust PM_{10} concentration from data in the Blue Skv Report for the sites located at Stockton and Modesto. Similar procedures are used to estimate the diesel exhaust PM_{10} concentrations for other locations in the SJV.

Table A-1 in Appendix A shows estimated diesel exhaust PM_{10} concentration for sites in the SJV. Also included are the total PM_{10} concentrations and an estimate of the primary PM_{10} concentrations based on the above methods.

3. Micro-environment Evaluation Data Requirement

As part of the evaluation of the exposure to the public of a pollutant source emitted in the atmosphere, the standard deviation of the ambient level is requested by exposure analysts. It is suggested that outdoor air does not have the same composition of pollutants as indoor air. The evaluation of outdoor air verses indoor air is beyond the scope of this analysis. However, it has been requested by CARB's Research Division to compute the standard deviation of the PM_{10} concentrations for their use in evaluating the exposure to the public.

To accomplish this task, the statewide PM_{10} data base was accessed. This is the same database used to summarize the PM_{10} data in the Blue Sky Report. Ambient PM_{10} concentrations are collected on a frequency of once every sixth day throughout the network. The methods utilized above to estimate diesel exhaust concentrations on an annual basis are computerized in order to use the PM_{10} on a once-in-sixth day basis. To conduct this analysis, there are approximately 304 sets of 24-hour samples evaluated on a basin-wide basis for the five year period, 1988-1992. The outcome of this analysis is the standard deviation of PM_{10} concentrations due to directly emitted diesel exhaust.

4. Interpolation Algorithms

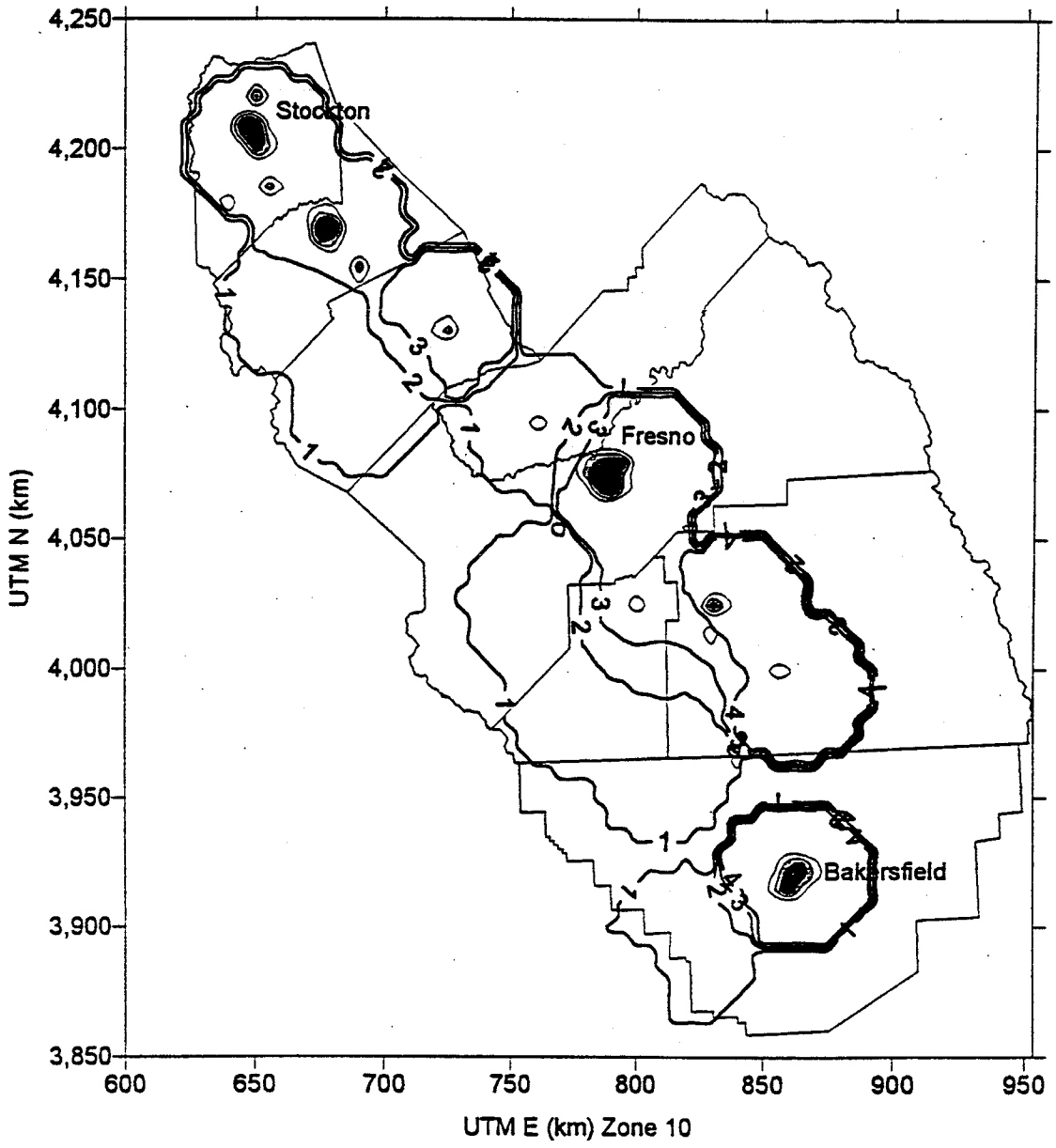
Figures 2A, 2B, and 2C show the modeling domain used for the interpolation model in the San Joaquin Valley PM_{10} analysis. Figures 2A and 2B show the interpolated diesel exhaust PM_{10} concentrations over the domain using a search radius of 30 kilometers and a weighting power factor of two. The domain is of sufficient size to include the locations of the monitoring stations identified in Table A-1 of Appendix A. The domain is digitized with a 5 kilometer resolution to encompass the UTM (Universal Transverse Mercator) Zone 10 coordinates, 600,000 meters east to 950,000 meters east and 3,850,000 meters north to 4,250,000 meters north. This configuration results in a grid with 71 X 81 (5751) cells. The locations of the monitoring sites

are digitized within the domain according to the Station ID number. (See Appendix B for the descriptions and digitized coordinates.)

Based on the diesel exhaust PM_{10} concentrations, and the interpolation model parameters as discussed above, the population-weighted annual average diesel exhaust PM_{10} concentration for the SJV is 2.6 $\mu g/m^3$. The standard deviation from the annual average is 1.2 $\mu g/m^3$, based on the variation in the product of PM_{10} measurements and population collected every sixth day during the 1988 - 1992 period.

Figure 2A

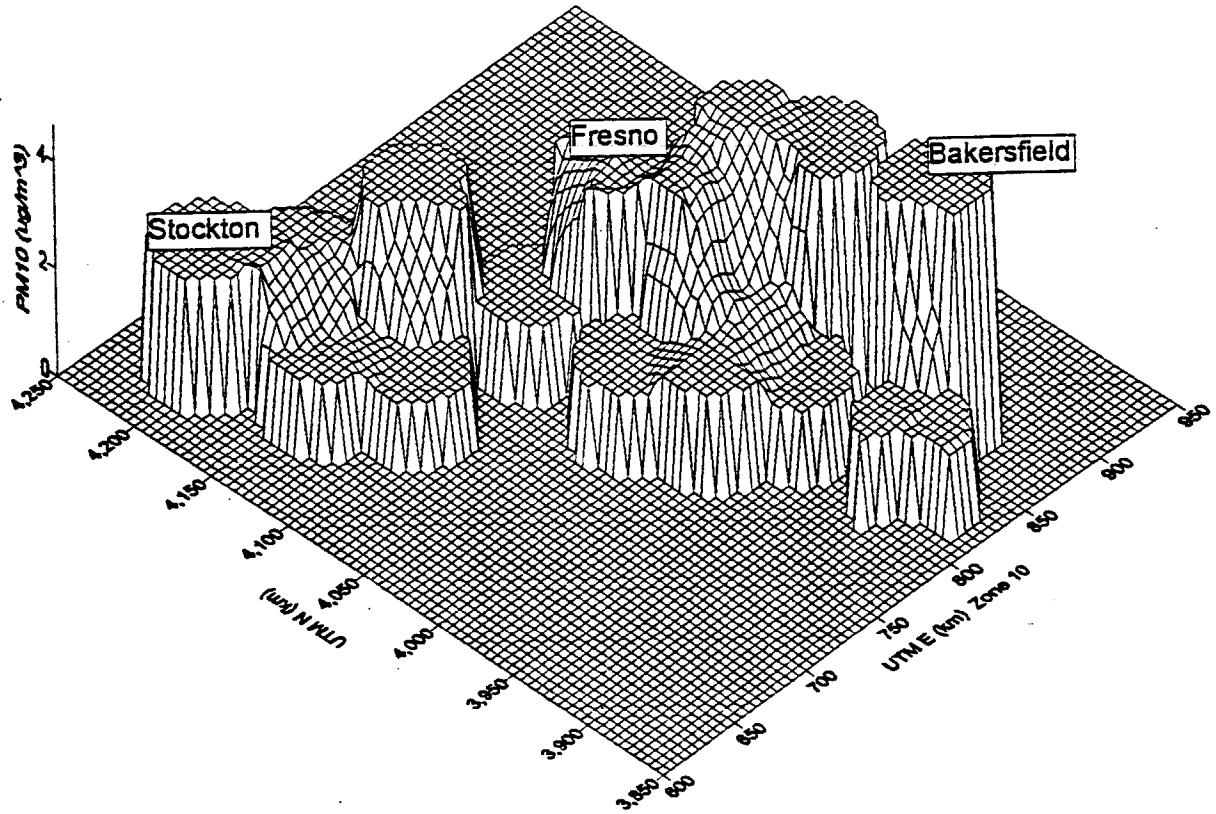
Estimated Annual PM_{10} Concentration
from Diesel Exhaust Emissions
in the San Joaquin Valley Air Basin



Each bold isopleth represents a change of 1.0 microgram per cubic meter.
Concentrations outside of the Air Basin are not represented.
Each shaded contour represents a change in population of 400 people per square kilometer.

Figure 2B

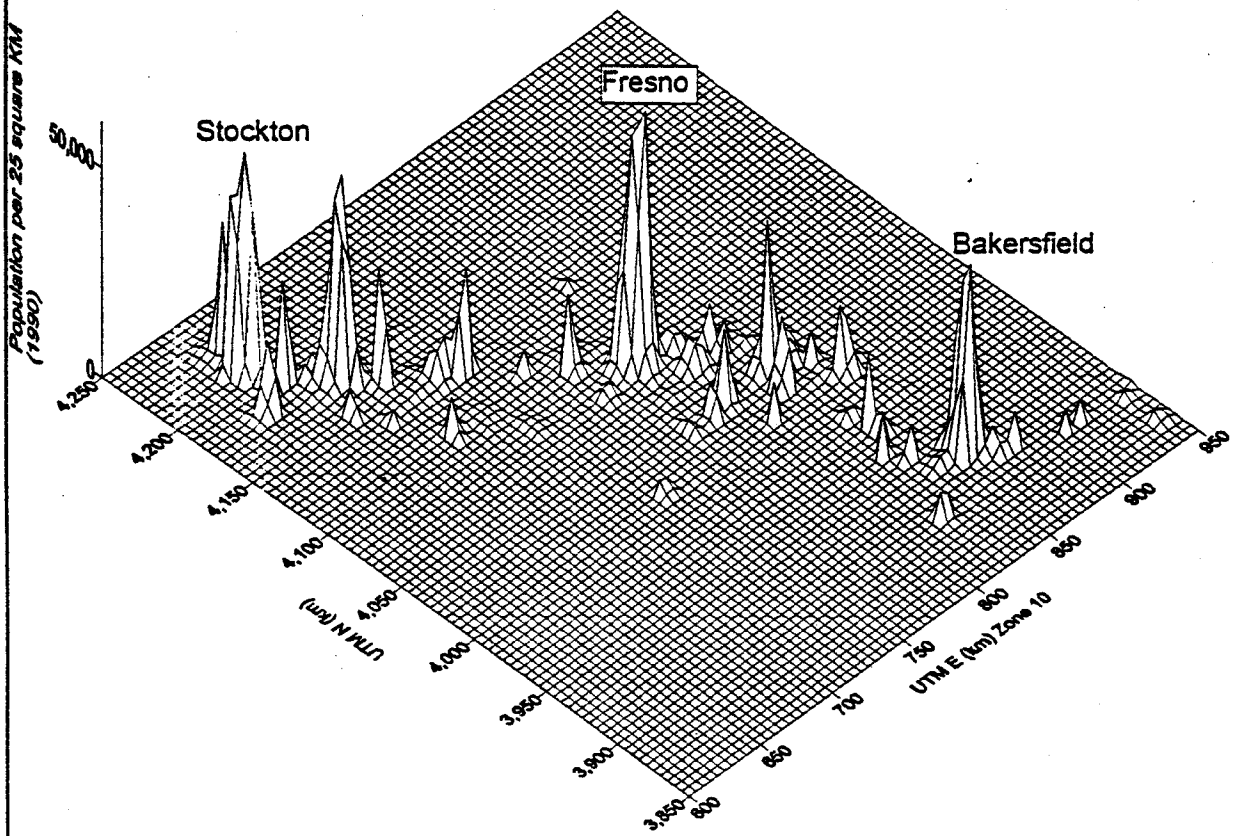
Estimated Annual PM_{10} Concentration
from Diesel Exhaust Emissions
in the San Joaquin Valley Air Basin



Concentrations outside of the Air Basin are not represented.

Figure 2C

1990 Population Distribution
in the San Joaquin Valley



5. Sensitivity Studies

To determine the sensitivity of the estimated population-weighted average concentrations to the interpolation variables, the interpolation model is evaluated using different values for the following variables: search radius, grid resolution, and weighting power. Table III-11 shows the results of these simulations with data from our November 8, 1993 analysis. Table III-12 shows the results of simulations with data from our current analysis. The fraction of the total population which coincides with an interpolated grid cell increases as the search radius increases. This is represented in column four of Tables III-11 and III-12 as a percentage.

Table III-11
PM_{10} Interpolation Sensitivity Summary
San Joaquin Valley Air Basin, November 8, 1993 Analysis

Search Radius (km)	Inverse Power (factor)	Grid Resolution (km)	Population w/in Interpolation Grids	Pop. Weighted Annual Average ($\mu g/m^3$)
50	2	5	98%	3.97
500	2	5	100%	3.84
500	2	2	100%	3.84
500	1	5	100%	3.42
500	3	5	100%	4.00

Table III-11 shows that the population-weighted average concentration increases about twelve and four percent as the inverse power factor incrementally increases from one to three, respectively. Generally, the range of the inverse power factor is from one to three. An inverse power factor of two is used for this analysis.

Table III-12
PM_{10} Interpolation Sensitivity Summary
San Joaquin Valley Air Basin, Current Analysis

Search Radius (km)	Inverse Power (factor)	Grid Resolution (km)	Population w/in Interpolation Grids	Pop. Weighted Annual Average ($\mu g/m^3$)
15	2	5	52%	2.60
30	2	5	87%	2.48
500	2	5	100%	2.46

As shown in Table III-11, when the search radius increases, the population within an interpolated grid cell also increases. The difference in the population-weighted average concentration from a 50 kilometer search radius to a 500 kilometer radius is less than five percent. As shown in Table III-12 the difference in the population-weighted average concentration from a 15 kilometer search radius to a 500 kilometer search radius is also five percent.

Since the interpolated value of a grid cell approaches the arithmetic mean of all discrete data points within the search radius, we limit the search radius to 30 kilometers. Too large of a search radius, 500 kilometers, will overestimate concentrations in sparsely populated areas. Presumably sparsely populated areas have fewer sources of diesel exhaust emissions. Although as seen in Tables III-11 and III-12, a large search radius has minimal effect on the calculated weighted average. Too small of a search radius will under-represent the population base. As shown in Table III-12, the represented population is 52 percent of the total for a search radius of 15 kilometers.

Boundary conditions are no longer an input into the interpolation model. Previously boundary conditions were used in the interpolation model for sparsely populated areas and near the boundaries of domains. Since the search radius has been limited to 30 kilometers, boundary conditions have a minimal effect and are no longer required for the interpolation model.

A grid cell resolution of five kilometers and two kilometers shows no difference in population-weighted average concentrations. To reduce computation time and reduce disk storage space, the five kilometer grid resolution is used for the analysis.

In summary, to estimate the population weighted annual average PM_{10} concentration due to direct emissions from diesel engine exhaust, a search radius of 30 kilometers, an inverse power factor of two, and a grid cell resolution of five kilometers is used in this analysis.

IV. ESTIMATING THE POPULATION-WEIGHTED AVERAGE AMBIENT DIESEL EXHAUST PM_{10} CONCENTRATION IN THE SOUTH COAST AIR BASIN

A. Method

In this section, the analysis and calculations used to estimate ambient diesel exhaust PM_{10} concentrations in the South Coast Air Basin (SCAB) are provided. The method is similar to that of the SJV. The South Coast Air Quality Management District (SCAQMD) prepared a PM_{10} report (SCAQMD 1991) in which speciated ambient PM_{10} concentrations are evaluated with a chemical mass balance analysis (SC PM_{10} Study). The results include PM_{10} apportioned to a motor vehicle fleet. The subset of the motor vehicle fleet PM_{10} concentration that is due to emissions from diesel exhaust was calculated. The diesel exhaust subset of concentrations is then estimated from the ambient PM_{10} monitoring network. Subsequently, the discrete data are interpolated onto a uniform grid and a population field is overlayed to estimate the population weighted average concentration.

B. Calculations

In this section, the calculations used to estimate ambient diesel exhaust PM_{10} concentrations for the SCAB are shown. Based on the following analysis, the population-weighted average concentration for diesel exhaust PM_{10} is estimated as 3.6 $\mu g/m^3$ in the SCAB.

1. Calculations for Ambient PM_{10} Concentration from Direct Diesel Exhaust Emissions in the South Coast Air Basin

Table IV-1 show results obtained from the SC PM_{10} Study which include the measured total ambient PM_{10} concentration. Also shown are the primary motor vehicle mass calculated with a chemical mass balance analysis. In addition, the previous version of the SC PM_{10} Study

from 1989 estimated the diesel exhaust mass with a CMB analysis. Finally, shown in Table IV-1 are our estimate of the diesel exhaust mass in the SCAB from the 1986 data.

Table IV-1
Ambient Annual Average PM_{10} Concentrations
in the South Coast Air Basin
1986 Data

Sampling Site	(1) Meas. Total ($\mu g/m^3$)	(2) Primary Motor Vehicle ($\mu g/m^3$)	(3) SCAQMD 89 Diesel Exhaust ($\mu g/m^3$)	(4) Direct Diesel Exhaust ($\mu g/m^3$)
Dntwn Los Angeles	60.2	6.9	5.6	5.0
Burbank	56.6	6.2	5.2	4.5
Long Beach	50.2	4.8	4.4	3.5
Lennox	47.0	4.6	3.9	3.3
Anaheim	52.1	3.5	3.6	2.5
Rubidoux	85.1	6.8	5.1	4.9
Uplands	58.0	3.6	3.6	2.6
Tanbark Flats	31.9	2.1	-	1.5
San Nicolas Isl.	21.1	0.5	-	0.4

Source: SCAQMD 1991

(1) Measured total PM_{10}.
(2) Calculated primary motor vehicle mass from CMB results.
(3) Calculated diesel exhaust mass from CMB results in SCAQMD 1989 analysis.
(4) Calculated diesel exhaust mass, estimated as a subset of (2).

As seen in Table IV-1, our estimate of diesel exhaust PM_{10} in the SCAB is less than that estimated in the 1989 results of the SC PM_{10} Study. Our estimates are based on the 1991 results of the SC PM_{10} Study. In the SC PM_{10} Study, the CMB analysis is based on enhanced source profiles which are designed to better represent the secondary organic carbon fraction. Therefore it is not unexpected that our estimate of the diesel exhaust PM_{10} in the SCAB shows a lower value than that estimated in the 1989 results of the SC PM_{10} Study.

The direct diesel exhaust PM_{10} concentration, column (4), in Table IV-1 is computed by scaling the primary motor vehicle PM_{10} concentration, column (2), by 0.724. This scale factor is determined from the ratio of diesel exhaust PM_{10} inventory to the total PM_{10} inventory due to petroleum-based fuel sources.

Table IV-2 shows the inventory of PM_{10} emissions from the combustion of petroleum based fuels in the SCAB, based on the 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis, January 1995. Crude oil (residual oil) combustion in the SCAB is speciated separately in the SC PM_{10} Study. Itemized in Table IV-2 are the emissions from on-road motor vehicles burning diesel fuel, other internal combustion engines that burn numbers one and two distillate fuels, on-road motor vehicles that burn gasoline, and the combustion of other petroleum based fuels (excluding crude oil).

Table IV-2
PM_{10} Emission Inventory
for Petroleum Based Fuels
in the South Coast Air Basin, 1990

Source	(tons per year)
Motor Vehicle Diesel	10,680[a]
Other Distillate Fuels	7,125[b]
Motor Vehicle Gasoline	1,000[c]
Other Petroleum Based Fuels	5,795[d]
Total	24,600

Source: 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis

(a) On road motor vehicle diesel engines (EMFAC7G)
(b) Other engines combusting #1 and #2 distillate oil (1/19/95 EI query)
(c) On road motor vehicle gasoline engines (EMFAC7G)
(d) Other combustion of petroleum based fuels excluding crude oils (1/19/95 EI query)

To derive the scaling factor, the numerator is 17,805 tons per year of PM_{10} emitted from engines burning numbers one and two fuel oil in the SCAB (17,805 = 10,680 + 7,125). The denominator becomes the emissions of all petroleum based fuels excluding crude oil, 24,600 tons per year. Therefore the diesel exhaust subset is 0.724 (0.724 = 17,805 / 24,600).

2. Estimation of Diesel Exhaust PM_{10} Concentrations from the Blue Sky Report in the South Coast Air Basin

Similar to the SJV, diesel exhaust PM_{10} concentrations are estimated from the Blue Sky Report. The following section describes the calculations for estimating the diesel exhaust PM_{10} concentration.

Table IV-3 shows the estimated diesel exhaust PM_{10} concentration for sites located in the SCAB for the five-year average including 1988 - 1992. Table IV-3 is estimated from data in the Blue Sky Report.

As an example to deriving the values in Table IV-3, the detailed calculation for data collected in 1990 for the sampling sites in Los Angeles and Riverside are given. It is assumed the composition of the data collected from the Blue Sky Report for the locations of Los Angeles and Riverside are similar to the data collected in the SC PM_{10} Study for downtown Los Angeles and Rubidoux. As such, the mass fraction, which are attributed to diesel exhaust, are assumed to be similar.

Table IV-4 shows the diesel exhaust PM_{10} as well as the total PM_{10} and primary PM_{10} concentrations for 1990 at two locations, Los Angeles and Riverside. The total PM_{10} are obtained directly from the Blue Sky Report. The diesel exhaust PM_{10} concentration is obtained by scaling the primary PM_{10} concentration by 0.1260 and 0.0906 for the data collected at Los Angeles and Riverside, respectively. These scalers are the fraction of diesel exhaust PM_{10} over primary PM_{10} for the Los Angeles site and the Rubidoux sites in the SC PM_{10} Study.

Table IV-3 Five Year Average, 1988 - 1992 Diesel Exhaust PM_{10} Concentration - South Coast Air Basin		
Site	Site Number	Diesel Exhaust PM_{10} ($\mu g/m^3$)
Azusa	(7000060)	4.44
Burbank	(7000069)	4.40
Hawthorne	(7000094)	2.99
Los Angeles	(7000087)	4.53
N Long Beach	(7000072)	3.23
S Clarity-SFe	(7000089)	3.98
Anaheim	(3000176)	2.17
El Toro	(3000186)	2.00
Los Alamitos	(3000190)	2.36
Newport Beach	(3000196)	1.50
Perris	(3300149)	2.92
Riverside-Rub	(3300144)	4.24
Banning-Alles	(3300150)	1.94
Temecula-Ranc	(3300160)	1.94
Fontana-Arrow	(3600197)	3.39
Lake Gregory	(3600181)	2.10
Ontario Airpo	(3600171)	3.43
San Bernadino	(3600203)	3.27

Table IV-4
1990 Annual Average PM_{10} Concentrations
Selected Sites in the South Coast Air Basin

Site	(1) Total PM_{10} ($\mu g/m^3$)	(2) Primary PM_{10} ($\mu g/m^3$)	(3) Diesel Exhaust PM_{10} ($\mu g/m^3$)
Los Angeles 7000087	53.2	35.2	4.44
Riverside 3300144	78.4	46.5	4.21

(1) Total PM_{10} from Blue Sky Report.
(2) Primary PM_{10} calculated as a subset of (1).
(3) Diesel Exhaust PM_{10} calculated as a subset of (2).

Table IV-5 shows the fraction representing diesel exhaust PM_{10} mass over primary PM_{10} mass as well as the calculated diesel exhaust PM_{10} and the primary PM_{10} concentrations for each of the sites from the SC PM_{10} Study. The fraction for Los Angeles and Rubidoux is 0.1260 and 0.0906, respectively. The diesel exhaust PM_{10} in Table IV-5 is obtained directly from Table IV-1 (we included three significant figures in Table IV-5 to avert round-off error). The primary PM_{10} concentration in Table IV-5 is calculated by subtracting the secondary PM_{10} from total PM_{10} concentration in the SC PM_{10} Study.

Table IV-5 Annual Average Primary PM_{10} and Diesel Exhaust PM_{10} Concentrations for the SCAQMD PM_{10} Report Sites			
Sampling Site	Primary ($\mu g/m^3$)	Diesel Exhaust ($\mu g/m^3$)	Fraction Diesel Ex / Primary
Dntwn Los Angeles	39.6	4.99	0.1260
Burbank	37.8	4.48	0.1185
Long Beach	31.6	3.47	0.1098
Lennox	28.2	3.33	0.1181
Anaheim	32.9	2.53	0.0769
Rubidoux	54.3	4.92	0.0906
Uplands	36.1	2.60	0.0720
Tanbark Flats	22.1	1.52	0.0688
San Nicolas Isl.	10.9	0.36	0.0330

Table IV-6 shows the primary PM_{10} concentrations obtained from the measurements in the SC PM_{10} Study. Also shown are the results of the secondary PM_{10} concentrations calculated from the SC PM_{10} Study. The primary PM_{10} concentrations are calculated by subtracting the secondary PM_{10} from the total measured PM_{10}. The primary PM_{10} concentration for Los Angeles in the SC PM_{10} Study is calculated as 39.6 $\mu g/m^3$ (39.6 = 60.2 - 6.7 - 11.2 - 2.7).

Table IV-6
Ambient Annual Average PM_{10} Concentrations
SCAQMD 1986 Data

Sampling Site	Measured Total ($\mu g/m^3$)	Secondary $(NH_4)_2SO_4$ ($\mu g/m^3$)	Secondary NH_4NO_3 ($\mu g/m^3$)	$NaNO_3$ + NaCl ($\mu g/m^3$)	Primary ($\mu g/m^3$)
Dntwn Los Angeles	60.2	6.7	11.2	2.7	39.6
Burbank	56.6	6.4	10.2	2.2	37.8
Long Beach	50.2	7.3	8.3	3.0	31.6
Lennox	47.0	7.2	7.8	3.8	28.2
Anaheim	52.1	6.3	9.9	3.0	32.9
Rubidoux	85.1	6.1	22.7	2.0	54.3
Uplands	58.0	5.9	14.4	1.6	36.1
Tanbark Flats	31.9	4.8	3.9	1.1	22.1
San Nicolas Isl.	21.1	2.0	2.0	6.2	10.9

To continue with the example, the primary PM_{10} for Los Angeles and Riverside in Table IV-4 is obtained by subtracting the secondary PM_{10} concentration from the total PM_{10} concentration obtained from the Blue Sky Report as shown in Table IV-7. In the case for the SCAB, the sulfates, nitrates, and chlorides are scaled by 1.04, 1.90, and 1.65, respectively, to obtain secondary PM_{10}. Therefore the primary PM_{10} for Los Angeles is 35.2 $\mu g/m^3$ (35.2 = 53.2 - 5.0(1.04) - 6.5(1.90) - 0.3(1.65)).

Table IV-7
1990 Annual Average PM_{10} Concentrations
Total, Anions, and Primary

Site	Total PM_{10} ($\mu g/m^3$)	$SO_4^=$ ($\mu g/m^3$)	NO_3^- ($\mu g/m^3$)	Cl^- ($\mu g/m^3$)	Primary PM_{10} ($\mu g/m^3$)
Los Angeles 7000087	53.2	5.0	6.5	0.3	35.2
Riverside 3300144	78.4	4.6	14.0	0.3	46.5

Similar to the approach used for our SJV analysis, the scaler for the anion-to-secondary-PM_{10} are derived based upon recommendations in (ARB/TS-87-002 1987) and results of the SC PM_{10} Study. The secondary ammonium sulphate concentration to the sulphate anion concentration are scaled to determine the sulphate scaler, 1.04, as shown in Table IV-8. The anion mass is from the ambient PM_{10} monitoring network. The sites from the ambient monitoring network, that coincide with the sites from the SC PM_{10} Study, are located at Burbank, Los Angeles, Long Beach, and Rubidoux. Therefore the scaler calculated, 1.04, is the mean of the scalers for these four sites rounded to three digits.

Table IV-8
Sulfates from SCAQMD PM_{10} Report
1986 Data

Sampling Site	(1) $SO_4^=$ ($\mu g/m^3$)	(2) $(NH_4)_2SO_4$ ($\mu g/m^3$)	(3) $((NH_4)_2SO_4)$ / $(SO_4^=)$
Burbank	6.37	6.4	1.005
Los Angeles	6.35	6.7	1.055
Long Beach	7.03	7.3	1.038
Rubidoux	5.79	6.1	1.054
MEAN			1.038

(1) speciated data from Blue Sky Report
(2) CMB results from SCAQMD PM_{10} report
(3) fraction = secondary PM_{10} / anion PM_{10}

It is further assumed that the chloride scaler from (ARB/TS-87-002 1987), 1.65, is applicable for our analysis. Therefore we can calculate an appropriate scaler for the nitrates with the SCAQMD PM_{10} report data as shown in Table IV-9. Although not specified in the SCAQMD PM_{10} report, it is assumed that results from the CMB represents marine mass from sodium chloride and sodium nitrate, similar to the DRI SJV PM_{10} Analysis. For example the scaler for the data collected at Burbank is 1.879 (1.879 = (10.2 + 2.2 - 0.239*1.65) / 6.39). The nitrate scaler used, 1.90, is the mean of the scalers for the fours sites listed in Table IV-9, rounded to three digits.

Table IV-9
Nitrates and Chlorides Concentrations from SCAQMD PM_{10} Report
1986 Data

Sampling Site	(1) NO_3^- ($\mu g/m^3$)	(2) Cl^- ($\mu g/m^3$)	(3) NH_4NO_3 ($\mu g/m^3$)	(4) Marine ($\mu g/m^3$)	(5) (NH_4NO_3 + $NaNO_3$) / (NO_3^-)
Burbank	6.39	0.239	10.2	2.2	1.879
Los Angeles	5.45	0.250	11.2	2.7	2.475
Long Beach	6.09	0.265	8.3	3.0	1.784
Rubidoux	16.47	0.250	22.7	2.0	1.475
MEAN					1.903

(1) and (2) speciated data, Blue Sky Report
(3) and (4) CMB results, SCAQMD PM_{10} Report
(5) fraction = secondary PM_{10} / anion PM_{10}

The above example is applicable for estimating the diesel exhaust PM_{10} concentration from data in the Blue Sky Report for the sites located at Los Angeles and Riverside. Similar procedures are used to estimated the diesel exhaust PM_{10} concentrations for other locations in the SCAB.

Table A-15 in Appendix A shows estimated diesel exhaust PM_{10} concentration for sites in the SCAB. Also included are the total PM_{10} concentrations and an estimate of the primary PM_{10} concentrations based on the above methods.

3. Micro-environment Evaluation Data Requirement

As discussed for the SJV, the standard deviation of the ambient level is requested by exposure analysts for their use in evaluating the exposure to the public. To accomplish this task, the statewide PM_{10} data base was accessed. This is the same database used to summarize the PM_{10} data in the Blue Sky Report. Ambient PM_{10} concentrations are collected on a frequency of once every sixth day throughout the network. The methods utilized above to estimate diesel exhaust concentrations on an annual basis are computerized in order to use the PM_{10} on a once-in-sixth day basis. To conduct this analysis, there are approximately 304 sets of 24-hour samples evaluated on a basin-wide basis for the five year period, 1988-1992. The outcome of this analysis is the standard deviation of PM_{10} concentrations due to directly emitted diesel exhaust.

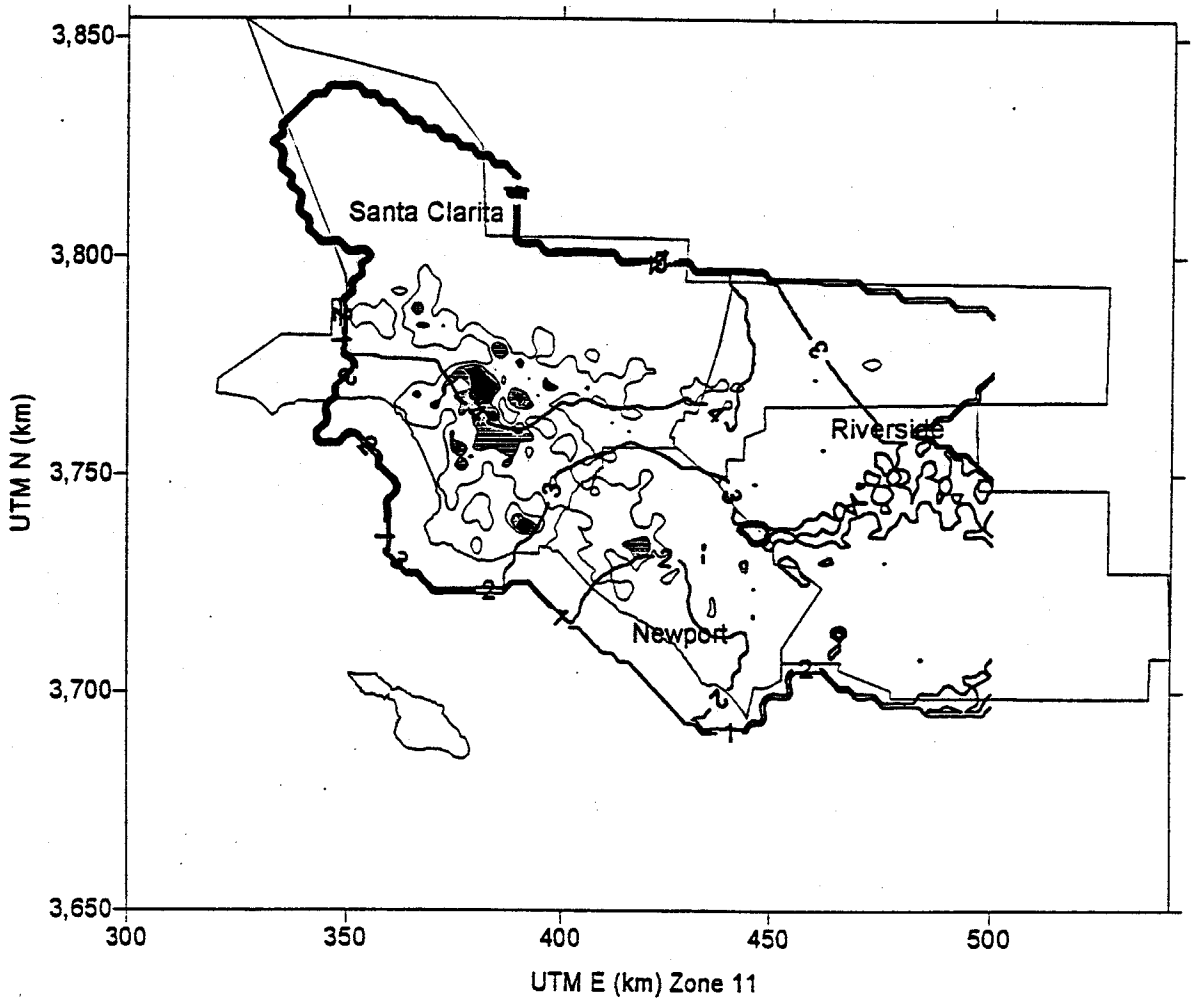
4. Interpolation Algorithms - South Coast Air Basin

Figures 3A, 3B, and 3C, show the modeling domain used for the interpolation model in the South Coast Air Basin. Figures 3A and 3B show the interpolated diesel exhaust PM_{10} concentrations over the domain using interpolation search radius of 30 kilometers and weighting power factor of two. The domain is digitized with a two kilometer resolution including UTM Zone 11 coordinates, 300,000 meters east to 500,000 meters east and 3,650,000 meters north to 3,850,000 meters north. This configuration results in a grid with 101 X 101 (10,201) cells. Listed in Appendix B are the PM_{10} ambient monitoring station descriptions and digitized coordinates.

Based on the diesel exhaust PM concentrations and the interpolation model parameters above, the population-weighted annual average diesel exhaust PM_{10} concentration for the SCAB is 3.6 $\mu g/m^3$. The standard deviation from the annual average is 1.4 $\mu g/m^3$ based on the variation in the product of PM_{10} measurements and population collected every sixth day during the 1988-1992 period.

Figure 3A

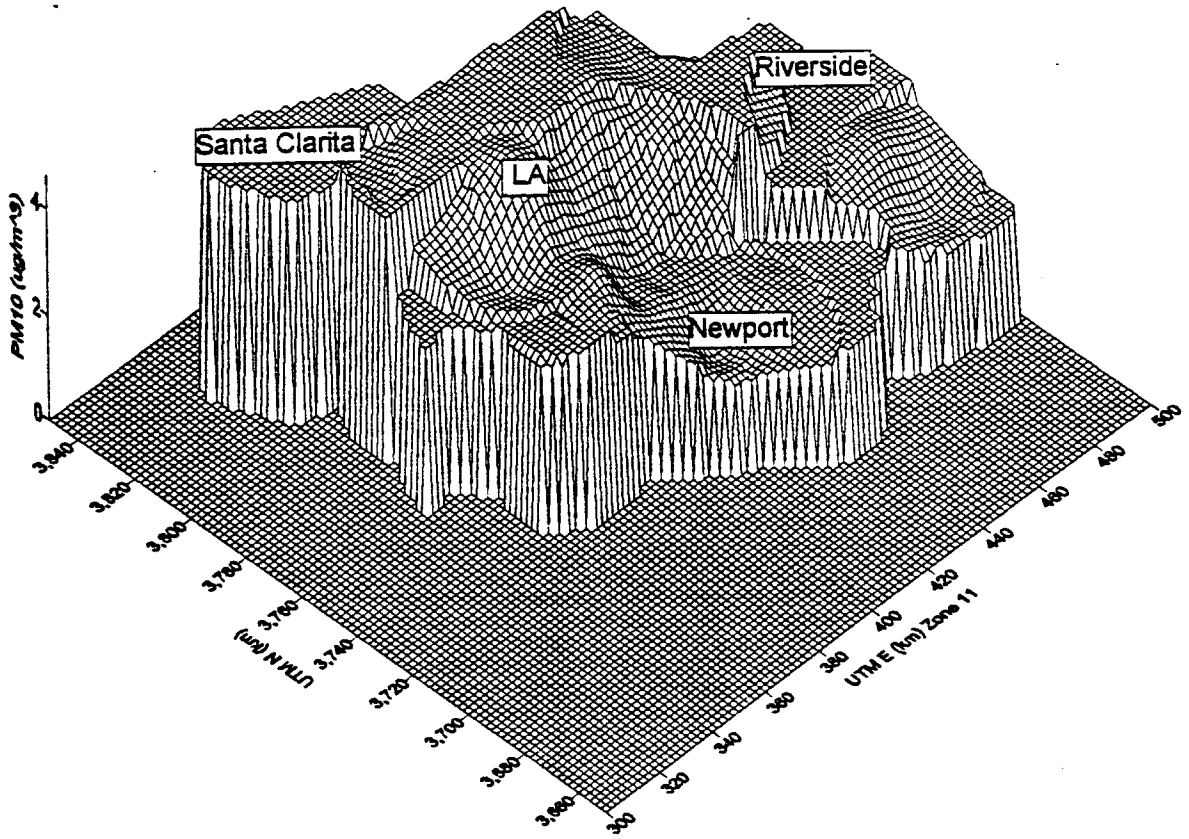
Estimated Annual PM_{10} Concentration
from Diesel Exhaust Emissions
in the South Coast Air Basin



Each heavy isopleth represents a change of 1.0 microgram per cubic meter.
Concentrations outside the Air Basin are not represented.
The interpolation isopleth search radius is limited to 30 kilometers.
Each shaded contour represents a change in population of 2,500 people per square kilometer.

Figure 3B

Estimated Annual PM_{10} Concentration
from Diesel Exhaust Emissions
in the South Coast Air Basin

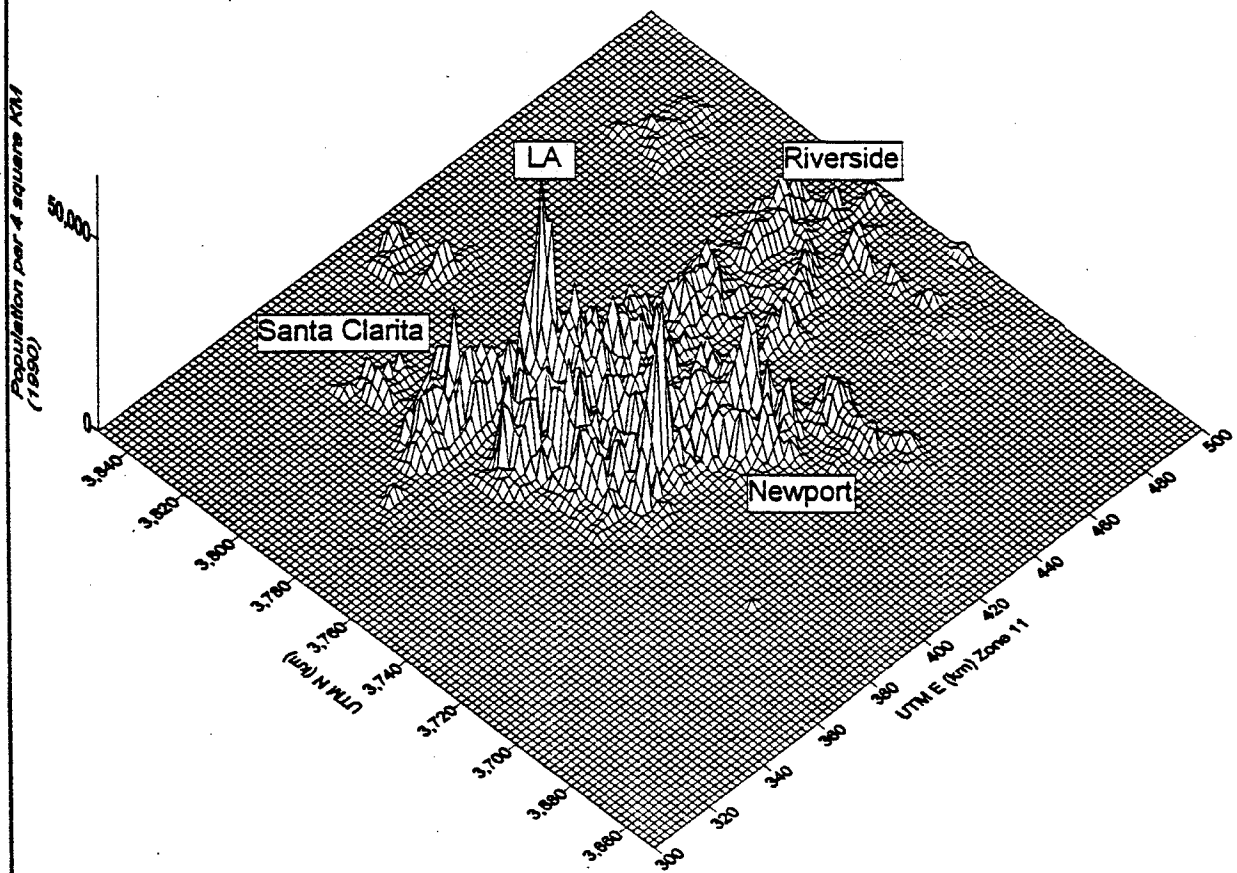


Concentrations outside of the Air Basin are not represented.
Interpolation search radius is limited to 30 kilometers.

ts: dexambv1.wpf

Figure 3C

1990 Population Distribution
in the South Coast Air Basin



5. Sensitivity Studies - South Coast Air Basin

Similar to the SJV, an investigation is made to evaluate the interpolation model for various values for the search radius. Table IV-10 shows the results of these simulations.

Table IV-10
PM_{10} Interpolation Sensitivity Summary
South Coast Air Basin

Search Radius (km)	Inverse Power (factor)	Grid Resolution (km)	Population W/in Intrp. Grids	Pop. Weighted Annual Average ($\mu g/m^3$)
15	2	2	68%	3.58
30	2	2	95%	3.51
500	2	2	97%	3.45

Table IV-10 shows population-weighted average concentration increases as the interpolation search radius decreases. The increase in concentration is less than five percent for this configuration. From those results a search radius of 30 kilometers is used for the analysis.

V. ESTIMATING THE POPULATION-WEIGHTED AVERAGE AMBIENT DIESEL EXHAUST PM_{10} CONCENTRATION IN THE SAN FRANCISCO BAY AREA AIR BASIN

A. Method

In this section, the analysis and calculations used to estimate ambient diesel exhaust PM_{10} concentrations in the San Francisco Bay Area Air Basin (SFBAAB) are provided. The method is similar to that of the SJV. The Bay Area Air Quality Management District (BAAQMD) and the Desert Research Institute evaluated speciated PM_{10} data collected in San Jose from December 16, 1991, through February 24, 1992, (Chow 1994). (This work is referred to as the San Jose PM_{10} Study.) The speciated PM_{10} data was evaluated with a chemical mass balance analysis. The results include PM_{10} apportioned to a motor vehicle fleet. The annual average PM_{10} concentrations are estimated from the winter-time measurements. Next a subset of motor vehicle PM_{10} concentration that is due to emissions from diesel exhaust is estimated. The diesel exhaust subset of concentrations are then estimated from the ambient PM_{10} monitoring network. Subsequently the discrete data are interpolated onto a uniform grid and a population field is overlayed to determine the population weighted average concentration.

