ANALYSIS OF INDOOR AND OUTDOOR PARTICULATE MATTER AT VARIOUS RESIDENCES IN THE EL PASO REGION

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Dedication

Without the support system I received from my family, none of this would have been made possible. Thank you all for believing in me and standing by my side when I needed you all the most. This thesis is dedicated to my loving parents who always had a warm welcome place for me; to my brothers, for being the best a brother could ask for; to Nadia, for being patient with me and for always being there for me when I needed you; to my grandparents, for being great pillars of support; and to my Aunt Lupe and Uncle Richard for their unbridled support. Thank you all!

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by

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THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING

Department of Civil Engineering

THE UNIVERSITY OF TEXAS AT EL PASO

August 2011

Acknowledgements

This research was made possible by the dedication and guidance provided by Dr. Wen-Whai Li of the Department of Civil Engineering at the University of Texas at El Paso (UTEP). I would also like to acknowledge Dr. Hector Olvera, who was always willing to give a helping hand and guidance whenever it was needed.

In addition, the help of the undergraduate and graduate members of the UTEP Air Quality Research Laboratory was paramount in ensuring everything was completed as per the full potential of the project.

Partial student support was received by the Center for Environmental Resource Management (CERM) and the Southwest Consortium for Environmental Research and Policy (SCERP). The UTEP Civil Engineering Department had also provided partial support throughout the duration of my graduate studies.

Abstract

This thesis is a presentation of particulate matter data collected from February 2007 to June 2008. Personal environment monitors (PEM), which measured 7-day $PM_{2.5}$ concentrations, had been deployed at 14 homes during the 2007 year and deployed in 16 different homes during the 2008 sampling year. Within each sampling year, sampling occurred for two one-week (7-day) periods during each season. In addition to PEM sampling, a tapered element oscillating microbalance (TEOM) continuous sampler had been deployed in both indoors and outdoors at one pre-selected household per week. Gravimetric, chemical, and black carbon analysis had been performed on the PEM $PM_{2.5}$ filters while time-series plots of the TEOM PM_{10} and $PM_{2.5}$ data were constructed to extract diurnal patterns from the data. Results from the TEOM data affirm the purported existence of a strong diurnal patter in particulate matter observations in the El Paso region.

Strong increases in particulate matter were seen, on average, between the hours of 06:00 and 10:00 (morning) and once again in the evening from 16:00 to 20:00. Of the TEOM data, the mean outdoor and indoor $PM_{2.5}$ concentrations were found to be 23.9 $\mu g/m^3$ and 17.8 $\mu g/m^3$, while the mean outdoor and indoor PM_{10} concentrations were found to be 27.3 $\mu g/m^3$ and 18.0 $\mu g/m^3$, respectively. Mean outdoor and indoor TEOM $PM_{2.5}$ concentrations were found to be, on average, greater during the summer seasons. The mean TEOM outdoor PM_{10} was also found to be greater during the summer seasons over the winter seasons, while the mean indoor PM_{10} TEOM concentration was found to be only slightly greater during the winter seasons over the summer seasons. Indoor/Outdoor (I/O) ratios for PM_{10} for all TEOM sampling locations during the entire study period were found to be greater, on average, than (I/O) ratios for $PM_{2.5}$ with values of 1.15 and 1.05, respectively.

A mean $PM_{2.5}$ concentration of 19.8 $\mu g/m^3$ was seen in the PEM indoor samples collected at all locations during the entire study period, while the mean winter concentration 22.9 $\mu g/m^3$ was shown to

be much higher than the mean summer concentration 16.8 $\mu g/m^3$. Results of an EDXRF analysis found that geologic elements (Al, Si, Ca, Fe, Ti, and K) were found to compose a majority of the total $PM_{2.5}$ mass at 17.4%, while toxic trace elements (Cu, Cr, As, Cd, and Pb) were found to compose only 0.19% of the total $PM_{2.5}$ mass. All analyzed elements (Σ Elements) were found to compose, on average, 24% of the total $PM_{2.5}$ mass collected using the PEM sampler. The mean black carbon (BC) concentration on the PEM filters for the entire study period was found to be 0.30 $\mu g/m^3$; BC concentrations were also found to be higher during the winter seasons, 0.38 $\mu g/m^3$, than the summer seasons, 0.21 $\mu g/m^3$. Black carbon was also found to compose, on average, 1.8% of the total $PM_{2.5}$ mass.

