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HECTOR A. QUEVEDO

Norman, Oklahoma

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CONCENTRATION AND DISTRIBUTION OF SUSPENDED PARTICULATE LEAD IN THE CITY OF JUAREZ, MEXICO

APPROVED BY

James M. Robertson

Larry Canter

Robert Y. Nelson

Raymond A. Mill

Leale E. Streebin

DISSERTATION COMMITTEE

To my wife Gloria, Daughter Rocio and son Hector R.

To my father and mother

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CONCENTRATION AND DISTRIBUTION OF SUSPENDED PARTICULATE LEAD IN THE CITY OF JUAREZ, MEXICO

CHAPTER I

INTRODUCTION

Particulate lead enters the atmosphere through both natural processes and by anthropogenic activities. Inputs from natural processes include emissions of radioactive precursors of elemental lead from the surface of most soils, dusts raised by wind forces, and volcanic activity and sea salt aerosols. However, these contributions are small when compared to man-made emissions from the combustion of leaded gasolines, industrial sources, and lead smelters.[1] Although stationary sources such as smelters only account for a small proportion of the total lead emitted, these sources may cause local ambient concentrations of lead to be greatly elevated.

In 1970, estimated lead emissions from primary lead and copper smelting operations amounted to about 3,000 metric tons in the United States.[2] Atmospheric lead levels reaching several hundred micrograms per cubic meter have been observed at ground level downwind from smelting industries. Studies around one smelter showed ranges of 15 to

269 micrograms of lead per cubic meter of air, with soil lead levels as high as 11,000 parts per million but decreasing exponentially with distance and reaching background several miles from the source.[3]

Epidemiological studies have shown that persons living near smelters may have increased levels of blood lead. One study[4] found that increased lead absorption in children, as defined by blood levels greater than 40 micrograms per 100 milliliters of blood, was greater in children living within one mile of the industrial source as compared to those living beyond that distance. In addition, a highly significant relationship was found between household dust lead levels and lead in the blood of these children.

It has been suggested that inhalation of lead by children living near smelters depends primarily upon particle size. Respiratory lead absorption is inversely proportional to particle size. For example, at least 30 percent of the particles below 2 micrometers in diameter are retained and subsequently absorbed through the respiratory system.[2]

The manifestation of plumbism or lead intoxication has been reviewed by several investigators. One study has shown that anemia, encephalopathy, and chronic renal diseases, as well as abnormalities of hemebiosynthesis and neuropsychologic functions, are the extreme consequences of increased lead absorption in children.[2] These manifestations of disease suggest the importance of additional studies regarding the health effects of lead to delimit the magnitude of the problem.

The present study was conducted in the city of Juárez, Chihuahua, Mexico, which is located just across the Rio Grande River from El Paso, Texas, on the Texas-Mexico border where the river flows southerly toward the Gulf of Mexico as is illustrated in Figure 1. The El Paso-Juárez area constitutes the most important metropolitan center along the United States-Mexico border with an estimated population of over one million people with approximately 600,000 in Juárez alone. This single community, divided between three states and two countries where the Rio Grande River joins the boundary of United States and Mexico, is characterized by a remarkable combination of topography, climatology, industrial and economic structures in which air pollution problems are common. In fact, the most relevant characteristics of the area are constituted by geographic features that have an important influence in the meteorological processes and by the complex industrial sources that dominate the area.

The Juárez metropolitan area was chosen for the present study in an effort to appraise more thoroughly the concentrations of lead, zinc, and cadmium associated with suspended particulate matter discharged by the local smelting industry in El Paso in a sampling period which started April 8, 1975, and ended April 10, 1976.

This research was initiated because several cases of environmental lead pollution intoxication had been discovered among the child population living near the smelter sources during a survey performed by the Ministry of Health and Welfare of Mexico.[4] The present field of study was also chosen because the region of interest presented a natural laboratory to study the different levels of atmospheric contaminants in an environment that contains an interesting combina-

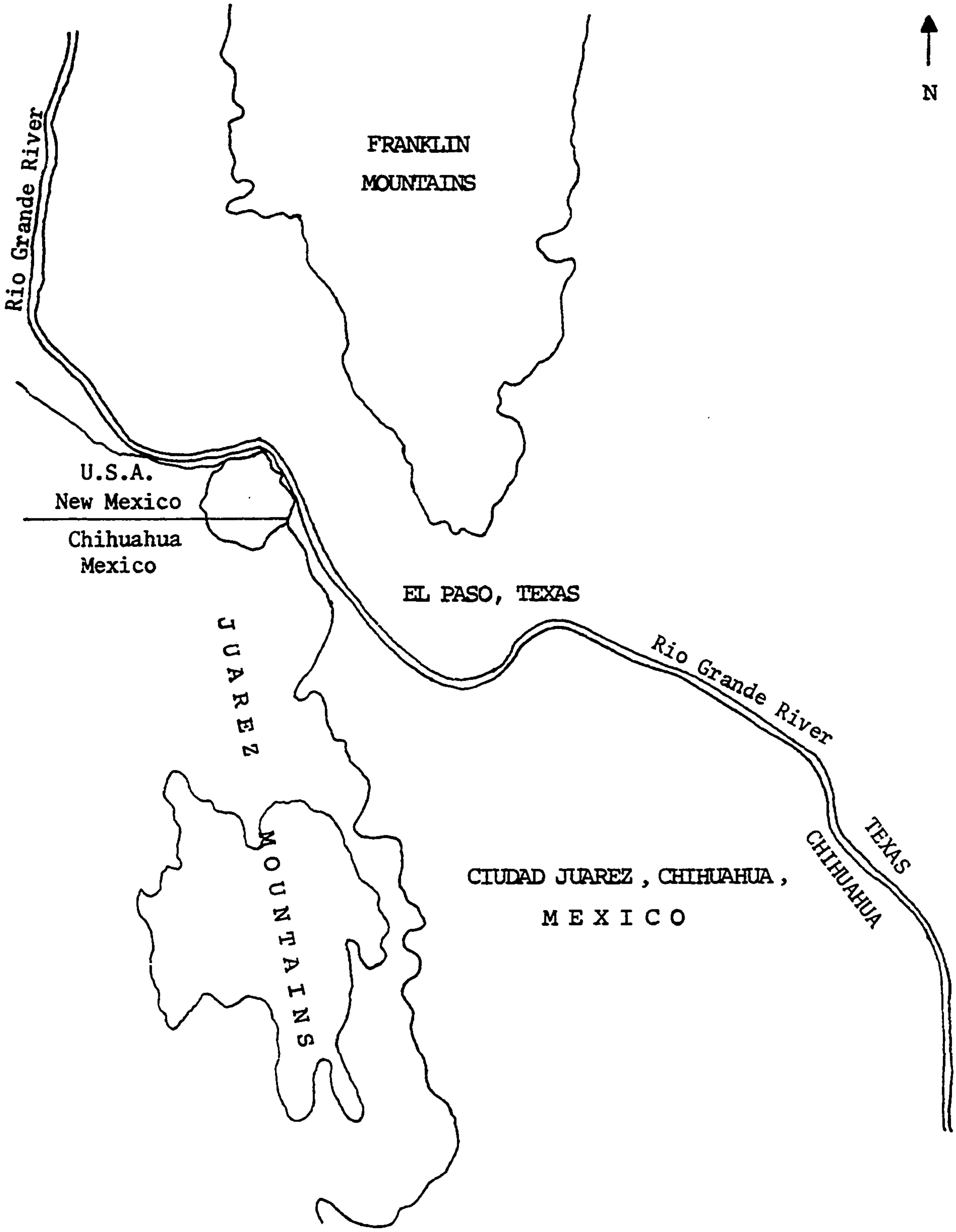


Figure 1. Map Showing the City of Juárez, Chihuahua, Mexico, and the City of El Paso, Texas.

tion of unique characteristics of climate and geography.

This research was designed to relate concentrations of atmospheric lead, zinc, and cadmium to each other. It was also designed to relate the concentrations of these metals to the distance from the smelting industry. Thirdly, it was designed to investigate the concentration and distribution of high and low levels of these metals in the Juarez metropolitan area. Although it was the purpose of this work to delineate the levels and origins of atmospheric contaminants around each of the nine sampling sites that composed the network, it was not in the scope of this investigation to account for precise or definite diffusion patterns due to the complex topographic features that made the projection of atmospheric inputs very difficult since a variety of local circulation systems occur as a result of temperature differentials.

CHAPTER II

BACKGROUND INFORMATION FOR STUDY

The present chapter discusses the sources of lead in the environment, lead effects on human beings, and the influence of meteorology in the distribution of this metal in the atmosphere.

Man's activities have resulted in many types of air pollution. One type which has caused much concern during recent years is particulate matter which contains heavy metals. Several reports of the levels of lead aerosols in the atmosphere suggested that there has been a substantial increase worldwide in recent years. Patterson[6] reported that the industrial use of lead today is so extensive that the amount of lead introduced into the urban environment each year is more than 100 times greater than the quantity of lead added to the oceans by natural means. Moreover, he found that the lead levels in the North Polar snows have increased from 90 grams per ton in 1950, to 210 grams per ton in 1965. In a recent study of San Diego, California, Chow, et al.,[7] suggested that the lead aerosol in that area is increasing at a rate of 5 percent per year. Likewise, an increase in lead from 0.16 to 2.6 micrograms per liter between 1904 and 1964, has been found in Greenland snows.[8]

The main sources of lead emission into the atmosphere include various industries and vehicular combustion of leaded gasolines. Accordingly, in terms of total atmospheric emissions, the combustion of alkylated gasoline accounts for 94.8 percent, followed by industry, 2.0 percent; by lead smelters, 0.5 percent; and by municipal refuse, 0.15 percent.[1]

For the El Paso-Juárez metropolitan area there have been several studies regarding environmental pollution by lead. Landrigan and colleagues[3] studied lead pollution near the local smelter on the western edge of El Paso, Texas. Measurements of heavy metals were performed by collecting samples of air, soil, dust, and human blood. The technique in the Landrigan study for sampling suspended particulate lead, zinc, and cadmium consisted of using high volume samplers with fiberglass filters. The two-year study (1971-1972) indicated the concentration of these three metals in air, dustfall, surface soil, and household dust was several times the background concentrations, with levels falling rapidly within two miles from the emitting source. Figure 2 shows the relationship between the atmospheric concentration of lead and distance from the smelter. An analogous situation is shown by the lead/bromine ratios; however, it was noticed that lead soil concentrations remained above background level for a distance of 6.5 miles.

The human studies performed by Landrigan suggested the concentration of lead in the blood of children decreased exponentially with distance from the source, with the highest levels found in those children living within one to two miles from the smelter. The conclusion of the study was that within a one-to-two mile radius of the smelting company it appeared to have been the sole source of lead in

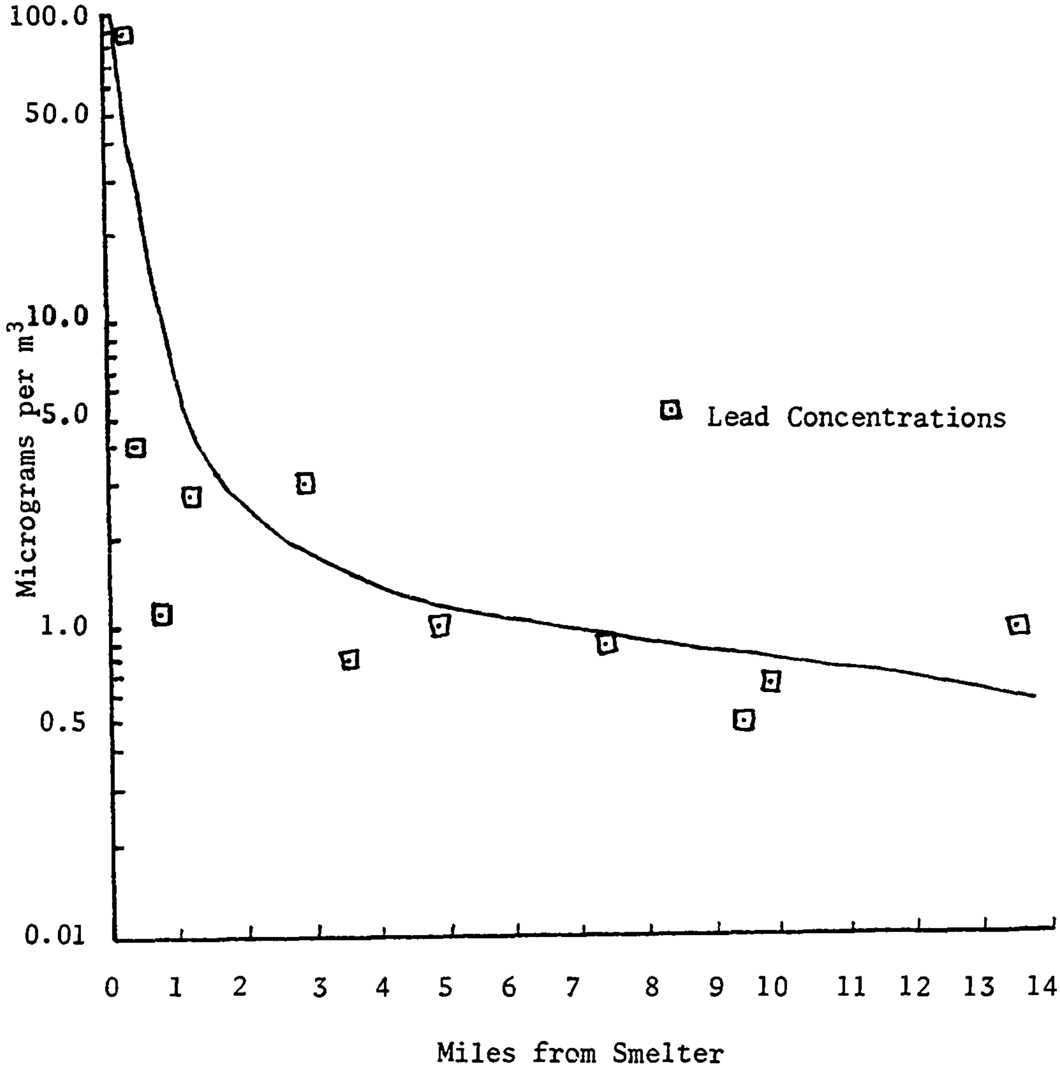


Figure 2. Lead Concentrations (Suspended Particulates), by Distance from Smelter, El Paso, Texas.

Source: Landrigan, P. J. et al.,"Epidemic Lead Absorption Near an Ore Smelter: The Role of Lead in Dust", New England J. Med. 292:123-129, 1975.

air and dust; however, beyond that distance other sources such as automotive emissions could have contributed an increasing fraction of the atmospheric levels and human uptakes.

Applegate, et al.,[8] in an effort to delimit the problem of pollutants suspected of coming from the smelting industry, conducted a survey in El Paso, Texas, for lead, zinc, and cadmium in soils. They found a statistical correlation between the three metals in soils and the straight line distance from the industry. The study concluded that at least part of the metals had their origin from the activities of the industrial source. If automobiles had been responsible for the total burden of lead concentrations, its distribution pattern would not be expected to be so near those of particulate zinc and cadmium. Nevertheless, it was difficult to determine from the data when or where in the smelting procedures the metals left the plant premises. They could have blown off storage piles of mineral ore prior to processing; they may have been emitted and dispersed during processing; or, perhaps, they represent a period of several years accumulations since the plant has been in operation for over 70 years.

Miller,[9] in an environmental study of soils in the El Paso area, found no relationship between soil types and lead content. Moreover, she found no relationship between concentration of lead in soils and vehicular traffic, thus concluding that the lack of correlation with traffic density was that lead from the smelter overlaps automobile-deposited lead.

Other reviews regarding environmental pollution by lead were done in the Juárez area by Odoñez, et al.[4] near the smelter located in El Paso. The research included an epidemiological study in which the distribution of lead in dust and in soils were correlated with lead in the blood of children. In fact, it was shown that families living near the smelter have abnormal levels of lead in blood, possibly with hematological and neuropsychological alterations attributable to the lead emitted by the smelter.

Epidemiological studies conducted in El Paso, Texas, regarding the relationship between low-level lead absorption and neuropsychologic function were investigated by Landrigan, et al.,[10] on a group of children living within four miles from the smelter. The results suggested performance IQ was significantly lower in children with greater than 40 micrograms of lead per 100 milliliters of blood. In addition, the group also showed subclinical weakness of wrist muscles. The conclusions suggested that low-level lead absorption may produce neuropsychological impairment.

Another report regarding hazards of lead absorption from emanations from European smelters operating for centuries was presented by Djuric, et al.[11] The study presented levels of lead in the surrounding air, soil, and vegetation, as well as, in the human population living near the emitting sources. It was shown that the average concentrations of amino-levulinic acid (ALA) in the urine of persons living near mining and smelting operations were more than twice the average of the control group. In addition, the excretion of ALA in the urine of smelter workmen was several times higher than the average of the control group. In this investigation ALA was used as an indicator to estimate lead exposure of the group under study.

The nature of lead in automotive exhaust has been reviewed or studied by several investigators. Until recently nearly all gasolines sold in the United States contained alkylated compounds added to correct the anti-knock quality of fuels. One study[12] suggested that the major portion of lead emitted from combustion of alkylated fuels is in the form of inorganic particulate solids composed of lead halide (PbClBr), or complexes of ammonium halide and lead halide, but only an extremely small amount of the organic (alkyl) form. Moreover, only a portion of the lead contained in the burned gasoline is emitted in the exhaust gas, with about one-fourth being retained in exhaust system deposits or in motor oil. In addition, the survey showed that the percentage of lead discharged in the exhaust depends on the conditions under which the car is driven, such as type of driving and speed. Finally, the study concluded that the diameter of particulate lead compounds ranged from 0.01 to 5 microns.

Another study of lead emissions from automobiles dealt with photochemical decomposition of lead halides.[13] According to this review, lead halide or lead bromochloride which is generated by burning leaded fuel mixed with dibromoethane and dichloroethane undergoes photochemical decomposition, with the formation of lead oxides such as PbO and the release of free halogens such as bromine and chlorine. This study suggested that once the oxides of lead reach the atmosphere they may catalyze the oxidation of gaseous contaminants in the atmosphere such as nitric oxide.

Information on the amount of lead emitted by automotive sources was reported by Smith in 1976.[14] Between 1923 and 1964, more than 2.6×10^9 kilograms of lead had been combusted by cars, with approximately 136×10^6 kilograms of the metal discharged by automotive exhausts in 1970. The report indicated automotive lead contributions to the roadside ecosystem may range from 40 milligrams to 130 milligrams per mile driven. This amount is transferred to the soil and vegetation via sedimentation, impaction, and precipitation.

Lead uptake by plants has been documented by several authors. Grossbalt, in 1972,[15] while reviewing the concentrations of lead in plants, concluded there is little effect on lead content of plants cultivated in soils with high levels of the metal, and atmospheric lead did not measurably increase the accumulation of the metal in plants. Another review regarding contamination of the roadside soil and vegetation with lead was reported by Lagerwerff and colleagues.[16] These investigators concluded the concentration of lead decreases with distance from the traffic source. Still further, contamination of plants by lead emissions from smelters was discussed by Rains.[17] He found no detectable differences in lead levels between washed and unwashed samples of wild oats. However, he did find substantial increases of lead on the exposed plants, especially during ripening and when new seasonal growth began. Furthermore, Carlson, et al.,[18] while examining the effects of heavy metals on corn and sunflowers, suggested that appreciable concentrations of lead do not measurably interfere with photosynthesis, stomatal opening, total biomass for roots, or leaf yellowing.

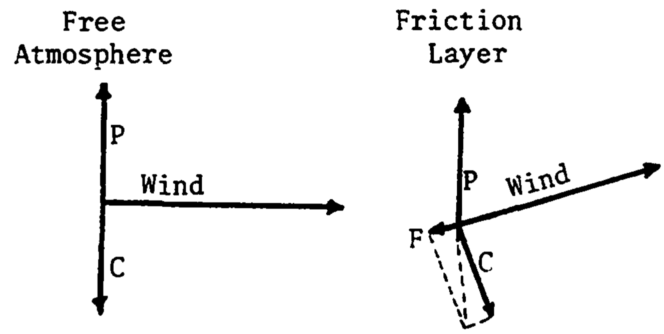
Meteorology and Air Pollution

The most important factors influencing the concentrations of air contaminants are the meteorological or weather conditions, the total amount and type of pollutants emitted and the configuration and type of emitting sources.[19] The meteorological factors contributing directly or indirectly to the dispersion of air pollutants are direction and velocity of wind, atmospheric stability, temperature, cloudiness, and rainfall. The most important factors enhancing air pollution potentials in any area are light winds, stable atmospheric conditions, and stagnating high pressure systems. On the macroscale, wind flow over the surface of the earth is caused by large scale pressure variations. On the microscale, variations of wind velocity result from a combination of different factors which influence the air movement. Two factors causing turbulent motion are the roughness of the surface of the earth and temperature differentials.

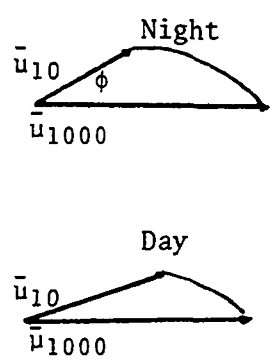
Air forced to move past an object protruding into the wind stream will tumble and turn on itself, producing eddies having sizes and speeds related to the mean wind speed and the form and size of the object. This results in mechanical turbulence.[20] The other type of turbulent motion results from parcels of superheated air rising from the earth's surface and being replaced by descending motion of cooler parcels of air from above. This results in thermal turbulence. In most cases, turbulence is a mixture of the two types, however, under special conditions air may move with essentially no turbulence, thus exhibiting laminar flow. Atmospheric temperature variations and wind flow are closely associated, general speaking, however, mechanical turbulence is related to neutral air thermal stability. The fluctuations produced mechanically by roughness elements in the wind stream are neither suppressed nor enhanced by the thermal structure of the air. By the same reasoning, thermal turbulence is associated with thermal instability because any fluctuations tend to be enhanced under these conditions. Laminar flow is associated with thermal stability because flow fluctuations are immediately dampened out.[20]

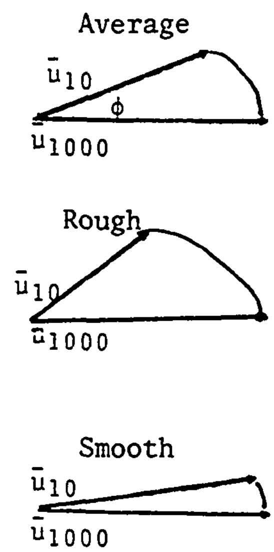
Measurements of wind speed such as those produced by mechanical and thermal turbulence may be taken by anemometers and vanes. Crosswind variations, for example, can be recorded by using a propeller vane; however, if vertical and angular departures of wind fluctuations are to be measured, the use of a bivane sensor is required. On the other hand, all three eddy components of wind fluctuations may be measured using a tri-axial anemometer. The relationship of wind velocity and height as a function of surface roughness and time of day is shown in Figure 3. Typical values of crosswind angular departures σ_θ and vertical angular departures σ_ϕ in a turbulent field, expressed as standard deviations as a function of height and thermal stability of the lower atmosphere are shown in Table I.

Wind variation in the atmosphere is one of the most important meteorological factors in air pollution dispersion. In fact, wind helps to scavenge the air by moving any contaminant away from its point of origin, by diluting its concentration directly, and by mixing it into a large volume through turbulence. Horizontal wind speeds which contribute the most to air pollution problems are those of seven miles per hour or less.[21] For the El



P = Pressure Gradient Force
C = Coriolis Force
F = Friction





ϕ = Angular Change

$\bar{u}_{10}$ = wind at 10 M. above ground

$\bar{u}_{1000}$ = wind at 1000 M. above ground

Figure 3. Change of Wind Direction with Height. Not only the wind speed, but the direction changes with height as a result of friction. The angular change is usually greater during the night than at day, and less over smooth surfaces than over complex terrain.

Source: ASME Committee on Air Pollution Controls, "Recommended Guide for the Prediction of the Dispersion of Airborne Effluents", copyright 1968, by the American Society of Mechanical Engineers, United Engineering Center, New York, New York, p.6.

TABLE I

Typical Values of Angular Departure (Degrees) in Turbulent Wind Fluctuations, Expressed as Standard Deviations, and Related to Height and to Thermal Stability of the Lower Atmosphere

Height (m)	Turbulence parameter	Stability class				
		Very stable	Stable	Neutral	Unstable	Very unstable
200	σ_θ	1°	3	7	12.5	25
	σ_ϕ	0.5°	1.5	5	12	20.5
	$\sigma_\theta/\sigma_\phi$	2.00	2.00	1.40	1.04	1.27
100	σ_θ	1	3.5	7.5	12.5	25
	σ_ϕ	1.5	2	5	9	17
	$\sigma_\theta/\sigma_\phi$	0.67	1.75	1.50	1.39	1.47
50	σ_θ	1.5	4.5	8	13	26
	σ_ϕ	2.5	2.5	5.5	8.5	15.5
	$\sigma_\theta/\sigma_\phi$	0.60	1.80	1.45	1.53	1.68
10	σ_θ	7	7	8.5	14.5	26.5
	σ_ϕ	4.5	3	6	8.5	14.5
	$\sigma_\theta/\sigma_\phi$	1.55	2.33	1.42	1.71	1.83

Source: A. C. Stern, H. C. Wohlers, R. W. Boubel and W. P. Lowry, Fundamentals of Air Pollution, New York and London: Academic Press, Inc. (1973), pp. 268-274.

Paso and Juárez metropolitan areas the hourly wind speeds of seven miles per hour or less occur with greatest frequency during September, October, November, and December. Low wind speeds occur least frequently during March, April, and May. Low wind speeds occur in this area primarily at night or early in the morning rather than late morning or afternoon.[21] Table II shows the percentage frequencies of various wind speeds at the weather station located at the El Paso International Airport. Table III shows a ten-year record of the percentage frequency of wind speeds of zero to three miles per hour, thus characterizing the most favorable conditions for occurrence of high ground level concentrations of air pollutants.

As far as wind direction is concerned, weather data for the El Paso International Airport indicates winds blow mostly from the north during winter and mostly from the south during the warm season, with the prevailing direction from the north by a small margin.[21] Table IV illustrates the percentage frequencies of wind direction and average speeds. Table V shows additional climatological data collected over a 50 year period at the airport. Moreover, Table VI shows the percentage frequencies of wind direction from a Texas Air Control Board weather station located in downtown El Paso on Campbell Street twenty feet above ground.