B. Calculations

In this section, the calculations used to estimate ambient diesel exhaust PM_{10} concentrations for the SFBAAB are shown. Based on the following analysis, the population-weighted average concentration for diesel exhaust PM_{10} concentration is estimated to be 2.5 $\mu g/m^3$ in the SFBAAB.

1. Calculations for Ambient PM_{10} Concentration from Direct Diesel Exhaust in the San Francisco Bay Area Air Basin

Table V-1 shows results obtained from the San Jose PM_{10} Study which include the measured total ambient PM_{10} concentration. Also shown are the primary motor vehicle concentrations calculated with a chemical mass balance analysis.

Table V-1
Ambient Annual Average PM_{10} Concentrations
in San Jose,
1991-1992 Winter Data

Sampling Site	(1) Measured Total ($\mu g/m^3$)	(2) Primary Motor Vehicle ($\mu g/m^3$)
San Jose 4th St	68.4	9.2
San Jose San Carlos	64.9	8.9

Source: San Jose PM_{10} Study

(1) Measured total PM_{10}.
(2) Primary motor vehicle mass from CMB results.

The annual average PM_{10} concentration due to motor vehicles can be estimated by two methods. First, the ratio of the winter-time motor vehicle PM_{10} concentration to the winter-time total PM_{10} concentration can be assumed to be valid for the annual average concentrations. Another method would be to evaluate the ratio of the winter-time motor vehicle PM_{10} concentration to annual average motor vehicle PM_{10} concentration in the SJV. Then use this ratio to estimate annual average motor vehicle PM_{10} concentrations in the SFBA.

The first method requires the evaluation of secondary PM_{10}. The relationship between winter-time secondary PM_{10} to summer-time secondary PM_{10} has not be evaluated thus far in this analysis. Therefore, the second method is used.

To estimate the annual average PM_{10} concentration from the winter-time PM_{10} concentration, due to emissions from motor vehicles, the annual-to-winter relationship in the SJV is evaluated. Table V-2 shows the motor vehicle PM_{10} concentration in the SJV for the winter-time average and the annual average for the data collected at the three urban locations. The scale of the annual average concentration to the winter average concentration is also shown in Table V-2. It is assumed the scale of annual-average mass to winter-average mass for the San Jose measurements are similar to the scale for the measurements collected at the three urban locations in the SJV. Therefore, we can estimate the annual average PM_{10} concentration due to motor vehicle emissions in San Jose by scaling the winter-time average concentration by 0.514.

Table V-2
PM_{10} Concentration Due to
Motor Vehicle Emissions in the San Joaquin Valley,
June 1988 to June 1989 Data

Site	Annual Average ($\mu g/m^3$)	Winter Average ($\mu g/m^3$)	(Annual) / (Winter)
Stockton	4.9	10.0	0.485
Fresno	6.5	14.5	0.449
Bakersfield	7.4	12.2	0.607
Mean			0.514

Source: DRI SJV PM_{10} Analysis

Note: Winter data are collected in the months of December, January and February, coincident months with the San Jose PM_{10} Study.

Table V-3 shows the estimated annual PM_{10} concentrations for the data collected in San Jose due to emissions from motor vehicles and diesel engines. The direct diesel exhaust PM_{10} concentration, column (2) in Table V-3, is computed by scaling the primary motor vehicle PM_{10} concentration, column (1), by 0.613. This scale factor is determined from the ratio of diesel exhaust PM_{10} inventory to the total PM_{10} inventory due to petroleum-based fuel sources in the SFBAAB.

Table V-3 Estimated Ambient PM_{10} Concentrations in San Jose, Annual Average		
Sampling Site	(1) Primary Motor Vehicle ($\mu g/m^3$)	(2) Direct Diesel Exhaust ($\mu g/m^3$)
San Jose 4th St	4.7	2.9
San Jose San Carlos	4.6	2.8
(1) Primary motor vehicle mass estimate. (2) Calculated diesel exhaust mass, estimated as a subset of (1).		

Table V-4 shows the inventory of PM_{10} emissions from the combustion of petroleum based fuels in the SFBAAB, based on the 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis, January 1995. Itemized in Table V-4 are the emissions from on-road motor vehicles burning diesel fuel, other internal combustion engines that burn numbers one and two distillate fuels, on-road motor vehicles that burn gasoline, and the combustion of other petroleum based fuels.

Table V-4 PM_{10} Emission Inventory for Petroleum Based Fuels in the San Francisco Bay Area Air Basin, 1990	
Source Type	(Tons per Year)
Motor Vehicle Diesel	3,017[a]
Other Distillate Fuels	1,945[b]
Motor Vehicle Gasoline	385[c]
Other Petroleum Based Fuels	2,746[d]
Total	8,093
Source: 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis	
(a) On road motor vehicle diesel engines (EMFAC7G) (b) Other engines combusting #1 and #2 distillate oil (1/19/95 EI query) (c) On road motor vehicle gasoline engines (EMFAC7G) (d) Other combustion of petroleum based fuels (1/19/95 EI query)	

To derive the scaling factor, the numerator is 4,962 tons per year of PM_{10} emitted from engines burning numbers one and two fuel oil in the SFBAAB (4,962 = 3,017 + 1,945). The denominator becomes the emissions of all petroleum based fuels, 8,093 tons per year. Therefore the diesel exhaust subset is 0.613 (0.613 = 4,962 / 8,093).

2. Estimation of Diesel Exhaust PM_{10} Concentrations from the Blue Sky Report in the San Francisco Bay Area Air Basin

Similar to the SJV, diesel exhaust PM_{10} concentrations are estimated from the Blue Sky Report. The following section describes the calculations for estimating the diesel exhaust PM_{10} concentration.

Table V-5 shows the estimated diesel exhaust PM_{10} concentration for sites located in the SFBAAB for the five-year average including 1988 - 1992. Table V-5 is estimated from data in the Blue Sky Report.

Table V-5
Five Year Average, 1988 - 1992
Diesel Exhaust PM_{10} Concentration,
San Francisco Bay Area Air Basin

Site	Site Number	Diesel Exhaust PM_{10} ($\mu g/m^3$)
Fremont-Chape	(6000336)	2.37
San Leandro-C	(6000343)	2.24
Bethel Island	(700442)	2.43
Concord-2975	(700440)	2.28
Richmond-13th	(700433)	2.01
San Rafael	(2100451)	2.24
Napa-Jefferso	(2800783)	2.76
San Francisco	(9000306)	2.49
Redwood City	(4100541)	2.46
San Jose-Moor	(4300377)	2.82

As an example to deriving the values in Table V-5, the detailed calculation for data collected in 1990 for the sampling site in San Jose are given. (A summary of the remaining calculations are available in Appendix A.) It is assumed that the composition of the data collected from the Blue Sky Report for the location at San Jose are similar to the data collected in the San Jose PM_{10} Study. As such, the mass fraction which are attributed to diesel exhaust are assumed to be similar.

Table V-6 show the diesel exhaust PM_{10} concentrations as well as the total PM_{10} and primary PM_{10} concentrations for 1990 at San Jose. The total PM_{10} concentrations are directly obtained from the Blue Sky Report. The diesel exhaust PM_{10} concentration is obtained by scaling the primary PM_{10} concentration by 0.1084 (see Table V-7). This scaler is the fraction of diesel exhaust PM_{10} concentration over primary PM_{10} concentration in the San Jose PM_{10} Study.

Table V-6
1990 Annual Average PM_{10} Concentration at
Select San Francisco Bay Area Air Basin Site

Site	Total PM_{10} ($\mu g/m^3$)	Primary PM_{10} ($\mu g/m^3$)	Diesel Exhaust PM_{10} ($\mu g/m^3$)
San Jose 4300377	35.4	25.7	2.79

Table V-7 shows the fraction representing diesel exhaust PM_{10} concentrations over primary PM_{10} concentrations as well as the calculated diesel exhaust PM_{10} and the primary PM_{10} concentration for each of the sites from the San Jose PM_{10} Study. The mean fraction for the data at both sites is 0.1084. The diesel exhaust PM_{10} concentration in Table V-7 is directly from Table V-3 (three significant figures are included in Table V-7 to avert round-off error). The primary PM_{10} concentration in Table V-7 is calculated by subtracting the secondary PM_{10} from total PM_{10} concentration in the San Jose PM_{10} Study.

Table V-7 Annual Average Primary PM_{10} and Diesel Exhaust PM_{10} Concentrations for the San Jose PM_{10} Study Sites			
Sampling Site	Primary ($\mu g/m^3$)	Diesel Exhaust ($\mu g/m^3$)	Fraction (Diesel Ex) / (Primary)
San Jose 4th St	26.0	2.88	0.1108
San Jose San Carlo	26.6	2.82	0.1060
MEAN			0.1084

To continue with the example, the primary PM_{10} concentration for San Jose 4th Street, in Table V-6, is obtained by subtracting the secondary PM_{10} concentration from the total PM_{10} concentration obtained from the Blue Sky Report as shown in Table V-8. In the case for the SFBAAB, the sulfates, nitrates, and chlorides are scaled by 1.14, 1.28, and 1.65, respectively, to obtain secondary PM_{10}. The secondary PM_{10} scalers are the same as those used for the SJV since the data are not available to develop scalers specific to the SFBAAB. Therefore the primary PM_{10} concentration for the San Jose site is 25.6 $\mu g/m^3$ (25.6 = 35.4 - 2.2(1.14) - 4.0(1.28) - 1.3(1.65)).

Table V-8 1990 Annual Average PM_{10} Concentrations, Total, Anions, and Primary					
Site	Total PM_{10} ($\mu g/m^3$)	$SO_4^=$ ($\mu g/m^3$)	NO_3- ($\mu g/m^3$)	Cl- ($\mu g/m^3$)	Primary PM_{10} ($\mu g/m^3$)
San Jose 4300377	35.4	2.2	4.0	1.3	25.6

The above example is applicable for estimating the diesel exhaust PM_{10} concentration from data in the Blue Sky Report for the site located at San Jose. Similar procedures are used to estimate the diesel exhaust PM_{10} concentrations for other locations in the SFBAAB.

Table A-13 in Appendix A shows the estimated diesel exhaust PM_{10} concentration for sites in the SFBAAB. Also included are the total PM_{10} concentrations and an estimate of the primary PM_{10} concentrations based on the above methods.

3. Micro-environment Evaluation Data Requirement

The computation of the standard deviation of the PM_{10} data is the same as for the SJV and the South Coast Air Basins.

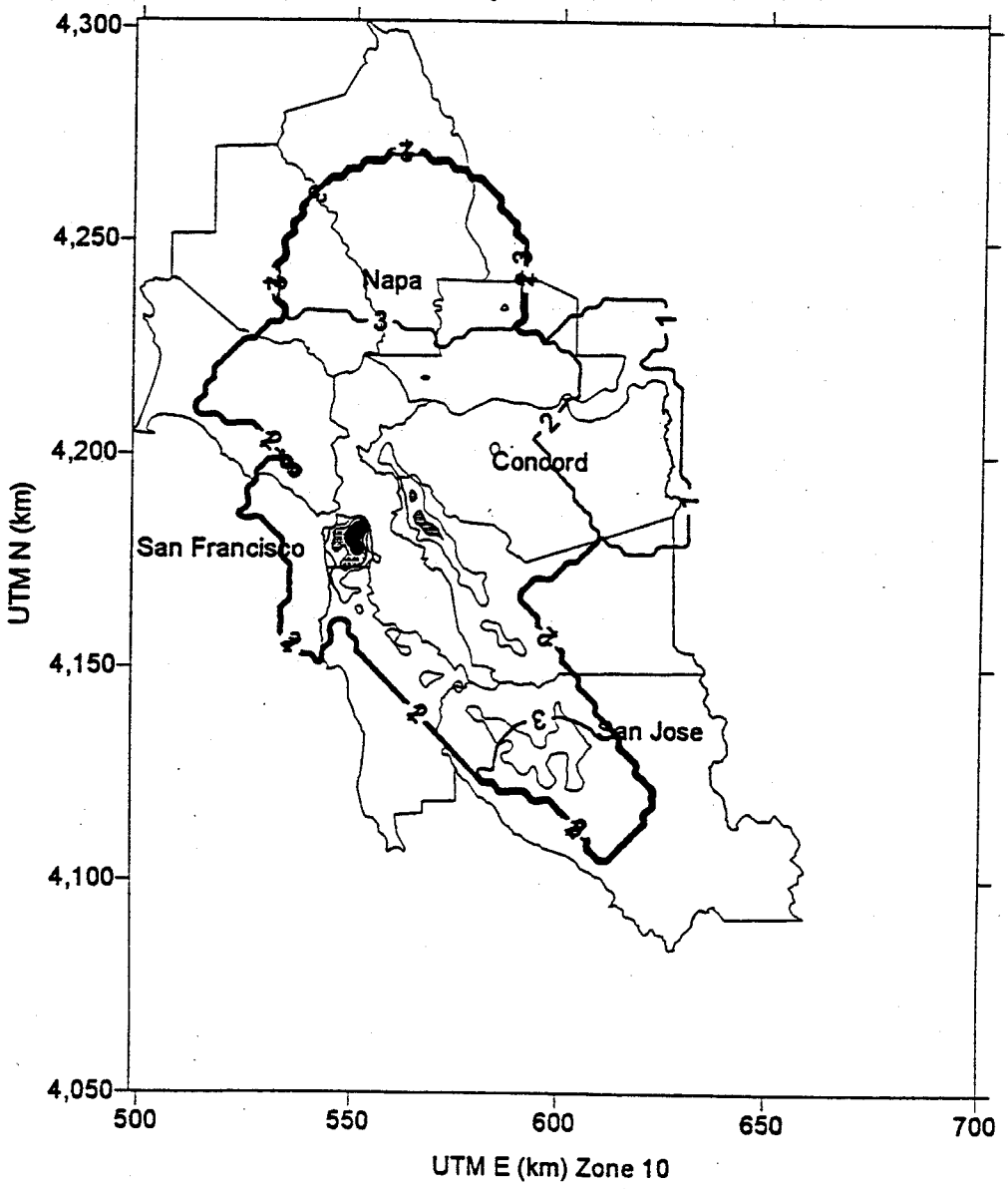
4. Interpolation Algorithms - San Francisco Bay Area Air Basin

Figures 4A, 4B, and 4C show the modeling domain used for the interpolation model in the San Francisco Bay Area Air Basin. Figures 4A and 4B show the interpolated diesel exhaust PM_{10} concentrations over the domain using interpolation search radius of 30 kilometers and weighting power factor of two. The domain is digitized with a two kilometer resolution including UTM Zone 10 coordinates, 500,000 meters east to 700,000 meters east and 4,050,000 meters north to 4,300,000 meters north. This configuration results in a grid with 101 X 126 (12,726) cells. Listed in Appendix B are the PM_{10} ambient monitoring station descriptions and digitized coordinates.

Based on the diesel exhaust PM concentrations and the interpolation model parameters above, the population-weighted annual average diesel exhaust PM_{10} concentration for the SFBAAB is 2.5 $\mu g/m^3$. The standard deviation from the annual average is 1.6 $\mu g/m^3$, based on the variation in the product of PM_{10} measurements and population collected every sixth day during the 1988 - 1992 period.

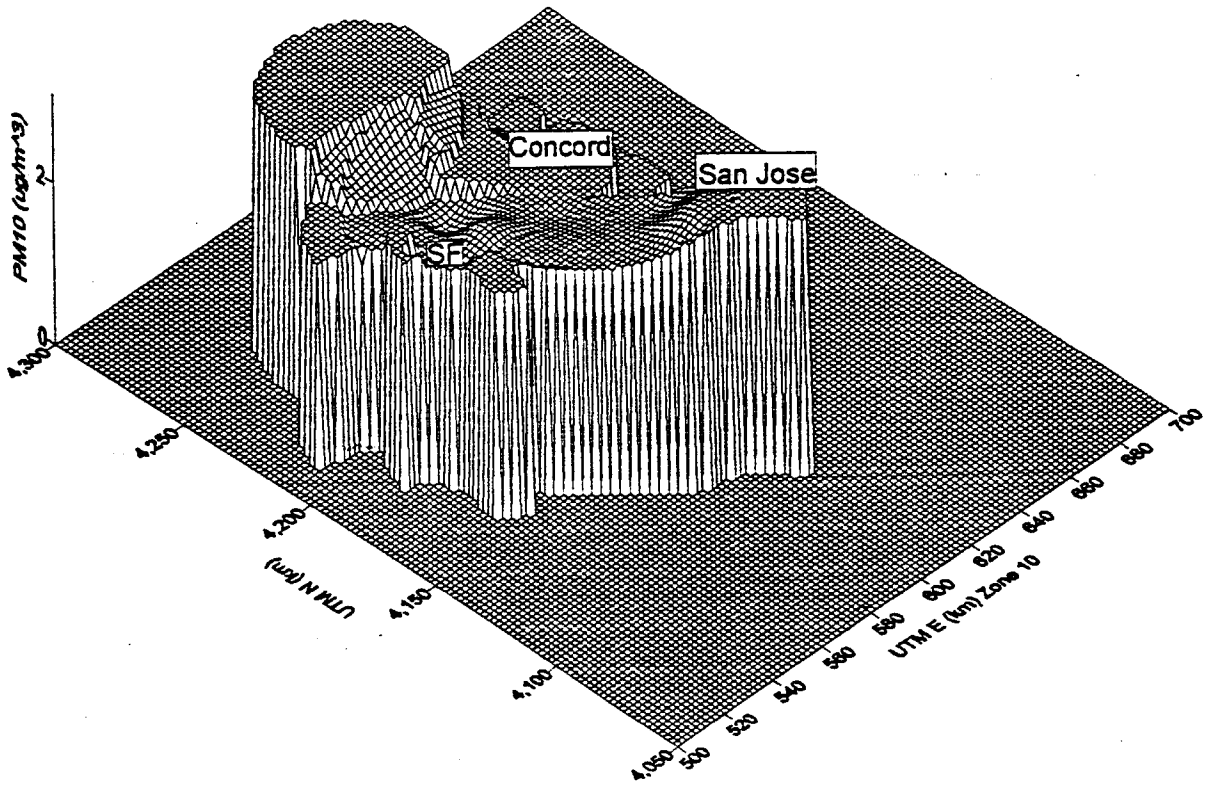
Figure 4A

Estimated Annual PM_{10} Concentration from Diesel Exhaust Emissions in the San Francisco Bay Area Air Basin



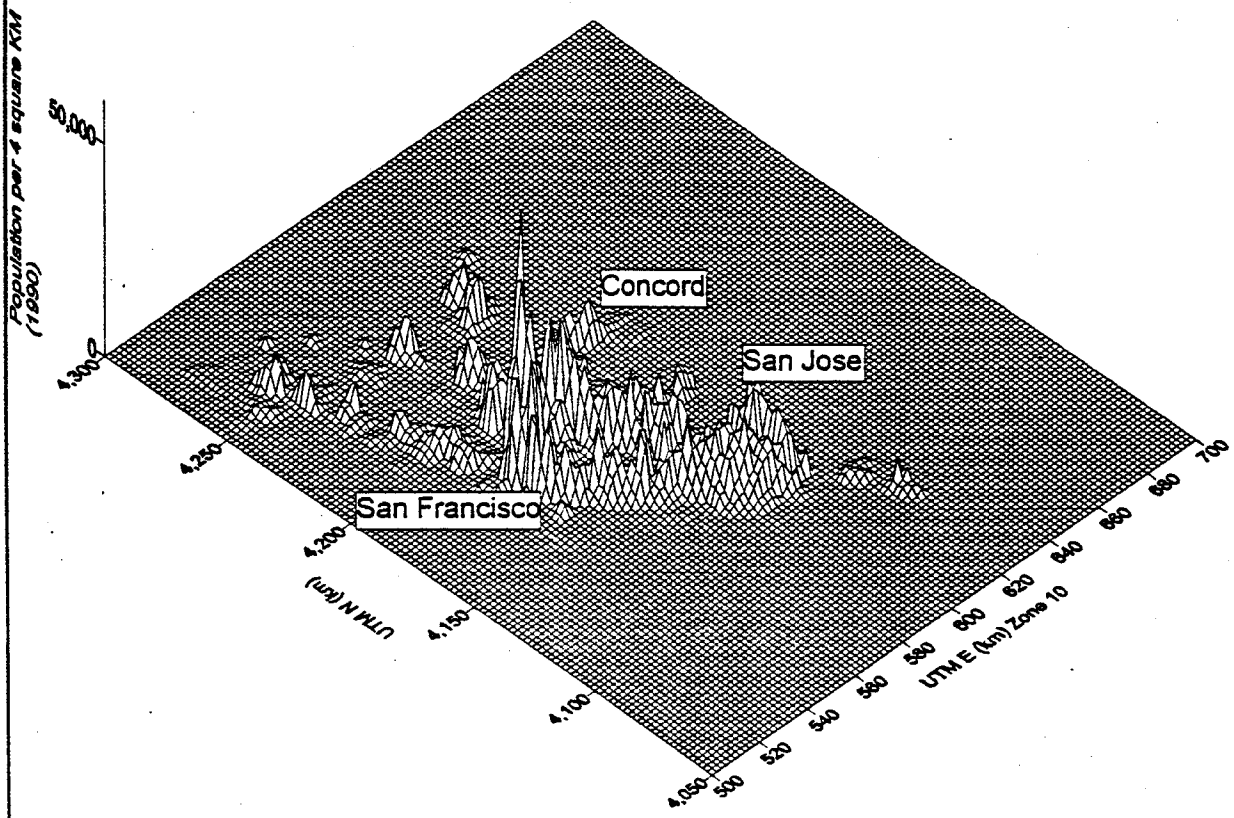
Each bold isopleth represents a change of 1.0 microgram per cubic meter.
Concentrations outside the Air Basin are not represented.
The interpolation isopleth search radius is limited to 30 kilometers.
Each shaded contour represents a change in population of 2,500 people per square kilometer.

Figure 4B
Estimated Annual PM_{10} Concentration
from Diesel Exhaust Emissions
in the San Francisco Bay Area Air Basin



Concentrations outside of the Air Basin are not represented.
Interpolation search radius is limited to 30 kilometers.

Figure 4C
1990 Population Distribution
in the San Francisco Bay Area Air Basin



5. Sensitivity Studies - San Francisco Bay Area Air Basin

Similar to the SJV, an investigation is made to evaluate the interpolation model for various values for the search radius. Table V-9 shows the results of these simulations.

Table V-9
PM_{10} Interpolation Sensitivity Summary
San Francisco Bay Area Air Basin

Search Radius (km)	Inverse Power (factor)	Grid Resolution (km)	Population W/in Intrp. Grids	Pop. Weighted Annual Average ($\mu g/m^3$)
30	2	2	93%	2.31
500	2	2	100%	2.31

Table V-9 shows population-weighted average concentration is insensitive to search radius between 30 kilometers to 500 kilometers. From those results, a search radius of 30 kilometers was used for our analysis.

VI. ESTIMATING THE POPULATION-WEIGHTED AVERAGE AMBIENT DIESEL EXHAUST PM_{10} CONCENTRATION IN THE SALTON SEA AIR BASIN

A. Method

In this section, the analysis and calculations used to estimate ambient diesel exhaust PM_{10} concentrations in the Salton Sea Air Basin are provided. The method is similar to that of the SCAB. The SC PM_{10} Study includes chemical mass balance analysis for PM_{10} data gathered from September 12, 1988, through October 31, 1989, in Indio and Palm Springs. These PM_{10} data may bias our results for this air basin towards overestimation because the data are collected near fire stations, a potential source of diesel exhaust emissions, at both locations. It was decided to use these data, even with the potential bias, for two reasons. First, the results of available chemical mass balance analysis are more indicative of site specific ambient air than a estimated result from other modeling methods. Secondly, the population in the air basin is less than two percent of the population in the other air basins were chemical mass balance results are available, SJVAB, SCAB, and SFBAAB. Therefore any bias introduced with this calculation will have minimal effects on the calculated state-wide population weighted average PM_{10} concentration.

B. Calculations

In this section, the calculations used to estimate ambient diesel exhaust PM_{10} concentrations for the Salton Sea Air Basin are shown. Based on the following analysis, the population-weighted average concentration for diesel exhaust PM_{10} concentration is estimated to be 2.6 $\mu g/m^3$ in the Salton Sea Air Basin.

1. Calculations for Ambient PM_{10} Concentration from Direct Diesel Exhaust Emissions in the Salton Sea Air Basin

Table VI-1 show results obtained from the SC PM_{10} Study which include the measured total ambient PM_{10} concentration. Also shown are the primary motor vehicle mass calculated with a chemical mass balance analysis. Finally, shown in Table IV-1 are our estimate of the diesel exhaust mass in the Salton Sea Air Basin from the 1988-1989 data.

Table VI-1
Ambient Annual Average PM_{10} Concentrations
in the Southeast Desert Air Basin,
9/88 through 10/89 Data

Sampling Site	(1) Meas. Total ($\mu g/m^3$)	(2) Primary Motor Vehicle ($\mu g/m^3$)	(3) Direct Diesel Exhaust ($\mu g/m^3$)
Indio	58.0	4.5	2.8
Palm Springs	35.1	2.4	1.5

Source: SC PM_{10} Study

(1) Measured total PM_{10}.
(2) Calculated primary motor vehicle mass from CMB results.
(3) Calculated diesel exhaust mass, estimated as a subset of (2).

The direct diesel exhaust PM_{10} concentration, column (3), in Table VI-1 is computed by scaling the primary motor vehicle PM_{10} concentration, column (2), by 0.625. This scale factor is determined from the ratio of diesel exhaust PM_{10} inventory to the total PM_{10} inventory due to petroleum-based fuel sources.

Table VI-2 shows the inventory of PM_{10} emissions from the combustion of petroleum based fuels in the former Southeast Desert Air Basin, based on the 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis, January 1995. (The emission inventory is based on the old Southeast Desert Air Basin designation because EMFAC7G does not include results for the newly designated Salton Sea Air Basin.) Itemized in Table VI-2 are the emissions from on-road motor

vehicles burning diesel fuel, other internal combustion engines that burn numbers one and two distillate fuels, on-road motor vehicles that burn gasoline, and the combustion of other petroleum based fuels.

Table VI-2
PM_{10} Emission Inventory
for Petroleum Based Fuels
in the former Southeast Desert Air Basin, 1990

Source Type	(Tons per Year)
Motor Vehicle Diesel	2,071[a]
Other Distillate Fuels	767[b]
Motor Vehicle Gasoline	123[c]
Other Petroleum Based Fuels	1,577[d]
Total	4,538

Source: 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis

(a) On road motor vehicle diesel engines (EMFAC7G)
(b) Other engines combusting #1 and #2 distillate oil (1/19/95 EI query)
(c) On road motor vehicle gasoline engines (EMFAC7G)
(d) Other combustion of petroleum based fuels (1/19/95 EI query)

To derive the scaling factor, the numerator is 2,838 tons per year of PM_{10} emitted from engines burning numbers one and two fuel oil in the Southeast Desert Air Basin (2,838 = 2,071 + 767). The denominator becomes the emissions of all petroleum based fuels, 4,538 tons per year. Therefore the diesel exhaust subset is 0.625 (0.625 = 2,838 / 4,538).

2. Estimation of Diesel Exhaust PM_{10} Concentrations from the Blue Sky Report in the Southeast Desert Air Basin

Table VI-3 shows the estimated diesel exhaust PM_{10} concentration for sites located in the Salton Sea Air Basin for the five-year average including 1988 - 1992. Table VI-3 is estimated from data in the Blue Sky Report.

Table VI-3 Five Year Average, 1988 - 1992 Diesel Exhaust PM_{10} Concentration, Salton Sea Air Basin		
Site	Site Number	Diesel Exhaust PM_{10} ($\mu g/m^3$)
Brawley-Main	(1300693)	3.01
El Centro-9th	(1300694)	2.74
Indio-Jackson	(3300157)	3.31
Palm Springs	(3300137)	1.64

As an example to deriving the values in Table VI-3, the detailed calculation for data collected in 1990 for the sampling sites in Indio are given. It is assumed that the composition of the data collected from the Blue Sky Report for the location of Indio are similar to the data collected in the SC PM_{10} Study for Indio and Palm Springs. As such, the mass fraction, which are attributed to diesel exhaust, are assumed to be similar.

Table VI-4 shows the diesel exhaust PM_{10} concentrations as well as the total PM_{10} and primary PM_{10} concentrations for 1990 at the Indio location. The total PM_{10} concentration is directly obtained from the Blue Sky Report. The diesel exhaust PM_{10} concentration is obtained by scaling the primary PM_{10} concentration by 0.0570 (see Table VI-5). This scaler is the mean fraction of diesel exhaust PM_{10} over primary PM_{10} for the Indio and Palm Springs sites in the SC PM_{10} Study.

Table VI-4 1990 Annual Average PM_{10} Concentrations, Select Sites in the Salton Sea Air Basin			
Site	(1) Total PM_{10} ($\mu g/m^3$)	(2) Primary PM_{10} ($\mu g/m^3$)	(3) Diesel Exhaust PM_{10} ($\mu g/m^3$)
Indio 3300157	79.3	70.6	4.03
(1) Total PM_{10} from Blue Sky Report. (2) Primary PM_{10} calculated as a subset of (1). (3) Diesel Exhaust PM_{10} calculated as a subset of (2).			

Table VI-5 shows the fraction representing diesel exhaust PM_{10} concentration over primary PM_{10} concentration as well as the calculated diesel exhaust PM_{10} and the primary PM_{10} concentration for each of the sites in the Salton Sea Air Basin from the SC PM_{10} Study. The mean fraction from the two sites is 0.0570 (see Table VI-5). The diesel exhaust PM_{10} concentration in Table VI-5 is obtained directly from Table VI-1. The primary PM_{10} concentration in Table VI-5 is calculated by subtracting the secondary PM_{10} concentration from total PM_{10} concentration in the SC PM_{10} Study.

Table VI-5
Annual Average Concentrations,
Primary PM_{10} and Diesel Exhaust PM_{10}
for the SC PM_{10} Study Sites in the Salton Sea Air Basin

Sampling Site	Primary ($\mu g/m^3$)	Diesel Exhaust ($\mu g/m^3$)	Fraction (Diesel Ex) / Primary
Indio	49.1	2.81	0.0572
Palm Springs	26.4	1.50	0.0568
MEAN			0.0570

Table VI-6 shows the primary PM_{10} concentration from the measurements in the SC PM_{10} Study. Also shown are the results of the secondary PM_{10} concentration calculations from the SC PM_{10} Study. The primary PM_{10} concentration is calculated by subtracting the secondary PM_{10} concentration from the total measured PM_{10} concentration. The primary PM_{10} concentration for Indio in the SC PM_{10} Study is calculated as 49.1 $\mu g/m^3$ (49.1 = 58.0 - 3.71 - 4.23 - 0.99).

Table VI-6
Ambient Annual Average PM_{10} Concentrations
Secondary Particulates
SCAQMD 1988 Data for the Salton Sea Air Basin

Sampling Site	Measured Total ($\mu g/m^3$)	Secondary $(NH_4)_2SO_4$ ($\mu g/m^3$)	Secondary NH_4NO_3 ($\mu g/m^3$)	$NaNO_3$ + NaCl ($\mu g/m^3$)	Primary ($\mu g/m^3$)
Indio	58.0	3.71	4.23	0.99	49.1
Palm Springs	35.1	3.86	4.35	0.49	26.4

To continue with the example, the primary PM_{10} concentration for Indio in Table VI-4 is obtained by subtracting the secondary PM_{10} concentration from the total PM_{10} concentration obtained from the Blue Sky Report as shown in Table VI-7. In the case for the Salton Sea Air Basin, the sulfates, nitrates, and chlorides are scaled by 1.14, 1.28, and 1.65, respectively, to obtain secondary PM_{10}. (The secondary PM_{10} scalers are the same as those used for the SJV since the data is not available to develop scalers specific to the Salton Sea Air Basin.) Therefore the primary PM_{10} for Indio is 70.6 $\mu g/m^3$ (70.6 = 79.3 - 3.2(1.14) - 3.7(1.28) - 0.2(1.65)).

Table VI-7
1990 Annual Average PM_{10} Concentrations,
Total, Anions, and Primary

Site	Total PM_{10} ($\mu g/m^3$)	$SO_4^=$ ($\mu g/m^3$)	NO_3^- ($\mu g/m^3$)	Cl^- ($\mu g/m^3$)	Primary PM_{10} ($\mu g/m^3$)
Indio 3300157	79.3	3.2	3.7	0.2	70.6

The above example is applicable for estimating the diesel exhaust PM_{10} concentration from data in the Blue Sky Report for the site located in the Salton Sea Air Basin. Table A-11 in Appendix A shows estimated diesel exhaust PM_{10} concentration for sites in the Salton Sea Air Basin. Also included are the total PM_{10} concentrations and an estimate of the primary PM_{10} concentrations based on the above methods.

VII. ESTIMATING THE POPULATION-WEIGHTED AVERAGE AMBIENT DIESEL EXHAUST PM_{10} CONCENTRATION IN OTHER AIR BASINS

A. Method

This section presents the analysis and calculations used to estimate ambient diesel exhaust PM_{10} concentrations for the other ten air basins in California.

The DRI SJV PM_{10} Analysis results applied to the San Joaquin Valley Air Basin are the basis for estimating the ambient diesel exhaust PM_{10} concentrations for the other air basins in California. Ambient PM_{10} concentrations are obtained from the Blue Sky Report for the years 1988 though 1992, with the monitoring sites identified as representing a rural or urban area.

A PM_{10} sample collected in any urban area of the state, other than the South Coast, the San Francisco Bay Area, or the Salton Sea Air Basins, are assumed to have similar characteristics to a PM_{10} sample collected in an urban area of the SJV, with respect to the identified categories and chemical speciation. Table III-5 identifies the urban and rural fraction of diesel exhaust PM_{10} concentration to the primary ambient PM_{10} concentration for the SJV. It is assumed that 0.0665 fraction of the annual primary PM_{10} concentration collected in Sacramento, for example, is attributed to diesel exhaust. For rural locations, 0.0329 fraction of the annual primary PM_{10} concentration is assumed to be from diesel exhaust.

Individual scaling factors to account for the different quantities of emissions in the other air basins are derived for each air basin. For example, the San Joaquin Valley Air Basin has more agricultural activity than the North Coast Air Basin. Thus, 1990 Emission Inventory for Diesel Exhaust Analysis is used to develop a scaling factor relative to the San Joaquin Valley. In the San Joaquin Valley, 1.29% of the PM_{10} emissions inventory are from diesel and turbine engine exhaust burning numbers one and two fuel oil. In the Sacramento Valley Air Basin,

1.97% of the PM_{10} emissions inventory are from diesel and turbine engine exhaust burning numbers one and two fuel oil. Therefore, the scaling factor for the Sacramento Valley Air Basin estimate is 1.53 (1.53 = 1.97% / 1.29%). The Sacramento Valley Air Basin estimate of diesel exhaust PM_{10} concentration is multiplied by the scale factor of 1.53 to account for the varied activity.

With an estimated PM_{10} concentration from diesel exhaust at various discrete locations, the interpolation model is applied, as discussed in section III. A., to estimate spatial concentrations within a defined domain for the other air basins.

The 1990 census data are distributed on a population grid which is superimposed on the interpolated concentration grid. The population-weighted average concentration for the air basin is then computed.

B. Calculations

Tables A-2 through A-15, in Appendix A, show the data obtained from the Blue Sky Report for PM_{10} measurements in the other air basins. Also shown in Tables A-2 through A-15 are the scaling factors used to adjust the PM_{10} concentrations from diesel engine exhaust relative to the SJV surrogate.

Table VII-1 shows the 1990 emission inventory for diesel exhaust emissions and total basin wide emissions per air basin extracted from the 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis. As discussed above, the inventory is used to determine an activity scale to estimate PM_{10} concentrations from diesel engine exhaust in other air basins relative to the SJV analysis.

Table VII-1
1990 PM_{10} Emission Inventory by Air Basin

Air Basin	(1) Turb. Eng. #1, #2 Fuel Oil (tons/year)	(2) Diesel & Turbine Engines (tons/year)	(3) All Sources (tons/year)	(4) (AB)/(SJV) Scale (factor)
Great Basin Valleys	-	131	30,406	.334
Lake County	-	57	6,695	.661
Lake Tahoe	-	46	3,394	1.047
Mountain Counties	.5	601	62,553	.745
North Central Coast	.0	853	54,276	1.218
North Coast	.0	747	41,910	1.382
Northeast Plateau	-	651	41,852	1.206
Sacramento Valley	3.0	3,486	177,071	1.526
San Diego	.0	2,511	114,051	1.707
San Francisco Bay Area	3.3	4,962	203,629	(a)
San Joaquin Valley	22.8	5,206	403,689	1.000
South Central Coast	1.2	1,605	75,144	1.656
South Coast	8.6	17,802	453,924	(a)
Southeast Desert	.8	2,837	485,226	.453[b]

Source: 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis, January 19, 1995 with EMFAC7G substitutions

(1) Emissions from turbine engines burning numbers one and two fuel oil.
(2) Emissions from diesel and turbine engines burning numbers one and two fuel oil.
(3) Emissions from all sources.
(4) Fractional scale with respect to the San Joaquin Valley.

(a) Scale with respect to the San Joaquin Valley is not needed because source apportionment results are available for these air basins.
(b) The Southeast Desert scale is used for the Mojave Desert Air Basin. Scale is not needed for the Salton Sea Air Basin.

Column (1) in Table VII-1 is the PM_{10} emission from turbine engines burning numbers one and two fuel oil. Column (2) in Table VII-1 is the PM_{10} emission from turbine and diesel engines burning numbers one and two fuel oil. (Column (1) is a subset of column (2).) We include all emissions from internal combustion engines burning numbers one and two fuel oil in

the diesel exhaust calculations since the contribution from turbine engines is small. The influence of the turbine engine emissions on the population-weighted average PM_{10} concentrations are negligible as seen in Table VII-1.

Table VII-2 shows the domain, UTM coordinates, and grid resolution for the fifteen air basins in this analysis. Physical barriers are digitized to represent mountain barriers for the interpolation model. This prevents the model from interpolating the concentration for a grid cell from a monitoring site located on the other side of a mountain range. For example, hills separate the Oakland-Hayward area from the Concord-Walnut Creek area. Therefore, a barrier is digitized to represent these hills. (The barrier coordinates can be seen in Appendix C.)

Figures 5A, 5B, and 5C show the modeling domain and interpolated PM_{10} concentrations attributed to diesel exhaust emissions from the San Diego Air Basin. The modeling domain and interpolated PM_{10} concentrations are plotted for the air basin with the highest population, the San Diego Air Basin.

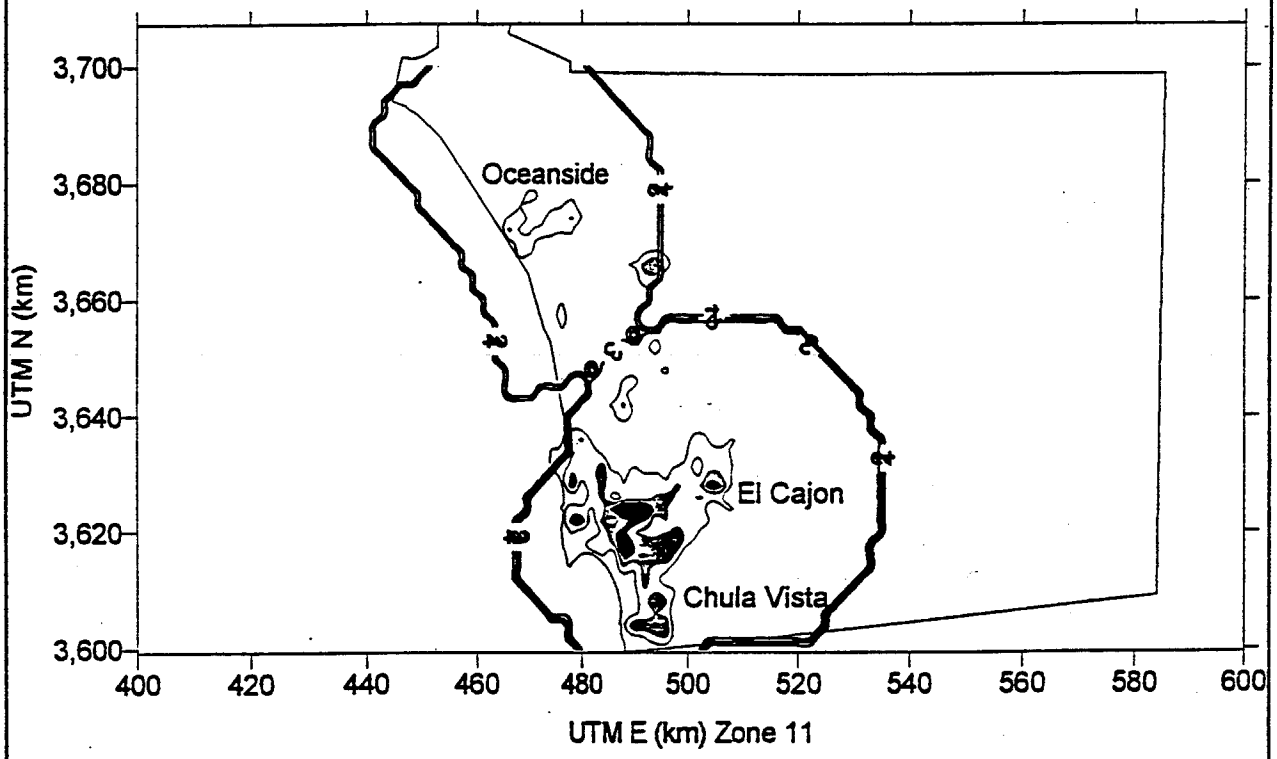
PM_{10} concentrations are interpolated for all of the air basins, except two. The Lake County and Lake Tahoe Air Basins have only one air monitoring location. Thus, it is assumed that the entire population with these two air basins are exposed to the concentrations measured at the monitoring locations. Table VII-2 shows no modeling domain for these two air basins.

Table VII-2
Modeling Domain for Air Basins

Air Basin	UTM Zone	UTM East (km)	UTM North (km)	Grid Resol. (km)	Number of East Grids	Number of North Grids
Great Basin Valleys	11	230.	3960.	5.	73	73
Lake County*	10	-	-	-	-	-
Lake Tahoe*	10	-	-	-	-	-
Mojave Desert	11	325.	3690.	5.	89	71
Mountain Counties	10	630.	4120.	5.	45	73
North Central Coast	10	560.	3960.	5.	39	35
North Coast	10	380.	4240.	5.	35	83
Northeast Plateau	10	450.	4400.	5.	63	51
Sacramento Valley	10	500.	4210.	5.	37	71
Salton Sea	11	510.	3600.	5.	52	37
San Diego	11	400.	3600.	2.	101	51
San Francisco Bay Area	10	500.	4050.	2.	101	126
San Joaquin Valley	10	600.	3850.	5.	71	81
South Central Coast	11	100.	3760.	2.	126	106
South Coast	11	300.	3650.	2.	101	101

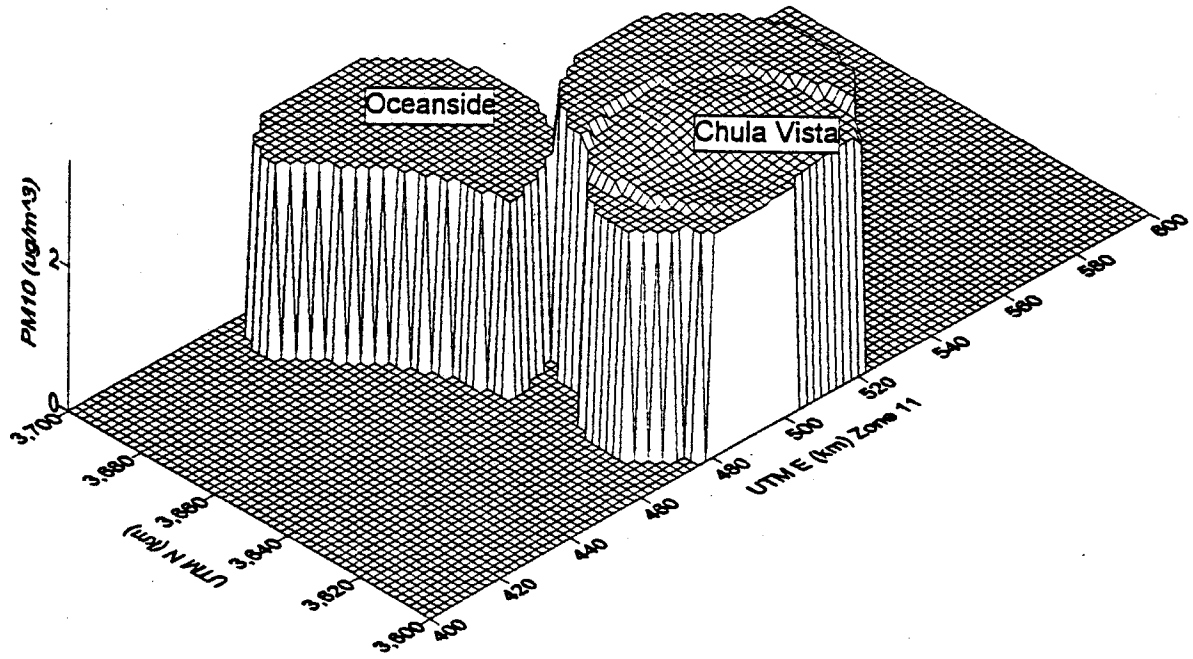
* These air basins have only one air monitoring location. Therefore we have no modeling domain for Lake County and Lake Tahoe Air Basins.

