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## Background and Recent Research on Particulate Matter in the Paso del Norte Border Region

*C. A. Rincón, J. R. Anderson, J. J. Bang, J. C. Greenlee,  
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### ABSTRACT

The Paso del Norte region is located midway along the U.S.-Mexican border where the Rio Grande/Río Bravo cuts through the Franklin Mountains to the north and the Sierra de Juárez to the south. The region encompasses the communities of Doña Ana County, N.M.; El Paso County, Tex.; and Municipio de Ciudad Juárez, Chih., which are separated by the river at the point where Ciudad Juárez, El Paso, and Sunland Park, N.M., meet. Paso del Norte, like most U.S.-Mexican border communities, is experiencing rapid urban growth in a semi-arid climate, where topography, meteorology, economic, and population pressures all combine to influence the air quality of the region.

Several locations in Paso del Norte currently do not meet their country's air quality standards for pollutants, including particulate matter (PM). Elevated PM concentrations have been associated with increased mortality rates and other adverse health effects (Pope, et al. 1991; Dockery, et al. 1993; Maynard and Maynard 2002; Peters, et al. 2001). In Ciudad Juárez, Romieu, et al. (2003) found associa-

tions between  $PM_{10}$  (matter with an aerodynamic diameter less than 10 micrometers [ $\mu m$ ]) concentrations and mortality for children in the lowest socioeconomic class. Because the region's air resources are shared across several political boundaries, understanding and managing PM emissions is a challenge.

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## Antecedentes e Investigaciones Recientes de Materia Particulada en la Región Fronteriza Paso del Norte

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### RESUMEN

La región Paso del Norte está ubicada medio camino a lo largo de la frontera México-E.U. donde el Río Grande/Río Bravo corta a través de las Montañas Franklin hacia el norte y las Montañas de Sierra de Juárez hacia el sur. La región abarca a las comunidades del condado de Doña Ana, Nuevo México; El Paso, Texas; y Ciudad Juárez, Chihuahua, las cuáles se encuentran separadas por el río en el punto en donde Ciudad Juárez, El Paso, y Sunland Park, Nuevo México, convergen. El Paso del Norte, como la mayoría de las comunidades fronterizas de México-E.U, está experimentando un crecimiento urbano rápido en un clima semiárido, donde la topografía, meteorología, y las presiones económicas, y demográficas se combinan para influenciar la calidad de aire de la región.

Varias áreas en Paso del Norte actualmente no cumplen las normas de calidad de aire para contaminantes de su país, incluyendo materia particulada (PM). Concentraciones elevadas de PM han sido asociadas con aumento en tasas de mortalidad y otros efectos adversos para la salud (Pope, et al. 1991; Dockery, et al. 1993; Maynard

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y Maynard 2002; Peters, et al. 2001). En Ciudad Juárez, Romieu, et al. (2003) encontraron asociaciones entre concentraciones  $PM_{10}$  (materia con un diámetro aerodinámico inferior a 10 micras [ $\mu m$ ]) y la mortalidad para niños en la clase socioeconómica mas baja. Debido a que los recursos atmosféricos de la región son compartidos a través de varias fronteras políticas, entender y administrar las emisiones PM es un reto.

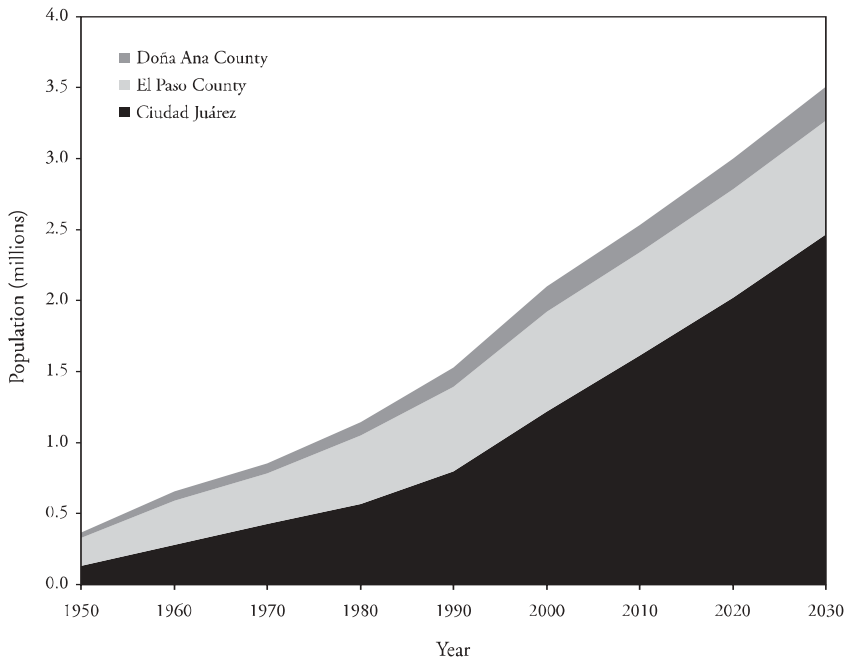
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## POPULATION