As mentioned previously, another factor affecting air pollution dispersion is the vertical motion of the air which depends on the temperature profile of the atmosphere. Atmospheric stability, in its simplest terms, is the tendency to resist or enhance vertical motion, or alternatively, to suppress or augment existing turbulence. Stability

TABLE II

Percentage Frequencies of Wind Speed,

El Paso International Airport, 1951-1960[22]

Month	0-7*	8-12	13-18	19-24	25 & Over
January	34.5	32.4	20.4	7.8	4.7
February	32.2	28.2	21.9	9.4	8.2
March	25.9	28.2	22.2	13.3	10.3
April	23.8	27.0	25.1	14.5	9.6
May	25.8	28.8	25.7	14.5	5.2
June	28.4	32.5	25.9	9.9	3.3
July	31.3	37.1	23.1	6.6	1.9
August	34.2	37.0	22.4	5.3	1.1
September	38.4	34.8	20.7	5.2	0.9
October	38.0	32.4	21.3	6.5	1.9
November	37.4	31.8	19.2	7.9	3.5
December	38.8	30.8	19.3	7.0	4.1
Annual	32.4	31.8	22.3	9.0	4.6

*miles per hour

TABLE III

Percentage Frequency of Wind Speeds from 0 to 3 Miles per

Hour, by Months; Measurements Taken Early in the Morning

and in the Afternoon, 1951-1960[22]

Time	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5 am	12	14	13	14	15	14	18	17	24	20	16	15
5 pm	7	8	4	2	3	7	2	5	4	7	15	10

TABLE IV

Percentage Frequencies of Wind Direction and Average Speed, El Paso, Texas, 1951-1960

	Hourly Observations of Wind Speed (m.p.h.)											
	January		February		March		April		May		June	
Direction	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed
N	13.6	10.4	10.7	11.0	6.7	11.5	5.6	10.5	5.4	11.0	6.1	10.8
NNE	10.9	9.8	8.4	10.5	5.6	10.6	3.6	9.4	4.3	10.2	4.7	10.0
NE	5.9	7.9	5.9	8.4	4.1	8.4	3.5	9.0	3.8	8.9	4.0	8.9
ENE	2.8	7.0	3.8	11.8	2.8	10.0	2.8	11.8	3.3	10.3	3.8	11.7
E	3.3	8.3	3.8	10.9	4.0	11.3	4.6	12.2	5.2	13.2	5.2	12.6
ESE	2.6	8.0	2.7	8.5	2.7	10.6	4.5	13.0	4.8	11.1	6.0	12.7
SE	4.2	7.5	4.3	7.4	4.7	8.5	5.0	9.8	6.6	10.2	7.8	10.7
SSE	5.4	8.7	5.7	8.5	5.3	8.7	6.3	9.8	7.3	9.6	9.4	10.4
S	8.5	8.4	8.3	8.7	7.5	8.4	7.1	9.3	7.0	9.2	8.5	9.2
SSW	4.9	9.1	4.4	9.9	5.9	9.7	5.0	10.9	5.8	11.1	5.0	10.1
SW	7.6	12.4	7.2	13.2	8.5	13.3	8.9	13.5	7.7	13.0	7.0	11.3
WSW	8.2	17.1	8.0	17.4	12.1	18.9	13.6	18.1	11.1	17.4	8.6	14.9
W	6.2	17.0	8.2	18.8	10.3	19.3	11.0	19.2	11.6	17.6	9.5	15.6
WNW	5.9	17.8	8.3	19.1	9.7	19.3	9.4	18.9	7.6	15.9	6.6	13.8
NW	4.3	12.4	5.0	14.7	6.5	15.3	5.2	14.6	4.5	12.7	3.8	10.3
NNW	3.8	10.0	3.8	10.1	3.2	11.8	2.8	10.8	3.0	10.7	3.3	10.1
Calm	1.8		1.5		1.1		1.2		1.1		0.7	
Total	100	10.9	100	12.2	100	13.4	100	13.6	100	12.6	100	11.6

TABLE IV (continued)

Hourly Observations of Wind Speed (m.p.h.)

Direction	July		August		September		October		November		December	
	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed
N	8.2	11.6	8.8	10.9	7.8	10.0	9.7	10.4	13.7	10.8	16.6	10.2
NNE	6.0	10.1	5.9	9.7	6.5	9.0	8.0	9.1	11.0	9.8	12.5	9.7
NE	5.5	9.0	4.5	8.5	6.6	8.8	7.2	8.5	8.1	8.8	7.6	8.1
ENE	4.1	10.7	4.0	10.0	4.5	10.1	4.7	10.0	4.3	9.8	4.1	10.1
E	7.7	12.0	6.0	10.9	6.6	11.1	7.3	11.1	4.9	10.4	3.8	8.5
ESE	7.2	12.4	6.2	10.4	6.9	11.8	6.3	11.5	3.4	9.5	2.6	8.0
SE	10.4	10.6	8.7	9.7	10.0	9.7	8.3	9.9	5.2	7.4	3.7	7.0
SSE	12.5	10.6	12.1	10.1	11.5	9.5	7.0	8.8	5.4	8.8	4.5	8.1
S	11.5	9.7	12.1	9.6	12.0	8.9	8.2	8.1	7.8	8.1	7.9	8.1
SSW	5.2	9.9	5.7	9.2	5.5	8.4	5.4	9.3	4.9	9.0	4.4	10.2
SW	5.9	10.2	6.0	9.7	4.9	1.9	6.8	10.8	6.3	11.9	6.8	12.1
WSW	4.2	11.8	5.0	12.4	4.1	12.1	5.5	13.5	5.9	15.1	5.6	15.5
W	3.5	11.1	4.3	11.9	3.9	12.4	4.9	14.2	4.9	16.3	5.5	16.2
WNW	2.3	12.8	3.2	11.8	2.8	11.2	3.0	13.2	4.3	17.1	5.0	17.8
NW	2.3	9.2	2.9	9.2	2.4	8.1	2.7	9.9	3.3	11.2	3.3	11.5
NNW	2.8	10.6	3.4	9.6	2.5	8.1	2.9	3.9	4.4	10.0	4.0	8.5
Calm	0.7		0.9		1.3		2.2		2.0		2.2	
Total	100	10.6	100	10.1	100	9.7	100	10.0	100	10.5	100	10.4
Annual Avg.												11.3

Source: "Summary of Hourly Observations," El Paso, Texas, Climatography of the United States, No. 82-41, Washington, D.C., 1963.

TABLE V

Climatological Data, El Paso International Airport

	°F		Inches		m.p.h.		Percentage				Avg. Daily
	Daily Max. T.	Daily Min. T.	Mean Rain	Mean Snow	Mean Hrly Wind Speed	Prevailing Direction	Possible Sunshine	Clear	Partly Cloudy	Cloudy	Solar Radiation Langleys
J	56.3	29.5	0.46	1.3	9.5	N	77	14	8	9	337
F	62.4	35.7	0.41	0.8	10.5	N	81	14	7	7	435
M	69.4	40.3	0.35	0.4	12.3	WSW	83	14	8	9	551
A	78.2	48.5	0.29	5	12.4	WSW	86	16	8	6	661
M	86.9	56.9	0.40	0	11.5	WSW	89	19	8	4	725
J	95.4	66.5	0.69	0	10.5	S	88	20	7	3	734
J	94.9	68.9	1.29	0	9.2	SSE	79	12	13	6	676
A	93.0	67.7	1.19	0	8.8	S	80	14	12	5	637
S	87.5	61.4	1.14	0	8.6	S	83	19	6	5	569
O	78.8	50.0	0.85	0	8.4	N	85	20	6	5	470
N	66.3	36.1	0.33	0.8	9.0	N	82	18	5	7	361
D	56.5	30.7	0.49	1.0	9.0	N	77	16	7	8	310
Yr	77.2	49.4	7.89	4.3	10	N	83	196	95	44	539

From: Climatology of the United States #60-41, Climates of the States - Texas, revised & reprinted, 1969.

TABLE VI

Weather Station on Campbell St., El Paso, Texas, 1975-76

Percentage Frequencies of Wind Direction

	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
April '75	-	-	3.3	-	-	10.0	10.0	13.3	-	13.3	10.0	30.0	10.1	-	-	-	100
May	-	-	-	-	-	3.2	6.5	22.6	6.5	19.4	16.0	12.9	6.5	6.4	-	-	100
June	-	-	-	-	-	4.7	16.7	30.0	13.3	3.3	6.7	6.7	10.0	3.3	6.7	-	100
July	-	-	-	-	-	3.2	41.9	45.2	-	-	3.2	6.5	-	-	-	-	100
August	-	-	-	19.4	45.2	9.7	9.7	6.5	-	3.2	-	3.2	3.1	-	-	-	100
Sept.	-	-	3.3	23.3	30.0	3.3	3.3	6.7	10.0	10.0	10.1	-	-	-	-	-	100
Oct.	-	-	-	12.9	3.2	9.7	9.7	12.9	3.2	16.1	3.2	9.7	12.9	6.5	-	-	100
Nov.	-	-	3.0	3.0	7.0	10.0	7.0	10.0	7.0	10.0	20.0	13.0	10.0	-	-	-	100
Dec.	-	-	7.0	3.2	9.7	3.2	9.7	6.5	6.5	9.7	9.7	12.9	16.1	6.5	-	-	100
Jan. '76	-	-	-	-	12.9	6.5	6.5	3.2	12.9	19.4	3.2	19.4	12.9	3.1	-	-	100
Feb.	-	-	-	-	3.5	6.9	10.3	13.8	17.2	6.9	6.9	13.8	20.7	-	-	-	100
March	-	-	-	6.5	3.2	3.2	6.5	16.1	9.7	12.9	6.5	9.7	22.6	3.1	-	-	100
April	-	-	-	3.3	3.3	10.0	3.3	16.7	10.0	10.0	3.3	20.0	16.7	3.4	-	-	100

is related to both wind shear and temperature structure, but is generally related to the latter which is used as an indicator of the condition.[23]

The rate of decrease of temperature with increase in height is called the lapse rate. If the rate of decrease of temperature refers to the air environment, it is called the environmental lapse rate; however, if it refers to a parcel of air moving within the air environment, it is called the process lapse rate or adiabatic lapse rate. Two significant lapse rates are the adiabatic lapse rate for dry air and the adiabatic lapse rate for saturated or moist air.[23] The adiabatic lapse rate for wet or moist air is smaller than for dry air because of the release of latent heat caused by changes in the phase of moisture contained in the parcel of air subjected to rapid pressure changes. In fact, when a small parcel of air is forced upward in the atmosphere it will expand and cool in lower pressure areas. Under the assumption there is no exchange of heat between the environment and the parcel of air, the rate at which cooling occurs during the ascent is the dry adiabatic lapse rate, whose value is approximately -10°C/1 Km. or -5.5°F/1000 ft. However, such process never occurs in the atmosphere since turbulence tends to destroy the theoretically isolated volume.[24]

When environmental conditions are such that the rate of change of temperature with height exceeds the dry adiabatic lapse rate, a superadiabatic condition develops. This condition results from strong solar heating which favors strong convection turbulence and an unstable atmosphere. A condition in which the lapse rate of the atmosphere is nearly identical to the adiabatic lapse rate implies no tendency for a displayed volume of air to gain or lose buoyancy. This condition is referred to as neutral and is associated with moderate to strong winds and overcast skies. However, a condition in which the environmental lapse rate is less than the adiabatic lapse rate is defined as subadiabatic or negative. This condition resists vertical motion and means that a rising parcel of air becomes cooler and denser than its surroundings. Under such conditions, it will tend to descend or return to its departing condition. A volume of air displaced downward becomes warmer and will rise to its original level. Finally, when the environmental lapse rate is constant with the altitude the condition is termed isothermal and indicates a slight tendency for a displaced parcel of air to resist vertical displacement.

An atmospheric condition which strongly resists vertical motion and tends to suppress turbulence is called an inversion. Inversions are classified as surface or radiation inversions, and elevated inversions. Surface inversions are usually found during nightime hours along with light winds and clear skies. Elevated inversions may be caused by subsidence, fronts and sea breezes. Figures 4 and 5 illustrate typical environmental lapse rates and elevated inversions, respectively.

The frequency of radiation inversions is quite important in an assessment of air pollution problems. In the El Paso-Juárez area, radiation inversions are most frequently present during the cold seasons. Figures 6 through 9 depict the frequency of thermal inversions for the state of Texas. In the El Paso-Juárez area, inversion are present during the spring months 30 to 35 percent of the time; in the summer, 25 percent of the time; in the fall, 40 to 45 percent of the time and in tendency for a displayed volume of air to gain or lose buoyancy. This condition is referred to as neutral and is associated with moderate to strong winds and overcast skies. However, a condition in which the environmental lapse rate is less than the adiabatic lapse rate is defined as subadiabatic or negative. This condition resists vertical motion and means that a rising parcel of air becomes cooler and denser than its surroundings. Under such conditions, it will tend to descend or return to its departing condition. A volume of air displaced downward becomes warmer and will rise to its original level. Finally, when the environmental lapse rate is constant with the altitude the condition is termed isothermal and indicates a slight tendency for a displaced parcel of air to resist vertical displacement.

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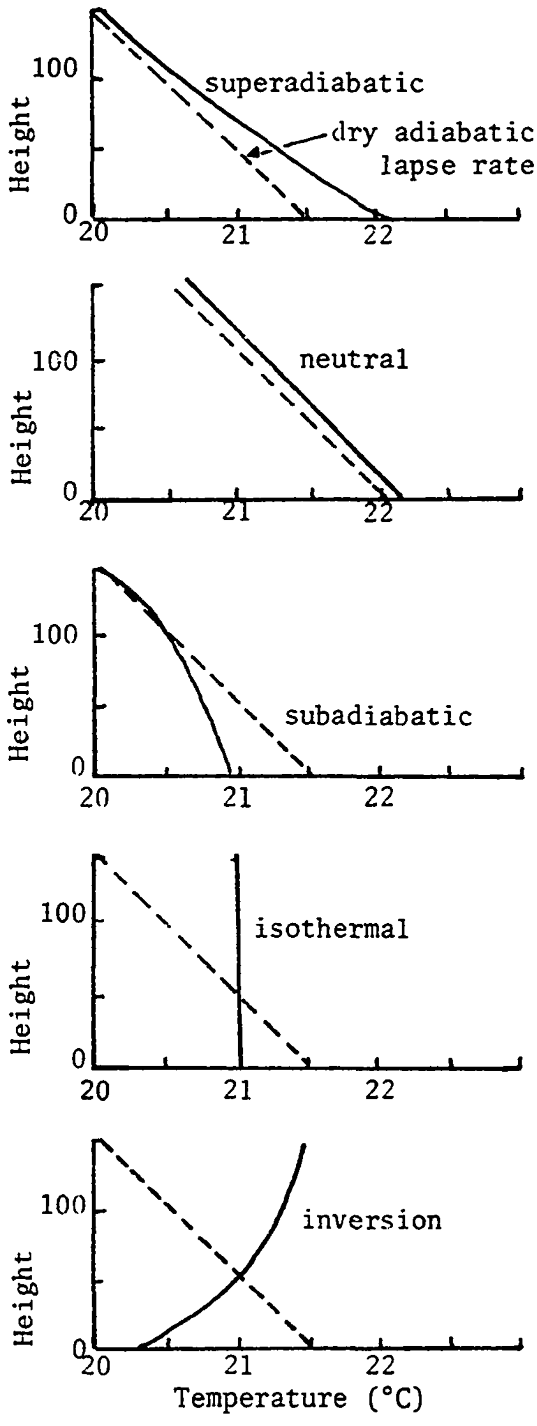


FIGURE 4.

TYPICAL ENVIRONMENTAL LAPSE RATES.

Typical examples of vertical temperature profiles are shown in comparison with the dry adiabatic lapse rate (-1C/100 m) which serves as a reference for distinguishing unstable from stable cases. The position of the dashed line representing the adiabatic lapse rate is not important; it is significant only as far as its slope is concerned.

SOURCE: ASME Committee on Air Pollution Controls, (sponsored by) Recommended Guide for the Prediction of the Dispersion of Airborne Effluents. Copyright 1968 by The American Society of Mechanical Engineers, United Engineering Center, New York, N.Y., p.9.

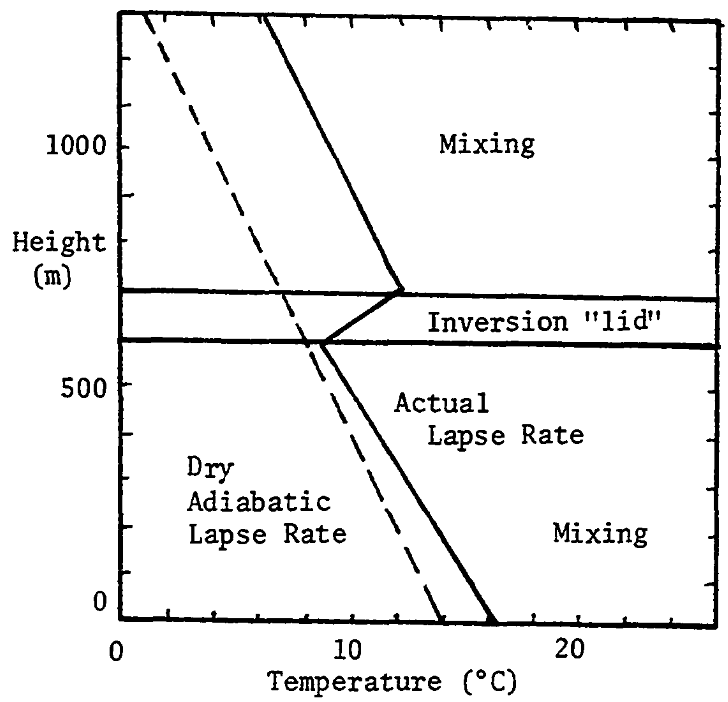


Figure 5. Elevated Inversion. Sometimes an inversion exists above the ground surface, acting as a barrier between the mixed layer close to the surface and that aloft.

Source: ASME Committee on Air Polution Controls, "Recommended Guide for the Prediction of the Dispersion of Airborne Effluents". Copyright 1968 by the American Society of Mechanical Engineers, United Engineering Center, New York, New York, p. 10.

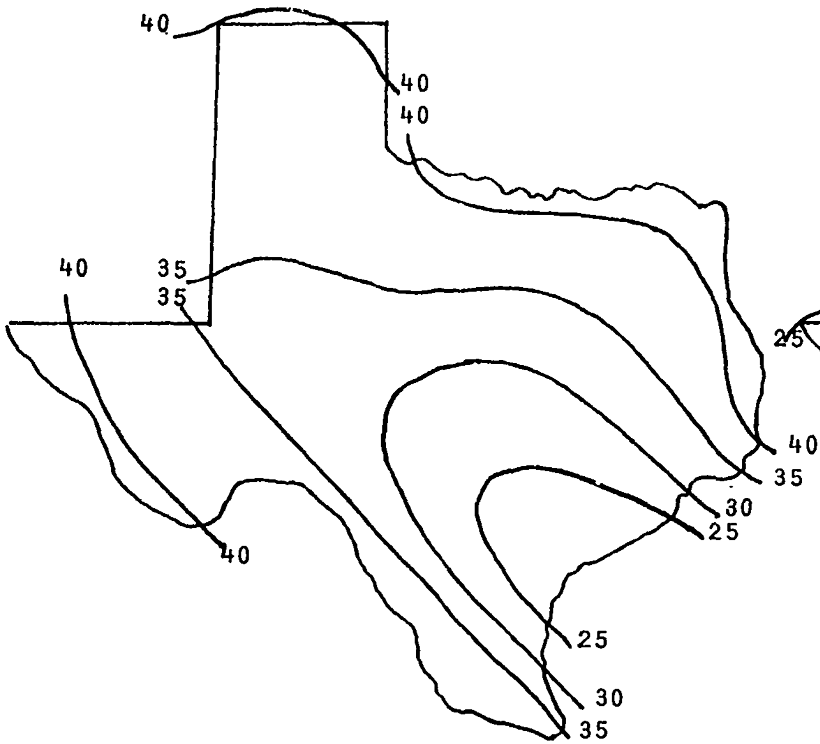


Figure 6. Frequency of Inversions and/or Isothermal Layers Based Below 500 Feet (percent of total hours), for Fall (Sept., Oct., Nov.).

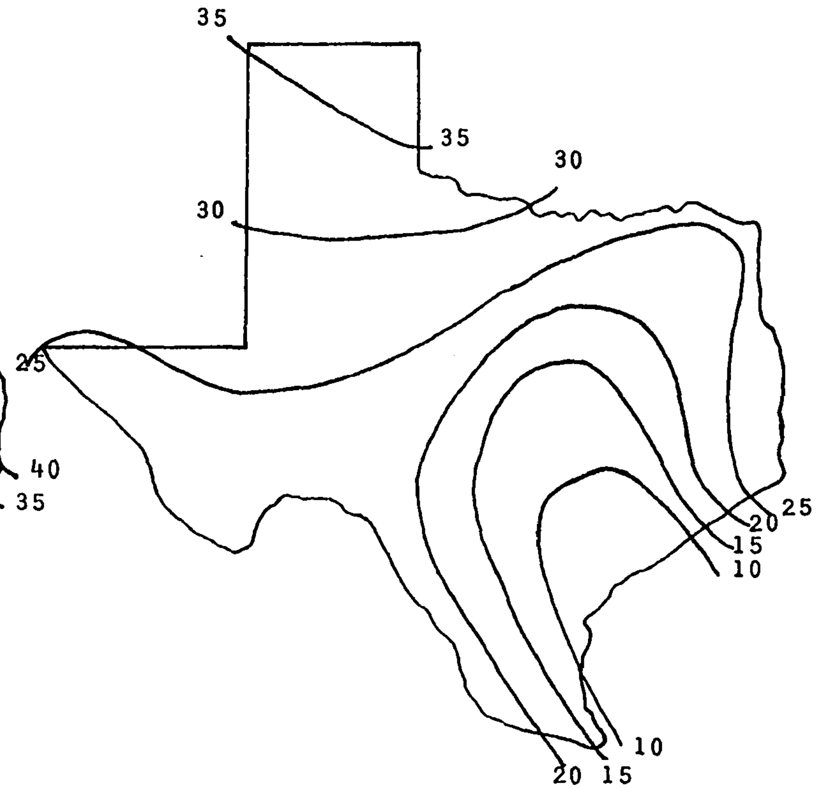


Figure 7. Frequency of Inversions and/or Isothermal Layers Based Below 500 Feet (percent of total hours), for Summer (June, July, August).

Source: C. R. Hosler, "Low-level Inversion Frequency in the Contiguous United States", <u>Monthly Weather Review</u> 89:319-339, (September 1961).

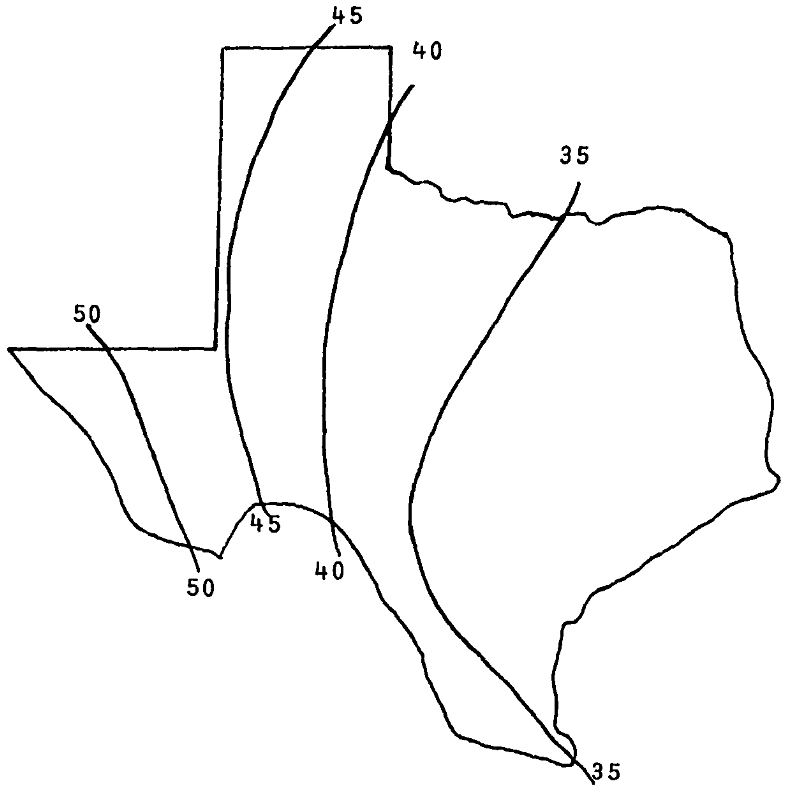


Figure 8. Frequency of Inversions and/or Isothermal Layers Based Below 500 Feet (percent of total hours), for Winter (Dec., Jan., Feb.).

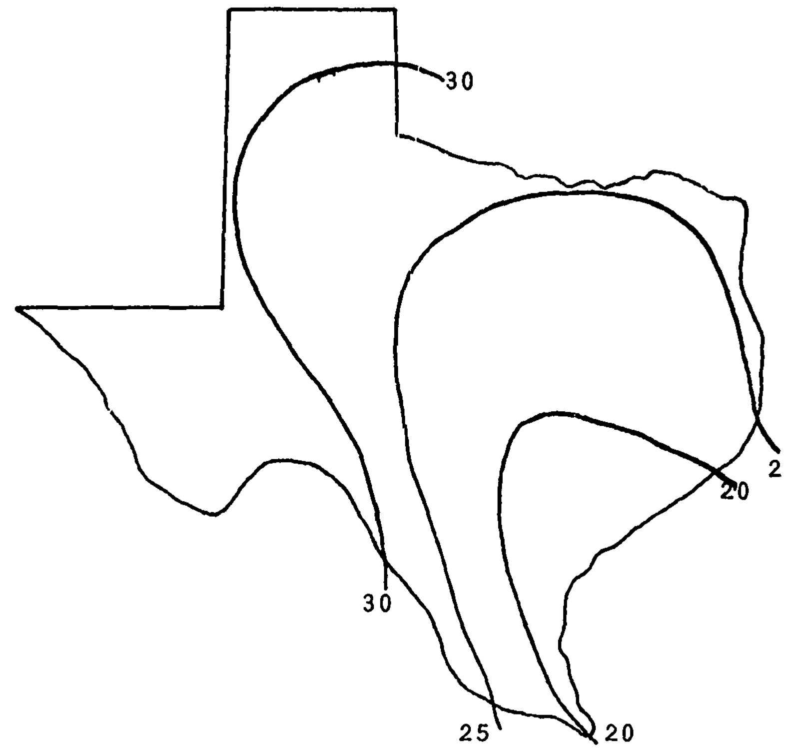


Figure 9. Frequency of Inversions and/or Isothermal Layers Based Below 500 Feet (percent of total hours), for Spring (March, April, May).

Source: C. R. Hosler, "Low-level Inversion Frequency in the Contiguous United States" , Monthly Weather Review 89-319-339, (September 1961).

the winter, 50 to 55 percent of the time.[21] The reasons for such high frequency wintertime inversions in west Texas include the higher elevations, drier air, cloudless nights, and the loose sandy soils which characterize the area.

The mechanisms causing thermal inversions involved during nocturnal radiational cooling are shown schematically in Figure 10. These mechanisms occur wherever the surface of the earth becomes cooler during the night by thermal radiation of energy. As a result of the decrease in the temperature of the ground, the lower atmosphere in contact with the surface loses sensible heat through conduction, convection, and more importantly, through radiation. Consequently, a temperature inversion is established between the cool level air and the warmer air above it.[25] The rate at which heat flows upward to the ground surface can be approximated by a formula assuming a linear dependence on the temperature gradient $\Delta T/\Delta d$, where Q_h is the heat flow, T is the temperature, and d is the depth below the surface:[25]

$$Q_h = -K_h \, \Delta T/\Delta d$$

The constant K_h, which is called the thermal conductivity, is dependent on the texture and composition of the soil, degree of compactness and the amount of moisture present. The value of K_h ranges from $0.2 W/m^2$-°C for dry soils to $2 W/m^2$-°C for moist soils, where W/m^2 is watts of heat conducted per square meter of soil surface.

