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An Air pollution source apportionment study for Billings MT : 1978 through 1980

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AN AIR POLLUTION SOURCE APPORTIONMENT STUDY FOR BILLINGS, MT: 1978 THROUGH 1980

by

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ABSTRACT

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An Air Pollution Source Apportionment Study for Billings, Montana: 1978 through 1980

Director: Dr. Ron Erickson

It is the purpose of this paper to determine the sources of air pollution particulates in Billings, Montana. The data used for this analysis was a result of the Montana Air Pollution Study (MAPS) conducted between middle 1978 to early 1980. Four general sizes of particulates are addressed: 1) total suspended particulates (as measured by the high-volume sampler, 2) fine particles (those particles less than 2.5 microns in diameter), 3) coarse particles (particles between 2.5 and 15 microns), and 4) inhalable particles (particles less than 15 microns).

The analysis was conducted using various simple and complex statistical methods. Comparisons were made between the air monitoring data, meteorological data, and emission-related data. Comparisons between emissions-related data such as the day of the week and wet day/dry days and ambient data were used to analyze possible sources. Enrichment factors were used to determine the effect of earth crustal materials on the particulate levels. Finally, factor analysis was used to apportion various sources by use of the elemental data developed from MAPS.

It is proposed that road dust, soils, and the like are the major contributor to total suspended particulate, coarse, and to some degree inhalable particulate in Billings. Fine particulate, on the other hand, seems to be more closely associated with automobile and industrial emissions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The purpose of this paper is to study and to analyze total and inhalable particulate air pollution in Billings, Montana. Total particulates are all particles suspended in the atmosphere, while inhalable particulates consist only of those particles that may enter the nose or mouth. Inhalable particulates are generally defined as those particles not exceeding 15 microns in diameter (mean Stoke's diameter). Specifically, this paper is concerned with the analysis of data collected in Billings during the course of the Montana Air Pollution Study (MAPS) from approximately January 1, 1978 through June 30, 1980. It is hoped that this paper will assist decision-makers in their attempt to control total and inhalable particulates in the atmosphere through a comprehension of the inter-relationships between the particles and meteorological, air monitoring, and emissions data. The key to intelligent decisions regarding the protection of human health from particulates is through an understanding of the particles and their source and behavior,as well as spatial and temporal distributions.

The primary objective of this paper, then, is to determine the major classes of air pollution sources in Billings, which is to say that the objective is to apportion the air pollution sources that significantly contribute to the suspended particulate levels in the area. The means of such a determination is through the analysis of the ambient air quality data, emission-related data, and meteorology.

It is concluded that the total suspended particulate values

observed in the city of Billings are most clearly associated with road dust, soil, and crustal earth materials. It is also concluded that the fine particulate data probably have major industrial and/or automotive exhaust as a major source.

BACKGROUND OF MAPS STUDY

The MAPS project was proposed in response to concern over high death rates in several Montana counties from a variety of cardiovascular and pulmonary diseases such as emphysema, chronic bronchitis and others. A review of death certificates from Deer Lodge, Lake, Missoula, and Silver Bow Counties revealed death rates from these diseases far above the national average. For example, death rates from these diseases in Missoula County were 49 percent above the national average for those people over 65, while the death rates in Deer Lodge and Silver Bow Counties were nearly twice the national average. In addition, these figures indicate that the death rates for women were as high or higher than for men. The later statistic would tend to rule out job-related causes, such as employment in mines or smelters.[1] It became apparent to the Montana Air Quality Bureau (AQB) that the causes may be associated with the surrounding environment, and since the deaths were due to pulmonary-related diseases, air pollution was a suspected cause. These statistics along with other associated data prompted the AQB to approach the 1977 Montana Legislature to request $1.07 million in order to determine how air pollution affects the health of the people in Montana. The Legislature granted the money for a two-year study of air pollution and health in Anaconda, Billings, Butte, Missoula, Columbia Falls, Colstrip, East Helena, and Hardin. The Montana Legislature allocated another $350,000 in the 1979 session to allow for the completion of the study.

In response to the legislative mandate, the Bureau undertook five health effect studies in various communities.2

1. Pulmonary function testing of school children (second through fifth grades). (All MAPS communities).

2. Pulmonary function testing of patients identified as having a chronic obstructive pulmonary disease (COPD). (Missoula).

3. Screening for the presence of possible carcinogenic substances in children's urine. (Butte-Anaconda).

4. Review of admissions for pulmonary-related diseases at all hospitals. (Entire state of Montana).

5. Death Certificate analysis for the period 1970-1975. (Deer Lodge, Lake, and Silver Bow Counties).

Significance of the MAPS Study

Principal investigators for the MAPS project devoted a great deal of attention to the comparisons of pulmonary function and particulates, and most especially inhalable particulates. The investigators generally found a negative correlation between inhalable particulates, and pulmonary function, which is to say that when the inhalable particulate levels were high, the ability of children and COPD patients to perform well was reduced. This correlation held true both for inter-city comparisons and comparisons with varying air pollution levels over time (seasonal).3

The results of these analyses are highly significant for two reasons:

1. Many of the consultants contacted to review the project felt that the project would find "no effect" since population and pollution levels in Montana's cities were too small to demonstrate effects, and

2. MAPS is one of the few studies ever conducted to address inhalable particulates and their relationship to human health.

Another point of interest in this study is that there is an apparent effect on the population at large and not just on a

"sensitive" population. The latter has been a point of contention between opposing groups in the establishment of ambient air quality standards, since some believe that the entire population ought to be protected rather than just "sensitive" individuals.

The Environmental Protection Agency (EPA) became sufficiently interested in the overall study to contract the AQB for $50,000 to write a report on results for its review. The report intitled Relationship Between Human Health and Inhalable Particulates, which was published in October 1980, contains the MAPS results with regard to particulates. It is apparent that EPA may use the information to set a national ambient standard for inhalable particulates. EPA has expressed an interest in this area for several years. Of late, numerous workshops have been conducted on the subject of inhalable particulates. These workshops have been dedicated to health effects, measurement techniques, and existing data bases. EPA currently has several inhalable particulate air monitoring networks throughout the United States. Montana, for instance, is part of the "Western Fine Particulate Program" sponsored by EPA and conducted by the University of California at Davis. EPA also is sponsoring research for methods of analysis and capture of inhalable particulate.

In summary, both the State of Montana and the EPA are interested in the measurement and the interpretation of total and inhalable particulates. EPA has suggested that an inhalable ambient standard is in the making. This interest in the measurement of inhalable particulates lends itself to a need for analysis of the associated factors affecting the data distribution.

Footnotes

[1]Stephen Medvec et al., Montana Air Pollution Study: Final Report, (Helena, MT: Montana Department of Health and Environmental Sciences, 1981), pp. 61-65.

[2]Montana Air Quality Bureau, Montana Air Pollution Study 1977-1979: Approach and Methodology, (Helena, MT: Montana Department of Health and Environmental Scineces, 1978), pp. 30-51.

[3]Montana Air Quality Bureau, Montana Air Pollution Study: Relationship between Human Health and Inhalable Particulate, (Helena, MT: Montana Department of Health and Environmental Sciences, 1980), pp. iii-v.

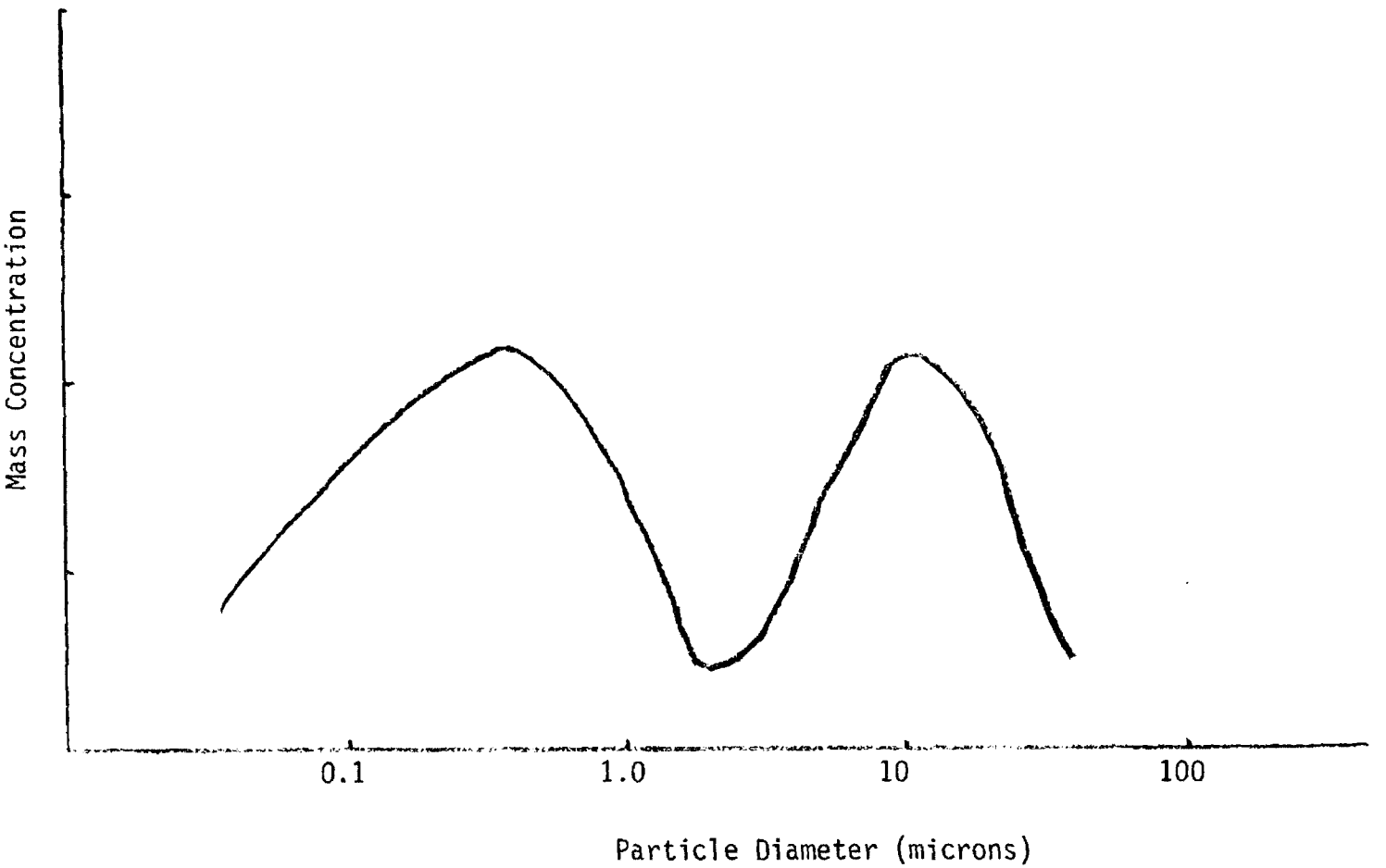
PARTICULATES AND THEIR MEASUREMENT

Air pollution measurement and control generally are separated into two classes: 1) gases and 2) particles. The most common gaseous air pollutants are sulfur dioxide, nitrogen dioxide, carbon monoxide, and ozone. These pollutants normally are measured with an instrument which constantly samples the air and responds to the appropriate pollutant with either an indication on a chart recorder or an analog signal (for computer processing and logging), or both. The measurement and the analysis of particulates, however, are usually quite different.

Particulates and Their Characteristics

Particulates may actually consist of liquid or solid particles. The larger particles (those greater than 10 or so microns in diameter) tend to fall out fairly rapidly. Particles sampled in the air normally vary from about .1 microns to as large as 50 microns, depending on the type of instrument used. Different sources of particles tend to possess quite different size characteristics. For example, tobacco smoke is between .001 and .2 microns, rain drops from 500 to 1000 microns, fog from 1 to 50 microns, pollens (causing hay fever) from 15 to 60 microns, and oil smoke from .05 to 1 micron.[1] The size uniqueness for various types of particulates lends itself to a unique size range distribution. Most urban areas typically possess a bimodal distribution such as the one shown in Figure 1. Note that the bimodal peaks occur near .5 micron and 10 microns. It is generally assumed that these two peaks represent quite different sources. The second peak tends to represent sources such as road dust, geologic materials, crushers, and

Figure 1



Source: John A. Cooper, Course Outline and Notes for Chemical and Physical Methods of Quantitative Source Apportionment, (Oregon Graduate Center, July, 1980), p. 42.

abrasive and/or cutting operations, while the first peak (near .5 microns) usually represents combustion type sources such as smoke, automotive exhaust, and so forth.[2]

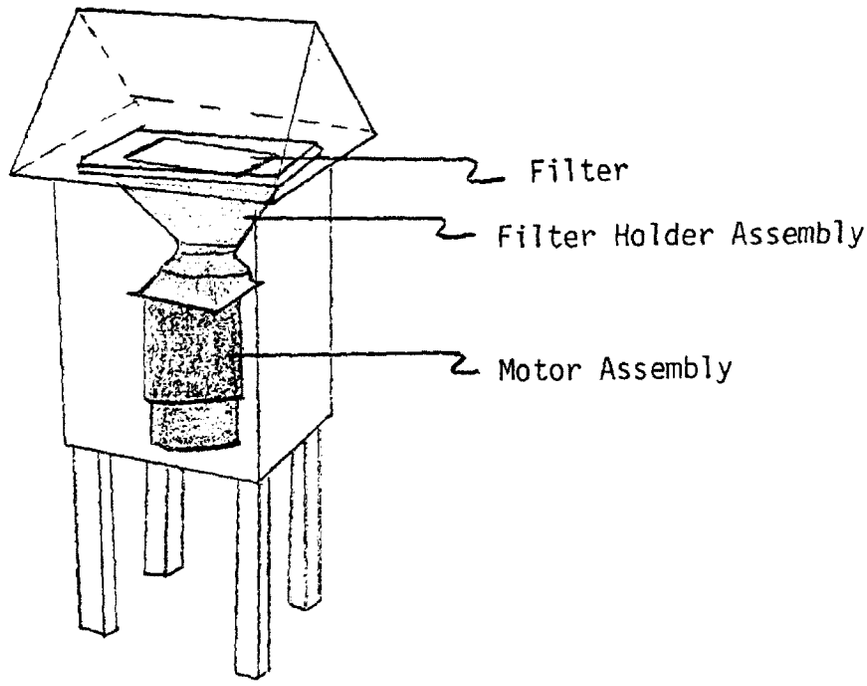
Particulate Measuring Devices

The most common type of measurement for particulates involves capturing the particles on a filter. In most instances, a clean filter is weighed in a laboratory and then exposed to the atmosphere. Air is drawn through the filter at a known rate during the sampling time. At the end of the sampling period, the filter is removed and then returned to the laboratory for reweighing. The difference in weight between the exposed and the unexposed filter divided by the volume of air passing through the filter during the run is a measurement of the concentration of particles in the air. The most common unit of measurement is micrograms per cubic meter (ug/m^3).

The high-volume sampler (hi-vol) has been in widespread use throughout the United States for many years, and continues to be a major instrument for monitoring air quality levels in virtually all state and county air pollution agencies. The hi-vol measures particles exactly as described above. The particles are collected on a 8 x 10 inch filter (usually fiberglass and sometimes cellulose). The filter is weighed in the laboratory and then sent to a field sampler, which consists of an aluminum housing, vacuum motor, filter holder assembly, and a flow-measuring device (see Figure 2). The hi-vol is almost always operated for 24-hours at a time (usually midnight to midnight). After the run is completed, the filter is returned to the laboratory for weighing and concentration calculation. The hi-vol is of such widespread use that it

Figure 2

High Volume Sampler



Source: Code of Federal Regulations, Chapter 40, Part 50, Appendix B

has been designated by the EPA and the State of Montana as the "reference method" for measuring total suspended particulates (TSP).[3] All current ambient standards for particulates must be based on this measuring device. Other devices cannot be used for determination of compliance with ambient standards unless they can be shown, through elaborate testing, to be equivalent to this method.