Population in the Paso del Norte region is increasing; the vast majority of growth is concentrated in the cities of El Paso, Tex.; Ciudad Juárez, Chih.; and Las Cruces, N.M. Unlike El Paso and Ciudad Juárez, which comprise the majority of the population in their respective county and municipality, the city of Las Cruces represents about half the population of Doña Ana County, N.M. Population growth in the region is the result of a combination of many factors, including the local and national economies, the work force, and constraints on available space. From 1990 through 2000, the growth rate for Ciudad Juárez averaged 4.36% annually—more than double that of its twin city, El Paso. The underlying reasons for this difference must be taken into account when predicting future growth rates. According to the 2000 census, approximately 2.25 million people reside in Paso del Norte, 1,257,926 of them in Ciudad Juárez. The El Paso County census reported 704,318 inhabitants, with a 1.45% annual growth rate throughout the 1990s; Doña Ana County reported 174,682 inhabitants. Figure 1 illustrates the historic and projected population growth for Paso del Norte from 1950 through 2030.

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Figure 1. Population Data for Doña Ana County, El Paso County, and Municipio de Ciudad Juárez



Source: Paso del Norte Water Task Force

## GEOGRAPHIC AND METEOROLOGICAL CHARACTERISTICS

Climate and topography are important factors in the formation and transport of air pollution in this region. The local topography is classified as complex terrain because of the moderately sized mountain ranges that lie north, south, and west of the central Ciudad Juárez urban area (Appendix Figure 1 [page 305]). Local elevations range from 1,150 meters (m) (3,773 feet) at the Rio Grande bed to 1,850 m (6,070 feet) at Range Peak, located in the Franklin Mountains. The Franklin Mountains run north-south and divide the urban areas of west and north central/northeast El Paso. Downtown El Paso lies just beyond the southern end of the Franklin

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Mountains. The Rio Grande flows south out of central New Mexico through the Mesilla Valley on the west side of the Franklin Mountains. A large igneous intrusion known as Sierra de Cristo Rey lies directly in the path of the river's southward course at the southern end of this valley. The river bends around Cristo Rey, cuts through the pass between the Franklin Mountains and Sierra de Juárez, flowing in a general southeasterly direction between the downtown districts of El Paso and Ciudad Juárez, and finally flows into the Brad Valley to the southeast.

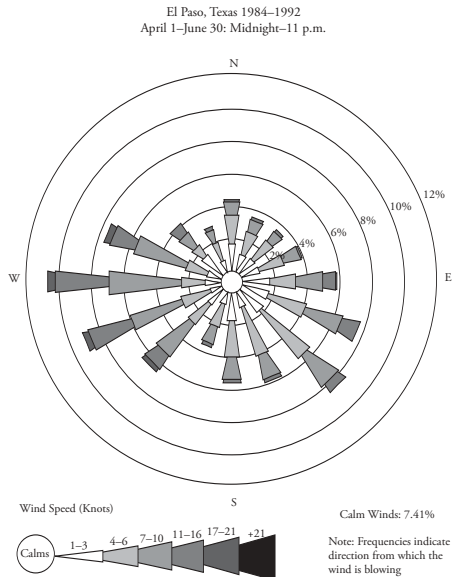
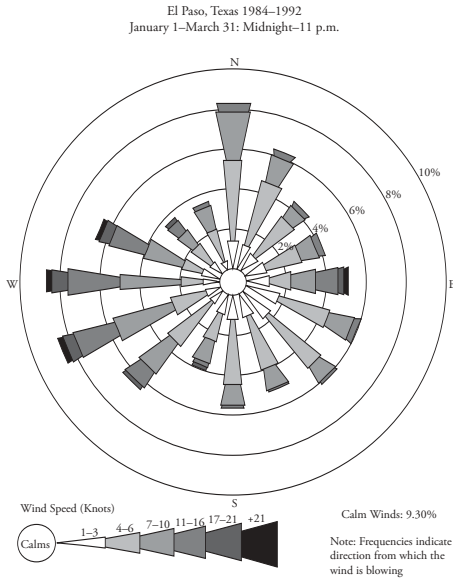
To the southwest of Ciudad Juárez lies the Sierra de Juárez, rising to 1,650 m (5,413 feet) above the valley floor. The Chihuahu Plateau lies to the south of Ciudad Juárez; it is characterized by relatively flat terrain, gradually increasing in altitude above the valley floor moving south. Northeast of downtown El Paso lies the extreme southern portion of the Tularosa Basin, bordered on the east by the Sacramento Mountains and on the west by the northern reaches of the Franklin Mountains. Much of the recent urban growth in El Paso is occurring in the northeast and northwest sections at the foot of the Franklin Mountains.

The weather in this region is mostly sunny and dry; it receives approximately 20 centimeters (cm) of rainfall annually, which occurs mostly during brief thunderstorms from July through September. The Paso del Norte region enjoys a wide range of seasonal conditions. Snow falls almost every year, but quickly melts due to the generally mild conditions that prevail during winter. Spring quickly fades into summer as temperatures usually reach the mid-80s to mid-90s (°F). From June to September, daily high temperatures are in the 90s and can stay close to or above 100°F for several consecutive days. Given that Paso del Norte is also a high desert region, the low for most nights will drop to the mid-60s and the relative humidity ranges between 10% and 35% for most of the year. Diurnal temperatures oscillate between 30°F and 40°F.