A close examination of soils occurring in the El Paso-Juarez area indicates that 55% is coarse loam and 24% is fine sand and loam. The balance consists of varied soil types, with most soils having particle sizes

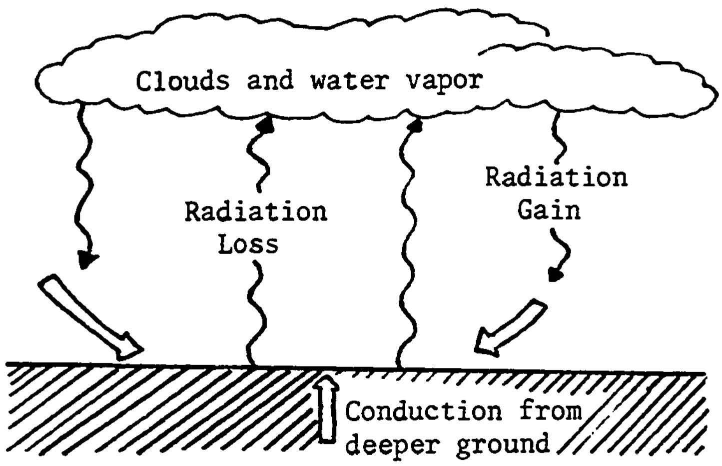


Figure 10. Mechanisms Involved in the Energy Flow to the Earth's Surface During Nocturnal Radiational Cooling.

Source: S. J. Williamson, Fundamentals of Air Pollution, Philippines: Addison-Sesley Publishing Co., Inc. (1973), p. 161.

of less than 10 microns.[22] It is possible that the type of soils found in the area play an important role in the high frequency of inversions characterizing the area, especially during the winter time.

Precipitation is of interest in air pollution since it provides a scrubbing mechanism by removing suspended particles from the atmosphere and depositing them on the surface of the earth. In the El Paso-Juárez area the expectancy of pollutant washout is small due to the semidesert conditions. Thunderstorm frequency is an important factor in evaluation of air pollution potential, regardless of the "washout" factor, since the strong horizontal and vertical motions often associated with this phenomenon are favorable for the rapid diffusion of pollutants.[22] For the El Paso-Juárez area thunderstorm occurrence is rather high during July and August, with an average of ten thunderstorm days each month, however, thunderstorms only rarely occur during the colder months.[22]

Other meteorological factors affecting ground level concentrations of air contaminants are mountain and valley winds. On a sunny day the layer of air near a heated mountain slope will warm faster through radiation and convection of heat from the ground. The relative buoyancy of the warmer air near the slope causes an upslope wind whose depth varies according to the intensity of sunlight and the slope of inclination, but it typically extends for several hundred meters above the terrain.[25] Late in the afternoon the process reverses. Loss of heat rapidly lowers the temperature of the slope and the adjacent layer of air, and this less-buoyant air drains down into the valleys. Downslope nocturnal winds encourage stable conditions when they converge on an enclosed valley. Cold, dense air around the valley floor can cause a ground-based inversion or strengthen an existing radiational inversion which can extend upward for several hundred meters.[25] Figure 11 illustrates the nature of mountain winds.

Plume Behavior as a Function of Atmospheric Stability

The nomenclature of continuous plumes from stack sources over level terrain is of interest in the study of meteorology as related to air pollution. Stack plumes can be classified as looping, coning or neutral, fanning, fumigating, and lofting. Looping plumes occur on clear days with an unstable temperature gradient. This is observed in the El Paso-Juarez area during warm afternoons when solar insulation is high and heating of the earth's surface is pronounced, thus causing the lifting of heated parcels of air which destroy the air stratification formed by nocturnal surface inversions. Also, generation of large eddies produced by thermal turbulence carries the plume up and down, dispersing it rapidly. High ground level concentrations near the source are likely to occur under this type of plume behavior.

Coning occurs with moderate wind speeds and overcast skies. High ground level concentrations are reached at greater distances from the source than for looping; however, less dispersion in general is likely to occur under this condition. Fanning is characterized by minimal vertical plume dispersion and occurs under stable conditions. However, the plume can meander and substantially disperse pollutants horizontally, thus complicating the prediction of ground level concentrations. When thermal turbulence reaches the plume release height, this condition is called fumigation and causes rapid downward mixing,

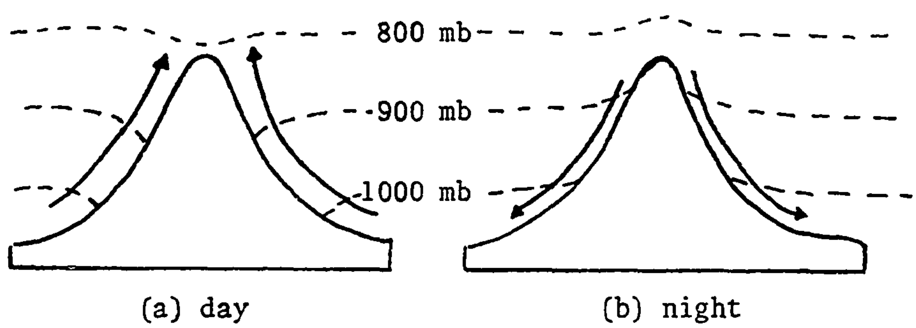


Figure 11. Schematic Representation of Nocturnal and Daytime Mountain Winds. (a) Upslope daytime wind. (b) Downslope nocturnal winds. The dashed curves represent contours of uniform pressure (isobars).

Source: S. J. Williamson, Fundamentals of Air Pollution, Philippines: Addison-Wesley Publishing Co., Inc. (1973), p.171.

resulting in high ground level concentrations.[26] Lofting occurs when elevated inversions are entirely below the plume release height. This condition inhibits downward mixing but enhances lateral and vertical diffusion.

Calculation of Dispersion and Deposition from Point Sources.

Several dispersion equations are based on the assumption that the concentration distribution of a dispersing plume or cloud is Gaussian. The Sutton and Bosanquet equations involve this assumption. However, the basic Gaussian equation is often used because it provides the greatest flexibility for adjustment to future developments and data.[24] The basic equation giving the concentration, χ, of a gas or aerosols (particles less than about 20 microns) at downstream points x,y,z from a continuous source with an effective emission height H is given by the following form:[24]

$$\chi_{\{x,y,z\}} = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}} \exp-(y^2/2\sigma_y^2) \left[\exp-\left\{\frac{(z-H)^2}{2\sigma_z^2}\right\} + \exp-\left\{\frac{(z+H)}{2\sigma_z^2}\right\}\right] \quad (I)$$

where χ = concentration of pollutants (units/m^3)

H = effective stack height of plume centerline when it becomes essentially level (m)

Q = rate of emission of pollutants (units/sec.)

x = horizontal distance parallel to the mean wind speed (m)

y = Horizontal distance perpendicular to x, called the crosswind distance (m)

z = vertical distance normal to x, also called the earth-air interface vertical distance (m)

$\bar{u}$ = mean wind speed at the height of point source. (m/sec.)

σ_y = horizontal or crosswind plume standard deviation. (m)

σ_z = vertical plume standard deviation. (m)

The effective stack height, H, is a function of the momentum, or exit velocity, and temperature of the gas coming from the stack. It is also a function of the prevailing meteorological conditions such as wind speed, atmospheric pressure, and air temperature at the actual stack height. The quantities σ_y and σ_z vary with the turbulent characteristics of the atmosphere, height above the surface, surface roughness, sampling time over which the concentration is to be calculated, wind speed, and distance from the source. For the parameters given in the equation, the sampling time is assumed to be about ten minutes, the stack height is in the lowest several hundred meters of the atmosphere, and the surface around the source is relatively open country.[27]

Table VII illustrates the different classes of atmospheric stability as a function of several environmental variables. Figures 12 and 13 provide the means of obtaining the numerical values of σ_y and σ_z, respectively.

There are several special cases of the Gaussian plume model. One is for the ground-level concentration X(x,y,0) and another is for the distribution of the ground-level concentration along the centerline of the plume X(x,0,0). The equation for the ground-level concentration from an elevated point source (z=0) is:[24]

$$X_{(x,y,0)} = \frac{Q}{\pi\sigma_y\sigma_z\bar{u}} \exp -\left\{\left(\frac{H^2}{2\sigma_z^2}\right) + \left(\frac{y^2}{2\sigma_y^2}\right)\right\} \qquad (II)$$

TABLE VII

Key to Stability Categories as a Function of Ambient Variables, with Notes Based on Comments of Turner, and Stern et al.[20]

Surface wind speed (10 m) ($m\ sec^{-1}$)	Day[a] Incoming solar radiation is ...			Night[a] Low level cloud cover is ...	
	Strong[b]	Moderate[c]	Slight	$\geq 4/8$[d]	$\leq 3/8$[d]
Less than 2	A	A,B	B	(X)	(X)
2 to 3	A,B	B	C	E	F
3 to 5	B	B,C	C	D	E
5 to 6	C	C,D	D	D	D
Above 6	C	D	D	D	D

[a]For central urban environments, classes, A, B, and C become B, C, and D; and class D is always used at night. Class A the most unstable; class F the most stable. "Night" refers to a period from one hour before sunset to one hour after sunrise. Neutral class D can be considered for overcast conditions during day or night.

[b]"Strong" refers to clear skies with zenith angles, $Z \leq 30°$.

[c]"Moderate" refers to clear skies with $30° < Z < 55°$ and "slight" insolation refers to clear skies with $15° < Z < 35°$.

[d]In the United States, cloud cover is in tenths rather than oktas. (X) Not defined; "plume" will not be identifiable.

Source: A. C. Stern et al., Fundamentals of Air Pollution, New York and London: Academic Press, Inc. (1973).

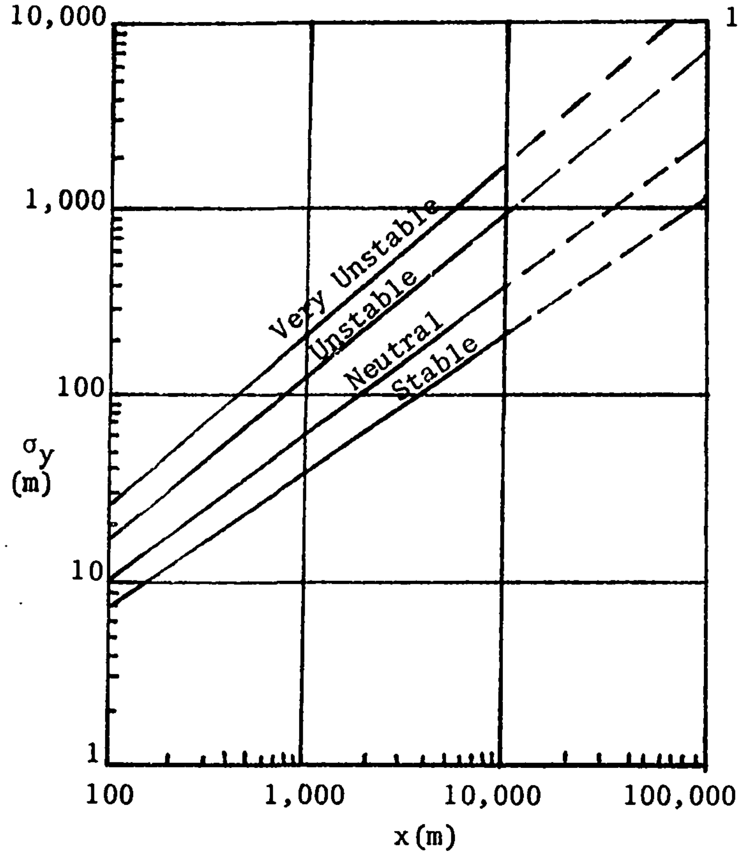


Figure 12. Horizontal Standard Deviations of a Plume. In the dispersion equations, the cross-wind plume standard deviations are functions of distance (x) and meteorological conditions. Four such plots are given in this figure. The dashed lines indicate that the relations are tentative and unreliable beyond 10,000 meters.

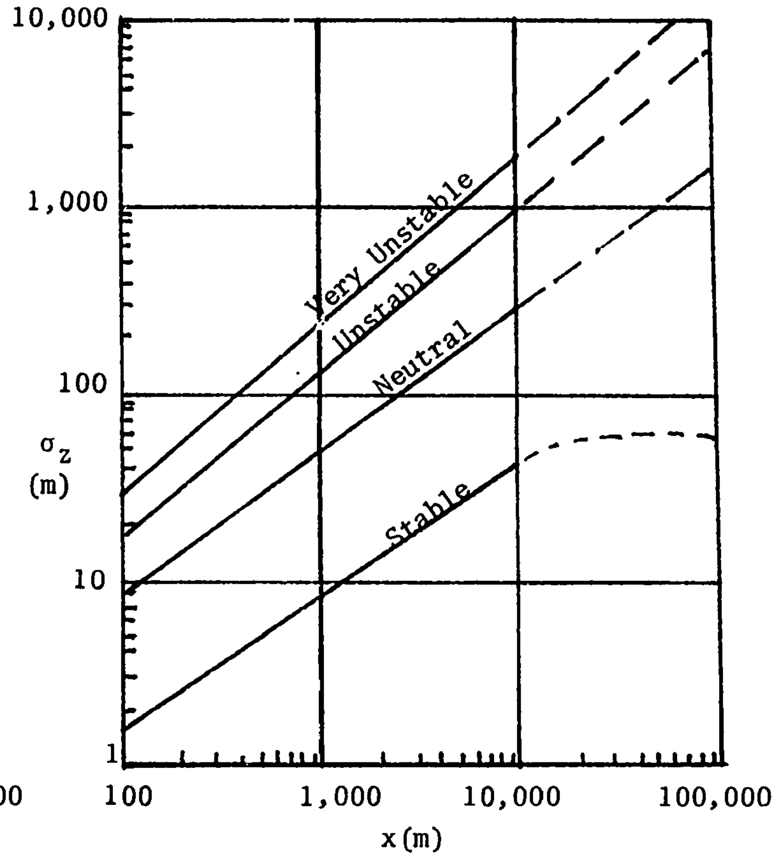


Figure 13. Vertical Standard Deviations of Plume. The stable plot approaches a constant beyond 10,000 meters because it is believed that vertical dispersion almost ceases in such conditions.

SOURCE: ASME Committee on Air Pollution Controls, (sponsored by) Recommended Guide for the Dispersion of Airborne Effluents. Copyright 1968, by the American Society of Mechanical Engineers, United Engineering Center, New York, N.Y., pp. 45-46

The ground level concentration directly downwind from an elevated source (y and z = 0) can be determined from:[24]

$$\chi_{\{x,0,0\}} = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp -(H^2/2\sigma_z^2) \qquad (III)$$

Figure 14 illustrates the coordinate system showing the Gaussian distributions in the horizontal and vertical directions. The diffusion equation for areas such as El Paso and Juárez would have limited use because the restrictions of the underlying assumptions. In fact, the complexities of the terrain and the heat island effect undoubtedly induce complications in the transport and diffusion of air pollutants, thus creating difficulty in projecting pollutant concentrations with any degree of confidence.

The "El Paso del Norte" pass, which is located in the Franklin, Cristo Rey, and Juárez mountain ranges induces complex wind patterns over the whole El Paso-Juárez area in variance with those observed at the El Paso International Airport. Studies conducted by Bhaduri[28] (personal communication) suggest the most dominant feature of the area is constituted by the Franklin and Juárez mountain ranges forming a constricted pass resembling the throat of a venturi meter. This could influence the air diffusion patterns, especially when the wind is blowing from the north. Comparison of the wind speeds at two different downtown locations and the El Paso International Airport for the period October 17, to November 14, 1968, reveals there is little relationship between the daily average wind speeds at the downtown locations and the airport. These monthly comparisons are depicted in Figures 15 and 16.

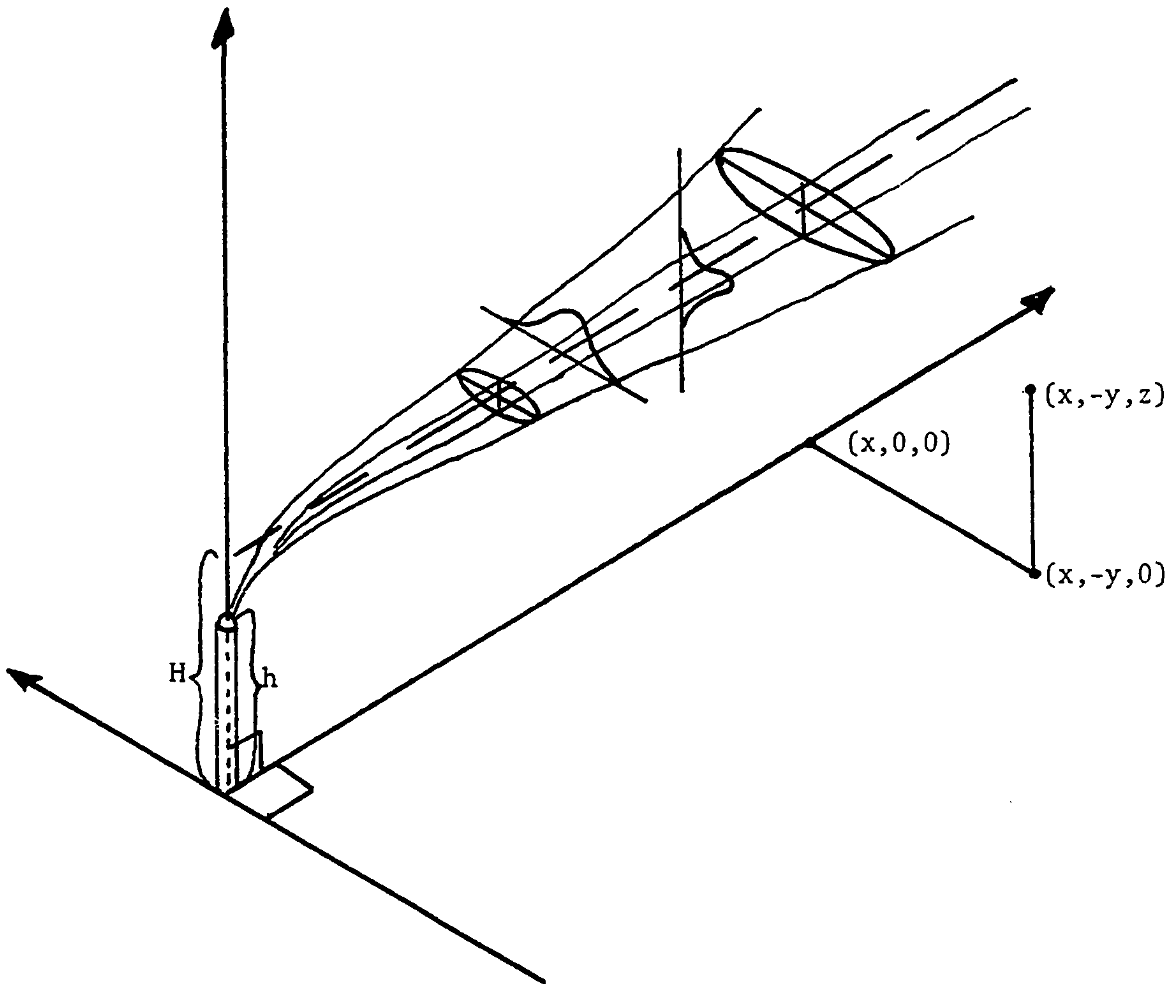


Figure 14 . Coordinate System Showing Gaussian Distributions of a Plume in the Horizontal and Vertical.

Source: D. B. Turner, "Workbook of Atmospheric Dispersion Estimates", U.S. Environmental Protection Agency, PHS. Pub. No. 999-AP-26 (1969), p. 84.

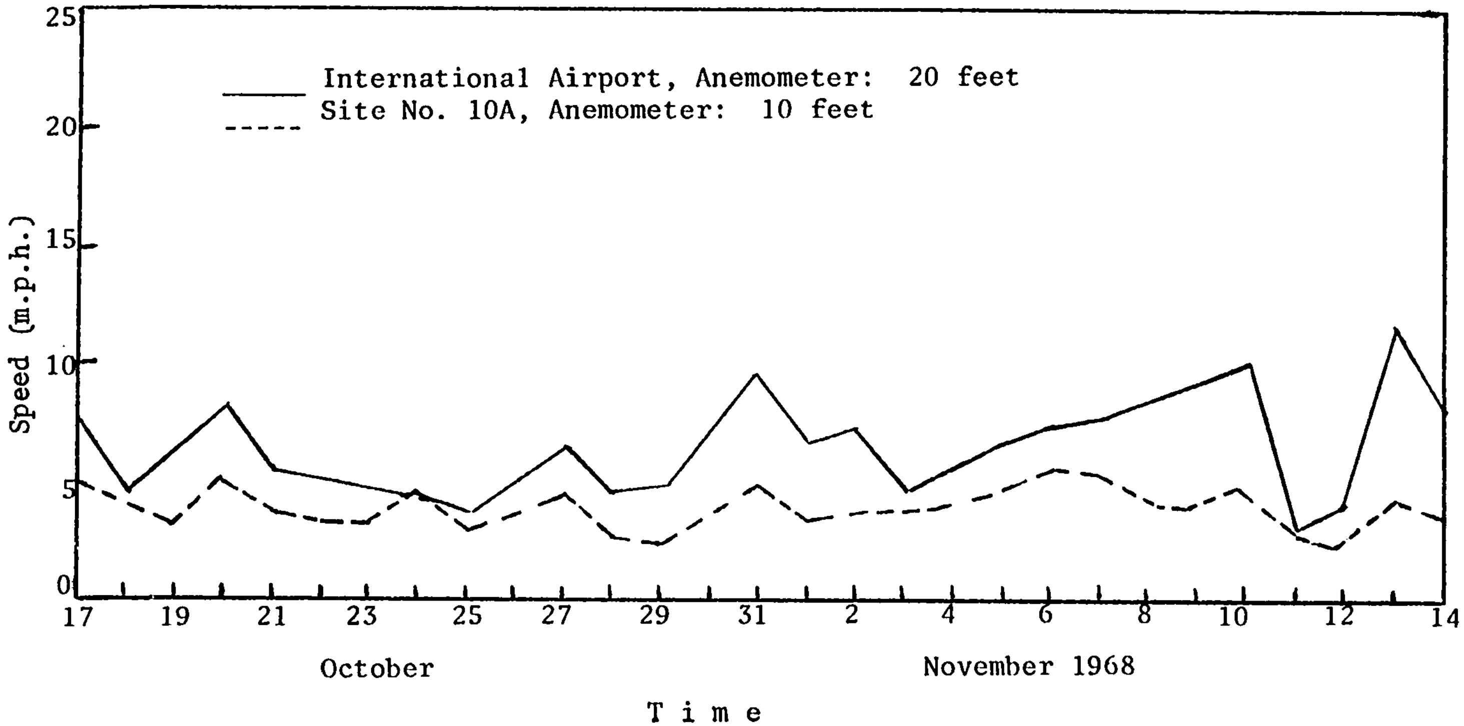


Figure 15. Comparison of Average Wind Speed at the El Paso International Airport Anemometer and El Paso City County Health Department Anemometer.

Source: Air Quality Survey, El Paso Metropolitan Area, Texas State Department of Health, October 15, November 15, 1968.

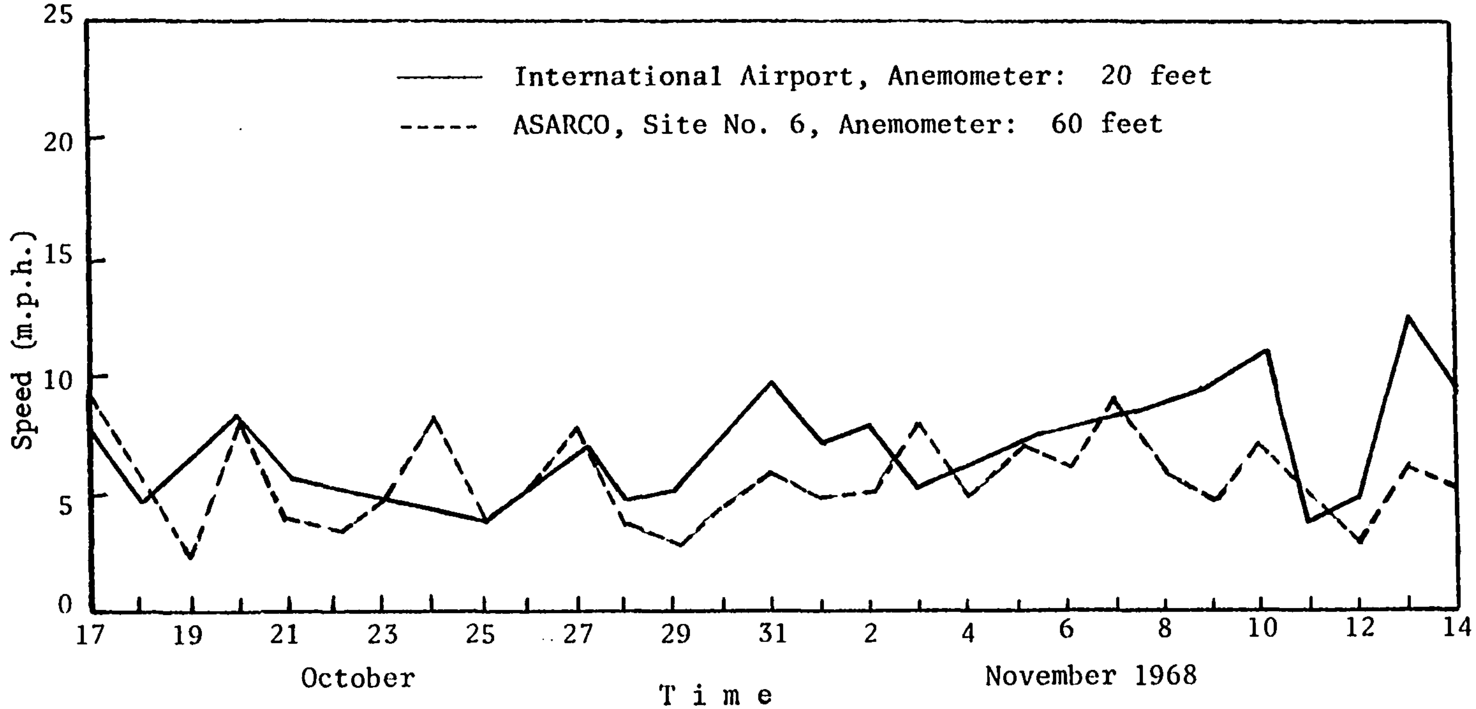


Figure 16. Comparison of Average Wind Speeds at the El Paso International Airport Anemometer and American Smelter and Refining Company Anemometer.

Source: Air Quality Survey, El Paso Metropolitan Area, Texas State Department of Health, October 15, November 15, 1968.

Comparison of the average wind speeds at three different locations in El Paso was made for October and November, 1975, with the results depicted in Figure 17. A Further comparison of wind directions for November 1975, of data from the airport and a downtown El Paso station (Campbell St.) is shown in Figure 18. In some instances the wind direction recorded at the same time from the two stations are 180° apart. Seasonal wind roses for these locations also reflect differences in wind speed and direction. These data are schematically shown in Figure 19.

The preceding discussion suggests that due to the complex topographic features characterizing the area, calculations of precise atmospheric inputs are difficult to predict with any degree of confidence and only rough approximations can be obtained by a modification of the basic diffusion equation.