Although the hi-vol is designated to measure total suspended particulates, as a practical matter it has the ability to measure only a certain size distribution of particles. The aerodynamic cut point (which will be explained latter) for the hi-vol is approximately 30 microns. The smallest measureable particle is about .01 microns, smaller than the trapping filter[4]. The filter media used by the MAPS project were glass-fiber and supplied by EPA as part of a national allocation for consistency among states. The filters are designed to capture 99 percent of all 0.3 micron particles (using the DOP test as described in the Federal Register).[5]

There are several distinct disadvantages to the hi-vol sampler relative to health effects. As the MAPS study has indicated, and other investigators have pointed out, the relationship between human health and particles is at least partially dependent upon the size of the particles in the air.[6] The hi-vol, however, appears to gather particles with a wide size range. Since it has the ability to capture larger particles, it is quite possible that in many instances the sampler could be biasing the results to larger values than may be represented among the smaller, more important particles. In other words, it takes only a few large particles to indicated high TSP readings when in fact

the small particulate concentration may be very low. The hi-vol sampler may, therefore, have only limited uses in health effects studies. This may not be true, of course, if it can be shown that a relationship exists between the smaller particles and TSP.

The hi-vol also has the further disadvantage that it is generally difficult to determine accurately the concentration of elements within the particulate. The fiber-glass filter is an excellent medium to capture particles and still allow a large air flow through the filter (approximately 1.2 cubic meters per minute). It is, however, not the best medium for elemental analysis because of the high and potentially variable background levels of these elements within the filter itself.

Many air pollution control agencies have used another type of sampler, known as the membrane sampler, to alleviate the second problem. The membrane sampler operates on the same principle, but uses a teflon filter to capture the particulates. A different size filter is used in the membrane sampler than the hi-vol as well as a larger carbon vane pump. This sampler was used by MAPS to obtain some elemental data which would not be obtainable through the hi-vol sampler.

Inhalable Particulate Measuring Devices

The collection and the measurement of inhalable particles is not a trivial task. Recently, various manufacturing companies have begun offering air monitoring devices that selectively sample only the smaller particles in the air. This type of sampler is extremely advantageous for health effects studies such as MAPS. In order to insure an up-to-date sampling network, the MAPS staff elected to purchase ten units of a

type of equipment knowns as a "virtual impactor" or "dichotomous sampler" from Sierra Corporation in California.[8] This type of sampler is clearly the "wave of the future" relative to other particulate samplers which are now becoming obsolete. The EPA and various private companies currently are producing another type of sampler that can be retrofitted onto the hi-vol in order to reduce costs of converting to inhalable particulate monitors. These retro-fitted samplers were not available during the MAPS project's design phase.

Collection of the inhalable particulates occurs on two filters, which are .47 micron pore size and are composed of a fluorocarbon-based material. This material is selected as a filter media when some of the filters are to be subjected to elemental analysis. In order to select the proper size ranges, the sampler draws air in through an aerosol inlet at approximately 16.7 liters/minute (an approximate breathing rate). The aerosol inlet deflects the flow of air vertically into the separation chamber (see Figure 3). The chamber is designed such that the upward air velocity is equal to the settling velocity of a 15-micron particle having a density of 1 gram per cubic centimeter (unit density). Thus, any particles larger than 15 microns settle out and do not enter the instrument.[9]

Having passed through the aerosol inlet, the particles are then accelerated downward through the impactor nozzle (see Figure 4). As the particles pass through the nozzle, they are suddenly accelerated by forcing a sharp 90° turn toward the horizontal. The speed of the air and the sharp turn are designed such that only particles less than 2.5 microns in diameter (unit density) are able to remain in the air flow.

Figure 3

Aerosol Inlet
Dichotomous Sampler

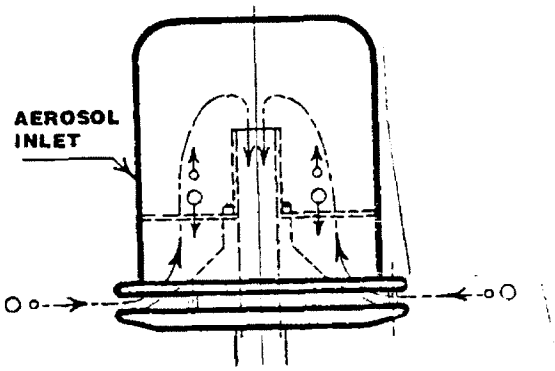
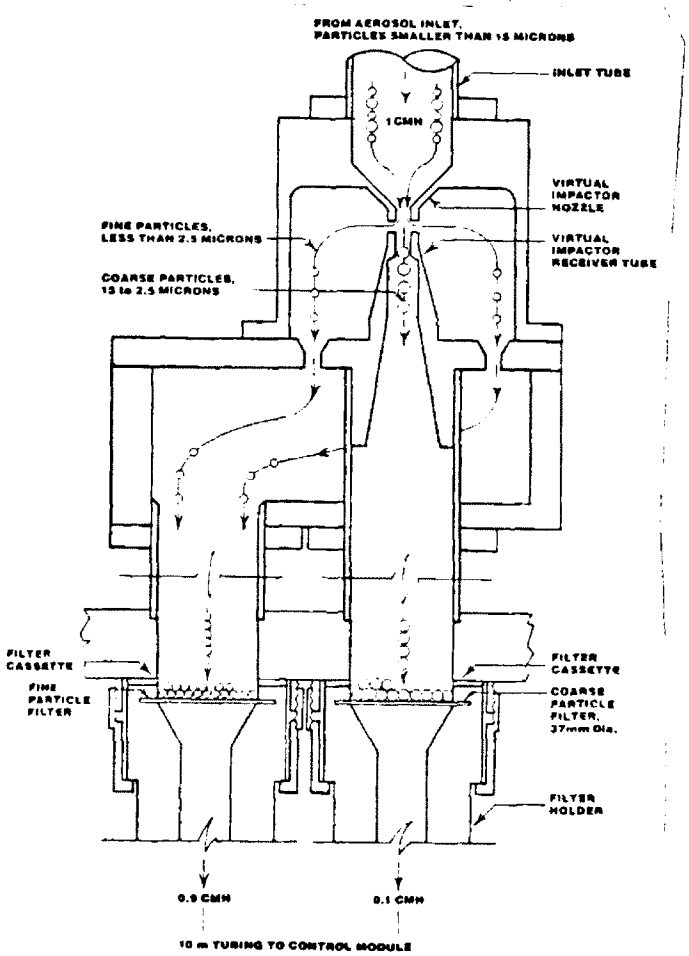


Figure 4

Nozzle Inlet
Dichotomous Sampler



The rest of the particles do not remain in the air flow, by virtue of their inertia, and impact into the "void" of the receiver tube. In order to prevent backflow, the receiver tube actually draws a small amount of air flow (1.67 liters/minute), which also prevents particles from being reintrained into the main air stream and thus deposited on the incorrect filter. This filter (and the associated particles on the filter) is known as the coarse filter since it contains particles between 15 microns (from the aerosol inlet) and 2.5 microns (from the impactor nozzle). The particles that are accelerated through and around the nozzle are known as the fine fraction, that is, particles less than 2.5 microns.[10] The sum of the two is commonly known as inhalable particles.

Both the fine and coarse particles are collected on a 37 mm diameter filter at a flow rate of 15.0 and 1.67 liters/minute, respectively. Since a portion of the aerosol inlet flow is actually diverted to the coarse filter (10 percent), a correction has to be made in the concentration calculation for the coarse and fine filter.

It is important to remember that the cut-off sizes (2.5 and 15 microns) are aerodynamic cut-off points, which is to say that the separation does not occur by some physical means of measuring each particle, but is done based on the aerodynamics of the particle. The cut-off size applies only to particles of unit density and of a spherical shape. The cut-point is also related only to probabilities. For example, if a 2.5 micron particle (unit density and spherical) were to enter the sampler, it would have a 50-50 chance of falling on the fine

filter. If, however, a 2.0 micron particle were to enter the sampler, it would have a 70-30 chance of falling on the fine filter. Figures 5 and 6 show the probability function for the aerosol inlet and the nozzle, respectively. Similarly, a particle of 20 microns will have approximately a 35 percent chance of entering the sampler.

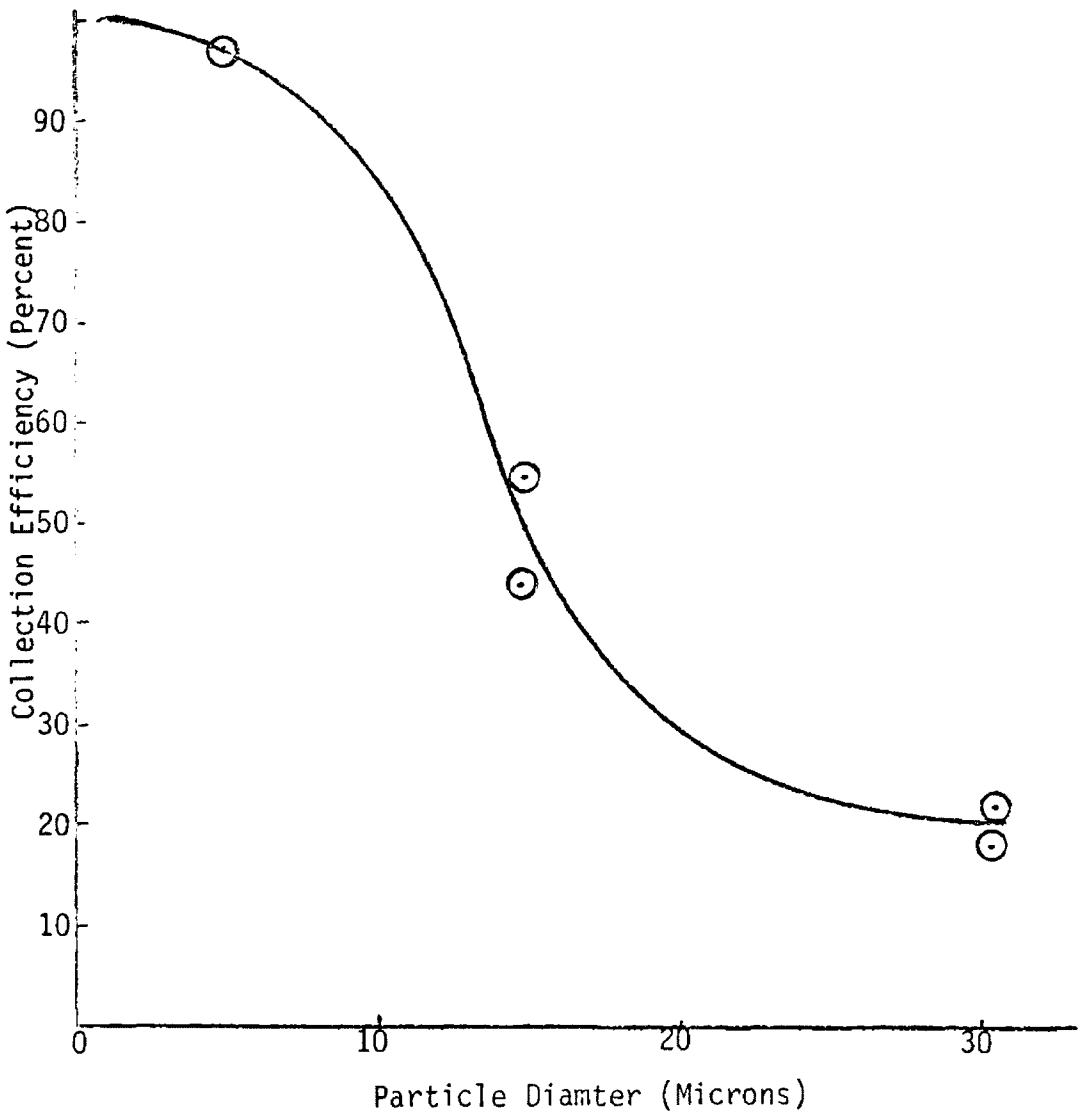
One may logically question the wisdom of such a sampling technique in light of the probabilities of obtaining the correct size particle on the correct filter. This method may not be as accurate in absolute terms of measuring concentrations of small particles as electron microscopes, optical microscopy, and so forth. There are, however, two significant advantages to the technique:

1. Cost. This method is considerably cheaper than electron microscopes and the intensive manpower that would be required for optical techniques.

2. Human Health. Although aerodynamic separation may appear to be a relatively inacurate method of separation, it is precisely the same method used by the mouth and nose. As one breathes, particles are drawn up through the nose and/or mouth. Particles are accelerated through sharp turns, which drop out larger particles. The reason for choosing the sample cut-point of 2.5 microns is that it is generally believed that particles of this size have the ability to enter the deep lung, while particles larger than this size will be removed between the throat and lung.

Figure 5

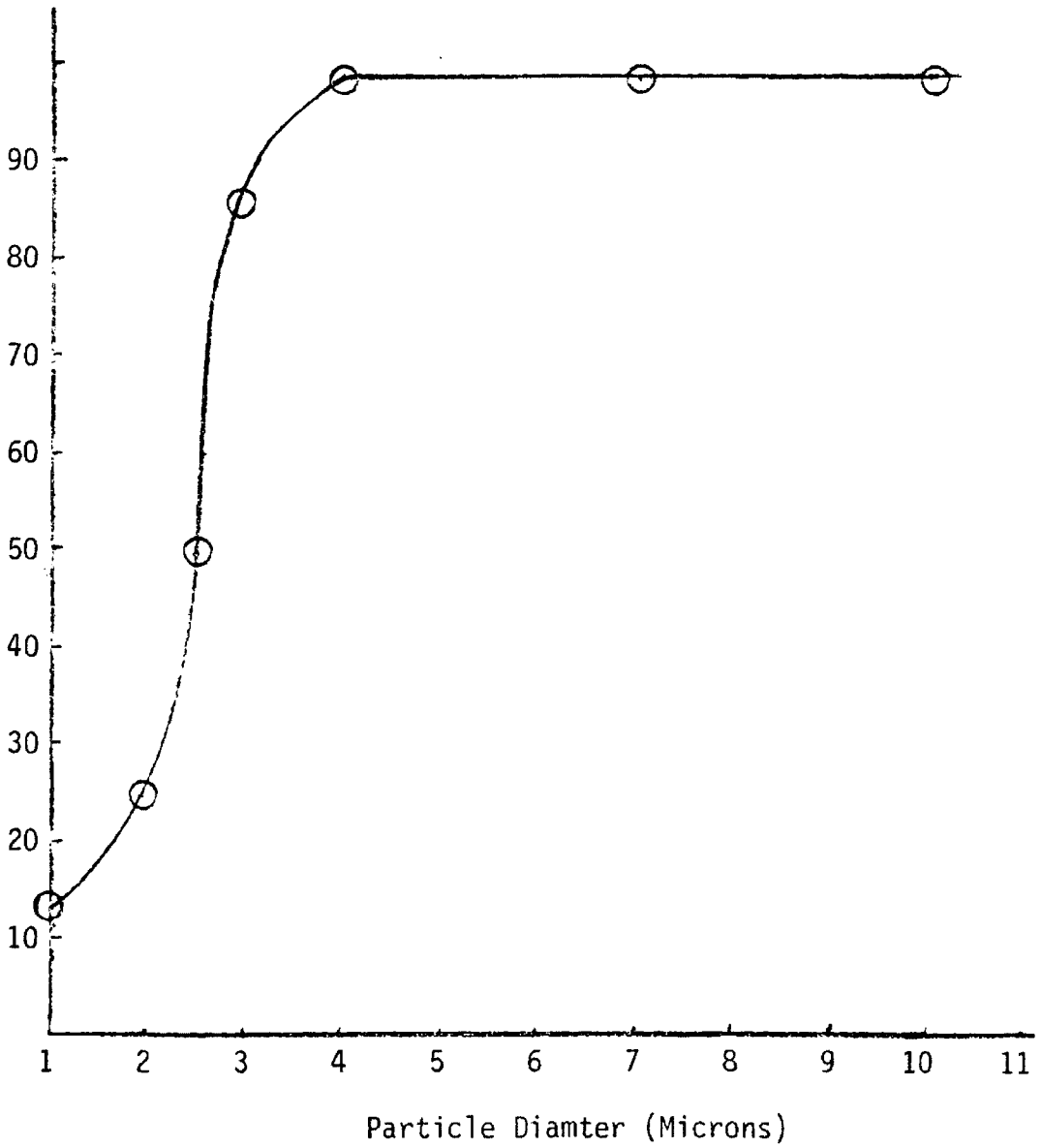
Collection Efficiency of Aerosol Inlet
Dichotomous Sampler



Source: Sierra Instruments, Inc., "Instruction Manual for Series 244 Dichotomous Sampler and Accessories.