The region's arid conditions, land cover, and periodic high-wind episodes combine to produce high crustal contributions to particulate matter (PM) levels. Figures 2a, 2b, 2c, and 2d are wind roses for the four seasons, which show that wind speed and direction vary by season. In the rural areas of Paso del Norte, the most common land cover is shrub and brush rangeland, and most of this soil is highly

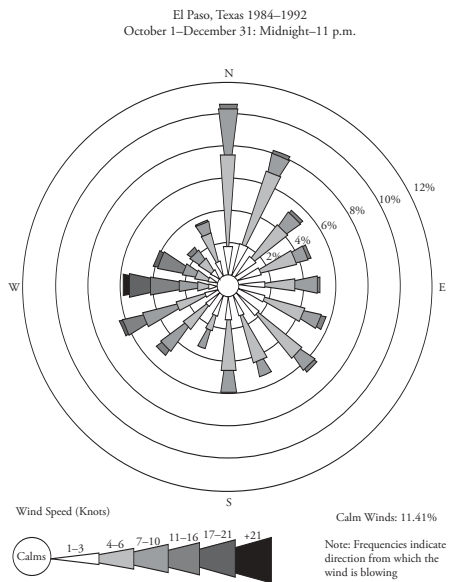
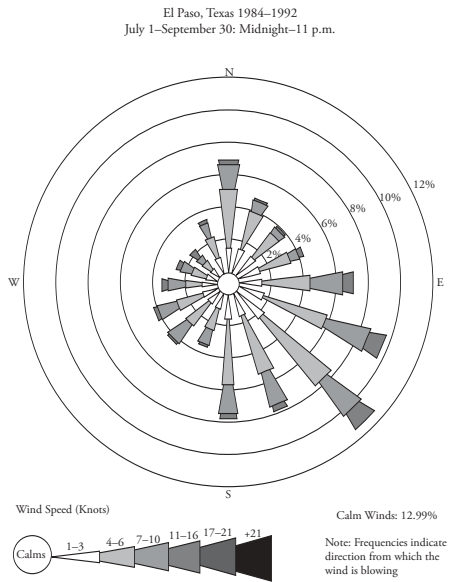
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Figure 2. Wind Roses for El Paso Showing the Average Wind Speed and Direction for January–March (a), April–June (b), July–September (c), and October–December (d) for 1984 to 1992



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## Figure 2. continued



Source: Authors

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susceptible to wind erosion (Okrasinski and Greenlee 2000). For example, Appendix Figure 2 (page 306) shows a map of Doña Ana County's wind erodibility. The nine wind erodibility groups, in order of progressively greater erodibility, are designated 1, 2, 3, 4, 4L, 5, 6, 7, and 8, and are detailed in Table 1.

During winter, atmospheric stagnation conditions marked by stable air masses and low wind speeds are often encountered in the region. These calm conditions result in pollutant buildup over time in the stable air mass. The region's complex topography (mountains) also serves as a dispersion barrier, trapping the local air pollution in the air basin (Appendix Figure 1 [page 305]). Pollutant dilution is further minimized during the evening and early morning hours by the formation of radiation inversions, which are stagnation events. Meteorological data taken during short-term  $PM_{10}$  (PM with an aerodynamic diameter of 10 micrometers [ $\mu m$ ] or less) studies confirm the presence of very shallow vertical mixing heights in the evening and early morning hours of the winter season. During these stagnant conditions, high PM levels are frequently observed (Chapter III).

## REGULATORY STATUS

Ciudad Juárez and El Paso exceed their country's ambient air quality standards. With the enacting of the U.S. Clean Air Act and its 1990 amendments, El Paso was classified as a non-attainment area for three of the six criteria pollutants—ozone ( $O_3$ ), carbon monoxide (CO), and  $PM_{10}$ —throughout most of the 1990s. In addition, portions of Doña Ana County exceed the National Ambient Air Quality Standards (NAAQS) for ozone and  $PM_{10}$ . Ciudad Juárez air quality exceeds the Mexican ambient air quality standards known as the Norma Oficial Mexicana (NOM) (SEMARNAT 1998) for  $PM_{10}$ , ozone, and carbon monoxide.

Under the provisions of the U.S. Clean Air Act, a non-attainment area is subject to stringent cleanup requirements and may be penalized for failure to meet the requirements specified by NAAQS. However, a border city such as El Paso may not be penalized if it can demonstrate it has taken all necessary measures to control sources within the region and its failure to meet NAAQS is due to emissions generated outside the United States (EPA 1990).

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Table 1. Wind Erodibility Groups

WEG	Properties of Soil Surface Layer	Wind Erodibility Tons/Acre/Year
1	Very fine sand, fine sand, sand, or coarse sand	310
2	Loamy very fine sand, loamy fine sand, loamy sand, loamy coarse sand, or sapric organic soil materials	134
3	Very fine sandy loam, fine sandy loam, sandy loam, or coarse sandy loam	86
4	Clay, silty clay, noncalcareous clay loam, or silty clay loam with >35% clay content	86
4L	Calcareous loam, silt loam, clay loam, or silty clay loam	86
5	Noncalcareous loam and silt loam with <20% clay content, or sandy clay loam, sandy clay, and hemic organic soil materials	56
6	Noncalcareous loam and silt loam with >20% clay content, or noncalcareous clay loam with <35% clay content	48
7	Silt, noncalcareous silty clay loam with >35% clay content, and fibric organic soil material	38
8	Soils not suitable for cultivation due to coarse fragments or wetness	Wind erosion not a problem