Production of Lead by Smelting and Refining

The American Smelting and Refining Company (ASARCO) of El Paso, Texas, had its begining in 1887. However, through the intervening years major additions were made including the construction of facilities for the recovery of zinc. Later on, in order to reduce ground level concentrations, a 612-foot lead plant stack was erected in 1951, and a 828-foot stack for a copper plant was built in 1967. Today, the annual smelting capacities of the industrial source are approximately 420,000 tons for the lead plant and 525,000 tons for the copper plant.[29]

In December 1971, during a court trial against ASARCO, El Paso City County Health Department found that during the preceding three years, the smelter had emitted approximately 4,999 tons of particulates

.......Texas Air Control Board, Anemometer on Ascarate Park: 20 feet
-------Texas Air Control Board, Anemometer on Campbell Street: 10 feet
_______International Airport, Anemometer: 20 feet

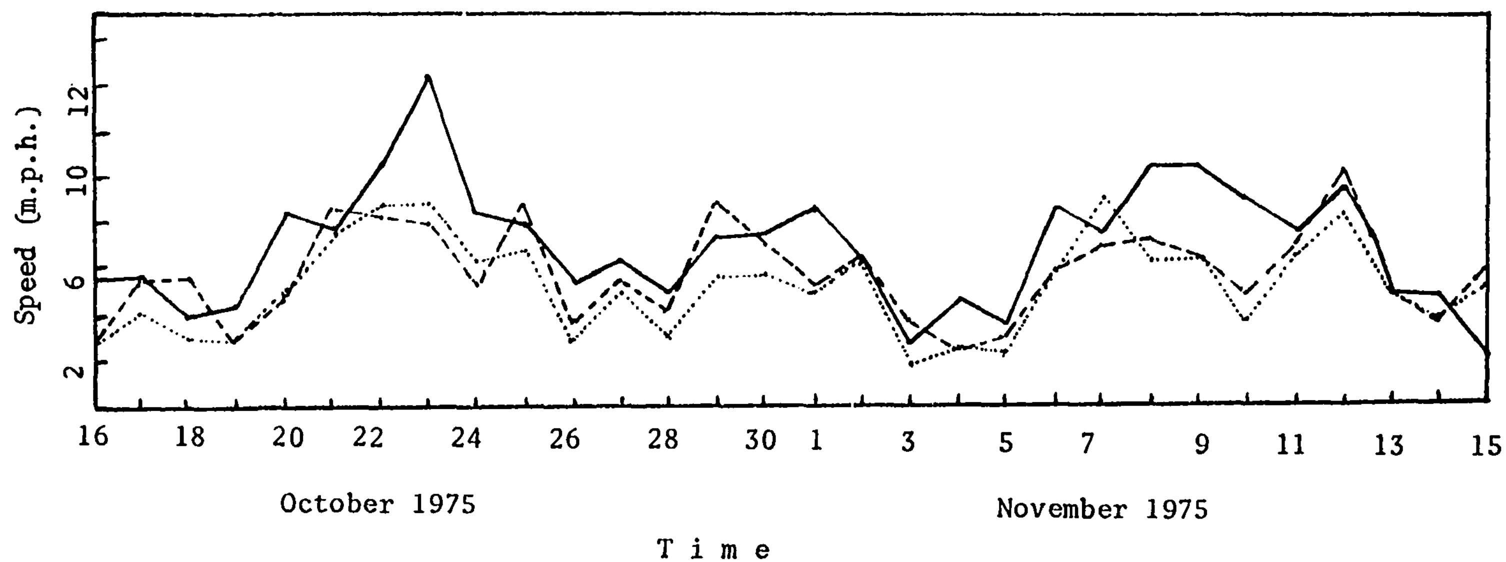


Figure 17 Comparison of Average Wind Speeds at the El Paso International Airport, Campbell Street and Ascarate Park Anemometers.

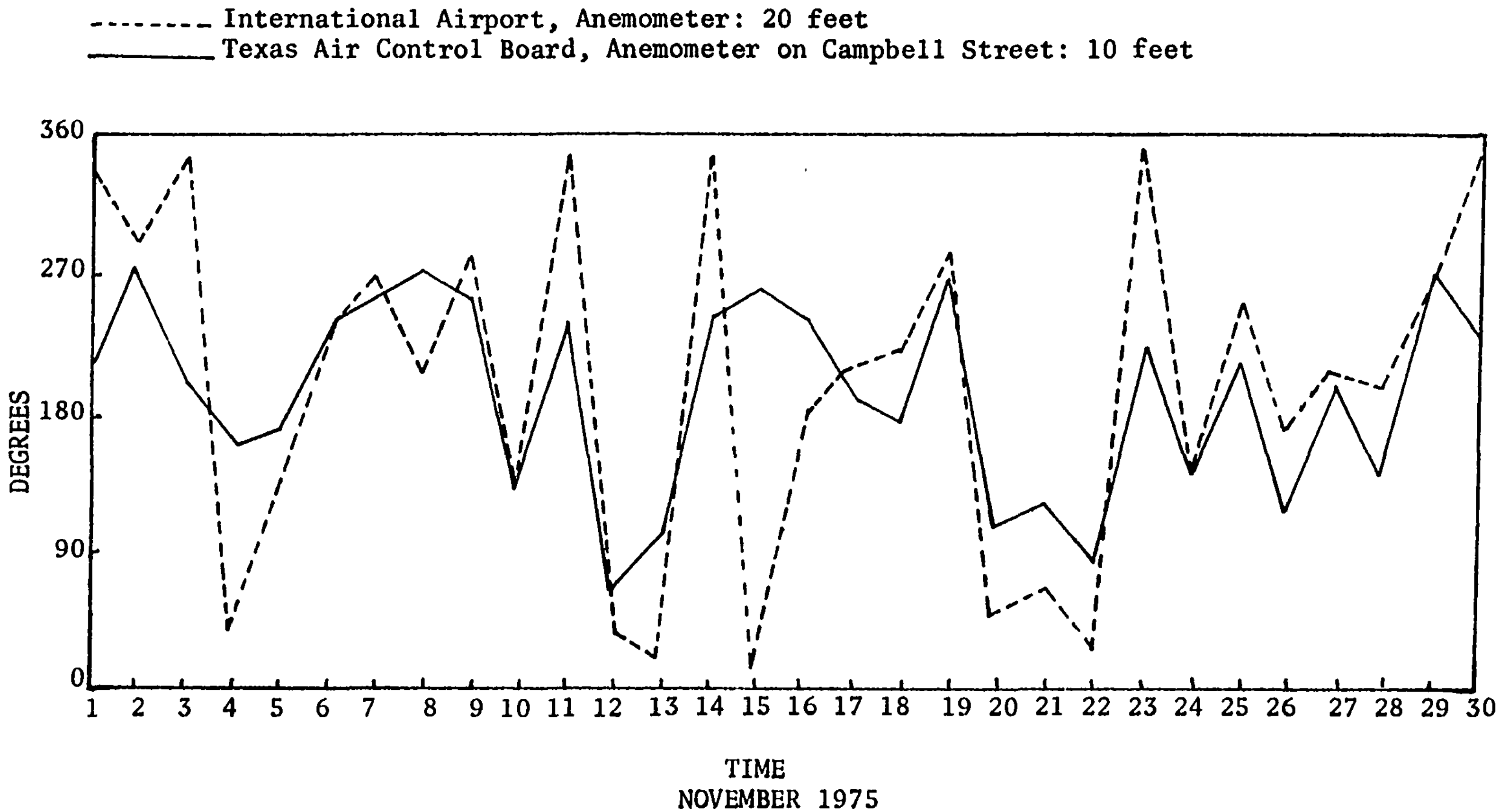


Figure 18. Comparison of Resultant Wind Direction at the El Paso International Airport and Texas Air Control Board Anemometers.

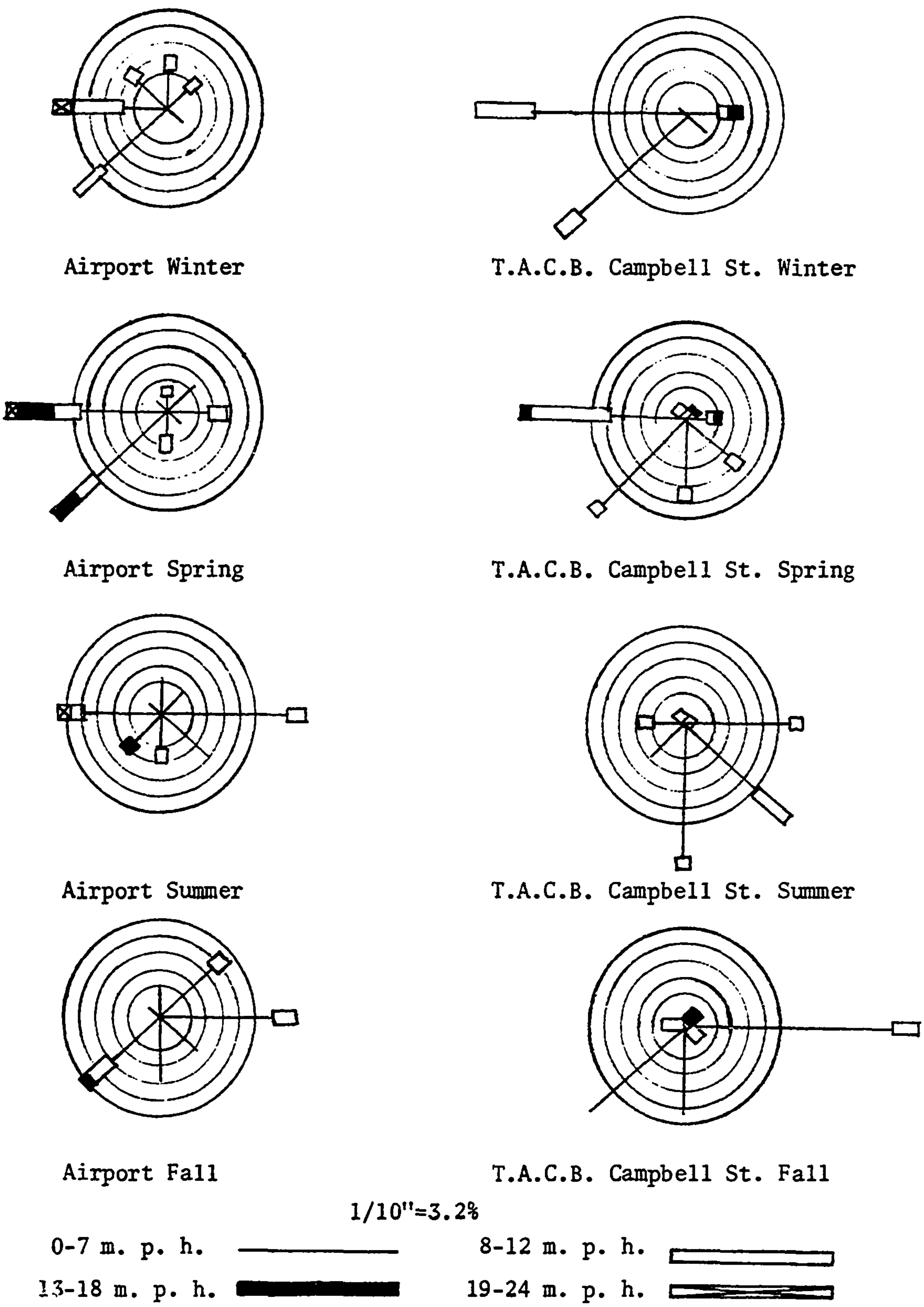


Figure 19. Seasonal Wind Roses of El Paso International Airport Anemometer and T. A. C. B. Anemometer on Campbell Street for Period April 1975, through April 1976.

through its stacks, including 1,116 tons of lead, 560 tons of zinc, and 1.2 tons of cadmium. Large quantities of particulate matter rich in heavy metals were also discharged through low-altitude vents and flues, and metal bearing dust was presumed to have been dispersed from uncovered rail cars, stockpiles, and slag heaps on the smelter premises.[3] Lead vapor emissions were not measured. Table VIII shows stack emissions of pollutants per year from the smelter from 1969, through 1971. This table shows approximate ratios of 2 to 1 and 100 to 1 for quantities of lead and zinc, and lead and cadmium, respectively.

Table VIII

Stack Emissions (Particulates) Per Year, El Paso Smelter
1969-1971

Year	Total Particulates (Tons)	Lead (Tons)	Zinc (Tons)	Cadmium (Tons)
1969	1,443	292	139	3.28
1970	2,274	511	264	4.90
1971	1,282	313	157	3.75
Totals	4,999	1,116	560	11.93

Source: Landrigan, P. J., S. H. Gehlbach, B. F., Rosenblum, J. M., Shoults, J., et al. "Epidemic Lead Absorption Near an Ore Smelter: The Role of Particulate Lead." New England J. Med. 292:123-129, 1975.

CHAPTER III

MATERIALS AND METHODS

In the planning of any study of atmospheric particulate matter, the most important facts to look for are the most practical, economical, and reliable type of equipment for the collection of the contaminant of interest. In the case of suspended particulate lead, the most commonly used sampling techniques for the collection of the metal on the particulate fraction are by means of filtration, impingement, scrubbing, and electrostatic precipitation. However, of all these methods available, the so-called High Volume Method (commonly called "Hi-Vol") has probably been used more widely than any other. One reason for this is that the equipment required is relatively inexpensive. Another reason is its ease of operation, and the accessibility of common equipment in most laboratories. The components of this kind of sampler are simply a metallic filter holder or adapter attached to a hosed vacuum sweeper motor which draws air through the previously placed filter media situated between the filter support screen and the gasket face plate. This type of sampler has been used on a large scale for more than fifteen years by the National Air Sampling Network.[30]

The factors that should be considered in the selection of the sampler locations are of paramount importance. These include the position of the sampler relative to localized sources of pollution, height above the ground, and sampling time. For example, if the method is designed to assess overall community-wide patterns, or to evaluate the typical values of contaminants over a large area, the samplers should be located outside localized or adjacent emitting sources of the pollutant of interest. If this procedure is not followed, the results would be a biased sample because under these conditions, the sample would be representative over an extremely small area rather than a wide community. The height of the samplers above ground is also an important variable and, accordingly, the monitors should be placed no more than 50 feet and no less than 20 feet above ground level.[31] However, if the assessment of an emitting industrial source is persued, the sampler should be located high enough to prevent the collection of dust and other particles raised by automobiles and other extraneous sources. The time of sampling is also important and, generally, it is desirable to collect the samples for a 24-hour period because this would allow a comparison of results to those obtained in other sampling sudies in the National Air Sampling Network.[31]

Sampling Site Selection

The sampling network utilized in this study consisted of nine stationary sampling sites established over an area covering some 21,620 hectares. Four of the sampling stations were already installed for previous studies done in the area. The network was extended by the addition of five more samplers. A thorough study of the most suitable places for the establishment of these five monitors was made. Variables, such as distance from the point source of interest, topographic features, strategic locations and facilities for electricity, security and accessibility were explored and accounted for. Finally, the most suitable places were chosen and appropriate permits for the establishment of the receptors in specific places were secured. At this point it is worth mentioning that there was some difficulty in securing the best locations for the establishment of the hi-vols, since in the area of study ample facilities for studies of this nature are not usually found. Nevertheless, arrangements were made by the author with the environmental office of Juarez and with municipal and federal agencies for the importation of the equipment into Mexico and for its proper installation. In addition, further arrangements were made through the intervention of the Pan American Health Office of El Paso, Texas, in order to secure the necessary permits for the utilization of the samplers already installed. The nature of these permits and documents is shown in the Appendix. Once the samplers were established and the network completed, the receptors were arbitrarily numbered for the purpose of facilitating the representation of the zones and for the collection and numbering of the samples. The characteristics of the network are depicted in Figure 20.

The physical description of the site locations were as follows:

Station No. 1 Located in a downtown commercial zone at a distance of 6.217 kilometers from the point source (smelter), and at an elevation of 1170 meters above sea level. Altitude of the structure was 9.14 meters above ground.

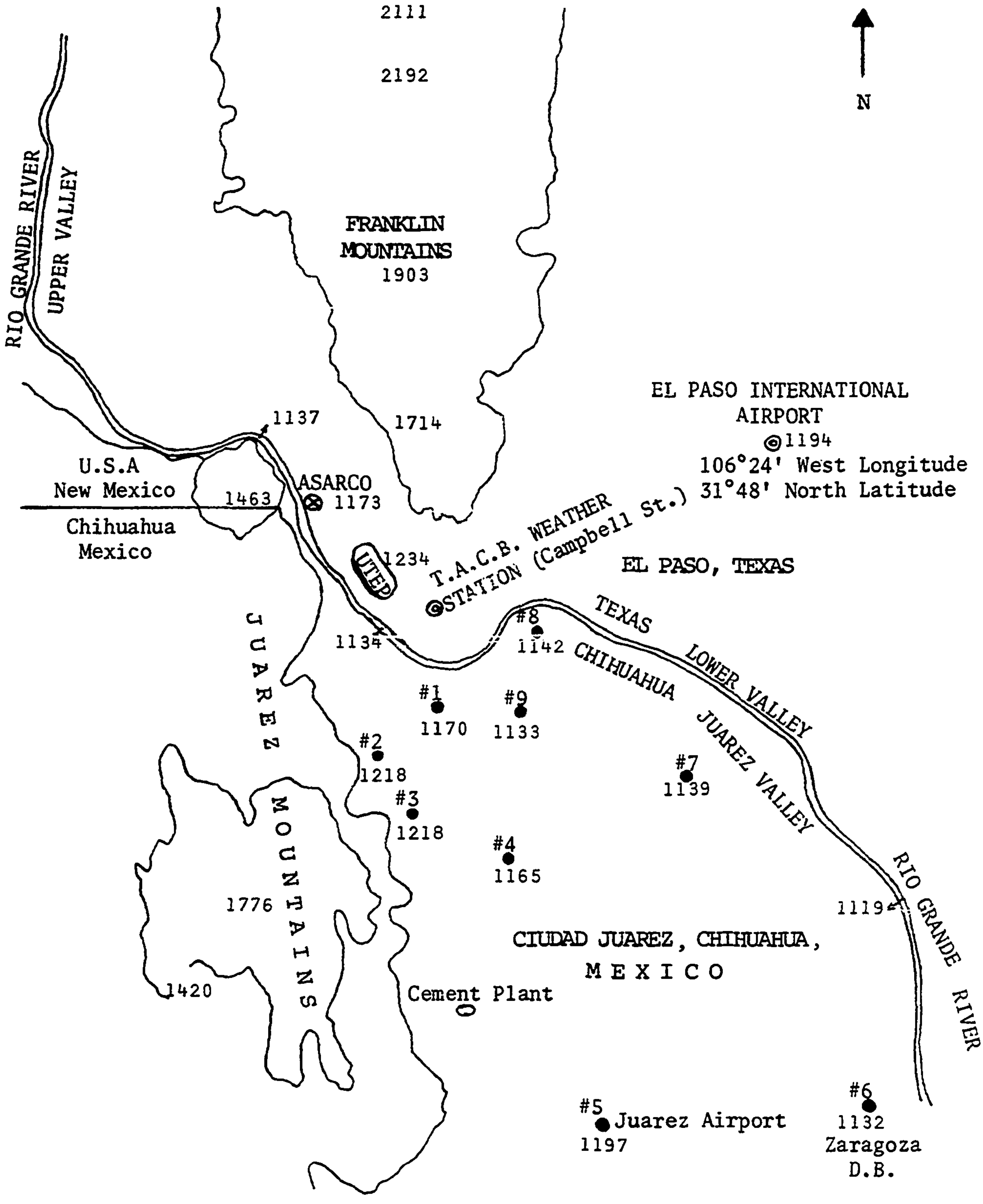


Figure 20. Location of Stationary Sampling Sites Utilized in the City of Juárez, Mexico, Showing the Locations of the Samplers and Elevations in Meters Above Sea Level.

Station No. 2 Located in a residential zone at a distance of 6.848 kilometers from the point source, and at an elevation of 1218 meters above sea level. Altitude of the structure was 4.57 meters above ground. (Addition)

Station No. 3 Located in a residential zone at a distance of 8.500 kilometers from the point source, and at an elevation of 1218 meters above sea level. Altitude of the structure was 4.57 meters above ground. (Addition)

Station No. 4 Located in a residential semi-industrial zone at a distance of 10.200 kilometers from the point source, and at an elevation of 1165 meters above sea level. Altitude of the structure was 6.09 meters above ground. (Addition)

Station No. 5 Located in a rural zone at a distance of 18.300 kilometers from the point source, and at an elevation of 1197 meters above sea level. Altitude of the structure was 15.24 meters above ground.

Station No. 6 Located in a semi-rural zone at a distance of 21.580 kilometers from the point source, and at an elevation of 1132 meters above sea level. Altitude of the structure was 5.49 meters above ground. (Addition)

Station No. 7 Located in a residential zone at a distance of 12.710 kilometers from the point source, and at an elevation of 1139 meters above sea level. Altitude of the structure was 9.14 meters above ground.

Station No. 8 Located in a national park at a distance of 6.675 kilometers from the point source, and at an elevation of 1142 meters above sea level. This sampler was situated at ground level. (Addition)

Station No. 9 Located in a residential-commercial zone at a distance of 7.818 kilometers from the point source, and at an elevation of 1133 meters above sea level. Altitude of the structure was 7.62 meters above ground.

As noted above, stations 1, 5, 7 and 9 were already established, and stations 2, 3, 4, 6 and 8 were added to the network at the begining of this study.

Sampling Equipment and Filtering Media

The type of samplers used for the study were General Metal Works Models 6 MWL-2000H and GMWL-2000 equipped with automatic timers and "visa float" flow meters for measuring flow rates through the filter media.

The filter type used for sampling particulate matter was a glassfiber filter, Gelman type A-E 8x10 inches. These filters were dried and weighed prior to use following the procedures outlined by the National Air Sampling Network, Division of Air Pollution, U. S. Environmental Protection Agency. This procedure consists of equilibrating each batch of filters at a temperature of approximately 75 °F and 50% relative humidity for approximately sixteen hours or overnight to insure uniformity of dryness of each filter before being weighed. The cooled filters are then weighed utilizing an analytical electric balance and the weights recorded.

The sampling facilities and glassfiber filters were provided by the Civil Engineering Department of the University of Texas at El Paso and by the Health Center of El Paso, Texas.

The samplers were operated every six days for a period of 24 hours. This schedule was not rigidly followed in some instances in which there were malfunctions in the motors and other operational problems. The operation and handling of the samplers was as follows: preweighed numbered filters were placed in the vertically-oriented shelters with the filter in a horizontal position. However, before the operation was done, filters were checked to insure that no holes or deformities on the surface were present. Additional care was taken in screwing the adaptor to insure an airtight seal. The initial and final air flow readings were measured with the flowmeter connected to the blower by rubber tubing. Before these values were recorded, additional care was taken to insure accurate airflow readings by shaking the visa float meter several times to insure free flowing movement. Otherwise dust and dirt might obstruct the air flow. Then the timer was set at the prescribed starting period which was usually from zero to 24 hours. After the period of exposure the filters were removed and placed in a manila folder. Figure 21 illustrates the type of information on the manila folder that was used for the storage of the used filters.

The collection of all the samples from the nine sampling sites was done personally by the author. The maintenance of the blowers

Figure 21. Typical Information Contained on a Manila Envelope for Storing High Volume Air Sample Used Filters.

HIGH VOLUME AIR SAMPLE DATA SHEET

Plant Name____________________

Plant Location____________________

Date____________________

Sampler No.____________________

Filter No.____________________

Initial Air Flow____________________

Final Air Flow____________________

Average Air Flow____________________

Time Begin____________________

Time End____________________

Received by____________________

LABORATORY DATA

Original Weight____________________

Final Weight____________________

Particulate Weight____________________

Remarks:

Sampled by____________________

such as worn brushes and calibration procedures was done in the Enviromental Sanitation Office of the El Paso Health Center.

Chemical and Analytical Studies

All the chemical and analytical determinations of the concentrations of lead, zinc, and cadmium were performed in the Department of Civil Engineering of the University of Texas at El Paso. The procedure for the digestion of the used filters was similar to that employed by the El Paso Health Center for the analysis of heavy metals with atomic absorption.

In essence, this procedure consisted of the following:

1. A strip of an area of seven square inches of dirty "Hi-Vol" filter was cut taking care that no uneven rips or spots were present across the strip.
2. The strip was cut into small pieces and placed into a 150 milliliter beaker and covered with a watch glass.
3. A volume of 50 ml. of 20% nitric acid (HNO_3) was added to the beaker containing the pieces of sample.
4. The solution was boiled on a hot plate, then small amounts of potassium chlorate ($KCIO_3$) were added, removing the watch glass, and slowly boiling the solution for ten minutes. Next, the beaker was removed from the hot plate, adding a few drops of concentrated hydrochloric acid (HCI).
5. The solution was boiled slowly until about 10 ml. of it was left.
6. Then the solution was removed from heat, cooled and filtered through a number 40 Whatman paper into a clean 50 ml. graduated cylinder.

7. The filter strips were washed in the beaker several times with hot deionized water adding the washings to filtrate through a funnel and Whatman filter until a final volume of 50 ml. was reached.
8. A blank solution was made to correct for impurities present in the filters by cutting a strip of the same size area (use thoroughly cleaned scissors) following the same procedure as for the dirty filters.
9. The solution was stored in teflon plastic bottles if analysis was to be delayed for a period of time.

The implications involved in the procedure mentioned above are to oxidize the metal ions in the sample when 20% nitric acid solution is added to the mixture. The purpose of boiling the solution is to activate the reaction rate and to remove all the nitrous acid (NO_2) formed as reduction products from the above oxidation. Furthermore, the removal of the watch glass makes possible the elimination of nitrous acid vapors which could otherwise cause interferences in the final determination of the metal ions. The addition of potassium chlorate is to help insure complete oxidation of all metal ions since this is another strong oxidizing agent. Still further, the addition of hydrochloric acid is to precipitate impurity metal ions such as mercury and silver as insoluble chlorides in a white precipitate. Finally, the washing with hot water is to bring back to solution the salts of lead chloride ($PbCI_2$), which is precipitated when hydrochloric acid is added.

All the glassware such as beakers, graduated cylinders, glass watches, funnels, teflon bottles, etc., used in the chemical procedures were cleaned with detergent, washed with water and nitric acid followed by several rinses of deionized distilled water and stored or used in such a way as to prevent any contamination by extraneous sources.

The analytical studies for this atmospheric sampling were performed using the technique of atomic absorption spectroscopy. The reasons for choosing this technique were simply to standarize the results for future comparisons since previous studies in the El Paso area were done using a similar technique. The type of device used for the present study was a Varian atomic absorption spectrophotometer Model AA 6 equipped with a Varian recorder and Westinghouse hollow cathode lamps.

The parameters used in the present analytical study were as follows:

Parameters for lead

Lamp current = 5 units (microamps)

Photomultiplier voltage range = 385-396

Wavelength = 217 (nm)

Width slit = 1.0 (nm)

Flame type = air-acetylene (oxidizing flame)

Mode = Concentration 3 Integral Mode

Parameters for zinc

Lamp current = 5 units (microamps)

Photomultiplier voltage range = 385-396

Wavelength = 213.95 (nm)

Width slit = 0.5 (nm)

Flame type = air-acetylene (oxidizing flame)

Mode = Concentration 3 Integral Mode

Parameters for cadmium

Lamp current = 3 units (microamps)

Photomultiplier voltage range = 385-390

Wavelength = 228.8 (nm)

Width slit = 0.5 (nm)

Flame type = air-acetylene (oxidizing flame)

Mode = Concentration 3 Integral Mode

The actual procedure followed for the measurements of each sample in the teflon bottles was done according to manufacturer's instructions.[32] Dilutions of individual samples were performed whenever it was estimated the concentration of lead exceeded 20 parts per million and were done usually in a ratio of 1:1. Dilutions for zinc were also done when necessary and in the order of 1:1 ratios.