Figure 6

Collection Efficiency of Nozzle
Dichotomous Sampler



Source: Sierra Instruments, Inc., "Instruction Manual for Series 244 Dichtomous Sampler and Accessores."

FOOTNOTES

[1]Paul Magill, Francis Holden, and Charles Ackley, Air Pollution Handbook, (New York: McGraw-Hill Book Company, Inc., 1959), p. 1-24.

[2]D. A. Lundgren, Mass Distribution of Larger Atmospheric Particles, Ph.D. Thesis, University of Minnesota, Minneapolis, MN, cited by U.S. Environmental Protection Agency, Air Quality Criteria for Particulate Matter and Sulfur Oxides, Volume II, Draft, (Research Triangle Park, NC: Environmental Criteria And Assesment Office, Office of Health and Environmental Assesment, Office of Research and Development, U.S. Environmental Protection Agency, 1981), pp. 2-45 - 2-50.

[3]Environmental Protection Agency Regulations on National Primary and Secondary Ambient Air Quality Standards, "National Primary Ambient Air Quality Standards for Particulate Matter," Federal Register, 40, Part 50.6, February 18, 1975, p. 7042.

[4]Paul Lioy, John Watson, and John Spengler, "APCA Specialty Conference Workshop on Baseline Data for Inhalable Particulate Matter," Journal of the Air Pollution Association, 30 (October, 1980), p. 1126.

[5]Environmental Protection Agency Regulations on National Primary and Secondary Ambient Air Quality Standards, "National Primay Ambient Air Quality Standards for Particulate Matter," pp. Appendix B.

[6]F. J. Miller, et. al., "Size Considerations for Establishing a Standard for Inhalable Particulates," Journal of the Air Pollution control Association, 29 (June 1979), pp. 610-615. M. Lippmann, and R. Albert, "The Effect of Particle Size on the Regional Deposition of Inhaled Aerosols in the Human Respiratory Tract," Journal of the American Industrial Hygene Association, 30 (1969), p. 257.

[7]Harold Robbins, et al., Montana Air Pollution Study: Air Monitoring Instrumentation, (Helena, MT: Montana Department of Health and Environmental Sciences, 1979), pp. 17-18.

[8]Ibid. pp. 18-21.

[9]Ibid. pp. 18-21, 26-27.

[10]Sierra Instruments Inc., Instruction Manual for Series 244 Dichotomous Sampler and Accessories, (Carmel Valley, CA: 1978).

MAPS PARTICULATE NETWORK

An air monitoring network was chosen and established in the communities of Anaconda, Billings, Butte, Great Falls, and Missoula. The total monitoring effort undertaken by MAPS included measurements of gases and particles. The measurement of particles also included, in some cases, an analysis of elemental composition. Particular attention was paid to those elements that may have or cause some health effect. Extensive meteorological monitoring also was conducted, including surface wind speed and direction, upper level wind speed and direction, atmospheric stability, and mixing heights.

The AQB in conjunction with the Air Monitoring Advisory Committee of the MAPS study selected the pollutants, sampling frequency, and location of the air monitoring stations. AQB staff generally decided on specific brands of instruments. The air monitoring sites were chosen to represent the study population's air pollution exposure according to the following criteria: school, transportation density, population, industrial activity, elevation, business density, distance from roads of high traffic flow, and open ventilation around the site (trees, buildings, and other obstructions). Table 1 is a comparison of the major site locations characteristics.

A map of Billings is included as Figure 7 and includes the sites of the air monitoring stations as well as the location of the pulmonary function testing of school children.

Table 1

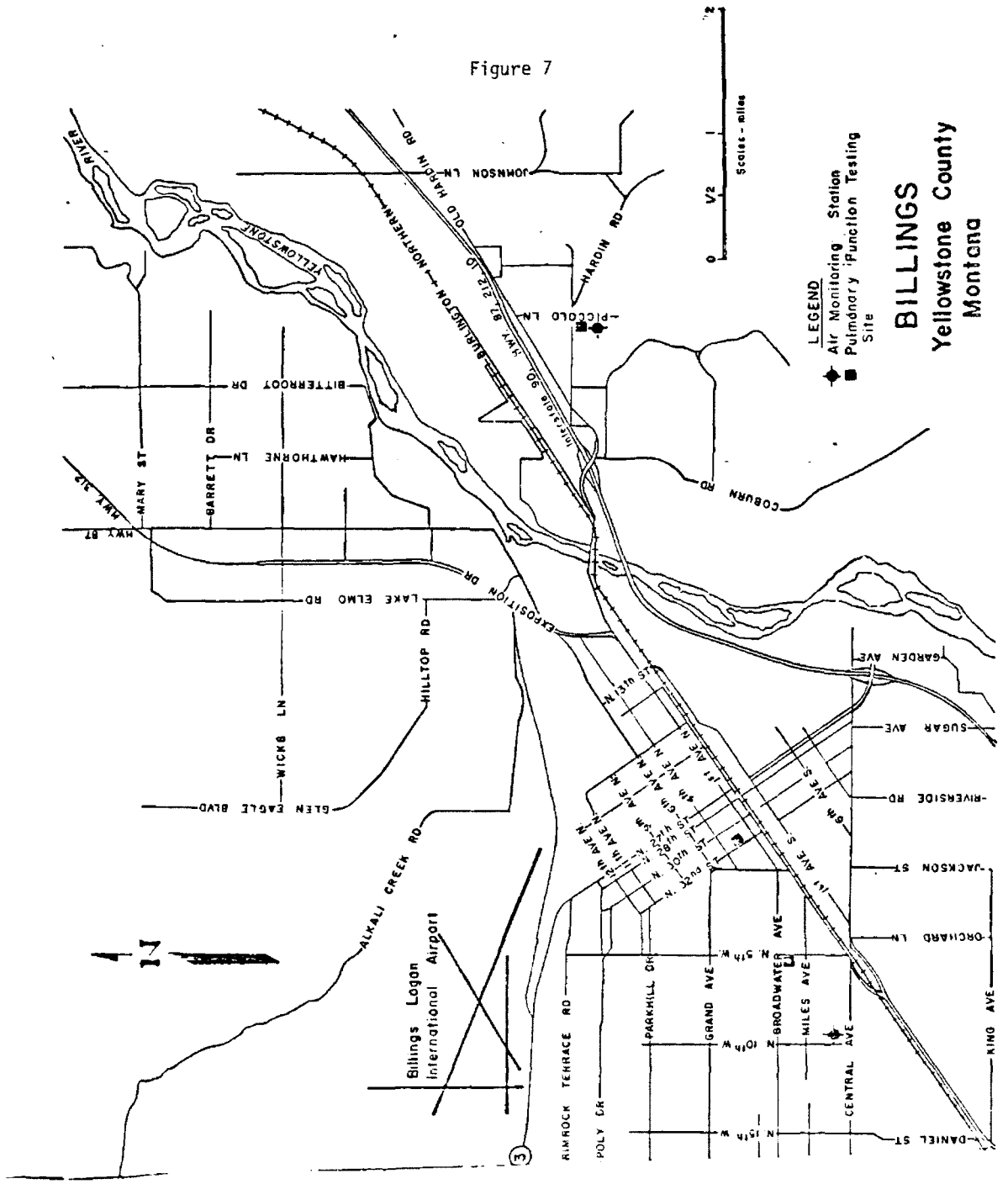
Qualitative Comparison of Ambient Air Monitoring Site Characteristics

	Missoula	Butte	Anaconda	Billings	G. Falls
Elevation	3180	5550	5260	3150	3336
Transportation Density	3	2	1	2	1
General Population Density	3	2	2	3	3
Light Business Density	3	3	1	2	1
Industry Density	1	3	3	1	1
Distance to High Traffic Roads	4	2	1	2	2
Ventilation of Site	1	1	2	4	2
	15	13	10	14	10

Scale: 1=minor/low density, 4=major/high density

Source: Montana Air Quality Bureau, Montana Air Pollution Study: Relationship Between Human Health and Inhalable Particulates, (Helena, MT: Montana Department of Health and Environmental Sciences, 1980), p. 28.

Figure 7



MAPS Particulate Instruments

Table 2 summarizes the types of instruments used in the MAPS project to monitor particulates. The instruments discussed in the previous chapter were used in the MAPS project. The dichotomous sampler, however, presented special problems to the AQB and MAPS staff. Numerous tests were conducted on the sampler to determine methods of transport of filters, calibration procedures, and the like. The sampler was set up to run for 24 hours once every three days because it was too expensive to attempt to run the sampler every day as would have been preferred. It was found that the best method of transfer to and from the laboratory was using hand-delivered petri dishes. Early experimentation revealed that the coarse filter tended to have particles fall off of the filter after the run unless there was a concerted effort not to tip the filters upside down. Throughout the MAPS project, therefore, no filters were ever mailed or shipped between the laboratory and field. All filters were hand-delivered to the laboratory after runs were completed.[1]

During the late fall and winter, a significant problem developed at two of the monitoring sites (Missoula and Butte). The air flow through the filters dropped significantly during the sample runs, which caused the AQB to invalidate these sample runs. During some preliminary testing, several samplers were operated continuously for up to six days with little or no drop in air flow. The flow drop did not seem to be caused by excessive mass loadings on the filters since these loadings were less than had been seen during the experimentation period. After further experimentation it was discovered that by heating the inlet tube and the filter area a marked improvement in air flow was noticed. The

Table 2

MAPS Particulate Monitors

Site Name	Instrument	Approximate Start Date
Lions' Park, Missoula	Hi-vol	11/77
Lions' Park, Missoula	Membrane	2/78
Lions' Park, Missoula	Beta Counter	6/78
Lions' Park, Missoula	Dichotomous	9/78
Lions' Park, Missoula	Nephelometer	1/78
McLeod Park, Missoula	Hi-vol	1/79
McLeod Park, Missoula	Dichotomous	1/79
Courthouse Roof, Missoula	Hi-vol	****
Courthouse Roof, Missoula	Dichotomous	10/78
Rose Park, Missoula	Hi-vol	10/78
Lincoln School, Anaconda	Hi-vol	5/78
Lincoln School, Anaconda	Dichotomous	8/78
Lincoln School, Anaconda	Membrane	7/78
Hi-Way Junction, Anaconda	Hi-vol	****
Hebgen Park, Butte	Hi-vol	6/78
Hebgen Park, Butte	Dichotomous	8/78
Hebgen Park, Butte	Membrane	8/78
Hebgen Park, Butte	Nephelometer	10/78
Floral Park, Butte	Hi-vol	11/78
Floral Park, Butte	Dichotomous	11/78
Dr. Canty's Office, Butte	Hi-vol	6/78
Kiwanis Park, Great Falls	Hi-vol	10/78
Kiwanis Park, Great Falls	Dichotomous	10/78
Central Park, Billings	Hi-vol	6/78
Central Park, Billings	Dichotomous	9/78
Central Park, Billings	Membrane	9/78
City Hall, Billings	Hi-vol	****
Lockwood School, Billings	Hi-vol	4/79
Lockwood School, Billings	Dichotomous	5/79
Grand Ave. School, Billings	Hi-vol	****
KGHL, Billings	Hi-vol	****

**** These sites were in operation several years before the start of the MAPS project.

Source: Montana Air Quality Bureau, Montana Air Pollution Study: Relationship Between Human Health and Inhalable Particulates, (Helena, MT: Montana Department of Health and Environmental Sciences, p. 28.

inlet tube and the filter holders for all samplers were insulated and heated using heating tape commonly used to keep water pipes from freezing. The heating tape probably heated the air only a few degrees Centigrade from ambient, depending on the ambient temperature. The tube felt warm to the touch during the sample, but not hot. The heating tape was equiped with a temperature switch so that it would shut off during warmer weather.[2]

Exactly why this improved the situation was never fully explained. Most of the staff believed that it had something to do with ice formation on the filters, while others felt that perhaps organic compounds were the culprit. The rationale for blaming the problem on ice was that the problem never occurred above freezing, and occurred frequently below freezing; especially on days when there was a morning fog and below freezing temperature. Others believed that perhaps the sampler was "boiling off" organic compounds with the heat tape and was therefore allowing air to pass easily through the filter. The problem seemed to be limited to the fine filter.

Automatic shut-off devices were purchased for the second year of operation to prevent the loss of data. The devices automatically shut down the instrument anytime the fine or coarse flow fell below a critical level.

Data Summary of Billings MAPS Network

The TSP monitors in Billings (Central Park) recorded a maximum annual geometric mean of 66 ug/m^3. This data shows compliance with the federal primary and the state standards, but not with the federal secon-

dary standard. At Central Park, the main site for the area, the highest TSP readings were observed in the summer and early fall, while the lowest readings appeared during the winter.

The inhalable particulate data exhibited the same overall tendancies as the TSP data. Maximum values were recorded during the late summer and in some cases winter as well. The inhalable particulate artimetic mean was about one half of the TSP mean, 81 versus 43 for Central Park. The concentration of fine particulate was 18 ug/m^3 for Central Park while the coarse concentration was 25 ug/m^3 for the MAPS study period.

The sulfur dioxide levels showed no violations of the Montana or federal ambient standards, but numerous low-level readings were observed. Most readings occurred during the early morning hours through approximately 10:00 a.m. The mean level of sulfur dioxide was .011 ppm. The ozone levels, on the other hand, generally were associated with warmer weather, which is not surprising since ozone may be formed with intense solar heating, nitrogen oxides, and hydrocarbons. The mean value was .020 ppm at Central Park. Nitrogen dioxide measured at Central Park revealed an annual average of .016 ppm, which compares to the federal and state annual average standard of .050 ppm. In contrast to ozone the highest levels of nitrogen dioxide were observed in the late fall and winter.

Several elements were analyzed on the hi-vol and membrane samplers throughout the MAPS project and those served as the major data block for determining sources in this paper.

FOOTNOTES

[1]Harold Robbins, Montana Air Pollution Study: Air Monitoring Instrumentation, (Helena, MT: Montana Department of Health and Environmental Sciences, 1979), pp. 18-21.

[2]Ibid.

METHODOLOGY

As stated in the introduction of this paper, the primary goal is to determine the contribution from various sources of air pollution to the particulate levels in Billings. Three types of information must be used to make these determinations: air quality data; meteorological data; and source or emission data. In order to make the data understandable, a number of statistical analyses were employed. The statistical analysis combined with the air quality and meteorological data served as the basis for the results and conclusions.

In order to provide a framework for analysis, it was necessary to establish a defined data base and method of data storage and retrieval. It was desired to obtain the greatest degree of resolution practicable. It was believed that this could be done by using the shortest time frame practicable for the analysis. A 24-hour average was chosen because almost all TSP and inhalable particulate data were available for only a one-day average. The time frame for the study was selected to be from January 1, 1977 through May 31, 1980. The beginning date was chosen to take advantage of some data collected in Billings prior to the implementation of the MAPS project (approximately June, 1978). The ending data coincides with the termination date of the ambient air quality network for the MAPS project. It was also decided to use the IBM 370 S158 computer facilites at the State of Montana's Administration Department. The data were stored on disk (unit #3330P1) and tape (9 track, standard IBM label), and the Statistical Package for the Social Sciences (SPSS)

was used for nearly all data analysis carried out in this project. The WTC ICIS 850 microcomputer was used for some small analysis work in the frequency distribution and enrichment factor calculations. SPSS provides a mechanism for inputing, outputing, and altering data on the system. Since the measuring time frame chosen was 24 hours, it was decided to input all data such that each variable would have a single value representing each day of the study period (1/1/77 through 5/31/80). If the data, for example, were coded in the Air Quality Bureau data system as hourly averages, some form of manipulation was necessary, usually averaging, to convert the data to a single daily value. Considering each day as a case, there were 1247 cases on the file. If no data were available for any particular date, the variable was coded as a missing value (usually -1.).

Variables Selected

Ambient air quality data, meteorological data, and emission-related data were used in this study. Emissions data is probably the weakest data set in the analysis. This is true because day-to-day emissions data is unavailable for most major industry and other area sources (home heating, road dust, agricultural dust, and so forth).

In order to counteract the lack of emissions data, various estimates of emissions-related variables were coded into the system. Among these variables are day of the week, month, season, weekend/weekday, and precipitation index. Although these variables do not represent any one particular source directly, they certainly are an indication of the variation of certain classes of sources.

Table 3 provides a description of all the variables coded onto the system, units of measure, start dates, and end dates.