Principle components analysis (PCA) was conducted on the EDXRF data and presented four primary components within the elemental data. The first component included Al, Ba, Ca, Fe, K, Mg, Mn, Pb, Sr, Ti, and V, while the second component included Cr, Ga, Mo, and Ni. The third component consists of As, Rh, and Te, while the final component was composed of what is believed to be salt (Na and Cl). The first component, composed of mostly geologic material, composed the greatest majority of elements found in the total PM mass, while the other components were mostly hypothesized to be related to industrial release in the area.

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1. Introduction

1.1. Introduction

El Paso County is located at the westernmost edge of Texas, adjoining the state of New Mexico and the Mexican state of Chihuahua. El Paso, TX is a predominately semi-arid area with an average (30 years) precipitation of 8.65 inches and average high and low temperatures of 76.8 □F and 50.6 □F, respectively. El Paso sees an average of 202 days with clear skies and 49 days with precipitation more than 0.01 inches. Mean wind directions in the area are from the southwest (229 degrees) direction. Table 1.1 depicts the meteorology variation found in El Paso according to each respective season.

El Paso averages 14.5 significant dust events per year; consequences of these episodes range from simple irritations and increased particulate matter concentrations to serious disruptive events. These events aggravate respiratory health problems and can even turn deadly, resulting in fatal collisions as a result of near-zero visibility on city roadways and highways in the surrounding desert (Novlan et al., 2006). El Paso is generally a flat desert area with a large range of mountains, known as the Franklin Mountains, which rise to over 3280 ft. (1000m) above the surrounding area and are a north-south oriented mountain chain that is approximately 23.1 km (14.4 miles) long and 5.0 km (3.1 miles) wide. The Franklins create a divide between the western one-third of the city of El Paso and the central and eastern two-thirds of the city.

Table 1.1: Meteorological Data Averages

Period	Average Temperature[2] (□C)	Average Precipitation[2] (cm)[2]	Average Wind Speed[2] (km/hr)	Prevailing Wind Direction[2] (degrees)
Annual	17.3	22.4	14.2	360
Winter (Dec.-Feb.)	7.2	1.2	13.6	333
Spring (March-May)	17.4	0.6	17.3	267
Summer (June-August)	27.2	3.2	13.6	183
Fall (Sept.-Nov.)	17.6	2.5	12.4	243

1: Source: National Climactic Data Center, Ashville, NC

2: Data based on 30 year averages

The El Paso region, which consists of El Paso, Texas, Sunland Park, New Mexico and Ciudad Juarez, Chihuahua, Mexico, has a population exceeding two million and is one of the largest metropolitan areas along the border. The region generally has poor visibility, especially in the winters which are susceptible to inversions, and respiratory problems are common place. The regional pollution problem is not only generated by inhabitants in the United States but also by those in surrounding areas such as Ciudad Juarez. In order to ensure that both countries work together to solve the regional pollution problem, the Border Environment Cooperation Commission (BECC) was created in 1993 under a side-agreement to the North American Free Trade Agreement (NAFTA). BECC aims at effectively enforce bi-national policies that aims to improve the air quality in the region. In concert with efforts by BECC, the United States Environmental Protection Agency (EPA) and the Texas Commission on Environmental Quality (TCEQ), the regional air quality in the El Paso region has progressively improved since 1990.

The use of fossil fuels or wood for heating and cooking in the area, the semi-arid weather, adverse meteorological conditions, and complex terrestrial features of the El Paso region are all contributors to the air pollution situation in the city. Poverty and industrialization in the Ciudad Juarez part of the El Paso/Juarez region are contributors to PM concentrations in the region (Espino et al., 2005). Higher levels of PM_{10} and $PM_{2.5}$ are witnessed in El Paso during the winter months when temperature inversions, along with calm conditions, trap PM in the ambient air.