Figure 5A
Estimated Annual PM_{10} Concentration from Diesel Exhaust Emissions in the San Diego Air Basin



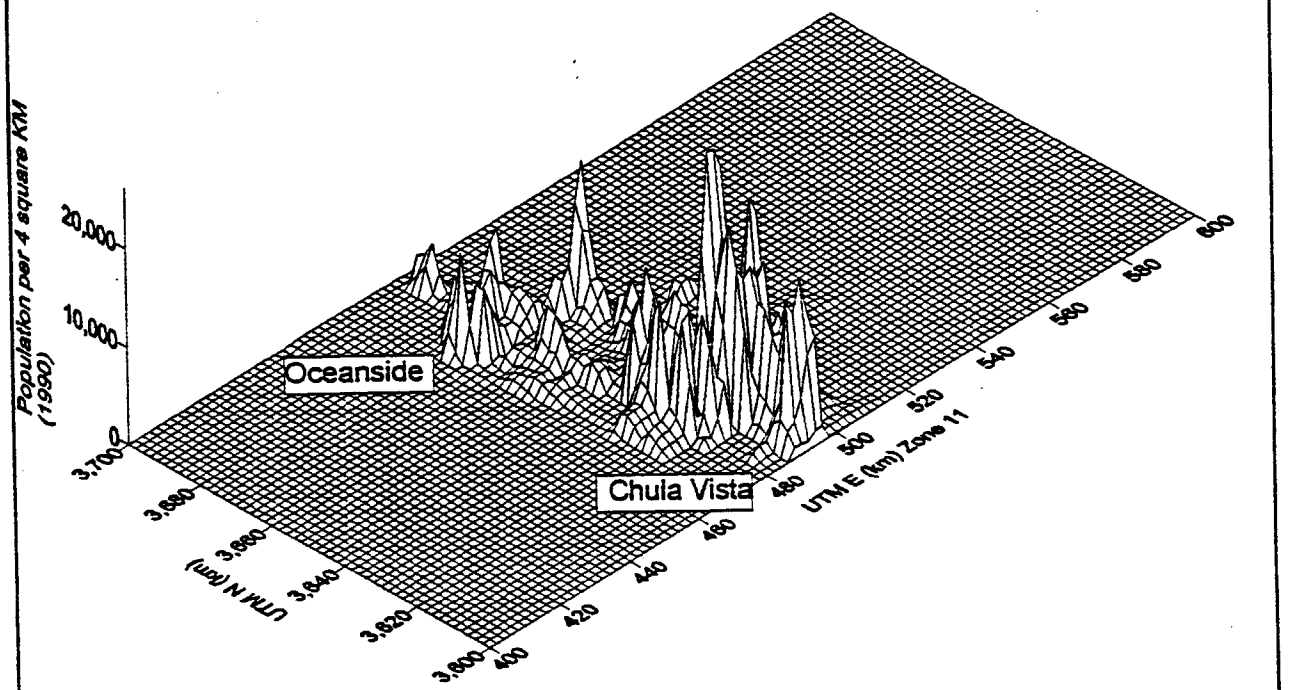
Each bold isopleth represents a change of 1.0 micrograms per cubic meter.
Concentrations outside the Air Basin are not represented.
The interpolation search radius is limited to 30 kilometers.
Each shaded contour represents a change in population of 1,250 people per square kilometer.

Figure 5B
Estimated Annual PM_{10} Concentration
from Diesel Exhaust Emissions
in the San Diego Air Basin



Concentrations outside of the Air Basin are not represented.
Interpolation search radius is limited to 30 kilometers.

Figure 5C
1990 Population Distribution
in the San Diego Air Basin



VIII. LINEAR ROLLBACK PROJECTING - 1995, 2000, 2010

Linear rollback techniques are used to project the ambient diesel exhaust PM_{10} concentration for the years 1995, 2000, and 2010. For this technique, a one-to-one correspondence between basin-wide emissions and source contributions at a given site is assumed. Thus, the only data requirement are an accurate emissions inventory for the base year.

Table VIII-1 shows the PM_{10} emissions inventory from diesel exhaust emissions for the base year, 1990, and the projected years, 1995, 2000, and 2010. As an example, the state-wide population weighted average diesel exhaust PM_{10} concentration is projected to the years 1995, 2000, and 2010 by scaling the base year concentration by 0.722, 0.603, and 0.575, respectively. The scaler for 1995 is calculated by dividing the 1995 emission inventory, 29,942, by the 1990 emission inventory, 41,493, from Table VIII-1 (0.722 = 29,942 / 41,493). The results are shown in Section X, Results.

Table VIII-1
Base Year and Projected
Diesel Exhaust PM_{10} Emission Inventory by Air Basin
1990, 1995, 2000, 2010

Air Basin	1990 (tons/year)	1995 (tons/year)	2000 (tons/year)	2010 (tons/year)
Great Basin Valleys	131	86	65	54
Lake County	57	43	40	39
Lake Tahoe	46	25	17	14
Mountain Counties	601	426	364	347
North Central Coast	853	593	471	441
North Coast	747	547	488	490
Northeast Plateau	651	462	389	361
Sacramento Valley	3,486	2,252	1,718	1,502
San Diego	2,511	1,614	1,204	1,054
San Francisco Bay Area	4,962	3,711	3,103	2,970
San Joaquin Valley	5,206	3,511	2,743	2,339
South Central Coast	1,605	1,108	938	888
South Coast	17,802	13,578	11,880	11,843
Southeast Desert	2,837	1,987	1,596	1,510
Total	41,493	29,942	25,017	23,853

Source: 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis, January 19, 1995 with EMFAC7G substitutions

Note: The total may not equal the sum from each air basin as reported in ARB Emission Inventory due to rounding emissions to the nearest ton per year.

IX. PREFACE TO THE RESULTS

The results of this analysis are a first order estimate of PM_{10} concentrations attributed to emissions from diesel exhaust. The estimates are the result of assumptions based on the best available data. However, these results may not be representative of actual ambient conditions because the estimated PM_{10} concentrations attributed to emissions from diesel engines may be influenced by some of the uncertainties in the input data, and the limitations of the modeling approach. The following briefly discusses these uncertainties and limitations and their implications on the results.

A. Uncertainties

1) Most PM_{10} air monitoring stations are located near population centers and possibly near sources of emissions from diesel engine exhaust. Careful selection of the monitoring stations eliminated data which are located to represent the highest concentration or source impact. However, using the remaining data in the interpolation model to calculate concentrations for sparsely populated areas may result in overestimation. The sparsely populated areas have minimal impact on the population-weighted average for the domain. Any bias introduced in the analysis is toward overestimation.

2) The analysis performed relies on the 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis. The inventory data are used to develop scaling factors for the ambient diesel exhaust PM_{10} concentration in the SJV as well as to extrapolate the method of determining impacts from diesel exhaust in the SJV to other air basins. The uncertainties associated with the inventory in this report are reflected in our results as well.

3) The DRI SJV PM_{10} Analysis used to estimate the diesel exhaust PM_{10} concentration in the San Joaquin Valley is the surrogate for estimating PM_{10} concentrations for other air basins. As previously stated in Section VII, the SJV values are scaled to represent the other air basins, excluding the SCAB, the SFBAAB, and the Salton Sea Air Basin. This, however, may not represent actual conditions for those air basins.

B. Limitations

1) The results from the modified interpolation model used in this analysis directly reflect the accuracy of the ambient input data. A more refined approach would be to obtain speciated PM_{10} samples from a network of monitoring sites adequately representing the state. The chemical profile of diesel exhaust would then be used in a chemical mass balance model to determine the portion of the PM_{10} sample attributed to diesel exhaust. Finally, the interpolation model could be used to determine the ambient PM_{10} concentration for a gridded receptor field over which the gridded population could be matched to determine the population exposure.

2) The Lake County, Lake Tahoe, Mountain Counties, North Coast, and the Northeast Plateau Air Basins do not have sufficient monitoring sites to represent the PM_{10} concentration when compared to the other air basins. Although values are reported for these locations (Table X-1), there is the possibility that with more monitoring sites, the reported values could change.

X. RESULTS

Table X-1 lists the summary of population-weighted 5-year average diesel exhaust PM_{10} concentrations per air basin and the statewide average. The 5-year average is the result of estimating diesel exhaust PM_{10} concentrations from five years of Blue Sky Report data, 1988 through 1992. Also shown are the 1990 population for the air basin and statewide. Figures 6A, 6B, and 6C show the interpolated PM_{10} concentration attributed to diesel exhaust emissions statewide.

Table X-1
Summary of Population-Weighted 5-Year Annual Average
PM_{10} Concentrations Attributed to Emissions from Diesel Exhaust

Air Basin	1990 Population (1000's)	Diesel Ex. PM_{10} ($\mu g/m^3$)	Std. Dev. Based on Measurements ($\mu g/m^3$)
Great Basin Valleys	29	0.2	-
Lake County	51	0.3	-
Lake Tahoe	21	1.0	-
Mojave Desert	557	0.8	-
Mountain Counties	485	0.6	-
North Central Coast	622	1.4	-
North Coast	564	1.2	-
Northeast Plateau	80	1.1	-
Sacramento Valley	2,219	2.5	1.4
Salton Sea	333	2.6	-
San Diego	2,504	2.9	1.1
San Francisco Bay	5,967	2.5	1.6
San Joaquin Valley	2,658	2.6	1.2
South Central Coast	1,232	1.8	-
South Coast	12,809	3.6	1.4
Statewide	30,131	3.0	1.1

For the San Joaquin Valley Air Basin, the population-weighted ambient PM_{10} concentration attributed to emissions from diesel exhaust is estimated to be 2.6 micrograms per cubic meter.

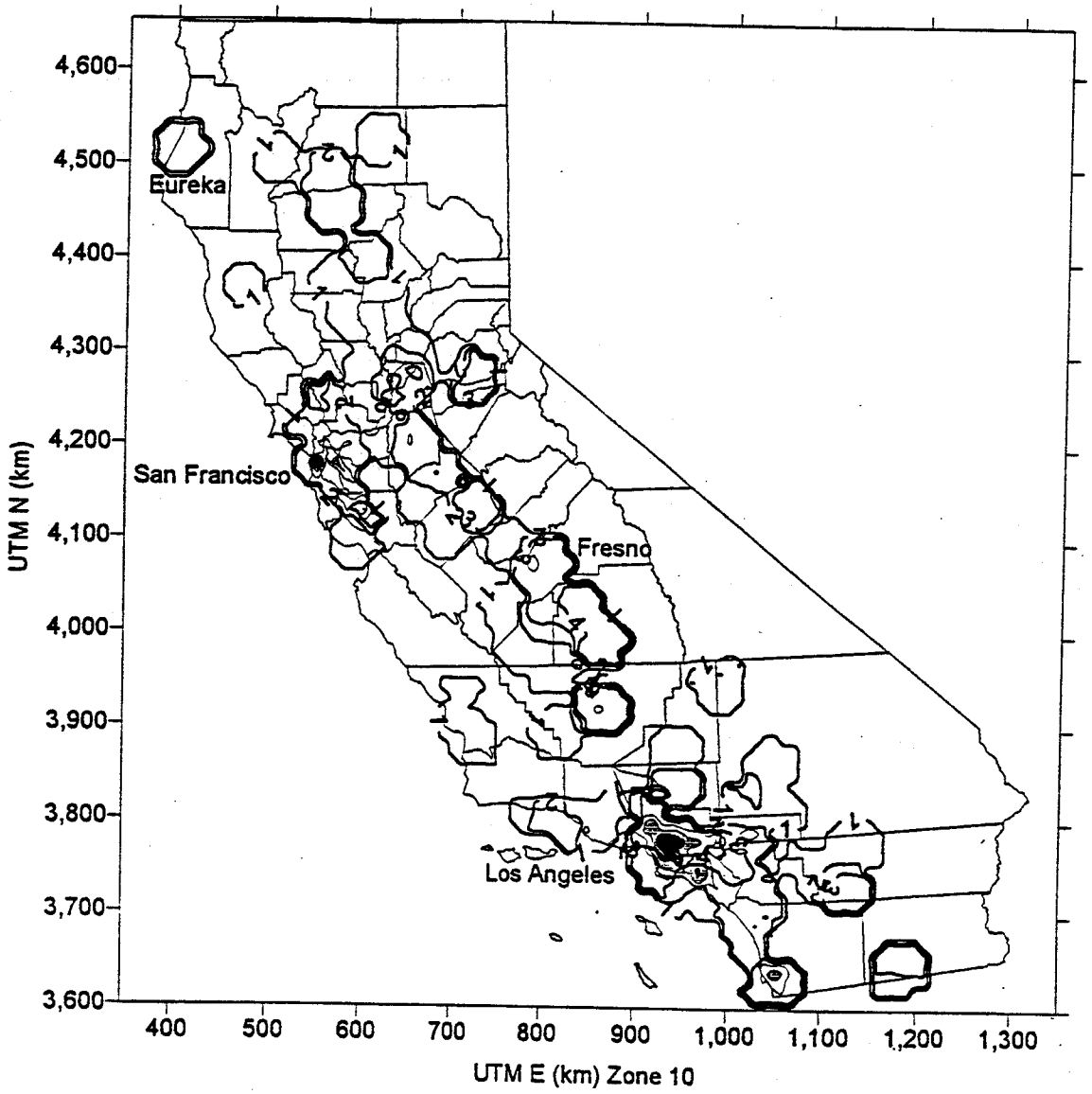
The air basin with the highest estimated population-weighted PM_{10} concentration is the South Coast Air Basin with 3.6 micrograms per cubic meter of PM_{10} attributed to emissions from diesel exhaust.

The air basin with the lowest estimated population-weighted PM_{10} concentration is the Great Basin Valleys Air Basin with 0.2 micrograms per cubic meter of PM_{10} attributed to emissions from diesel exhaust. These low values are presumably due to the limited emissions of diesel exhaust.

The standard deviation of the estimated diesel exhaust concentration based on the PM_{10} measurements are computed only for those air basins with the largest populations. This is done in order to minimize computation time. As previously discussed, the standard deviation is based on approximately 304 sets of 24-hour measurements evaluated on a basin-wide basis.

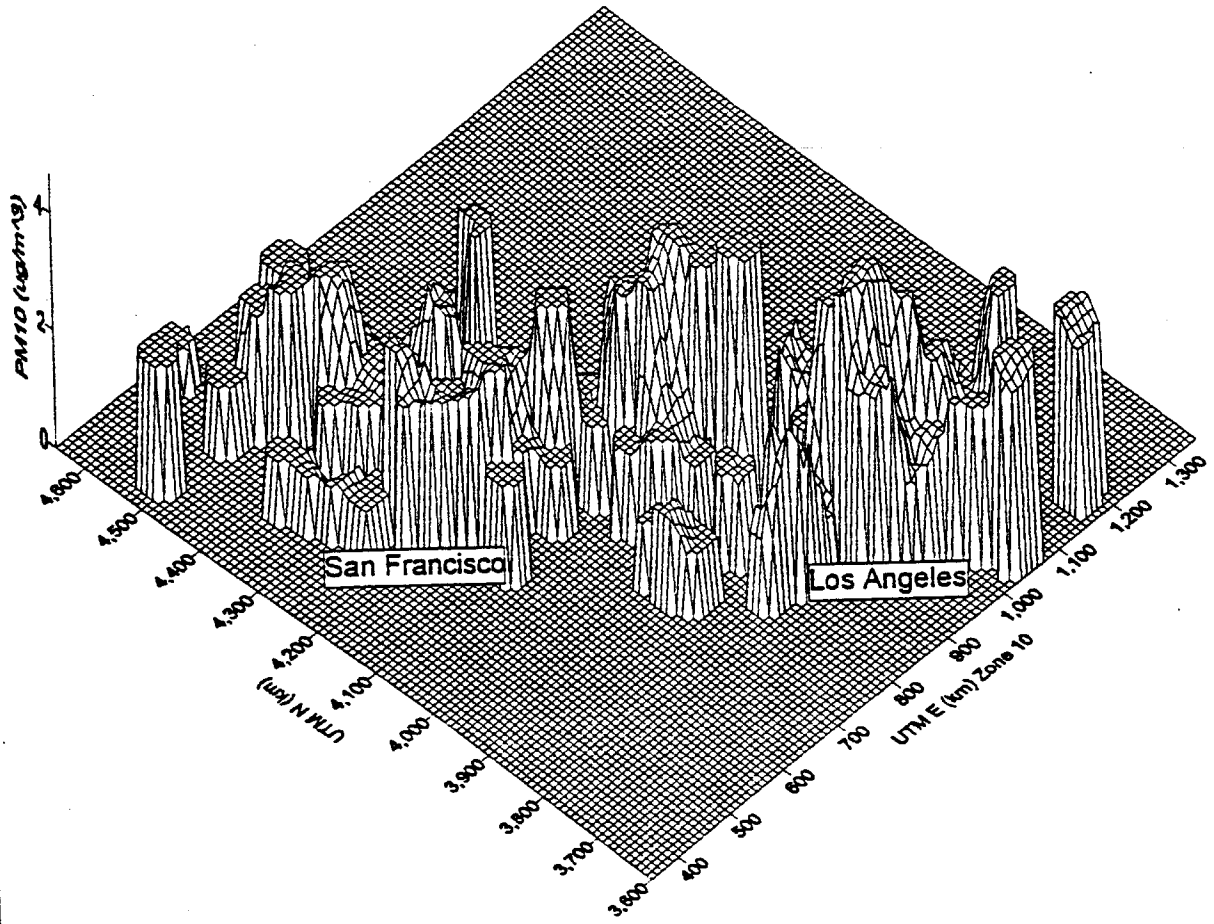
Table X-2 lists the projected diesel exhaust PM_{10} concentrations per air basin for the years 1995, 2000, and 2010. The PM_{10} concentrations are estimated with the linear rollback method discussed above. Also included are the estimated diesel exhaust PM_{10} concentrations for the base year, 1990. Table X-2 shows a decrease in the state-wide average of about one third for 1995 and then a nearly constant concentration through the year 2010. These projected concentrations are based entirely on the forecasted emission inventory of diesel exhaust emissions.

Figure 6A
Estimated Annual PM_{10} Concentration from Diesel Exhaust Emissions in California



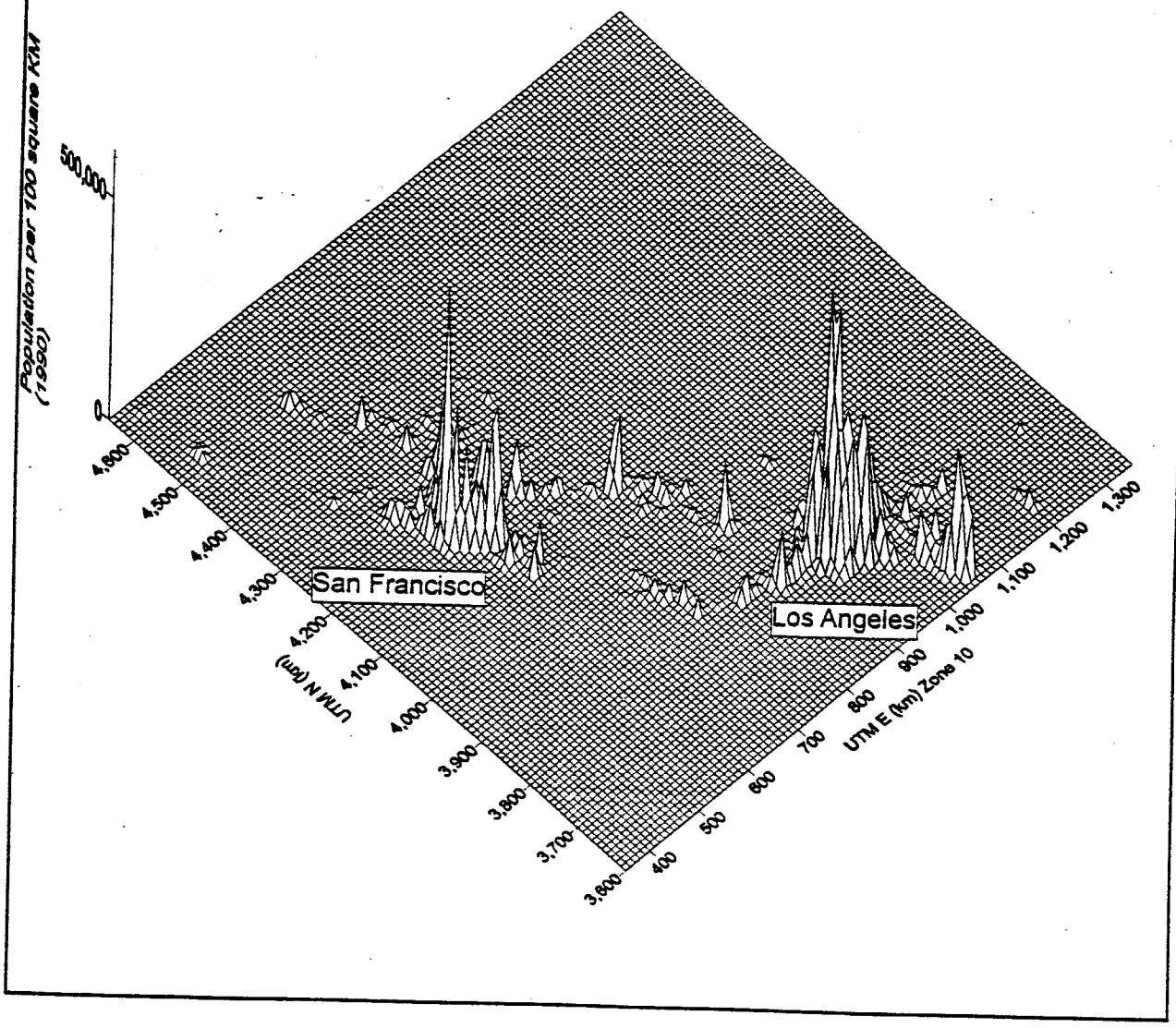
Each bold isopleth represents a change of 1.0 micrograms per cubic meter.
Concentrations outside of the state are not represented.
The interpolation search radius is limited to 30 kilometers.
Each shaded contour represents a change in population of 1,000 per square kilometer.

Figure 6B
Estimated Annual PM_{10} Concentration
from Diesel Exhaust Emissions
in California



Concentrations outside of the state are not represented.
Interpolation search radius is limited to 30 kilometers.

Figure 6C
1990 Population Distribution
in California



ts: dexambv3 wpf

Table X-2
Projected PM_{10} Concentrations
Attributed to Emissions from Diesel Exhaust
1990, 1995, 2000, 2010

Air Basin	Base Year 1990 ($\mu g/m^3$)	1995 ($\mu g/m^3$)	2000 ($\mu g/m^3$)	2010 ($\mu g/m^3$)
Great Basin Valleys	0.2	0.1	0.1	0.1
Lake County	0.3	0.2	0.2	0.2
Lake Tahoe	1.0	0.5	0.4	0.3
Mojave Desert	0.8	0.6	0.4	0.4
Mountain Counties	0.6	0.4	0.4	0.3
North Central Coast	1.4	1.0	0.8	0.7
North Coast	1.2	0.9	0.8	0.8
Northeast Plateau	1.1	0.8	0.7	0.6
Sacramento Valley	2.5	1.6	1.2	1.1
Salton Sea	2.6	1.8	1.5	1.4
San Diego	2.9	1.9	1.4	1.2
San Francisco Bay	2.5	1.9	1.6	1.5
San Joaquin Valley	2.6	1.7	1.3	1.2
South Central Coast	1.8	1.2	1.1	1.0
South Coast	3.6	2.7	2.4	2.4
Statewide	3.0	2.2	1.8	1.7

GLOSSARY/ ACRONYMS

BAAQMD: Bay Area Air Quality Management District

Blue Sky Report: Items 4) through 9) in Reference list, (e.g., California Air Resources Board California Air Quality Data Summary of 1987 Air Quality Data Gaseous & Particulate Pollutants, Annual Summary Vol. XIX Technical Support Division 1987.)

CARB: California Air Resources Board

CMB: Chemical Mass Balance

DRI: Desert Research Institute

DRI SJV PM_{10} Analysis: Item 1) in Reference list, (i.e., Desert Research Institute San Joaquin Valley Air Quality Study Phase 2: PM-10 Modeling and Analysis Volume I: Receptor Modeling Source Apportionment, DRI Document No. 8929.1F October 11, 1990.)

EMFAC7E: CARB's on road mobile source emission factor model, version 7E

EMFAC7F: CARB's on road mobile source emission factor model, version 7F

PM_{10}: Particulate matter ten microns ($10x10^{-6}$ meters) and smaller

SAI: Systems Applications International

San Jose PM_{10} Study: Item 10) in Reference list, (i.e., Chow, J. C., Fairley, D., Watson, J. G., De Mandel, R., Fujita, E. M., Lowenthal, D. H., Lu, Z., Frazier, C. A., Long, G., Cordova, J., "Source Apportionment of Wintertime PM_{10} at San Jose, CA," May 18, 1994, Submitted for publication.)

SC: South Coast

SC PM_{10} Study: Item 12) in Reference list, (i.e., South Coast Air Quality Management District, Air Quality Management Plan 1991 Revision, Technical Report V-F, PM_{10} Source Apportionment for the South Coast Air Basin, July 1991.)

SCAB: South Coast Air Basin

SCAQMD: South Coast Air Quality Management District

SFBA: San Francisco Bay Area

SFBAAB: San Francisco Bay Area Air Basin

SJV: San Joaquin Valley

UTM: Universal Transverse Mercator

$\mu g/m^3$: micrograms per cubic meter

REFERENCES

1) Desert Research Institute San Joaquin Valley Air Quality Study Phase 2: PM-10 Modeling and Analysis Volume I: Receptor Modeling Source Apportionment, DRI Document No. 8929.1F October 11, 1990.

2) California Air Resources Board 1990 PM_{10} Emission Inventory for Diesel Exhaust Analysis Emission Inventory Branch, Technical Support Division, January 1995.

3) California Air Resources Board, Technical Support Division Nature and Causes of the PM_{10} Problem in California, Technical Report, ARB/TS-87-002, May 1987.

4) California Air Resources Board California Air Quality Data Summary of 1987 Air Quality Data Gaseous & Particulate Pollutants, Annual Summary Vol. XIX Technical Support Division 1987.

5) California Air Resources Board, California Air Quality Data Summary of 1988 Air Quality Data Gaseous & Particulate Pollutants, Annual Summary Vol. XX Technical Support Division 1988.

6) California Air Resources Board, California Air Quality Data Summary of 1989 Air Quality Data Gaseous & Particulate Pollutants, Annual Summary Vol. XXI Technical Support Division 1989.

7) California Air Resources Board, California Air Quality Data Summary of 1990 Air Quality Data Gaseous & Particulate Pollutants, Annual Summary Vol. XXII Technical Support Division 1990.

8) California Air Resources Board, California Air Quality Data Summary of 1991 Air Quality Data Gaseous & Particulate Pollutants, Annual Summary Vol. XXIII Technical Support Division 1991.

9) California Air Resources Board, California Air Quality Data Summary of 1992 Air Quality Data Gaseous & Particulate Pollutants, Annual Summary Vol. XXIV Technical Support Division 1992.

10) Chow, J. C., Fairley, D., Watson, J. G., De Mandel, R., Fujita, E. M., Lowenthal, D. H., Lu, Z., Frazier, C. A., Long, G., Cordova, J., "Source Apportionment of Wintertime PM_{10} at San Jose, CA," May 18, 1994, Submitted for publication.

11) Department of Finance Population Estimates of California Cities and Counties, Report 92 E-1, Demographic Research Unit, May 1992.

12) South Coast Air Quality Management District, Air Quality Management Plan 1991 Revision, Technical Report V-F, PM_{10} Source Apportionment for the South Coast Air Basin, July 1991.

13) Systems Applications International, Diesel Particulate Matter in California: Exposure Assessment, Final Report, SYSAPP94-94/077, September 30, 1994.

14) U.S. Department of Commerce, Bureau of the Census, 1990 Census Data, Population, and Digitized Census Tracts.

APPENDIX A

Blue Sky Report PM_{10} and Diesel PM_{10} Tables

filename: DESPAM2.XLS, March 18, 1997
SMPA:73
Response to Public Comments 01 (Secondary PM10, Site Representation)
SO4 Scalar 1.182 1.038 SCAB only
NO3 Scalar 1.282 1.903 SCAB only
Cl Sclr in ca 1.65 1.65 SCAB only

Spatial Scale
MI Microscale
MS Middle Scale
NS Neighborhood Scale
US Urban Scale
RS Regional Scale

Monitoring Objectives
MC Highest Concentration
RC Representative Concentration
SM Impact
BL Background Level

Table A-1
San Joaquin Valley Annual PM-10 Concentrations (Zone 10)
(AM: Arithmetic Mean)

Station Name / ID Number	1988 AM	1988 SO4	1988 NO3	1988 Cl	1988 Cp/t	1988 Ep/t	1988 Ppm	1989 AM	1989 SO4	1989 NO3	1989 Cl	1989 Cp/t	1989 Ep/t	1989 Ppm	1990 AM	1990 SO4	1990 NO3	1990 Cl	1990 Cp/t	1990 Ep/t	1990 Ppm	1991 AM	1991 SO4	1991 NO3	1991 Cl	1991 Cp/t	1991 Ep/t	1991 Ppm	1992 AM	1992 SO4	1992 NO3	1992 Cl	1992 Cp/t	1992 Ep/t	1992 Ppm	88-92 T AM	88-92 P AM	88-92 P p/t	P d/p	AB scale	88-92 DEX	Low MI	Spc Mon Scl Obj
Clovis-900 N 1400248	N/A							N/A							N/A							49.1 43	1.99 43	4.05 43	0.17 43	0.02		48.3	46.6 56	2.08 57	5.78 57	0.21 57	0.78		36.5	47.7 99	38.1	0.800	0.0607	1	2.62	O	MS BC
Five Points 1000229	51.6 57	2.35 57	4.87 55	0.13 56	0.02		42.3	50.6 56	2.35 56	7.66 56	0.15 56	0.75		37.7	63.4 56	2.36 56	7.77 56	0.19 56	0.0		50.4	37.6 26	2.08 26	7.56 26	0.3 26	0.67		25.3	46.9 11	2.08 11	9.28 11	0.36 11	0.69		32.4	52.5 306	40.6	0.773	0.0317	1	1.28	O	RS BL
Fresno-Cal St 1000241	51.6 51	2.58 51	5.53 48	0.1 45	0.0		41.4	56.6 58	2.66 58	8.26 58	0.15 58	0.76		43	70.3 12	2.56 12	17.2 12	0.15 12	0.66		45.1	N/A														55.0 121	42.5	0.761	0.0607	1	2.92	O	MS BC
Fresno-Olive 1000236	65.7 56	2.63 55	6.21 56	0.12 51	0.01		54.5	77.3 53	2.88 53	10.9 53	0.26 53	0.77		59.7	160.7 3	5.03 3	35.5 3	0.91 3	0.66		91.0	N/A														73.3 112	50.0	0.781	0.0607	1	3.90	O	MS BC
Fresno-1625 I 1000266	N/A							N/A							69.2 65	3.3 66	8.2 66	0.31 66	0.01		55.7	59.6 58	2.36 58	7.6 58	0.31 58	0.79		47.2	48.2 55	2.32 56	6.13 56	0.19 56	0.78		37.5	58.6 358	46.2	0.792	0.0607	1	3.16	O	MS BC
Fresno-4760 E 1000264	N/A						102.0 16					0.77	79.4	66 59					0.81	53.1	62.3 53					0.79	49.3	52.5 55					0.78	40.8	64.1 188	50.6	0.790	0.0607	1	3.48	O	MS MC
Bkrsfld-Calif 1500251																												53 66	3.05 66	5.25 66	0.21 66	0.0		42.6	51.0 66	42.6	0.805	0.0727	1	3.10	X O	MS BC
Bakersfield C 1500203	71.3 56	4.08 56	6.86 56	0.13 49	0.78		57	80.6 55	3.98 56	11.1 56	0.2 56	0.76		61.5	79.1 58	3.39 59	11.2 59	0.28 59	0.76		60.6	60.9 47	3.03 48	9.78 48	0.23 48	0.78		43.6	60.6 57	3.37 59	7.24 59	0.18 59	0.78		47.2	74.7 293	57.5	0.773	0.0727	1	4.20	O	MS BC
Bora Refuge 1500205	N/A						46.0 10	3.33 16	16.3 16	0.06 16	0.62		41.8	43.5 60	2.31 60	9.7 60	0.1 60	0.68		39.9	36.1 39	2.32 39	5.36 39	0.3 39	0.76		28.2	37.6 60	2.28 60	6.39 60	0.3 60	0.77		29.1	43.5 196	30.2	0.732	0.0373	1	1.11	O	US BC
Oildale-3311 1500247	77.8 56	5.06 56	9.31 56	0.16 48	0.77		60	66 60	3.67 60	10.6 60	0.22 60	0.73		49.2	70 63	3.32 63	11.8 63	0.33 63	0.75		91	70 63	3.35 63	9.83 63	0.18 63	0.76		51.3	54.8 59	3.16 59	6.61 59	0.17 59	0.78		43.6	67.7 298	50.9	0.753	0.0727	1	3.70	X	MS SM
Taft College 1500250	N/A							N/A							66.0 24	3.07 24	8.78 24	0.1 24	0.76		92.2	55.7 58	3.33 60	6.67 60	0.26 60	0.77		42.7	62.1 59	2.97 59	8.26 59	0.13 59	0.76		32	52.0 342	39.9	0.766	0.0398	1	1.59	O	MS BC
Taft-W 10th S 1500213	59.6 57	4.66 57	6.02 56	0.13 50	0.78		46.4	48.7 59	3.05 59	8.88 59	0.19 59	0.76		48.6	70 3	5.8 3	21.6 3	0.14 3	0.67		44.8	N/A														50.6 119	48.9	0.766	0.0398	1	1.37	O	UB BC
Corcoran-Van 1600715	52.6 57	2.82 57	5.87 54	0.1 52	0.78		41.5	67.5 53	3.08 53	10.6 53	0.28 53	0.76		49.9	59.3 57	2.47 57	10.1 57	0.36 57	0.73		43.3	70 51	2.66 51	8.58 51	0.24 51	0.0		55.7	55.9 55	2.62 55	7.32 55	0.20 55	0.78		43.5	60.8 273	46.6	0.766	0.0371	1	1.76	O	MS BC
Hanford 1600701	52.3 56	2.81 55	6.08 52	0.1 53	0.78		40.9	67.3 57	3.02 56	11.7 56	0.25 56	0.72		46.8	59.5 53	2.7 53	11 53	0.25 53	0.71		42.1	62.8 56	2.66 56	8.32 56	0.25 56	0.78		48.9	54.3 57	2.53 59	7.68 59	0.22 59	0.76		41.1	59.3 297	44.3	0.748	0.0727	1	3.22	O	MS BC
Kettleman Cit 1600716	63.7 59	2.9 59	6.82 56	0.13 55	0.79		36.6	67.8 51	2.6 52	8.82 52	0.16 52	0.7		33.3	66.6 55	3.3 55	8.22 55	0.12 55	0.78		51.1	58.9 56	2.17 56	6.76 56	0.22 56	0.0		47.4	68.3 58	3.19 59	8.25 59	0.22 59	0.0		38.6	52.8 279	41.0	0.780	0.0373	1	1.53	O	MS BC
Madera-Librar 2000002	52.8 60	3.48 60	6.34 58	0.12 53	0.78		41.6	56.4 60	2.6 60	8.39 60	0.16 60	0.76		40.4	52.6 57	2.31 58	8.05 58	0.13 58	0.75		39.3	51.7 60	2.3 60	7.28 60	0.21 60	0.76		39.4	49.9 54	2.13 55	5.63 55	0.2 55	0.77		33.9	51.3 291	39.8	0.763	0.0317	1	1.24	O	MS BC
Los Banos 2400522	51.6 18					0.79	42.2	60.8 58					0.72	29.8	37.2 60					0.74	27.4	42.6 57	2.52 27	8.07 27	0.43 27	0.65		27.6	33.7 55	1.83 55	4.97 55	0.35 55	0.73		26.7	39.7 240	28.6	0.715	0.0317	1	0.90	O	MS BC
Merced 2400521	51.6 50	2.83 50	6.28 49	0.11 43	0.79		40.6	53.5 60	2.76 60	8.61 60	0.26 60	0.72		37.9	54.3 60	2.37 60	8.61 60	0.19 60	0.74		39.9	51.9 59	2.62 59	8.12 59	0.27 59	0.76		38.3	45.0 57	2.37 57	6.42 57	0.28 57	0.75		34.5	51.3 286	38.2	0.745	0.0727	1	2.76	O	MS BC
Stockton-Hazе 3980252	50.9 55	3.69 55	6.06 54	0.29 52	0.78		39.6	51.3 56	2.72 56	6.86 56	0.49 56	0.75		38.6	51.6 63	2.61 63	6.88 63	0.52 63	0.75		38.7	52.5 53	2.83 53	7.4 53	0.51 53	0.76		38.9	44.0 53	2.82 53	6.3 53	0.55 53	0.76		32.9	50.2 280	37.8	0.753	0.0580	1	2.19	O	MS BC
Crows Landing 5000571	47.9 53					0.75	35.8	47.8 60					0.73	36.8	45.7 61					0.7	33.2	36.2 20					0.73	19								44.8 194	32.6	0.726	0.0317	1	1.03	O	MS BC
Modesto-Oakda 5000558	48.6 59	3.34 58	7.17 57	0.3 56	0.75		36.2	53.6 55	3.49 55	8.46 55	0.38 55	0.73		39	48.9 18	2.37 18	8.08 18	0.23 18	0.7		34.4	N/A														50.6 332	37.1	0.734	0.0580	1	2.15	O	MS BC
Modesto-1100 5000567	N/A						56.2 56					0.71	[illegible]	[illegible]	50 61	2.16 45	9.38 45	0.28 45	0.8		40.3	52.6 60	3.8 60	8.17 60	0.43 60	C		36.2	43.6 62	2.37 62	7.05 62	0.3 62	0.72		31.4	49.0 237	37.2	0.765	0.0580	1	2.16	O	MS BC
Westley-Truck 5000572	N/A						N/A								33.3 66					0.8	26.8	36.3 20					0.73	22								32.6 68	25.3	0.782	0.0373	1	0.98		
Porterville-C 5400579	N/A						48.3 52					0.74	46.6	61.1 51					0.75	45.8	52.2 28					0.77	46.6								50.9 132	44.3	0.750	0.0727	1	3.21	O	MS BC
Visalia-Churc 5600568	67.6 61	3.1 61	8.91 60	0.15 57	0.78		52.6	68.5 58	3.88 58	11.3 57	0.15 58	0.76		50.7	79.6 58	3.8 58	12.8 58	0.38 58	0.75		59.9	65.6 52	3.55 52	9.3 52	0.31 52	0.77		50.3	56.7 47	2.68 50	8.51 50	0.16 50	0.76		40.4	67.7 276	51.2	0.756	0.0727	1	3.72	O	MS BC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-2
Great Basin Valleys PM-10 Annual Concentrations (Zone 11)

Station N / ID Numbe	1988 AM	1988 SO4	1988 NO3	1988 Cl	1988 Cp/t	1988 Ep/t	1988 Ppm	1989 AM	1989 SO4	1989 NO3	1989 Cl	1989 Cp/t	1989 Ep/t	1989 Ppm	1990 AM	1990 SO4	1990 NO3	1990 Cl	1990 Cp/t	1990 Ep/t	1990 Ppm	1991 AM	1991 SO4	1991 NO3	1991 Cl	1991 Cp/t	1991 Ep/t	1991 Ppm	1992 AM	1992 SO4	1992 NO3	1992 Cl	1992 Cp/t	1992 Ep/t	1992 Ppm	88-92 T AM	88-92 P AM	88-92 P p/t	P d/p	AB scale	88-92 DEX	Low MI	Spc Mon Scl Obj
Big Pine 1400709	14.3 66					0.87	12.4	7.8 30					0.69	7.03	N/A							N/A														33.1 56	11.6	0.870	0.0329	0.336	0.11	X O	MS BC
Bishop-S Main 1400716	12.9 15					0.87	20.6	N/A							N/A							N/A														32.0 16	20.6	0.868	0.0329	0.336	0.31	X O	MS BC
Bishop-N Main 1400717	21.1 46					0.87	20.1	27 61					0.89	24	25.6 59					0.87	22	28.3 26					0.85	24.1								25.8 190	23.5	0.872	0.0329	0.336	0.25	O	MS BC

Filename: DEXPAN3.XLS, March 18, 1997
[illegible]
Response to Public Comments #1 (Secondary PM10, Site Representation)
SO4 Scaler 1.142 1.018 SCAB only
NO3 Scaler 1.282 1.901 SCAB only
Cl Sclr in ss 1.65 1.65 SCAB only

Spatial Scale
MI Microscale
MS Middle Scale
NS Neighborhood Scale
US Urban Scale
RS Regional Scale

Monitoring Objectives
HC Highest Concentration
RC Representative Concentration
IM Impact
BL Background Level

Coso Jct-1UME 1400718	46.4 41					0.87	40.3	26.6 49					0.89	21.5	16 49					0.87	15.6	15 35					0.85	12.8	20.6 29					0.85	17.3	25.6 203	22.2	0.869	0.0329	0.334	0.24		O	NS RC
Coso Junction 1400696	22 59					0.87	19.1	25.5 62					0.89	22.7	29.8 60					0.87	25.6	18.8 60					0.85	16	18.1 32					0.85	15.3	21.2 273	20.3	0.860	0.0329	0.334	0.22		O	NS RC
Independnce 477 1400740	18.5 60					0.87	16.1	14.5 55					0.89	12.9	15.9 56					0.87	13.8	14.8 29					0.85	12.7								15.9 160	13.8	0.871	0.0329	0.334	0.15		O	NS RC
Independnce 467 1400708	19 39					0.87	16.5	13 9					0.89	11.6	N/A							N/A														17.8 48	15.6	0.871	0.0329	0.334	0.17	X	O	NS RC
Keeler 1400697	32.9 41					0.87	28.6	78.1 57					0.89	69.5	54.5 60					0.87	47.2	34.1 45					0.85	29.1	39.2 54					0.85	33.2	48.3 277	42.0	0.878	0.0329	0.334	0.46		O	NS RC
Lone Pine 1400699	31.1 61	1.44 60	0.58 60	0.26 54	0.87		10.3	23.1 61	1.16 59	0.57 59	0.28 59	0.89		20.6	17.6 60	1.01 59	0.71 59	0.17 59	0.87		15.2	18.9 59	1.26 59	0.72 59	0.26 59	0.85		16.1	18.3 56	1.28 56	0.73 56	0.24 56	0.85		15.5	19.8 297	17.2	0.866	0.0329	0.334	0.19		O	NS RC
Olancha Wd 1400718	19.5 59					0.87	16.9	25.9 52					0.89	23.1	23.6 55					0.87	20.4	18 59					0.85	15.3	22.1 58					0.85	18.7	21.7 275	18.8	0.866	0.0329	0.334	0.21		O	NS RC
Bodie Sim NE 2600784	N/A							14.6 18					0.95	13.8	8.3 35					0.94	7.84	7.7 28					0.92	7.08								9.7 73	9.1	0.939	0.0329	0.334	0.10		O	NS RC
Lee Vining 2600779	15.3 48					0.94	14.4	13.6 60					0.95	12.9	13.6 62					0.94	12.8	12.6 58					0.92	11.6	13.6 59					0.92	12.4	13.4 287	12.8	0.935	0.0329	0.334	0.14		O	NS RC
Mammoth L-Gat 2600785	38.6 65	1.06 61	0.6 60	0.14 57	0.94		36.6	34.5 56	0.83 54	0.58 54	0.12 54	0.85		32.6	40.6 58	0.89 58	0.75 58	0.1 58	0.94		30.3	34.4 48	1.18 46	0.91 48	0.18 48	0.92		31.6	37.6 60	1.22 58	0.86 58	0.22 58	0.92		34.7	36.8 283	34.5	0.935	0.0325	0.334	0.38		O	NS RC
Mammoth L-Sho 2600786	10.6 7					0.94	9.95	N/A							N/A							N/A														10.4 7	10.0	0.940	0.0329	0.334	0.11	X	O	NS RC
Mono Lake 2600782	10.7 60					0.94	10.1	9.8 139					0.95	9.36	10.7 168					0.94	10.1	11.5 87					0.93	13.4	21.8 78					0.92	20.3	12.6 521	11.8	0.934	0.0329	0.334	0.13		O	NS RC
Mono Lake-Wrm 2600789	N/A							N/A							N/A							8.6 8					0.93	7.9	46.3 11					0.92	40.3	43.7 31	40.6	0.924	0.0329	0.334	0.44	X	O	RS RC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-5
Lake County PM-10 Annual Concentrations (Zone 10)

Station Name/ ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1989 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1990 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1991 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1992 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	88-92 T AM	88-92 F AM	88-92 F p/t	F d/p	AB scale	88-92 DEX	Low N	NO	Spc Scl / Mon Obj
Lakeport 1700711	33 54	0.81 19	0.45 17	0.29 17	0.85		11	13.9 56					0.84	10.5	11.4 56					0.84	9.55	13.6 56					0.84	10.6	11.9 58					0.84	9.97	12.4 282	10.6	0.840	0.0329	0.661	0.23		O	NS RC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-6
Lake Tahoe PM-10 Annual Concentrations (Zone 10)

Station Name/ ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1989 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1990 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1991 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1992 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	88-92 T AM	88-92 F AM	88-92 F p/t	F d/p	AB scale	88-92 DEX	Low N	NO	Spc Scl / Mon Obj
S Lake Tahoe 909684	34.5 54	1.15 18	0.93 18	0.91 16	0.88		30.5	28.6 50					0.91	25.8	30.7 61					0.91	27.8	30.1 55					0.91	25.5	28.1 53					0.91	25.5	30.8 281	27.8	0.901	0.0329	1.047	0.93		O	NS RC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-7
Mojave Desert Annual PM-10 Concentrations (Zone 11)