Ambient Air Quality Data

As described above, a number of ambient air quality parameters were available for analysis. Nearly all of the ambient air quality data were coded onto the SPSS system. As it turned out, some of the data were rather limited and proved to be of no real help in the analysis. Total hydrocarbons are an example of this since the data were available for only a very limited period of approximately eight months. The following variables were chosen and coded into the system.

Total Suspended Particulate

Total suspended particulate (TSP) was available at six sites in or near Billings. Only the Central Park and Lockwood sites were exlusively MAPS sites, while the other four sites were in operation during the study, but operated by the Yellowstone County Air Pollution Agency. These four sites were operated one day in every six as part of the national air monitoring schedule. Table 4 indicates the approximate location of these and the upper air monitoring sites. All available data were entered into the SPSS system for all six sites. The data were available only as 24-hour averages (midnight to midnight).

Inhalable, Coarse, and Fine Particulate.

The greatest amount of these data was available at Central Park. The data spans approximately September 1978 through April 1980. All

Table 3

SPSS Coded Data - All Variables

Location	Variable	Units	Approx. Start Date	Approx. End Date
Central Park	TSP	ug/m^3	6/78	4/80
Central Park	Fine	ug/m^3	9/78	4/80
Central Park	Coarse	ug/m^3	9/78	4/80
Central Park	Inhalable	ug/m^3	9/78	4/80
Central Park	Aluminum-M	ug/m^3	11/78	4/80
Central Park	Arsenic-HV	ug/m^3	6/78	4/80
Central Park	Arsenic-M	ug/m^3	12/78	4/80
Central Park	Cadmium-HV	ug/m^3	6/78	4/80
Central Park	Cadmium-M	ug/m^3	11/78	4/80
Central Park	Copper-HV	ug/m^3	6/78	4/80
Central Park	Copper-M	ug/m^3	11/78	4/80
Central Park	Iron-M	ug/m^3	6/78	4/80
Central Park	Lead-HV	ug/m^3	6/78	4/80
Central Park	Lead-M	ug/m^3	11/78	4/80
Central Park	Manganese-HV	ug/m^3	6/78	4/80
Central Park	Manganese-M	ug/m^3	11/78	4/80
Central Park	Nickel-HV	ug/m^3	6/78	4/80
Central Park	Zinc-M	ug/m^3	11/78	4/80
Central Park	Nitrate-HV	ug/m^3	6/78	4/80
Central Park	Sulfate-HV	ug/m^3	6/78	4/80
Central Park	Sulfur Dioxide	ppm	7/78	4/80
Central Park	Nitrogen Dioxide	ppm	7/78	4/80
Central Park	Ozone	ppm	7/78	4/80
Central Park	Wind Speed	meter/sec	10/79	3/80
Central Park	Wind Direction	Cardinal Direction	10/79	3/80
Vo-Tech	Stability	Pasquill	9/78	3/80
Airport	Wind Speed	meters/sec	4/78	4/80
Airport	Wind Direction	Cardinal Direction	4/78	4/80
Airport	Temperature	centigrade	4/78	4/80
Airport	Dew Point	centigrade	4/78	4/80
Airport	Station Pressure	millimeters	4/78	4/80
Airport	Visibility	miles	4/78	4/80
Airport	Precipitation	inches x 100	4/78	4/80
Airport	Precipitation Index	*******	4/80	4/80

Table 3 Continued

Location	Variable	Units	Approx. Start Date	Approx. End Date
City Hall	TSP	ug/m^3	1/77	5/80
KGHL	TSP	ug/m^3	1/77	5/80
Grand Ave. Sch.	TSP	ug/m^3	1/77	5/80
Lockwood School	TSP	ug/m^3	4/79	4/80
Lockwood School	Fine	ug/m^3	5/79	4/80
Lockwood School	Coarse	ug/m^3	5/79	4/80
Lockwood School	Inhalable	ug/m^3	5/79	4/80

Where: ug/m^3 = micrograms per cubic meter
TSP = Total Suspended Particulate
Fine = fine particles (less than 2.5 microns)
Coarse = coarse particles (between 15 and 2.5 microns)
Inhalable = inhalable particles (less than 15 microns)
HV = high volume sampler
M = membrane sampler
Cardinal Direction = predominant wind during the 24-hour period coded only as one of 9 classes:
0=calm 1=north
2=northeast 3=east 4=southeast 5=south
6=southwest 7=west 8=northwest.
Pasquill = stability clases defined by Pasquill, coded as:
1=A 2=B 3=C 4=D 5=E 6=F

Note:

Numerous other variables were added and used from time-to-time throughout the analysis. These variables, such as factor scores, were not presented here because they were only temporary in nature used during a single computer run. Other variables were modified from this original list and were also used for single computer runs.

Table 4

Air Monitoring Location Descriptions

Site	Description
Central Park	The Central Park monitoring site was located one block off of Central Ave. in Central Park. It was located approximately on the northern edge of the park just slightly (50 meters) west of the center. It was located next to an unpaved alley (15 meters) and 15 meters due east of the school administration building and workshop. It was only 5 meters north of the tennis courts and could be described as being on the corner of 9th St. W. and Cook Ave. The site was residential in nature although it was one city block (approximately 150 meters) from a busy avenue (Central Ave.). The probes were approximately 3.5 meters from the ground.
City Hall	City Hall monitoring station was located on the roof of the city hall building which is between 2nd and 3rd Ave. N. on 27th St. N. The samplers were approximately 15 meters above the ground and could be characterized as the Central Business District. The area was subjected to heavy traffic flow in the downtown section. There was probably heavy traffic flow throughout the week, particularly Monday thruough Saturday.
KGHL	The KGHL monitoring station was located at the KGHL transmitting facilities on the frontage road on the south side of Interstate 90. The site is approximately 3.75 miles west of Billings just off of Highway 10 (frontage road). The sampler sits on the roof of the KGHL radio station house and is approximatley 30 meters from the frontage road and about 80 meters from Interstate 90. The sampler is approximately 4 meters above ground. The area could be generally classified as rural with some road source influence.
Grand Ave. School	This sampler is located atop of the Grand Ave. School in Billings. The school is located on the corner of Grand Ave. and 13th St. W. The area could be characterized as commercial with a heavy volume of traffic along Grand Ave. the sampler is located on the roof approximately 5 meters above ground and about 25 meters from Grand Ave.

Table 4 Continued

Lockwood School	The Lockwood School site was located approximately 30 meters due west of Lockwood School. The school is near the corner of Highway 87 (Old Hardin Road) and Piccolo Lane. The sampler was located atop an air monitoring sampling trailer approximately 3.5 meters above the ground. The sampler was actually located just inside a football/recreation area for the students. A small unpaved service road ran within 10 meters of the sampler. The estimated traffic on the road would be less than 100 vehicles per day. The nearest tree was 25 meters from the sampler. The Continental Oil refinery is located about 2.6 miles to the WSW while the Exxon refinery and Montana Sulfur are approximately 1.2 miles to the north and 1.3 miles to the NNE respectively. The area could be characterized as a mix of residential and industrial. Some rural activities are prevelant approximately 2 miles from the sampler.
Vo-Tech Site	The vo-tech site was used to balloon launchings, upper air, and stability data. The site was located at the vo-tech school on Central Ave. at approximately Shilo Road. The site is relatively free from obstructions making it ideal for balloon launches.

three size ranges (inhalable - less than 15 microns, coarse - between 2.5 and 15 microns, and fine - less than 2.5 microns) were coded into the system. Some limited data were also available at the Lockwood air monitoring site. The Lockwood data spans April 1979 through March 1980.

Sulfur Dioxide

Sulfur dioxide was measured in Billings at the Central Park site almost exclusively. The data were available in one-hour averages and therefore scalar-averaged to determine a single 24-hour number for the SPSS system. These data were collected between June 1978 and January 1980. A Thermo Electron Corporation Model 43 pulsed fluorescence analyzer was installed at the site. This method is exclusive to sulfur dioxide and does not contain any appreciable positive or negative biases toward other sulfur compounds.[1] The same instrument and averaging also was available at the Lockwood site. The Lockwood site, however, had very little data for the purposes of this paper. Less than eight months of data were collected which yields little value for these purposes. It was therefore decided not to code this data onto the system.

Sulfur dioxide has many man-made and natural sources. It would be safe to assume that almost 100 percent of the sulfur dioxide in Billings is a result of man's activities.[2] Sulfur dioxide is one of the major emissions from refineries, sugar plants, and power plants, all of which are in or near Billings.[3] It would not be unreasonable to assume that most sulfur dioxide in Billings is a result of various industries.

Nitrogen Dioxide

Nitrogen dioxide was measured at the Central Park air monitoring station. The same time-averaging intervals were applied as described for sulfur dioxide. The measurement method was chemiluminescense by use of a Bendix Corporation Model 8101 $NO-NO_2-NO_x$ analyzer. This analyzer measures NO and NO_x by use of the chemiluminescence of the reaction:

$$NO + O_3 \longrightarrow NO_2 + O_2 + h\nu$$

where hv is a light particle measured through use of a photomultiplier tube. NO_2 is assumed to be the difference of NOx - NO.[4] The same data limitation described in sulfur dioxide also applied for nitrogen dioxide. The Lockwood data therefore were not coded.

Nitrogen oxide compounds generally can be considered to be a result of combustion and various chemical industries. Nitric oxide and nitrogen dioxide are common compounds eminating from automotive exhaust.

Ozone

Ozone was measured exclusively at the Central Park site. the data were measured on an hourly basis and converted to a 24-hour value by averaging all valid hourly readings. Ozone was measured using the chemiluminescence technique of the Bendix Corporation Model 8002 ozone analyzer. This instrument takes advantage of the reaction between ozone and ethylene to produce light which is measured by use of a photomultiplier tube.[6]

Ozone is generally the product of a reaction among sunlight, oxides of nitrogen, and hydrocarbons.[7] Generally speaking, Billings has the highest ozone concentration in the state.

Meteorological Data

As one would suppose, meteorological variables greatly influence the concentration of air pollutants in any locality. It is important to point out, however, that meteorological conditions do not cause air pollution, but merely assist in reducing concentrations or exacerbate the condition.

There were two sources of information concerning meteorology in the Billings area: 1) National Weather Service, and 2) Air Quality Bureau (MAPS). The National Weather Service (NWS) has the most complete data record for the times of interest. The MAPS data, however, were more appropriately located and recorded. The NWS station is located at Logan International Airport on the rims above Billings, approximately 300 feet above the valley floor. The MAPS stations, however, were located at the Central Park station and at the west end of Billings next to the Vo-Tech center on Central Avenue. The MAPS sites were preferred since they were located where the air pollutants were being measured. As is many times the case, data completeness had to be balanced with overall accuracy.

A comparison was made between some of the NWS data and the MAPS data. Appendix A is a description of the comparison and associated results. Based on this information, it was decided to use the NWS data since it was more complete than the MAPS's data. The results of Appendix A also indicates that there would not be significant errors from calculations reached from either data set except for wind direction. Wind direction, therefore, was not used in any analyses. The following variables were coded.

Wind Speed

It was anticipated that wind speed would play a major role in explaining some of the variance seen with many air pollution variables. Increasing wind speed would generally decrease air pollution, especially particulates.

All NWS data from Billings are available for only a three-hour observation. To convert these data to a 24-hour value, an arithmetic average of the eight observations was employed. The data also were coded to meters per second on the SPSS system.

Wind Direction

Wind direction can be an invaluable aid to determine emission sources that are having a major influence on air pollution measured at any one station. Large concentrations of a pollutant consistently occuring from one direction may indicate a major source in that direction.

The coding of these data proved to be more difficult than wind speed. Average values do not seem appropriate since false directions can be obtained. For example, if the wind direction were northwest for four observations (315°) and the other four observations were the northeast (45°), the arithmetic average would be 180°. This is clearly not the "true" average direction, as the average direction would have been more appropriately from the north. It was decided to avoid this problem through the use of predominent (most frequently occuring) wind direction. To accomplish this goal, the data were coded by the following:

a. Each observation was converted to one of the nine classes:

Class	Degrees	Direction
0	Calm Wind	
1	337° to 22°	North
2	22° to 67°	Northeast
3	67° to 112°	East
4	112° to 157°	Southeast
5	157° to 202°	South
6	202° to 247°	Southwest
7	247° to 292°	West
8	292° to 337°	Northwest

Note: All NWS data is coded to the nearest 10 degrees only. The MAPS data was coded to the nearest degree.

b. For each 24-hour period, the most frequently occuring class (predominent wind direction) for coding to the SPSS system.

c. A FORTRAN program was written to accomplish the above task.

d. In the event of a tie between two classes, the lowest number class was chosen.

Dew Point

Dew point was coded into the system using the NWS data and an arithmetic average of the eight three-hour observations. Dew point was chosen because of its measure of the amount of water vapor in the atmosphere. Dew point is defined as the temperature at which a given parcel of air must be cooled, held at constant pressure, in order for saturation to occur. Pilots long have used the difference between temperature and dew point to indicate saturation and hence possible freezing on the wings and structure of any given aircraft.

Dew point was believed to be of some significance since water influences particulates. The amount of water in the air can influence the types of particles generated by emission sources and can influence their behavior in the atmosphere. Dew point was coded in centigrade on the SPSS system.

Temperature

Temperature was averaged for the eight three-hour observations using the NWS data. Temperature can be used to estimate the seasons, and in conjunction with dew point and relative humidity, can indicate the amount of water vapor in the atmosphere. The temperature was coded in degrees centigrade on the SPSS system.

Relative Humidity

Relative humidity was coded and used as a measure of water vapor in the atmosphere. The units of measurement is percentage. The relative humidity was calculated for each three-hour observation by using the following:[7]

$$\text{Relative Humidity} = \left(\frac{173 - .1T + DP}{173 + .9T}\right)^8$$

where: T = temperature (^oF)
DP = dew point (^oF)

The 24-hour value was calculated by using the mean of the eight observations.

Visibility

The weather observer at the NWS codes visibility of the atmosphere every three hours. This is done by observing the farthest distance one can see an object clearly. In this case, it is done by observing various land marks with known distances. An arithmetic average also was employed with this variable. The visibility in the atmosphere would be expected to correlate with particulates, especially small particles, and to some extent gases. The data were coded in miles.

Station Pressure

Station pressure was coded by averaging each of the eight observations. The station pressure is the barometric pressure of the site without any corrections to sea level. The data were coded and stored on the system in millimeters of mercury.

This parameter provides an indication of various weather phenomena or changing weather patterns.

Precipitation

Precipitation data were already recorded in 24-hour values for the Billings area. These data were introduced onto the system in inches of precipitation multiplied by 100. Precipitation can clearly have a major impact on particles in the air, as large amounts of rain or snow can greatly reduce the effect of road dust, field dust, and the like on particulate concentrations.

Snow on Ground

The amount of snow on the ground, recorded in inches, also was available from the same source as precipitation.[9] These data were coded into the system in inches of snow cover. The amount of snow on the ground also serves to influence the particulate concentrations. Any appreciable amount of snow on the ground would certainly limit emissions from fields, playgrounds, and so forth. It would probably not limit the emissions of major industry stacks, assuming the industry production generally remains constant throughout the year.

Emissions Related Data

As already mentioned, specific emissions data were not available for the Billings area. It was necessary, therefore, to use indicators of types of sources of air pollution rather than an actual emission rate. Each variable selected provides some insight as to the type of sources that may affect the ambient air quality.

Day of the Week

For each 24-hour value, a variable was calculated to represent the day of the week. The following scheme was coded:

Coded Value	Representation
1	Sunday
2	Monday
3	Tuesday
4	Wednesday
5	Thursday
6	Friday
7	Saturday

It was believed that this variable can be an important indicator with respect to man's activities. For example, there is clearly a difference between what one does on Monday through Friday versus Sunday's activities. Each of the days of the week may be associated with different kinds of activities. Major industries, on the other hand, usually have a continuous operation that is independent of the day of the week. This provides an opportunity to differentiate between the effects of man's day-to-day activities, while holding major industry emissions, as a result of production, at a constant. Sunday is likely to be a key day for this analysis since automobile traffic would likely be a minimum on that day.