Sample Calculations

The final results of the concentrations of each individual sample were expressed in micrograms of the metal per cubic meter. The procedure followed for such calculations was similar to that employed by the El Paso Health Center.[33] An example of the steps followed for the elaborated calculations of the concentration of airborne lead for a specific sample code number 55 taken on Monday, June 2, 1975, corresponding to station No. 1 (5+5=10 or 1) were as follows:

Airflow calculations

(1) Initial airflow reading	51 cfm
(2) Final airflow reading	44 cfm
(3) Average airflow reading= $\frac{51\text{ cfm} + 44\text{cfm}}{2}$	47.5 cfm
(4) Time began 6/2/75	0 hrs
(5) Time ended 6/3/75	24 hrs

(6) Total minutes of sample = hrs x 60 min/hr

= 24 hrs x 60 min/hr 1440 min

(7) Total volume of sample in ft^3 = (47.5 cfm) x (1440 min)

= 68400 ft^3

(8) Total volume of sample in m^3 = (68400 ft^3)/(35.314 ft^3/m^3)

= 1936.91 m^3

Calculations of micrograms per filter

(9) PPM of lead (atomic absorption reading) = 1.719 ppm

(10) PPM of blank (atomic absorption reading) = 0.156 ppm

(11) Corrected concentration of sample = 1.719-0.156 = 1.563 ppm

(12) Total micrograms per filter = (1.563 ppm or μg/ml)x(450 ml/filter)*

= 703.35 μg/filter

Calculations of concentrations of lead per cubic meter

(13) Micrograms of lead per cubic meter of air of sample number 55 of station No. 1 = (703.35 μg/filter)/(1936.91 m^3) = 0.3630 μg/m^3

Explanation of symbols and abbreviations for the preceeding example is as follows:

cfm - cubic feet per minute

hr or hrs - hour or hours

min - minutes

ft^3 - cubic feet

m^3 - cubic meters

ppm - parts per million

g - grams

ml. - milliliters

μg - micrograms

$$*450 \text{ ml/filter} = \frac{\text{50 ml of solution x atomic absorption reading in } \mu\text{g/ml}}{\text{1/9 of the total area of the filter which is 63 in}^2}$$

CHAPTER IV

OBSERVATIONS AND DISCUSSION

As stated previously, other studies in the area have suggested the main contributor of lead is the smelting industry located on the western edge of El Paso, Texas. One of the goals of the present study was to confirm and extend these findings. For this purpose, several approaches were taken. Air samples (448) from a twelve-month period (April 8, 1975 through April 10, 1976) were processed by calculating the monthly mean concentrations of lead, zinc, and cadmium expressed in micrograms per cubic meter of air. Table IX shows the tabulated monthly and annual means of the three metals for each of the nine receptors; in addition, other characteristics of the sampling sites such as straight distances from the smelter in kilometers, elevation in meters above sea level, and direction in degrees from the smelter are presented.

It was necessary to correlate lead and zinc concentrations in an effort to distiguish the automotive emission lead from smelting emission lead. This was performed under the assumption that the ore smelter was the sole source of zinc in the area. One approach was taken by using regression and correlation methods. Regression methods were used to determine the functional relationship between the variables, while

TABLE IX

Tabulation of Monthly, Annual and Seasonal Mean Concentrations of Atmospheric Lead, Zinc, and Cadmium Corresponding to Each of the Nine Sampling Sites, in Addition to the Characteristics of Each Station such as Straight Distance, Altitude Above Sea Level, and Direction in Degrees from the Smelting Industry.

Description Source-Site	Station #1 Commercial			Station #2 Residential			Station #3 Residential			Station #4 Semi-Industrial			Station #5 Rural		
Straight Distances from Smelter (kms)	6.217			6.848			8.500			10.200			18.300		
Direction from Smelter (°)	141 SE			160 SSE			155 SE			144 SE			152 SE		
Altitude Above Sea Level (meters)	1170			1218			1218			1165			1197		
	Monthly Mean Concentrations of Lead, Zinc, and Cadmium in Micrograms per Cubic Meter														
Date	Pb	Zn	Cd	Pb	Zn	Cd	Pb	Zn	Cd	Pb	Zn	Cd	Pb	Zn	Cd
April, 1975	1.28	0.18	0.0049	0.37	0.07	0.0063	0.25	0.02	0.0046	0.19	0.08	0.0021	0.08	0.02	0.0010
May	2.49	0.39	0.1171	0.69	0.17	0.0171	0.44	0.14	0.0099	0.74	0.25	0.0302	0.29	0.12	0.0053
June	1.69	0.47	0.0294	0.66	0.07	0.0072	0.53	0.06	0.0067	0.54	0.15	0.0075	0.07	0.01	0.0043
July	0.92	0.11	0.0095	0.49	0.08	0.0047	0.39	0.06	0.0070	0.31	0.08	0.0064	0.09	0.07	0.0019
August	0.84	0.22	0.0198	0.40	0.07	0.0142	0.44	0.05	0.0017	0.39	0.08	0.0053	0.14	0.07	0.0020
September	0.42	0.06	0.0018	0.33	0.19	0.1013	0.71	0.24	0.1287	0.61	0.26	0.0096	0.36	0.19	0.0000
October	1.93	0.68	0.0264	0.58	0.20	0.0132	0.40	0.17	0.0069	0.42	0.27	0.0137	0.10	0.05	0.0000
November	4.03	1.16	0.1376	0.28	0.09	0.0037	1.39	0.50	0.0587	1.48	0.50	0.0240	0.66	0.34	0.0178
December	5.71	1.94	0.1403	0.51	0.22	0.0226	1.08	0.29	0.1050	0.76	0.29	0.0196	0.68	0.35	0.0160
January, 1976	2.27	0.65	0.0554	0.52	0.21	0.0205	1.95	0.75	0.0649	1.30	0.40	0.0323	0.67	0.37	0.0206
February	2.42	0.38	0.0272	0.78	0.26	0.0208	0.92	0.27	0.0137	1.11	0.35	0.0172	0.50	0.24	0.0100
March	0.47	0.09	0.0000	0.49	0.22	0.0000	0.99	0.53	0.0042	0.85	0.30	0.0100	0.03	0.00	0.0000
Annual Mean	2.04	0.53	0.0475	0.51	0.15	0.0118	0.79	0.26	0.0343	0.73	0.25	0.0148	0.31	0.15	0.0063
Annual Standard Deviation	1.55	0.61	0.0553	0.15	0.07	0.0088	0.50	0.23	0.0443	0.42	0.14	0.0099	0.26	0.14	0.0079
Mean and Standard Deviation March-September	1.16	0.22	0.0261	0.51	0.12	0.0073	0.54	0.15	0.0233	0.52	0.17	0.0102	0.15	0.08	0.0021
	0.74	0.16	0.0415	0.14	0.07	0.0064	0.24	0.18	0.0466	0.24	0.10	0.0092	0.12	0.07	0.0020
Mean and Standard Deviation Oct-Feb	3.27	0.96	0.0774	0.53	0.20	0.0182	1.15	0.40	0.0345	1.01	0.36	0.0214	0.52	0.27	0.0129
	1.59	0.61	0.0573	0.18	0.06	0.0078	0.57	0.23	0.0213	0.43	0.09	0.0072	0.25	0.13	0.0082

TABLE IX (continued)

Description Source-Site	Station #6 Semi-Rural			Station #7 Residential			Station #8 National Park			Station #9 Commercial Residentail		
Straight Distances from Smelter (kms)	21.580			12.710			6.675			7.818		
Direction from Smelter (°)	132 SE			121 SE			117 SE			129 SE		
Altitude Above Sea Level (meters)	1132			1139			1142			1133		
	Monthly Mean Concentrations of Lead, Zinc, and Cadmium in Micrograms per Cubic Meter											
Date	Pb	Zn	Cd	Pb	Zn	Cd	Pb	Zn	Cd	Pb	Zn	Cd
April, 1975	0.40	0.13	0.0430	0.35	0.06	0.0078	0.70	0.26	0.0106	1.97	0.46	0.0208
May	0.87	0.28	0.1101	0.48	0.18	0.0325	0.85	0.22	0.0647	3.40	0.57	0.1407
June	0.80	0.19	0.0067	0.37	0.10	0.0061	0.66	0.19	0.0029	2.57	0.50	0.0291
July	0.41	0.04	0.0181	0.38	0.01	0.0000	0.49	0.06	0.0075	0.88	0.05	0.0015
August	0.41	0.01	0.0076	0.19	0.08	0.0064	0.34	0.12	0.0049	0.85	0.11	0.0104
September	0.17	0.06	0.0000	0.58	0.13	0.0005	0.51	0.12	0.0054	0.76	0.05	0.0000
October	0.50	0.16	0.0006	0.60	0.13	0.0050	2.12	0.68	0.0332	1.90	0.28	0.0107
November	1.12	0.25	0.0018	1.36	0.27	0.0061	3.39	1.11	0.0917	4.29	1.04	0.0950
December	1.65	0.43	0.0356	1.18	0.29	0.0288	1.89	0.51	0.0352	3.18	0.89	0.0650
January, 1976	1.61	0.40	0.0374	1.04	0.40	0.0297	2.01	0.98	0.0792	3.79	1.18	0.0513
February	0.64	0.11	0.0000	0.88	0.10	0.0040	2.07	0.45	0.0309	2.71	0.48	0.0208
March	0.41	0.26	0.0005	0.66	0.12	0.0000	0.76	0.54	0.0381	0.90	0.20	0.0000
Annual Mean	0.75	0.19	0.0222	0.67	0.16	0.0111	1.32	0.44	0.0340	2.27	0.48	0.0371
Annual Standard Deviation	0.48	0.14	0.0319	0.37	0.11	0.0127	0.96	0.34	0.0305	1.23	0.38	0.0438
Mean and Standard	0.50	0.14	0.0266	0.43	0.11	0.0076	0.59	0.20	0.0192	1.62	0.28	0.0289
Deviation March-September	0.25	0.11	0.0397	0.16	0.05	0.0115	0.14	0.16	0.0234	1.05	0.23	0.0505
Mean and Standard	1.10	0.27	0.0151	1.01	0.24	0.0147	2.30	0.73	0.0548	3.17	0.77	0.0486
Deviation Oct-Feb	0.53	0.14	0.0196	0.29	0.12	0.0133	0.82	0.29	0.0285	0.93	0.38	0.0341

correlation methods were used to measure the degree of association of the variables. The method of least squares used for all the calculations to obtain the regression or estimating equation was that of a straight line. This method gives excellent results when the assumptions of normality are met.[34] Moreover, the method has the property that the sum of the squared vertical deviations to the means or observations on the scattergram are smaller that the similar sum of any other line. The least square line or sample regression line used to estimate the population regression line and any parameter associated with it was:

$$Y' = \bar{Y} + b(X-\bar{X})$$

where Y' and X represent any point on the line; the quantity b is the slope of the regression line and $\bar{Y}$ is the ordinate of the line at point X. However, if the line is computed in the form Y' = a +bX, then the quantity a becomes the $\bar{Y}$ intercept.

Correlations of Lead, Zinc, and Cadmium Concentrations

The concentrations of lead, zinc, and cadmium at each site were correlated utilizing the annual and seasonal means. This was accomplished by partitioning the data into two seasons: one corresponding to the winter and fall months (October through February) and the other to the spring and summer months (March through September). This is illustrated in Table X. The criteria followed in the partition of the data was to determine the overall effect of wind speed and direction and the frequency of thermal inversions on the distribution and concentration of suspended particulate lead, zinc, and cadmium. This was done since previous meteorological records of wind patterns taken at the El Paso International Airport had shown during the cold season the prevalence of the wind

TABLE X

Simple Regression and Correlation Analysis of Concentrations of Suspended Particulate Lead, Zinc, and Cadmium for Each of the Nine Sampling Receptors on a Yearly and Biseasonal Basis.

	Regression and Correlation Analysis on Lead (y) and Zinc (x)								
Receptor No.	1	2	3	4	5	6	7	8	9
Yearly Basis									
Y-Intercept	0.6064	0.4339	0.2604	0.0219	0.0265	0.1421	0.2702	0.2418	0.7853
Slope	2.7172	0.4900	2.0661	2.8062	1.8320	3.1401	2.5814	2.4596	3.0596
r-Corr. Coef.	0.9583	0.4339	0.9423	0.9325	0.9929	0.8755	0.7852	0.8910	0.9372
Period Mar-Sep									
Y-Intercept	0.3936	0.4862	0.3349	0.1248	0.0311	0.2894	0.2898	0.4630	0.4005
Slope	3.7064	0.0303	1.2778	2.3054	1.7541	1.4890	1.4428	0.7081	4.3952
r-Corr. Coef.	0.8573	0.0144	0.9439	0.9361	0.9601	0.6471	0.4996	0.6336	0.9469
Period Oct-Feb									
Y-Intercept	0.9032	0.0224	0.1982	-0.5379	0.0225	0.1208	0.6703	0.5215	1.4198
Slope	2.4624	2.6104	2.3986	4.2870	1.8499	3.6414	1.4357	2.0926	2.2664
r-Corr. Coef.	0.9549	0.9267	0.9673	0.9319	0.9941	0.9706	0.6090	0.6811	0.9271
	Regression and Correlation Analysis on Lead (y) and Cadmium (x)								
Period Mar-Sep									
Y-Intercept	0.6060	0.4171	0.4984	0.3506	0.1372	0.3921	0.4380	0.5049	1.0967
Slope	25.3155	9.9805	1.6029	16.6765	6.8889	3.8995	-1.0460	5.4245	18.0413
r-Corr. Coef.	0.9729	0.4583	0.3056	0.6468	0.1132	0.6235	-0.0764	0.7200	0.8700
Period Oct-Feb									
Y-Intercept	1.3222	0.2740	0.4430	0.0841	0.1461	0.7298	0.9035	1.4868	2.0072
Slope	25.1973	16.0861	20.4361	43.5363	29.1834	24.8116	7.3686	14.9735	24.8522
r-Corr. Coef.	0.9127	0.7052	0.9322	0.7331	0.9657	0.9120	0.3372	0.7044	0.8750
	Regression and Correlation Analysis on Zinc (y) and Cadmium (x)								
Period Mar-Sep									
Y-Intercept	0.1509	0.1080	0.1394	0.1102	0.0704	0.1025	0.0747	0.1526	0.1839
Slope	2.5415	0.7535	0.7621	6.0313	-0.8860	1.3585	2.9472	3.2961	3.2237
r-Corr. Coef.	0.6724	0.4050	0.1967	0.5761	-0.0266	0.4997	0.6217	0.4882	0.7216
Period Oct-Feb									
Y-Intercept	0.2349	0.0763	0.2835	0.1895	0.0638	0.1671	0.1252	0.2295	0.3318
Slope	9.3966	7.4077	2.2572	8.0756	16.0088	6.8220	7.6622	9.5577	9.1058
r-Corr. Coef.	0.8777	0.9148	0.3933	0.6256	0.9858	0.9407	0.8267	0.9596	0.8146

direction is from the north. In addition, the frequency of thermal inversions as well as low wind speeds is greater during winter time. This situation would tend to increase the concentration of particulate matter in the Juárez area, since the point source of interest is situated northwest of the city.

A close examination of Table X shows moderately high statistical association between the lead, zinc, and cadmium for most sampling sites. This was especially true during the winter season. These observations suggest that at least for that period of sampling, the lead, zinc, and cadmium may have had a common source. A similar situation is reflected in Figure 22 which shows the least squares line determining the functional relationship between the annual mean concentrations of atmospheric lead and cadmium.

Furthermore, a thorough examination of Table IX also shows an increasing concentration of the three metals during the winter period, a finding suggesting that northerly winds, as well as thermal inversions, do have an important influence in the accumulation of pollutants during that period of the year. Figure 23 shows maximum peaks are attained during months of November, December, and January and minimum peaks during the warm season, which in this case, was from March to September. Still further, Table IX shows the seasonal concentrations of the metals of each site are likely to be higher during winter time than during the summer period. These situations are illustrated in Figures 24, 25, and 26. Figure 24, for example, shows higher levels for all the sites are obtained during the period October through February as compared to the rest of the year. On

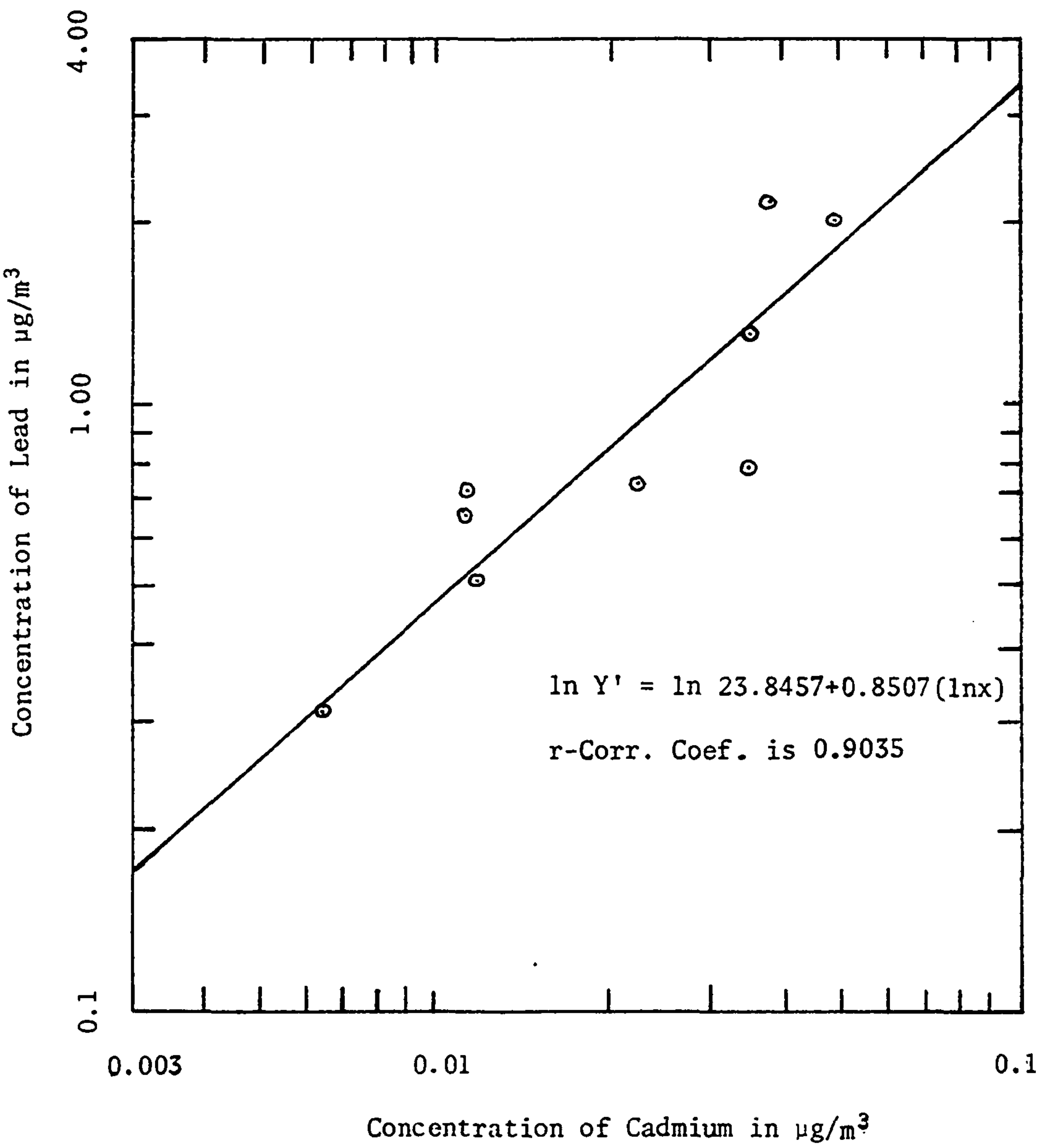


Figure 22. Annual Mean Concentrations of Lead and Cadmium with Line of Best Fit.

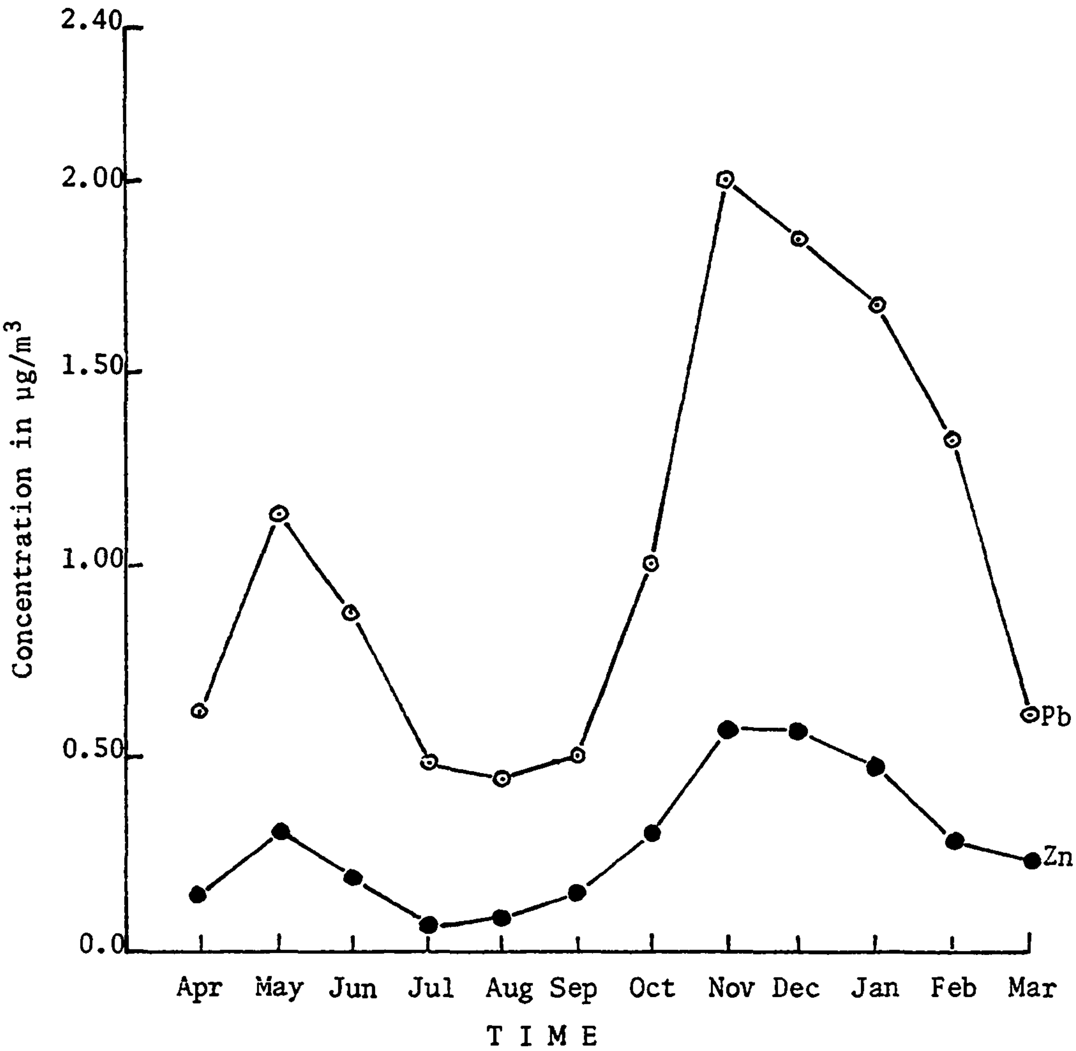


Figure 23. Relationship between Concentrations of Lead and Zinc as a Function of Months Showing Maximum and Minimum Peaks for Sampling Period Corresponding to April 1975 through March 1976.

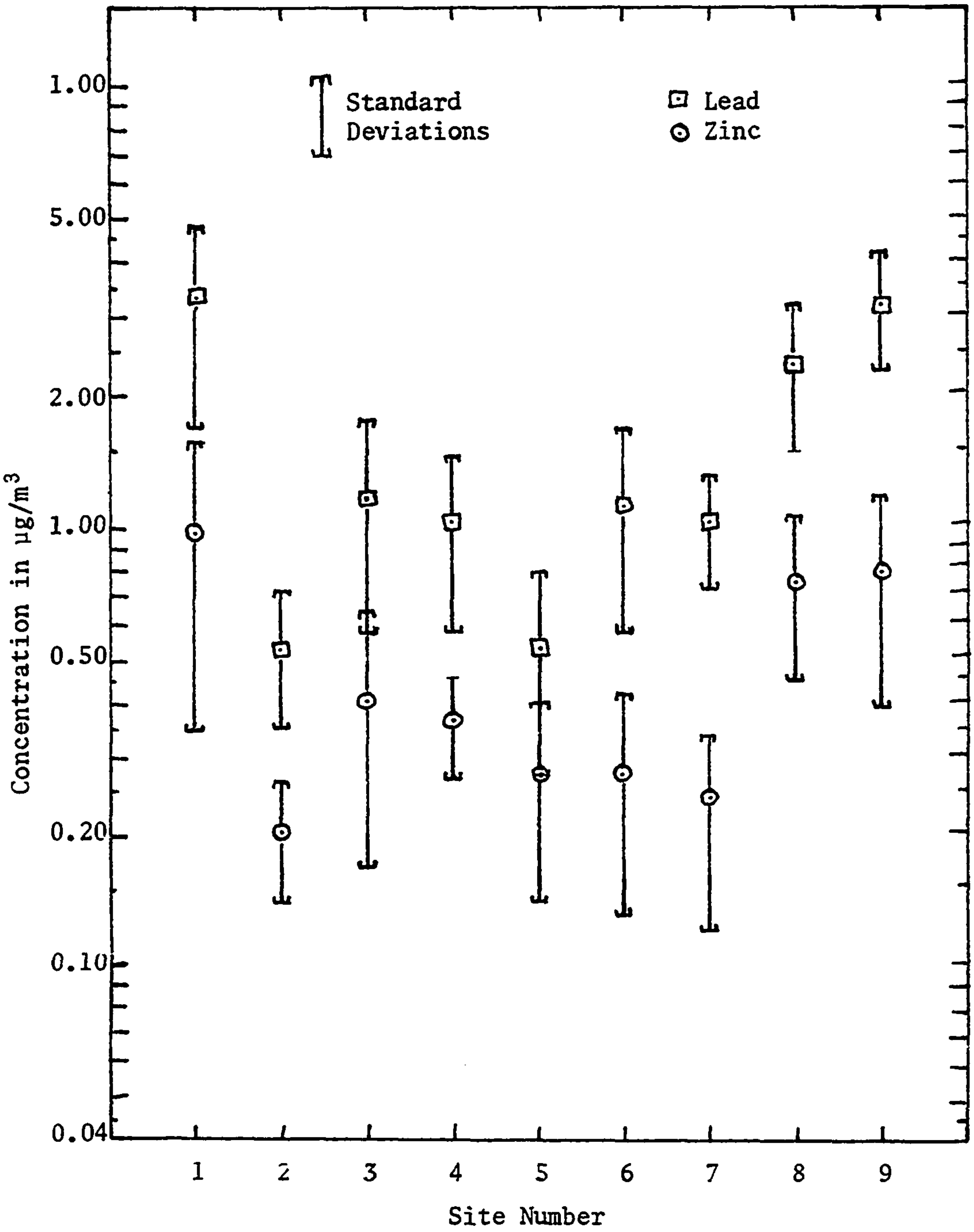


Figure 24. Monthly Mean Concentrations and Standard Deviations of Suspended Particulate Lead and Zinc of Each Site Corresponding to Period of October 1975 through February 1976.