Station Name/ ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1989 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1990 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1991 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	1992 AM	SO4	NO3	Cl	Cp/t	Bp/t	Ppm	88-92 T AM	88-92 F AM	88-92 F p/t	F d/p	AB scale	88-92 DEX	Low N	NO	Spc Scl / Mon Obj
China Lake 1500211	N/A							21.5 11	0.83 11	1.26 11	0.13 11	0.87		18.8	19.2 50	1.56 50	1.37 50	0.13 50	0.81		15.5	46.1 45	1.07 45	1.33 45	0.30 45	0.9		41.5	20.1 50	1.78 50	1.65 50	0.27 50	0.77		15.5	27.4 156	21.2	0.847	0.0329	0.453	0.35		O	RS BL
Mojave 1500207	56.8 27	3.09 29	2.13 29	0.2 21	0.88		48.2	N/A							N/A							N/A														56.8 27	48.2	0.880	0.0329	0.453	0.72	X	O	US RC
Mojave Airport 1500249	N/A							28.6 40	1.85 40	2.46 40	0.09 40	0.81		23.2	35.1 54	1.75 54	2.24 54	0.09 54	0.86		30.1	30.7 45	1.72 39	1.33 39	0.16 39	0.79		24.2	25.6 50	1.74 51	1.74 51	0.18 51	0.82		21.3	30.2 169	24.9	0.824	0.0329	0.453	0.37		O	NS RC
Lancaster 7000082	N/A							41 56	2.68 56	2.12 56	0.16 56	0.88		41.2	38.9 8	1.16 8	1.61 8	0.15 9	0.88		25.1	N/A 6														46.5 65	39.0	0.876	0.0665	0.453	1.17		O	NS RC
Lancaster-WPo 7000096	N/A							N/A							57.6 56	2.83 50	2.56 50	0.19 50	0.88		50.8	56.8 57	2.54 58	2.59 59	0.13 59	0.89		50.4	32.4 59	2.38 59	2.36 59	0.18 59	0.81		26.4	48.4 166	42.6	0.868	0.0665	0.453	1.26		O	NS RC
Blythe-Murphy 3100161	N/A							N/A							N/A							45.3 25	2.43 25	1.04 25	0.45 25	0.89		40.5	43.2 26	2.22 26	1.1 26	0.67 26	0.89		38.5	44.2 51	39.4	0.892	0.0329	0.453	0.59	X	O	NS RC
Barstow 3600155	36.1 58	2.16 56	2.28 56	0.15 56	0.84		30.2	43.1 56	3.08 58	3.27 58	0.13 58	0.84		36.3	40.3 44	2.38 44	2.59 44	0.21 44	0.87		42	36.2 51	2.39 51	3.04 51	0.11 51	0.81		29.4	31.6 60	2.69 61	2.08 61	0.14 61	0.81		25.4	30.5 273	32.2	0.836	0.0329	0.453	0.48		O	NS RC
Hesperia-Oliv 3600201	N/A							56.3 59	2.44 59	4.55 59	0.13 59	0.84		47.4	46.1 51	2.61 56	2.95 56	0.21 56	0.85		39	35.5 2	1.02 1	1.68 1	0.22 1	0.9		31.0	30.5 61	2.76 61	1.15 61	0.16 61	0.81		12	47.1 175	39.3	0.835	0.0329	0.453	0.59		O	NS RC

Filename: DEKPAM2.XLS, March 18, 1997
EMFAC7G
Response to Public Comments #1 (Secondary PM10, Site Representation)
SO4 Scalar 1.162 1.030 SCAB only
NO3 Scalar 1.282 1.903 SCAB only
Cl Scl: In ca 1.65 1.65 SCAB only

Spatial Scale
MI Microscale
MS Middle Scale
NS Neighborhood Scale
US Urban Scale
RS Regional Scale

Monitoring Objectives
MC Highest Concentration
RC Representative Concentration
IM Impact
BL Background Level

Station Name/ ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	88-92 T AM	88-92 P AM	88-92 F p/t	F d/p	AB scale	88-92 DEK	Low H	MO	Spc Scl	Non Obj
Lucerne Valle 3600208	N/A							N/A							44.6 35	2.01 35	2.07 35	0.2 35	0.86		30.1	43.9 44	2.07 44	3.91 44	0.2 44	0.85		37.5	23.5 47	2 49	1.01 49	0.16 49	0.79	10.4	36.5 126	31.0	0.849	0.0329	0.653	0.46		0	MS	BC
Trona-Market 3600188	62.7 55	1.18 55	2.67 53	1.06 51	0.8		34.2	60.5 55	1.08 55	1.87 55	1.31 55	0.83		40.4	60.3 59	1.03 59	2.39 59	1.31 59	0.8		38.7	61.1 59	0.16 58	2.49 58	1.23 58	0.76		31.8	36.8 59	3.48 58	3.15 58	1.35 58	0.77	28.2	61.5 270	36.8	0.798	0.0329	0.653	0.51		0	MS	BC
Victorville 3600199	62.9 44	3.72 44	2.8 42	0.09 39	0.86		36.1	N/A							N/A							N/A													43.9 44	36.1	0.861	0.0329	0.653	0.56		0	MS	BC
Twentynine Pa 3600191	N/A							46.5 49	1.6 49	2.11 49	0.15 49	0.9		41.7	36.6 51	1.6 51	1.71 51	0.19 51	0.87		30	40.6 44	1.68 44	3.2 44	0.21 44	0.87		35.3	35.6 60	1.76 60	1.33 60	0.16 60	0.85	21.6	36.0 204	31.5	0.875	0.0329	0.653	0.47		0	MS	BC
Victorville-F. 3600190	N/A							N/A							55.3 21	3.36 22	2.31 22	0.2 22	0.87		48.2	N/A														55.3 21	48.3	0.871	0.0329	0.653	0.72	X			
Victorville-A 3600209	N/A							N/A							N/A							46.7 31	3.69 32	3.93 32	0.16 32	0.78		35.3	33.6 60	2.48 60	2.61 60	0.16 60	0.82	27.4	37.4 91	30.3	0.804	0.0329	0.653	0.45		0	MS	BC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-6
Mountain Counties PM-10 Annual Concentrations (Zone 10)

Station Name/ ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	88-92 T AM	88-92 P AM	88-92 F p/t	F d/p	AB scale	88-92 DEK	Low H	MO	Spc Scl	Non Obj
Placerville-L 900626 -	24.7 25	1.03 8	0.8 7	0.11 7	0.9		32.3	26.6 62					0.83	22	27.9 26					0.83	23	N/A																						
Placvll-Gold 900690																																				36.4 91	22.5	0.866	0.0329	0.765	0.55		0	MS	BC
Yosemite Vill. 3200742	58.0 25					0.83	54.6	38 40					0.83	31.4	46.6 65					0.83	43.3	47.5 56					0.83	46.2	30.9 57					0.92	28.5	24.4 39					0.92	22.5	26.6 39	22.5	0.822	0.0329	0.765	0.55	X	0	MS	BC
Glenshire-Pin 3900788																																				43.0 263	39.2	0.913	0.0329	0.765	0.96		0	MS	BC
Grass Valley 3900796	39 33	1.2 1	1.1 1	0.03 1	0.9		36.2	36.4 69					0.83	30.1	37.6 57					0.83	35.7	36 66					0.83	36.3	35.5 63					0.92	33.5	34.6 34	31.0	0.923	0.0329	0.765	0.76	X	0	MS	BC
Grass Vly-166 3900798	N/A							N/A							N/A							31.5 16					0.83	30.1	22.5 59					0.92	20.7	26.1 260	23.9	0.897	0.0329	0.765	0.58		0	MS	BC
Nevada City-W 3900797																																				33.0 69	32.6	0.923	0.0329	0.765	0.84		0	MS	BC
Truckee-Fire 3900796	37.6 46					0.96	35.7	33 43					0.91	30.1	37 57					0.83	34.6	37.7 59					0.83	30.1	34.3 43					0.92	33.5	36.4 216	33.9	0.931	0.0329	0.765	0.83		0	MS	BC
Colfax-City M. 3100818	N/A							31.2 19					0.91	30.2	33.3 21					0.83	30.1	33.6 37					0.83	31.1	25.1 58					0.92	23.1	29.3 321	27.0	0.924	0.0329	0.765	0.66		0	MS	BC
Quincy-CHP Bu 3200819	53.7 69	1.23 66	0.72 65	0.11 63	0.85		51.2	37.3 37	1.04 37	0.86 37	0.11 37	0.91		35.2	N/A							N/A														43.5 86	40.0	0.941	0.0329	0.765	0.88		0	MS	BC
Graegle 3200832	N/A							N/A							N/A							19.7 93					0.83	17.6	19.7 62					0.92	18.2	19.3 135	17.7	0.926	0.0329	0.765	0.63		0	MS	BC
Quincy-No Chu 3200821	N/A							77.9 16	1.18 16	1.28 16	0.17 16	0.96		76.7	30.2 56	1.17 58	0.87 58	0.1 58	0.93		35.6	42.6 52	1.22 52	1 52	0.18 52	0.93		30.6	37.7 57	1.28 58	0.96 58	0.17 58	0.92	34.7	43.0 181	38.9	0.933	0.0329	0.765	0.98		0	MS	BC
Quincy-So Rod 3200817	N/A							N/A							N/A							N/A							N/A																
Loyalton-389 4600854	N/A							N/A							N/A							36.9 54					0.83	25	32.6 60					0.92	30	29.9 116	27.7	0.926	0.0329	0.765	0.68	X	0	MS	BC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-7
North Central Coast Annual PM-10 Concentrations (Zone 10)

Station Name/ ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	88-92 T AM	88-92 P AM	88-92 F p/t	F d/p	AB scale	88-92 DEK	Low H	MO	Spc Scl	Non Obj
Carmel Valley 2700550																																												
King City-750 2700551	N/A							N/A							29.1 29					0.7	20.6	26.5 54					0.7	17.2	20.5 63					0.7	14.6	20.5 63	16.6	0.702	0.0665	1.216	1.17	X	0	MS	BC
Monterey-Silv. 2700552																																				26.1 138	16.9	0.702	0.0329	1.216	0.68		0	MS	BC
Salinas II 2700544	33 61	2.07 30	3.01 19	1.27 17	0.66		14.7	25.3 57					0.7	17.6	22.6 61					0.7	15.9	21 56					0.7	16.2	21.5 61					0.7	9.76	13.9 43	9.6	0.702	0.0665	1.216	0.79	X	0	MS	BC
Hollister-Pal 3500829	26.6 53	1.66 18	3.11 18	0.6 14	0.73		18.1	24.6 60					0.73	17.6	21.3 55					0.73	15.5	22.3 55					0.73	16.2	20.5 60					0.73	14.9	23.1 296	15.9	0.689	0.0665	1.216	1.29		0	MS	HC
Santa Cruz-Bo 4400850	30.2 65	1.61 8	1.77 7	0.85 8	0.82		24.7	30.4 51					0.75	22.7	24.1 58					0.75	18	24.3 58					0.75	18.2	23.5 56					0.75	16.8	26.0 260	19.8	0.761	0.0665	1.216	1.68		0	MS	BC
Watsonville A																																				22.4	16.7	0.747	0.0329	1.216	0.67	X	0	MS	BC

Filename: SEXPM2.XLS, March 10, 1997
IMPACT9
Response to Public Comments 01 (Secondary PM10, Site Representation)
SO4 Scalar 1.162 1.018 SCAB only
NO3 Scalar 1.162 1.061 SCAB only
Cl Scalr in 95 1.45 1.45 SCAB only

Spatial Scale
MI Microscale
MS Middle Scale
NS Neighborhood Scale
US Urban Scale
RS Regional Scale

Monitoring Objectives
MC Highest Concentration
RC Representative Concentration
IM Impact
BL Background Level

440665)

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-9
North Coast Annual PM-10 Concentrations (Zone 10)

Station Name / ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	88-92 T AM	88-92 P AM	88-92 P p/t	F d/p	AB scale	88-92 DEX	Low MC N	Spc Mon Scl Obj
Crescent City 4006651	31.0 15	1.75 11	0.76 9	0.56 11	0.56		13.3	N/A							N/A							N/A													33.0 15	13.3	0.559	0.0329	1.382	0.61	X 0	MU BC
Eureka-HD 5th 1200583	36.8 60	2.77 20	1.54 16	5.51 16	0.61		22.6	31.6 60					0.65	20.6	28.3 60					0.65	18.6	32.4 54					0.65	21.1	30.8 58					0.65	20	32.0 292	20.5	0.642	0.0665	1.384	1.69	0	HS BC
Eureka-Library 1200768	28.9 51	1.19 50	0.76 48	0.27 48	0.9		26.1	30.1 60	1.34 60	0.81 60	0.32 60	0.9		27	32 62	1.1 62	0.55 62	0.19 62	0.9		19.7	23.8 56	1.23 56	1.27 56	0.46 56	0.84		20	21.6 57	1.17 57	0.86 57	0.35 57	0.86		18.4	25.2 286	22.3	0.882	0.0329	1.382	1.01	0	NS BC
Willits-Pitch 1300751	33.8 62	1.13 62	0.69 61	0.46 59	0.91		31	38.5 60	1.01 50	0.57 50	0.36 50	0.92		28	31.9 59	1 59	0.8 59	0.28 59	0.91		21.6	25.6 60	1.13 60	0.78 60	0.53 60	0.88		22.3	22 61	1 61	0.6 61	0.57 61	0.87		19.1	26.8 292	23.5	0.906	0.0329	1.382	1.07	0	NS BC
Cloverdale 4900086	28.2 76					0.9	25.9	29 24					0.9	26.2	25.6 72					0.9	23	27.3 68					0.9	24.7	28.7 55					0.9	16.6	22.6 164	20.8	0.805	0.0329	1.382	0.93	0	NS BC
Guerneville CE 4900095	N/A							N/A							23.9 65					0.9	21.6	25.6 62					0.9	23.3	28.6 57					0.9	17.1	21.9 263	19.8	0.905	0.0329	1.382	0.90	0	NS BC
Healdsburg-111 4900098	26.3 71					0.9	22.3	N/A							20.5 67							N/A							28.9 69							28.3 66	26.3	0.933	0.0329	1.382	1.20	0	NS BC
Weaverville-H 5100912	28.2 66	0.98 65	0.45 62	0.12 62	0.93		26.3	N/A							N/A							N/A																					

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-8
Northeast Plateau Annual PM-10 Concentrations (Zone 10)

Station Name / ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	88-92 T AM	88-92 P AM	88-92 P p/t	F d/p	AB scale	88-92 DEX	Low MC N	Spc Mon Scl Obj
Alturas 2 Mon 2500766	33.7 19					0.91	29.9	35 34					0.91	33	30 34					0.91	33	30.1 33					0.91	27.6	40.3 7					0.91	36.8	33.9 106	31.9	0.918	0.0329	1.306	1.33	0	NS BC
Yreka 4700868	36.8 81	1.38 20	0.75 16	0.17 16	0.89		22.1	35 61					0.91	23.9	33.3 59					0.91	31.9	34.8 50					0.91	22.7	23.9 57					0.91	31.9	36.8 288	32.3	0.988	0.0329	1.306	0.88	0	NS BC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-10
Sacramento Valley Annual PM-10 Concentrations (Zone 10)

Station Name / ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	88-92 T AM	88-92 P AM	88-92 P p/t	F d/p	AB scale	88-92 DEX	Low MC N	Spc Mon Scl Obj
Biggs-9th & C 4006517	43.2 61					0.87	36.7	35.7 59					0.87	31.1	32.6 8					0.87	28.6	N/A													0.87	31.3	36.6 128	31.6	0.870	0.0329	1.526	1.69	0	NS BC
Chico-Manzanit 4006020																												36 40							36.6 40	31.3	0.870	0.0665	1.526	3.18	X 0	NS BC
Chico-Salem S 4006033	N/A							56.5 11					0.87	49.3	36.4 33					0.87	31.7	46.0 72					0.87	35.5	33.1 30					0.87	27.1	38.6 186	33.5	0.870	0.0665	1.526	3.40	0	NS BC
Chico-CSUC 4006038	33.7 58	1.37 19	1.0 17	0.32 17	0.8		26.0	31.6 46					0.87	27.5	N/A							N/A															32.8 104	27.2	0.830	0.0665	1.526	2.76	0	NS BC
Colusa-Sunrise 4006606	33.0 55	1.43 19	5.08 18	0.18 19	0.72		24.4	30.1 60					0.82	26.6	33.2 73	1.73 6	1.66 6	0.33 6	0.87		28.9	41.2 61	1.87 19	3.92 19	0.36 19	0.81		34.1	29.7 70	1.16 23	1.73 23	0.3 23	0.87		25.6	33.6 319	27.6	0.825	0.0329	1.526	1.39	0	NS BC
Willows-Villa 1106613	35.6 59	1.61 20	3.86 19	0.17 19	0.81		28.8	27.3 60					0.84	20.9	29.3 71					0.84	26.7	36.5 72					0.84	29.1	28.8 71					0.87	25.1	31.1 333	26.1	0.841	0.0329	1.526	1.51	0	NS BC
Auburn-Dewitt 3100813	29.5 56					0.81	23.9	25.8 61					0.81	20.8	26.1 60					0.81	21.3	33.2 25					0.8	26.6	25.1 52					0.83	20.7	27.3 264	23.2	0.833	0.0329	1.526	1.11	0	NS BC
Lincoln 3100816	38.6 56	1.75 2	1.5 2	0.13 2	0.89		36.3	34.6 58					0.81	28.2	36.5 59					0.81	29.6	40.2 32					0.8	32.2	31.1 53					0.83	25.7	35.7 249	28.7	0.833	0.0329	1.526	1.69	0	NS BC
Rocklin-Sierr 3100830	31.9 61	1.67 19	1.65 19	0.33 16	0.79		25.3	28.7 58					0.81	23.3	36.1 58					0.81	31.2	32.5 24					0.8	18								20.2 197	22.6	0.892	0.0665	1.526	2.30	0	NS NC
Rocklin-5000 3100820	N/A							N/A							N/A							46.5 2					0.8	37.3	27.5 61					0.83	32.7	38.4 61	33.4	0.825	0.0665	1.526	2.36	X 0	NS BC
Citrus Hts-Ba 3400292	40.3 56	1.86 55	1.76 53	0.17 51	0.82		33.1	42.6 60	1.97 60	0.68 60	0.27 60	0.8		33.9	42.7 66	1.96 67	0.51 67	0.24 67	0.8		34.3	39.5 56	1.81 56	1.97 56	0.33 56	0.8		31.7	33.7 65	1.66 65	1.9 65	0.21 65	0.83		27.9	39.7 303	32.1	0.809	0.0665	1.526	3.26	0	NS BC
Mth Highlands	N/A							39.7					0.8	31.6	37.6					0.8	30	33.3					0.8	26.7	33.1					0.81	25.7	35.7	28.8	0.807	0.0665	1.526	2.92	0	NS BC

filename: DEXPAM2.XLS, March 10, 1997
EMFAC7G
Response to Public Comments #1 (Secondary PM10, Site Representation)
SO4 Scalar 1.162 1.038 SCAB only
NO3 Scalar 1.282 1.303 SCAB only
Cl Sclr in cs 1.65 1.65 SCAB only

Spatial Scale
MI Microscale
MS Middle Scale
NS Neighborhood Scale
US Urban Scale
RS Regional Scale

Monitoring Objectives
HC Highest Concentration
RC Representative Concentration
IM Impact
BL Background Level

1400294								60							57							28							60							205									
Sacto-Del Pas 1400295	36.3 57					0.82	29.8	40.3 56					0.8	32.1	37.6 59					0.8	30.2	42.3 11					0.8	33.0	37.8 46					0.83	33	36.2 233	29.3	0.809	0.0665	1.526	2.97		0	NS	RC
Sacto-Earhart 1400307	N/A							42 40					0.8	33.4	N/A							24.6 24					0.8	19.6	23.2 50					0.83	19.2	30.8 114	24.3	0.807	0.0665	1.526	2.46		0	NS	RC
Sacto-1309 T 1400305	N/A							N/A							78.5 26					0.8	63	46.1 69					0.8	37.1	32.2 71					0.83	26.6	45.3 166	36.7	0.810	0.0665	1.526	3.72		0	NS	RC
Sacto-Branch 1400283	N/A							42.5 58					0.8	33.8	35.3 58					0.8	30.3	34.3 59					0.8	27.8	30.4 53					0.83	25.1	35.7 228	28.8	0.805	0.0665	1.526	2.92		0	NS	RC
Sacto-MD Stoc 1400277	42.4 60					0.82	34.8	47 59					0.8	37.6	N/A							35.1 58					0.8	28.3	29.8 59					0.83	24.6	38.7 236	31.3	0.810	0.0665	1.526	3.10		0	NS	PC
Burney 6500556	N/A							34 45					0.87	29.7	34.5 46					0.87	30.2	33.9 55					0.87	29.6	34.3 41					0.87	30	34.2 187	29.9	0.874	0.0329	1.526	1.50		0	NS	RC
Redding-MD 4500555	26.3 61	1.06 21	1.62 19	0.13 20	0.88		23.1	26.8 54					0.87	23.4	25 52					0.87	21.9	20.5 58					0.87	24.9	24.9 55					0.87	21.8	26.3 280	21.8	0.875	0.0665	1.526	2.38		0	NS	RC
Vacaville-Mer 4800881	35 15					0.84	29.3	37.8 29					0.84	31.6	36.8 41					0.84	33.4	40.6 43					0.84	34	24.6 58					0.84	20.6	31.7 186	26.5	0.837	0.0329	1.526	1.33		0	US	RC
Yuba City-AQ 5100895	37.4 54	1.38 17	4.31 14	0.17 16	0.8		30	35 49					0.84	29.3	N/A							N/A														36.3 183	28.7	0.818	0.0329	1.526	1.49		0	NS	RC
Yuba City-Alm 5100898	N/A							40.1 10					0.84	50.3	39.6 71					0.84	33.1	41.1 69					0.84	34.4	35.6 71					0.84	29.8	38.7 221	33.2	0.837	0.0329	1.526	1.67		0	NS	RC
Red Bluff 5200901	43.2 58	1.52 18	3 17	0.18 16	0.86		37.3	31.7 59					0.86	27.4	29.7 60					0.86	25.6	32.4 60					0.86	28	29.3 61					0.86	25.3	33.2 298	28.7	0.863	0.0665	1.526	2.91		0	NS	RC
West Sacto 15 5700570	N/A							N/A							54.2 19					0.79	42.7	46.8 44					0.79	36.9	34.7 58					0.79	27.3	42.2 121	33.2	0.788	0.0665	1.526	3.27		0	US	RC
Woodland-Main 5700569	40.3 57	1.79 18	7.69 18	0.18 17	0.7		28.1	35.1 54					0.79	27.6	31 59					0.79	24.4	43.0 26					0.79	34.6								36.5 188	27.7	0.759	0.0329	1.526	1.19		0	US	RC
Woodland-Butt 5700579																													42.7 62					0.79	33.6	42.7 62	33.6	0.788	0.0329	1.526	1.69	X	0	US	RC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-11
Salton Sea Annual PM-10 Concentrations (Zone 11)

Station Name/ ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	88-92 T AM	88-92 F AM	88-92 F p/t	F d/p	AB scale	88-92 DEX	Low N	NO	Spc Scl	Mon Obj
Brawley-Main 1300693	65.9 58	2.38 55	3.01 54	0.41 54	0.89		49.0	77.1 58	2.66 58	3.83 58	1.11 58	0.89		68.4	57.1 61	3.44 61	3.32 61	0.46 61	0.88		50.7	61.1 56	2.81 56	3.37 56	0.74 56	0.87		54.7	47.3 60	3.44 60	1.97 60	0.61 60	0.87		41.1	60.6 288	52.0	0.881	0.0570	1	3.01		0	NS	RC
El Centro-9th 1300694	59.7 55	2.89 55	3.16 55	0.81 55	0.87		52.2	72.4 57	3.99 57	3.71 57	1.16 57	0.86		61.6	45.6 60	3.5 61	2.16 61	0.52 61	0.86		38.9	56.6 62	3.40 62	2.0 62	0.8 62	0.86		48.7	41.4 46	3.6 46	1.96 46	0.57 46	0.84		36	56.6 280	48.1	0.866	0.0570	1	2.76		0	NS	RC
Indio-Jackson 1300157	48.5 61	3.05 61	2.45 61	0.28 61	0.85		41.4	90.3 58	1.21 58	3.40 58	0.32 58	0.9		81.6	79.3 59	1.21 59	3.65 59	0.21 59	0.89		70.6	69 59	3.34 59	3.38 59	0.26 59	0.88		60.4	43.4 59	2.72 59	3.17 59	0.15 59	0.86		37.3	65.0 296	58.3	0.881	0.0570	1	3.31		0	NS	RC
Palm Springs 1300137	29.2 60	2.86 60	3.85 60	0.2 60	0.75		21.9	44.6 60	2.86 60	3.9 60	0.15 60	0.81		36.1	34.5 59	3.48 59	2.61 59	0.2 59	0.81		28	42.9 56	3.04 56	2.74 56	0.2 56	0.83		35.6	29.6 60	3.01 60	2.28 60	0.15 60	0.7		23.1	36.1 285	28.9	0.800	0.0570	1	1.64		0	NS	RC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-12
San Diego Annual PM-10 Concentrations (Zone 11)

Station Name/ ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	88-92 T AM	88-92 F AM	88-92 F p/t	F d/p	AB scale	88-92 DEX	Low N	NO	Spc Scl	Mon Obj
Chula Vista 6000114	31 56	3.16 17	2.99 15	0.95 14	0.71		22	36.7 61					0.67	24.6	32 62					0.67	21.4	31.8 60					0.67	22.6	29 60					0.67	19.4	32.5 299	22.0	0.677	0.0665	1.707	2.50		0	NS	RC
El Cajon-Redw 6000133	39.9 59	4.47 57	3.28 56	0.18 52	0.76		30.3	44.6 61	4.53 61	4.63 61	0.15 61	0.74		32.9	37 59	3.43 61	3.74 61	0.52 61	0.74		27.4	40.7 60	4.55 60	4.91 60	0.59 60	0.69		28.2	35.8 58	3.76 59	3.75 59	0.31 59	0.73		26.2	39.7 299	29.1	0.733	0.0665	1.707	3.30		0	NS	RC
Oceanside-Mis 6000136	36 59	4.84 62	4.68 60	0.61 57	0.65		23.5	38.3 61	4.39 61	5.26 61	0.77 61	0.66		25.4	33 61	3.82 61	4.52 61	0.88 61	0.65		21.4	34.8 60	4.48 61	5.85 62	1.05 60	0.61		22.5	29.1 57	3.73 59	3.77 59	0.81 59	0.64		18.7	34.7 298	22.3	0.643	0.0665	1.707	2.53		0	NS	RC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-13
San Francisco Bay Area Annual PM-10 Concentrations (Zone 10)

Station Name/ ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	88-92 T AM	88-92 F AM	88-92 F p/t	F d/p	AB scale	88-92 DEX	Low N	NO	Spc Scl	Mon Obj
Fremont-Chape 6000336	N/A							32.6 48	2.34 48	2.22 48	1.09 48	0.78		25.3	32.4 61	2.3 61	4.09 61	1.68 61	0.67		21.8	33.7 59	2.43 59	4.67 59	1.62 59	0.66		22.3	26.3 61	2.16 61	2.93 61	0.69 61	0.72		19	31.2 228	21.9	0.702	0.1084	1	2.37		0	NS	RC

Filename: DEXPAN2.XLS, March 14, 1997
ENPAC7G
Response to Public Comments #1 (Secondary PM10, Site Representation)
SO4 Scalar 1.043 1.018 SCAB only
NO3 Scalar 1.202 1.903 SCAB only
Cl Sclr in de 1.65 1.65 SCAB only

Spatial Scale
MI Microscale
MS Middle Scale
NS Neighborhood Scale
US Urban Scale
RS Regional Scale

Monitoring Objectives
HC Hig[illegible]ration
RC Re[illegible] Concentration
IM Impact
BL Background Level

Livermore-Int 6000140	33.2 60	1.61 60	2.26 58	0.34 56	0.84	27	37.4 61	2.47 61	2.7 61	0.71 61	0.8
San Leandro-C 6000141	N/A						N/A				
Bethel Island 700442	35 61	2 61	1.85 59	0.26 58	0.78	27.4	30 61	2.46 61	3.46 61	0.42 61	0.77
Concord-2975 700440	30.4 60	1.77 60	2.48 58	0.42 56	0.78	32.5	30.5 61	2.61 61	2.29 61	0.68 61	0.77
Richmond-13th 700415	N/A						30.7 40	3 40	1.86 40	1.08 40	0.71
San Rafael 2100451	27.5 56	1.53 54	1.11 52	0.68 51	0.84	31.2	29.9 61	2.43 61	1.51 61	1.17 61	0.78
Napa-Jefferson 2800763	31 57	1.45 57	1.7 56	0.57 54	0.85	36.2	32 61	1.67 61	1.4 61	0.9 61	0.84
San Francisco 9000306	30.1 59	1.95 59	2.05 57	1.43 55	0.75	22.1	36 62	2.92 61	1.66 61	2.31 61	0.74
Redwood City 4100541	30.6 55	1.47 55	1.92 52	0.73 54	0.81	33.2	33.3 61	2.16 61	2.83 61	1.09 61	0.79
San Jose-Moor 4300197	35 40	1.68 40	2.09 40	0.30 40	0.85	29.8	30 61	2.46 61	3.08 61	0.68 61	0.79
San Jose-4th 4300193	30.6 133	1.82 64	3.27 58	0.83 58	0.82	32.4	41.3 181	2.38 61	3.24 61	0.72 61	0.81
San Jose-528 4300191	N/A						N/A				
San Jose-M BC 5300290	N/A						40.6 27	2.34 27	2.34 27	0.3 27	0.85

Livermore-Int 6000140	29.9	32.7 61	2.13 61	3.59 61	1.2 61	0.72	31.7	36.5 60	2.39 60	4.91 60	1.17 60	0.7
San Leandro-C 6000141		36.5 36	2.36 36	4.66 36	1.56 36	0.67	33.1	32.4 60	2.66 60	3.71 60	1.76 60	0.67
Bethel Island 700442	32.4	30.5 61	2.19 61	3.66 61	0.83 61	0.7	20.5	33.4 60	2.6 60	5.22 60	0.88 60	0.67
Concord-2975 700440	31.5	27.1 62	2.3 62	2.78 62	1.21 62	0.7	18.9	31.2 60	2.46 60	4.09 60	1.19 60	0.66
Richmond-13th 700415	31.8	26.5 61	2.55 61	2.75 61	2.02 61	0.63	16.7	28.1 59	3.06 59	3.54 59	2.1 59	0.61
San Rafael 2100451	33.3	26 61	1.85 61	2.02 61	1.6 61	0.72	18.7	30.4 60	2.47 60	3.09 60	1.07 60	0.68
Napa-Jefferson 2800763	26.0	36.1 61	1.72 61	2.03 61	1.25 61	0.81	27.5	33 60	3.02 60	3.23 60	1.13 60	0.74
San Francisco 9000306	26.5	34 61	2.62 61	3.08 61	2.8 61	0.66	22.4	34.0 60	2.70 60	3.7 60	2.97 60	0.65
Redwood City 4100541	26.4	28.2 61	1.79 59	2.76 59	1.66 59	0.71	19.9	32.1 60	2.23 60	3.69 60	1.77 60	0.66
San Jose-Moor 4300197	30.1	35.4 61	3.17 61	4.01 61	1.29 61	0.72	25.7	36.4 60	3.45 60	5.01 60	1.30 60	0.66
San Jose-4th 4300193	33.2	33.6 170	2.85 59	4.02 58	1.21 59	0.72	34.1	33 176	3.35 58	5.01 58	1.08 60	0.8
San Jose-528 4300191		40.3 61	3.13 61	4.09 61	1.13 61	0.74	30.7	34.8 60	3.34 60	4.5 60	1.14 60	0.7
San Jose-M BC 5300290	34.4	33.3 60	1.88 60	3.98 60	1.21 60	0.73	24.5	37.9 60	3.25 60	4.58 60	1.20 60	0.72

Livermore-Int 6000140	25.6	29 61	1.93 61	2.46 61	0.51 61	0.79	22.0	33.6 303	25.0	0.769	0.1084	1	2.80	O	NS	HC
San Leandro-C 6000141	21.7	28.9 61	2.05 61	2.14 61	0.83 61	0.74	18.4	29.7 147	20.6	0.696	0.1084	1	2.24	O	US	RC
Bethel Island 700442	22.3	26.1 61	2.07 61	2.83 61	0.3 61	0.75	19.6	30.6 304	22.6	0.733	0.1084	1	2.43	O	NS	RC
Concord-2975 700440	21.2	26 61	2.33 61	2.48 61	0.59 61	0.74	19.3	28.6 304	21.1	0.736	0.1084	1	2.28	O	NS	RC
Richmond-13th 700415	17.8	26.1 61	2.75 61	3 61	1.32 61	0.7	18.4	27.0 220	18.5	0.663	0.1084	1	2.01	O	NS	RC
San Rafael 2100451	20.5	24.5 61	2.24 61	1.86 61	0.88 61	0.74	18.1	27.7 297	20.7	0.748	0.1084	1	2.24	O	NS	RC
Napa-Jefferson 2800763	24.6	27 61	1.89 61	1.51 61	0.6 61	0.82	22.3	31.4 300	25.4	0.809	0.1084	1	2.76	O	NS	RC
San Francisco 9000306	22.1	31.6 61	2.70 61	2.85 61	1.69 61	0.68	21.5	33.3 303	22.9	0.691	0.1084	1	2.49	O	NS	RC
Redwood City 4100541	21.9	26.7 61	1.88 61	2.38 61	0.78 61	0.77	22.1	30.2 298	22.7	0.752	0.1084	1	2.46	O	NS	RC
San Jose-Moor 4300197	24.9	30.3 61	3.03 61	3.18 61	0.53 61	0.74	21	34.4 261	26.1	0.753	0.1084	1	3.02	O	NS	RC
San Jose-4th 4300193	24.5	33.3 61	3.18 61	1.46 61	0.63 61	0.76	25.4	34.4 713	26.6	0.784	0.1084	1	3.00	O	NS	HC
San Jose-528 4300191	24.1	31.8 61	3.09 61	3.35 61	0.47 61	0.77	24.8	35.6 182	26.4	0.744	0.1084	1	2.86	O	NS	HC
San Jose-M BC 5300290	27.3	34 61	2.23 61	3.56 61	0.68 61	0.76	25.8	35.0 300	27.0	0.754	0.1084	1	2.92	O	NS	HC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-10
South Central Coast Annual PM-10 Concentrations (Zone 11)

Station Name/ ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm
Arroyo Grande 4000851														
Atascadero-Lo 4000867	35.2 10					0.52	16.1	29.5 59					0.52	15.3
Morro Bay 4000833	N/A							N/A						
Nipomo 4000814	N/A							N/A						
Nipomo-Bucaly 4000848	N/A							34.3 61					0.48	23.6
Nipomo-Guadal 4000849	N/A							N/A						
Paso Robles 4000812	N/A							N/A						
Pa Mble-335 S 4000850	N/A							N/A						
San Luis Obis 4000835	22.5 58	2.69 58	2.24 56	1.05 55	0.66		14.8	25.9 57	2.45 57	2.51 57	1.28 57	0.69		17.0
Goleta 4200361	31.2 55	2.74 18	3.05 17	0.57 17	0.75		21.5	37.6 8					0.7	26.2
El Capitan Be 4200370	N/A							N/A						
Lompoc South 4200188														
Santa Barbara 4200186	N/A							42.9 49					0.7	30.1
Santa Maria 4200156	31.2 57	1.59 58	2.16 56	1.11 56	0.74		24.6	33.7 58	3.3 58	2.63 58	1.77 58	0.7		21.6
El Rio-Rio Me 5600419	36.5 46	5.08 38	3.63 38	0.28 38	0.7		25.6	39.9 61	4.1 61	4.69 61	0.8 61	0.7		27.9
Ojai-Maricopa 5600410	34 59					0.75	25.3	35.9 61					0.7	25.1
Piru-2 SW 5600427	30.2 60	2.95 24	4.01 21	0.17 20	0.77		29.4	35.9 60					0.71	25.5
Simi Valley	41.1	4.49	4.04	0.13	0.75		30.6	42.3	4.71	5.14	0.17	0.71		30

Station Name/ ID Number	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm
Arroyo Grande 4000851														
Atascadero-Lo 4000867	26.5 56					0.66	17	26.4 64					0.61	16.1
Morro Bay 4000833	25.8 14					0.66	16.6	33.3 55					0.61	13.6
Nipomo 4000814	26.6 53					0.66	17.1	33.4 59					0.61	16.3
Nipomo-Bucaly 4000848	30.6 60					0.66	18.6	40.3 31					0.61	30.1
Nipomo-Guadal 4000849	N/A							35.4 33					0.61	15.6
Paso Robles 4000812	22.8 29					0.66	14.6	N/A						
Pa Mble-335 S 4000850	N/A							37.3 16					0.61	23.8
San Luis Obis 4000835	21 58	2.31 60	2.22 60	1.31 60	0.68		13.6	24.4 58	3.76 58	2.73 58	1.72 58	0.65		14.0
Goleta 4200361	N/A							N/A						
El Capitan Be 4200370	N/A							28 27					0.69	30
Lompoc South 4200188														
Santa Barbara 4200186	36.0 59					0.7	25.9	34.6 56					0.60	25.2
Santa Maria 4200156	26.4 57	3.06 57	2.37 57	1.28 57	0.7		20	30.7 37	3.17 38	3.10 38	1.13 38	0.69		21.1
El Rio-Rio Me 5600419	35 61	3.74 61	3.8 61	0.64 61	0.71		24.8	32.1 57	4.36 57	4.49 57	0.72 57	0.63		20.2
Ojai-Maricopa 5600410	37.8 37					0.71	26.8	33.4 60					0.61	20.4
Piru-2 SW 5600427	34 40					0.74	25.1	36.2 60					0.67	24.2
Simi Valley	34.5	3.5	3.76	0.13	0.74		25.5	38.6	4.33	5.82	0.26	0.67		25.8

Station Name/ ID Number	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Fpm	88-92 T AM	88-92 P AM	88-92 F p/t	F d/p	AS scale	88-92 DEX	Low N	NO	Spc Scl	Mon Obj
Arroyo Grande 4000851	43.8 42					0.66	30.2	43.8 42	30.2	0.658	0.0329	1.656	1.53	X	X	NS	IN
Atascadero-Lo 4000867	34.1 54					0.66	15.9	27.1 211	16.2	0.597	0.0329	1.656	0.88		O	NS	RC
Morro Bay 4000833	30.4 61					0.66	12.0	31.4 133	13.6	0.615	0.0329	1.656	0.74		O	NS	RC
Nipomo 4000814	30.3 60					0.66	16	26.7 172	15.7	0.637	0.0329	1.656	0.86		O	NS	RC
Nipomo-Bucaly 4000848								35.1 122	22.7	0.649	0.0329	1.656	1.24		O	NS	RC
Nipomo-Guadal 4000849	30.1 60					0.66	19.0	28.8 93	18.3	0.643	0.0329	1.656	1.00		X	NS	IN
Paso Robles 4000812								22.8 29	14.6	0.662	0.0329	1.656	0.80	X			
Pa Mble-335 S 4000850	24.7 54					0.66	16.3	27.6 70	17.8	0.644	0.0329	1.656	0.97		O	NS	RC
San Luis Obis 4000835	18.9 58	3.26 59	1.96 59	1.04 59	0.66		13.1	22.7 290	14.8	0.651	0.0665	1.656	1.61		O	NS	RC
Goleta 4200361								32.0 63	23.8	0.744	0.0329	1.656	1.38		O	NS	RC
El Capitan Be 4200370	33.6 56					0.67	15.8	35.4 83	17.2	0.677	0.0329	1.656	0.93		O	NS	RC
Lompoc South 4200188	21.5 3					0.67	14.4	21.5 3	14.4	0.670	0.0329	1.656	0.78	X	O	NS	RC
Santa Barbara 4200186	30.5 58					0.67	20.4	36.8 322	25.2	0.692	0.0665	1.656	2.76		O	NS	RC
Santa Maria 4200156	26.6 59	3.38 59	2.09 59	1.36 59	0.67		17.8	30.5 268	21.4	0.703	0.0329	1.656	1.17		O	NS	HC
El Rio-Rio Me 5600419	27.7 60	3.39 60	3.39 60	0.55 60	0.67		18.6	34.2 285	23.4	0.683	0.0329	1.656	1.27		O	NS	RC
Ojai-Maricopa 5600410	24.9 58					0.67	18	33.1 275	22.9	0.691	0.0329	1.656	1.35		O	NS	RC
Piru-2 SW 5600427	30.7 60					0.71	21.7	35.1 280	25.2	0.718	0.0329	1.656	1.17		O	NS	RC
Simi Valley	31.7	3.66	3.81	0.15	0.71		22.4	37.5	26.8	0.714	0.0329	1.656	1.46		O	NS	HC

Filename: DEXPAN3.XLS, March 18, 1997
EMFACTG
Response to Public Comments #1 (Secondary PM10, Site Representation)

SO4 Scalar	1.142	1.038	SCAB only
NO3 Scalar	1.282	1.303	SCAB only
Cl Sclr in ca	1.65	1.65	SCAB only

Spatial Scale
MI Microscale
MS Middle Scale
NS Neighborhood Scale
US Urban Scale
RS Regional Scale

Monitoring Objectives
HC Highest Concentration
RC Representative Concentration
IM Impact
BL Background Level

Station	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	88-92 T AM	88-92 P AM	88-92 F p/t	F d/p	AB scale	88-92 DEK	Low N	NO	Spc Mon Scl Obj
5600434	61	59	57	55				55	58	58	50				59	60	60	60				56	56	56	56				61	60	60	60				292								
Thousand Oaks 5600435																													31.2 30					0.71	22	31.2 30	22.0	0.706	0.0320	1.656	1.20	X	O	NS RC
Ventura-Main 5600431	34.5 51					0.75	25.7	36.1 59					0.71	25.6	30.6 41					0.74	22.5	31.7 50					0.67	21.2	25.9 56					0.71	18.3	31.8 266	22.6	0.713	0.0665	1.656	3.49		O	NS RC

NOTE: The number of observations is below the arithmetic mean as an integer.