Weeday/Weekend

It was anticipated that the coding of each day of the week might cause some difficulty in analysis for small data sets. It also was anticipated that the differences between the days of the week could be condensed into only two categories: weekday and weekend, which were coded as follows:

Coded Value	Representation
1	Sundays and Holidays Holidays: New Year Easter July 4 Labor Day Thanksgiving Christmas
2	Weekdays

This variable was coded to ease not only some of the restraints with regards to small data sets, but also to ease calculation and interpretation. It does not provide any significant information beyond the day of the week coding, except to add holidays to the analysis. No distinction is made in either the day of the week variable nor in the weekend/weekday variable between years.

Season

Almost all air pollution data exhibit a large degree of variance between each season. It follows, therefore, that a coding of the season would be a logical method to distinguish sources and variation. Each season, particularly summer and winter, yields different types of air pollution sources. Outdoor activities are greatly increased in the

summer, including automotive traffic, as opposed to the winter (see Tables 5 and 6). A comparison of air pollution values within each season may be mandatory for some analyses. The data were coded as follows:

Coded Value	Representation
1	Winter (December 1 through Feb. 28)
2	Spring (March 1 through May 31)
3	Summer (June 1 through August 31)
4	Fall (September 30 through Nov. 30)

As in the cases above, no discrimination was made between the years.

Month

As an aid in the analysis of the data's trends and yearly fluctuations, a monthly value was coded. This variable was used not only to graph the data, but also as an aid to interpret seasonal variations. The following form was used:

Coded Value	Representation
1	January, 1977
2	February, 1977
3	March, 1977
...	...
40	April, 1980
41	May, 1980

Precipitation Index

Although this variable is perhaps purely a meteorological one, it is discussed here since an index was developed to explain more specifically the variance in the particulate data. Precipitation alone may not reflect changes in particulate data since the precipitation data are recorded on the same day as the monitoring data. As an example of this problem, it would not be unusual to have a significant rainfall from a thunderstorm in late afternoon. By late afternoon, however, the particulate monitoring have already been operated for 15 to 20 hours. This

Table 5

Billings Traffic
Grand Avenue (Site: A-22)
1977

Month	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Monthly Mean
January	13,980	21,055	20,294	20,548	21,212	22,321	18,531	19,528
February	17,567	23,674	22,418	22,499	23,349	26,417	25,761	23,162
March	17,338	23,210	22,231	22,551	23,730	26,314	26,561	22,988
April	17,392	24,098	23,805	23,749	24,653	27,237	25,759	23,992
May	17,240	21,829	24,265	23,656	24,946	27,202	24,868	23,204
June	18,305	23,850	24,247	24,082	25,636	27,223	25,153	24,123
July	16,747	21,829	23,499	24,545	24,624	26,218	22,727	22,789
August	18,693	24,794	24,232	24,399	25,033	27,049	25,090	24,212
September	16,961	22,222	24,014	22,998	24,590	27,541	24,754	23,482
October	16,908	23,288	23,125	23,123	24,344	27,116	25,624	23,224
November	15,959	22,258	22,768	23,247	20,567	24,521	22,423	21,766
December	14,359	21,391	23,707	23,681	24,368	24,601	24,284	22,542
Daily Mean for Year	16,787	22,792	23,217	23,256	23,291	26,147	24,219	22,918

Note: All values are in units of vehicles per day

Source: Montana Department of Highways, "Automatic Recorder Data by Months," Helena, MT.

Table 6

Billings Traffic
Grand Avenue (Site: A-22)
1978

Month	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Monthly Mean
January	12,653	18,547	29,322	19,524	20,509	23,426	21,238	19,232
February	14,977	21,422	21,492	20,128	21,397	23,579	22,542	20,791
March	12,155	16,838	16,317	17,458	17,809	19,977	19,414	17,262
April	16,649	22,335	21,831	21,647	24,332	27,509	24,263	22,509
May	17,095	21,829	24,145	23,881	24,946	27,202	24,867	23,410
June	12,610	15,680	16,216	17,787	20,632	22,253	18,840	18,173
July	16,841	23,657	20,979	25,077	25,703	27,681	22,917	22,827
August	18,468	24,755	24,723	24,897	25,836	27,084	24,945	24,461
September	17,780	22,410	24,251	23,840	24,468	27,500	24,755	23,742
October	16,851	23,193	23,141	23,123	24,369	27,116	25,385	23,341
November			Counter hit by car		-Not repaired or replaced-			
December			"			"		

Note: All values recorded in units of vehicles per day

Source: Montana Department of Highways, "Automatic Recorder Data by Months," Helena, MT

presents a problem since the rainfall will not genuinely reflect on the particulate measurement of the day. The next day, however, might be have some relationship to the rainfall of the previous afternoon. An index was developed, based on conversations with Bob Boldi (Environmental Studies student at the University of Montana), using the weighting of the rainfall on the day of the air monitoring measurement with the four days prior to the measurement.

The purpose of this type of an index was to partially take into account this type of phenomena: the affect rain has on particulate several days after the occurance of the rain. The index attempts to place a decreasing emphasis on the rainfall for each passing day up to four days. The reason for emphasis on past precipitation is that rain will tend to hold particles down on the soil and roads for as long as there exists some moisture in the dust or soil. The index can best be illustrated through the following example.

Day #	1	2	3	4	5	6	7	8	9	10
Precipitation	5	20	10	0	5	5	10	15	0	0

Precipitation Index for Day 7 = 10/1 + 5/2 + 5/3 + 0/4 + 10/5 = 16.2
Precipitation Index for Day 8 = 15/1 + 10/2 + 5/3 + 5/4 + 0/5 = 22.9
Precipitation Index for Day 9 = 0/1 + 15/2 + 10/3 + 5/4 + 5/5 = 13.1

In each case, the precipitation for the measurement day is divided by the number of days elapsed plus 1 and summed for the four previous days. This index, therefore, takes into account the amount of rain received over the past four days and places less significance on the past days by dividing by the number of days elapsed plus one. To simplify the process, the data were coded to the nearest whole number. A FORTRAN program was written to perform the index calculation.

Traffic Data

The number of vehicles passing a given intersection in one day ought to assist any analysis on the impact of vehicles on air pollution. It would be reasonable to expect certain relationships to develop between traffic counts and air pollution data, if vehicles are having a major influence on the ambient air quality levels.

A permanent traffic counter was installed in Billings several years ago. As luck would have it, the traffic counter was struck by a car in November, 1978. Unfortunately, the Highway Department has neither repaired nor replaced the traffic counter device. Some data, however, were salvaged from their partial operation during the time of study, and are presented in Tables 5 and 6. The data clearly indicate as previously suspected, that the traffic patterns vary not only from season to season, but also from day to day. Sunday has the overall lowest traffic with a two-year average of 16,816 vehicles per day. The largest traffic volume day was Friday with an average of 26,587 vehicles per day, an increase of 58 percent above Sunday. The average traffic volume for each month and day of the week are listed in the tables.

The limited traffic data available confirmed the previous hypothesis that man's activities, at least in terms of vehicle traffic, change from season to season and day to day. If vehicles do affect air pollution readings, one ought to be able to observe a relationship between days of the week and vehicles per day, at least within any one season.

Elemental Analysis

The high-volume filters and some membrane samples were analyzed for their elemental composition. In each instance a portion of the filters

was treated to remove the particulate. The particulates were then analyzed through the use of absorption spectrophotometry for eleven elements or ions, as follows:

Aluminum	(Al)
Arsenic	(As)
Cadmium	(Cd)
Copper	(Cu)
Iron	(Fe)
Lead	(Pb)
Manganese	(Mn)
Nickel	(Ni)
Vanadium	(V)
Nitrate	(NO_3)
Sulfate	(SO_4)

Several problems developed during the analysis of the filters. The hi-vol filters were not without some background concentrations of some metals in the filter. It was found that aluminum, iron, and zinc had the most variable concentrations. Because of the high degree of variability, it was decided not to use the hi-vol data for these elements. The membrane data were used in their place. The membrane data were not used exclusively for all elements since the data set for this variable was smaller than that for the hi-vol. This limitation could cause some errors in analysis when making direct comparisons between one metal and another. The membrane sampler has a lower air flow, which would tend to measure smaller particles than the hi-vol. For this reason, no direct comparisons were made between metals as measured by different filters. It also turned out that little to no vanadium was discovered on any of the filters. Nearly every analysis for vanadium produced values near or below the detection limit. This result was found consistently in all MAPS communities. It was somewhat suprising since it was expected to find some vanadium as a result of diesel exhaust. Vanadium, therefore, was not coded onto the system.

The elemental data can provide a very useful tool to determine different air pollution sources, as sources of a general category or class tend to have similar types of elements. For example, automobile exhaust characteristically emits more lead and bromine than would be found in the earth's crust. Aluminum, silicon, and iron are typical elements from the soil, and so forth.

Statistical Methods

Each analysis chosen had its own built-in advantages and disadvantages. The number of variables affecting particulate data is almost overwhelming. This paper, therefore, takes a step-by-step approach using different analyses and comparisons and then combines the results of each analysis into an overall summary and conclusion.

When confronted with the problem of determining the sources and the characteristics of particulate data, many types of analysis must be considered. No single analysis for this data set would be likely to provide overwhelming evidence for source apportionment. The best one can hope for is that each analysis will provide some clue or inference into what sources cause or significantly contribute to particulate air pollution. The analyses used in this paper, therefore, do not in and of themselves provide specific answers. However, the results of several varied analyses surely can lead one to some basic conclusions regarding source contributions.

The approaches taken are generally statistical in nature. The following types of analysis were used in the paper. A short description of the usefulness of each method is provided.

Frequency Distributions

The frequency of occurrence of particulate readings often aids in determining the source or sources responsible for the air monitoring readings. For example, a number of authors point out that particulate data usually exhibit a log-normal distribution, which is to say that the logarithms of the individual readings usually will be manifested in a normal distribution.[10] Data not exhibiting this distribution ususally indicate that the monitor is significantly influenced by a single major source as opposed to a group of smaller sources (area sources). This is particularly true when the quantity of larger values exceeds normal expectations.[11] An analysis was conducted on most particulate monitoring sites in Billings, including the inhalable particulate sites. A chi-square test for normality was applied to the data as well as a calculation of the kurtosis and the skewness. The data also were plotted for easier readability and interpretation.

Monthly and Seasonal Variations

Air pollution data can vary from month to month and season to season for two essential reasons: 1) emission sources vary from season to season and 2) meteorological changes occur from season to season. A study of the air pollution variance within this category, therefore, can lead to suggestions on sources of particulates. As an example, one can analyze the variation of sulfur dioxide to determine how meteorology affects gases and small particles. This analysis can be done because the production of sulfur dioxide remains relatively constant throughout the year. (Most major industries, with the exception of Great Western, in Billings tend to produce their product at a steady rate and therefore produce sulfur dioxide at a steady rate.[3] Most of the seasonal and

monthly variance of this variable can be attributed to meteorology). Other gases and small particles that do not exhibit this pattern are in all likelihood exhibiting a variation in emission rate from season to season.

The analysis can be carried even further in some instances. A comparison of two different stations should have the same monthly and seasonal patterns if the emission sources exhibit the same variation (since it is safe to assume that the meteorology is basically the same for the city of Billings). If these two stations differ in their data distribution, then they also must vary in their affecting sources.

To aid in the analysis, monthly graphs, monthly tables, and seasonal tables were produced.

Day of the Week

Another simple analysis used to determine emission sources was that of comparing data from different days of the week. It can be assumed that meteorology does not vary significantly with days of the week, which in turn leads to the conclusion that any observed differences between separate days of the week must be associated with different emission sources from those days. The most obvious example of these changes in emissions is man's general outdoor activities. Car traffic, for instance, is greatly reduced in Billings on Sunday as opposed to any other day of the week (see Tables 5 and 6). If these activities have no real effect on air pollution levels, it would be logical to assume that there should be no difference between readings on Sunday and any other day of the week.

In order to assist in the analysis, some of the data were coded

using only weekend versus weekday rather than all seven days of the week. The appropriate tables and graphs are given to aid in interpretation.

Wet Day/Dry Day

The amount of particulates in the air can be related to rain and snow fall. If more rain falls during or just prior to a day of sampling, the lower readings can be expected. Two processes account for this: 1) washout, the case where rain or snow actually absorbs or adsorbs particles in the air, or 2) suppression, the case where the rain or snow holds particles to the ground and inhibits them from entering the atmosphere. It is relatively clear that the difference in particulate levels between wet days and dry days will give an indication of the amount of particulates contributed to the atmosphere from the ground and/or the amount of particulates that can be washed out of the atmosphere. If the difference between these two categories is insignificant, one would assume that (1) there is little contribution from the ground and/or (2) a significant amount of the particulates in the atmosphere can not be washed out as a result of rain or snow.

Enrichment Factors

A relatively new method used for source identification is that of enrichment factors. The enrichment factor model is used to assess the amount of particulate from one element, which is enriched from the same elemental concentration in the soil. This method, therefore, can be used to determine the relative contribution of the soil elements to the particulate measuring device.[4]

The enrichment factor model compares the ratio of the elemental composition of the ambient air to the elemental composition of the characteristic element with the concentration of elemental in the soil to the concentration of the characteristic element in the soil. The enrichment factor is:[5]

$$\text{Enrichment Factor} = \frac{(C_{ia}/C_{na})}{(C_{ic}/C_{nc})}$$

Cnc = concentration (ug/g) of unique elemetal in the soil or crustal earth.

C_{na} = concentration (ug/m^3) of unique element to in the ambient air

Cic = concentration (ug/g) of element in the soil whose enrichment is sought.

Cia = concentration (ug/m^3) of element in the ambient air whose enrichment is to be determined.

Elements whose enrichment factor are significantly larger than one are assumed to be due to non-background sources within the airshed. Elements whose enrichment factor are near or equal to one are assumed to be from geological sources such as soil or rock particles.

The selection of the characteristic element could be significant. The most common elements used in these analyses seem to be scandium (Sc), aluminum, and iron. The MAPS project did not perform any analysis of scandium and therefore aluminum was chosen. Another important factor to the analysis is the correct ratio in the denominator of the equation. Several sources exist for these data. The most popular source seems to be the concentrations suggested by Mason,[7] which are generally used for large-scale areas. Such data were used in some comparisons in Colstrip, Montana[8] and in the southwestern desert of the United States.[9] In addition to the figures provided by Mason[10], the MAPS project made some analysis of the soil and road dust in the Billings area.[11] In order to

reflect the greatest degree of accuracy, enrichment factors were calculated using both sources of information.

Factor Analysis

Factor analysis is a multivariate statistical technique that condenses a large number of variables into a few larger variables called factors. These factors can then more easily be analyzed than than an analysis of each and every original variable in the data set. Factor analysis was developed to explain intelligence test scores, and has been used rather extensively in the biological and social sciences.[12] It has received some attention in the study of air pollution within the past ten years. Hopke, et. al.,[13] Blifford and Meeker,[14] and Thurston and Spengler[15] have used this technique to determine major classification of air pollution sources and the influence of meteorology on these sources.

Factor analysis can be applied to air pollution and may be well suited for an analysis of elemental particulate data. For this study a large amount of data from nine elements and two ions (nitrate and sulfate) exist. Many of the elements are related to each other in various simple and complex manners. As an example, iron is a relatively major consitiuent of soils and rocks.[16] It also can be an emission from major industries, notably the steel industry. One may not be able to use iron by itself to determine if the major source was the industry or the soil. Factor analysis, on the other hand, can at least assist in this determination. A complete explanation of factor analysis will not be attempted. Various statistical books can be referred to for a more thorough explanation.[17] This method, however, has several relatively simple but significant properties explained below.