Source: Okrasinski and Greenlee 2000

Although air quality in El Paso has improved gradually since 1990, it is still classified as non-attainment for ozone, carbon monoxide, and PM<sub>10</sub> (TNRCC 1999a, 1999b, 1999c). According to data collected by the state and local environmental agencies on both sides of the border, PM concentrations are higher near:

- South-central El Paso, near the University of Texas at El Paso (UTEP) campus at Vilas Elementary School (Appendix Figure 1 [page 305], UTEP site)
- The Sun Metro public transit terminal (Appendix Figure 1 [page 305], Sun Metro site)

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- The brick-making community in central Ciudad Juárez (Appendix Figure 1 [page 305], Advanced Transformer site)

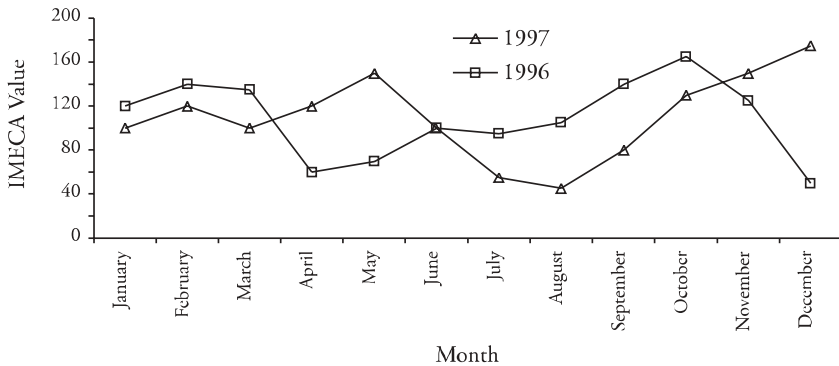
All of these sites regularly report PM concentrations at or above the PM NAAQS for their respective country. For example, during the last quarter of 1998, the 24-hour average  $PM_{10}$  standard was exceeded at least five times in Ciudad Juárez (EPCCHED 1999).

As the population in Paso del Norte continues to expand, meeting ambient standards for PM will remain a challenge. Average annual concentrations in Ciudad Juárez are increasing. The Ciudad Juárez Air Quality Management Plan for 1998 through 2002, a plan similar to the U.S. State Implementation Plans, reports that 23% of the  $PM_{10}$  measurements exceeded 100 Índice Metropolitano de Calidad del Aire (Air Quality Metropolitan Index, in Spanish IMECA) points during 1996; in 1997 the percentage decreased to 18%. However,  $PM_{10}$  monitoring in Ciudad Juárez is conducted with hand-operated equipment, taking, on average, 24-hour samples once every six days. Therefore, approximately 61 measurements are collected annually. In terms of the number of standard exceedances, PM is similar to ozone; however, the percentages are much higher for  $PM_{10}$  (around 20%). For this reason, it will be important to incorporate continuous  $PM_{10}$  monitoring equipment into the monitoring stations because this pollutant could be the most relevant for Ciudad Juárez. In addition, although Mexico does not have an air quality standard for particulates smaller than  $2.5 \mu m$  ( $PM_{2.5}$ ), the initiation of its monitoring is highly recommended in the Paso del Norte airbasin.

Figure 3 indicates that the maximum monthly  $PM_{10}$  levels occasionally reach nearly 200 IMECA points. Most months had values exceeding 100 IMECA points.

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Figure 3. Maximum Monthly IMECA of PM<sub>10</sub> in  
Ciudad Juárez, 1996–1997



Source: Ciudad Juarez Air Quality Management Plan 1998–2000

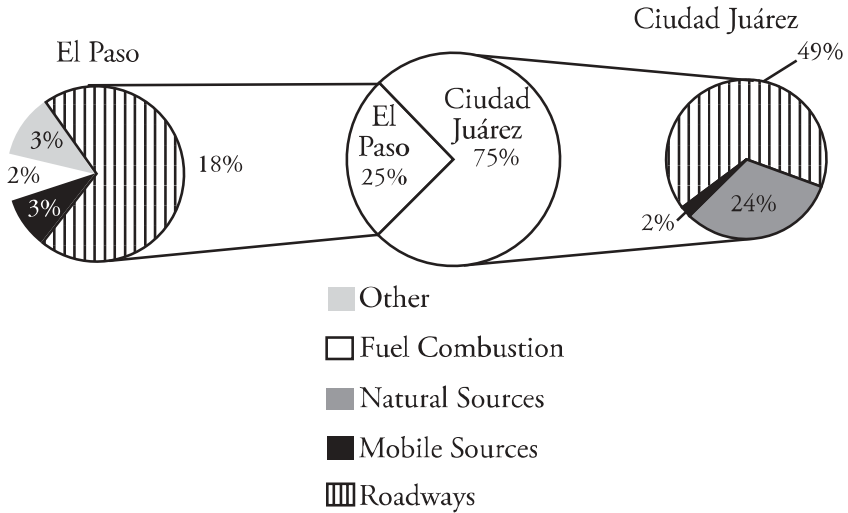
## MAJOR SOURCES OF PARTICULATE MATTER

According to the most recent emissions inventory (1996) for El Paso-Ciudad Juárez, Ciudad Juárez contributes 75% of the PM<sub>10</sub> emissions; the largest contributors are road dust, followed by wind erosion of soil (Figure 4). It is estimated that 50% of the urban roads in Ciudad Juárez are unpaved (Gonzalez 1998). In El Paso, the majority of its PM<sub>10</sub> emissions also come from road dust, followed by mobile sources. El Paso County has approximately 800 miles of unpaved roads, but these roads see very little vehicle traffic and are generally in undeveloped areas. It is worthwhile to note that in El Paso, PM emissions from paved roads far outweigh those from unpaved roads (TNRCC 1996). In Doña Ana County, PM<sub>10</sub> is dominated by wind erosion of soil.