Table A-19
South Coast Annual PM-10 Concentrations (Zone 11)

Station Name/ ID Number	1988 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1989 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm
Avalon-Crescen 7000097	N/A							N/A						
Azusa 7000060	63.1 61	5.75 61	5.18 61	0.19 60	0.74		46.0	60.7 59	6.78 59	7.14 59	0.21 59	0.68		41.4
Burbank 7000069	62.1 59	6.36 55	6.6 55	0.2 59	0.69		43.6	64.7 58	5.89 58	6.67 58	0.26 58	0.64		41.6
Hawthorne 7000094	N/A							49.7 55	6.42 55	5.18 55	0.52 55	0.65		32.3
Los Angeles 7000087	58.1 58	6.59 58	6.24 58	0.39 58	0.87		39.1	61.1 58	5.95 58	6.24 58	0.26 58	0.64		38.8
N Long Beach 7000072	52.6 60	6.62 60	5.15 60	0.42 59	0.67		35	50.5 59	6.28 59	5.9 59	0.39 59	0.64		32.1
S Clarita-Hon 7000095	N/A							63.7 41	4.91 41	5.1 41	0.16 41	0.76		48.6
S Clarity-SFe 7000089	N/A							56.3 39	4.43 39	2.79 39	0.16 39	0.82		46.2
Anaheim 3000176	N/A							N/A						
El Toro 3000186	38.4 61	4.64 61	4.15 61	0.36 61	0.65		25.1	41.7 60	4.63 60	4.01 60	0.41 60	0.69		28.6
Los Alamitos 3000190	45.6 57	5.43 57	4.23 57	0.37 57	0.69		31.3	46.2 55	5.25 55	5.16 55	0.48 55	0.65		30.1
Newport Beach 3000196	N/A							N/A						
Perris 3300149	59.9 55	4.17 55	6.2 55	0.38 55	0.72		43.3	61.4 59	4.15 59	0.73 59	0.16 59	0.65		40.2
Riverside-Rub 3300144	96.0 61	5.78 61	16.88 61	0.36 61	0.59		56.2	94.2 61	5.77 61	18.4 61	0.28 61	0.56		52.7
Banning-Allee 3300150	42 57	3.31 57	4.69 57	0.24 56	0.78		30.3	47.2 60	3.46 60	5.89 60	0.15 59	0.87		37.0
Temecula-Ranch 3300160	N/A							N/A						
Fontana-Arrow 3600197	81 60	6.07 55	10.01 55	0.3 59	0.68		55.3	77.1 61	5.21 61	13.3 61	0.39 61	0.6		45.9
Lake Gregory 3600181	N/A							40 51	2.73 54	4.07 54	0.13 54	0.71		28.5
Ontario Airpo 3600171	74.8 60	5.92 60	9.78 60	0.21 59	0.66		49.7	79 61	5.66 61	14.1 61	0.23 61	0.58		45.9
San Bernadino 3600203	80.2 56	5.35 56	11.2 56	0.22 56	0.66		53	80.5 59	5.32 59	14.9 59	0.18 59	0.58		46.4

Station Name/ ID Number	1990 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	1991 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm
Avalon-Crescen 7000097	24.2 19	3.77 21	2.37 21	0.75 21	0.6		14.5	N/A						
Azusa 7000060	50.9 60	4.51 60	6.35 60	0.16 60	0.69		38.1	66.3 57	6.57 57	7.87 57	0.21 57	0.67		44.2
Burbank 7000069	52.1 60	4.03 60	6.01 60	0.21 60	0.68		35.5	54.8 60	6.58 60	8.05 60	0.35 60	0.59		32.2
Hawthorne 7000094	41.2 60	5.01 60	4.28 60	0.45 60	0.66		27.1	38.6 60	7.07 60	6.12 60	0.78 59	0.57		22.1
Los Angeles 7000087	53.2 60	5.04 60	6.54 60	0.31 60	0.66		35	57.1 57	7.18 57	7.08 57	0.44 57	0.62		35.4
N Long Beach 7000072	44.3 58	4.86 59	5 59	0.39 59	0.66		29.1	39.8 39	6.35 39	4.82 39	0.62 39	0.58		23.1
S Clarita-Hon 7000095	28.6 5	1.44 5	2.74 5	0.17 5	0.76		21.6	N/A						
S Clarity-SFe 7000089	43.2 57	3.63 58	3.82 58	0.17 57	0.77		33.2	47.1 57	4.77 58	3.91 58	0.18 58	0.73		34.4
Anaheim 3000176	48.8 59	4.48 59	5.76 58	0.24 58	0.67		32.0	45.3 59	5.17 59	6 59	0.68 59	0.6		27.3
El Toro 3000186	43.1 55	3.86 55	4.33 55	0.43 55	0.7		30.1	36.6 57	4.5 57	4.1 57	0.52 57	0.64		23.5
Los Alamitos 3000190	N/A							N/A						
Newport Beach 3000196	N/A							31.1 29	4.12 29	2.5 29	0.19 29	0.64		19.9
Perris 3300149	58.9 61	3.4 61	7.03 61	0.2 61	0.71		41.7	48.8 60	3.91 60	6.03 60	0.23 60	0.67		32.9
Riverside-Rub 3300144	78.4 61	4.56 61	14.5 61	0.28 61	0.58		45.7	74 60	5.8 60	14.1 60	0.26 60	0.57		43.1
Banning-Allee 3300150	35.4 54	2.73 52	5.18 54	0.17 54	0.63		22.4	37.8 57	3.6 57	4.4 57	0.2 57	0.66		25
Temecula-Ranch 3300160	N/A							39 29	4.67 29	3.09 29	0.13 29	0.77		30
Fontana-Arrow 3600197	77.6 59	4.27 59	8.70 59	0.38 59	0.72		56	68.6 58	8.3 58	9.33 58	0.3 55	0.63		39.3
Lake Gregory 3600181	36.6 59	2.64 58	3.45 58	0.22 59	0.74		26.9	39.3 48	3.02 48	4.26 48	0.12 48	0.71		27.9
Ontario Airpo 3600171	71.7 59	4.09 59	10.9 59	0.27 59	0.64		45.5	68.4 58	6.03 58	11 58	0.2 58	0.6		40.9
San Bernadino 3600203	65 60	4.08 60	9.54 60	0.23 60	0.65		42.3	60.6 60	5.07 60	9.78 60	0.2 60	0.6		36.4

Station Name/ ID Number	1992 AM	SO4	NO3	Cl	Cp/t	Ep/t	Ppm	88-92 T AM	88-92 P AM	88-92 F p/t	F d/p	AB scale	88-92 DEK	Low N	NO	Spc Mon Scl Obj
Avalon-Crescen 7000097								24.2 19	14.5	0.601	0.0330	1	0.48	X		
Azusa 7000060	47.4 61	4.81 61	5.56 61	0.16 61	0.67		31.9	50.6 208	40.4	0.692	0.1098	1	4.46		O	[illegible]
Burbank 7000069	49 58	4.7 59	5.13 59	0.19 59	0.69		34.1	56.6 295	37.2	0.657	0.1105	1	4.40		O	NS RC
Hawthorne 7000094	32.7 56	4.66 60	3.89 60	0.41 60	0.61		19.8	40.6 229	25.3	0.625	0.1101	1	2.99		O	NS RC
Los Angeles 7000087	48 61	4.97 61	5.71 61	0.27 61	0.66		31.6	55.4 284	35.9	0.648	0.1260	1	4.51		O	NS RC
N Long Beach 7000072	38.6 57	4.66 59	4.26 59	0.23 59	0.66		25.3	45.6 273	30.6	0.665	0.1098	1	3.23		O	NS RC
S Clarita-Hon 7000095								59.9 86	45.7	0.763	0.1105	1	5.41	X		
S Clarity-SFe 7000089	35.8 60	3.6 60	3.33 60	0.14 60	0.7		25	44.5 213	33.6	0.755	0.1105	1	3.98		O	NS RC
Anaheim 3000176	39.6 56	4.54 58	5.35 58	0.28 58	0.61		24.2	44.6 174	28.2	0.632	0.0769	1	2.17		O	NS RC
El Toro 3000186	34.4 60	4.06 61	3.43 61	0.25 61	0.68		23.3	38.8 293	26.1	0.671	0.0769	1	2.00		O	NS RC
Los Alamitos 3000190								45.9 112	30.7	0.670	0.0769	1	2.36		O	NS RC
Newport Beach 3000196	31.3 60	4.37 60	3.57 60	0.4 60	0.62		19.3	31.3 89	19.5	0.623	0.0769	1	1.50		O	NS RC
Perris 3300149	44.7 58	3.57 58	5.04 58	0.13 58	0.7		31.2	56.7 293	37.8	0.691	0.0771	1	2.92		O	NS RC
Riverside-Rub 3300144	61.5 62	4.55 61	10.6 61	0.17 61	0.59		36.6	81.0 305	46.0	0.570	0.0806	1	4.26		O	NS HC
Banning-Allee 3300150	34.3 46	3.37 46	4.07 46	0.18 46	0.62		21.2	39.7 274	25.2	0.635	0.0771	1	1.94		O	NS RC
Temecula-Ranch 3300160	30.9 57	3.43 58	3.23 58	0.16 58	0.73		22.6	33.6 86	25.1	0.747	0.0771	1	1.94		O	NS RC
Fontana-Arrow 3600197	86.1 55	4.78 54	7.21 54	0.16 54	0.84		37.2	71.4 307	47.3	0.680	0.0720	1	3.38		O	NS HC
Lake Gregory 3600181	33.3 26	3.32 26	2.01 26	0.27 26	0.72		23.9	37.8 186	27.2	0.719	0.0771	1	2.18		O	NS RC
Ontario Airpo 3600171	78.9 59	4.84 60	9.31 60	0.2 60	0.71		55.8	74.6 297	47.6	0.638	0.0720	1	3.43		O	NS RC
San Bernadino 3600203	56.7 60	4.45 60	8.07 60	0.14 60	0.62		35	68.4 295	42.4	0.620	0.0771	1	3.27		X	NS HC

NOTE: The number of observations is below the arithmetic mean as an integer.

APPENDIX B

Monitor Coordinates
Zone 10
Zone 11

Zone 10 Monitor Locations

		UTM E	UTM N
393	10 2		
200601	BEAR VALLEY-HWY 4	760900.	4265324.
400621	CHICO	599976.	4398597.
400628	CHICO-MANZANITA	598753.	4401144.
400630	CHICO-STATE	598905.	4398585.
400633	CHICO-SALEM ST	599100.	4398250.
400635	EAST BIGGS	614641.	4363343.
400637	BIGGS 9TH&C GROSS ESTIMATE	611000.	4363500.
500631	SAN ANDREAS	704345.	4229445.
600643	COLUSA-FAIRGROUNDS	584908.	4339527.
600645	ARBUCKLE HILLGATE RD 2W	578667.	4318347.
700426	WALNUT CREEK	581100.	4197902.
700430	PITTSBURG	597250.	4209421.
700432	POINT RICHMOND	554100.	4197617.
700434	MARTINEZ-JONES ST	579749.	4206304.
700437	CROCKETT-KENDALL AVE	568457.	4212058.
700440	CONCORD-2975 TREAT BLVD	585701.	4199242.
700442	BETHEL ISLAND RD	619271.	4207648.
800651	CRESCENT CITY-GROSS EST	400000.	4622820.
900000	EL DORADO-PLACERVILLE	691230.	4289275.
900664	PLACERVILLE	690879.	4288800.
900666	GEORGETOWN	687872.	4308625.
900671	SOUTH LAKE TAHOE-CALTRANS	759795.	4310972.
900673	SLY PARK DAM	717310.	4289941.
900675	STRAWBERRY	753240.	4300265.
900678	SOUTH LAKE TAHOE-DUNLAP	760112.	4311597.
900680		763632.	4314496.
900684	SO LAKE TAHOE-3377 TAHOE	762894.	4314934.
900686	PLACERVILLE-LIBRARY	689071.	4288601.
1000231	COALINGA	737679.	4003155.
1000241	FRESNO-CAL STATE #2	798583.	4077500.
1000244	FRESNO-4706 E DRUMOND	798300.	4065500.
1000248	CLOVIS-908 N VILLA AVE	801760.	4079370.
1100671	WILLOWS	569807.	4375636.
1100673	WILLOWS-VILLA AVE	568048.	4374664.
1200503	EUREKA-H.D. 6TH AND I ST	402053.	4517203.
1200513	EUREKA-FORT HUMBOLDT	399695.	4514367.
1200520	WILLOW CRK-CSD HWY 96	446690.	4532722.
1200579	EUREKA-SOUTH BROADWAY	398823.	4510617.
1500203	CHESTER ST	861844.	3919959.
1500213	TAFT-NORTH 10TH ST	818589.	3895200.
1500250	TAFT COLLEGE	819000.	3892380.
1600701	HANFORD	806071.	4023904.
1600715	CORCORAN-VAN DORSTE AVE	810826.	3997373.
1700712	KELSEYVILLE	513873.	4222261.
1700714	KELSEYVILLE-DORN RD	513629.	4222878.
1700716	MIDDLETOWN	533319.	4287046.
1700718	WHISPERING PINES	525515.	4296078.
1700720	ANDERSON SPRINGS	527143.	4292539.
1700722	COBB-1/2 NW	523870.	4297644.
1700724	HOBERGS-2 1/2 WSW	519890.	4298558.
1700726	ANDERSON SPRINGS-1/2 NE	527387.	4291800.
1700728	GLENBROOK-HIGH VALLEY RD	521092.	4299796.
1700731	COBB-BINKLEY RANCH	518897.	4300375.
1800721	SUSANVILLE	700905.	4476050.
2000002	MADERA-LIBRARY	761662.	4094391.
2100451	SAN RAFAEL	542257.	4202632.
2200742	YOSEMITE VILLAGE GR EST	822000.	4180700.
2300753	WILLITS-FIREHOUSE	469893.	4362433.
2300760	FORT BRAGG-SO MAIN	430794.	4368015.
2300763	UKIAH-HEALTH DEPT	481568.	4334281.
2400000	MERCED	721587.	4130880.
2400522	LOS BANOS	691305.	4103634.
2400525	LOS BANOS II	694151.	4107992.
2400527	MERCED COLLEGE	722942.	4135539.
2500762	CEDARVILLE AIRPORT	736086.	4603347.
2500764	ALTURAS-600 S MAIN ST EST	705190.	4594850.
2700536	SALINAS-ALISAL	613818.	4428394.
2700538	MONTEREY-APCD	598343.	4050459.
2700540	SAN ARDO	689232.	3988251.
2700544	SALINAS II	622162.	4061953.
2700546	BRADLEY CDF FIRE STATION	698331.	3971279.
2700548	SAN ARDO-SO TEXACO FIELDS	692439.	3979072.
2700550	CARMEL VALLEY-3S FORD RD	613697.	4039492.
2800783	NAPA-JEFFERSON ST	561661.	4240359.
2900793	SODA SPRINGS-DONNER	727000.	4355937.
2900796	GRASS VALLEY-HENDERS G EST	667300.	4342500.
3100809	AUBURN-DEWITT CENTER	663957.	4311332.
3100811	N LAKE TAHOE-USCG STN	749055.	4340871.
3100813	AUBURN-DEWITT-C AVE	664318.	4311339.
3100815	TAHOE CITY-150 W. LAKE BL	747000.	4339015.
3100818	COLFAX-CITY HALL	677188.	4329669.
3200812	QUINCY-HOSPITAL	674058.	4423980.
3200814	QUINCY-CAL DEPT FSTRY	590614.	4421144.
3200816	QUINCY-PLUMAS DISTR HOSP	673663.	4425671.
3200818	QUINCY CO. FAIRGROUNDS	677995.	4423148.
3200820	QUINCY COUNTY COURTHOUSE	675169.	4422156.
3200822	GRAEAGLE	703900.	4406500.
3400277	SACTO-H.D. STOCKTON BLVD	634336.	4268222.
3400280	SACTO-7TH AND I ST	610246.	4169359.
3400283	SACTO-BRANCH CENTER RD	644988.	4268343.
3400285	NORTH HIGHLANDS	641576.	4284597.
3400287	FOLSOM	657817.	4282093.
3400289	SACRAMENTO-EL CMNO/WATT	641003.	4274656.
3400291	SACTO-1131 S ST	631167.	4271003.
3400293	CITRUS HTS-SUNRISE BLVD	652253.	4281031.
3400295	SACRAMENTO-DEL PASO MANOR	642206.	4274984.
3400297	ARB-T STREET STOCKROOM	719125.	4265156.
3400299	ARB-T STREET QA	719125.	4265156.
3400301	ELK GROVE-VIA MEDIA	641505.	4251601.

		UTM E	UTM N
300000	AMADOR-JACKSON	695161.	4246804.
400626	OROVILLE-BIRD ST	624295.	4374437.
400629	CHICO-CITY LIBRARY	598905.	4398585.
400631	PARADISE-FIRE STN NO 1	618275.	4400863.
400634	OROVILLE-COUNTY CENTER	623154.	4378582.
400636	GRIDLEY 608 COWEE RD	614926.	4353785.
500000	CALAVERAS-SAN ADREAS	704321.	4230373.
600000	COLUSA	584911.	4339223.
600644	ARBUCKLE-LUCAS STREET	582246.	4318843.
600646	COLUSA-100 SUNRISE BLVD	584908.	4339527.
700429	PORT CHICAGO	591811.	3657067.
700431	NORTH RICHMOND	555640.	4200925.
700433	RICHMOND-13TH ST	556596.	4200253.
700436	CONCORD-TREAT BLVD	585701.	4199242.
700438	BRENTWOOD-FIRE DPT	614977.	4199015.
700441	RICHMOND-1065 7TH ST	555959.	4200648.
800000	DEL NORTE-CRESCENT CITY	409997.	4627925.
800652	GASQUET RANGER STA	420347.	4632890.
900663	CAMINO	702459.	4289550.
900665	LUTHER PASS	758696.	4310625.
900670	PLACERVILLE-FAIRLANE DR	689119.	4286601.
900672	PLACERVILLE AIRPORT	694399.	4288113.
900674	KYBURZ FIRE STATION	738822.	4297964.
900677	LOON LAKE-POWER HOUSE	732206.	4317671.
900679	COLOMA-PARK HDQS	683339.	4296179.
900683		765078.	4314514.
900685	SO LAKE TAHOE-CALTRANS Y	759871.	4311589.
1000229	FIVE POINTS	759529.	4025525.
1000234	FRESNO-OLIVE AVE.	796132.	4071305.
1000242	FIREBAUGH-LASSEN PARK	726266.	4083070.
1000246	FRESNO-3425 1ST STREET	796680.	4074680.
1100000	GLENN-WILLOWS	568769.	4374211.
1100672	WILLOWS-5M WEST	558019.	4374734.
1200000	HUMBOLDT EUREKA	401582.	4516999.
1200506	EUREKA-HIGHWAY DEPT	400960.	4516078.
1200519	EUREKA-SO BROADWAY	398823.	4510617.
1200521	EUREKA-2615 MYRTLE AVE	405075.	4515222.
1500000	KERN-MOJAVE	940971.	3889087.
1500205	KERN-WILDLIFE REFUGE	810200.	3962000.
1500243	OILDALE-3311 MANOR	860583.	3922915.
1501000	FELLOWS-APROX. LOCATION	811700.	3895300.
1600714	KETTLEMAN CITY CAL TRANS	776729.	3988683.
1700000	LAKE-LAKEPORT	507213.	4320271.
1700713	LAKEPORT-LAKEPORT BLVD	506444.	4320019.
1700715	UPPERLAKE	508206.	4335683.
1700717	CLEARLAKE HIGHLANDS-FD	530639.	4311785.
1700719	KELSEYVILLE-KELSEY CRK DR	513230.	4316207.
1700721	HOBERGS-HWY 175	526562.	3412211.
1700723	WHSPRNG PINES 3/4 ENE	526046.	4296109.
1700725	HOBERGS-1 MILE NW	522537.	4300105.
1700727	COBB-4WEST PP17	518469.	4297632.
1700729	HOBERGS-15385TRINITY RD	524012.	4298570.
1800000	LASSEN SUSANVILLE	674170.	4525800.
1800722	HERLONG-DEPOT BLDG T75	745635.	4447253.
2000003	MADERA-HEALTH DEPT	766927.	4093907.
2100452	KENTFIELD	539826.	4200773.
2300000	MENDOCINO-UKIAH	482718.	4333233.
2300756	FORT BRAGG-CENTRAL	430922.	4366378.
2300762	UKIAH-FIREHOUSE	482141.	4333046.
2300764	UKIAH-COUNTY LIBRARY	482256.	4334320.
2400521	MERCED	724000.	4133000.
2400524	MERCED-18TH & S	722258.	4131605.
2400526	MERCED-HEALTH DEPT	721587.	4130878.
2500000	MODOC-ALTURAS	704497.	4596950.
2500763	ALTURAS-1610 OAK STREET	705094.	4596347.
2700532	MONTEREY PENINSULA COL	607333.	4050967.
2700537	GONZALES-HIGH SCHOOL	639594.	4041629.
2700539	CARMEL VALLEY	606993.	4042303.
2700543	KING CITY-PEARL ST	758130.	4010429.
2700545	SAN ARDO WATER DIST OFF	689890.	3989129.
2700547	SAN ARDO-NO TEXACO FIELDS	690965.	3983448.
2700549	MOSS LANDING-2F	612558.	4072132.
2700551	KING CITY	667100.	4408700.
2900000	NEVADA-NEVADA CITY	669707.	4346455.
2900794	TRUCKEE-FIRE STATION G EST	743100.	4356500.
3100000	PLACER-AUBURN	666173.	4309068.
3100810	ROCKLIN-SIERRA COLLEGE	655607.	4294972.
3100812	WEIMAR-1329 PONDEROSA WY	678195.	4320894.
3100814	TAHOE CITY-NO LK TAHOE BL	745933.	4329351.
3100816	LINCOLN GROSS ESTIMATE	648400.	4306000.
3200000	PLUMAS-QUINCY	675211.	4420310.
3200813	PORTOLA	716578.	4419519.
3200815	STORRIE-ROGERS FLAT	647216.	4424742.
3200817	QUINCY-SO. REDBRG GROS EST	675500.	4422000.
3200819	QUINCY-CHP BUILDING	674400.	4424289.
3200821	QUINCY-267 NO CH GROS EST	675600.	4422500.
3400276	SACTO-13TH AND J ST	629231.	4269523.
3400278	SACTO-CREEKSIDE SCHOOL	639887.	4274792.
3400282	SACTO-1025 P ST	631130.	4270324.
3400284	RANCHO CORDOVA	650409.	4273656.
3400286	SACTO-MEADOWVIEW RD	633165.	4260031.
3400288	RIO LINDA FIRE STATION	634976.	4283339.
3400290	SHERMAN ISLAND	612498.	4214117.
3400292	SACTO-10TH & P(TRAILER)	631154.	4270324.
3400294	NORTH HIGHLANDS-BLACKFOOT	640852.	4285906.
3400296	SACRAMENTO-FLORIN	634556.	4260886.
3400298	CAL EXPO/AM YOUTH HOSTEL	637418.	4272066.
3400300	SACRAMENTO-CO. AG. OFFICE	645351.	4245562.
3400302	SAC METRO AIRPORT-TOWER	622581.	4283230.

Zone 10 Monitor Locations

3400303	SACRAMENTO EXEC AIRPORT	630786.	4263195.
3400305	SACTO-1309 T	718541.	4271464.
3500000	SAN BENITO-HOLLISTER	645622.	4079275.
3900251	STOCKTON-SO AMERICAN	653759.	4201503.
3900253	COLONIAL HEIGHTS	653655.	4207050.
3900255	LODI	653176.	4221847.
3900257	STOCKTON-HOTEL	650830.	4201449.
3900260	LODI-HAM	650075.	4219933.
3900262	STOCKTON-4SE/CA YOUTH CTR	658493.	4195363.
3900264	STOCKTON-PACIFIC AVE	647849.	4207007.
3900266	STOCKTON-4310 CLAREMONT	648567.	4206433.
4000832	PASO ROBLES	709070.	3943685.
4000834	NIPOMO	728043.	3880322.
4000836	ARROYO GRANDE-BRANCH ST	720363.	3889598.
4000838	PISMO BEACH-11NW	695049.	3898328.
4000840	PASO ROBLES-AIRPORT	713951.	3950122.
4000842	MORRO BAY-BAYWOOD SUB STA	698879.	3915089.
4000844	GROVER CITY-LESAGE DRIVE	710253.	4111152.
4000846	NIPOMO MESA-950 GUADALUPE	721961.	3880172.
4000850	PASO ROBLES-23S SAN	708900.	3946300.
4100545	BURLINGAME-BURLINGAME AVE	557786.	4159210.
4200356	SANTA MARIA-LIBRARY	734364.	3871232.
4200364	SANTA MARIA-E MAIN ST	734744.	3871242.
4200366	SANTA MARIA-BRIARWOOD DR	729656.	3864607.
4200368	SANTA MARIA-ORCURTT HILL	735979.	3857799.
4200370	EL CAPITAN BEACH	773089.	3817068.
4200373	SANTA BARBARA-CHNL,HONDO	764811.	3808995.
4200378		803332.	3813503.
4200382	VANDENBERG AFB-WATT RD	719029.	3851151.
4300377	SAN JOSE-MOORPARK	595132.	4130335.
4300381	MOUNTAIN VIEW	583280.	4138839.
4300384	SUNNYVALE	585909.	4136710.
4300386	SAN JOSE-PIEDMONT RD	602463.	4138742.
4300388	SARATOGA-HWY 85 & SP RR	585635.	4127429.
4300390	SAN JOSE-W SAN CARLOS	595250.	4121140.
4400000	SANTA CRUZ	590482.	4093303.
4400846	SCOTTS VALLEY	587242.	4100570.
4400848	SCOTTS VLY-SKY PK AIRPORT	586203.	4100746.
4400850	SANTA CRUZ-966 BOSTWICK	590210.	4093361.
4500553	REDDING-MARKET	551597.	4493148.
4500556	BURNEY	612077.	4526628.
4500559	BUCKEYE ELEMENTARY SCH	550995.	4498660.
4500561	MOUNTAIN GATE	557235.	4508851.
4500563	BURNEY-1.5N-BLACK RANCH R	613517.	4528902.
4500565	BURNEY-HIGH SCHOOL	613810.	4526562.
4600852	SIERRA CITY	703593.	4382101.
4600854	LOYALTON	735500.	4395500.
4700861	YREKA	530148.	4619710.
4700868	FORT JONES	512500.	4605160.
4700870	MONTAGUE	542952.	4622855.
4800875	FAIRFIELD-BAAPCD	582548.	4233304.
4800877	RIO VISTA-MAIN ST	614676.	4223859.
4800879	VALLEJO-TUOLUMNE	567072.	4217441.
4800881	VACAVILLE MERC GROSS EST.	588600.	4245600.
4900883	PETALUMA-PAYRAN	532695.	4232394.
4900885	HEALDSBURG	511221.	4274007.
4900887	SONOMA-1ST ST	547512.	4238570.
4900889	LYTTON-3 1/2 EAST	516556.	4278515.
4900891	CLOVERDALE-6 1/2 ENE	508198.	4297921.
4900893	SANTA ROSA-837 FIFTH ST	525501.	4255054.
4900895	GUERNEVILLE-CHURCH & 1ST	500242.	4261238.
4900898	HEALDSBURG-133 MATHERSON	511608.	4273730.
5000557	MODESTO-J ST	676608.	4167644.
5000559	SALIDA	667988.	4144000.
5000562	TURLOCK-MONTE VISTA	689981.	4155542.
5000564	OAKDALE	687990.	4181492.
5000566	VALLEY HOME-SCHOOL	683593.	4188734.
5000568	MODESTO-814 14TH ST	677023.	4167742.
5000570	MODESTO-7007 JENNINGS RD	670088.	4155574.
5000572	WESTLY TRUCK STOP	655710.	4153170.
5100892	LIVE OAK-FIRE STN	615012.	4347929.
5100894	SUTTER CITY	608002.	4334878.
5100897	PLEASANT GROVE-4SW	629088.	4291753.
5200000	TEHAMA-RED BLUFF	563850.	4448165.
5200906	RED BLUFF-LINCOLN	564328.	4447550.
5200908	LOS MOLINOS	578211.	4431644.
5300912	WEAVERVILLE-HOSP	505165.	4502621.
5300914	HAYFORK RANGER STATION	486217.	4488820.
5400579	PORTERVILLE-COURTHOUSE	861780.	3993400.
5500921	COLUMBIA	727281.	4212007.
5500923	TUOLUMNE CITY	743097.	4205398.
5500925	COLUMBIA-PARK HDQRS	728256.	4212898.
5500927	SONORA-105 S WASHINGTON	730007.	4207054.
5700568	DAVIS-5TH ST	609633.	4267074.
5700570	WEST SACRAMENTO-15TH ST	628592.	4270066.
5700572	MADISON-MAIN ST	589879.	4281933.
5700574	DUNNIGAN REST IS E AREA	588918.	4305105.
5700576	BRODERICK-30S 3RD	629235.	4272238.
5800932	WHEATLAND	636369.	4318886.
6000326	BERKELEY	564568.	4192175.
6000328	SAN LEANDRO	573789.	4174656.
6000333	FREMONT-UNION ST	576522.	4159730.
6000335	LIVERMORE-RAILROAD	607920.	4171117.
6000337	HAYWARD-LA MESA	585196.	4167769.
6000339	OAKLAND-ALICE	564562.	4183609.
6000341	BERKLEY-UC SPACE SCI. BLDG.	567136.	4191828.
9000303	SAN FRANCISCO-ELLIS ST	551024.	4181757.
9000306	SAN FRANCISCO-10 ARKANSAS	553042.	4179828.
3400304	ARB-T STREET LAB	718541.	4271464.
3400307	SACTO EARHART GROSS EST.	622600.	4283500.
3500823	HOLLISTER-1979 FAIRVIEW	646128.	4078635.
3900252	STOCKTON-HAZELTON ST	652122.	4201597.
3900254	TRACY	639491.	4179050.
3900256	STOCKTON-SO FRESNO	653759.	4201503.
3900259	NEW JERUSALEM	647929.	4169945.
3900261	UNION ISLAND	636739.	4189949.
3900263	RIPON-FIRE STATION	665434.	4178265.
3900265	STOCKTON-HAMMER LN	646124.	4209285.
3900267	STOCKTON-13521 E MARIPOSA	662885.	4196898.
4000833	MORRO BAY	730165.	3916452.
4000835	SAN LUIS OBISPO-MARSH	713344.	3906850.
4000837	MORRO BAY-JR HIGH	694548.	3916844.
4000839	ARROYO GRANDE-LOPEZ W PLT	724383.	3895031.
4000841	PISMO BEACH-601 BELLO RD	715814.	3891277.
4000843	SAN LUIS OBISPO-GOLDTREE	709511.	3910799.
4000845	SAN LUIS OBISPO-7920LEWIS	716834.	3896393.
4000849	NIPOMO-GUADAL	721960.	3880170.
4100541	REDWOOD CITY	570486.	4148335.
4100547	PACIFICA-SAN PEDRO	544113.	4161191.
4200360	LOMPOC-G ST	774905.	3823012.
4200365	LOMPOC-JALAMA RD	737150.	3822094.
4200367	SANTA MARIA-LK MARIE EST	732061.	3861924.
4200369	SANTA YNEZ AIRPORT	768624.	3832698.
4200371	SANTA MARIA-GLACIER LANE	739935.	3862096.
4200377	SANTA MARIA-MCCLELLAND ST	734506.	3870619.
4200381	LOMPOC-128 SOUTH H ST	733160.	3835589.
4200383	VANDENBERG AFB-HERADO AVE	725697.	3846904.
4300380	LOS GATOS	590612.	4120328.
4300382	SAN JOSE-4TH ST	598547.	4132964.
4300385	GILROY-MONTEREY ST	632233.	4095854.
4300387	MOUNTAIN VIEW-CUESTA	581705.	4136480.
4300389	GILROY-9TH ST	626847.	4095617.
4300391	SAN JOSE-528 TULLY	601100.	4129200.
4400845	APTOS	595690.	4094099.
4400847	FELTON	582252.	4100613.
4400849	SANTA CRUZ-610 FREDRICK	588701.	4093437.
4500000	SHASTA-REDDING	552189.	4492476.
4500555	REDDING-H.D. ROOF	552568.	4488808.
4500558	ANDERSON-CENTER ST	559005.	4477906.
4500560	REDDING-1855 PLACER ST	551298.	4492222.
4500562	ANDERSON-1225 KIMBERLY RD	562908.	4475902.
4500564	REDDING-1615 CONTINENTAL	551977.	4492628.
4600000	SIERRA-SIERRA CITY	703305.	4382130.
4600853	SIERRAVILLE-CALTRANS YARD	730071.	4385656.
4700000	SISKIYOU-YREKA	530494.	4[illegible]021.
4700866	MT SHASTA	557196.	4[illegible]828.
4700869	WEED-FOREST GUARD STA	550833.	45[illegible]898.
4800874	VALLEJO-BAAPCD	567072.	4217441.
4800876	BENICIA	579304.	4206917.
4800878	VACAVILLE	588486.	4246066.
4800880	RIO VISTA-ARMY FACILITY	614479.	4222316.
4900000	SONOMA-HEALDSBURG	511608.	4274040.
4900884	SANTA ROSA-HUMBOLDT ST	525090.	4254742.
4900886	CLOVERDALE-GROSS ESTIMATE	496730.	4295130.
4900888	GEYSERVILLE-GYSRVILLE RD	508937.	4283898.
4900890	WHISPERING PINES-3MI E	520258.	4295785.
4900892	GUERNEVILLE-FIRE STA	500339.	4261761.
4900894	GEYSERVILLE-REDWOOD FWY	506979.	4285160.
4900896	CALDWELL PINES [E	520258.	4295785.
5000556	MODESTO	676479.	4166808.
5000558	MODESTO-OAKDALE RD	680099.	4169507.
5000561	TURLOCK	691001.	4151773.
5000563	TURLOCK-W MONTE VISTA	690294.	4151507.
5000565	HUGHSON	689009.	4163691.
5000567	MODESTO-1100 I STREET	676736.	4168539.
5000569	MODESTO-2700STANDIFORD RD	672632.	4172492.
5000571	CROWS LANDING-DAVIS RD	666415.	4139780.
5100000	SUTTER-YUBA CITY	621035.	4330448.
5100893	PLEASANT GROVE	629852.	4298210.
5100895	YUBA CITY-AG BLDG	620737.	4331058.
5100898	YC ALMOND ST GROSS EST.	619500.	4332800.
5200901	RED BLUFF	566183.	4451882.
5200907	CORNING	571975.	4337238.
5300000	TRINITY-WEAVERVILLE	505629.	4508946.
5300913	WEAVERVILLE-CALTRANS	505184.	4509187.
5400568	VISALIA-CHURCH ST	837973.	4022939.
5500000	TUOLOMNE-SONORA	729814.	4206991.
5500922	SONORA	729829.	4207296.
5500924	SONORA-FORREST RD	729237.	4206632.
5500926	SONORA-155 S WASHINGTON	730058.	4206992.
5700567	DAVIS	610379.	4267394.
5700569	WOODLAND-W MAIN ST	605406.	4280949.
5700571	DUNNIGAN-MAIN ST	589635.	4305636.
5700573	DAVIS-1503 BROWN DR	607584.	4268187.
5700575	DAVIS GOLF COURSE	606239.	4271035.
5800000	YUBA-WHEATLAND	637079.	4319611.
5800933	SMARTVILLE	648633.	4338320.
6000327	OAKLAND	740658.	4186937.
6000331	LIVERMORE-RINCON	608776.	4169339.
6000334	OAKLAND-JACKSON	564561.	4183730.
6000336	FREMONT-CHAPEL WAY	591836.	4154585.
6000338	OAKLAND-MTN BLVD	569338.	4182753.
6000340	LIVERMORE OLD FST ST	608799.	4171175.
6000343	SAN LEANDRO	576200.	4175500.
9000304	SAN FRANCISCO-23RD ST	554314.	4179898.

Zone 11 Monitor Locations

213	10	2	UTM E	UTM N
1300693	BRAWLEY-401 MAIN STREET		636933.	3649720.
1400696	COSO JUNCTION-EST		416000.	3989000.
1400699	LONE PINE-EST		405000.	4051000.
1400703	INDEPENDENCE #67-EST		393000.	4072000.
1400710	OLANCHA-EST		406000.	4016000.
1400717	BISHOP-EST		377000.	4136000.
1500207	MOJAVE GROSS ESTIMATE		393480.	3878750.
1500249	MOJAVE AIRPORT GROSS EST.		393500.	3878030.
2600782	MONO LAKE-EST		312500.	4210000.
2600786	MAMMOTH LAKES SHERWIN-EST		338000.	4169000.
3000176	ANAHEIM		415476.	3742470.
3000178	ORANGE COUNTY AIRPORT		433622.	3734473.
3000186	EL TORO		435975.	3720875.
3000188	SAN JUAN CAPISTRANO		438328.	3706045.
3000190	LOS ALAMITOS-ORANGEWOOD		404471.	3739802.
3000192	COSTA MESA-PLACENTIA		413794.	3724220.
3000194	ANAHEIM-500 W BROADWAY		415023.	3743645.
3300126	RIVERSIDE-11TH ST MALL		458418.	3756508.
3300128	CORONA		442962.	3747348.
3300137	PALM SPRINGS-FIRE STN		542529.	3745701.
3300140	NORCO-PRADO PARK		445136.	3754604.
3300142	RIVERSIDE-TRAILER		464730.	3755804.
3300146	RIVERSIDE-MAGNOLIA		463036.	3755996.
3300149	PERRIS		477555.	3729649.
3300151	TEMECULA		487615.	3706533.
3300153	PALO VERDE-SAN DIEGO G&E		709218.	3699549.
3300155	NORCO-NORCONIAN		447183.	3753299.
3300157	INDIO-JACKSON		572819.	3729899.
3300160	TEMECULA-RANCH		484800.	3707300.
3600151	SAN BERNARDINO		473635.	3773331.
3600155	BARSTOW		497868.	3861077.
3600161	CUCAMONGA-UCR LEMON #2		453870.	3771312.
3600164	UPLAND-ORANGE #1 UCR		441580.	3773229.
3600166	RIALTO AIRPORT		462311.	3780022.
3600170	FONTANA-CYPRESS		458495.	3774063.
3600172	CRESTLINE		472602.	3788056.
3600174	UPLAND-CIVIC CENTER		440041.	3773053.
3600176	FONTANA-FOOTHILL TRAILER		455369.	3773923.
3600182	YUCAIPA		495001.	3767967.
3600187	NEEDLES-BAILEY		443563.	3854782.
3600189	UPLAND-POST OFFICE		441580.	3773229.
3600191	TWENTYNINE PALMS-ADOBE		587228.	3778195.
3600193	FONTANA REDWOOD		455421.	3774077.
3600195	MT BALDY-FIRE DEPT		439475.	3788519.
3600197	FONTANA-ARROW HWY		453417.	3773101.
3600199	VICTORVILLE-15579 8TH STR		473234.	3821288.
3600201	HESPERIA-17288 OLIVES		473835.	3808350.
3600203	SAN BERNARDINO 4TH ST.		474789.	3773882.
3600208	LUCERNE VALLEY		504600.	3811100.
4000832	PASO ROBLES		159070.	3943685.
4000834	NIPOMO		178043.	3880322.
4000836	ARROYO GRANDE-BRANCH ST		720363.	3889598.
4000838	PISMO BEACH-11NW		695049.	3898328.
4000840	PASO ROBLES-AIRPORT		713951.	3950122.
4000842	MORRO BAY-BAYWOOD SUB STA		698879.	3915089.
4000844	GROVER CITY-LESAGE DRIVE		710253.	4111152.
4000846	NIPOMO MESA-950 GUADALUPE		721961.	3880172.
4000848	NIPOMO-EUCALY		180400.	3880500.
4000850	PASO ROBLES 235 SAN		158900.	3946300.
4200360	LOMPOC-G ST		774905.	3823012.
4200364	SANTA MARIA-E MAIN ST		734744.	3871242.
4200366	SANTA MARIA-BRIARWOOD DR		729656.	3864607.
4200368	SANTA MARIA-ORCURTT HILL		735979.	3857799.
4200370	EL CAPITAN BEACH		223089.	3817068.
4200373	SANTA BARBARA-CHNL, HONDO		764811.	3808995.
4200378			803332.	3811503.
4200382	VANDENBERG AFB-WATT RD		719029.	3851151.
4200388	SANTA BARBARA-CARRILLO		251649.	3812000.
5600402	OJAI		293769.	3813648.
5600412	PORT HUENEME		296549.	3779343.
5600415	THOUSAND OAKS - WINDSOR		328045.	3785002.
5600418	PIRU		335258.	3804840.
5600420	VENTURA-FIGUEROA		288361.	3794751.
5600422	OJAI-1401 MARICOPA HWY		293790.	3813432.
5600427	PIRU-2SW		332369.	3807634.
5600429	VENTURA CO-W CASITAS PASS		277891.	3807509.
5600431	LA CONCHITA-7128 SANTA PA		274897.	3805269.
5600433	VENTURA-EMMA WOOD ST. BE.		287046.	3796538.
7000001	LOS ANGELES-DOWNTOWN		385363.	3767614.
7000069	BURBANK		378705.	3782269.
7000072	NORTH LONG BEACH		390002.	3743038.
7000075	POMONA		430714.	3769637.
7000078	REDONDO BEACH		372030.	3746929.
7000081	NEWHALL		359188.	3805835.
7000083	PASADENA-WALNUT		396287.	3779163.
7000085	PICO RIVERA		402278.	3764128.
7000087	LOS ANGELES-NO MAIN		386932.	3770091.
7000089	SANTA CLARITA-SAN FERNANDO		359200.	3811600.
7000091	WEST LOS ANGELES-VA HOSP		365680.	3768551.
7000095	SC HONBY ST GROSS ESTIMATE		358200.	3809200.
7000097	AVALON-CRESC		376500.	3690000.
7000580	TEMPLE CITY		401511.	3774209.
7000585	RIO HONDO-PUENTE HILLS		406127.	3764274.
7000587	HARBOR CITY		381157.	3736830.
7000589	SAN FERNANDO-CITY HALL		367583.	3794373.
7000592	SANDBERG-US WTHR STA		341909.	3845648.
7000594	BURBANK-1915 MONTEREY AVE		377134.	3783553.
7000597	VICTORIA-1000 VICTORIA #2		384553.	3747354.
7000599	BEVERLY HILLS-FRANKLIN CN		370095.	3774405.
8000114	CHULA VISTA		494736.	3609280.

		UTM E	UTM N
1300694	EL CENTRO-150 9TH ST.	634695.	3629073.
1400697	KEELER-EST	422000.	4038000.
1400700	INDEPENDENCE #77-EST	395000.	4075000.
1400709	BIG PINE-EST	385000.	4113000.
1400716	BISHOP 125 S MAIN-EST	377000.	4130000.
1400718	COSO JUNCTION 10 MI E-EST	430000.	3989000.
1500211	CHINA LAKE GROSS EST.	439700.	3945100.
2600779	LEE VINING-EST	315000.	4205000.
2600785	MAMMOTH LAKES-EST	338000.	4165000.
2600788	BODIE-11 MILES SE	331100.	4218400.
3000177	LA HABRA	412113.	3754175.
3000185	COSTA MESA-HARBOR	414759.	3725505.
3000187	SANTA ANA-POLICE STN	419472.	3734643.
3000189	LAGUNA BEACH-BROADWAY	427533.	3711879.
3000191	SANTA ANA-WEIR CANYON RD	430635.	3748354.
3000193	LAGUNA BEACH-1535 ARROYO	428300.	3720888.
3000196	NEWPORT BEACH	416300.	3770000.
3300127	BEAUMONT	503081.	3754569.
3300132	BLYTHE	727339.	3720302.
3300139	INDIO-OASIS ST	572248.	3730573.
3300141	HEMET-STATE ST	502830.	3733730.
3300144	RIVERSIDE-RUBIDOUX	461726.	3762068.
3300147	RIVERSIDE-UCR WTHR SHACK	467056.	4201050.
3300150	BANNING-ALLESANDRO	511682.	3753960.
3300152	ELSINORE	467558.	3726906.
3300154	NORCO-5TH STREET	447934.	3754403.
3300156	RIVERSIDE-RCC	464869.	3758699.
3300158	JOSHUA TREE - LOST HORSE	574633.	3764412.
3300161	BLYTHE-WMURPH	727300.	3720300.
3600153	UPLAND-JUSTICE CT	464648.	3774962.
3600160	UPLAND-UCR LEMON #1	443128.	3775067.
3600162	CHINO AIRPORT	439984.	3763998.
3600165	REDLANDS	482824.	3768135.
3600168	VICTORVILLE	473107.	3821289.
3600171	ONTARIO AIRPORT	445778.	3768121.
3600173	CHINO-RIVERSIDE AVE	436267.	3764331.
3600175	UPLAND ARB	442044.	3773626.
3600181	LAKE GREGORY	474753.	3789036.
3600184	BIG BEAR LAKE	509029.	3789376.
3600188	TRONA-MARKET ST	436090.	3957328.
3600190	VICTORVILLE-FAIRGROUNDS	471141.	3820186.
3600192	REDLANDS-UNIV OF GROVE	486158.	3769362.
3600194	SAN BERNARDINO-E 3RD	474533.	3773883.
3600196	CAJON-3 NW	453995.	3796846.
3600198	CHINO-13251 CENTRAL AVE	436518.	3763559.
3600200	JOSHUA TREE-LOST HORSE RS	574633.	3[illegible]4410.
3600202	VICTORVILLE-CIVIC DR	470677.	3[illegible]8524.
3600204	REDLANDS DEARBORN	485260.	3[illegible]8025.
3600209	VICTORVILLE-ARMAGOS	470100.	3819500.
4000833	MORRO BAY	180165.	3916452.
4000835	SAN LUIS OBISPO-MARSH	163344.	3906850.
4000837	MORRO BAY-JR HIGH	694548.	3916844.
4000839	ARROYO GRANDE-LOPEZ W PLT	724383.	3895031.
4000841	PISMO BEACH-601 BELLO RD	715814.	3891277.
4000843	SAN LUIS OBISPO-GOLDTREE	709511.	3910799.
4000845	SAN LUIS OBISPO-7020LEWIS	716834.	3898393.
4000847	ATASCADERO-GROSS ESTIMATE	161800.	3929900.
4000849	NIPOMO-GUADAL	171961.	3880172.
4200356	SANTA MARIA-LIBRARY	184364.	3871232.
4200363	GOLETA-GROSS ESTIMATE	240200.	3814000.
4200365	LOMPOC-JALAMA RD	737150.	3822094.
4200367	SANTA MARIA-LE MARIE EST	732061.	3861924.
4200369	SANTA YNEZ AIRPORT	768624.	3832698.
4200371	SANTA MARIA-GLACIER LANE	739935.	3862096.
4200377	SANTA MARIA-MCCLELLAND ST	734506.	3870619.
4200381	LOMPOC-128 SOUTH H ST	733160.	3835589.
4200383	VANDENBERG AFB-HERADO AVE	725697.	3846904.
5600401	VENTURA	289816.	3795735.
5600404	SANTA PAULA	310180.	3803190.
5600413	SIMI VALLEY	344915.	3794013.
5600416	CAMARILLO-ELM DR	312273.	3787738.
5600419	EL RIO-RIO MESA SCHOOL	302638.	3792220.
5600421	VENTURA-MAIN ST	289042.	3795444.
5600426	FILLMORE-OAK FLAT STATION	324708.	3815880.
5600428	ANACAPA ISLAND-LIGHTHOUSE	281993.	3766167.
5600430	OJAI-1768 MARICOPA HWY	291424.	3813824.
5600432	SAN NICOLAS ISLAND	271746.	3680375.
5600434	SIMI VALLEY-54[illegible] LOCHRAN	344915.	3794013.
7000060	AZUSA	414916.	3777405.
7000071	WEST LOS ANGELES	367688.	3767260.
7000074	RESEDA	358722.	3785136.
7000076	LENNOX	373501.	3755073.
7000080	WHITTIER	405280.	3753963.
7000082	LANCASTER	395682.	3841523.
7000084	LYNWOOD	388186.	3754765.
7000086	WEST LA-ROBERTSON	372271.	3768552.
7000088	PASADENA-WILSON	396087.	3777348.
7000090	EL MONTE-9150 FLAIR DR	401495.	3770235.
7000094	HAWTHORNE	373476.	3755104.
7000086	LANCASTER-WEST PONDEROSA	394000.	3839000.
7000579	EL MONTE-9528 TELSTAR	401928.	3769923.
7000581	MT LEE	378312.	3777684.
7000586	DOMINGUEZ-CAL STATE	384312.	3742336.
7000588	GLENDALE-MT THOM	385273.	3783327.
7000591	GLENDORA-LAUREL	421531.	3778149.
7000593	LANCASTER-NORTH CEDAR AVE	395814.	3839704.
7000596	CARSON-VICTORIA STREET	383683.	3747734.
7000598	TANBARK FLATS	429754.	3785230.
7000600	INDUSTRY - 1470 DON JULIAN	410394.	3765157.
8000115	ESCONDIDO-VALLEY PKWY	493755.	3664924.

Zone 11 Monitor Locations

8000120	SAN DIEGO-ISLAND AVE	485606.	3620867.
8000128	ALPINE-VICTORIA	523398.	3632647.
8000131	EL CAJON-REDWOOD AVE	505462.	3627971.
8000134	OCEANSIDE-1701 MISSION AVE	465825.	3673635.
9900001	SAN NICOLAS ISLAND	271746.	3681480.
8000123	SAN DIEGO-OVERLAND	487520.	3632104.
8000130	SAN DIEGO-1133 UNION ST	484511.	3619760.
8000133	DEL MAR-MIRACOSTA COLLEGE	475387.	3645860.
8000135	SAN DIEGO-880 FRONT ST	484641.	3619575.
9900002	CLAREMONT COLLEGE	432355.	3773281.