Recall that the object of factor analysis is to reduce a set of variables to a smaller subset of variables called factors; i.e., factor analysis replaces a large set of intercorrelated variables with a smaller set of independent variables (factors). Factor analysis has as its starting point the correlation matrix of the variables in question. In our case, the correlation matrix is composed of all the elemental data collected at Central Park (Table 18). The second step involves the exploration of data-reduction possibilities by constructing new variables based on the interrelationships seen in the correlation matrix. Two methods can be employed to determine these factors. The first is known as the principal component model and is reflected as an exact mathematical transformation of the original data. The second method is known as the classical-factor model, which assumes that some unique factor is found for every variable. The principal component model is expresed below:

$$z_j = a_{j1}F_1 + a_{j2}F_2 + \cdots + a_{jn}F_n$$

where: z_j = variable j of the original data set

F_i = factor i

a_{ji} = standardized multiple regression coefficient of variable j on factor i

a_{jn} is often referred to as the factor loading, that is it represents the significance of each of the factors to each specific variable. Notice that the variable is completely explained by the sum of all of the factors. The counter part to this mode is the classical-factor model as described below:

$$z_j = a_{j1}F_1 + a_{j2}F_2 + \cdots + a_{jn}F_n + d_jU_j$$

where: U_j = unique factor for variable j

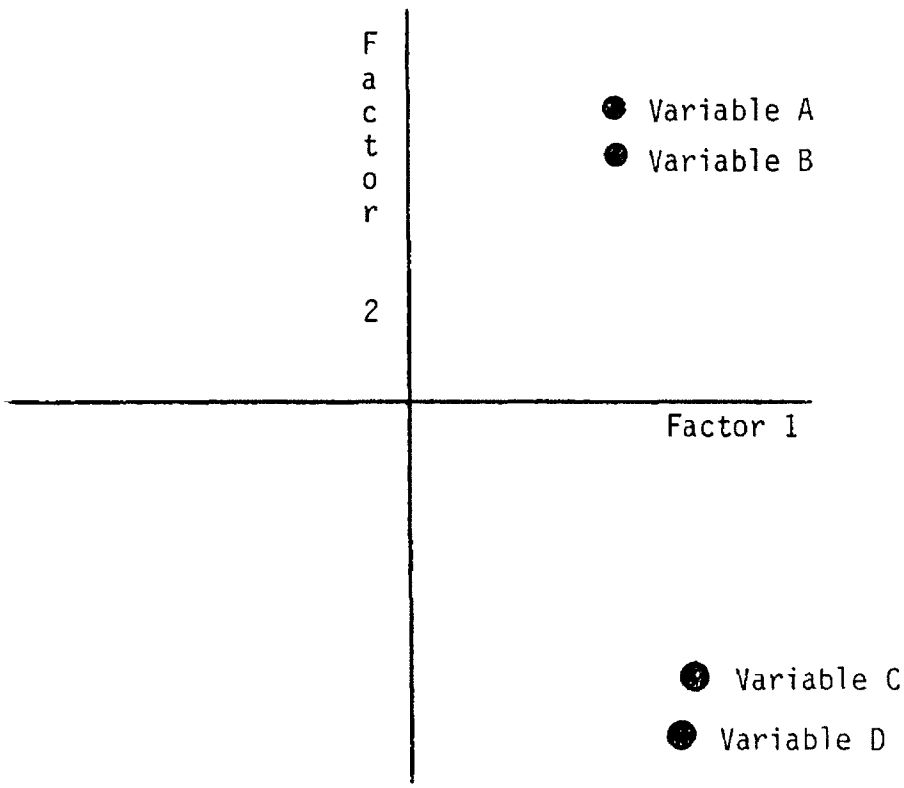
d_j = standardized multiple regression coefficient coefficient on unique factor j.

The model also assumes that the correlation between any factor and U_j is zero and that no correlation exists between each U_j for all j. It is only important to note that each factor contributes to the explanation of variable z_j, but that there is a unique factor (U_j) which is necessary to explain the total variance in z_j.

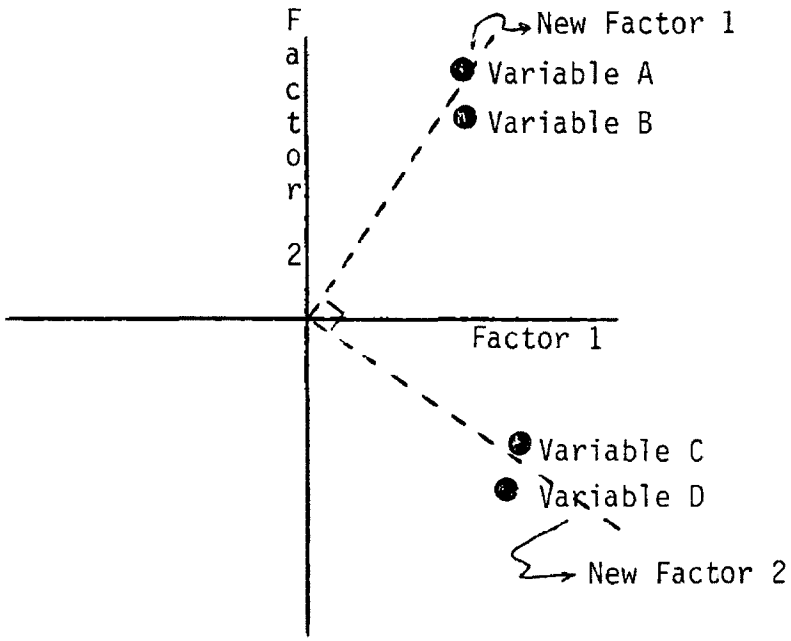
Although both methods of estimating factors were used in this paper, only the first method, principal components, was used for actual analysis presented. It was found that the use of either method did not significantly alter the results of the paper. The principal components analysis was preferred since a) it was not clear which values should be used for explaining the unique and common factors, factors F_1 through F_m, (some computer estimations were available through SPSS), b) it was not clear if this method affects the basic structure or meaning of the original variables, thereby distorting the analysis, and c) the use of principal components provided the most meaningful solution to the problem.

The third and final step in factor analysis is the so-called rotation of the factor solution. The solution of the principal components analysis yields several orthogonal (independent) factors. The consideration of independent factors can be displayed as the x and y axes for two factors. It is the object of factor analysis to obtain factors that most closely explain one or more variables with only one factor, and hence a smaller, easy-to-interpret data set. The actual solutions

from step number two do not always yield easily interpreted solutions, especially if more than 3 or 4 factors are considered. The principal component solution, therefore, can be rotated (orthogonally) such that the resulting factors are more closely associated with each variable. This is best illustrated through an example. The figure below illustrates what might be the outcome of a particular principlal component analysis.



Note that none of the variables are closely associated with any of the two factors. Each variable is only about half way (correlations equal approximately + and - .50) related to any one factor. If one were to rotate the two factors approximately 45 degrees counterclockwise, the rotated solution would look as follows:



Note how the rotated solution is closely related to the new factors, which is precisely what was done throughout these analyses. The results of these three steps yield a number of factors, usually three or four which have the following properties and meanings:

a. All factors are independent of each other (orthogonal);

b. The rotated factors have some representation to the original variables;

c. Each factor will be heavily loaded, that is the aji values are large with only a few variables;

d. Since each factor is orthogonal, it will represent some independent source or character of air pollution data; and

e. These factors can, therefore, be interpreted to represent an air pollution source.

This exact analysis also was applied to the corresponding meteorological data. Various variables were represented by individual factors. A realistic interpretation of the factors is suggested. A comparison was then made between these meteorological factors and the elemental factors to determine the way meteorology influences different sources of particulates.

Footnotes

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[3]Montana Air Quality Bureau Emission Inventory File, 1981.

[4]Harold Robbins, Montana Air Pollution Study: Air Monitoring Instrumentation,pp. 9-10.

[5]Stanley Manahan, Environmental Chemistry, (Boston, MA: William Grant Press, Inc., 1972), p. 323.

[6]Harold Robbins, Montana Air Pollution Study: Air Monitoring Instrumentaton, p. 11.

[7]National Climatic Center, Reference Manual for WBAN Hourly Surface Observations 144, (Asheville, NC: Data Procssing Division, ETAC, USAF, National Oceanic and Atmospheric Administration, 1970), p. 13.

[8]National Climatic Center, Climatological Data: Montana, Volume 81-83, (Asheville, NC: Environmental Data and Information Service, National Oceanic and Atmospheric Adminsitration, 1978-1980).

[9]Ibid.

[10]Ralph Larsen, A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards, (Washington D.C.: U.S. Government Printing Office, Publication Number AP-89, 1971. John Yocom et. al., "Determining the Contributions of Traditional and Nontraditional Sources of particulate Matter," Journal of the Air Pollution Control Association 31, (January 1981), pp. 17-20. Committee on Prevention of Significant Deterioration; of Air Quality, On Prevention of Significant Deterioration, (Washington, D.C.: National Academy Press, 1981), pp. 64-65. K. T. Whitby, "The Physical Characteristics of Sulfur Aerosols," Atmospheric Environment 12 (January 1978), p. 135. [11]Edward Brookman, and John Yocum, A Case Study in the Use of Ambient Data for Source Assessment, (Washington, D.C.: U.S. Envioronmental Protection Agency, Office of Research and Developement, Publication Number: EPA-600/7-80-080, 1980), pp. 8-10.

[12]Personal discussion with Dean Arthun, Regional Engineer for the Air Quality Bureau in Billings, MT., May 1981.

[13]John Cooper, and John Watson, "Receptor Oriented Methods of Air Particulate Source Apportionment," Journal of the Air Pollution Control Association 30, (October, 1980), p. 1123.

[14]Ibid.

[15]J. L. Moyers, et. al., "Evaluation of Particulate Trace Species in a Southwest Desert Atmosphere," Environmental Science and Technology 11, (August, 1977), p. 793. W. H. Zoller, E. S. Gladney, and R. A. Duce, "Atmospheric Concentrations and Sources of Trace Elements at the South Pole," Science 183 (March, 1974), pp. 198-200. Arthur Struempler, "Trace Element Composition in Atmospheric Particles During 1973 and the Summer of 1974 at Chadron, Nebraska," Environmental Science and Technology 9, (December 1975), pp. 1166-1167. Eric Crecelius et. al., "Background Air Particulate Chemistry near Colstrip, Montana," Environmental Science and Technology 14, (April 1980), pp. 424-425.

[16]Brian Mason, Principles of Geochemistry, (New York: John Wiley, 2nd Edition, 1958), p. 44.

[17]Eric Creclius et. al., "Background Air Particulate Chemistry near Colstrip, Montana," pp. 424-425.

[18]J. L. Moyers, et. al., "Evaluation of Particulate Chemistry near Colstrip, Montana," p. 793.

[19]Brian Mason, Principles of Geochemistry, p. 44.

[20]Russel Bohn, Update and Improvement of the Emission Inventory for MAPS Study Areas, (Kansas City, Missouri: Midwest Research Institute, 1979), pp. 14-16.

[21]Irving Blifford, and Gary Meeker, "A Factor Analysis Model of Large Scale Pollution," Atmospheric Environment 1 (January 1967), pp. 147-157.

[22]Phillip Hopke, "The Use of Multivariate Analysis to Identify Sources of Selected elements in the Boston Urban Aerosol," Atmospheric Environment 10 (May 1976), pp. 1015-1025.

[23]Irving Blifford, and Gary Meeker, "A Factor Analysis Model of Large Scale Pollution," pp. 147-157.

[24]George Thurston, and John Spengler, "An Assessment of Fine Particulate Sources and Their Interactions with Meteorological Influences via Factor Analysis," pp. 286-287.

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Results and Discussion

The results of the various analyses are explained below and organized by each type of analysis described in the Methodology chapter of this paper. A summary of the results and conclusions are provieded in the final chapter.

Frequency Distribtuion

A frequency distribtuion for all particulate monitoring sites was prepared (Appendix B). As described in the Analysis Methods chapter, several authors have suggest that one can typically expect a log-normal distribution for particulate data.[1] Brookman and Yocom[2] suggested that particulate data exhibiting this distribution are generally influenced by large-scale or general sources. Data that do not exhibit a near log-normal distribution or data that deviates at the extremes are probably influenced by a major local source such as a stack or a strong area source within a specific wind direction from the sampling site.

Since Billings has several major industries (Montana Power Company, Exxon, Connoco Inc., Great Western, and Montana Sulfur) within a few miles of all but one sampling site (KGHL), it would be logical to assume that these sources may influence the particulate levels. If this is the case, then some deviation from log-normality may exist. On the other hand, if the major area sources such as soil dust, road dust, home heating, and so forth are the major contributors to particulates, then the log-normal distribution should be generally strong.

One must be careful not to attach too much significance to this particular analysis. Other authors have suggested that the log normal distribution is not the only distributions that these data can possess.[3] This analysis, therefore, can only be interpreted as an indication of the validity of the above hypotheses.

Appendix C provides a description of the chi-square statistics and graphs of the data distribution. The information in Appendix C is reduced here in Table 7 below.

Table 7

Site	Mean	Median	Skewness	Kurtosis	Chi-Square Statistic
Central Park TSP	4.21	4.29	-0.5	-0.3	25.1
Central Park Inhalable	3.61	3.59	-0.2	-0.1	6.3
Central Park Coarse	2.81	2.93	-0.2	-0.9	18.7
Central Park Fine	2.78	2.82	-0.4	1.2	9.3
City Hall TSP	4.17	4.21	-0.3	0.2	15.0
Grand Ave. School TSP	3.92	4.02	-1.4	3.5	51.5
Lockwood School TSP	3.90	3.90	0.5	0.3	12.1

Units = Natural log of ug/m^3

All data above are calculated using the natural log (base e) of the particulate readings. By using the natural log of the data, one would expect a normal distribution to appear. The median is a measure of the data's middle values; that is, the middle value of those data lying exactly on the 50th percentile. In a perfect normal distribution, the median and mean are equal. The data above indicate close agreement between the two.

The skewness and kurtosis are statistics that indicate the relative shape of a curve.[4] The skewness measures the degree to which a distribution of cases approximates a normal curve and may be referred to the third moment of the mean. If the skewness is zero, then a completely

symmetric bell-shaped curve is in existence. A value greater than zero indicates that the data are clustered to the right of the mean, while a negative value indicates the data are clustered to the left of the mean. The kurtosis measures the relative flatness or peakedness of the curve. A value of zero indicates a normal distribution. Positive values of kurtosis indicate the distribution is more peaked (narrow) that a normal distribution, while a negative value reflects a flatter curve.

In all cases in Table 7, there are no data that exhibit an unusually large or small skewness or kurtosis, save one. The Grand Ave. School site appears to have a distribution shifted slightly to the left and of somewhat flatter distribution that expected. All other cases, on the other hand, seem to fall within a normal random error expected with any sampled population.

The mean, median, skewness, and kurtosis were calculated using the SPSS statistical package described earlier. The median, skewness, and kurtosis were calculated using a simple algorithm rather than the definition formula, and have no effect on the calculation's accuracy.

Thg chi-square statistic was calculated using the data generated from the SPSS package. The actual statistics, however, were calculated using a BASIC program written for this purpose. The chi-square statistic was used in order to determine the goodness of fit to the log-normal distribution. The chi-square test was applied by comparing the number of occurences within various cells ($1/2$ standard deviation in this instance) to the expected number of occurences within the same cells. The expected number of occurences was based on what would be observed in a perfectly log-normal distribution.

If the chi-square value is above a certain critical value, one can reject the hypothesis that the distribution is log-normally distributed. For purposes of this study, it was decided to use a 1 percent probability value since not all of the data distributions were spread exactly over the same time periods. A distribution of 15 months of data would be slightly biased since there are apparently more samples gathered in one season than the others. The critical value for chi-square in this case is 21.7; that is, if the data do possess a log-normal distribution, the probability that the null hypothesis (that the data are log-normal) will be incorrectly rejected is .01 (1 percent).

Table 7 indicates that only two sites failed the chi-square test, although one other parameter nearly failed. The Central Park TSP site and the Grand Ave. School TSP site both exhibited data distributions that were probably not log-normal. The Central Park coarse particulates leads one to nearly the same conclusion.

These results are somewhat surprising. The Lockwood School site, for example, is probably the site that would be most strongly influenced by a major industrial source. This is true since it is not only the site nearest to these industries, but it is also the site that exhibited the greatest amount of sulfur dioxide. Sulfur dioxide is a major constituent of the pollutant gases released from these industries. Lockwood School, however, does apparently possess a log-normal distribution. Central Park, on the other hand, is the most residentially oriented site within the study area. One would have expected, therefore, that this site would have a log-normal distribution. Grand Ave. School is located along Grand Avenue, a very busy highway by Montana standards. It could probably be characterized as a mixed com-

mercial and residential area. The chi-square test seems to indicate that this site is the most heavily influenced site by a single or directional source. The most obvious source that comes to mind at this site would have to be automotive traffic. The TSP could be either the vehicles themselves or the road dust emitted from their travel. Let us examine this hypothesis in a little more detail.