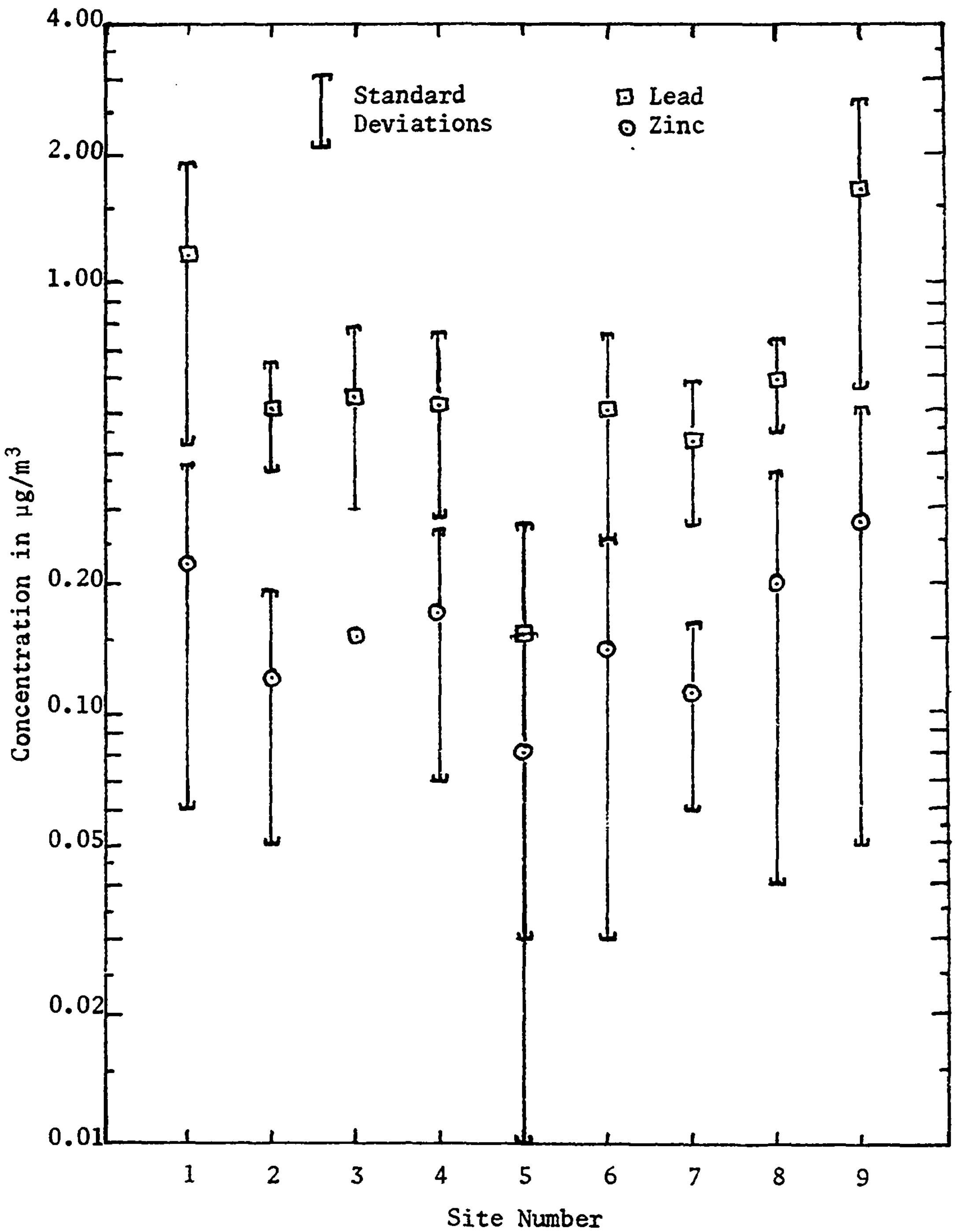


Figure 25. Monthly Mean Concentrations and Standard Deviations of Suspended Particulate Lead and Zinc of Each Site Corresponding to Period of April through September 1975, and March of 1976.

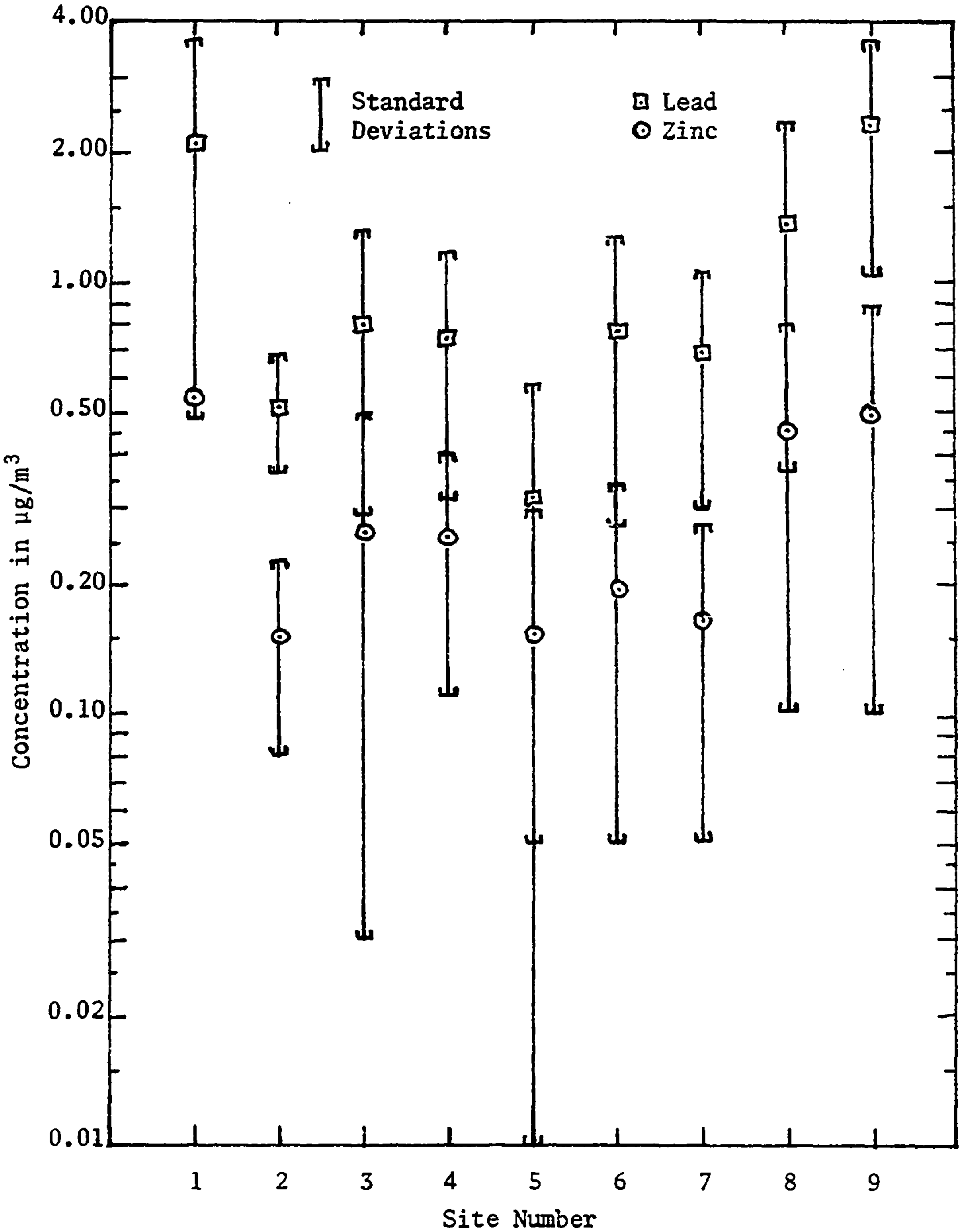


Figure 26. Annual Mean Concentrations and Standard Deviations of Suspended Particulate Lead and Zinc of Each Site Corresponding to Period of April 8, 1975 through April 10, 1976.

the other hand, Figure 25 shows lower levels of the three metals are obtained during the period March to September. In addition, the lower levels recorded during this season of the year suggests that southerly winds and turbulent conditions, so common during that period of the year, provide a natural flushing action of the atmosphere by dispersing and diluting atmospheric contaminants.

Relationship between Concentration and Distance

Studies of concentrations of suspended particulate matter with distance from the smelting industry in El Paso, Texas, indicate an inverse relationship between concentrations of heavy metals in the particulates and distance from the emitting source. Another goal of the present study was to compare similar data taken on the Mexican side with the data on the El Paso side. Table IX describes the distance in kilometers of each monitor from the ore smelter in question. The arbitrarily numbered stations show a range of 6.2 kilometers for the nearest receptor to the point source to 21.5 kilometers for the farthest station. Figure 27 shows the relationship between the annual concentrations of lead, zinc, and cadmium to distance from the emitting source. Similarly, Figures 28 and 29 illustrate the relationship between the two variables, concentration and distance, but with the data divided into two seasons. The line of best fit, $\ln Y' = bx + \ln a$, which excludes the data of station 2 shows the best representative value for the set of data between the concentration of the three metals and distance in kilometers from the emitting source. A close examination of these graphs shows a

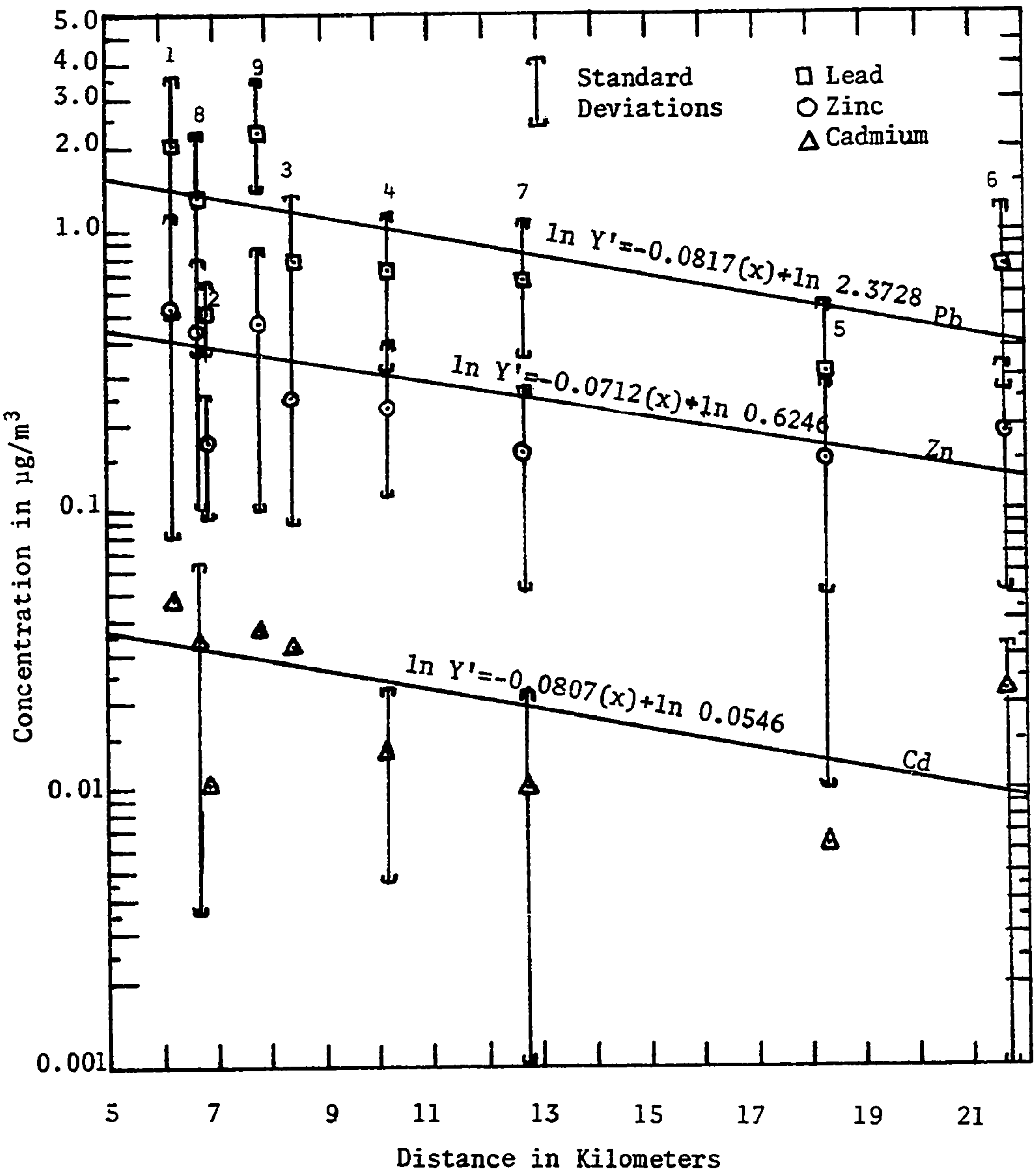


Figure 27. Annual Mean Concentrations and Standard Deviations of Suspended Particulate Lead, Zinc, and Cadmium of Each Site Corresponding to Period of April 8, 1975 through April 10, 1976 as a Function of Distance from the Point Source with Line of Best Fit.

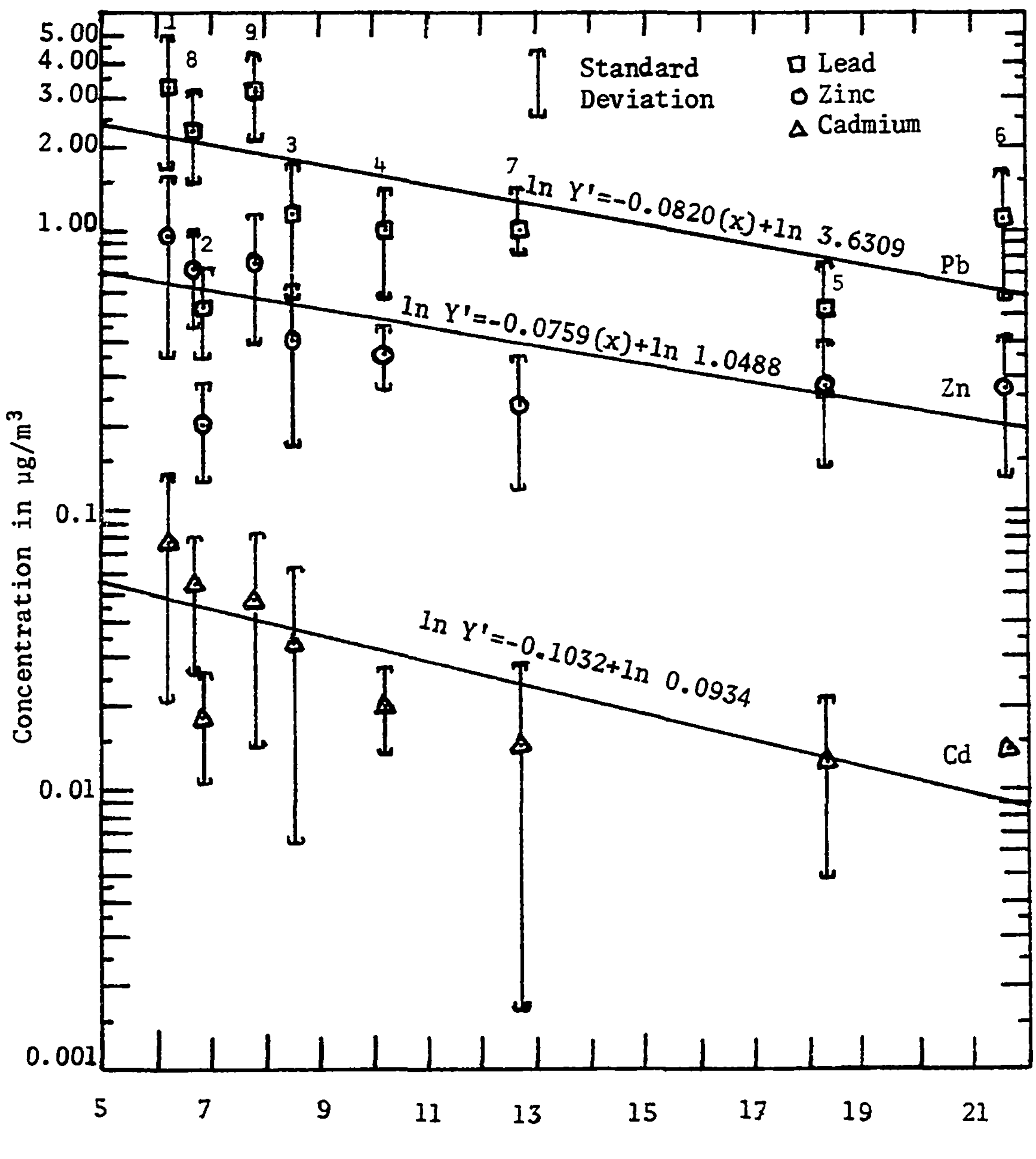


Figure 28. Seasonal Mean Concentrations and Standard Deviations of Suspended Particulate Lead, Zinc, and Cadmium of Each Site Corresponding to Period October 1975 through February 1976 as a Function of Distance from the Point Source with Line of Best Fit.

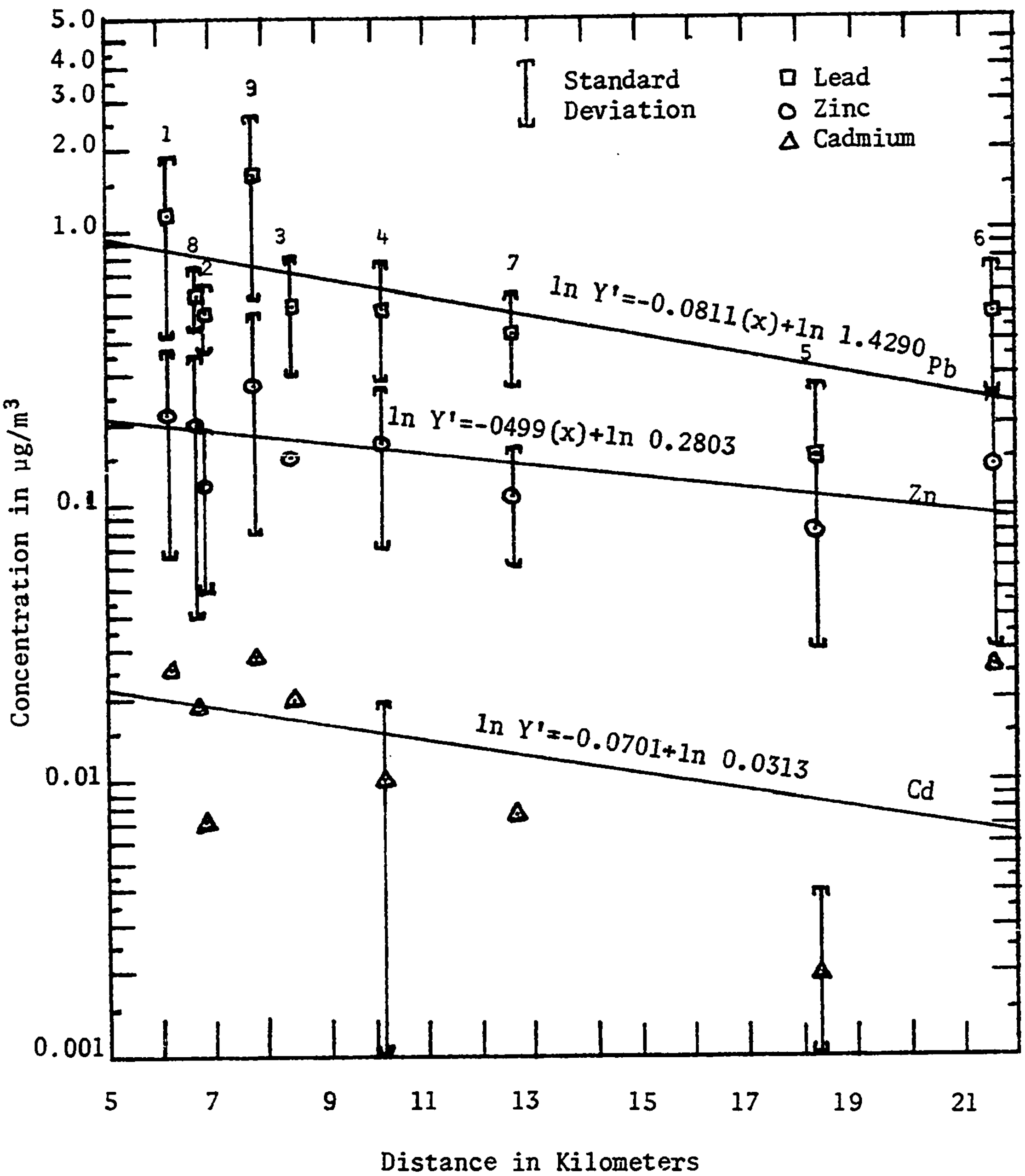
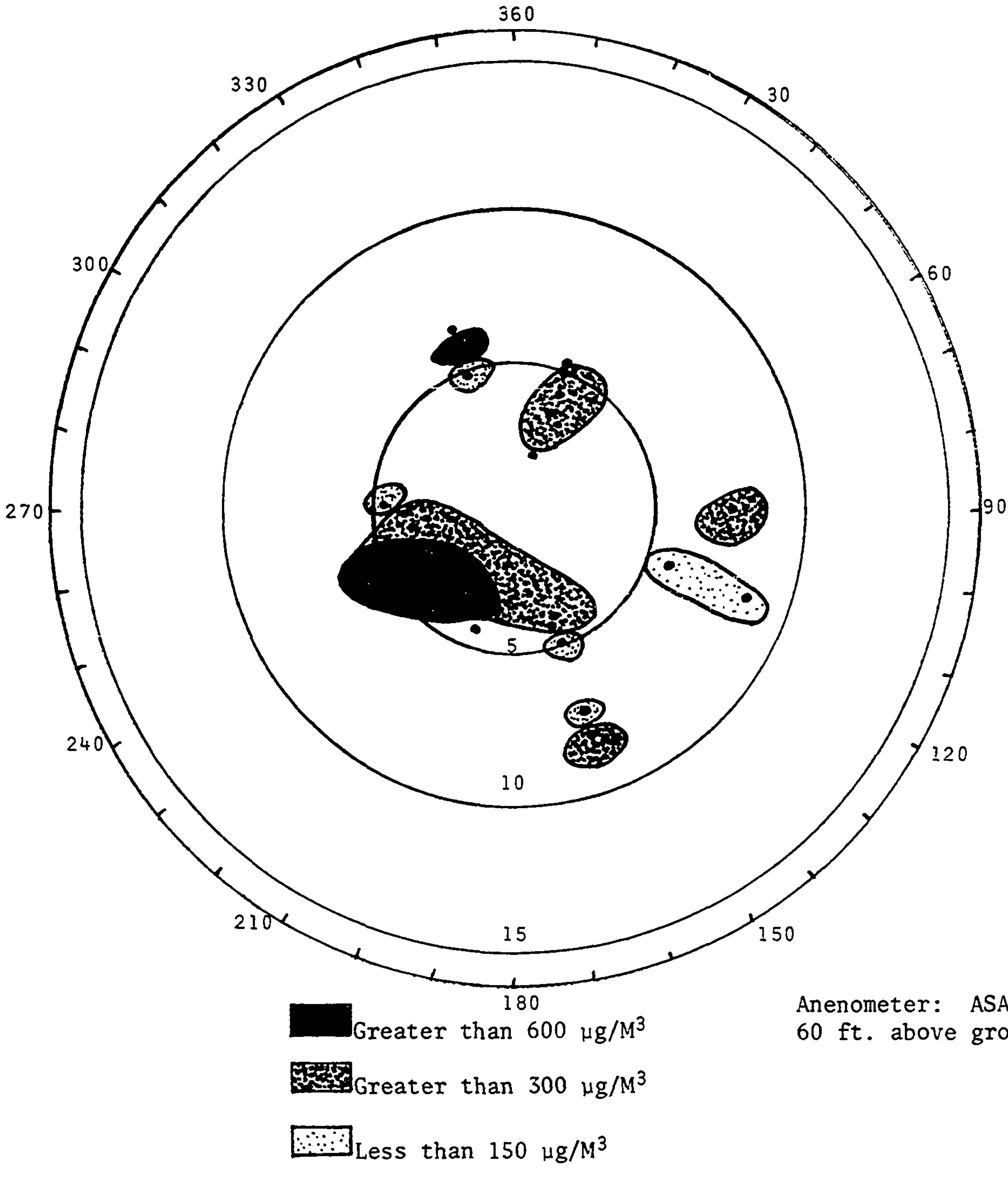


Figure 29. Seasonal Mean Concentrations and Standard Deviations of Suspended Particulate Lead, Zinc, and Cadmium of Each Site Corresponding to Period of April through September 1975 as a Function of Distance from the Point Source with Line of Best Fit.

discrepancy in the levels of lead, zinc, and cadmium corresponding to site number 2 which was the third nearest to the source. This receptor was located on a hillside of the Juárez Mountains at an elevation of 1219 meters, and at a distance of 6.848 kilometers from the stack. A possible explanation for such occurrence could be given in terms of localized meteorological conditions around that area. In support of this idea the geographic description of the El Paso-Juárez area shows a wide range of elevations provided by mountain ranges. The river bed of the Rio Grande River which is constricted to its narrowest local dimensions in downtown El Paso area has slopes climbing above 1000 meters in height within a few kilometers on the northeast and southwest sides of the river. It is possible that due to the steep conditions of the mountain slopes around station 2, drainage wind currents would tend to modify wind patterns around that area (Webb, personal communication).[35] All these factors combined undoubtedly introduce a variety of mesoscale effects through local circulation systems caused by differential heating and cooling of local areas as result of altitude, surface conditions, and degree of pollution of atmospheric layers.[36] Studies done in El Paso[22] regarding the relationship between the concentration of suspended particulate matter as related to prevailing wind direction and wind speed at the American Smelting and Refining Company for the period October 24 to November 14, 1968, show concentrations were higher with low wind speeds in a direction to the west-southwest of receptor 2 on the Mexican side. This receptor was located about 160° from this industrial source. Although this finding suggests low concentrations of particulate matter tend to be directed toward site number 2 under these conditions, a much longer period of record is needed for a valid comparison. This situation is depicted in Figure 30.

A further examination of Figures 27, 28, and 29 reflect higher levels at stations located in sites adjacent to the river. This finding could be due to the mountain and valley winds so common in places with very large and prominent landforms such as the area of study. It has been observed that the low lying areas along the Rio Grande River register lower minimum temperatures than those at higher elevations near the hills.[23] The downslope nocturnal winds tend to drain into the lower area of the El Paso-Juárez Valley and deepen with time. This aggravates the temperature inversions forming along areas near the river even without the addition of a cold mass of air. The stable layer, resulting from this phenomenon, would tend to encourage the concentrations of atmospheric pollutants emitted in those places. Figure 2, for example, shows the relationship of atmospheric levels of lead for the El Paso area from a study performed in 1974, illustrating the fact that higher levels were recorded in a location situated in the river plain at a distance of 21.5 kilometers from the smelter. This observation is similar to the concentrations recorded around station 6 which was situated in the river plain near Isleta, Texas (Figure 26). In general terms, the circulation of wind currents in the El Paso-Juárez area can be described as movement of winter winds down the Rio Grande River and Tularosa Valleys from the north and up the valleys from the south during the warm season.[22,36]



Anenometer: ASARCO, 60 ft. above ground.