In addition, vehicles and other combustion sources contribute to PM<sub>10</sub> concentrations and are more significant contributors to PM<sub>2.5</sub> levels. Approximately 333,000 vehicles are registered in El Paso and 420,000 vehicles are registered in Ciudad Juárez. An average of approximately 40,000 vehicles cross the U.S.-Mexican border into El Paso each day (EPMPO 1998). On average, Mexican vehicles have higher emissions than U.S. vehicles but are driven less often. In addition, the low per capita income in the region manifests itself in

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Figure 4. 1996 PM<sub>10</sub> Emissions Inventory for the Paso del Norte



Source: Authors

the burning of scrap wood and refuse material for home heating and cooking in the more economically disadvantaged regions of Ciudad Juárez, El Paso, and Sunland Park. These activities can have a significant effect on PM levels, particularly during the winter season because of its stagnant air conditions. Finally, small amounts of PM come from commercial and industrial activities such as refining, smelting, scrap-metal foundries, agricultural activities, open-burning batch-type brick making, maquiladoras in Ciudad Juárez, and quarry operations and electric generation in El Paso. Some of these activities, such as smelting, can have a significant effect on PM composition (as discussed in Chapter V).

Chapter II provides an extensive inventory of emission sources along the U.S.-Mexican border. Chapter VI discusses important organic contributors to PM and identifies several sources that are characteristic of the border region, including refuse burning and brick kilns. Chapter V discusses sources of metal emissions in the Paso del Norte airshed.

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Collecting an integrated emission inventory for an airbasin such as Paso del Norte's is a challenge. In the United States, emission sources are divided into three categories: mobile, point, and area. Yet in Mexico, emission sources are categorized by economic sector: industrial, commercial and service, transportation, and natural sources. As in all emissions inventories, there are levels of uncertainty in emissions estimation that influence an inventory's overall accuracy. In Paso del Norte, there are uncertainties associated with the estimation methodologies themselves, in addition to the fact that there are source categories for which emissions estimates are currently unavailable.

### SIZE AND COMPOSITION OF PARTICULATE MATTER

The composition of PM in Paso del Norte differs from the PM found in other regions of the United States because of the significant contribution from geologic sources. For example, along the East Coast sulfates are significant, and in the Los Angeles basin nitrates are significant (Tropp, et al. 1998; Dattner 1994). The geologic contribution to PM is predominantly found in the coarser fraction of PM (PM<sub>2.5</sub> to PM<sub>10</sub>) (Chapter III).

In the 1970s, the Paso del Norte airshed had high levels of airborne lead (see Chapter V for additional details on historical levels of airborne metals). During that time, 12 sampling sites regularly exceeded the U.S. Environmental Protection Agency's (EPA) quarterly average lead standard of 1.5 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ), with one location reporting a quarterly average lead concentration of 15.5  $\mu\text{g}/\text{m}^3$  (Dattner 1996). Because of concerns over the health effects of lead, the U.S. and Mexican governments successfully implemented measures to reduce ambient lead concentrations. These included the elimination of leaded fuel used in motor vehicles and more stringent controls on the American Smelting and Refining Company (Asarco) metal smelter in El Paso (Appendix Figure 1 [page 305]). Starting in 1972, some U.S. vehicles could not use leaded fuel, and by 1980 very few new cars could use leaded fuel. By 1990, most Texas gas stations stopped selling leaded fuels. Mexico adopted similar regulations and also dramatically reduced

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the use of leaded fuel. In the late 1970s, the American Smelting and Refining Company (Asarco) modernized its lead plant, and between 1984 and 1992 closed its arsenic, lead, antimony, and cadmium processes.