If the above hypothesis were true, then it would be reasonable to assume that other sites which are close to major roadways would also not have a strong log-normal distribution. City Hall and Central Park are both somewhat near major roadways. City hall in particular is located in downtown Billings (approximatley 14 meter above ground, however), which could certainly have this influence. The chi-square statistic for City hall is also large but not statistically significant. The Central Park site was located about one city block from Central Avenue, also a major road. One might therefore expect some influence from the road to break down the log-normal distribution. The coarse particulate data also provide an insight into the matter, since they almost rejected the null hypothesis. A single influence may affect the coarse data. This single influence is apparently not major industry since a site very close to industry did not show this same pattern. Several authors have shown that particles generated from vehicular traffic possess the same size distribution as might be exptected on the coarse filter.[5]

A general summary of this section leads to several observations:

1. The median and mean are generally similar for all sites.
2. Only Grand Avenue School had larger than expected skewness and kurtosis.

3. Central Park TSP and Grand Avenue School TSP failed the chi-square test for log-normality. Central Park coarse, on the other hand, nearly fails the log-normal test.

It appears, therefore, that there may be some local directional source that may be affecting these two sites. An inventory of the source near these sites probably only suggest automotive-related emissions.

Month and Season Variations

Concentrations of particulates can and often do vary from month to month and season to season. These changes can be accounted for by either changes in emission sources or by changes in meteorology or both. A review of the data values between seasons and months can assist one to understand some of the sources of particulates that are likely affecting the sampling instruments.

Monthly graphs were prepared for all of the particulate monitoring sites and included as Appendix D. These graphs represent the monthly average particulate or gaseous concentration plotted against time (1978 through May 1980).

In order to aid in the interpretation and presentation of the data, the following table was constructed.

Table 8

Air Quality Versus Seasonal Means

Site	Spring Mean	#	Summer Mean	#	Fall Mean	#	Winter Mean	#
Central Park TSP	82	75	103	146	90	118	51	139
Central Park Inhalable	32	26	54	29	50	47	31	25
Central Park Coarse	14	26	39	29	30	47	14	27
Central Park Fine	18	26	16	29	20	47	11	27
Lockwood School TSP	56	34	64	39	85	35	38	44
Lockwood School Inh.	--	--	33	7	21	26	21	2
Lockwood School Coarse	--	--	11	7	0.5	26	0	2

Table 8 Continued

Site	Spring Mean	Spring #	Summer Mean	Summer #	Fall Mean	Fall #	Winter Mean	Winter #
Lockwood School Fine	--	--	22	7	20	26	21	2
City Hall TSP	89	56	72	44	73	38	31	52
KGHL TSP	45	55	47	44	50	40	34	58
Grand Ave. School TSP	88	53	61	43	60	35	46	52
Central Park SO_2	7	79	7	156	14	97	15	165
Central Park NO_2	16	12	12	36	16	122	17	90
Central Park O_3	26	82	29	147	14	162	16	158

The particulate data means are measured in units of micrograms per cubic meter, while the gaseous data (SO_2, NO_2, and O_3) are measured in parts per billion (volume). The "#" represents the number of days with valid data for each particular case. The City Hall, KGHL, and Grand Avenue sites also included 1977 data, which was done because these three sites were only operated once every six days, yielding less data than Central Park. Addition of the year 1977 provided sufficient data to allow conclusions to be drawn.

The seasonal data was combined for all years. The seasons are defined below:

Spring = March 1 to May 31

Summer = June 1 to August 31

Fall = September 1 to November 30

Winter = December 1 to February 28 (or 29)

The purpose of combining the years was to provide enough cases (days) to allow conclusions to be drawn from the data. The Lockwood site for inhalable, coarse, and fine particulates did not provide enough cases to allow any conclusions on seasonal or monthly variations. The gaseous

data were added for purposes of comparing with possible sources. All calculations were performed with the SPSS computer package previously described.

The data have an immediate and obvious trend. Summer readings are larger than for all other seasons for all inhalable, coarse, and TSP variables. (This comes as somewhat of a surprise since the meteorological conditions are usually worse in the fall and winter). As an aid to this interpretation, it is of interest to note the seasonal variation for sulfur dioxide. Sulfur dioxide in Billings is emitted at a relatively constant rate. There are, quite naturally, variations in the sulfur dioxide emission, but most industries tend to operate at maximum production throughout the year. One exception would be Great Western Sugar, which operates only in the summer and fall.[6]

The sulfur dioxide data, however, have a definite seasonal variation; the largest readings occur in the winter and fall. This is opposite to the production by Great Western, and at variance with the observed TSP readings. Since winter and fall provide the worst meteorological mixing, one might presuppose that the TSP levels should follow the same pattern.

Since this is obviously not the case, it must be concluded that meteorology is not the overriding factor in explaining the variation among the seasons. This is especially noticeable when observing the spring data at Grand Avenue School, City Hall, and Central Park. Meteorologically speaking, spring is the season with the best dilution and mixing characteristics. All other things being equal, one would expect spring to be probably one of the best seasons for reduced air

pollution levels. Since this is not the case, the conclusion is that the significant sources of particulates must have a major impact on emission rates in the spring and summer. Conversely, the emissions must be greatly reduced during the winter.

The inhalable particulate data at Central Park shows the same general trend and conclusions. The coarse data seem to magnify the effects of summer and dampen the higher spring values occurring at City Hall and Grand Avenue School. The fine particulate data, however, generally have the same levels during all seasons except winter. Winter seems to be reduced by about one-half of fall. The data collected at the KGHL monitoring site show similar characteristics to those of the Central Park fine data. The spring, summer, and fall have relatively speaking the same values, while winter is the only season with significantly lower values. These data are significant in that the KGHL is a rural site for the Billings area, located near agricultural fields and approximatley 150 meters from Interstate 90. It is not purely a rural site relative to the rest of the state, but it is rural relative to the Billings area and Yellowstone River Basin.

The evidence presented points to the conclusion that the major sources of particulates in an around Billings must be associated with warmer temperatures or perhaps the lack of snow cover. Since mixing conditions are good in the summer and spring, there must be some overriding source(s) contributing to these higher particulate levels. It is also apparently associated with man's activities since this is also the time when outdoor activities are at their greatest. Automotive traffic is also at its peak in the late summer and early fall according

to the traffic counter data on Grand Avenue (Tables 5 and 6). Traffic patterns indicate that the highest counts occur in the late spring through the fall, which appears to correlate with the TSP and coarse readings at the air pollution monitoring station.

An analysis of variance (ANOVA) was performed on all variables. The null hypothesis for this statistical test is that the mean value for each season do not significantly differ from one another; that is to say, that the means for each season are equal. In every case, save one, the analysis provided sufficient evidence to reject the hypothesis. The only excpetion was Central Park fine particualte. The analysis reinforces previous statements, which suggest that real difference can be found between each season. The ANOVA test does not segregate the means but tests them all at one time. For example,

Central Park TSP

Hypothesis: Summer mean = Fall mean = Winter mean = Spring mean

The analysis does not divulge which seasons were significantly different, but only that the above hypothesis is not correct. (Other analyses, such as contrast methods, could have been employed to determine which season(s) were statistically different).

A closer look at the monthly patterns reveals that March is particularly high for TSP levels at Grand School and City Hall, both near heavy traffic areas. This may be due to the extra road dust accumulation from sanding during winter operations. March is a typical month for roads to become clear again, and could therefore possess an excess of particles that may become airborne from automotive traffic.

The monthly and seasonal variations can be characterized and summarized as follows:

1. Highest seasonal values occur in the summer for TSP and coarse particulates.
2. The lowest seasonal values are consistently in the winter.
3. The coarse particulate data generally follows the patterns above and emphasizes the high values in summer.
4. The fine particulate data does not exhibit such an obvious variation. An analysis of variance (ANOVA) performed on these data failed to reject the null hypothesis that all seasons are equal.
5. The particulate sources are probably not from major industrial stacks since the particulate distribution was counter to the sulfur dioxide distribution.
6. The readings are probably associated with man's activities and appear to be relatively associated with automobile traffic.

Day of Week Comparison

A comparison was made between particulate levels for different days of the week. The purpose of such a comparison is to determine differences in air pollution readings between two separate sets of man's activities. For this comparison the day of the week (Sunday through Saturday) was coded on the SPSS file as previously described. A comparison was then made between values of one day of the week versus the others. Since it is reasonable to assume that meteorology is not affected by the day of the week, then any differences seen between different days can be attributed to human activities.

All computations were performed on the SPSS statistical package as previously described. Appendix E consists of the original results by comparing days of the week both as all seasons combined and by season. Computations also were made for weekend versus weekday, although not

presented. An analysis of the data suggested that Saturday and Sunday were quite different from each other with regard to particulate levels. Another analysis was made comparing Sundays with the other days of the week. A summary of these data is presented below in Table 9.

Unfortunately, there was not enough data to make conclusions on many seasonal comparisons. Comparisons made with the number of cases less than ten was considered to be inappropriate. The other data, however, do yield some interesting observations.

In addition to the comparisons in Table 9, a t-test was conducted on all of the season-combined data. The t-test is a statistical technique somewhat similar to the ANOVA test described in the previous section. The t-test, however, attepts to compare the differences in mean, if any, between two populations. For this case, the null hypothesis is that the mean particulate levels on Sundays are equal to the particulate levels on all other days. The following table (Table 10) provides a summary of those results.

For the seaons-combined data, nearly every variable exhibited a lower mean during Sunday than the rest of the week. Two notable exceptions were Lockwood School and KGHL. It is relatively easy to explain any lack of variation at KGHL since it is a rural site. Presumably man's activities do not change as greatly in a rural setting as in an urban one from day to the next. Lockwood School, on the other hand, is not so easy to explain. Lockwood School might be described as a suburban setting with some industrial influences as previously noted.

Table 9

Sunday versus Rest of the Week

	All Seasons				Spring				Summer				Fall				Winter			
	Sunday		Other		Sunday		Other		Sunday		Other		Sunday		Other		Sunday		Other	
	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#
Central Park TSP	67	52	83	456	71	8	83	67	85	19	106	127	72	11	92	107	40	14	52	125
Central Park Inh.	39	17	45	110	30	3	32	23	42	3	56	26	49	7	50	40	24	4	33	21
Central Park Coarse	24	18	26	111	17	3	14	23	34	3	39	26	31	3	30	40	14	5	14	22
Central Park Fine	14	18	19	111	14	3	18	23	8	3	17	26	18	7	20	40	12	5	21	22
Lockwood School TSP	61	20	59	132	60	5	56	29	46	4	66	35	129	4	79	31	32	7	39	37
City Hall TSP	62	28	74	162	83	8	90	48	55	6	75	38	71	6	74	32	39	8	57	44
Grand Ave. School TSP	57	26	66	157	82	8	89	45	51	5	63	38	58	6	61	29	32	7	49	45
KGHL TSP	43	27	43	170	55	8	43	47	42	5	48	39	52	6	49	34	27	8	35	50
Central Park SO_2	98	70	110	427	79	10	68	69	55	22	72	134	106	14	142	83	140	24	146	141

Central Park and Lockwood School: 1978 through May 1980
All other sites : 1977 through May 1980

= number of days with valid data (cases)

Units = Particulates = micrograms per cubic meter
Sulfur Dioxide = parts per billion (volume)

Table 10

T-Test
Sunday Versus Rest of the Week

Variable/Site	T-Value	Degrees of Freedom	Probability Value	Stat. Different ?
Central Park TSP	-2.20	476	.028	Yes
Central Park Inhalable	-0.88	125	.379	No
Central Park Coarse	-0.24	127	.810	No
Central Park Fine	-2.07	127	.041	Yes
Lockwood School TSP	0.17	150	.861	No
City Hall TSP	-1.72	188	.088	Borderline
Grand Ave. School TSP	-1.00	181	.320	No
KGHL TSP	0.03	195	.976	No
Central Park SO_2	-0.96	495	.339	No

Note: Explanation of statistics on the following page. Data represents all seasons combined.

It is reasonable to assume that man's activities change between Sundays and the rest of the week. Major industrial emissions, therefore, could be responsible for the lack of difference between the two time frames.

Most cases, however, showed some difference between Sundays and the rest of the week. Only about three comparisons showed any statistical difference, with City Hall a borderline case. The Central Park TSP site showed the strongest trend between days of the week. Since this is a reaonably reliable residential site, it could be explained by less vehicular traffic in the area. The station was located within a park and next to a tennis court and presumably would have received greater use during Sunday than any other day of the week (except the winter). This increased use in the Park did not cause an accompanying increase in particualte levels. It is difficult to explain the observed difference between Sunday and the rest of the week for the Central Park fine particulate. It appears that the sources of the fine particulate are related to the days of the week. If one assumes that man-induced activities are responsible for increasing air pollution levels, then the fine particulates are even more difficult to explain. Most of man's activities, save combustion, are generally assumed to be coarse or larger particles. If fine particulates decrease during Sunday, as indicated, then the cause of that reduction is difficult to explain unless automotive emissions are the culprit. The only other plausible explanation would be that the mean value of fine particulates is invalid because the population size (18) is insufficient. Again, major industry is probably not responsible for such a decrease on Sunday since it operates at a relatively constant rate.

Perhaps commercial and weekday-related services to industry are responsible for the decrease in fine particulate.

It may be possible to attribute the difference between Sunday and the rest of the week, even though all cases are not statistically significant, to automotive-related differences. Unfortunately, no day-of-the-week traffic counts were available for Billings. Data do exist, however, for Great Falls and Missoula. The Missoula traffic counter is located near Orange Street bridge, while the Great Falls counter is located on Tenth Avenue South between Ninth and Tenth Street. This locations are similar to the Billings counter in that they are all located on busy avenues of travel in each city. Table 11 below summarizes these data for the two-year period of 1978-1979.

Table 11

Traffic Count: Missoula and Great Falls Versus Day of Week

	Missoula			Great Falls		
	Vehicles per day	% of Mean	# of days sampled	Vehicles per day	% of Mean	# of days sampled
Sunday	11,753	63	72	21,829	73	126
Monday	20,223	109	71	30,498	102	126
Tuesday	20,050	108	72	31,128	104	126
Wednesday	20,089	109	72	31,413	105	126
Thursday	19,995	107	72	32,221	108	126
Friday	22,106	119	72	33,737	113	126
Saturday	16,235	87	72	28,541	95	126
Mean	18,633	100	72	29,909	100	126

Despite the fact that we are dealing with two separate cities, the traffic patterns for each day of the week are suprisingly similar. If one were to rank the days of the week from increasing to decreasing values, the following would occur:

Sunday	= 1	(approx. 70% of mean) -lowest-
Saturday	= 2	(approx. 90% of mean)
Monday through Thursday	= 3	(approx. 106% of mean)
Friday	= 4	(approx. 116% of mean) -highest-

Since these two independent cities in Montana have very similar traffic patterns, it would not be unreasonable to assume that Billings has the same weekly variations. If automobile traffic is responsible for any major particulate readings, one should expect to find difference between Sunday and the rest of the week. The traffic patterns indicate that the ratio between the mean for Sunday and the mean for the rest of the week is approximately .60 for Missoula and .70 for Great Falls. Applying these data to Billings leads one to assume that the difference in traffic flow between Sunday and the rest of the week is approximately a 35 percent reduction in traffic on Sunday.

Quite naturally, this conclusion and comparison should not come without giving some consideration to the Billings area. For example, the City Hall site probably experiences a greater reduction in traffic on Sunday than does the Grand Avenue School. This occurs because the City Hall site is located downtown and most downtown stores are closed on Sunday, while the Grand Avenue site, located on Grand Avenue, has many shopping areas open on Sunday. This interpretation fits the observed data rather well. The City Hall site showed a larger reduction

reduction in TSP than did the Grand Avenue site during Sundays.

The data from this day of the week comparison was somewhat confusing and contradictory. The results are summarized below.

1. All sites, save one, displayed less particulates on Sunday than the rest of the week

2. Only the Central Park TSP, Central Park fine, and to some degree the City Hall TSP showed statistically significant differences between Sunday and the rest of the week.

3. The sites showing the least variation were Lockwood School TSP and KGHL TSP. KGHL can be explained due to its rural nature, while Lockwood was not as satisfactorally resolved.

4. Not enough data existed to make meaningful comparisons betweeen days of the week within each sason.

5. An analysis of day of the week traffic patterns in Missoula and Great Falls presented results that were quite similar. It is assumed, therefore, that Billings has the same pattern:

   Sunday = 1 (lowest)
   Saturday = 2
   Monday through Thursday = 3
   Friday = 4 (highest)

   Since the particulate data had a similar pattern, it is logical to assume that traffic has an influence on some of the readings.