Figure 30. Relationship of Concentration of Suspended Particulate Matter to Prevailing Wind Direction and Average Hourly Wind Speed, ASARCO, El Paso, Texas, October 24 - November 14, 1968.

Source: Air Quality Survey, El Paso Metropolitan Area, October 15 - November 15, 1968, Texas State Dept. of Health, pp. 125-139.

A close examination of specific sampling dates during the months of November, December, and January shows that the highest levels of lead, zinc, and cadmium were recorded under low wind speed conditions whose range was from 2.5 to 7 miles per hour as recorded from the El Paso International Airport and Campbell Street anemometers. This observation suggests that low wind speeds as well as thermal inversions play an important part in the concentration and distribution of pollutants in the area.

Delimiting Concentration and Distribution of Lead

Still further, in an effort to test the relationship of the mean levels of the metals, an analysis of variance was performed. The estimation of the population means was designed by running a statistical two way analysis of variance by taking the station variable as blocks and the month factor as treatment. Again the data were divided into two seasons and the sites and monthly concentrations of lead and zinc were statistically examined. Tables XI through XIV depict the results of the analysis of variance tables on the two variables with the corresponding calculations of sum of squares, degrees of freedom, error mean squares, and the F-ratios. The results of these tests imply a significant difference among the levels by the sites as well as the month factors, except in the case of zinc corresponding to the warm season. Although the F-ratios showed a significant difference among the concentrations of the metals around the sampling sites and in the monthly levels, it was necessary to determine which ones were equal and which ones were different. For this purpose the new multiple test developed by Duncan was performed. This test is used to rank the means according to their

TABLE XI

Two Way Analysis of Variance Table for Mean Concentrations of Lead for Site and Month Variables Corresponding to Period October-February

Source of Variation	D.F.	Sum of Squares	Mean Square	Calculated-F	Tabled-F
Due to Blocks (sites)	8	45.4239	5.6779	14.0694	2.2600
Due to Treatments	4	5.7476	1.4369	3.5605	2.6896
Error (residual)	32	12.9141	.4035		

TABLE XII

Two Way Analysis of Variance Table for Mean Concentrations of Zinc for Site and Month Variables Corresponding to Period October-February

Source of Variation	D.F.	Sum of Squares	Mean Square	Calculated-F	Tabled-F
Due to Blocks (sites)	8	3.1696	.3962	6.4136	2.26
Due to Treatments	4	.9197	.2299	3.7219	2.69
Error (residual)	32	1.9768	.0617		

TABLE XIII

Two Way Analysis of Variance Table for Mean Concentrations of Lead for Site and Month Variables Corresponding to Period March-September

Source of Variation	D.F.	Sum of Squares	Mean Square	Calculated-F	Tabled-F
Due to Blocks (sites)	8	10.9957	1.3744	8.2781	2.10
Due to Treatments	6	3.4741	.5790	3.4873	2.69
Error (residual)	48	7.9696	.1660		

TABLE XIV

Two Way Analysis of Variance Table for Mean Concentrations of Zinc for Site and Month Variables Corresponding to Period March-September

Source of Variation	D.F.	Sum of Squares	Mean Square	Calculated-F	Tabled-F
Due to Blocks (sites)	8	.2207	.0275	2.0889	2.10
Due to Treatments	6	.2918	.0486	3.6831	2.69
Error (residual)	48	.6339	.0132		

magnitudes after they become known. Tables XV and XVI display the results obtained by the use of this estimator. The results of the concentrations of the sampling sites for lead corresponding to the cold season suggest that stations 1 and 9 appear to have significantly higher levels than stations 2, 3, 4, 5, 6 and 7. The position of site 8, however, did not show a statistical difference. Sites 2 and 5, on the other hand, showed a significantly lower level than sites 1,8, and 9. A similar situation is suggested in the distribution of zinc for the same period of sampling. However, for the warm season site 9 appeared to have significantly higher levels than the remaining samplers.

In regard to the monthly concentrations and distributions of lead, the months of November, December, and January appeared to be significantly higher than the months of February and October. On the other hand, for the summer period the months of July and August, statistically speaking, appeared to have significantly lower levels than May or June.

The foregoing statistical tests suggest that people living near sites 1 and 9 are exposed to higher atmospheric levels of lead, especially during the months of November, December, and January. In contrast, for the same period of sampling, populations living around sites 2 and 5 were exposed to much lower levels. A similar situation is reflected for the warm season for persons living around stations 5 and 7 which appeared to be less exposed to the metal.

Other observations made on individual sampling days point out that the highest levels of atmospheric lead and zinc occurred during December and corresponded to site number 1. Moreover, the highest levels of atmospheric cadmium were recorded during the months of November and December and corresponded to site number 1.

TABLE XV

Duncan's New Multiple Range Test Relating the Seasonal Concentrations of Lead and Zinc to the Site Variable

Period Oct. to Feb. for Atmospheric Lead

Sites	1	9	8	3	7	6	4	2	5
Seasonal Means	3.27	3.174	2.296	1.148	1.124	1.104	1.041	.534	.522

Error Mean Square - .4035
Observations per Mean - 5

Period Oct. to Feb. for Atmospheric Zinc

Sites	1	9	8	3	4	5	6	7	2
Seasonal Means	.962	.774	.746	.396	.362	.2701	.27	.244	.196

Error Mean Square - .0617
Observations per Mean - 5

Period April - Sept. 1975, March 1976 for Atmospheric Lead

Sites	9	1	8	3	4	2	6	7	5
Seasonal Means	1.62	1.16	.59	.54	.52	.51	.50	.43	.15

Error Mean Square - .1660
Observations per Mean - 7

Period April - Sept. 1975, March 1976 for Atmospheric Zinc

Sites	9	1	8	4	3	6	2	7	5
Seasonal Means	.28	.22	.20	.17	.15	.14	.12	.11	.08

Error Mean Square - .0132
Observations per Mean - 7

TABLE XVI

Duncan's New Multiple Range Test Relating the Seasonal Concentrations of Lead and Zinc to the Month Variable.

Period Oct. to Feb. for Atmospheric Zinc

Months	Jan	Nov	Dec	Oct	Feb
Monthly Means	.5933	.5844	.3788	.2944	.2933

No. of Means - 5
Error Mean Square - 0.0617
Observations per Mean - 9

Period Oct. to Feb. for Atmospheric Lead

Months	Nov	Dec	Jan	Feb	Oct
Monthly Means	2.0000	1.8488	1.6844	1.3666	1.0144

No. of Means - 5
Error Mean Square - 0.4035
Observations per Mean - 9

Period April - Sept. 1975, March 1976 for Atmospheric Lead

Months	May	Jun	Apr	Mar	Sep	Jul	Aug
Monthly Means	1.1400	.8766	.6188	.6088	.4944	.4844	.4444

No. of Means - 7
Error Mean Square - .1660
Observations per Mean - 9

Period April - Sept. 1975, March 1976 for Atmospheric Zinc

Months	May	Mar	Jun	Sep	Apr	Aug	Jul
Monthly Means	.2577	.2422	.1933	.1444	.1422	.0900	.0622

No. of Means - 7
Error Mean Square - .0132
Observations per Mean - 9

Estimation of Annual Average Concentrations of Lead at Receptor Points

For point sources that emit at a constant rate from hour to hour and day to day, calculations of annual average concentrations of atmospheric contaminants can be made using a simple adaptation of the basic dispersion equation whose form is satisfactory for rough approximations of downwind concentrations for an angular sector:

$$\chi\{x,0,f\} = \frac{360\ f}{\phi\ 100}\ \frac{Q}{\pi^{3/2}\ 2^{1/2}\ \bar{u}\ x}\ \frac{1}{\sigma_z}\ \exp-(H^2/2\sigma_z^2) \qquad (IV)$$

where: χ = annual average ground-level concentrations at distance x downwind

f = percentage of time the wind is from a given direction under a given atmospheric stability condition

ϕ = angular width of a direction sector (deg)

Under the assumption that the effluent from a point source within a specific sector is distributed uniformily on the horizontal over a period of time, estimates of annual average concentrations can be made for any distance in any direction utilizing the appropriate wind rose. This equation gives a concentration pattern of the form illustrated in Figure 31.

Estimations of annual average concentrations of suspended particulate lead for the present study were done utilizing the basic dispersion equation (IV). The unstable meteorological condition was used in the computational procedures of sector concentrations. The combination of meteorological parameters for the calculations were those corresponding to the sampling period as is illustrated in

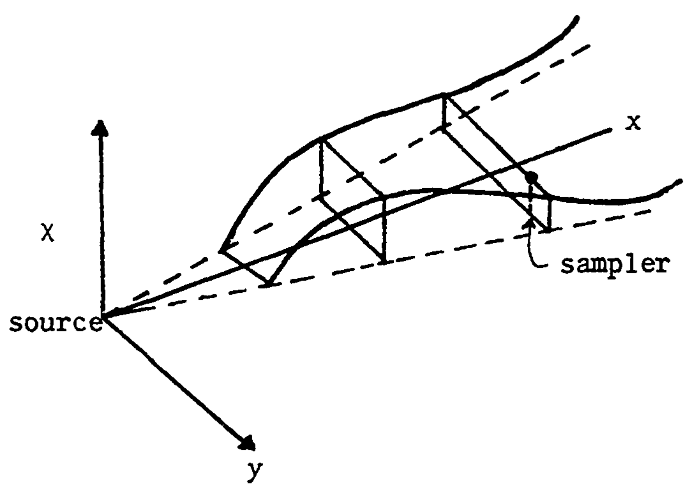


Figure 31. SECTOR ESTIMATE OF RECEPTOR CONCENTRATION
Equation (IV) represents the long-term mean concentration in a given sector if one assumes a uniform angular distribution of the wind direction whenever the wind is within the sector. The concentration builds up to a maximum and decreases again downwind, but it is uniform in the y-direction.

SOURCE: ASME Committee on Air Pollution Controls, (sponsored by) Recommended Guide for the Dispersion of Airborne Effluents. Copyright 1968, by the American Society of Mechanical Engineers, United Engineering Center, New York, N. Y., p.52.

Table XVII. The pollutant release rate (Q), was calculated by converting the annual average in tons per year to micrograms per second from the emissions rate inventories of Table VIII. The vertical plume standard deviation (σ_z) was calculated from Figure 13. The effective stack height (H) was obtained from an effluent stack inspection of the smelter lead plant by the Texas Air Control Board. The various x distances were calculated on a scale from a map secured from the Department of Planning and Research of the city of El Paso, Texas.

For the calculations of the annual average levels, a series of random combinations of angular sectors were tried by dividing the area into five portions. A letter was arbitrarily assigned to each angular sector. For example, sector A which included direction sector degree 288°-315° (WNW-NW) affecting receptors number 6, 7, 8, and 9 to the ESE and SE was first calculated. Next, angular sector B which included direction sector degree 298°-322° (WNW-NW) affecting receptors 1, 4, 6, and 9 to the ESE and SE was calculated. Similarly, estimations for angular sector C were done. This sector included direction sector degree 324°-350° (NW-NNW) affecting receptors 2, 3, and 5 to the SE and SSE. Moreover, calculations for angular sector D were also performed. This sector included direction sector degree 310°-356° (NW-NNW) affecting receptors 1, 2, 3, 4, and 5 to the SE and SSE. Finally, calculations for a main angular sector which included direction sector degree 289°-344° (WNW-NNW) affecting receptors 1, 3, 4, 5, 6, 7, 8, and 9 to the ESE-SSE were performed. This was done under the assumption that on a yearly basis the center of the plume line from the point source is between stations 1 and 9.

TABLE XVII

Percentage Frequencies of Resultant Wind Direction and Average Speed for Data from El Paso International Airport for Period from April 8, 1975 to April 10, 1976.

	Daily Observations of Wind Speed (m.p.h.)											
	April		May		June		July		August		September	
Direction	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed	%	Avg. Speed
N	3.33	6.8	-	-	-	-	3.23	6.8	-	-	-	-
NNE	3.33	5.5	6.45	7.9	-	-	-	-	9.68	6.5	13.33	5.3
NE	-	-	3.23	4.5	-	-	9.68	7.4	3.23	5.9	13.33	8.1
ENE	10.00	10.00	-	-	3.30	7.1	12.90	6.5	16.13	7.0	16.68	8.1
E	3.67	6.8	12.90	6.4	6.67	8.4	19.33	7.5	19.35	7.7	16.68	7.8
ESE	3.33	5.5	6.45	7.6	3.30	8.6	12.90	6.3	19.35	6.1	13.33	6.9
SE	-	-	-	-	10.00	5.8	9.68	8.2	6.44	5.5	3.33	4.9
SSE	-	-	6.45	7.1	6.67	10.5	16.14	6.3	6.45	6.7	3.33	5.6
S	3.33	5.0	6.45	7.0	6.67	5.8	3.23	9.8	-	-	3.33	6.8
SSW	10.00	6.1	6.45	5.5	3.30	7.1	6.45	7.9	3.23	7.1	6.67	5.0
SW	23.55	7.6	22.58	12.7	20.00	10.9	-	-	-	-	3.33	5.2
WSW	16.67	11.2	12.90	7.1	16.67	10.5	3.23	6.2	3.23	6.8	3.33	9.2
W	13.33	11.9	9.68	8.7	13.33	10.00	-	-	3.23	5.9	-	-
WNW	6.13	17.2	3.23	6.2	6.79	9.7	3.23	6.2	3.23	8.5	3.23	10.4
NW	3.33	5.5	3.23	9.5	-	-	-	-	3.23	5.5	-	-
NNW	-	-	-	-	3.30	8.2	-	-	3.23	5.9	-	-
Total	100		100		100		100		100		100	

TABLE XVII (continued)

Daily Observations of Wind Speed (m.p.h.)

Direction	October %	October Avg. Speed	November %	November Avg. Speed	December %	December Avg. Speed	January %	January Avg. Speed	February %	February Avg. Speed	March %	March Avg. Speed
N	3.23	8.8	6.67	3.5	16.10	5.2	9.68	5.2	10.34	7.0	3.23	9.4
NNE	6.45	4.6	10.00	4.8	12.90	5.2	12.90	5.1	13.73	5.8	6.45	6.0
NE	-	-	6.67	5.5	9.68	3.7	12.90	4.8	-	-	6.45	10.6
ENE	19.35	6.8	3.33	5.6	6.45	5.5	12.90	6.2	6.90	5.5	3.23	7.1
E	6.45	4.1	-	-	-	-	-	-	-	-	-	-
ESE	6.45	6.5	3.33	3.5	-	-	6.45	4.5	3.45	7.2	-	-
SE	3.23	4.3	6.67	5.5	3.23	3.5	6.45	3.2	-	-	-	-
SSE	3.23	4.0	3.33	4.6	3.23	2.9	-	-	6.90	4.9	3.23	3.7
S	6.45	5.9	3.33	3.2	9.68	3.3	-	-	10.34	6.9	9.68	6.3
SSW	12.90	9.2	13.33	8.5	3.23	7.6	12.90	5.2	10.34	6.9	6.45	12.7
SW	25.80	8.6	6.67	9.1	9.68	14.2	-	-	21.00	9.6	29.01	14.4
WSW	-	-	3.33	14.5	3.23	7.5	12.90	12.3	6.90	12.5	6.45	7.7
W	3.23	7.8	6.67	13.8	6.45	5.3	9.68	8.2	10.34	13.1	16.13	14.2
WNW	3.23	8.3	10.00	9.7	9.68	6.7	-	-	-	-	3.23	10.2
NW	-	-	3.33	8.5	3.23	6.5	-	-	-	-	3.23	15.4
NNW	-	-	13.33	5.3	3.23	5.0	3.24	9.1	-	-	3.23	9.1
Total	100		100		100		100		100		100	

The calculations and results corresponding to each one of these five angular sectors are depicted in Table XVIII. The first column shows the receptor number included within each specific sector. The second column shows the distance in meters from the point source to the receptor number normal to the center of the plume line. The third column shows the vertical plume standard deviations in meters. Similarly, column 6 shows the vertical wind exponential corresponding to each receptor. The last two columns show the results of the calculated and actual annual average concentrations for each case under consideration.

Visual observations of the area suggest that during the cold season low insulation conditions occur. On the other hand, during the warm season it is observed that only about less than half of the time high insulation conditions occur. In addition, studies of mixing heights as those illustrated in Figures 6 through 9 indicate that the area is characterized by a high frequency of stable conditions. Based on these facts a value of approximately 30% of unstable conditions was taken to account for the percentage occurrence of this atmospheric stability condition. The calculated values of column 7, therefore, must be multiplied by 0.30.

Next, statistical correlations were performed for each combination of angular sectors taking the absolute values of column 7 as x variables and the actual annual concentrations as y variables.

The results of these statistical calculations are illustrated in Figures 32 through 36. The line of best fit shows the underlying patterns connecting the five sets of data, with its corresponding r correlation coefficients.

TABLE XVIII

Calculations and Results Corresponding to Each one of the Four Angular Sectors (A,B,C,D), and Main Angular Sector.

Station No.	x (m)	σ_z (m)	$\sigma_z x$ ($10^5 m^2$)	$2\sigma_z^2$ ($10^5 m^2$)	$\exp-\left[\frac{H^2}{2\sigma_z^2}\right]$	Calc. Data χ $\mu g/m^3$	Actual Data χ $\mu g/m^3$
			Angular Sector (A) WNW-NW (288°-315°)				
8	6583	630	41.472	7.938	0.9358	0.0529	1.32
9	7772	730	56.735	10.665	0.9118	0.0393	2.27
7	12435	1150	143.000	26.450	0.9803	0.0161	0.67
6	21396	1685	360.520	56.784	0.9907	0.0064	0.76
			Angular Sector (B) WNW-NW (298°-322°)				
1	6126	580	35.530	6.720	0.9247	0.0687	2.04
9	7772	730	56.730	10.650	0.9518	0.0443	2.27
4	10058	910	91.520	16.560	0.9687	0.0279	0.73
6	21488	1690	363.140	57.120	0.9908	0.0072	0.76
			Angular Sector (C) NW-NNW (324°-350°)				
2	6949	660	45.860	8.712	0.9413	0.0332	0.51
3	8412	800	67.290	12.800	0.9597	0.0224	0.79
5	18105	1500	271.570	45.000	0.9884	0.0057	0.31
			Angular Sector (D) NW-NNW (310°-356°)				
1	5943	600	35.658	7.200	0.9294	0.0477	2.04
2	6766	635	44.317	8.580	0.9405	0.0389	0.51
3	8485	800	67.880	12.800	0.9597	0.0259	0.79
4	10058	910	91.527	16.562	0.9687	0.0194	0.73
5	18178	1500	272.670	45.000	0.9884	0.0066	0.31
			Angular Sector (Main) WNW-NNW (289°-344°)				
1	6126	580	35.530	6.728	0.9247	0.0691	2.04
8	6309	610	38.487	7.442	0.9317	0.0643	1.32
9	7772	730	56.735	10.658	0.9518	0.0446	2.27
3	7863	765	60.150	11.704	0.9560	0.0422	0.79
4	10058	910	91.520	16.562	0.9870	0.0287	0.73
7	12252	1050	128.640	22.050	0.9764	0.0202	0.67
5	17373	1500	260.600	45.000	0.9884	0.0101	0.31
6	21488	1690	363.140	57.120	0.9908	0.0072	0.76

The emission rate (Q) equals 107.108 x 10^5 µg/second
The percentage of the time the wind is from a given direction (f value) equals 5.7%, 5.7%, 2.5%, 4.5% and 9.4% for sectors A,B,C,D, and main angular sector, respectively.
The effective stack height (H) equals 229 meters

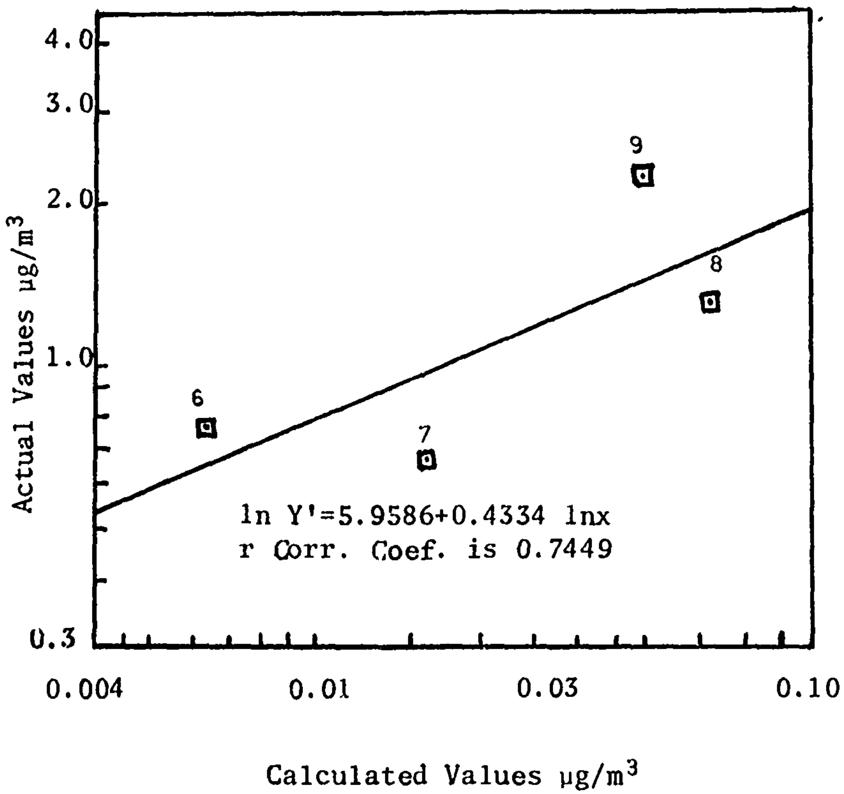


Figure 32. Sector (A) WNW-NW (288°-315°).

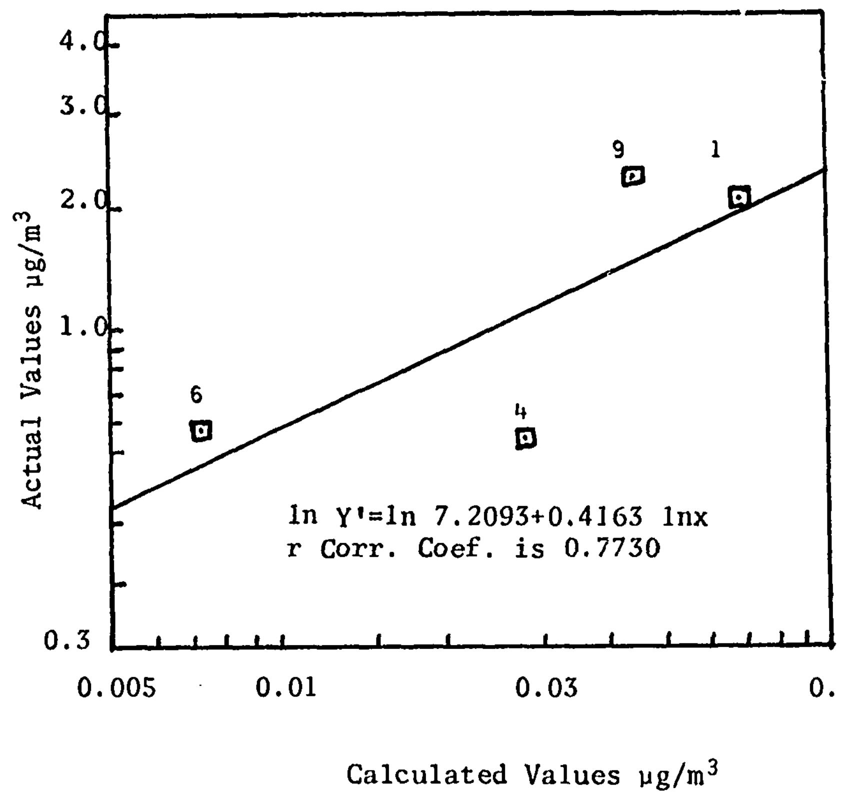


Figure 33. Sector (B) WNW-NW (298°-322°).

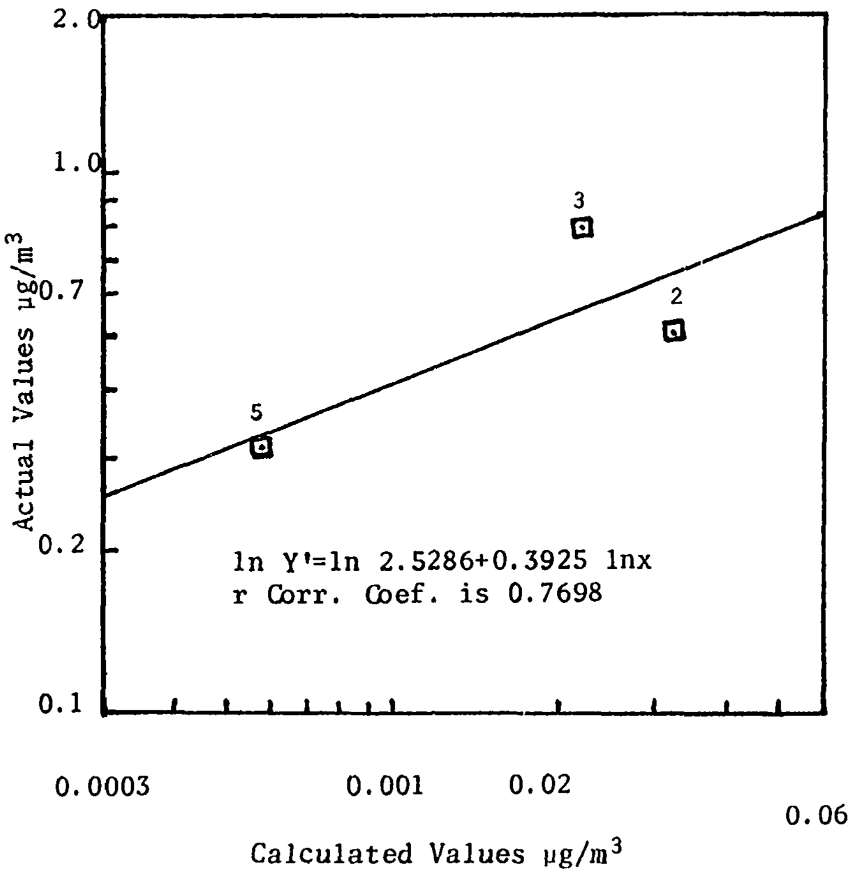


Figure 34. Sector (C) NW-NNW (324°-350°).