The US EPA's regulatory PM_{10} standard was frequently violated in the border region, including El Paso, with far fewer reported violations of the $PM_{2.5}$ standard (EPA, 2011a). As a result of the frequent PM_{10} violations, El Paso has been classified as a moderate "non-attainment" area with regard to PM_{10} as of 1991 (EPA, 2011a, 2011b). It has been shown that episodic (short-lived, high concentration) events contribute many of the violations of the PM_{10} National Ambient Air Quality Standards (NAAQS). PM_{10} NAAQS are based on a maximum 24-h averaged concentration of 150 $\mu g/m^3$ as well as an annual-averaged cap of 50.0 $\mu g/m^3$.The aforementioned averaging obscures short-term peak doses and may misrepresent epidemiological dangers of PM (Staniswalis et al., 2005).

There are many local electronics, transportation, textile, machinery and refining industries in the El Paso area that contribute to the local PM pollution problem. The surrounding desert landscape is also another major source for the area's pollution problem and it has long been noted that there is a high natural ambient mineral material loading in the region (Dattner, 1994; Einfeld & Church, 1995). Unregulated kilns, for the manufacturing of bricks in particular, are reported to burn toxic waste fuels such as tires or used motor oil and are considered major contributors to PM_{10} pollution in the region (Lauer et al., 2009). The preparation of food with wood, propane, or natural gas coupled with frequent major meteorological events; along with the arid weather, further complicate the local PM pollution problem. Analysis of $PM_{2.5}$ samples collected using indoor personal environment monitors may help to

provide an insight as to the primary components of pollutants found in indoor $PM_{2.5}$ which may be contributed to the releases of the aforementioned activities in El Paso.

There are several commonly agreed on factors which can be attributed to the pollution problem in El Paso. El Paso is mostly surrounded by desert land which produces large amounts of dust during episodes of high winds. There are also a large number of unpaved roads in the area surrounding El Paso as well as in areas in Mexico located along the border with El Paso which can also be attributed to the creation of fugitive dust in the area. Many of the same areas along the border in Mexico burn scrap wood and other refuse material for home heating and cooking in the much colder winter months of the year. The burning of such material may release metals into the atmosphere and may exacerbate PM concentrations in the region (Espino et al., 2005). Commercial activities such as scrap metal foundries, refining, smelting, various agricultural activities and brick kilns also contribute to the local pollution problem.

In the United States, PM concentrations have decreased on average since interest for certain size of particles invoked national monitoring programs. Monitoring for $PM_{2.5}$ began nationwide as of the year 2000 and according to Figure 1.1, the $PM_{2.5}$ levels in the United States has decreased by 27%. Based on Figure 1.2, PM_{10} levels in the United States have decreased 38% since nationwide monitoring began in 1990. The decrease in PM in the United States is a direct result of the efforts of the EPA, state, tribal and local agencies which use the monitoring data to ensure that PM in the air is at respectable levels that protect public health and the environment.