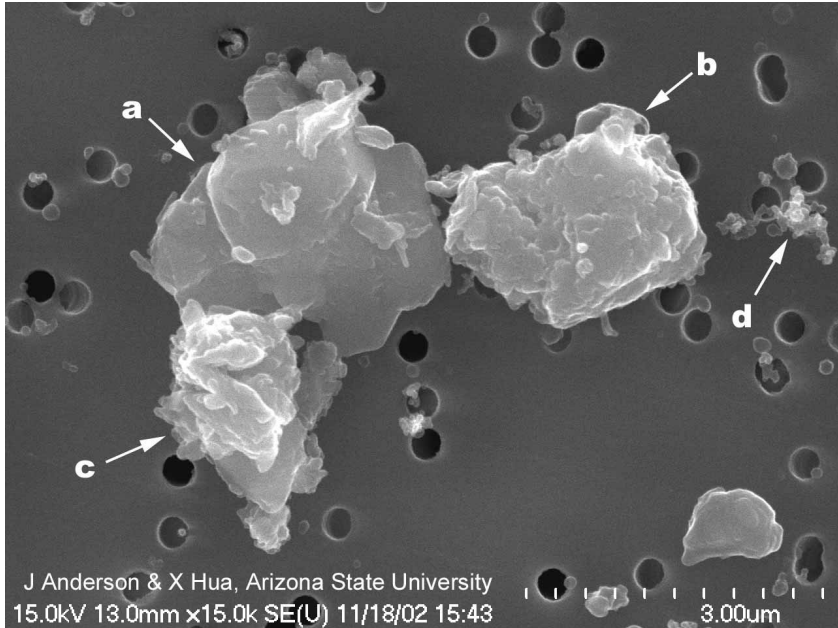
Between 1972 and 1995, airborne lead concentrations in the Paso del Norte airshed decreased by approximately 90%. Currently, the concentrations of metals-associated anthropogenic sources, such as smelters (arsenic, copper, chromium, and lead), are highest in ambient PM and surface soil samples collected in the urban core of El Paso-Ciudad Juárez and near the Asarco smelter (for additional details on this, see Chapter V).

As the levels of lead and other toxic metals have declined, attention has shifted to reducing the contributions of geologic sources to PM levels and to reducing contributions from combustion sources such as brick kilns and residential burning. Chapter VI provides details about organic contributions to PM in the Paso del Norte airshed. The source apportionment techniques discussed in Chapter VI provide a measure of the different contributions in different locations as a function of time.

Advanced techniques are also helping improve the understanding of the composition and sources of PM in the region. Chapter IV presents microscopy results of various types of PM identified in the region. Figure 5 shows an example of several types of particles common to the U.S.-Mexican border.

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Figure 5. Scanning Electron Microscopy Images  
of Aerosol Samples



Notes: (a) calcium sulfate, (b) calcium carbonate with minor aggregated aluminosilicate, (c) aluminosilicate (clay), (d) black carbon (soot and small carbon cenospheres). Many other small black carbon particles are unlabeled (15,000X). These are reasonably representative of particles within the twin cities of Douglas-Agua Prieta, although the complexity in the variety of particle types (especially black carbon) and their aggregation cannot be represented in just a few images. Phase identifications are made from energy dispersive x-ray spectra. Samples were collected through the PM<sub>10</sub> inlet onto polycarbonate membrane filters with 0.4  $\mu\text{m}$  pores. Images were taken with the Hitachi S-4700 scanning electron microscope, with 15 kV accelerating voltage. Source: J. Anderson and X. Hua

## AIR QUALITY MONITORING

Air quality monitoring networks have been deployed throughout the air basin to measure population exposure to  $PM_{10}$ ,  $PM_{2.5}$ , carbon monoxide, and ozone (Appendix Figure 1 [page 305]). There are nine monitoring sites operated by the Texas Commission on Environmental Quality (TCEQ) in El Paso, 11 stations in Doña Ana County operated by the New Mexico Environment Department (NMED), and six monitoring sites in El Paso operated by El Paso City-County Health and Environmental District (EPCCHED). The Ciudad Juárez General Directorate of Ecology and Public Safety (in Spanish DGEPC) obtains daily air quality data from equipment at five Ciudad Juárez air quality monitoring sites. EPCCHED provides maintenance, quality control, and technical support for these stations.

Because new monitors are required to measure  $PM_{2.5}$  under the new U.S. fine particle standard, TCEQ has established a  $PM_{2.5}$  monitoring site for El Paso. EPA and the Mexican Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT) are working on a proposal to deploy  $PM_{2.5}$  monitors in Ciudad Juárez.

Chapters III, IV, V, and VI present PM measurements and analysis of PM collected at several of the monitoring sites shown in Appendix Figure 1 (page 305). The following paragraphs describe a few of the key monitoring sites in more detail.

### *United States*

The Chamizal site is located in south El Paso, west of the Cordova International Bridge. It is in an enclosed area set aside for air monitoring at Chamizal National Park. It is a designated EPA State and Local Air Monitoring Site and Photochemical Air Monitoring Station network where daily, 24-hour Federal Reference Method  $PM_{2.5}$  samples are collected. It is also a TCEQ Continuous Air Monitoring Station (CAMS 41) where hourly Beta Attenuation Monitor (BAM)  $PM_{10}$  and meteorological data are continuously recorded. The area is classified as a mixed residential and semi-industrial area. This site is subject to vehicular traffic sitting idle during rush hour at the international border crossing.

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The Sun Metro site is an urban commercial/industrial site approximately four kilometers (km) from Chamizal. It is located in southwest El Paso just north of the Rio Grande and south of Interstate 10. The site is collocated to TCEQ's CAMS 40, where hourly BAM  $PM_{10}$  and meteorological data are continuously recorded. This site is subject to the effects of vehicular traffic during rush hour from Interstate 10 in El Paso and the effects of unpaved roads in Ciudad Juárez. Additionally, it is subjected to the effects of heavy wood and cardboard burning for home heating from Ciudad Juárez homes.