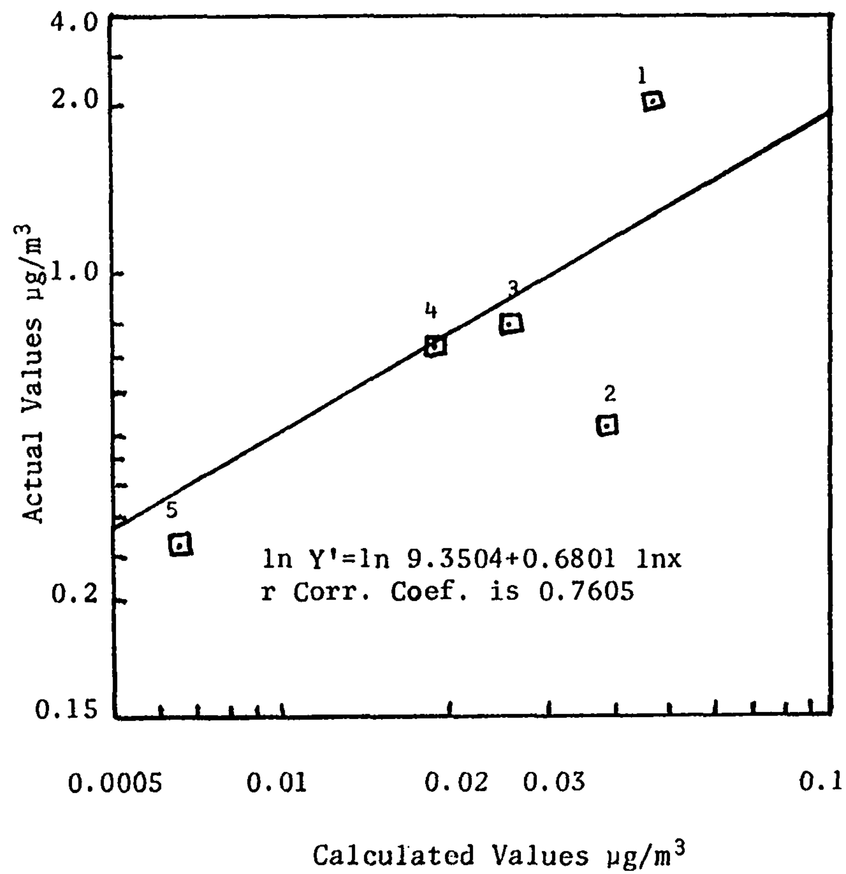


Figure 35 Sector (D) NW-NNW (310°-356°).

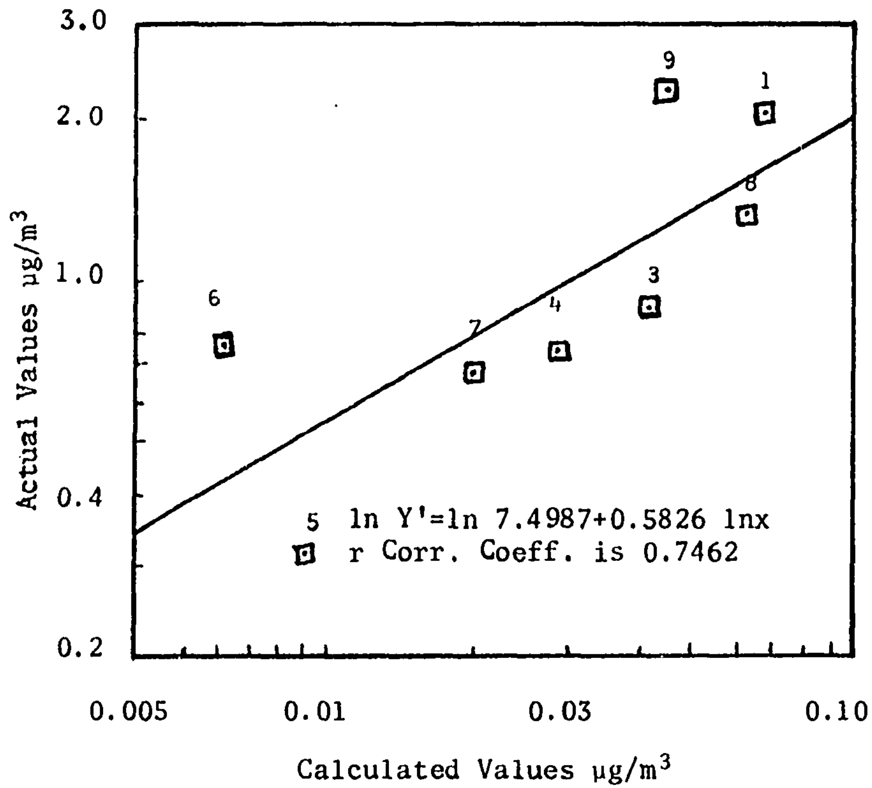


Figure 36. Main Angular Sector WNW-NNW (289°-344°).

The fact that there exists a fairly good association between the variables for each random selection of angular sectors (r correlation coefficient equal to 0.7449, 0.7730, 07698, and 0.7462 corresponding to sector A, B, C, D, and main angular sector, respectively), statistically speaking, suggests that the model of the dispersion equation (IV) used for such calculations can be applied to estimate rough annual average concentrations in the area of study despite the complexities of the terrain. On the other hand, when station number 2 is included in the calculations of the main angular sector, the diffusion model cannot be used with a fair degree of confidence (r equals 0.5364) when receptor 2 is included. This situation is something to be expected since the diffusion model (IV) assumes uniform angular distribution of the wind direction which, in this situation, does not seem to be the case due to localized meteorological conditions characterizing the area around station number 2 as explained previously.

CHAPTER V

SUMMARY AND CONCLUSIONS

This research was designed to investigate the concentration and distribution of particulate lead, zinc, and cadmium in the atmosphere of the city of Juárez, Mexico, emitted from the local smelter in El Paso, Texas for a period of twelve months. Nine high volume air samplers were used to monitor an area covering approximately 21,000 hectares under varying meteorological conditions. The samplers were operated for 24 hours every six days following the procedures recommended by the Texas Air Control Board. The chemical method used for the extraction of particulate lead, zinc, and cadmium was by oxidation using nitric acid. Atomic absorption spectrophotometry was used to quantify the extracted metals.

This study was designed to confirm and extend data gathered in the neighboring city of El Paso, Texas. To that end, concentrations of atmospheric particulate lead and zinc were related utilizing regression and correlation methods. Another approach was to determine the concentrations of the three metals as a function of distance from the smelting industry. This was accomplished by plotting the distribution of the metals on an annual and biseasonal basis utilizing the method of least squares for the estimation of the best fitting line. Still another approach was taken by delimiting the concentrations and distributions of the three metals utilizing analysis of variance methods.

Finally, a statistical correlation between annual average field concentrations and calculated annual average values was also performed.

Based on the results of field measurements and of scientific methods, the following conclusions were drawn:

1. The relationship between the winter mean concentrations of lead and zinc is linear. The moderately high statistical correlation index relating the percentage of association of the variables for most cases implies that atmospheric lead and zinc for the cold season may have had a common source.

2. An analogous situation was found in the relationship between the winter mean concentrations of zinc and cadmium.

3. An inverse relationship existed between the concentration of the three metals and distance from the emitting source (smelter).

4. The concentrations of lead, zinc, and cadmium were substantially higher during the period of October through February; lower levels of the contaminants were found during the spring and summer seasons.

5. Higher levels were recorded by samplers situated near the river plain; lower concentrations were found at higher elevations.

6. Low wind speeds as well as thermal inversions have an important effect in the accumulation of pollutants.

7. The highest concentrations for the period of sampling were recorded at sites 1 and 9 which were situated at 6.2 and 7.8 kilometers from the source respectively. The lowest levels were found at sites 5 and 2 situated at 18.3 and 6.8 kilometers from the

point source respectively.

8. Generally speaking, circulation of wind patterns in the El Paso-Juárez area, as suggested by the concentration and distribution of lead, zinc, and cadmium, can be described as movement of winter winds down the Rio Grande River from the north during the cold season and up the valley from the south during the warm season.

9. The correlation between the annual average field concentrations and annual average calculated values corresponding to each angular sector under consideration, statistically speaking, suggests that on a yearly basis rough approximations of annual average concentrations of atmospheric particulate lead can be obtained by the use of the modified basic dispersion equation with its parametric variables despite the complexities of the terrain.

10. In view of the complex geographic conditions characterizing the El Paso-Juárez area, it is concluded that it is not possible at the present time to calculate the sophisticated atmospheric inputs needed by modern industrial technology of the region.

Further air pollution studies are recommended for prolonged periods of time. In addition, an extended sampling network is necessary. Although the present study points out that annual long-term concentrations distribution can be approximated by the use of the modified basic dispersion equation, it would be necessary to extend the network as well as the sampling period before precise mean levels can be estimated and final conclusions can be drawn about diffusion patterns for the area since the present study covered only a twelve month sampling period and only nine receptor points.

Furthermore, it is recommended that a mesoscale meteorological observation network be established and operated in the El Paso-Juárez area. The appropriate design of a grid system of such magnitude would provide the atmospheric data input necessary for a better evaluation of the environmental impacts presented by the various complex industrial sources characterizing the area. One approach to the problem of establishing and operating a system of this nature would be by joint cooperation of the public school system, private institutions, and local governmental agencies.

As an alternate solution to the problem, it is recommended that field tracer studies be considered. However, it is important to note that a tracer for atmospheric studies should possess certain characteristics appropriate for the particular area surveyed. For example, it should be unique in the region of study, that is, a negligible background of the tracer should be found in the environment. It should be nontoxic, detectable in small quantities, and easily dispersed. Tracers such as fluorescent dyes and pigments, gases, and smoke can be used. Moreover, radioactive materials and constant level balloons can prove satisfactory.

Furthermore, another way of assessing present or future environmental pollution problems is through the use of modeling systems. Wind tunnel experiments, for example, can be effective in areas of complex topographic features. For the area of El Paso-Juárez modeling systems of this nature should be procured and completed as soon as possible.

The potential health hazards presented by exposure to atmospheric lead is of vital importance. In most instances, although the levels of lead found in the present study did not exceed the standard of 5 micrograms of lead per cubic meter of air averaged over 30 days as imposed by the city of El Paso, Texas, (the city of Juarez does not have any lead standards), the potential long-term health effects of the concentrations of the metal in question can not be overlooked. Ordoñez, et al., have shown that 5% of the children between the ages of one through nine living near stations 1, 2, 3, 4, 8 and 9 had blood lead levels greater than 40 micrograms per 100 milliliters of blood. That study did not include any measurements of lead on atmospheric dust. It did include measurements of lead in household dust, garden soil, and pottery used in cooking. A correlation was found between blood lead levels and lead in household dusts and soils; no correlation was found between blood lead levels and lead in pottery. Data prescnted in this study (Table IX) precludes atmospheric lead as the major source of lead found in children by the Ordoñez, et al., study. Their suggestion that the children ingested the lead orally from household dusts and soils appears to be valid. Data presented here further suggests that the smelter is a constant source of lead. Normal diffusion patterns plus sand storms continually replenish the lead "sinks" of household dusts and garden soils.

It is recommended that additional blood tests be made among the child population to delimit the effects of chronic low level absorption of lead as well as the variations of lead in the blood due to changes in diet, exercise, and living conditions. This information would be valuable in the development of specific studies to assess the effects associated with the ingestion of the metal utilizing appropriate parameters for the Mexican infantile population.

The chemistry and physical characteristics of lead in the environment should be reviewed and studied. The chemical forms of lead, especially the mechanisms of biotransformation through the environment, should be investigated. In addition, forms and particle sizes of the various chemical species should be procured.

Furthermore, it is recommended that soil samples be surveyed through the entire area. This, in fact, would help delimit the residual effects of lead in the soils, since the industrial source has been in operation for more than seventy years.

Similarly, automotive emission contributions should be investigated. Bromine-lead ratios, as well as isotopic ratios, would provide the means to account for contributions by automobiles and other sources of lead such as battery plants and open burning of refuse and junked cars.

Finally, plant studies of susceptible species should be carried on to assess the degree of absorbance of crops and vegetables and of livestock grazing in contaminated field. This would undoubtedly be valuable information in estimating the potential health effects that might be associated with the consumption of these kinds of foods.

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APPENDIX

THE DEPARTMENT OF THE TREASURY
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LIST ARTICLES EXPORTED

Hi-vol, General Motor Works, serial 9867
Hi-vol, RAC, serial 7977
Hi-vol, RAC, Serial 8046
Hi-vol, RAC, Serial-8025
Hi-vol, RAC, Serial 8040
AISI Sampler, RAC, UEEP 49239
six extension cords

SIGNATURE (Owner or Agent) Howard C. [signature]

DATE FEB 11 1975

The Above-Described Articles Were:

EXAMINED		LADEN under my supervision	
DATE	PORT	DATE FEB 11 197	PORT Bridge of the Americas
SIGNATURE OF CUSTOMS OFFICER		SIGNATURE OF CUSTOMS OFFICER	

CERTIFICATE ON RETURN

Duty-free entry is claimed for the described articles as having been exported without benefit of drawback and are returned unchanged except as noted: (use reverse if needed)

SIGNATURE OF IMPORTER	DATE

GPO 963-606

FORM
CUSTOMS 4455
JAN. 1970

Certifying officers shall draw lines through all unused spaces with ink or indelible pencil.

ESTADOS UNIDOS MEXICANOS

SECRETARIA
DE
SALUBRIDAD Y ASISTENCIA

CG-3

DEPENDENCIA SUBSECRETARIA DE MEJORAMIENTO DEL AMBIENTE

SECCION DELEGACION FRONTERIZA

MESA

NUMERO DEL OFICIO 024-75

EXPEDIENTE

ASUNTO: se solicita acuerdo.-

Cd. Juárez, Chih., 28 FEB. 1975

C. Administrador de la Aduana,
Lic. Humberto García de Alba,
P r e s e n t e . -

En relación con la plática verbal que sostuvimos, estoy suplicando por medio del presente se sirva dictar el acuerdo necesario para internar temporalmente 5 muestreadores de alto volúmen Números 47492, 47493, 47494, 47495 y 47496 y 1 muestreador de cinta No. 49239.

Los primeros cinco muestreadores los construye la General Metal Works y el de Cinta la Research Appliance Co.

Adjunto le estoy enviando a usted la fotografía de los 5 muestreadores de Alto Volúmen y sus caracteristicas.

Del muestreador de Cinta no tenemos la fotogra-

En relación con la plática verbal que sostuvimos, estoy suplicando por medio del presente se sirva dictar el acuerdo necesario para internar temporalmente 5 muestreadores de alto volúmen Números 47492, 47493, 47494, 47495 y 47496 y 1 muestreador de cinta No. 49239.

Los primeros cinco muestreadores los construye la General Metal Works y el de Cinta la Research Appliance Co.

Adjunto le estoy enviando a usted la fotografía de los 5 muestreadores de Alto Volúmen y sus caracteristicas.

Del muestreador de Cinta no tenemos la fotografía a la mano pero le señalo las caracteristicas:

No. 492239
Serie G-223004-SER
115 watts, 60 ciclos
0-100 microamperes DC
peso.- 46 libras
altura 11 1/2 '' largo 22 1/2'' y 12'' fondo

Aduana Fronteriza
1974
Juárez, Chih.

Estos muestreadores servirán como base de un programa conjunto de muestreo que llevarán a cabo la Universidad Autónoma de Cd. Juárez y la Universidad de Texas en el Paso, en relación con los trabajos de coordinación binacional que llevamos en la zona. Los muestreadores quedarán al cuidado directo del Sr. Rector de la U.A.C.J. Dr. René Franco Barreno en el domicilio de la Rectoría en Ave. López Mateos No. 20.

Estos aparatos los utilizaremos en principio durante un período de tres meses, aunque es posible que el mismo se alargue de acuerdo con las necesidades del programa.

T. G. N.

SECRETARIA
DE
SALUBRIDAD Y ASISTENCIA

CG-3

DEPENDENCIA SUBSECRETARIA DE MEJORAMIENTO DEL AMBIENTE

SECCION DELEGACION FRONTERIZA

MESA

NUMERO DEL OFICIO 024-75 #2

EXPEDIENTE

ASUNTO:

A t e n t a m e n t e
SUFRAGIO EFECTIVO. NO REELECCION
EL DELEGADO FRONTERIZO

GERMAN SANCHEZ TRUJILLO

c.c.p. C.P.T. Francisco Vizcaino Murray.- Subsecretario
c.c.p. C. Ing. Jorge Munguía Bárcena.- Director Gral. de Operación
c.c.p. C. Ing. Luis Erklich.- Director Gral. Investigación
c.c.p. C. Dr. Manuel Mondragón y Kalb Subdirector Gral. Técnico
c.c.p. C. Dr. René Franco Barreno.- Rector de la U.A.C.J.- Cd.

GERMAN SANCHEZ TRUJILLO

c.c.p. C.P.T. Francisco Vizcaino Murray.- Subsecretario
c.c.p. C. Ing. Jorge Munguía Bárcena.- Director Gral. de Operación
c.c.p. C. Ing. Luis [illegible]klich.- Director Gral. Investigación
c.c.p. C. Dr. Manuel Mondragón y Kalb Subdirector Gral. Técnico
c.c.p. C. Dr. René Franco Barreno.- Rector de la U.A.C.J.- Cd.

GST/mgtm.-

CC. JEFES DE LA SOBREVIGILANCIA Y DE PUNTO EN LA GARITA CORTE DE CORDOVA:

Permítase la importación temporal por el término de TRES MESES de los aparatos que se especifican en la relación anexa debiendo confrontar tanto a su entrada como a su retorno al extranjero las caracteristicas de los mismos.-

Cd. Juárez, Chih., 28 de febrero de 1975.

El Administrador

~~Lic. Humberto García de Alba~~

Aduana Fronteriza

Ciudad Juárez, Chih.

SE INTERNO AL PAIS EL 28 DE FEB/75

AL CONTESTAR ESTE AVISO CITENSE LOS DATOS CONTENIDOS EN EL CUADRO DEL ANGULO SUPERIOR DERECHO.

T. C. N.

OFICINA CENTRAL
DPTO. DE CONTROL SANITARIO
PREVENCION Y CONTROL DE LA
CONTAMINACION
CORRESPONDENCIA
5022-

01644
Rel. a estaciones de muestreo.

Chihuahua, Chih. 19 de Feb. de 1975.-

C. DR. EDMUNDO HERRERA NEGRETE
DIRECTOR DEL CENTRO DE SALUD
"LUIS GRAVILIO MUÑOZ"
CD. JUAREZ, CHIH.

Se ha recibido en esta Jefatura a mi cargo, solicitud para utilizar las estaciones de muestreo existentes en esa localidad en un estudio para conocer la distribución de plomo- según programa que se anexa, por lo cual solicito de Ud. se sirva considerar lo anterior para auxiliar al Sr. Hector A. Quevedo M. quien ya ha sostenido pláticas al respecto con - la Oficina Sanitaria Panamericana de el Paso, Tex. y con el- C. Germán Sánchez Trujillo Delegado de la Subsecretaría de- Mejoramiento del Ambiente.

1 ANEXO:

ATENTAMENTE
"SUFRAGIO EFECTIVO NO REELECCION"
EL JEFE DE LOS SERVICIOS

DR. CARLOS [illegible]

C.c.p.- C. Germán Sánchez Trujillo.-Delegado de la Subsecretaría de Mejoramiento del Ambiete.- Cd. Juárez, Chih.
C.c.p.- C. Ing. Guillermo H. Dávila.- Oficina Sanitaria Panamericana. El Paso Tex.
C.c.p.- C. Hector A. Quevedo M. Rio Bolsa No.1031 Col. Los - Nogales, Cd. Juárez, Chih.

CTH/AECS/elrc.

Serv. Coord. de Sa[illegible]

PRESIDENCIA MUNICIPAL
Cd. Juárez, Chih.

Sección GOBERNACION.
Referencia
Expediente
Núm. de Oficio SA-992.

ASUNTO:

C. HECTOR A. QUEVEDO,
RIO VOLGA #1031,
P R E S E N T E.

En relación con su escrito de fecha 16 de marzo del año en curso, en el que nos hace saber que se llevará acabo un estudio para conocer la distribución atmosférica de metales pesados tóxicos en el área de Ciudad Juárez, y que para tal efecto se formará una red de monitoreo consistente en nueve estaciones muestreadoras, dos de las cuales estarán situadas en las Colonias Vicente Guerrero y Galeana en la Avenida División del Norte y Joaquín Amaro a la altura de la Delegación de Policía número 13 y otra entre las Calles Zihuatanejo y Flores Magón a la altura de la Delegación de Policía número 17.

Por lo que, por tal motivo y de acuerdo con su solicitud, se le dan facilidades para que establezca dichas Estaciones de muestreo en los sitios antes mencionados.

Reitero a Usted las seguridades de mi consideración distinguida.

A t e n t a m e n t e.
Cd. Juárez, Chih., a 16 de marzo de 197[illegible].
SUFRAGIO EFECTIVO: NO REELECCION.
EL PRESIDENTE MUNICIPAL.

PRESIDENCIA MUNICIPAL
Cd. Juarez, Chih.

DR. RAUL H. LEZAMA.

EL SECRETARIO.

LIC. CARLOS M[illegible] CALDERA.

c.c.p. C. Inspector de Policía, a efecto de que dé las facilidades del caso.

ml.

AL CONTESTAR SIRVASE CITAR INVARIABLEMENTE
EL NUM. DE OFICIO Y EXPEDIENTE.

PRESIDENCIA MUNICIPAL
Cd. Juárez, Chih.

Sección GOBERNACION.
Referencia
Expediente
Núm. de Oficio S -1012.

ASUNTO:

C. HECTOR A. QUEVEDO,
RIO VOLGA #1031,
P R E S E N T E.

En relación con su escrito de fecha 18 de marzo - del año en curso, en el que nos hace saber que se llevará acabo un estudio para conocer la distribución --- atmosférica de metales pesados tóxicos en el área de-- Ciudad Juárez, y que para tal efecto se formará una -- red de monitoreo consistente en nueve estaciones muestreadoras, una de las cuales estará situada en Zaragoza, Distrito Bravos.

Por lo que, por tal motivo y de acuerdo con su -- solicitud, POR ACUERDO SUPERIOR, se le dan facilidades para que establezca dichas Estaciones de Muestreo en - los sitios antes mencionados.

Reitero a Usted las seguridades de mi consideración distinguida.

A t e n t a m e n t e .
Cd. Juárez, Chih., a 19 de marzo de 1979.
SUFRAGIO EFECTIVO: NO REELECCION.
EL SECRETARIO DEL H. AYUNTAMIENTO.

ESTADOS UNIDOS MEXICANOS
PRESIDENCIA MUNICIPAL
CD. JUAREZ, CHIH.

LIC. CARLOS MONGES CALDERA.

c.c.p. C. Inspector de Policía, a efecto de que dé --- las facilidades del caso.

AL CONTESTAR SIRVASE CITAR INVARIABLEMENTE
EL NUM. DE OFICIO Y EXPEDIENTE.

ml.

COMISION FEDERAL DE ELECTRICIDAD
DIVISION NORTE

113

REGION CIUDAD JUAREZ, CHIH.
SUPTCIA. REGIONAL AREA TECNICA
EXPEDIENTE 5305/113/1
MEMORANDUM No. SATR-024/76

ASUNTO: Sobre permiso.

Cd. Juárez, Chih., a

A QUIEN CORRESPONDA:

Con fecha 1o. de Abril de 1975 se le - concedió permiso al Sr. Héctor A. Quevedo para que instalara un mues — treador de alto vólumen (HI-VOL) en nuestro predio de la Comisión - - - Federal de Electricidad del Fraccionamiento "El Mirador", con el objeto de llevar a cabo un estudio de la distribución de plomo atmosférico por un período de 12 Meses.

Se extiende el presente como testimo - nio para los fines que el Sr. Quevedo juzgue conveniente.

Muy Atentamente.

Ing. L.H. Aguilar
Supte. Reg. Area Técnica

c.c.p.- Archivo.

I'LHA/lad.-
2-25-76

Campestre Juárez, S. C.
PARTIDO SENECU. D. B.
TEL. 3-08-35 APARTADO 146
CD. JUAREZ. CHIH.

A QUIEN CORRESPONDA:

Por medio de la presente hacemos constar que a solicitud de él y con el objeto de servirse de ello como investigación para la obtención de su doctorado en ingeniería ambiental con ésta fecha ésta institución concede permiso al Sr. Ing. Héctor A. Quevedo Urias con el objeto de que instale en las áreas que él considere más convenientes un muestreador de alto volúmen (Hi-vol.), para un estudio de contaminación atmosférico por plomo durante el período de 12 meses.

Extendemos la presente constancia a solicitud del interesado y para los fines que el considere convenientes.

Cd. Juárez, Chih. lo. de Abril de 1975

CAMPESTRE JUAREZ, S. C.

ARTURO PORRAS N.
GERENTE

Correspondencia Particular del
Presidente de la
Junta Federal de Mejoras Materiales
Cd. Juárez, Chih.

A 2 de Marzo de 1976.

A QUIEN CORRESPONDA:

Con fecha lo. de Abril de 1975, se - le concedió permiso al señor Héctor Adolfo Quevedo para que instalara un muestreador de alto volúmen (HI-VOL) en el Parque de El Chamizal -- de esta Junta Federal de Mejoras Materiales a - mi cargo, con el objeto de llevar a cabo un estudio de contaminación atmosférica por plomo por el lapso de doce meses.

Se extiende la presente como testimonio para los fines que el señor Quevedo juzgue - convenientes.

Ing. Rafael Pérez Serna.

AÑO INTERNACIONAL DE LA MUJER

SECRETARIA
DE
SALUBRIDAD Y ASISTENCIA

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CG-2

DEPENDENCIA SUBSECRETARIA DE MEJORAMIENTO DEL AMBIENTE

SECCION DELEGACION FRONTERIZA

MESA

NUMERO DEL OFICIO 076-75

EXPEDIENTE

ASUNTO: se solicita acuerdo

Cd. Juárez, Chih., 23 de Julio de 1975.-

C. Administrador de la Aduana,
Lic. Humberto García de Alba,
P r e s e n t e .-

Suplico a usted de la manera mas atenta se sirva dictar su acuerdo necesario para internar temporalmente dos muestreadores de Alto Volúmen, similares a los que utilizamos desde el mes de Marzo del año en curso.

Dichos muestreadores los construye la General Metal Works de los E.U.A.

Estos aparatos se utilizarán en el programa conjunto de muestreo que estan llevando a cabo la Universidad Autónoma de Ciudad Juárez y la Universidad de Texas en El Paso como parte de los trabajos de coordinación binacional que ...

C. Administrador de la Aduana,
Lic. Humberto García de Alba,
P r e s e n t e .-

Suplico a usted de la manera mas atenta se sirva dictar su acuerdo necesario para internar temporalmente dos muestreadores de Alto Volúmon, similares a los que utilizamos desde el mes de Marzo del año en curso.

Dichos muestreadores los construye la General Metal Works de los E.U.A.

Estos aparatos se utilizarán en el programa conjunto de muestreo que estan llevando a cabo la Universidad Autónoma de Ciudad Juárez y la Universidad de Texas en El Paso como parte de los trabajos de coordinación binacional que manejamos en la zona.

Los muestreadores quedarán al cuidado directo del Dr. René Franco Barreno, Rector de la U.A.C.J. Los aparatos serán utilizados en principio durante un período de tres meses, aunque es posible que el período se alargue de acuerdo con las necesidades del programa.

A t e n t a m e n t e
SUFRAGIO EFECTIVO. NO REELECCION
EL DELEGADO FRONTERIZO

GERMAN SANCHEZ TRUJILLO

AL CONTESTAR ESTE AVISO CITENSE LOS DATOS CONTENIDOS EN EL CUADRO DEL ANGULO SUPERIOR DERECHO.

c.c.p. C.P.T. Francisco Vizcaino Murray.- Subsecretario
c.c.p. C.Ing. Jorge Munguía Bárcena.- Dir. Gral. de Operación
c.c.p. C.Ing. Luis Erklich.- Dir. Gral. de Investigación
c.c.p. C. Dr. Manuel Mondragón y Kalb Subdirector Gral. Técnico
c.c.p. C. Dr. René Franco Barreno Rector de la U.A.C.J. Cd.

GST/mgtm.-