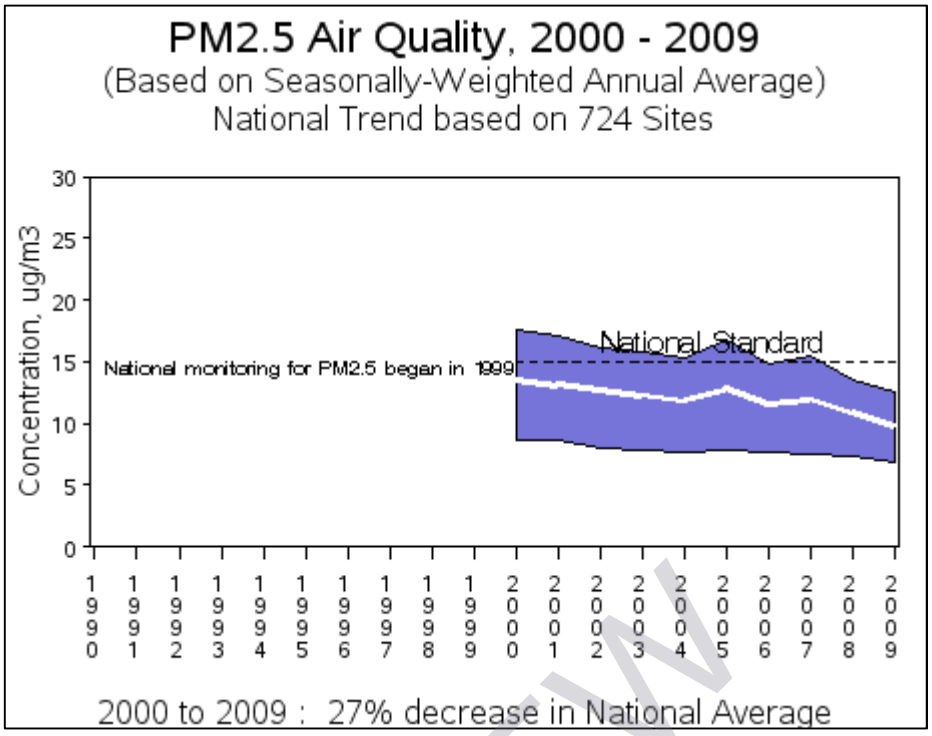

Figure 1.1: National $PM_{2.5}$ Air Quality, 2000-2009

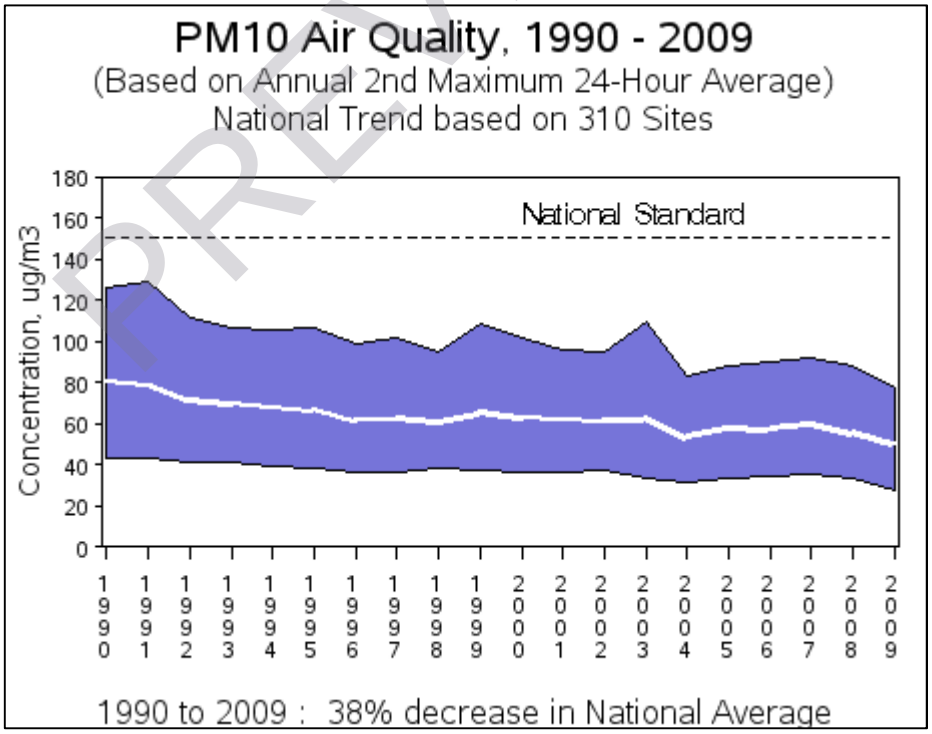

Figure 1.2: National PM_{10} Air Quality, 1990-2009

In the El Paso region, PM levels have decreased as well with regard to PM_{10} and $PM_{2.5}$ since 2003. Figure 1.3 is a plot of the annual 2nd maximum 24-hour average PM_{10} concentrations for El Paso over the span of about 20 years. Figure 1.4 is a plot of the weighted annual mean concentrations for $PM_{2.5}$ for El Paso since 1999, which is when the air quality monitoring program began for $PM_{2.5}$. The weighted annual mean is the weighted arithmetic mean of 24-hour values for the year and compensates for scheduled sampling that did not occur.