Appendix C

Barrier Coordinates

	UTM E1	UTM N1	UTM E2	UTM N2
Zone 10 Barrier Coordinates				
50				
CRZ1	547000.	4163000.	553000.	4151000.
CRZ2	553000.	4151000.	582000.	4123000.
CRZ3	582000.	4123000.	599000.	4118000.
CRZ4	599000.	4118000.	625000.	4089000.
MARN	528000.	4206000.	538000.	4194000.
EBY1	562000.	4211000.	589000.	4170000.
EBY2	589000.	4170000.	621000.	4124000.
EBY3	621000.	4124000.	621001.	4165000.
EBY4	593000.	4205000.	621001.	4165000.
GABI	632000.	4073000.	735000.	3962000.
JACK	446000.	4373000.	460000.	4325000.
MSTR	500000.	4280000.	533000.	4280000.
EDGA	500000.	4280000.	500001.	4238000.
SNR1	737000.	4341000.	758000.	4353000.
SNR2	758000.	4353000.	775000.	4374000.
SNR3	737000.	4341000.	747000.	4303000.
SNR4	747000.	4303000.	753000.	4288000.
SNR5	753000.	4288000.	771000.	4295000.
SNR6	771000.	4295000.	775000.	4374000.
SED1	880000.	3850000.	960000.	3960000.
SED2	880000.	3850000.	965000.	3805000.
SED3	965000.	3805000.	1065000.	3785000.
SED4	1055000.	3755000.	1065000.	3785000.
SED5	1055000.	3755000.	1135000.	3610000.
SMON	867500.	3775000.	927000.	3776999.
SSSN	883500.	3804000.	907000.	3800999.
SGB1	917500.	3805000.	1007500.	3795000.
SGB2	935000.	3830000.	942500.	3802500.
SANA	990000.	3741500.	1017500.	3712500.
SED1	1007000.	3795000.	1110000.	3790000.
SED2	1065000.	3767500.	1065001.	3794000.
SJC1	1072500.	3744499.	1089000.	3700000.
SJC2	1055000.	3747500.	1077500.	3744499.
SIMI	885000.	3787500.	907000.	3800999.
SMON	867500.	3775000.	927000.	3776999.
SSSN	883500.	3804000.	907000.	3800999.
SGB1	917500.	3805000.	1007500.	3795000.
SGB2	935000.	3830000.	942500.	3802500.
SAND	880000.	3855000.	935000.	3830000.
SANA	990000.	3741500.	1017500.	3712500.
SBD1	1007000.	3795000.	1110000.	3790000.
SBD2	1065000.	3767500.	1065001.	3794000.
SJC1	1072500.	3744499.	1092500.	3680000.
SJC2	1055000.	3747500.	1077500.	3744499.
SIMI	885000.	3787500.	907000.	3800999.
YNEZ	760000.	3821000.	859800.	3820500.
SLR1	647000.	3971800.	705500.	3921200.
SLR2	705500.	3921200.	766500.	3897200.
LOPR	766500.	3897200.	771800.	3880500.
SAMM	771800.	3880500.	859800.	3820500.
Zone 11 Barrier Coordinates				
31				
SED1	330000.	3850000.	410000.	3960000.
SED2	330000.	3850000.	415000.	3805000.
SED3	415000.	3805000.	515000.	3785000.
SED4	505000.	3755000.	515000.	3785000.
SED5	505000.	3755000.	585000.	3610000.
SMON	317500.	3775000.	377000.	3776999.
SSSN	333500.	3804000.	357000.	3800999.
SGB1	367500.	3805000.	457500.	3795000.
SGB2	385000.	3830000.	392500.	3802500.
SANA	440000.	3741500.	467500.	3712500.
SBD1	457000.	3795000.	560000.	3790000.
SBD2	515000.	3767500.	515001.	3794000.
SJC1	522500.	3744499.	542500.	3680000.
SJC2	505000.	3747500.	527500.	3744499.
SIMI	335000.	3787500.	357000.	3800999.
SMON	317500.	3775000.	377000.	3776999.
SSSN	333500.	3804000.	357000.	3800999.
SGB1	367500.	3805000.	457500.	3795000.
SGB2	385000.	3830000.	392500.	3802500.
SAND	330000.	3855000.	385000.	3830000.
SANA	440000.	3741500.	467500.	3712500.
SBD1	457000.	3795000.	560000.	3790000.
SBD2	515000.	3767500.	515001.	3794000.
SJC1	522500.	3744499.	542500.	3680000.
SJC2	505000.	3747500.	527500.	3744499.
SIMI	335000.	3787500.	357000.	3800999.
YNEZ	210000.	3821000.	309800.	3820500.
SLR1	97000.	3971800.	155500.	3921200.
SLR2	155500.	3921200.	216500.	3897200.
LOPR	216500.	3897200.	221800.	3880500.
SAMM	221800.	3880500.	309800.	3820500.

APPENDIX C

EVALUATION OF PM_{10} CARBON SAMPLES FOR DIESEL EXHAUST CONTRIBUTION

Evaluation of Carbon Samples Collected Near a Freeway to Determine the Above Ambient Levels of PM_{10} due to Direct Emissions from Diesel Engine Exhaust

July 19, 1996

Introduction:

At the request of the Stationary Source Division of the California Air Resources Board, the Technical Support Division estimated the above ambient PM_{10} concentration due to exhaust from primary emissions from diesel engines near a freeway for a two day event. This is accomplished by evaluating ambient carbon data collected for two days in December 1993, near the Long Beach Freeway. The sampling sites are located one kilometer north of the Long Beach/San Diego Freeway interchange.

Sampling Data:

The Monitoring and Laboratory Division gathered carbon samples in ambient air near the Long Beach Freeway for two time periods, May 17-21, 1993 and December 6-9, 1993. The sampling was conducted for PM_{10}, particulates that are ten microns and smaller (1 micron = 1 μm = $1x10^{-6}$ meters). Insufficient data were gathered during the May sampling to determine above ambient levels of carbon as will be discussed later in this report.

The data for the May sampling period are collected on either side of the Long Beach Freeway, north of the Long Beach/San Diego Freeway interchange, as

shown in Figure 1 (all Figures are located at the end of the report). The sampling site on the west side of the Long Beach Freeway, West1May, is located in a clearing approximately five meters from the freeway fenceline. A second sampling site, West2May, is located approximately 200 meters due west of West1May. The sampling site located on the east side of the freeway, East1May, is located approximately 10 meters from the freeway fenceline.

The data collected during the May sampling period were for two-day periods and are shown in Table 1 and Figure 2. The first two-day period, Days1-2, begins at 1415 hours on Monday May 17 and ends at 0935 hours on May 19 for West1May. The second two-day period, Days 3-4, begins at 1050 hours on May 19 and ends at 0850 hours on Friday May 21. The start and stop times for West2May and East1May lag by five to fifteen minutes, the time required for personnel to attend the equipment. The data collected are corrected to 25 degrees Celsius.

Table 1
Two-Day Carbon Measurements, Collected May 1993
($\mu g/m^3$)

	Days1-2, May 17 - May 19			Days3-4, May 19 - May 21		
Site	min.	mean	max.	min.	mean	max.
West1May						
EC	0.63	0.72	0.83	na	na	na
OC	4.45	5.25	6.41	na	na	na
West2May						
EC	0.30	0.34	0.37	na	na	na
OC	4.59	5.15	5.92	na	na	na
East1May						
EC	na	na	na	1.44	1.61	1.69
OC	na	na	na	5.62	6.36	7.52

EC = Elemental Carbon, OC = Organic Carbon, na = not available

Three samples are collocated at each site for the data in Table 1. The minimum, mean, and maximum of the three samples are reported. The laboratory that extracted the mass off the filters reported a coefficient of variation of 8.1% and 2.6% in other experiments (Fung 1990) for the elemental carbon and organic carbon, respectively. An evaluation of the laboratory techniques for data collected in May shows the error in the measured air volume through the filters is less than plus or minus 1.7%.

The uses of these data in Table 1 are limited since carbon data were not collected simultaneously at all locations and a sampler was not located to represent background conditions. Further evaluation of the carbon data collected in May is not conducted. However, the data may be used for comparative purposes with the data collected in December of 1993.

During the December sampling period, the data are collected on either side of the Long Beach Freeway north of the locations used in the May sampling period as well as sampling on the roof of a school gymnasium as shown in Figure 1. The sampler located to the west of the freeway, West1Dec, is located next to the freeway fenceline. The elevation at this location is approximately two meters above the freeway elevation. The sampler located to the east of the freeway, East1Dec, is approximately five meters from the freeway fenceline. The third sampling location, East2Dec, is 2.8 kilometers east of the freeway located on the roof of a school gymnasium.

Figure 3 and Table 2 show the ambient measurements of carbon for the December time period. Data are collected for three consecutive 24-hour periods. The first 24-hour period, D1, begins at 1545 hours on Monday, December 6 and ends at 1602 hours on December 7 for West1Dec. The second 24-hour period, D2, begins at 1605 hours on December 7 and ends at 1602 hours on December 8. The third 24-hour period, D3, begins at 1606 hours on December 8 and ends at 1517 hours on Thursday, December 9. The start and stop times for East1Dec and East2Dec lag by 10 to 87 minutes with respect to West1Dec, the time required for personnel to attend the equipment. The data are corrected to 25 degrees Celsius.

Table 2
24-Hour Carbon Measurements, Collected December 1993
($\mu g/m^3$)

	D1, Dec. 6 - Dec. 7			D2, Dec. 7 - Dec. 8			D3, Dec. 8 - Dec. 9		
Site	crse	fine	total	crse	fine	total	crse	fine	total
West1Dec									
EC	1.72	7.70	9.42	1.26	4.14	5.39	0.89	5.07	5.96
OC	4.78	8.32	13.10	3.96	8.81	12.77	3.47	9.20	12.67
(collocated)									
EC	na	na	na	na	na	na	0.83	4.90	5.74
OC	na	na	na	na	na	na	3.28	9.22	12.50
East1Dec									
EC	0.76	2.96	3.72	1.40	5.24	6.64	0.95	3.28	4.23
OC	3.95	8.52	12.47	2.89	7.47	10.36	3.02	6.04	9.06
East2Dec									
EC	na	na	na	0.83	3.71	4.54	0.61	2.35	2.96
OC	na	na	na	3.48	8.17	11.66	2.78	6.57	9.36

EC = Elemental Carbon, OC = Organic Carbon, na = not available
crse = 2.5 to 10 μm, fine = less than 2.5 μm

The carbon data shown in Table 2 are separated into the course fraction, 2.5 μm to 10 μm, and the fine fraction, less than 2.5 μm. In addition, only one collocated sample was located at West1Dec on D3. Because resources were limited, collocation samples were sacrificed in order to collect samples at more locations. In contrast, during the May sampling period, triplicate collocation occurred at every sampling location. For most of the data in Table 2, it is not known if the results are high, low, or near the mean of the variability.

Table 3 shows the total carbon measurements from the December sampling period as well as the minimum and maximum values. The measured value for

West1Dec on D3 is the mean of the collocated samples. The minimum and maximum values are calculated based on a coefficient of variation for the mass measurement on the filters, a 95% confidence level, and an uncertainty of 1.7% in the sampling volume measurement. The coefficient of variation for the elemental carbon measurements and the organic carbon measurements is 8.1% and 2.6%, respectively. The values for coefficient of variation and uncertainty are based upon the discussion given for Table 1.

Table 3
24-hour Carbon Measurements and Uncertainty, Collected December 1993
($\mu g/m^3$)

	D1, Dec. 6 - Dec. 7			D2, Dec. 7 - Dec. 8			D3, Dec. 8 - Dec. 9		
Site	min.	meas.	max.	min.	meas.	max.	min.	meas.	max.
West1Dec									
EC	6.72	9.42	13.20	3.84	5.39	7.55	4.17	5.85	8.20
OC	11.63	13.10	14.75	11.33	12.77	14.38	11.17	12.59	14.18
East1Dec									
EC	2.65	3.72	5.21	4.73	6.64	9.30	3.02	4.23	5.93
OC	11.07	12.47	14.04	9.20	10.36	11.67	8.04	9.06	10.20
East2Dec									
EC	na	na	na	3.24	4.54	6.36	2.11	2.96	4.14
OC	na	na	na	10.34	11.66	13.13	8.31	9.36	10.54

EC = Elemental Carbon, OC = Organic Carbon, na = not available

Meteorological Data:

A portable meteorological station was located at West2May and East1Dec for the May and December sampling periods, respectively, as shown in Figure 1. Meteorological data are collected two meters above grade. The instruments are aligned to true north. The meteorological data collected, wind speed, wind direction, and ambient air temperature, are recorded on a strip chart. The meteorological equipment does not undergo a rigorous quality assurance program as detailed in US-EPA (1987). Therefore the meteorological data should only be used for qualitative assessments.

Table 4 show the meteorological data summaries for the May and December sampling periods. Figures 4 and 5 show the wind rose summaries for the May and December sampling periods, respectively. Wind speeds below 0.5 meters/second are considered to be calm. The hourly averaged meteorological data are available in Appendix A.

Table 4
Meteorological Data Summary, May and December 1993

Sampling Period	Period	Mean Temp. (F)	Mean Scaler Wind Speed (m/s)	%Calm
Days1-2 (May)	2-days	66	2.06	0
Days3-4 (May)	2-days	67	1.61	16
D1 (December)	24-hours	55	0.72	42
D2 (December)	24-hours	55	0.89	34
D3 (December)	24-hours	55	0.80	27

With the increase in calm hours, the measured carbon concentrations also tend to increase. This is observed by reviewing Figures 2, 3, 4, and 5. The most

notable exception to this generalization is sample East1Dec on day D1 for elemental carbon.

Traffic Count:

The Air Resources Board staff in the Stationary Source Division collected traffic count data for a 24-hour period beginning at 1530 hours on Tuesday December 7, and ending at 1520 hours on December 8. Staff counted heavy duty diesel trucks traveling in both direction on the Long Beach Freeway passing by the West1Dec and the East1Dec sampling locations. Trucks were counted for one minute durations at ten minute intervals. The hourly truck volume were calculated by multiplying by ten, assuming constant flow for a ten minute interval. Table 5 below shows a summary of their results. The first half hour of data was added to the last half hour of data so that Table 5 could begin at 1600 hours.

Table 5
Heavy Duty Diesel Truck Traffic Hourly Volume Summary
Long Beach Freeway, 1993

Day	Hour	Truck Volume	Day	Hour	Truck Volume
Dec. 7	1600	1,590	Dec. 8	0400	420
Dec. 7	1700	910	Dec. 8	0500	650
Dec. 7	1800	590	Dec. 8	0600	900
Dec. 7	1900	610	Dec. 8	0700	1,330
Dec. 7	2000	400	Dec. 8	0800	1,830
Dec. 7	2100	280	Dec. 8	0900	2,000
Dec. 7	2200	220	Dec. 8	1000	1,930
Dec. 7	2300	180	Dec. 8	1100	2,280
Dec. 7	2400	170	Dec. 8	1200	1,830
Dec. 8	0100	230	Dec. 8	1300	2,030
Dec. 8	0200	210	Dec. 8	1400	1,880
Dec. 8	0300	250	Dec. 8	1500	1,860
				Total	24,580

Above Ambient Carbon PM_{10} due to Freeway Emissions:

The samples collected during the May period were located too close to the freeway to consider any of them representative of ambient conditions. Therefore no attempt is made to calculate any contributions from the freeway for this time period.

For the December sampling period, the sampling location East2Dec is intended to represent background conditions. It is located on the roof of a school approximately 1.5 kilometers from the San Diego Freeway, Figure 1. Samples were collected at this location for days D2 and D3. Since the winds vary directions during any 24-hour period, a background site representative of 24-hour upwind conditions is not available.

The organic carbon levels collected at East2Dec appear to be biased by being influenced by some local source. As seen in Figure 3b, the levels of organic carbon at East2Dec are generally the same or greater than the levels of organic carbon at East1Dec. Possible reasons for this bias could include the emissions from the grill at the school's cafeteria (the school menu during the days of sampling is not available), or emissions from local neighborhood backyard charcoal grills (the location of East2Dec is in a residential neighborhood).

Assuming the samples collected at East2Dec represent ambient upwind background conditions, the ambient measurements can be subtracted from the measurements collected at West1Dec and East1Dec to estimate the above ambient carbon PM_{10} due to freeway emissions. This may underestimate the contribution from the Long Beach Freeway because the samples collected at East2Dec may overestimate the ambient levels of carbon for reasons discussed above. Table 6

show the above ambient levels of carbon in the PM_{10} range collected at West1Dec and East1Dec for days D2 and D3.

Table 6
24-hour Above Ambient Carbon Estimates and Uncertainty for the Long Beach Freeway
December 1993
($\mu g/m^3$)

	D2, Dec. 7 - Dec. 8			D3, Dec. 8 - Dec. 9		
Site	min.	meas.	max.	min.	meas.	max.
West1Dec						
EC	0.00	0.85	4.31	0.03	2.89	6.09
OC	0.00	1.11	1.80	0.63	3.23	5.87
East1Dec						
EC	0.00	2.10	6.06	0.00	1.27	3.82
OC	0.00	0.00	1.33	0.00	0.00	1.89

EC = Elemental Carbon, OC = Organic Carbon
Note: These values are likely to be underestimated because a true upwind sampler representative of ambient conditions is not available and the organic carbon samples at East2Dec may be biased.

Above Ambient Diesel Exhaust PM_{10}:

The emissions of elemental carbon along freeways most likely come from exhaust from diesel or gasoline engines, tire wear, or paved road dust. Estimates of PM emissions from motor vehicles are derived from Air Resources Board's EMFAC7F emissions model. The EMFAC7F estimates of PM emissions for the Los Angeles County portion of the South Coast Air Basin for the base year 1990 are shown in Table 7.

Table 7
PM Emission Estimates for Los Angeles County within the South Coast Air Basin (EMFAC7F, 1990 base year)

PM Source	PM (tons per day)	PM_{10} (tons per day)
Diesel Engine Exhaust	20.91	20.07
Gasoline Engine Exhaust	2.51	2.49
Tire Wear	42.13	16.85

Note: PM_{10} is estimated as 0.994, 0.96, 0.40 of PM for the diesel engine exhaust, gasoline engine exhaust, and tire wear emissions, respectively per ARB's Emission Inventory Branch.

Source profiles available in the literature for elemental and organic carbon content for various emissions are shown in Table 8. The emission sources shown in Table 8 are from diesel and gasoline engine exhaust, tire wear, motor vehicle exhaust (motor vehicle exhaust profiles are a combination of both diesel and gasoline engine exhaust), paved road dust, and brake lining dust. The standard deviations (SD) of the values reported in Table 8 are cited in the respective reference, except for Hildemann (1991), which were not reported. Hildemann (1991) reports that the concentrations measured in at least half of the experiments are greater than zero by at least twice the standard deviation of the analytical method. Therefore under worst-case conditions the standard deviation for Hildemann (1991) is assumed to be half the reported value.

Table 8
Elemental and Organic Carbon Source Profiles

Source	Size	%EC	SD%	%OC	SD%	Reference
Diesel Engine						
PHDIES	$PM_{2.5}$	32.9	8.0	40.1	6.6	Watson (1994)
DEXTR	PM_2	40.5	20.2	32.6	16.3	Hildemann (1991)
WHDIEC	$PM_{2.5}$	43.4	7.6	49.1	12.7	Chow (1990)
Gasoline Engine						
PHAUTO	$PM_{2.5}$	13.5	8.02	30.1	12.3	Watson (1994)
CATAT	PM_2	22.6	11.3	50.1	25.0	Hildemann (1991)
NCATA	PM_2	8.01	4.0	65.5	32.7	Hildemann (1991)
Tire wear						
TW	PM_{CRS}	15.3	7.6	36.0	18.0	Hildemann (1991)
CC	-	29.	-	58.	-	Hildemann (1991)
Motor Vehicle						
MOVES1	$PM_{2.5}$	45.4	16.5	52.8	21.6	Watson (1994)
MOVES2	$PM_{2.5}$	54.2	19.8	49.8	24.2	Watson (1994)
PHRD	$PM_{2.5}$	36.5	11.0	39.0	18.6	Watson (1994)
Paved Road Dust						
PVRD	PM_2	1.06	0.53	13.5	6.7	Hildemann (1991)
PRLBPC	$PM_{2.5}$	2.21	0.43	19.6	3.4	Watson (1994)
Brake Lining Dust						
BRKE	PM_2	2.61	1.3	10.7	5.3	Hildemann (1991)

NOTES:

EC = Elemental Carbon, OC = Organic Carbon, SD = Standard Deviation

Watson (1994) CMB PM10 Southern California Air Quality Study

MOVES1	SCAB Dyno. Composite LD, HD, unleaded, leaded, diesel, tire wear
MOVES2	SCAB Dyno. Composite LD, HD, unleaded, leaded, diesel

(Table 8 continued on next page.)

Table 8 (continued) Elemental and Organic Carbon Source Profiles	
PHAUTO	Phoenix Gas Dyno. Inspection and Maintenance Program (I&M)
PHRD	Phoenix MV Urban Roadside
PHDIES	Phoenix diesel Dyno. I&M
PRLBPC	Long Beach paved road profile composite
Hildemann (1991) Chemical Composition of Emissions from Urban Sources,	
TW	Radial Toyo tire (195/60R15 with 7,200 miles). Fine PM could not be separated, therefore a course (CRS) PM sample is used. Course PM is not defined by Hildemann (1991). SD is taken at half the reported value.
CC	Estimate from chemical composition.
DEXTR	Two diesel trucks. One 2-axle and one 3-axle from the City of Pasadena. SD is taken at half the reported value as above. EC loading may be lower than an average fleet based on author.
CATAT	7 catalyst equipped autos
NCATA	6 non-catalyst equipped autos
PVRD	Pasadena area streets, dust from a 2-week dry period.
BRKE	Dust from a drum brake. Split between EC and OC is uncertain.
Chow (1990) SJV AQS Phase 2 PM10 Modeling and Analysis	
WHDIEC	Wheeler Weigh Station Diesel Truck Emissions

In order to determine the above ambient PM_{10} concentration due to emissions from diesel engine exhaust, a system of equations is developed assuming the following:

1. The contributions to the carbon estimates in Table 6 are from diesel and gasoline engine exhaust, tire wear, and paved road dust. It is assumed the contribution from brake lining dust are negligible for motor vehicle emissions on freeways. As such, equations (1) and (2) follow.

$$EC_{AA}=EC_{DEX}+EC_{GEX}+EC_{TW}+EC_{PRD} \quad (1)$$

$$OC_{AA}=OC_{DEX}+OC_{GEX}+OC_{TW}+OC_{PRD} \quad (2)$$

Where,

EC = Elemental Carbon concentration,

OC = Organic Carbon concentration,

and the subscripts are as follows,

AA = Above Ambient,

DEX = Diesel engine EXhaust,

GEX = Gasoline engine EXhaust,

TW = Tire Wear, and

PRD = Paved Road Dust.

2. The relative fraction of elemental and organic carbon to total PM_{10} from each of the emission sources are represented in Table 8. As such, equations (3) and (4) follow for diesel engine exhaust.

$$EC_{DEX}=f_{ecd}PM_{DEX} \quad (3)$$

$$OC_{DEX}=f_{ocd}PM_{DEX} \quad (4)$$

Where,

f_{ecd} = Fraction Elemental Carbon of PM concentration from Diesel engine exhaust (0.329 for PHDIES), and

f_{ocd} = Fraction Organic Carbon of PM concentration from Diesel engine exhaust (0.401 for PHDIES).

Similarly for gasoline engine exhaust equations (5) and (6) are shown.

$$EC_{GEX}=f_{ecg}PM_{GEX} \quad (5)$$

$$OC_{GEX}=f_{ocg}PM_{GEX} \quad (6)$$

Equations (7) and (8) are shown for tire wear.

$$EC_{TW}=f_{ect}PM_{TW} \quad (7)$$

$$OC_{TW}=f_{oct}PM_{TW} \quad (8)$$

Equations (9) and (10) are shown for paved road dust.

$$EC_{PRD}=f_{ecp}PM_{PRD} \quad (9)$$

$$OC_{PRD}=f_{ocp}PM_{PRD} \quad (10)$$

3. The relative ambient PM_{10} concentrations for diesel and gasoline engine exhaust, and tire wear are similar to the PM_{10} emissions in Table 7. Equations (11) and (12) follow.

$$\frac{PM_{GEX}}{PM_{DEX}}=\frac{EI_{GEX}}{EI_{DEX}} \quad (11)$$

$$\frac{PM_{TW}}{PM_{DEX}}=\frac{EI_{TW}}{EI_{DEX}} \quad (12)$$

Where,

EI_{DEX} = Emission Inventory PM_{10} from Diesel Engine Exhaust (20.07 tons per day from Table 7),

EI_{GEX} = Emission Inventory PM_{10} from Gasoline Engine Exhaust (2.49 tons per day), and

EI_{TW} = Emission Inventory PM_{10} from Tire Wear (16.85 tons per day).

The number of variables in equation (1) are reduced by systematically substituting EC_{GEX} with equations (5), (11), and (3); and EC_{TW} with equations (7), (12), and (3). The number of variables in equation (2) are reduced by systematically substituting OC_{DEX} with equations (4) and (3); OC_{GEX} with equations (6), (11), and (3); OC_{TW} with equations (8), (12), and (3); and OC_{PRD} with equations (10) and (9). Equations (1) and (2) are rewritten and shown as equations (13) and (14).

$$EC_{AA}=EC_{DEX}\left(1+\frac{f_{ecg}}{f_{ecd}}\frac{EI_{GEX}}{EI_{DEX}}+\frac{f_{ect}}{f_{ecd}}\frac{EI_{TW}}{EI_{DEX}}\right)+EC_{PRD} \qquad (13)$$

$$OC_{AA}=EC_{DEX}\left(\frac{f_{ocd}}{f_{ecd}}+\frac{f_{ocg}}{f_{ecd}}\frac{EI_{GEX}}{EI_{DEX}}+\frac{f_{oct}}{f_{ecd}}\frac{EI_{TW}}{EI_{DEX}}\right)+EC_{PRD}\frac{f_{ocp}}{f_{ecp}} \qquad (14)$$

Equations (13) and (14) have two unknown variables, EC_{DEX} and EC_{PRD}. As a result of the range in the values of some of the known variables (i.e., EC_{AA}, OC_{AA}, f_{ecd}, f_{ocd}, f_{ecg}, f_{ocg}, f_{ect}, f_{oct}, f_{ecp}, and f_{ocp}) the solution for the unknown variables is a range of estimated values. Each of the carbon profiles for diesel engine exhaust, f_{ecd} and f_{ocd}, found in Table 8 are used independently and as an arithmetic mean. The carbon profiles used for gasoline engine exhaust, tire wear, and paved road

dust emissions (i.e., f_{ecg}, f_{ocg}, f_e f_{oct}, f_{ecp}, and f_{ocp}) are CATAT, TW, and PRLBPC, from Table 8, respectively.

Table 9 shows the estimated above ambient levels of PM_{10} concentrations due to freeway emissions from diesel and gasoline engine exhaust, tire wear, and road dust. The arithmetic mean of the diesel exhaust carbon profiles are represented in Table 9. Figure 6 shows the same results for diesel engine exhaust only. The results from the individual carbon profiles, PHDIES, DEXTR, and WHDIEC, varied by less than ten percent of the mean. These values may be biased toward underestimation because a true upwind sampler representative of ambient conditions is not available to determine above ambient measurements.

Table 9
24-hour Above Ambient PM_{10} Concentration Estimates and Uncertainty, December 1993
($\mu g/m^3$)

	D2, Dec. 7 - Dec. 8			D3, Dec. 8 - Dec. 9		
Site / Source	min.	meas.	max.	min.	meas.	max.
West1Dec						
Diesel Engine	0	1.3	2.2	0	4.0	7.5
Gasoline Engine	0	0.2	0.3	0	0.5	0.9
Tire Wear	0	1.0	1.8	0	3.3	6.3
Road Dust	0	0.7	0.7	0	0.8	0.5
East1Dec						
Diesel Engine	0	0.7	1.6	0	1.1	2.4
Gasoline Engine	0	0.1	0.2	0	0.1	0.3
Tire Wear	0	0.6	1.4	0	0.9	2.0
Road Dust	0	0.6	0.4	0	0.6	0.3

Note: These values may be biased toward underestimation because a true upwind sampler is not available.

Methods to minimize the uncertainty on future data gathering efforts include the following:

1. Collect the total PM_{10} . This will eliminate the dependency on the emissions inventory, Table 7.
2. Collect three or more measurements for each sample. The standard deviation of the elemental carbon laboratory results is significant. Collecting three or more measurements will demonstrate more confidence in the mean.
3. Collect ambient data in shorter time periods (less than 24-hours). Ideally, hourly samples would provide the most robust data to separate ambient from above ambient levels of carbon.
4. Speciate all measurements and perform a chemical mass balance analysis on the data.

Dispersion Modeling:

The CALINE4 air dispersion model is used to estimate the PM_{10} concentration at field of receptors lying on a line perpendicular from the freeway alignment at 20 meter intervals out to 500 meters. To model PM_{10} concentrations, the freeway is digitized out to one kilometer from the West1Dec and East1Dec sampling locations in both the north and south directions.

The emission rate input to the model is 0.682 grams of PM_{10} per vehicle mile traveled. The emission rate is based upon the results from EMFAC7F, representing the basinwide motor vehicle fleet in the South Coast Air Basin for diesel engine exhaust. In addition, it is assumed the average speed on the freeway is 55 miles per hour. As a result, a speed correction factor, 0.2697, was used to adjust the particulate emission rate from representing an average 7.57 miles per hour to an average 55 miles per hour. EMFAC7F and previous versions of EMFAC do not have a speed correction factor for particulates from diesel engines. The above speed correction factor is proposed for EMFAC7G. Since EMFAC7G is still undergoing evaluation, the results of our CALINE4 estimates are preliminary and subject to revision. Appendix B shows the input file for the model run.

The model is run on an hourly basis. The emission rate is varied to represent the diurnal traffic pattern displayed in Table 5. The meteorological data are varied to represent the measurements shown in Appendix A for the time period of D2 and D3. Wind speeds of less than 0.5 m/s were set to 0.5 m/s. This occurred approximately 30% of the time. Since the meteorological data does not conform to the US-EPA guidance (US-EPA 1987), the particulate speed correction factor is still undergoing evaluation, and that CALINE4 is not designed to model calm conditions, the results from the modeling analysis are used only to establish the rate at which the estimated concentrations decrease with increased distance from

the emission source. The absolute value of the estimated concentrations calculated with the CALINE4 model are not used for further calculations in this analysis.

The resulting concentrations from the CALINE4 modeling analysis as well as the concentrations estimated from the measured carbon, from Table 9, are shown in Table 10. The uncertainty in the modeled values is not estimated because of the above described limitations. The results in Table 10 show the modeling results overestimated the measured results by less than an order of magnitude. Some of the possible reasons the modeling results could have overestimated the measured results are discussed below.

1. The ambient levels are underestimated because a true upwind ambient level measurement is not available.
2. The meteorological data are not quality assured and therefore there may be a bias in the results.
3. Approximately 30 percent of the wind speeds are less than 0.5 m/s. Traditionally, Gaussian based dispersion models are not designed for calm winds, and therefore, there may be a bias in the results.
4. The emission rate may be overestimated for the conditions. The emission rate is based on an average driving cycle which includes acceleration and deceleration. Generally the traffic on the freeway is under steady state conditions.

Table 1
Preliminary CALINE4 Modeling Results
Above Ambient PM_{10} Due to Emissions From Diesel Engine Exhaust
Near the Long Beach Freeway

	D2, Dec. 7 - Dec. 8			D3, Dec. 8 - Dec. 9		
	Estimate from CALINE4 Modeling	Estimate from Measurements		Estimate from CALINE4 Modeling	Estimate from Measurements	
Location	($\mu g/m^3$)	Min. ($\mu g/m^3$)	Max. ($\mu g/m^3$)	($\mu g/m^3$)	Min. ($\mu g/m^3$)	Max. ($\mu g/m^3$)
West1Dec	14.	0	2.2	12.	0	2.4
East1Dec	12.	0	1.6	16.	0	7.5

The modeled results are preliminary pending the release of EMFAC7G and the availability of meteorological data meeting requirements in US-EPA (1987).

The modeling results are scaled to represent the measured concentrations in order to show the distribution of the impacts due to the freeway emissions. Table 11 show the distributed above ambient level of PM_{10} due to emissions from diesel engines on the freeway. Figure 7 shows the same results graphically. The bias in the values reported in Table 11 and Figure 7 is towards underestimation because a true upwind sampler is not available.

Table 11

Calculated Above Ambient Distribution of PM_{10} due to Primary Diesel Engine Exhaust From the Long Beach Freeway for Two 24-Hour Periods

Distance from Freeway Center	Calculated Concentration			
	D2, Dec. 7 - Dec. 8		D3, Dec. 8 - Dec. 9	
(meters)	Meas. ($\mu g/m^3$)	Max. ($\mu g/m^3$)	Meas. ($\mu g/m^3$)	Max. ($\mu g/m^3$)
-500	0.13	0.23	0.37	0.69
-400	0.15	0.26	0.43	0.91
-300	0.19	0.33	0.52	0.98
-200	0.26	0.44	0.69	1.3
-100	0.42	0.71	1.2	2.2
-80	0.50	0.85	1.4	2.6
-60	0.62	1.1	1.7	3.2
-40	0.86	1.5	2.4	4.6
-20	1.3	2.2	4.2	7.9
0				
20	0.84	1.9	1.3	2.9
40	0.53	1.2	0.85	1.8
60	0.42	0.95	0.66	1.4
80	0.35	0.81	0.56	1.2
100	0.32	0.72	0.49	1.1
200	0.22	0.51	0.32	0.70
300	0.19	0.43	0.25	0.55
400	0.16	0.36	0.22	0.48
500	0.14	0.31	0.20	0.43

Meas. are values derived from measurements.
Max. are values derived from the upper range of the measurements uncertainty.
Minimum values are zero.

Note: The calculated concentrations are biased toward underestimation because true upwind measurements representative of ambient conditions were not available.

References:

California Environmental Protection Agency (1995), Air Resources Board, Source Test Report, Source-Impacted Ambient Air Sampling for PM-10/Carbon, Engineering and Laboratory Branch, Monitoring and Laboratory Division, Project No. C93-080, February 3, 1995.

Chow, J. C., (1990) San Joaquin Valley Air Quality Study, Phase 2: PM_{10} Modeling and Analysis, Volume I: Receptor Modeling Source Apportionment, Final Report, DRI Document No. 8929.1F, JPA Contract #88-1, October 11, 1990, Desert Research Institute, PO Box 60220, Reno, NV 89506.

Fung, K. (1990) Particulate Carbon Speciation by MnO_2 Oxidation, "Aerosol Science and Technology" 12:122-127.

Hildemann, L. M. (1991) Chemical Composition of Emissions from Urban Sources of Fine Organic Aerosol, "Environ. Sci. Technol.," Vol. 25, No. 4.

State of California Department of Transportation (1984), CALINE4 - A Dispersion Model for Predicting Air Pollution Concentrations Near Roadways, Report No. FHWA/CA/TL-84/15, November 1984.

US-EPA (June 1987) On-Site Meteorological Program Guidance For Regulatory Modeling Applications, EPA-450/4-87-013.

Watson, J. (1994) Chemical Mass Balance Source Apportionment of PM_{10} during the Southern California Air Quality Study, "Aerosol Science and Technology" 21:1-36.

Appendix A

Meteorological Data Collected Near the Long Beach Freeway 1993

December 1993
The first record is for December 6, 1993 at 1600 hours.

Day/Hour	Temp F	Speed MPH	Dir. deg	Swing deg
616	62	3.7	260	120
617	60	2.9	260	90
618	58	1.5	260	100
619	56	0.8	270	60
620	52	0.0	110	2
621	50	0.0	130	2
622	50	0.0	90	2
623	50	0.6	60	10
624	49	0.0	60	2
701	50	1.4	30	10
702	49	2.6	30	10
703	47	0.2	60	10
704	45	0.5	90	20
705	45	1.4	60	20
706	46	1.0	60	20
707	46	2.0	50	30
708	50	0.8	50	30
709	56	1.9	320	120
710	62	1.1	70	90
711	68	1.4	120	120
712	70	2.4	240	120
713	69	3.0	180	70
714	68	4.0	240	120
715	65	5.0	270	120
716	61	5.0	260	120
717	59	2.6	260	90
718	58	2.2	270	90
719	55	1.3	270	120
720	54	0.9	320	60
721	50	0.8	120	10
722	49	0.7	130	10
723	49	0.7	30	10
724	50	1.4	20	10
801	48	1.2	340	10
802	47	0.8	60	10
803	47	0.8	60	10
804	46	1.8	50	30
805	45	1.5	30	30
806	44	0.9	180	30
807	44	0.8	80	30
808	50	1.6	60	60
809	55	1.2	150	360
810	63	2.2	290	120
811	66	3.5	290	120
812	68	4.1	280	120
813	70	2.9	240	150
814	70	4.5	280	100
815	64	4.9	270	100
816	62	3.8	270	70
817	60	2.9	260	70
818	58	2.4	100	40
819	54	1.7	220	30
820	54	0.9	100	10
821	50	1.0	100	10
822	50	0.8	150	10
823	50	1.0	60	10
824	50	0.2	70	10
901	49	1.4	40	30
902	48	1.5	30	30
903	49	1.2	60	30
904	48	0.5	60	10
905	48	1.1	60	10
906	48	1.1	60	30
907	50	1.5	50	30
908	52	2.2	60	30
909	60	1.8	60	60
910	62	2.3	90	150
911	66	1.2	140	150
912	69	1.7	230	100
913	69	4.5	220	70
914	70	3.9	210	70

Note: The data for hour x represents the average from hr x to hr x+1.

May 1993
The first record is for May 17, 1993 at 1400 hours.

Day/Hour	Temp F	Speed MPH	Dir. deg	Swing deg
1714	78	8.0	260	90
1715	75	8.5	270	90
1716	72	8.0	250	90
1717	69	8.2	240	90
1718	65	6.5	240	90
1719	62	6.5	260	90
1720	61	5.8	260	90
1721	61	5.8	240	60
1722	61	4.3	250	80
1723	60	2.0	270	90
1724	60	2.9	270	90
1801	60	3.5	270	90
1802	60	1.1	250	70
1803	59	1.5	50	30
1804	56	1.2	60	10
1805	55	2.1	50	10
1806	59	2.0	50	30
1807	64	3.4	50	30
1808	70	2.6	60	60
1809	74	2.9	310	50
1810	79	3.0	270	60
1811	80	4.5	270	70
1812	79	7.5	270	80
1813	75	8.0	270	70
1814	76	7.8	270	90
1815	75	8.2	270	90
1816	73	9.3	270	90
1817	71	9.0	270	90
1818	70	7.2	250	90
1819	65	5.6	260	90
1820	65	4.5	260	90
1821	64	4.4	270	80
1822	64	5.3	260	80
1823	63	4.8	270	70
1824	62	3.5	270	80
1901	61	4.0	270	70
1902	61	1.2	250	30
1903	60	1.9	270	40
1904	60	2.0	300	30
1905	59	3.0	280	30
1906	59	2.4	290	30
1907	65	2.5	50	90
1908	70	3.0	20	60
1909	75	2.8	60	90
1910	75	5.8	120	90
1911	75	5.4	120	100
1912	76	5.5	140	90
1913	78	7.4	270	80
1914	76	7.0	260	90
1915	79	7.8	280	100
1916	75	7.5	240	100
1917	78	6.4	270	90
1918	75	6.8	250	90
1919	70	6.0	260	90
1920	68	3.9	270	90
1921	67	3.0	280	60
1922	66	2.6	270	70
1923	65	2.8	250	60
1924	65	2.8	250	60
2001	63	4.0	240	60
2002	62	2.0	270	30
2003	62	2.0	270	50
2004	62	3.8	250	60
2005	62	3.6	250	80
2006	62	3.0	250	70
2007	62	4.5	230	80
2008	65	2.9	270	70
2009	68	2.0	180	70
2010	68	4.0	160	90
2011	69	3.6	180	90
2012	70	5.5	150	100
2013	72	4.5	180	90
2014	72	3.0	100	120
2015	72	4.6	230	90
2016	72	7.3	270	70
2017	72	6.0	250	90
2018	70	5.5	240	90
2019	65	4.9	270	80
2020	64	4.6	250	90
2021	63	1.5	240	60
2022	62	2.1	240	60
2023	62	1.5	270	50
2024	61	0.0	270	1
2101	60	0.0	350	1
2102	59	0.0	350	1
2103	60	0.0	300	1
2104	61	1.5	330	10
2105	59	0.0	330	1
2106	60	0.0	330	1
2107	65	1.0	290	30

Appendix B

CALINE4 Dispersion Modeling Input File Example

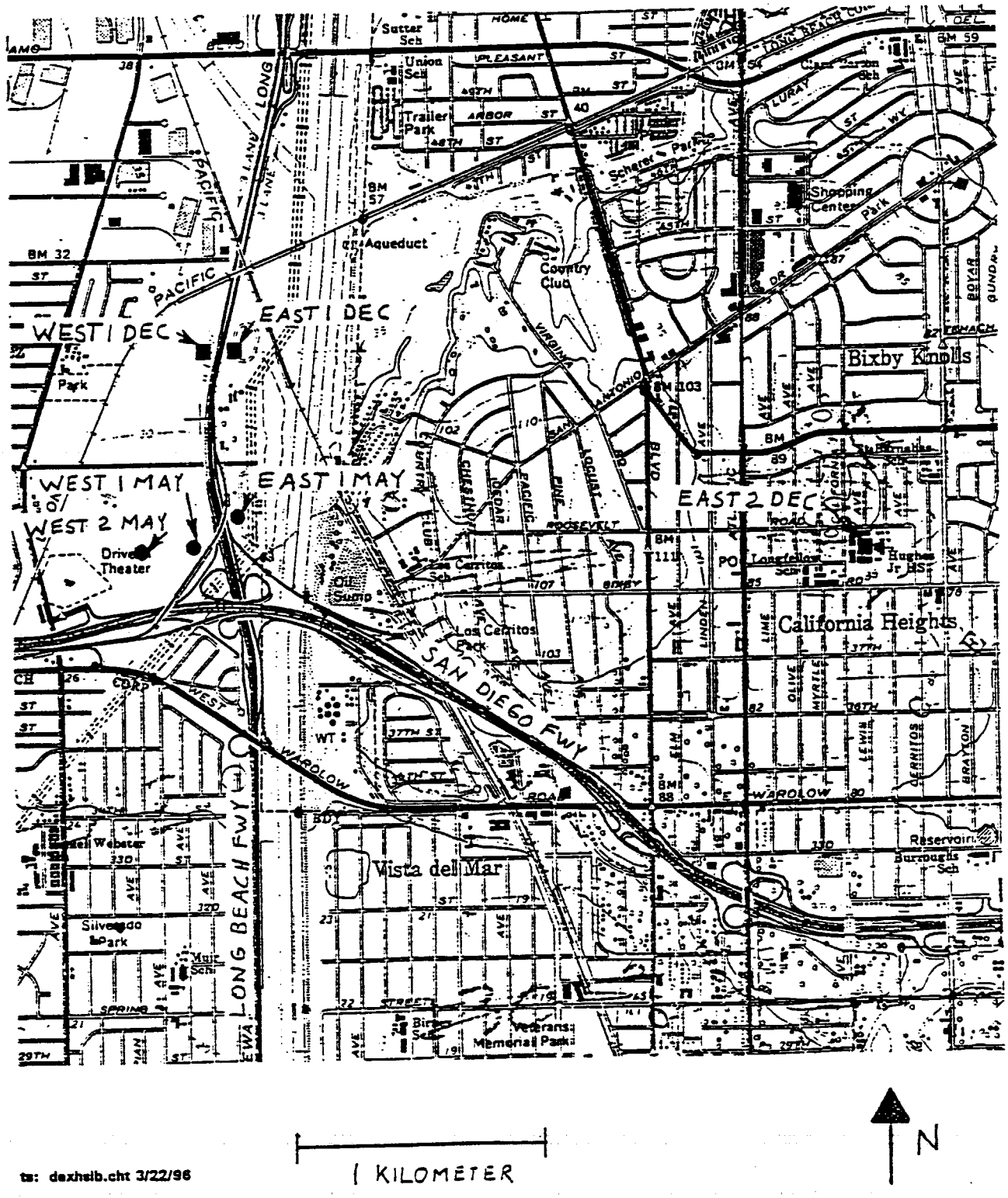
```
Diesel PM10 - I-710 Long Beach
4Diesel PM-10
 100.00  10.00    .00     0.00      52      3    1.00      1      0  10.00
      26.5000         0.000           1.00000
      20.0000         0.000           1.00000
      40.0000         0.000           1.00000
      60.0000         0.000           1.00000
      80.0000         0.000           1.00000
     100.0000         0.000           1.00000
     120.0000         0.000           1.00000
     140.0000         0.000           1.00000
     160.0000         0.000           1.00000
     180.0000         0.000           1.00000
     200.0000         0.000           1.00000
     220.0000         0.000           1.00000
     240.0000         0.000           1.00000
     260.0000         0.000           1.00000
     280.0000         0.000           1.00000
     300.0000         0.000           1.00000
     320.0000         0.000           1.00000
     340.0000         0.000           1.00000
     360.0000         0.000           1.00000
     380.0000         0.000           1.00000
     400.0000         0.000           1.00000
     420.0000         0.000           1.00000
     440.0000         0.000           1.00000
     460.0000         0.000           1.00000
     480.0000         0.000           1.00000
     500.0000         0.000           1.00000
     -22.0000         0.000           1.00000
     -20.0000         0.000           1.00000
     -40.0000         0.000           1.00000
     -60.0000         0.000           1.00000
     -80.0000         0.000           1.00000
    -100.0000         0.000           1.00000
    -120.0000         0.000           1.00000
    -140.0000         0.000           1.00000
    -160.0000         0.000           1.00000
    -180.0000         0.000           1.00000
    -200.0000         0.000           1.00000
    -220.0000         0.000           1.00000
    -240.0000         0.000           1.00000
    -260.0000         0.000           1.00000
    -280.0000         0.000           1.00000
    -300.0000         0.000           1.00000
    -320.0000         0.000           1.00000
    -340.0000         0.000           1.00000
    -360.0000         0.000           1.00000
    -380.0000         0.000           1.00000
    -400.0000         0.000           1.00000
    -420.0000         0.000           1.00000
    -440.0000         0.000           1.00000
    -460.0000         0.000           1.00000
    -480.0000         0.000           1.00000
    -500.0000         0.000           1.00000
I-710A
I-710B
I-710C
 1     66. -1000.    -51.   -437.   0.0  43.9  0.0  0.0  1
 1                   -36.   -142.   0.0  43.9  0.0  0.0  1
 1                   244.   1000.   0.0  43.9  0.0  0.0  1
11101Freeway Traffic
 2280.0  2280.0  2280.0  2280.0  2280.0  2280.0
 0.6820  0.6820  0.6820  0.6820  0.6820  0.6820
 0.0000  1.0000  6       1000.0  25.000  0.00000  15.000
```