### *Mexico*

The Club 20-30 site is located east of downtown Ciudad Juárez. The site contains a high-volume  $PM_{10}$  sampler co-managed by the Environmental Department of Ciudad Juárez (EDCJ) and EPCCHED. The surrounding area is heavily populated and close to a major road with heavy vehicle traffic during rush hour.

The Advanced Transformer site is located in the maquiladora industry district. The brick kiln district is located just south of the site, and heavy burning occurs daily. The site contains a high volume  $PM_{10}$  sampler co-managed by EDCJ and EPCCHED.

The Misión site is located at the foothills of the Sierra de Juárez, in the southwest portion of the air basin. The surrounding area is heavily populated and the site is located in a community with unpaved roads where residents burn materials during winter months. Located to the south of this site is a cement factory. The site represents a typical residential location on the outskirts of Ciudad Juárez.

## PREVIOUS STUDIES

This section summarizes results from studies conducted in the last several years to characterize the sources of pollution and the state of air quality in Paso del Norte. Special attention is given to studies aimed at achieving a better understanding of the physical and chemical processes that lead to high concentrations of fine particulates

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and ozone. Similarly, a brief description is made of studies currently being conducted and those completed, the results of which will be forthcoming.

### *El Paso/Juárez Saturation PM<sub>10</sub> Study (Kemp 1990)*

Given that the city of El Paso has exceeded the U.S. air quality standard for PM<sub>10</sub> since the standard's promulgation in 1987, the Texas Air Control Board (TACB) was required to design a State Implementation Plan to control this pollutant in the area. In response, this study was conducted in December 1989 and represents the first formal opportunity for conducting joint work on both sides of the border. The study's general objectives were to:

- Characterize the PM<sub>10</sub> levels in the area and determine what the PM<sub>10</sub> concentrations are in areas of the basin not sampled regularly and whether the current monitoring system for PM<sub>10</sub> adequately characterizes the atmospheric environment
- Develop parameters and protocols for handling portable monitoring equipment for PM<sub>10</sub> in future short-term studies

One of the study's most significant results is that according to three-and-a-half-hour samples taken during the first two weeks of December 1989, the PM<sub>10</sub> concentrations varied between 24 µg/m<sup>3</sup> (in Sunland Park, near the border between Texas and New Mexico) and 745 µg/m<sup>3</sup> (in Ciudad Juárez's west side). The levels of PM<sub>10</sub> on the eastern side of the basin were approximately 90 µg/m<sup>3</sup>.

The 22-hour samples taken on December 11, 1989, were used to interpolate data and generate a map of contours to estimate basin-wide concentrations. According to these estimations, the greatest PM<sub>10</sub> levels were observed toward the south of the junction between the borders of New Mexico, Texas, and Chihuahua.

The study's general conclusions indicate two points. First, the highest levels were regularly found along both sides of the border in the regions not covered by the local monitoring system. Second, the PM<sub>10</sub> monitoring system has proved to be of little value for its characterization of the distribution of PM<sub>10</sub> in the basin.

*LIDAR-Observed Wind Patterns in the Mexico-  
New Mexico-Texas Border Region (Barr, et al.  
1994)*

In collaboration with the Physical Sciences Laboratory at New Mexico State University and other institutions, Los Alamos National Laboratory participated in a short but intense field campaign during the first two weeks of September 1994. Its intent was to study the patterns of wind circulation that contribute to the presence of high ozone levels in the region.

Some of the principal results indicate that the growth in the mixing layer during the days analyzed can be described in three stages: slow growth, almost uniform (200 meters per hour [m/h]) from 8:00 am until after midday; intermediate growth (approximately 400 m/h) with convective heterogeneity until the beginning of the afternoon when the humid convection begins; and vigorous growth, whose quickness is governed by the magnitude of the humid convection.

The data generated by the Light Detection and Ranging (LIDAR) system allowed the visualization of some of the characteristics of the transport and dispersion patterns. For example, it was found, at least during the days analyzed, that the dominant winds in Sunland Park generally flow from the southeast.

From the previous results, the authors concluded that the shallowness of the mixing layer, combined with southern and eastern winds, are probably the source of the brown cloud observed toward the north near Las Cruces. As such, they have concluded that when considering Sunland Park's ozone problems, the area analyzed should be extended several kilometers to the south and east because ozone is a product of photochemical reactions with pollutants transported from distant locations in the south and east, and air in Sunland Park is generally not at a standstill.

*Winter Season Air Pollution in El Paso-Ciudad  
Juárez (Einfeld and Hugh 1995)*

This report summarizes numerous research efforts conducted since the 1980s in the Paso del Norte area, highlighting the work sponsored by the U.S. Congress and administered by EPA. The summary outlines aspects such as spatial and seasonal distribution of the pollutants and the polluting potential from both mobile and stationary sources located on both sides of the border.

*Paso del Norte Pilot Border Study of Ozone  
Precursors and Air Toxins*

EPA designed this pilot study to plan the development of an intense study monitoring ozone precursors and air toxins for the summer of 1996. The pilot study, conducted in 1995, was aimed at obtaining preliminary information on pollutant concentrations and to test sampling and analysis methods that would be used in the principal study, scheduled to be conducted during the summer of 1996.

In developing this study, two sites were selected—one in Ciudad Juárez and the other in El Paso. The El Paso site was located at the Sun Metro monitoring station and the Ciudad Juárez site was located at the Tecnológico monitoring station. The final results identified sampling and analysis methods for the chemical species in the international air basin.