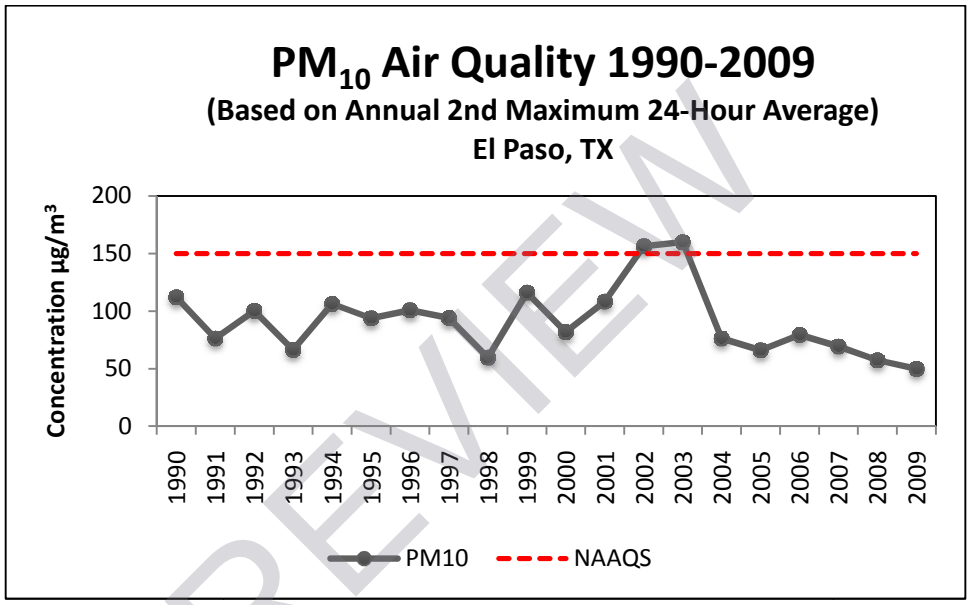

Figure 1.3: El Paso PM_{10} Air Quality; 1990-2009

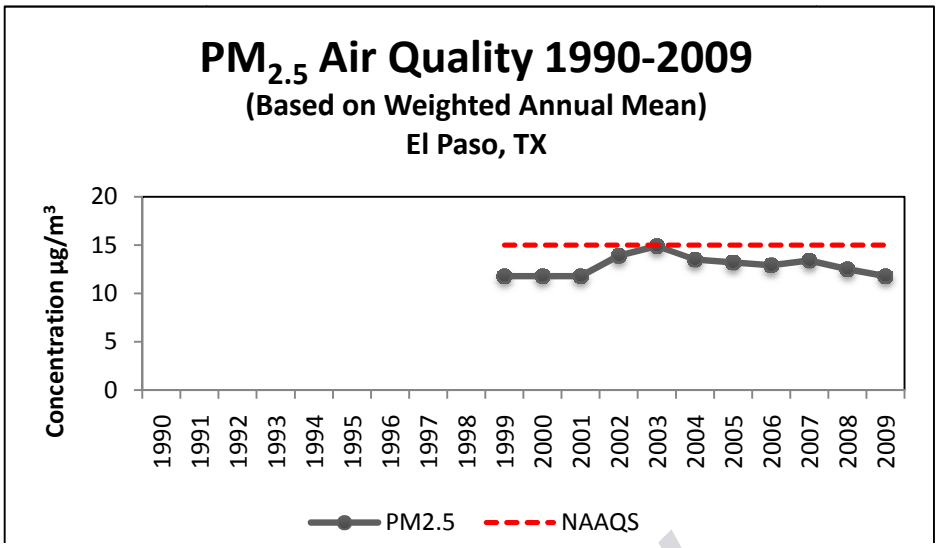

Figure 1.4: El Paso $PM_{2.5}$ Air Quality; 1990-2009

It should be noted that the variation in weighted annual mean $PM_{2.5}$ concentration are not as pronounced as the variation in annual 2nd maximum 24-hour average PM_{10} concentrations. This may be due to either increases or decreases in severe meteorological conditions which predominantly affect PM_{10} concentrations.

Based on commercial and industrial activities in the area, coupled with chronic PM_{10} "non-attainment" status, El Paso can only benefit from any research studies which aim to characterize indoor and outdoor PM in the region. Basic understating of any diurnal variations that exist in PM in El Paso may help investigators to understand when and why PM may be troublesome. Also, any insight into the elemental constitution of PM in the region may also help investigators pinpoint possible sources of PM which may possibly contribute to the local PM pollution problem.