The following is an excerpt from the CALINE4 FORTRAN code which was modified to accept hourly adjustments for vehicle traffic counts.

```
c Vphadj adjusts vehicle peak hourly counts to a diurnal hour by hour
c Profile - this statement can be changed to fit any particular profile
c
c The following profile is for freeway truck traffic observed on
c the Long Beach Freeway one mile north the the San Diego Freeway
c interchange.  The data were gathered on December 7-8, 1993.  The
c peak one hour truck traffic count was 2280 trucks/hour.
      data vphadj/.10,.09,.11,.18,.29,.39,.58,.80,.88,.85,1.0,.80,
     &            .89,.82,.82,.70,.40,.26,.27,.18,.12,.10,.08,.07/
c
```

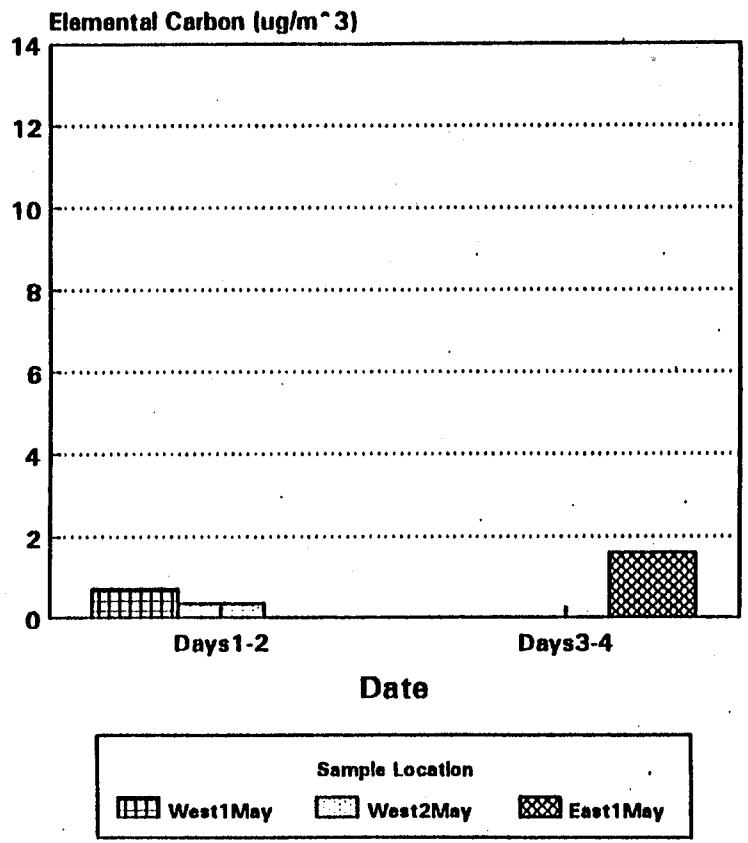
ts: dexlbfwy.wpf

Figure 1
Elemental Carbon Sampling Locations



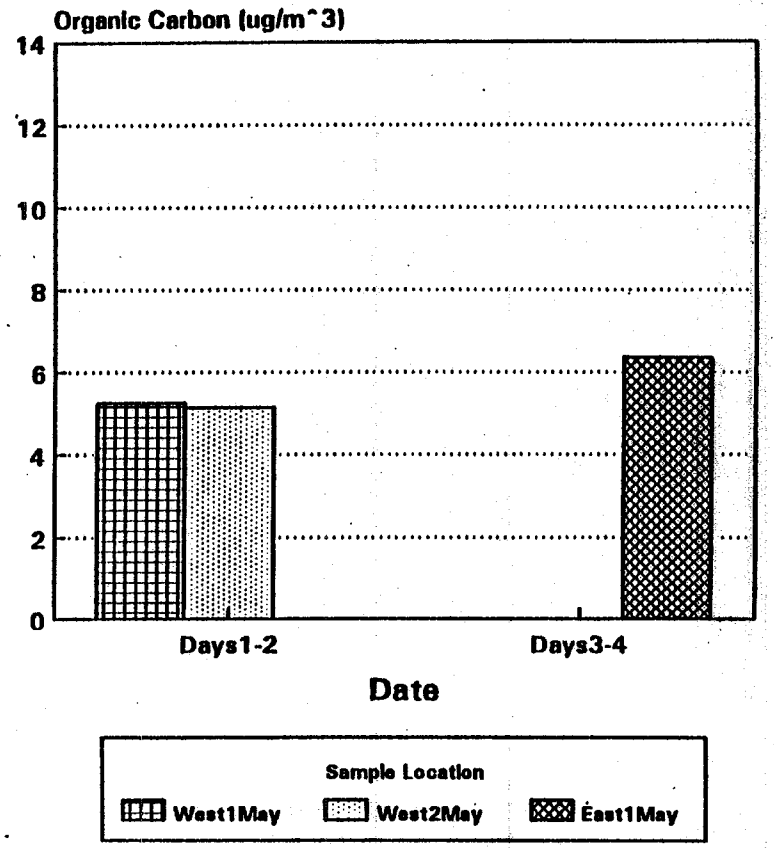
ts: dexhsib.cht 3/22/96

Figure 2a
Elemental Carbon Measurements
Two-Day Samples, Long Beach 5/93



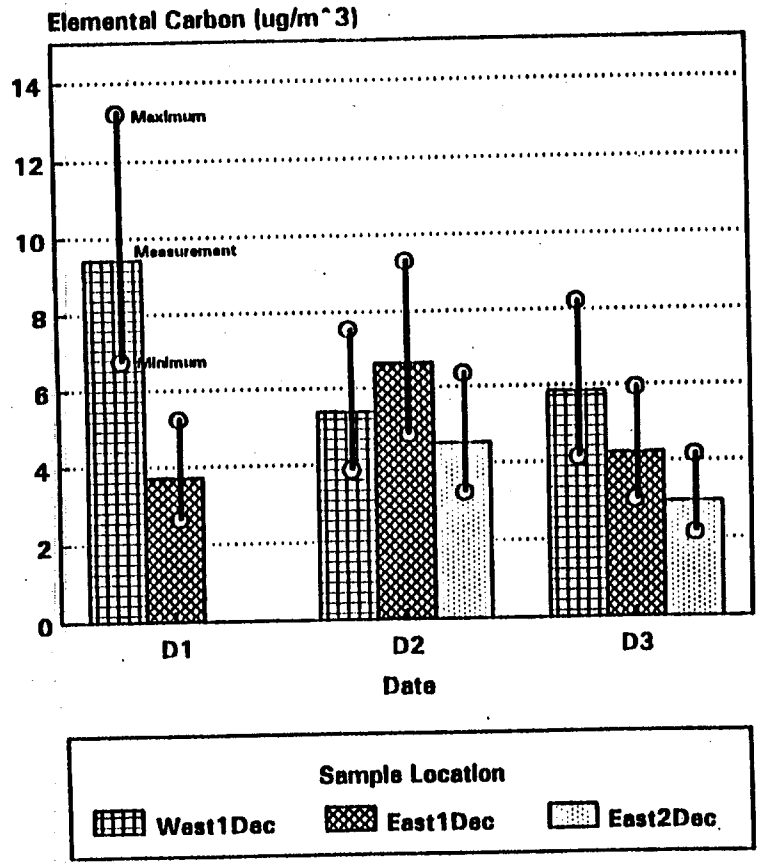
to: dextoem.oht 4/26/96

Figure 2b
Organic Carbon Measurements
Two-Day Samples, Long Beach 5/93



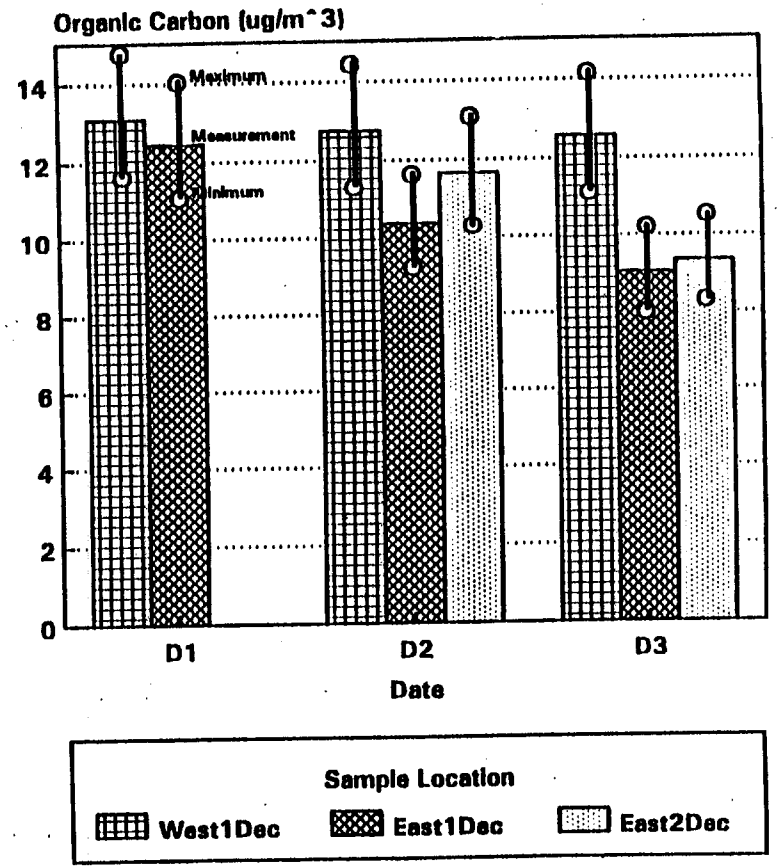
to: dextoem.oht 4/26/96

Figure 3a
Elemental Carbon Measurements
24-Hour Samples, Long Beach 12/93



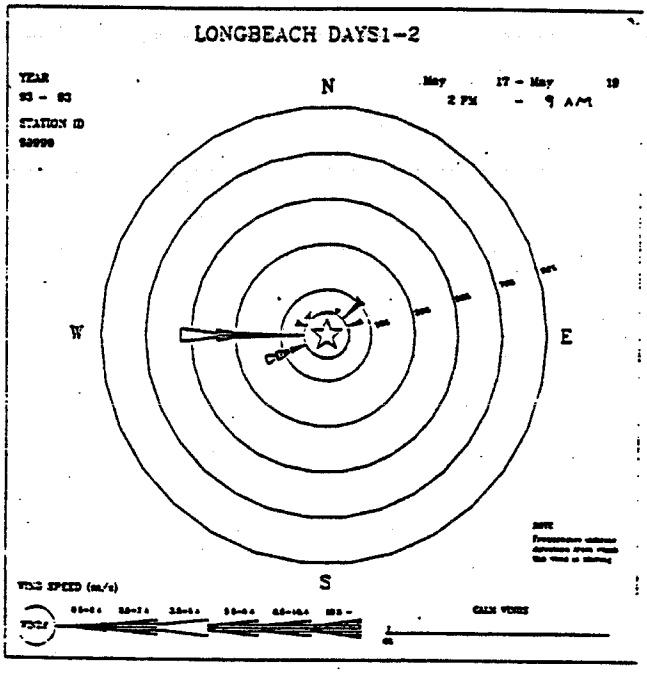
tc: dustec.ch1 4/25/96

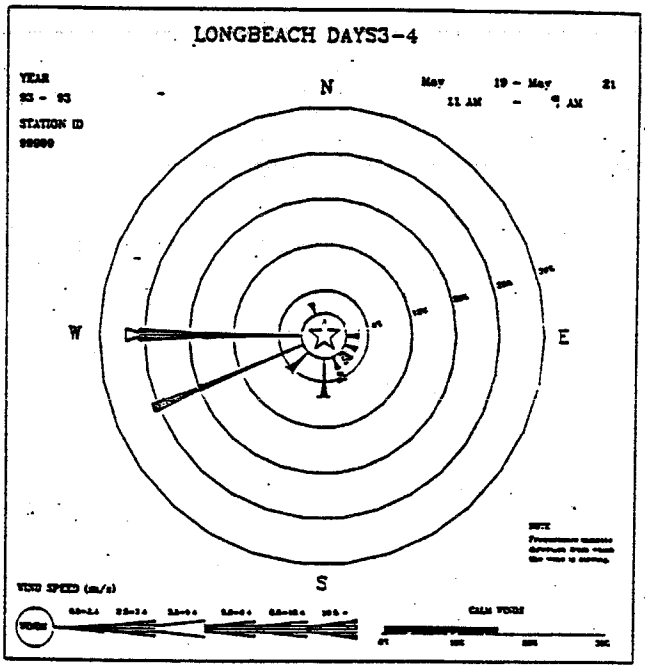
Figure 3b
Organic Carbon Measurements
24-Hour Samples, Long Beach 12/93



tc: dustec.ch1 4/25/96

Figure 4
Wind Rose Summary, Long Beach Freeway
May 17-21, 1993

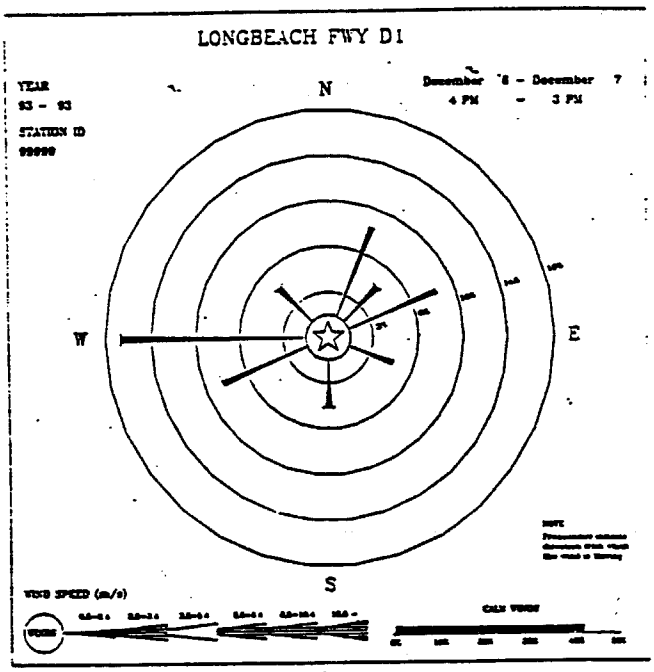


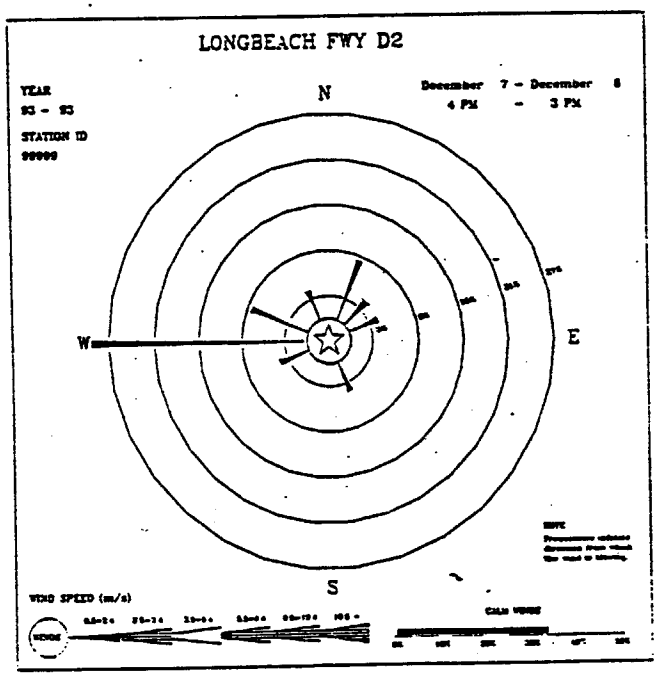


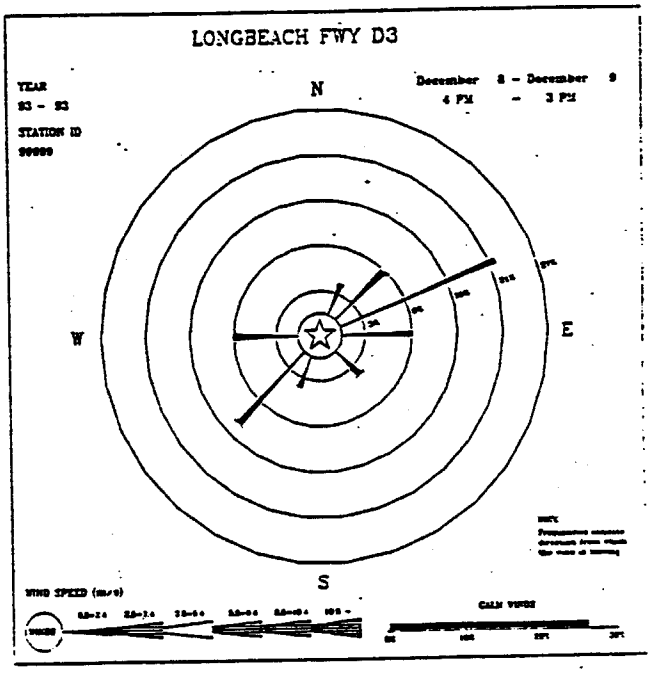
Note: The percentage scales change between plots.

tm: dexhsib2.cht 3/28/96

Figure 5
Wind Rose Summary, Long Beach Freeway
December 6-9, 1993





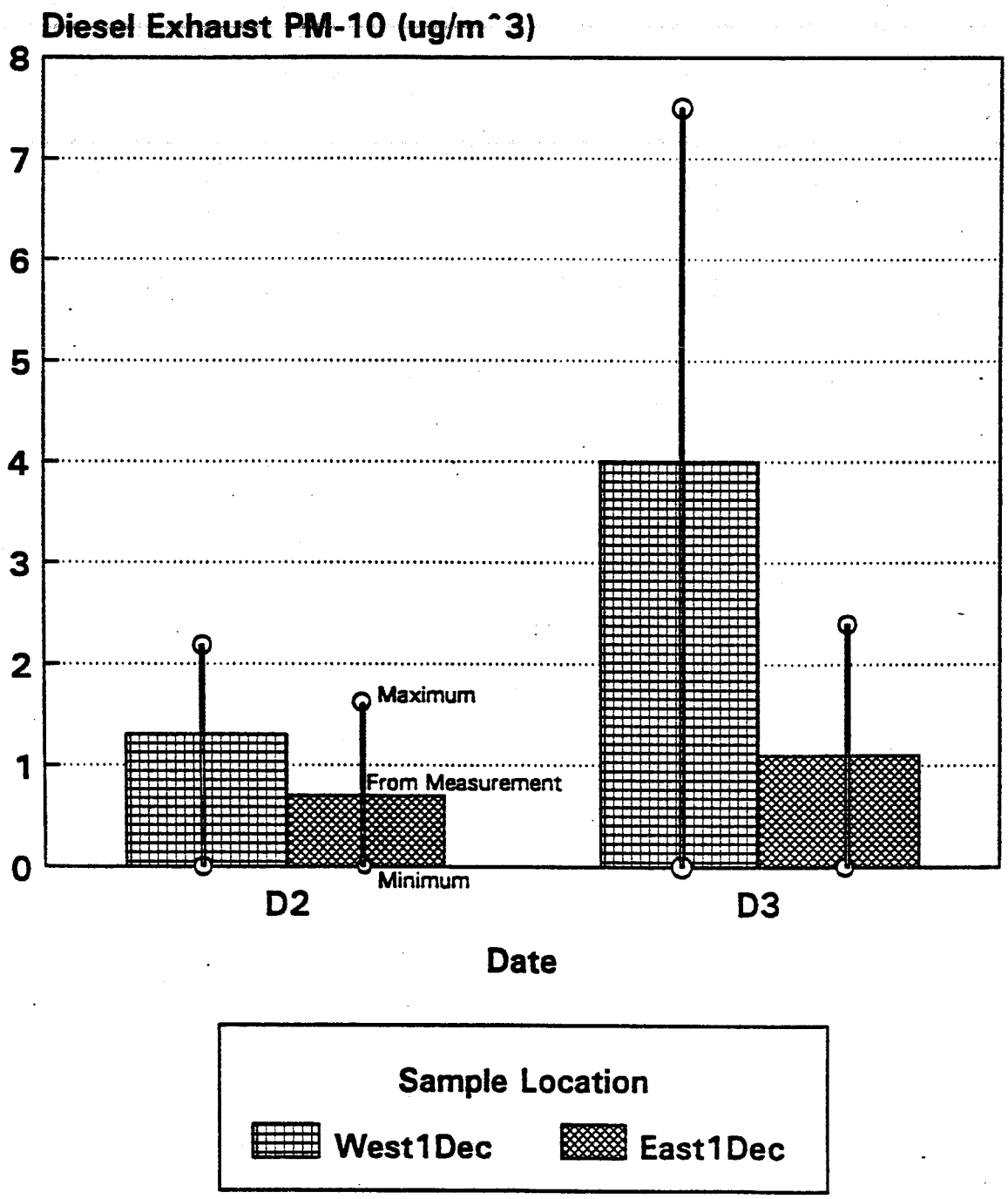


Note: The percentage scales change between plots.

ts: dexhslb3.cht 3/28/96

Figure 6

Above Ambient Diesel Exhaust PM10 Est.
From 24-Hour C Samples, Long Beach 12/93



ts:dexdex.cht 7/18/96

Figure 7a
Above Ambient Diesel Exhaust PM10 Est.
Distribution From Freeway, Day D2

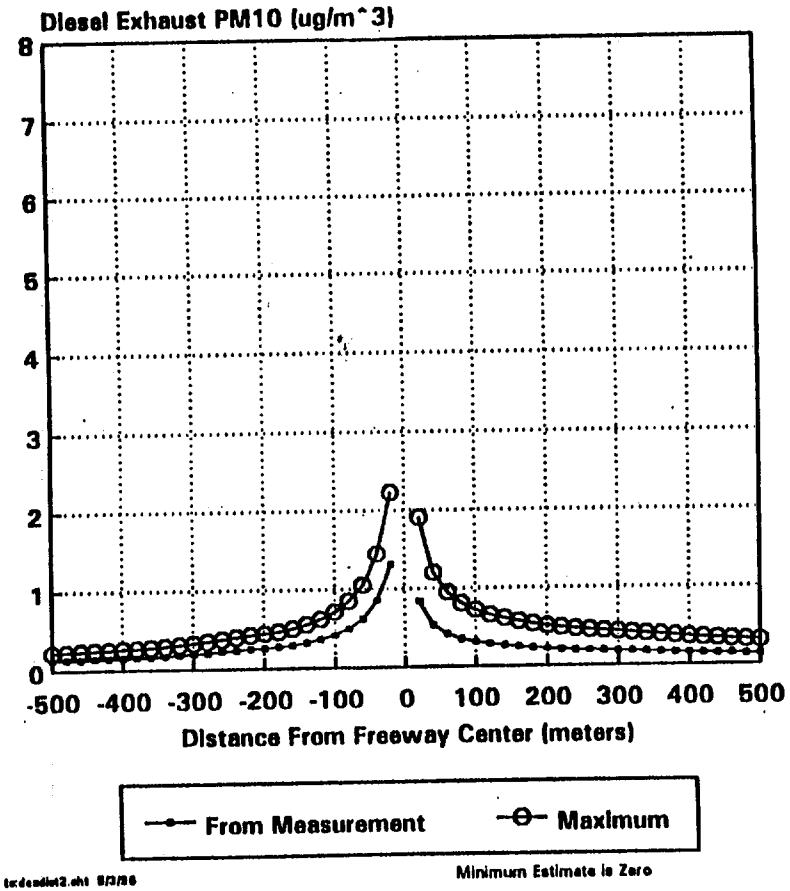
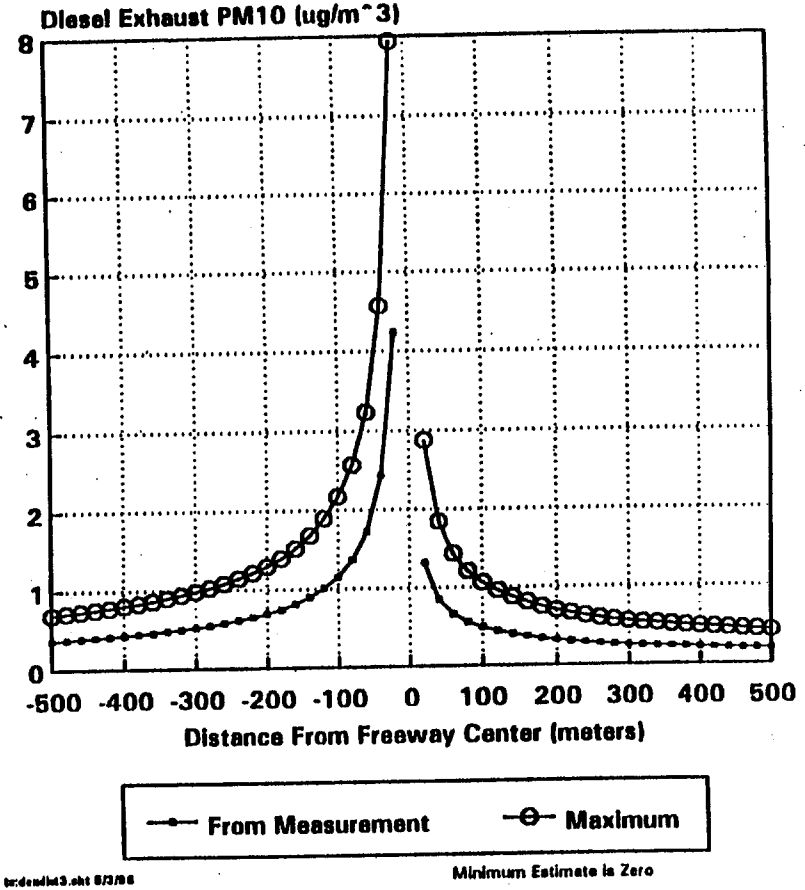


Figure 7b
Above Ambient Diesel Exhaust PM10 Est.
Distribution From Freeway, Day D3



APPENDIX D

CALIFORNIANS' INDOOR AND TOTAL AIR EXPOSURES TO DIESEL EXHAUST PARTICLES

CALIFORNIANS' INDOOR AND TOTAL AIR EXPOSURES TO DIESEL EXHAUST PARTICLES

By

Peggy Jenkins

Steve Hui

Susan Lum

Research Division
California Air Resources Board
California Environmental Protection Agency

December 1997

TABLE OF CONTENTS

LIST OF TABLES

CALIFORNIANS' INDOOR AND TOTAL AIR EXPOSURES TO DIESEL EXHAUST PARTICLES

EXECUTIVE SUMMARY

People spend a majority of their time indoors. To accurately estimate the population's exposure to toxic air pollutants, risk assessors must consider both the amount of time people spend in different environments and the concentrations of the pollutants of interest in those environments.

To estimate Californians' exposures to diesel exhaust particles, Air Resources Board (ARB) staff used estimates of population-weighted ambient diesel exhaust particle concentrations (discussed in Chapter 4, Sections B and C of the main Part A report) in a model that can estimate indoor air concentrations, population indoor air exposure, and total air exposure. The model, called the California Population Indoor Exposure Model (CPIEM), was recently developed under contract to the ARB to improve estimates of population exposures to toxic air pollutants. The model generally uses distributions of data (rather than single values) as inputs, and a Monte Carlo (repeated random sampling) simulation approach.

Because representative data on indoor concentrations of diesel exhaust particles are not available, population-weighted outdoor concentrations of diesel exhaust particles plus other inputs (such as distributions of California building air exchange rates) were used in a mass-balance model (provided as one of two modules in CPIEM) to estimate indoor air concentrations of diesel exhaust particles for different indoor environments. Using these indoor air concentration distribution estimates, the second module of CPIEM that combines activity pattern data and air concentration data was used to estimate Californians' exposures to diesel exhaust particles across all enclosed environments. In addition, CPIEM was used to provide estimates of the population's total air exposure to diesel exhaust particles by combining indoor and outdoor air exposure estimates.

In estimating indoor air concentrations for different indoor environments, input data and various assumed values for six parameters were entered into the mass balance model. The six parameters were: the outdoor concentration distributions of diesel exhaust particles; air exchange rates; penetration factor; volume of the indoor space; indoor source emissions rate (set to zero); and a net loss factor that accounts for removal of particles from the indoor space. The statewide population-weighted annual average outdoor diesel exhaust particle concentration estimate of 3.0 $\pm$ 1.1 $\mu g/m^3$ (standard deviation) was used as the outdoor concentration input distribution. The mass-balance module was used to estimate indoor diesel exhaust particle concentrations for the four indoor environments (residences, office buildings, schools, and stores/retail buildings) in CPIEM for which specific data for one or more of the input parameters are available. Estimated indoor concentrations for these environments are shown in Table 1 and range from 1.6 $\pm$ 0.7 $\mu g/m^3$ to 2.1 $\pm$ 0.9 $\mu g/m^3$.

No data for input parameters were found for the other four enclosed environments used in the exposure module of CPIEM; consequently, those environments were assigned surrogate diesel exhaust particle distributions equal to the distributions estimated for similar types of buildings or

environments. As shown in Table 1, industrial plants and enclosed vehicles were assigned the outdoor concentration values, restaurants and lounges were assumed to have levels similar to those found in stores and retail buildings, and "other indoor places" were assumed to have levels similar to those in office buildings.

The distributions of indoor concentration estimates shown in Table 1 were used as inputs in the exposure module of CPIEM, which combines concentration data and data on Californians' activity patterns to develop time-weighted population exposure estimates. The results of the exposure modeling, shown in Table 2, indicate that Californians are exposed to average diesel exhaust particle concentrations of 2.0 ± 0.7 $\mu g/m^3$ in indoor environments. The population time-weighted average total air exposure concentration across all environments (including outdoors) is 2.1 ± 0.8 $\mu g/m^3$. Because these numbers are significant to only one digit, both the average indoor exposure concentration and the average total air exposure concentration are estimated to be 2 ± 1 $\mu g/m^3$. This is about two-thirds of the population-weighted ambient annual average concentration. The integrated exposure estimates in Table 2 provide estimates of the average exposure to diesel exhaust particles experienced by Californians indoors and across all environments. Both the integrated exposure estimates and the average air exposure concentration estimates take into account the differences in air concentrations in different environments and the time spent by Californians in those environments.

Similar indoor concentration and exposure calculations were conducted for the South Coast Air Basin and the San Francisco Bay Area. For the South Coast, the outdoor concentration input distribution was 3.6 ± 1.4 $\mu g/m^3$; the resulting estimated population average indoor exposure concentration was 2.4 ± 0.9 $\mu g/m^3$, and the population average total exposure concentration was 2.5 ± 0.9 $\mu g/m^3$. The input outdoor concentration distribution used for the San Francisco Bay Area was 2.5 ± 1.6 $\mu g/m^3$; the resulting estimated population average indoor exposure concentration was 1.7 ± 0.9 $\mu g/m^3$, and the population average total exposure concentration was 1.7 ± 0.9 $\mu g/m^3$.

It is important to note that the estimates provided in this report are population estimates based on very limited input data and a number of assumptions. These estimates are "improved" over previous estimates because they incorporate into the exposure calculation both Californians' activity patterns and the reduced air concentrations of diesel exhaust particles in indoor environments relative to levels measured at ambient monitoring stations. However, they include notable uncertainty and may not adequately reflect the great variability of exposures that Californians are likely to experience over time. Of particular concern is the fact that higher exposures (the upper tail of the distribution) are likely to be underestimated and are not fully identified in this type of analysis, largely because the primary input (the annual average outdoor concentration calculated from ambient station data) does not necessarily reflect elevated diesel exhaust particle levels in "hot spot" locations. Individuals whose occupation or leisure activities keep them in close proximity to diesel exhaust for extended periods would be exposed to much higher levels of diesel exhaust particles than are reflected by the average estimated levels (and the distributions) shown in Tables 1 and 2.

TABLE 1. ESTIMATED STATEWIDE AIR CONCENTRATIONS OF DIESEL EXHAUST PARTICLES USED AS EXPOSURE MODULE INPUTS
($\mu g/m^3$)*

ENVIRONMENT	ESTIMATED MEAN (+ std dev)	SURROGATE MEAN (+ std dev)
Residences	1.9 ± 0.9	
Offices	1.6 ± 0.7	
Schools	1.9 ± 0.8	
Stores/Public/Retail Bldgs.	2.1 ± 0.9	
Outdoor Places	3.0 ± 1.1	
Industrial Plants		3.0 ± 1.1 (outdoors)
Restaurant/Lounges		2.1 ± 0.9 (retail)
Other Indoor Places		1.6 ± 0.7 (office)
Enclosed Vehicles		3.0 ± 1.1 (outdoors)

* Values significant only to one digit (whole micrograms); calculated values shown here are rounded to two digits for informational purposes.

TABLE 2. ESTIMATED EXPOSURE OF CALIFORNIANS TO DIESEL EXHAUST PARTICLES

	TIME IN ENVT. (mean hours)	INTEGRATED DAILY EXPOSURE (μg-hr/m^3)	AVERAGE AIR EXPOSURE CONCENTRATION ($\mu g/m^3$)*
TOTAL INDOOR (ENCLOSED) EXPOSURE	22.5	44 ± 17	2.0 ± 0.7
TOTAL AIR EXPOSURE	24	49 ± 17	2.1 ± 0.8

* Values significant only to one digit (whole micrograms); calculated values shown here are rounded to two digits for informational purposes.

I. INTRODUCTION

The Air Resources Board's (ARB's) toxic air contaminant identification process requires a thorough risk characterization of chemicals that are under consideration for identification. An accurate risk characterization in turn depends on careful evaluation and integration of both toxicity and exposure information. Exposure of an individual in a particular environment is calculated as the product of the pollutant air concentration in that environment times the length of time that the individual is in that environment (Ott, 1982; Duan, 1982; NAS, 1991). Exposure across an entire day is the sum of exposures in all of the different locations visited by the individual. Thus, in order to assess the population's true exposures to a pollutant, it is necessary to know the time people spend in different locations and the associated concentrations of the pollutant in those locations.

Indoor exposure assessment is a critical part of the overall evaluation of Californians' air exposures because Californians spend, on average, 87 percent of their time indoors (Jenkins et al., 1992; Phillips et al., 1991). However, indoor exposure to diesel exhaust particles cannot be directly assessed because representative indoor measurements of diesel exhaust are not available. An alternative to collecting numerous new field measurements is to use existing information on outdoor concentrations, indoor-outdoor air exchange rates, building characteristics, human activity patterns, and other information in a mathematical model to estimate population exposures.

This Appendix describes the development of estimates of Californians' indoor and total air exposures to diesel exhaust particles using the California Population Indoor Exposure Model (CPIEM), which is discussed further below. Estimates were developed using two "modules" (subroutines) of CPIEM in a two-step process.

1. First, diesel exhaust particle concentrations were estimated for various indoor environments using a mass balance equation module.

2. Through a second module, the indoor concentration estimates obtained from the first step were combined with activity pattern data to estimate the population's indoor air exposure and total air exposure (indoor plus outdoor exposure) to diesel exhaust particles.

Diesel exhaust is a complex mixture of many chemical species including gases, semi-volatile organic chemicals, and particles (Sawyer and Johnson, 1995). No single constituent of diesel exhaust as yet serves as a unique, measurable marker of exposure, although fine particles and elemental carbon have been used as indices of diesel exhaust particulate matter (Watts, 1995). Consequently, air measurements for diesel exhaust concentrations are very limited and do not account for all diesel exhaust components. Using ambient PM10 concentration data, an outdoor air model, and supporting information, ARB staff have estimated the portion of outdoor PM10 concentrations attributable to diesel exhaust and have calculated population-weighted ambient concentrations of diesel exhaust particles. The

rationale for, and derivation of, the ambient population-weighted diesel exhaust particle estimates are presented in Chapter 4, Sections B and C of the main Part A report. Those estimates provide the outdoor air concentration input values for the model used to estimate indoor and total air exposures in this appendix.

II. THE CALIFORNIA POPULATION INDOOR EXPOSURE MODEL (CPIEM)

A. MODEL OVERVIEW

CPIEM is a computer model recently developed under contract to the ARB for estimating the population's indoor exposure to toxic air pollutants (Koontz, 1995). CPIEM has two main modules. The primary function of CPIEM, accomplished by one module, is to combine indoor air concentration data and outdoor air concentration data with information on Californians' activity patterns (primarily time spent in different environments) to estimate indoor and total inhalation exposure distributions. If indoor air concentration information is not available, a second module can estimate indoor air concentrations using the outdoor air concentration data in a mass-balance equation. CPIEM utilizes input distributions when they are available, and uses Monte Carlo simulation (repeated random sampling from a distribution) for deriving the estimates. The model can also estimate potential inhaled dose distributions, but the breathing rate inputs for different age groups and activity levels need to be refined prior to formal use. Consequently, inhaled dose estimates are not included in this appendix.

B. INDOOR AIR AND TOTAL AIR EXPOSURE ESTIMATES

The first module of CPIEM can provide population exposure estimates for one or more environments. The module calculates exposure for a given individual as the sum of the products of the air concentration in each environment and the amount of time spent in each environment (duration of exposure) for nine different environments (discussed below). The sum of the indoor environment exposures for each individual provides an estimate of their total indoor air exposure; by aggregating the indoor exposure estimates across the population, the model develops a distribution of total indoor air exposure. When the outdoor environment is included, the model estimates a "total air exposure" distribution that accounts for all exposures across the entire day.

To estimate indoor exposure, the module requires two primary inputs: indoor concentration distributions and activity pattern data (time spent in different locations). The model can utilize either measured or modeled concentration distributions for one or more environments; this information is usually provided by the model user, although some indoor concentration data for some pollutants is provided with the model. For time spent in different locations (duration of exposure), the model utilizes data from two human activity pattern surveys sponsored by ARB (Wiley et al., 1991a,b). Those surveys obtained 24-hour activity data for 2,962 Californians of all ages who were reasonably representative of the California

population (Jenkins et al., 1992; Phillips et al., 1991). The data on time spent in different locations have been grouped into nine categories of environments and are provided as part of the model.

The environment categories include:

(1) Residences: all places inside a home

(2) Offices: office buildings, banks, post offices

(3) Industrial Plants: industrial plants or factories

(4) Schools: inside school buildings

(5) Stores and Other Public Buildings (category designated "Retail" buildings in this report): grocery stores, shopping malls, hospitals, churches, indoor gyms or health clubs.

(6) Restaurants and Lounges: restaurants, bars or night clubs

(7) Other Indoor Locations: hotels, dry cleaners, beauty parlors/barber shops, auto repair shops, varying work places, other indoor locations.

(8) Enclosed Vehicles: travel in cars, trucks, buses, trains, or airplanes.

(9) Outdoor Locations: pool or yard at home, at a park, or other outdoor locations; walking outdoors; waiting at a bus or train or ride stop; riding a bicycle, motorcycle or scooter; in a stroller (child).

Results of this module are provided in exposure units of μg-hr/m^3, which is an estimate of the integrated exposure across the entire day or time period. ARB staff used these model results to calculate the average population indoor and total air exposure concentration estimates that also are presented in this report. These time-weighted air exposure concentrations are somewhat comparable to the outdoor population-weighted concentration estimates presented elsewhere in this report and to similar outdoor population-weighted concentration estimates presented in previous identification reports developed for ARB's Toxic Air Contaminant Program.

C. INDOOR AIR CONCENTRATION ESTIMATES

Another module of CPIEM can estimate indoor air concentrations for one or more indoor environments. This module is available as a first step in modeling exposure estimates for the many pollutants for which indoor concentration data are not available. The mass balance

equation used in this module calculates the indoor air concentration as the amount of the pollutant that enters the indoor space from the outdoors plus the amount of pollutant that is generated indoors less the amount that is removed through various removal mechanisms such as deposition or reactivity. It is assumed that the air in the indoor space is well mixed (essentially a single chamber). This approach has been employed by other researchers in modeling indoor pollutant concentrations and sources (Suh et al., 1994; Klepeis et al., 1994; Koontz et al., 1993), and is especially appropriate in cases where there are few or no indoor sources of the pollutant of concern and for long-term population exposure estimation.

The mass balance equation used in the calculation of indoor concentrations is:

$$C_i = \frac{P\,a\,C_o + (S_i / V)}{a + k}$$

Where C_i = Indoor air concentration of pollutant

P = Penetration; the portion of the outdoor pollutant concentration that penetrates through the building shell with a given volume of air exchanged.

a = Air exchange rate (AER) or air changes per hour (ACH)

C_o = Outdoor air concentration of pollutant

S_i = Total indoor source emission rate of pollutant

V = Volume of the indoor space

k = Portion of pollutant lost indoors per hour due to deposition and other removal mechanisms

As indicated by the equation, the calculation of pollutant concentrations in an indoor environment depends on six major parameters. These parameters and their use in estimating indoor concentrations of diesel exhaust particles are discussed further below.

III. INPUT PARAMETERS FOR MODELING INDOOR AIR CONCENTRATIONS OF DIESEL EXHAUST PARTICLES

CPIEM'S mass-balance module was used to estimate indoor diesel exhaust particle concentrations for the four (of eight) indoor environments specified by CPIEM for which

data for some of the input parameters are available. The input parameters and assumptions used in the mass balance equation are discussed below.

A. OUTDOOR CONCENTRATION DISTRIBUTIONS

Outdoor concentrations of diesel exhaust particles were estimated from ambient PM10 monitoring data as previously mentioned and as described in Chapter 4, Sections B and C, of the main Part A report. The population-weighted ambient concentrations estimated for the State, the South Coast Air Basin, and the San Francisco Bay Area are shown in Table 3.

TABLE 3. ESTIMATED OUTDOOR POPULATION-WEIGHTED CONCENTRATIONS USED AS MODEL INPUTS

	Outdoor Concentrations ($\mu g/m^3$ + std dev)
Statewide	3.0 $\pm$ 1.1
South Coast Air Basin	3.6 $\pm$ 1.4
San Francisco Bay Air Basin	2.5 $\pm$ 1.6

These estimates were used for the outdoor concentration (C_o) input values for the CPIEM mass balance module. For a given region (e.g., statewide), the outdoor concentration distribution shown in Table 3 provided the input values for calculating indoor concentration estimates for each of the four environments for which information for the other parameters was available.

B. INDOOR SOURCE EMISSIONS

It was assumed that there are no indoor sources of diesel exhaust in indoor environments or in the "enclosed vehicle" environment. Thus, S_i was set equal to zero.

For residential buildings, the only significant indoor source would be diesel-powered passenger cars and trucks parked in attached, enclosed garages. However, based on results from the ARB motor vehicle emission inventory (MVEI) 7G computer model, only about 1.4 percent of light duty automobiles and trucks were diesel-powered in 1994, and only a portion of those vehicles would be expected to be parked in attached, enclosed garages. Emissions would typically be brief (during start-up or parking), and the amount of exhaust entering the living areas of the home typically would be minimal. Therefore, this source is considered to be negligible for residential buildings on a population-wide basis.

For non-residential buildings, the "Industrial Plant" and "Other Indoor Location" environments may have occasional indoor sources such as diesel-powered tools, machinery, forklifts and vehicles. Such sources may be used in enclosed work spaces or near outdoor air intakes that suck the exhaust in and deliver it to indoor work spaces. However, it is difficult to quantify the contribution of such sources to indoor concentrations for two reasons. First, there are no readily available data on the number and frequency of use of such potential sources in and near enclosed environments. Also, most of the workplaces in which they are used are not tightly enclosed and are open to the outdoor air (and/or have very high ventilation/air exchange rates). Potential exposures in occupational or other environments likely to have high diesel exhaust levels are best estimated using a scenario-based approach.

Therefore, for the purpose of estimating population exposures to diesel exhaust particles in this report, the emission rate of diesel exhaust particles from sources inside non-residential buildings was generally assumed to be negligible, and S_i was set equal to zero.

C. VOLUME OF INDOOR SPACE

The volume of indoor space is highly variable among different styles and types of buildings. Some building volume data are provided with CPIEM. However, in the mass balance calculation of indoor diesel exhaust particle concentrations, the indoor source emission term is divided by the volume of indoor space. Because the indoor source term was set equal to zero (assumption of no indoor sources), S_i/V equals zero and building volume estimates consequently have no effect on the results of this particular modeling scenario.

D. AIR EXCHANGE RATES

Air exchange rate is the rate at which the air in an indoor airspace is exchanged with the same volume of outdoor air. Air exchange rates usually are expressed in units of volumes per hour, i.e., 2 AERs mean that twice the volume of air in the indoor airspace is exchanged per hour. Indoor-outdoor air exchange rates fluctuate over time, depending on weather conditions and the operating characteristics of the building. In residential buildings, the opening of doors and windows and the use of whole house fans and swamp coolers are major determinants of air exchange rates. Wind and temperature can cause different pressures between the outdoor air and the indoor air that can increase or decrease infiltration. In commercial buildings, the operation of the heating, ventilating, and air conditioning (HVAC) system, especially one that uses an economizer cycle (which is affected by the temperature difference), is a major determinant of the air exchange rate. The operation of systems without outdoor air intakes also affects air exchange rates because of duct and damper leakage. Because of these and other factors, outdoor air exchange in a building is dynamic, and the building will exhibit different air exchange rates at different times.

1. Residential Buildings

ARB developed air exchange rate inputs for residential buildings based on measured values from California studies, data from other studies, and consideration of California-specific factors. A number of investigators have reported air exchange rates for homes in California (Ozkaynak et al., 1994; Sheldon et al., 1993; BSG, 1990; Wilson et al., 1993; ADM, 1990; Pellizzari et al., 1989; Wilson et al., 1986), and input files of air exchange rates from some of these California studies are included with CPIEM (Koontz et al., 1995). The U.S. Environmental Protection Agency also has compiled a comprehensive database containing over 3,000 air exchange rate measurements nationwide (Koontz and Rector, 1993). The air exchange rates reported in the California studies are listed in Table C1 (see attached tables).