*Operating Plan for Ozone Modeling Data  
Collection in El Paso-Ciudad Juárez-Sunland  
Park (Roberts, et al. 1996)*

Considering the need to better address the tropospheric ozone problems in the El Paso-Ciudad Juárez-Sunland Park area and that the majority of studies conducted to date had focused on collecting PM<sub>10</sub> and carbon monoxide data, EPA sponsored a field study for the collection of sufficient data to support the region's ozone modeling activities. The final objective was to develop an air quality model validated for a variety of meteorological conditions that could be used to evaluate the potential effect of future scenarios.

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The design of the operating plan for the data collection was located within this context. One of the most important tasks in developing the design was reviewing all the information generated by previous studies in the area. The review allowed a statistical characterization of the high ozone concentration, a general description of the air quality (including basic statistics on how, when, and how frequently ozone episodes occur), a preliminary characterization of meteorological and air quality phenomena associated with ozone episodes, and a preliminary characterization of volatile organic compounds (VOCs) in the area.

Some of the principal conclusions drawn from analyzing the information were:

- The majority of ozone standard exceedances are from June to October; the greatest concentrations are in August
- The accumulation of pollutants in high areas plays an important role in high ozone concentration events
- The surface area wind patterns vary significantly
- The daily profiles of the mixing layer heights probably play an important role in high ozone concentrations
- The monitoring system requires modification or amplification to adequately characterize the volatile organic compounds and the carbonyls in the region's air

### *Analysis of Meteorological and Air Quality Data for the 1996 Paso del Norte Ozone Study (Roberts, et al. 1997)*

This study analyzes the meteorological and air quality data collected in Paso del Norte during the summer of 1996. Its objective was to characterize the meteorological and air quality processes that influence the formation and transport of ozone precursors and ozone itself within the study area. The study also aimed to provide information on the initial and border conditions that should be used during the later meteorological and photochemical modeling of the atmospheric basin.

As a result of this analysis, a simple conceptual model of the episodes of high ozone concentration in the area was developed. A conceptual model is a description of the most important phenomena

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and characteristics that produce ozone episodes. An ozone episode is a day in which the air quality standard for this pollutant is exceeded at minimally one of the sampling sites.

The following highlights the principal characteristics of the conceptual model as well as some other important conclusions from this study. Table 2 indicates the work considered in this study, as well as the institutions that conducted it. According to the authors, some of the primary conclusions reported are:

- Industrial sources are not a significant source of particulates in Paso del Norte
- Winter levels of  $PM_{10}$  are greater in the central areas of Ciudad Juárez and El Paso; in general, there is a concentration gradient that tends to increase toward Ciudad Juárez
- Average emissions of vehicles in Ciudad Juárez are three times greater than those of vehicles in El Paso
- The number of kilometers that vehicles in El Paso travel is three times greater than those of vehicles in Ciudad Juárez
- Atmospheric stability during winter and complex topography significantly limit the dilution of pollutants in the region
- During the winter season,  $PM_{10}$  concentrations in Paso del Norte reach levels that exceed the U.S. air quality standard for this pollutant

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in the Paso del Norte Border Region

Table 2. Ambient Air Quality Studies Conducted in  
Paso del Norte from 1983 to 1994

Title of Study	Participating Institutions
Carbon monoxide studies	University of Texas at El Paso, 1983
Inhaleable fraction particulates evaluation	Environmental Research and Technology, Inc. 1983
Air quality database	Radian Corporation, 1983
Quantitative microscopic study in El Paso	Energy Technology Consultants, 1983
LIDAR study	Environmental Monitoring Systems Laboratory, 1989
Visibility and high wind study	University of Texas at El Paso, 1989
PM <sub>10</sub> saturation study	EPA Region 6, 1989
Gasoline vapor pressure study in Ciudad Juárez	SEDESOL and others, 1990
Research on emissions control device tampering	Colorado State University, 1990
Ciudad Juárez emissions inventory	Alliance Technologies and others, 1990
Short-term winter particulate study	Texas Air Control Board, Sandia National Laboratories, 1990
Evaluation and recommendations of the PM <sub>10</sub> modeling plan	Systems Application International, 1991
Development of State Implementation Plan for PM <sub>10</sub>	Texas Natural Resource Conservation Commission, 1991
Ciudad Juárez industrial emissions study	EPA-SEDESOL, 1992-93
Vehicle emissions remote sensing study	University of Denver, 1993
MOBILE5 reviews	Energy and Environmental Analysis Inc., 1993
Characterization of Ciudad Juárez's vehicle fleet	Texas Transportation Institute, 1993
Ciudad Juárez brick kiln study	El Paso Natural Gas Co./FEMAP, 1993
Pollution emissions from residential heating systems	University of Utah, 1993
Temperature and high wind data collection	University of Texas at El Paso, 1993
Use of oxygenated fuels in Ciudad Juárez-El Paso	SEDESOL and others, 1993
Other activities	Paso del Norte Air Quality Task Force, 1993
Comparison of inspection and maintenance programs in Ciudad Juárez and El Paso	Paso del Norte Air Quality Task Force, 1994
Technology transfer session with inspection and maintenance technicians	Colorado State University, 1994

Source: Authors

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