1.2. Research Objective

This study was designed to monitor indoor and outdoor air quality by randomly selecting 12 houses from a cohort constructed for the use in an epidemiological study in the area which would be representative of different strata. It is part of a National Institute of Health (NIH) sponsored project to study the impacts of PM pollution on asthmatic children in El Paso. The scope of the NIH project is an attempt to characterize the time-resolved indoor and outdoor (I/O) PM, nitrogen dioxide (NO_2), and

ozone concentrations in spatially selected Latino households throughout the El Paso region while this project aimed to define the diurnal pattern of I/O PM mass concentrations in two major fractions: coarse PM (PM_{10}, PM with aerodynamic diameters of less than 10 μm) and fine PM ($PM_{2.5}$, PM with aerodynamic diameters of less than 2.5 μm). The chemical composition of PM was of interest in addition to the mass characteristics. Energy dispersive x-ray fluorescence (EDXRF), a preferred method for the analysis of trace elements in PM collected on filters, was used to characterize the chemical composition of $PM_{2.5}$. In addition, the black carbon (BC) content of $PM_{2.5}$ was investigated as well.

2. Particulate Matter and Related Health Effects

2.1. Particulate Matter

Particulate matter is a complex mixture of extremely small particles and liquid droplets that vary in size, shape, surface area, solubility, chemical composition and origin. PM is composed of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. The size of particles is directly linked to their potential for causing health problems. Once particles smaller than 10 microns are inhaled, these particles affect the heart and lungs and cause serious health effects. Through inertial impaction, coarse PM is generally removed in the upper respiratory tract, while fine PM has the ability to penetrate much further into the lower respiratory tract (Kennedy, 2007).

The Environmental Protection Agency (EPA) groups PM into two categories:

- "**Inhalable coarse particles**," such as those found near roadways and dusty industries, have aerodynamic diameters larger than 2.5 μm and smaller than 10 μm in diameter. Usually comprised of suspended or re-suspended dust from industrial processes, agriculture, construction, road traffic, plant pollen and other natural sources.

- "**Fine particles**," such as those found in smoke and haze, have an aerodynamic diameter less than or equal to 2.5 μm. Fine particles are responsible for reduced visibility in certain parts of the United States. These particles can be directly emitted from combustion sources such as automobiles, wood burning, or they can form when gases emitted from power plants, cement plants, or steel mills react in the air. This mode of particles also consists of transformation products such as sulfates and nitrates which are formed of primary sulfur and nitrogen oxide emissions along with secondary organic aerosols from volatile organic compounds (VOC).

Fine-mode and coarse-mode particles differ not only in size and morphology (e.g., smooth droplets vs. rough solid particles) but also in formation mechanisms and sources; along with differences in chemical, physical, and biological properties. They also differ in terms of dosimetry (deposition in the respiratory system), toxicity, and health effects as observed by epidemiologic studies. PM transport generally occurs through convection, diffusion and, for particles larger than 1μm, diffusion (Kennedy, 2007)

Fine particles are a major cause of reduced visibility in parts of the United States. The EPA regulates inhalable particles (fine and coarse) while particles larger than 10 μm (sand and large dust) are not regulated by EPA. The Clean Air Act requires the EPA to set National Ambient Air Quality Standards (NAAQS) for six criteria pollutants, of which PM is one of these. The remaining criteria pollutants are ozone, carbon monoxide, nitrogen dioxides (NO_2), sulfur dioxide and lead. The purpose of regulation for the aforementioned criteria pollutants is that epidemiologic studies have attributed daily exposure to one or more of the criteria pollutants with an increase in lower respiratory tract effects, exacerbation of asthma and increased daily mortality (Pope, 2000). The Clean Air Act established two types of national air quality standards for PM pollution. Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against visibility impairment, damage to animals, crops, vegetation, and buildings. The air quality standards for PM in 2006 were revised by the EPA to tighten the 24-hour fine PM standard from the level of 65.0 micrograms per cubic meter ($\mu g/m^3$) to 35.0 $\mu g/m^3$, and retain the current annual fine PM standard at 15 $\mu g/m^3$. The EPA decided to retain the existing 24-hour PM_{10} standard of 150 $\mu g/m^3$ and revoked the annual PM_{10} standard, because available evidence does not suggest a link between long-term exposure to PM_{10} and health problems.