The estimated residential air exchange rate input parameters used for residential buildings were: a mean of 1.2 AER, a standard deviation of 1.0, and a lognormal distribution (CPIEM requires the user to specify the form of the distribution in addition to the mean and standard deviation when the user is providing the input data). From inspection of Table C1, the range of the mean air exchange rates measured for California homes in winter and for newer California homes is about 0.5 to 0.9 AER. The mean air exchange rates measured in summer for California homes have a higher and broader range (as expected), from about 0.7 to 2.8 AER. Spring and fall rates typically fall between summer and winter rates. Combining air exchange rates from both winter and summer data, and taking into account the fact that a majority of Californians live along the coast or in southern California where mild climate predominates (and windows are therefore open more of the time), a value of 1.2 AER was estimated to reasonably approximate the annual average air exchange rate. A value of 1.0 was chosen to reasonably approximate the standard deviation and to reflect the range of potential high air exchange rates that occur in homes in mild weather, and low rates that occur in extremely tight homes. These values are intermediate between values for the California winter and summer data sets, which is appropriate for estimating the annual average air exchange rates. However, they may not fully reflect the large variability of air exchange rates identified in some studies.

2. Non-residential Buildings

Recently, Grot (1995) completed a study of air exchange rates and other building characteristics in 49 non-residential buildings in various cities of California. This study is useful because it provides statewide California air exchange rate data for three different non-residential types of buildings--office, retail, and school buildings. Although air exchange measurements were made under operating conditions that may not fully represent conditions across a day or season, the buildings were randomly selected and the study covered several seasons; thus, the data from this study were assumed to provide reasonable approximations of ACHs for California non-residential buildings. Other data for non-residential buildings in other states also were examined. Persily (1989) provides a useful summary of air exchange rate studies conducted over the years in 14 large office buildings in different U.S. cities. Turk et al. (1987) measured both whole building air

exchange rates and indoor air quality in 38 commercial buildings in the Pacific Northwest. The air exchange rates reported in all of these studies are shown in Table C2, attached.

a. Office Buildings

The input parameter assumed for office building air exchange rate was a lognormal distribution with a mean of 1.35 and a standard deviation of 0.7. This input was chosen based primarily on Grot's (1995) findings for 22 office buildings in California. The choice is generally supported by the results of Persily (1989) and Turk et al. (1987), taking into account climatic differences and other factors that differ between California buildings and buildings in other parts of the country.

b. Retail Buildings

The input parameter assumed for retail building air exchange rate was a lognormal distribution with a mean of 2.22 and a standard deviation of 1.6. This input was chosen based primarily on Grot's (1995) findings for 13 retail buildings of varying sizes in California. The choice is generally supported by the results of Turk et al. (1987).

c. Schools

The input parameter assumed for air exchange rates in schools was a lognormal distribution with a mean of 2.45 and a standard deviation of 1.6. These assumed values were chosen based primarily on Grot's (1995) findings for 14 schools in California. These values are generally supported by the results of Turk et al. (1987).

E. PENETRATION FACTOR

The penetration factor denotes, for a given volume of air that enters the building, the fraction of the outdoor contaminant mass in that volume of air that moves through the building shell to the indoor air space without interception. The penetration factor ranges from zero to one and is dimensionless. For residential buildings, the main route of entry of outdoor air is through open windows and doors and cracks in the building shell. However, for most non-residential buildings, the primary route of entry of outdoor air is the air handling system that actively draws air into the building (Fisk, 1986). In this case, a fraction of the contaminant in the incoming outdoor air may also be removed by filtering devices in the air handling system. The rationale for the selection of penetration factors for residential buildings and non-residential buildings is presented below.

1. Residential Buildings

Attached Table C3 lists penetration factors for homes reported by different researchers. Penetration factors are calculated based on measurements of other parameters, mainly indoor and outdoor concentrations of fine particles or particle species of interest. The values of the

penetration factor for fine particles in residences have generally been reported in the range of 0.70 to 0.85 (Suh, et al., 1994; Koutrakis et al., 1992; Dockery and Spengler, 1981). However, Ozkaynak et al. (1994) and Thatcher and Layton (1995) recently reported penetration factors very near or equal to 1.0. Thatcher and Layton (1995) explained that the apparent difference in results may be due to the fact that more recent investigators accounted for the effect of particle deposition indoors before calculating penetration factors, while the earlier investigators did not. In essence, the loss of incoming particles could be partly or completely attributable either to the scrubbing effect of the building shell (the penetration factor) or to the settling of particles indoors (the decay/removal factors).

Based on the literature cited in Table C3, the assumed input for residential penetration factor was a triangular distribution with minimum, mode and maximum at 0.7, 0.95, and 1.0, respectively. The choice of using 1.0 as the maximum and 0.95 for the mode is strongly supported by penetration factors estimated by Ozkaynak et al. (1994) from the Particle Total Exposure Assessment Methodology (PTEAM) study. That study is particularly important because it was a California study of a large number of homes, and included over 2,750 particle samples. For homes studied in PTEAM, investigators calculated penetration factors of 1.0 or slightly less than 1.0 for PM2.5, PM10, and 14 elemental species. The values selected for the upper part of the triangular distribution are also supported by test house data (Thatcher and Layton, 1995). The selection of 0.7 for the minimum value of the triangular distribution reflects the results of other pertinent studies listed in Table C3, and acknowledges that in some buildings, under certain conditions, penetration may be notably less than 1.0. Lower penetration values would be expected in very tight homes in cold weather or under conditions in which the particles of concern are reactive, "sticky" or quick to agglomerate.

2. Non-residential Buildings

Estimation of the penetration factor for commercial or public buildings is complicated by the fact that some of them have mechanical ventilation systems that filter much of the air that is brought in from outdoors, and some do not. Preliminary data from a survey of 88 California non-residential buildings indicate that about 72 percent of them have some type of filtration system (BSG, 1993). The percentages of office, retail and school buildings that had filtration systems were 73, 64, and 76, respectively, as shown in attached Table C4.

The penetration factor for non-residential buildings, then, is determined by two components. One component accounts for the particle loss by filtration for the portion of air that is brought into the building by the mechanical ventilation system. The other component accounts for particle loss when unfiltered air enters the building. The formula used to derive the penetration factor input parameters for non-residential buildings is:

$$P_{total} = p(n) + (1- E)(1-n)$$

where

p is the penetration factor for unfiltered air that enters the building through leakage or open windows or doors;

E is the efficiency of the filtration device in the air handling system, and denotes the percent of particles removed from the air as the air passes through the filter; and

n is the fraction of air that enters the building unfiltered, through leakage or open windows and doors.

Thus, (1-E) is the portion of particles that travels through the filter and is not captured by it, and (1-n) is the fraction of outdoor air entering the building that goes through the air handling system and through the filtering device.

Total penetration was calculated for non-residential buildings using the values shown in attached Table C5. Penetration for unfiltered air (p) was assumed to be one. The estimate of n was based on the ratio of measured infiltration rates to measured total air exchange rates reported by Grot (1995). Grot reported that the ratio of the median air infiltration rate to the median total air exchange rate is about 0.3 for office buildings, about 0.6 for retail buildings, and about 0.15 for schools. Therefore, the assumed n values for office, retail, and school buildings were 0.3, 0.6, and 0.15, respectively.

Specific data on the particle removal efficiency of filters in use are not available. A few studies included minor discussions of filter efficiencies as part of particle concentration measurements (Weschler et al., 1995, 1983; Ligocki et al., 1993; Sinclair et al., 1992, 1990). The filter efficiencies of some types of filters are listed in Table C5. Using the filter efficiency value (E) and the assumed n values, plus assuming a penetration factor of 1.0 for unfiltered air for all the three types of non-residential buildings, composite penetration factors were estimated using the equation above. These estimates are shown in Table C5.

a. Office Buildings

Based on the estimates in Table C5, the input parameter for penetration factor for office buildings was assumed to be a triangular distribution with minimum, mode, and maximum at 0.4, 0.7, and 1.0, respectively.

The upper limit of the distribution was set at 1.0 because about a quarter of office buildings do not have any air cleaning capability, usually because they do not have a central ventilation system. In such buildings, essentially 100 percent of the particles in outdoor air volumes that enter the building would penetrate into the building. The lower limit of the distribution was set at 0.4 based on the data for office buildings that use high efficiency filters for high

technology equipment. The mode of 0.7 was chosen because three-quarters of the buildings have filtration devices, so some particle loss would be expected, but most would have low or medium efficiency filters and varying levels of maintenance, warranting a middle value.

b. Retail Buildings

Based on the estimates in Table C5, the input parameter for penetration factor was assumed to be a triangular distribution with minimum, mode, and maximum at 0.6, 0.9, and 1.0, respectively.

The upper limit of the distribution was set at 1.0 because more than a quarter of retail buildings do not have any air cleaning capability (BSG, 1993). Thus, 100 percent of the outdoor particles in a given outdoor air exchange volume would enter the building. The minimum and the mode (0.6 and 0.9) were set somewhat higher than the comparable values selected for office buildings because retail buildings are typically accessible to the public, and opened doors allow higher outdoor air infiltration. In addition, retail buildings generally would be expected to have less efficient filters and greater variability in air handling systems than office buildings.

c. Schools

Based on the estimates in Table C5, the input parameter for penetration factor for school buildings was assumed to be a triangular distribution with minimum, mode, and maximum at 0.5, 0.8, and 1.0, respectively.

The upper limit of the distribution was set at 1.0 for the same reasons given for office and retail buildings, above. The mode was set at 0.8 and the minimum at 0.5 based on the considerations that schools tend to have open doors for some time during a day, gymnasiums and other specialty buildings may not have filtration devices even though other school buildings might, and more low-efficiency filters and fewer high-efficiency filters are used in schools than are used in office buildings.

F. INDOOR DEPOSITION AND REMOVAL FACTORS

Once particles have entered an indoor environment, their concentration in the indoor air can change by various removal mechanisms such as deposition, transformation, decay, decomposition, and adsorption. For PM10, the primary indoor removal mechanism is assumed to be particle deposition. Usually, particles with larger aerodynamic diameters

deposit faster than those with smaller aerodynamic diameters (Frey, 1989). However, extremely small particles (diameters smaller than 0.1 um) may experience high removal rates as well because of other factors such as electrostatic forces (Nazaroff et al., 1993; Nazaroff and Cass, 1989a,b).

Deposition rates and deposition velocities have been reported for particles with different aerodynamic diameters (Thatcher and Layton, 1995; Ozkaynak et al., 1994; Sinclair et al., 1992, 1990; Ligocki, 1990; Nazaroff et al., 1990a,b). The deposition rates and deposition velocities measured or estimated in these studies are listed in Table C6. For particles within certain size ranges, the deposition velocities and rates are comparable.

The deposition (removal) rates reported by Ozkaynak et al. (1994) and Thatcher and Layton (1995) were used to develop the input distribution for the k value (removal term) in CPIEM's mass balance equation. The same k distribution was used as the input value for all the modeled indoor environments because the very limited data available do not support the use of different k values for different indoor environments. Particles were assumed to behave essentially the same in the various indoor environments.

Thus, the indoor removal factor, k, for the four modeled indoor environments was assumed to have a lognormal distribution, a mean of 0.4 hr^{-1} and a standard deviation of 0.3. The chosen mean of 0.4 hr^{-1} for the distribution was based primarily on the mean deposition rate of 0.39 $\pm$ 0.16 hr^{-1} for PM2.5 reported by Ozkaynak et al. (1994). The assumed mean value of 0.4 is reasonable because it is based on a study of 178 California homes, because about 60 percent of indoor PM10 is in the PM2.5 fraction (Ozkaynak et al., 1994; Clayton et al., 1991), and because 90 percent of diesel particles by weight are smaller than 1.0 μm in diameter (Watts, 1995). The assumption of a standard deviation of 0.3 was based on consideration of the mean PM10 deposition rate and standard deviation of 0.65 $\pm$ 0.28 hr^{-1} reported by Ozkaynak et al. (1994). The lognormal distribution extends the upper tail of the distribution to allow for inclusion of some infrequent high values reported by Thatcher and Layton (1995).

G. SUMMARY OF INPUT PARAMETERS FOR INDOOR CONCENTRATION MODELED ESTIMATES

The input parameters used in CPIEM to estimate indoor air concentrations for the indoor environments are summarized in Table 4.

All input parameters were the same for the South Coast and San Francisco Bay regional modeling runs as for the statewide calculations, except that the outdoor concentration distributions were 3.6 $\pm$ 1.4 $\mu g/m^3$ for the South Coast and 2.5 $\pm$ 1.6 $\mu g/m^3$ for the San Francisco Bay area.

TABLE 4. INPUT VALUES FOR INDOOR AIR CONCENTRATION MODELING: STATEWIDE ESTIMATES

PARAMETER	UNITS	RESIDENCES	OFFICES	SCHOOLS	RETAIL
OUTDOOR CONC. (C_o)	$\mu g/m^3$				
Form		Lognormal	Lognormal	Lognormal	Lognormal
Mean, std dev		3.0,1.1	3.0,1.1	3.0,1.1	3.0,1.1
PENETRATION (P)	-				
Form		Triangular	Triangular	Triangular	Triangular
Min, mode, max		.7,.95,1.0	.4,.7,1.0	.5,.8,1.0	.6,.9,1.0
AIR EXCHANGE RATE (a)	/hr				
Form		Lognormal	Lognormal	Lognormal	Lognormal
Mean, std dev		1.2,1.0	1.35,.7	2.45,1.6	2.22,1.6
INDOOR EMISSION RATE (S_i)	NA*	0	0	0	0
INDOOR VOLUME (V)	m^3	NA	NA	NA	NA
INDOOR REMOVAL (k)	frac-				
Form	tion	Lognormal	Lognormal	Lognormal	Lognormal
Mean, std dev	/hr	.4,.3	.4,.3	.4,.3	.4,.3

*NA - not applicable for this modeling exercise

IV. INDOOR AIR CONCENTRATION MODELED ESTIMATES

Input data shown in Table 4 were entered into the model to generate the indoor air concentration estimates for residences, office buildings, retail buildings, and schools. For each environment, 10 runs were executed. For each of the 10 runs, CPIEM was set to generate 500 trials, with a different random number seed specified for each of the runs. Results for the 10 runs were averaged. The averaged results of the indoor air concentration estimates for the four environments are shown in Table 5.

TABLE 5. ESTIMATED INDOOR DIESEL EXHAUST PARTICLE CONCENTRATIONS
($\mu g/m^3$)

	MEAN + Std Dev		
ENVIRONMENTS	Statewide	South Coast	San Fran Bay
Residences	1.9 ± 0.9	2.3 ± 1.1	1.6 ± 1.1
Office Buildings	1.6 ± 0.7	1.9 ± 0.9	1.3 ± 0.9
Schools	1.9 ± 0.8	2.3 ± 1.0	1.6 ± 1.0
Retail (Stores & Public Buildings)	2.1 ± 0.9	2.5 ± 1.1	1.7 ± 1.2

The indoor diesel exhaust particle concentrations estimated for the four environments are fairly similar but reflect the differences expected due to higher filter efficiency in some office buildings relative to other categories of buildings and higher air exchange in retail and public buildings. The estimated indoor concentrations are notably lower than the population-weighted outdoor exposure concentrations used as inputs for each region. Although these indoor and outdoor concentration estimates are not directly comparable (because the outdoor values are population-weighted and the indoor values are time-weighted), the comparison generally indicates that the indoor concentration results are reasonable--they are in the expected direction (lower) and reflect the approximate reduction that would be expected in indoor concentrations relative to outdoor concentrations.

V. INDOOR AND TOTAL AIR EXPOSURE ESTIMATES FOR DIESEL EXHAUST PARTICLES

A. INPUT PARAMETERS

The major input parameters that are required by CPIEM to estimate population exposure are the air concentration distributions for the eight indoor environments and for the outdoor environment. As indicated previously, input data were not available for all the parameters of the mass-balance equation for each of the eight indoor environments in CPIEM. Input data for parameters for the mass balance equation were available for only four of the indoor environments; thus, diesel exhaust particle concentrations could only be estimated for four of the eight categories of indoor environments in CPIEM. For the other four indoor environments (industrial plants, enclosed vehicles, restaurants and lounges, and "other indoor places"), surrogate indoor air concentration distributions were used as inputs for the CPIEM exposure module. For each of these environments, the surrogate indoor air concentration distribution used in the exposure module was the indoor concentration

distribution estimat
in building and air

The outdoor concei
distribution for ind
trucks typically hav
concentrations clos
likely to experience
to diesel sources.
concentrations fron
concentrations.

Restaurants and lou
surrogate air conce
generally have air l
of buildings includ
distribution was us
category includes a
air exchange condi
the broadest range

The estimated and
exposures for the C
residents are show

TABLE 6. A
S

ENVIRONMENT
Residences
Office Buildings
Schools
Retail/Stores/Public
Outdoor Locations
Industrial Plants
Restaurant/Lounges
Other Indoor Places
Enclosed Vehicles

profile data set also was used for the South Coast and San Francisco Bay area because there are only small differences in activity patterns across California et al., 1991a,b), and those differences are minor relative to other factors in th estimation exercise. Also, the sample size for each region is notably smaller, profiles are weighted; thus, the use of subsets of the activity profile data set, allowable, would potentially introduce some error into the calculation.

B. RESULTS -- ESTIMATED POPULATION EXPOSURE TO DIES PARTICLES

For each exposure module run, the number of trials was set to use the comple of activity profiles; thus, each profile in the activity file was used once. Five made with a different random number seed specified for each run. The expos produced by CPIEM are integrated exposure estimates in units of microgram-meter (μg-h/m^3). The population exposure concentrations (μg/m^3) were calcu the model by dividing the individual integrated exposure estimates for the dif environments calculated in CPIEM by the amount of time the person spends i environments. Both the integrated exposure estimates and the population exp concentration estimates for the California population are presented in Table 9 integrated exposure estimates and population exposure concentration estimate Coast population and for the San Francisco Bay area population are provided and 11, respectively.

Based on the estimates displayed in Table 9, the majority of exposure occurs because people spend the greatest amount of their time there. However, the exposure concentration (concentration "weighted" by the duration of exposur enclosed vehicles and outdoors, as expected. The population mean total indo is 1.99 μg/m^3 and the population mean total air exposure is 2.05 μg/m^3. Thes exposure concentrations are essentially equal, indicating that outdoor exposu portion of the population's overall exposures on an annual basis. However, in mind that the calculations presented here do not fully take into account the exposures that some individuals experience on a daily basis due to their occu or personal activity patterns. Also, it must be kept in mind that, in this mod the estimated exposures are all attributable to outdoor sources of diesel exhau vehicles), and that any indoor sources would add significantly to the exposur who spend time in that indoor environment.

TABLE 9. CALIFORNIA STATEWIDE POPULATION EXPOSURE ESTIMATES FOR DIESEL EXHAUST PARTICLES

ENVIRONMENT	TIME SPENT (hours) MEAN + Std Dev	INTEGRATED EXPOSURE (μg-h/m^3) MEAN + Std Dev	POPULATION EXPOSURE CONCENTRATION (μg/m^3) MEAN + Std Dev
Residences	16.2 $\pm$ 4.6	30.9 $\pm$ 17.2	1.9 $\pm$ 0.9
Office Buildings	1.0 $\pm$ 2.6	1.6 $\pm$ 4.5	0.4 $\pm$ 0.7
Industrial Plants	0.5 $\pm$ 2.0	1.5 $\pm$ 6.4	0.2 $\pm$ 0.9
Schools	0.8 $\pm$ 2.1	1.6 $\pm$ 4.5	0.3 $\pm$ 0.8
Enclosed Vehicles	1.5 $\pm$ 1.7	4.6 $\pm$ 5.8	2.6 $\pm$ 1.5
Retail (Stores & Public Buildings	1.3 $\pm$ 2.3	2.6 $\pm$ 5.3	1.1 $\pm$ 1.2
Restaurants/Lounges	0.5 $\pm$ 1.4	1.1 $\pm$ 3.0	0.7 $\pm$ 1.1
Other Indoor Places	0.6 $\pm$ 1.9	0.9 $\pm$ 3.2	0.4 $\pm$ 0.8
Outdoor Places	1.5 $\pm$ 2.3	4.6 $\pm$ 7.6	1.9 $\pm$ 1.7
TOTAL INDOOR EXPOSURE	22.5 $\pm$ 2.3	44.7 $\pm$ 16.7	2.0 $\pm$ 0.7
TOTAL AIR EXPOSURE	24.0 $\pm$ 0	49.3 $\pm$ 16.6	2.1 $\pm$ 0.7

*Exposure values are significant to whole numbers; decimal shown for information only.

TABLE 10. SOUTH COAST POPULATION EXPOSURE ESTIMATES FOR DIESEL EXHAUST PARTICLES

ENVIRONMENT	TIME SPENT (hours) MEAN + Std Dev	INTEGRATED EXPOSURE (μg-h/m^3) MEAN + Std Dev	POPULATION EXPOSURE CONCENTRATION (μg/m^3) MEAN + Std Dev
Residences	16.2 ± 4.6	37.1 ± 21.8	2.3 ± 1.1
Office Buildings	1.0 ± 2.6	1.9 ± 5.4	0.4 ± 0.9
Industrial Plants	0.5 ± 2.0	1.8 ± 7.7	0.3 ± 1.1
Schools	0.8 ± 2.1	1.9 ± 5.4	0.4 ± 1.0
Enclosed Vehicles	1.5 ± 1.7	5.6 ± 7.0	3.1 ± 1.8
Retail (Stores & Public Buildings	1.3 ± 2.3	3.1 ± 6.4	1.3 ± 1.5
Restaurants/Lounges	0.5 ± 1.4	1.3 ± 3.7	0.8 ± 1.3
Other Indoor Places	0.6 ± 1.9	1.0 ± 3.8	0.4 ± 0.9
Outdoor Places	1.5 ± 2.3	5.5 ± 9.3	2.3 ± 2.0
TOTAL INDOOR EXPOSURE	22.5 ± 2.3	53.8 ± 20.9	2.4 ± 0.9
TOTAL AIR EXPOSURE	24.0 ± 0	59.2 ± 20.8	2.5 ± 0.9

*Exposure values are significant to whole numbers; decimal shown for information only.

Results for the South Coast population show that total indoor exposure and total air exposure are slightly higher than the statewide estimates but are essentially the same. Due to rounding conventions, however, the total indoor exposure concentration for South Coast residents is estimated to be 2 μg/m^3, while the total air population exposure concentration is estimated to be 3 μg/m^3.

TABLE 11. SAN FRANCISCO BAY AREA POPULATION EXPOSURE ESTIMATES FOR DIESEL EXHAUST PARTICLES

ENVIRONMENT	TIME SPENT (hours) MEAN + Std Dev	INTEGRATED EXPOSURE (μg-h/m^3) MEAN + Std Dev	POPULATION EXPOSURE CONCENTRATION (μg/m^3) MEAN + Std Dev
Residences	16.2 $\pm$ 4.6	25.9 $\pm$ 20.5	1.6 $\pm$ 1.1
Office Buildings	1.0 $\pm$ 2.6	1.3 $\pm$ 4.2	0.3 $\pm$ 0.7
Industrial Plants	0.5 $\pm$ 2.0	1.3 $\pm$ 6.0	0.2 $\pm$ 0.8
Schools	0.8 $\pm$ 2.1	1.4 $\pm$ 4.3	0.3 $\pm$ 0.8
Enclosed Vehicles	1.5 $\pm$ 1.7	3.9 $\pm$ 5.7	2.1 $\pm$ 1.7
Retail (Stores & Public Buildings)	1.3 $\pm$ 2.3	2.2 $\pm$ 5.0	0.9 $\pm$ 1.2
Restaurants/Lounges	0.5 $\pm$ 1.4	0.9 $\pm$ 2.8	0.6 $\pm$ 1.0
Other Indoor Places	0.6 $\pm$ 1.9	0.7 $\pm$ 2.9	0.3 $\pm$ 0.7
Outdoor Places	1.5 $\pm$ 2.3	3.8 $\pm$ 7.3	1.6 $\pm$ 1.7
TOTAL INDOOR EXPOSURE	22.5 $\pm$ 2.3	37.5 $\pm$ 21.1	1.7 $\pm$ 0.9
TOTAL AIR EXPOSURE	24.0 $\pm$ 0	41.3 $\pm$ 21.3	1.7 $\pm$ 0.9

* Exposure values are significant to whole numbers; decimal shown for information only.

Estimates of San Francisco Bay Area residents' exposures are slightly less than those for the statewide and South Coast populations. However, the indoor and total air exposure concentration estimates both round to 2 μg/m^3, similar to the statewide estimates.

VI. DISCUSSION AND CONCLUSIONS

This exposure assessment incorporates into the population exposure estimate both Californians' activity patterns and estimates of the reduced air concentrations of diesel exhaust particles in indoor environments relative to levels measured at ambient monitoring stations. This assessment takes advantage of recently reported data from California indoor air quality and building ventilation studies and California-specific activity pattern data. It also utilizes a recently developed exposure assessment model, CPIEM. Thus, it should provide some improvement over previous estimates of diesel exhaust particle exposure.

The model used in this assessment has not yet undergone rigorous validation; however, several evaluation and validation exercises have been completed (Koontz et al., 1995), and the model has performed reasonably well. The mass balance portion of the model is similar

to other mass balance models used for similar purposes, and the exposure module uses approaches similar to other population exposure models available for specific compounds. Thus, for this exposure assessment, it is likely that the assumptions and limitations related to the model inputs are greater sources of uncertainty than are the model calculations.

Any error associated with the exposure estimates provided here is likely to result in an underestimation, rather than overestimation, of the population's exposure to diesel exhaust. The use of the statewide and region-wide population-weighted outdoor concentration estimates of diesel exhaust particles as major inputs for the exposure model may not fully capture the higher exposure levels experienced by individuals whose occupation or hobbies bring them regularly in close proximity to diesel exhaust. For example, diesel particle levels ranging from 4 to 1,740 $\mu g/m^3$ have been measured in work environments of miners, forklift operators, firefighters, truck drivers, and railroad workers, and personal exposures to diesel exhaust have been shown to be very high for operators of diesel-powered equipment and vehicles (Watts, 1995). However, depending on their specific location, these elevated levels of diesel exhaust would not necessarily contribute proportionately to levels measured at ambient monitoring stations. Thus, a scenario-based exposure modeling approach would better identify the upper end of the population exposure distribution. Such a scenario-based assessment is provided in the main part of this exposure assessment report.

In conclusion, the estimates developed in this modeling exercise are believed to provide the best available estimates of the population's average exposure to diesel exhaust particles and to provide a reasonable estimate of the range of exposures experienced, but they probably do not fully reflect the higher exposures experienced by some subgroups of the population.

REFERENCES

Adams W.C. (1993), "Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities," California Air Resources Board Final Report, Contract No. A033-205.

ADM (1990), "Pilot Residential Air Exchange Survey, Task 2: Pilot Infiltration Study, Indoor Air Quality Assessment Project," Report to the California Energy Commission prepared by ADM Associates, Inc., Sacramento, CA, Contract No. 400-88-020.

BSG (1993) "Outdoor Air Exchange Rates in Nonresidential Buildings, Task 2: Survey Instrument Selected Sample Pilot Study," Report to the California Energy Commission prepared by the Berkeley Solar Group, Oakland, CA, Contract No. 400-90-028.

BSG (1990), "Occupancy Patterns and Energy Consumption in New California Houses (1984-1988)," California Energy Commission Consultant Report (P400-90-009), prepared by Berkeley Solar Group and Xenergy, Oakland, CA.

Clayton, C.A., E.D. Pellizzari, and R.W. Wiener (1991), "Use of a Pilot Study for Designing a Large-scale Probability Study of Personal Exposure to Aerosols," Journal of Exposure Analysis and Environmental Epidemiology 1(4): 407-421.

Dockery, D.W. and J.D. Spengler (1981), "Indoor-Outdoor Relationships of Respirable Sulfates and Particles," Atmospheric Environment 15: 335-343.

Duan, N. (1982), "Models for Human Exposure to Air Pollution," Environment International 8: 305-309.

Fisk, W.J. (1989), "Research Review: Indoor Air Quality Control Techniques," Presented at IAQ 86: Managing Indoor Air for Health and Energy Conservation, April 20-23, 1986, Atlanta, GA, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., LBL-21557.

Frey, A.H. (1989), "Enhancing Air Purification," in *The Human Equation: Health and Comfort*, Proceedings of the ASHRAE/SOEH Conference, IAQ 89. April 17-20, 1989, San Diego, California, pp. 46-55.

Grot, R.A. (1995) "Air Change Rates in Non-residential Buildings in California," California Energy Commission Consultant Report P400-91-034BCN.

Jenkins, P. L., T. J. Phillips, E. J. Mulberg and S. P. Hui (1992), "Activity patterns of Californians: use of and proximity to indoor pollutant sources." Atmospheric Environment 26A(12): 2141-2148.

Kado, N.Y., S.D. Colome, M.T. Kleinman, D.P.H. Hsieh and P. Jaques (1994), "Indoor-Outdoor Concentrations and Correlations of PM10-Associated Mutagenic Activity in Nonsmokers' and Asthmatics' Homes," Environ. Sci. Technol. 28: 1073-1078.

Klepeis, N. E., Ott, W. R. and Switzer, P. (1994), " A total human exposure model (THEM) for respirable suspended particles (RSP)," Proceedings of the 87th annual meeting and exhibition of the Air & Waste Management Association, Cincinnati, OH, June 1994, Volume 9, Paper No. 94-WA75A.03.

Koontz, M.D., W.C. Evans and C.R Wikes (1995), "Development of a Model for Assessing Indoor Exposure to Air Pollutants," Draft Final Report to the California Air Resources Board, Contract No. A933-157.

Koontz, M.D., W.C. Evans, N. L. Nagda and P.L. Jenkins (1993), "Development of a Model for Indoor Air Pollutant Exposure Distributions," American Society for Testing and Materials, Philadelphia, 1993, pp. 271-279.

Koontz, M.D. and H.E. Rector (1993), "Estimation of Distributions for Residential Air Exchange Rates," U.S. EPA Final Report, prepared by GEOMET under contract Nos. 68-D9-0166, and 68-D3-0013.

Koutrakis, P., S.L.K. Briggs and B.P. Leaderer (1992), "Source Apportionment of Indoor Aerosols in Suffolk and Onondaga Counties, New York," Environ. Sci. Technol. 26:521-527.

Lewis, C.W. (1991), "Sources of Air Pollutants Indoors: VOC and Fine Particulate Species," Journal of Exposure Analysis and Environmental Epidemiology 1(1): 31-44.

Ligocki, M.P., L.G. Salmon, T. Fall, M.C. Jones, W.W. Nazaroff and G.R. Cass (1993), "Characteristics of Airborne Particles Inside Southern California Museums," Atmospheric Environment 27A (5): 697-711.

Ligocki, M.P., H.I.H. Lui, G.R. Cass and W. John (1990), "Measurements of Particle Deposition Rates Inside Southern California Museums," Aerosol Science and Technology 13:85-101.

Nazaroff, W.W., A.J. Gadgil, and C.J. Weschler (1993), "Critique of the Use of Deposition Velocity in Modeling Indoor Air Quality," in: *Modeling of Indoor Air Quality and Exposures*, ASTM STP1205, N.L. Nagda Ed., American Society for Testing and Materials, Philadelphia 1993, pp. 81-104.

Nazaroff, W.W. and G.R. Cass (1989a), "Mass-Transport Aspects of Pollutant Removal at Indoor Surfaces," Environment International, Vol. 15, pp. 567-584.

Nazaroff, W.W. and G.R. Cass (1989b), "Mathematical Modeling of Indoor Aerosol Dynamics," Environ. Sci. Technol. 23 (2): 157-166.

Nazaroff, W.W., L.G. Salmon and G.R. Cass (1990a), "Concentration and Fate of Airborne Particles in Museums," Environ. Sci. Technol. 24 (1): 66-77.

Nazaroff, W.W., M.P. Ligocki, T. Ma and G.R. Cass (1990b), "Particle Deposition in Museums: Comparison of Modeling and Measurement Results," Aerosol Science and Technology 13: 332-348.

NRC (1991), *Human Exposure Assessment for Airborne Pollutants: Advances and Opportunities*, National Research Council, National Academy of Sciences, Washington, DC.

Ott, W. (1982), "Concepts of Human Exposure to Air Pollution," Environment International 7: 179-186.

Ozkaynak, H., J. Xue, R. Weker, D. Butler, P. Koutrakis and J. Spengler (1994), "The Particle TEAM (PTEAM) Study: Analysis of the Data," May 1994 report to the U.S. EPA., Volume III of Final Report.

Pellizzari, E.D., L.C. Michael, K. Perritt, D.J. Smith, T.D. Hartwell and J. Sebestik (1989), "Development and Implementation of Exposure Assessment Procedures for Toxic Air Pollutants in Several Los Angeles County, California Communities," Final Report to the California Air Resources Board, Contract No. A5-174-33.

Persily, A (1989), "Ventilation Rates in Office Buildings," in *The Human Equation: Health and Comfort*, Proceedings of the ASHRAE/SOEH Conference, IAQ 89. April 17-20, 1989, San Diego, CA pp. 128-136.

Phillips, T., P. Jenkins and E. Mulberg (1991), "Children in California: Activity Patterns and Presence of Pollution Sources." Proceedings of the 84th Annual Meeting of the Air and Waste Management Association, Pittsburgh, PA. Volume 17, Paper No. 91-172.5.

Sawyer R.F. and J.H. Johnson (1995), "Diesel Emissions and Control Technology" in: *Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects*, a special report to the Health Effects Institute, April 1995.

Sheldon, L., A. Clayton, J. Keever, R. Perritt and D. Whitaker (1993), "Indoor Concentrations of Polycyclic Aromatic Hydrocarbons in California Residences," Draft Final Report to the Air Resources Board, Contract No. A033-132.

Sinclair, J.D., L.A. Psota-Kelty and G.A. Peins (1992), "Indoor/Outdoor Relationships of Airborne Ionic Substances: Comparison of Electronic Equipment Room and Factory Environments," Atmospheric Environment 26A(5), pp. 871-882.

Sinclair, J.D., L.A. Psota-Kelty, C.J. Weschler and H.C. Shields (1990), "Measurements and Modeling of Airborne Concentrations and Indoor Surface Accumulation Rates of Ionic Substances at Neenah, Wisconsin," Atmospheric Environment 24A(3): 627-638.

Suh, H.H., P. Koutrakis and J.D. Spengler (1994), "The Relationship between Airborne Acidity and Ammonia in Indoor Environments," Journal of Exposure Analysis and Environmental Epidemiology 4(1): 1-22.

Thatcher, T.L. and D.W. Layton (1995) "Deposition, Resuspension, and Penetration of Particles within a Residence," Atmospheric Environment, 29(13): 1487-1497.

Turk, B.H., J.T. Brown, K. Geisling-Sobotka, D.A. Froehlich, D.T. Grimsrud, J. Harrison, J.F. Koonce, R.J. Prill and K.L. Revzan (1987), "Indoor Air Quality and Ventilation Measurements in 38 Pacific Northwest Commercial Buildings," Volume 1, LBL-22315 ½, Lawrence Berkeley Laboratory.

Watts W.F. (1995), "Assessment of Occupational Exposure to Diesel Emissions" in: *Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects*, a special report to the Health Effects Institute, April 1995.

Weschler, C.J., H.C. Shields and B. Shah (1995), "Understanding and Controlling the Indoor Concentration of Sub-Micron Particles at a Commercial Building in Southern California," Presented at the 88th Annual Meeting of Air and Waste Management Association, June 18-23, 1995, Paper No. 95-MP4.01.

Weschler, C.J., S.P. Kelty and J.E. Lingousky (1983), "The Effect of Building Fan Operation on Indoor-Outdoor Dust Relationships," Journal of the Air Pollution Control Association 33:624-629

Wiley J.A., J.P. Robinson, T. Piazza, K. Garrett, K. Cirksena, Y-T Cheng and G. Martin (1991a), "Activity Patterns of California Residents," California Air Resources Board Final Report, Contract No. A6-177-33.

Wiley J.A., J.P. Robinson, Y-T Cheng, T. Piazza, L. Stork and K. Pladsen (1991b), "Study of Children's Activity Patterns," California Air Resources Board Final Report, Contract No. A773-149.

Wilson, A.L., S.D. Colome and Y. Tian (1993) "California Residential Indoor Air Quality Study, Volume 1: Methodology and Descriptive Statistics," Prepared for Gas Research Institute, Pacific Gas and Electric Company and Southern California Gas Company by Integrated Environmental Services, Irvine, CA.

Wilson A.L., S.D. Colome, P.E. Baker and E.W. Becker (1986), "Residential Indoor Air Quality Characterization Study of Nitrogen Dioxide," Phase I Final Report for Southern California Gas Company.

TABLE C1. AIR EXCHANGE RATES FOR RESIDENTIAL BUILDINGS

	Air Changes / Hour	Reference
PTEAM (So. CA, 175 homes, fall)		Ozkaynak et al., 1994
mean	1.25 (1.02)*	
median (50th percentile)	1.0	
25th / 75th percentiles	0.5 / 1.7	
PAH Study (No. CA)		Sheldon et al., 1993
Placerville (130 homes, winter)		
mean	0.65 (0.41)	
range	0.09 - 2.53	
Roseville (137 homes, winter)		
mean	0.63 (0.36)	
range	0.17 - 2.38	
CEC CA Study (40 post-'83 homes, summer, fall & winter)		BSG, 1990
median / mean	0.44 / 0.53 (0.3)	
CA IAQ Study (Statewide, more in So. Coast, 287 homes, Dec '91 - April '92)		Wilson et al., 1993
median / mean	0.46 / 0.57 (0.43)	
SCG So. CA Studies	(Median / Mean)	Wilson et al., 1986
March '84 (571 homes)	0.62 / 0.78 (0.63)	
July '84 (426 homes)	1.08 / 1.51 (1.47)	
Jan. '85 (371 homes)	0.45 / 0.58 (0.47)	
ADM (Central & So. CA, 29 pre-'75 homes, summer)		ADM, 1990
mean	0.7 (0.52)	
TEAMLA1 (52 homes, winter)		Pellizzari et al., 1989
mean	0.94 (0.82)	reported by Koontz, 1995
TEAMLA2 (43 homes, summer)		Pellizzari et al., 1989
mean	2.83 (2.54)	reported by Koontz, 1995

* numbers in parentheses are standard deviations

TABLE C2. AIR EXCHANGE RATES FOR COMMERCIAL AND PUBLIC BUILDINGS

	Air Changes / Hour	Reference
CEC CA study		Grot, 1995
School (14 bldgs)		
mean	2.45	
median	2.24	
range	0.56-8.72	
Office (22 bldgs)		
mean	1.35	
median	1.09	
range	0.17-4.73	
Retail (13 bldgs)		
mean	2.22	
median	1.79	
range	0.42-9.09	
NIST study of 14 buildings (over 3,000 measurements)		Persily, 1989
mean	0.94	
median	0.89	
range	0.25-1.65	
NW States - LBL study/38 bldgs		Turk et al., 1987
mean / Std. deviation	1.5 (0.87)	
range	0.3-4.1	

TABLE C3. PENETRATION FACTORS FOR RESIDENTIAL BUILDINGS

Penetration Factor	Particle Size (μm)	No. of Homes	Measurement Method	Reference
1	PM2.5	178	model calculation	Ozkaynak et al., 1994
~1	PM10	178		
~1	PM1-10	1 test house	model calculation	Thatcher & Layton, 1995
~0.84	<2.5	394	model calculation	Koutrakis et al., 1992
0.7-0.75	<2.5	68	I/O conc. ratio	Dockery & Spengler, 1981
0.85	<2.5	47	model calculation	Suh et al., 1994

TABLE C4. FILTRATION SURVEY DATA (BSG, 1993)

	With Filtration	Without Filtration	Unknown	No. of Buildings
Office				26
Large buildings	6	0	0	6
Small buildings	13	6	1	20
Percent	73%	23%	4%	
Retail				28
Large buildings	11	1	4	16
Small buildings	7	2	3	12
Percent	64%	11%	25%	
School	26	8	0	34
Percent	76%	24%	0%	
Total	63	17	8	88
Percent of Total	72%	19%	9%	100%

TABLE C5. PENETRATION FACTORS FOR COMMERCIAL AND PUBLIC BUILDINGS

	p	n	E†	P (total)*	Types of Building	† Reference for E
Office	1	0.3	0.85	0.41	electron. equip.	Sinclair et al., 1990
	1	0.3	0.40	0.72	Telecommun.	Weschler et al., 1995
	1	0.3	0.85	0.41	Telephone switching	Weschler et al., 1983
	1	0.3	0.12	0.92	Telephone switching	Weschler et al., 1983
	1	0.3	0.35	0.76	museum	Ligocki et al., 1993
	1	0.3	0.15	0.90	manufacturing	Sinclair et al., 1992
	1	0.3	0.00	1.00	no filter	
Retail	1	0.6	0.35	0.86	museum	Ligocki et al., 1993
	1	0.6	0.12	0.95	polyester mat filter	Weschler et al., 1983
	1	0.6	0.00	1.00	no filter	
School	1	0.15	0.35	0.70	museum	Ligocki et al., 1993
	1	0.15	0.12	0.90	polyester mat filter	Weschler et al., 1983
	1	0.15	0.00	1.00	no filter	

E = filter efficiency
n = unfiltered fraction of air
p = penetration factor for unfiltered air

*** P (total) = (p*n)+[(1-E)(1-n)]**

Table C6. INDOOR DEPOSITION VELOCITIES AND DEPOSITION RATES OF PARTICLES

PARAMETER VALUE	PARTICLE SIZE	SETTING	REFERENCE
Deposition Velocity			
0.7 - 4.2 m/hr	1 - 10 microns	Test House	Thatcher & Layton, 1995
(4.7-72) $x10^{-3}$ m/hr	0.05 microns	Museum	Nazaroff et al., 1990
(0.4-12) $x10^{-3}$ m/hr 0.072 m/hr 3.6 m/hr	1 microns <2.5 microns 2.5-15 microns	Test Building	Weschler, 1983
10^{-3} - 10^{-2} m/hr(vert) 10^{-3} - 1.0 m/hr(hor)	0.05-1 micron	Museum	Ligocki , 1990
0.216 m/hr 25.2 m/hr	<2.5 microns 2.5 - 15 microns	Factory/Manufacturing	Sinclair et al., 1992
0.014 - 2.16 m/hr 24 m/hr	<2.5 microns 2.5 - 15 microns	Electronic Building	Sinclair et al., 1990
Deposition Rate			
0.25 - 0.75 hr^{-1} 0.75 - 1.78 hr^{-1}	1 - 3 microns 3 - 10 microns	Test House	Thatcher & Layton, 1995
0.39 ± 0.16 hr^{-1} 0.65 ± 0.28 hr^{-1} 1.0 hr^{-1}	<2.5 microns <10 microns between 2.5 and 10 microns	178 Homes	Ozkaynak et al., 1994

APPENDIX E

GLOSSARY

GLOSSARY

Adsorption: Adhesion of molecules of gas, liquid, or dissolved solids to a surface.

Ambient Air: The surrounding or encompassing atmosphere. In the context of air monitoring, ambient air is often used to refer only to "outdoor" air, even though indoor air is "ambient" to a person who is indoors.

Dry Deposition: Dry deposition refers to the transport of gases and particles from the atmosphere to the Earth's surface, including to soil, vegetation, water surfaces (lakes, rivers, and oceans), and to snow-covered ground.

Elemental Carbon: Solid black non-volatile carbonaceous particles similar to impure graphite commonly called elemental carbon, graphitic carbon, or soot. These particles are small (0.01 to 0.08 μm in diameter) and can be easily inhaled into the deep areas of the respiratory tract.

Isomer: A compound having the same percentage composition and molecular weight as another compound but differing in chemical or physical properties.

Near Source: A stationary or area source that emits pollution in above-ambient exposure concentrations so that the risk is increased for individuals living and/or working near the source.

Marker: A substance unique to a process emission that can be used to quantify the emission in the air. A "marker" for diesel exhaust would be unique to diesel exhaust, allowing the exhaust mixture to be qualified (to know it's there) and quantified (to know how much is there).

Micron (μm): A unit of length equal to one millionth of a meter.

Mobile Source: Source of air pollution such as automobiles, motorcycles, trucks, off-road vehicles, boats, and airplanes.

Nitrogen Oxides (NO_x): Air polluting gases generated by combustion processes. They comprise of colorless nitrous oxide (N_20), colorless nitric oxide (NO), and the reddish-brown-colored nitrogen dioxide (NO_2). Other nitrogen oxides of less significance are nitrogen tetroxide (N_2O_4), and nitrogen pentoxide (N_2O_5).

Polycyclic Aromatic Hydrocarbons (PAH): Organic compounds which include only carbon and hydrogen with a fused ring structure containing at least two benzene (six-sided) rings. PAH may also contain additional fused rings that are not six-sided.

$PM_{2.5}$: Particulate matter equal to or less than 2.5 μm in diameter.

PM_{10}: Particulate matter equal to or smaller than 10 μm in diameter.

Soluble Organic Fraction (SOF): The amount of the total particulate mass that can be extracted by organic solvents such as dichloromethane. The SOF includes extractable compounds such as aldehydes, alkanes, alkenes, aliphatic hydrocarbons, polycyclic aromatic hydrocarbons (PAH) and PAH-derivatives.

Sulfur Dioxide (SO_2): A heavy, pungent, colorless, gaseous air pollutant formed primarily by combustion of fossil fuels.

Toxic Air Contaminant (TAC): A substance identified by the State of California as "an air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health." (Health and Safety Code , section 39660.)

Tracer: A constituent of a complex mixture that can be used to estimate the presence and quantity of the mixture in the ambient air. An effective diesel exhaust tracer would be consistently emitted in the exhaust, and could be monitored in the ambient air. Elemental carbon, diesel fuel additives, engine oil combustion products, and PAH ratios have been used as tracers by various researchers.

Wet Deposition: Wet deposition refers to the removal of particles and particle-associated chemicals from the atmosphere by precipitation events (i.e., rain, snow, and precipitating fogs).