6. Outdoor recreational activities are probably not a major contributor to particulate values as automotive traffic, since one would expect Saturday and Sunday to be higher than the rest of the week. The observed data indicate the opposite effect to this pattern.

Wet Day/Dry Day Comparisons

It is easy to envision how the amount of rainfall or snowfall can affect particulate readings. During periods of rain or snow, the ground remains wet and tends to hold particles on the ground regardless of the various activites to make them airborne, such as wind and traffic. Rain or snow can actually wash out particles in the air, further reducing the particulate readings. In order to estimate the impact of this affect, a precipitation index was used as described in the methodology and

analysis method chapters. The raw precipitation data were obtained from the National Oceanic and Atmospheric Administration and coded onto the SPSS data file. Snow fall was included in this data as an equivalent amount of rain. The precipitaiton index was calculated using a FORTRAN program and also coded onto the SPSS system.

In order to simplify the analysis, it was decided to use a simple wet day versus dry day comparison. A critical value of 5 was chosen to represent a wet day. This number was chosen for various reasons:

1. The index value had to be low enough such that there would be enough data to perform statistical comparisons; and

2. Various other values for an index were compared. It was found that an index of greater than 5 produced essentially the same results as 5. Smaller indexes, however, caused a significant difference in the outcome of subsequent analyses. It was concluded that 5 provided the maximum amount of data for statistical analysis without sacrificing any of the results.

A comparison was made between the particulate readings for days having a precipitation readings greater than 5 (wet day) against the particulate readings for days observing a precipitaion index less than or equal to 5 (dry day). The following table (Table 12) is a summary of these data.

A quick review of the table indicates that nearly every variable exhibited a lower mean during wet days as opposed to dry days. The same trend is noticed not only for all seasons combined, but for all individual seasons as well. In order to aid further in the interpretation, a t-test was computed on the data set. The hypothesis of the test was the mean value during the wet day equaled (i.e., was not statistically different from) the mean value during the dry days. Table 13 is a summary of these data.

Table 12

Wet Day/Dry Day Comparisons

	All Seasons				Spring				Summer				Fall				Winter			
	Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry	
	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#	Mean	#
Central Park TSP	59	173	94	305	57	33	101	42	79	58	119	88	58	33	102	85	37	49	59	90
Central Park Inh.	16	44	26	83	26	12	37	14	39	10	62	19	30	13	58	34	22	9	37	16
Central Park Coarse	14	45	24	84	12	12	17	14	22	10	47	19	14	13	36	34	6	10	37	16
Central Park Fine	16	45	20	84	15	12	20	14	17	10	15	19	16	13	22	34	17	10	20	17
Lockwood School TSP	42	42	79	50	50	10	79	7	49	12	81	13	39	6	123	14	30	14	40	16
City Hall TSP	63	58	88	70	81	18	117	17	69	14	89	17	58	9	87	14	41	17	65	22
Grand Ave. TSP	34	55	83	67	78	17	125	15	60	13	74	16	32	7	79	13	35	18	65	23
KGHL TSP	37	58	52	73	35	17	49	16	37	13	58	17	46	9	65	16	34	19	40	24
Central Park SO_2	100	180	112	317	58	38	80	41	49	54	80	102	145	30	133	67	151	58	142	107

Central Park and Lockwood School: 1978 through May 1980
All other monitoring sites : 1977 through May 1980

Units: Particulates = ug/m^3
Sulfur Dioxide = parts per billion

= number of days with valid data (cases)

Table 13 more clearly shows the trend that wet days have a major effect on the particulate readings. Only fine particulate failed to show any degree of significance between wet and dry days over all seasons. The Central Park fine, however, was borderline. It is not too surprising that the sulfur dioxide values for all seasons did not show any diffeence. The sulfur dioxide comparison was based upon a precipitation index which takes into accout previous amounts of precipitation and not just the day in question. The Central Park fine particulate, however, apparently shows signs of having characteristics of both the TSP and gases. This is perfectly logical since smaller particles begin to behave more like gas molecules than particulates if the composition is small enough.

It would seem to be a logical conclusion to state that sources controlled by precipitation have a major impact upon the particulate levels in Billings, at least as far as all seasons combined are concerned. Clearly, when one removes these sources of air pollution, via precipitation, the readings are generally reduced. The ratio between wet and dry days varies from about .41 to .72 for all TSP sites. The inhalable and coarse particulates are within the same range at .62 and .58 respectively. Only the fine fraction stands alone with a ratio of .80. Central Park TSP, Lockwood TSP, and Grand Ave. School TSP show the greatest effect of precipitation. These reductions are rather

Table 13

Wet Day/Dry Day Statistical Summary

	All Seasons		Srping		Summer		Fall		Winter	
	Pro.	SD	Pro.	SD	Pro.	SD	Pro.	SD	Pro.	SD
Central Park TSP	.000	Yes	.000	Yes	.000	Yes	.000	Yes	.000	Yes
Central Park Inh.	.000	Yes	.115	No	.004	Yes	.002	Yes	********	
Central Park Coarse	.000	Yes	.181	No	.001	Yes	.004	Yes	.097	?
Central Park Fine	.072	?	.143	No	.611	No	.061	?	.550	No
Lockwood School TSP	.000	Yes	********		.011	Yes	*********		.056	?
City Hall TSP	.000	Yes	.012	Yes	.027	Yes	*********		.024	Yes
Grand Ave. TSP	.000	Yes	.013	Yes	.114	No	*********		.038	Yes
KGHL TSP	.000	Yes	.031	Yes	.004	Yes	*********		.323	No

Where:

Pro. = probability value expressed in decimal
SD = Statistical Difference? Yes, No, or ?

If the probability value was less than .05, then SD responded to by a "Yes". If the value was greater than .10, then the response was "No". Each other value received a "?" since it was a borderline case.

substantial and constitute a major portion of the TSP levels found in the area. This means that between 29 percent and 59 percent of the TSP, inhalable, and coarse readings are a product of these sources. These figures are not exact in that the selection between wet and dry days is somewhat arbitrary.

It seems rather obvious that the general source of this particulate must be the ground, roads, streets, and so forth. Rainfall does not significantly change the emissions from major smoke stacks, car and truck exhaust, home heating, and so forth. It appears, then, that this source(s) must be related to the earth or deposited onto the earth. These types of sources can be grouped into three general classes: 1) agricultural soil and dust, 2) road dust, and 3) dust generated from general outdoor activities such as playgrounds, parks, and the like. The wet day/dry day analysis does not provide enough general information to apportion each of these sources.

It could be argued that the effect of road dust in this comparison is inaccurate since the traffic volume is less during wet days thereby causing a reduction in particulate readings unrelated to precipitation. A comparison was made betweeen wet-day automotive counts and dry-day automotive counts in Missoula and Great Falls. This comparison is given on Table 14 below.

Table 14

Traffic Count versus Wet-Day/Dry-Day

	Wet Day Mean	Dry Day Mean	T-Value	Degrees Freedom	Probability Level	Stat. Sign.?
Missoula	18,720	18,603	0.33	498	.738	No
Great Falls	30,850	31,141	-0.28	845	.780	No

Mean = mean daily traffic count

The data from Missoula and Great Falls clearly indicate that the traffic patterns do not change between wet and dry days. It is assumed that Billings shows the same trends. The reduction in TSP is more likely to be a function of the three categories stated in the previous paragraph.

A review of the seasonal comparisons between wet and dry days does not yield any major variations from the season-combined comparisons. The statistical analysis, however, gives more cases where one cannot deny the hypothesis that the two means are the same. The raw data, on the other hand, contain only one particulate example where the particulate wet day is equal to or greater than the particulate dry day; i.e., the summer for Central Park fine particulates. The values are nearly equal in any event and do not appear to exhibit any significant results.

The sulfur dioxide data, however, are somewhat disturbing. Both the spring and summer data show a statistical difference between wet and dry days while the fall and winter do not. The overall wet versus dry comparison shows no difference. No explanation for the difference in the summer and spring can be offered except that sulfur dioxide is less

soluble in warm water than in colder water and the wind direction may vary from one season to the next during wet days.

A summary of the results of this section is provided below.

1. Wet days display significantly less particulate levels than do dry days.

2. The ratio of wet day means to dry day means ranges from .41 to .72 for all particulates, except Central Park fine, which displayed a ratio of .80.

3. The seasonal comparisons displayed the same conclusions but with less statistical significance.

4. The sulfur dioxide data showed no statistical difference between wet days for all seasons combined. A significant difference between wet and dry days was observed, however, in the spring and summer. The reason for the variation is not clear, but could be due to sulfur dioxides solubility at lower temperatures and/or changing wind patterns between wet and dry days.

5. No reduced traffic flow for wet days is suspected, based on Misssoula and Great Falls data. Thus, one cannot account for the decreased values based on a decrease in vehicular use.

Enrichment Factor

Several authors in the past ten years have used enrichment factors to determine sources of particulate values as measured by high-volume, membrane, and dichotomous samplers.[7] The purpose of enrichment factors is to determine if the concentrations of selected elements are likely to be from the crustal earth or other background material. The enrichment factor model is more fully explained in the Methodology chapter.

An attempt was made to determine whether any measured elements in Billings existed due to some source other than the crustal earth. The identification of such elements could assist in defining the source. Some careful checking of the data was necessary before this step was finally executed.

Most authors chose to use data collected on a dichotomous or membrane sampler. The reason for this choice is that these two samplers allow for a more accurate determination of chemical elements and ions within the collected particulate. In the MAPS study, however, the most complete data set resided within the high-volume elemental determinations. A comparison had to be made between data collected on a reliable sample device to data collected via the high-volume sampler.

In the winter of 1978-79, several dichotomous samples were collected and sent to Bob Stevens in Research Triangle Park EPA for analysis. The analysis method used was x-ray fluorescence, which is a non-destructive method capable of analyzing 30 elements with essentially one measurement. It was decided, therefore, to compare enrichment factors using these data with enrichment factors collected through the use of the high-volume sampler. Enrichment factors were calculated for the dichotomous data using the crustal earth concentrations as determined by Mason.[8] The characteristic element chosen was silicon since it best represented a unique element related to the soil. Although an enrichment factor was calculated for each of the eight samples, the factors were averaged to try to represent the winter values.

Enrichment factors also were calculated for the winter months using the high-volume data collected in the MAPS study. Of the three most commonly sited elements in the literature as a characteristic element, only aluminum was available. Therefore, the data were calculated using aluminum as the normalizing element. The crustal earth concentrations provided by Mason[9] also was used to determine enrichment factors. Table 15 below is a comparison between the two enrichment factors.

Table 15

Enrichment Factor Comparison

Element	Dichotomous Mason Silicon	High-Volume Mason Aluminum
Aluminum	2.4	1.0
Phosphorous	12.0	***
Sulfur	1,598.0	***
Manganese	***	3.0
Iron	1.5	1.7
Zinc	78.8	18.1
Bromine	19,372.0	***
Strontium	3.4	***
Lead	8,765.0	1,050.0
Copper	37.3	91.1

Dichotomous = samples analyzed by x-ray fluorescence by EPA
High-Volume = samples analyzed on the hi-vol filter by Department of Health using atomic absorption.

Comparing aluminume results yields an estimate of error that can be expected from the two methods. Since aluminum was the characteristic element for the high-volume analysis, the enrichment factor, quite naturally, was one. For dichotomous data, however, the value was 2.4. It would appear to be inappropriate to suggest that any element whose enrichment factor was only slightly greater than 2 was enriched from something other than crustal earth.

Although the values betwen the dichotomous and TSP data vary, the conclusions drawn from each sampler are the same. Both methods suggest than iron is not enriched and lead is heavily enriched. Lead found on these filters cannot be explained by the crustal earth, while the iron found on the filters in all likelihood is a product of the crustal earth. The magnitude of enrichment by copper, zinc, and lead are not in close agreement between the methods, but the conclusions are generally the same.

The enrichment factors were then calculated using the entire data set for the high-volume and membrane filters. The results of those enrichments are supplied in Table 16 below.

Table 16

Enrichment Factors - Department of Health Data
Crustal Earth - Mason
Aluminum

Element	All Seasons	Spring	Summer	Fall	Winter
Aluminum	1.0	1.0	1.0	1.0	1.0
Arsenic	39.6	15.0	17.2	8.5	174.3
Cadmium*	1,204.4	637.0	572.5	422.9	5,036.5
Copper	91.1	86.3	58.3	91.4	142.8
Iron	1.7	1.8	1.9	1.8	1.4
Lead	1,050.0	819.4	612.1	917.1	2,166.9
Manganese	3.0	3.2	3.0	1.7	4.6
Nickel	18.6	29.8	5.3	14.3	41.7
Zinc	18.1	15.8	13.1	18.2	30.7

*The concentrations reported by Mason of cadmium in the crustal earth was near the detectability of the methodology. Enrichment Factors, therefore, may not be fully accurate.

Table 16 shows that lead is certainly heavily enriched compared to all other elements. No conclusions were drawn with cadmium since according to the Mason figures, it was near the detectability limits. A small error in the measurement of cadmium by Mason, therefore, could

have a large impact upon the resultant enrichment factor. It also appears that copper and arsenic are enriched. Nickel and zinc appear to be enriched but not nearly to the degree of the above mentioned elements. Iron and manganese do not appear to be enriched and are probably related to the crustal earth.

The change in enrichment factors between the seasons is also of interest. Winter is clearly the season of the highest enrichment, which comes as no surprise since winter also contains a great deal of snow cover, effectively reducing the contributions of crustal earth to the filters. The fact that the enrichment factor changes (lower in nearly every case) from winter to the other seasons is an indication that crustal earth materials contribute to particulate concentrations during the other seasons. Since summer contained the lowest enrichment factors, it must have been the season with the greatest concentration of crustal earth materials.

The analysis was carried one step further by using a different background ratio (i.e., denominator in the enrichment factor model). Rather than using only data generated by Mason, which represents the earth as a whole, it was decided to seek out data that were more closely associated with Billings. The Emissions Inventroy portion of the MAPS project sampled various sources in most of the major MAPS communities. In Billings, samples were taken of certain sources, including roads (paved, unpaved, travel lanes, and curbs) and soil. It was decided to use the agricultural field samples to represent the background concentration in Billings. The field sample was analyzed by Midwest

Research Inc. using a total digestion procedure, and is reported as follows in units of micrograms per cubic meter.

Aluminum = 68,200.
Arsenic = 4.92
Cadmium = 0.99
Copper = 248.
Iron = 27,400.
Lead = 33.2
Zinc = 136.
Vanadium = 96.

These figures were then applied to the high-volume and membrane data for Central Park. The enrichment factors are presented in Table 17 below.

Table 17

Enrichment Factors - Department of Health
Agriculatural Soil near Billings
MRI Data
Aluminum

Element	All Seasons	Spring	Summer	Fall	Winter
Aluminum	1.0	1.0	1.0	1.0	1.0
Arsenic	33.8	12.8	14.6	7.2	148.6
Cadmium	153.1	81.0	72.8	53.7	640.1
Copper	21.6	20.4	13.8	21.6	33.8
Iron	2.6	2.8	2.9	2.7	2.1
Lead	424.6	331.3	247.5	370.8	876.0
Zinc	14.8	12.9	10.7	14.8	25.0

The results are quite similar to Table 16 except that they are scaled down in magnitude for most elements. This scaling down reflects the elevated concentrations of elements in the Billings soil relatiave to those reported by Mason. It is believed that these data better

represent the contribution of these elements to the filter from surrounding dust and soil. Aluminum and iron are clearly not enriched from sources other than the soil (assuming that aluminum is indeed a unique or characteristic element of soil). Cadmium and lead are highly enriched by some surrounding source or sources. The source of the cadmium is not clear. Lead concentrations, on the other hand, are possibly functions of automotive exhaust[10]. Fortunately, the concentrations of cadmium found on the high-volume filter are quite low and probably do not represent a threat to human health.

As before, zinc seems to be enriched although not highly. It may be that zinc has several sources other than just the soil. This would dilute its enrichment factor such that it would not display an obvious trend. Arsenic is in the same general category but is more enriched than zinc. The actual values of arsenic on the high-volume filters were also quite low, like cadmium, and do not apparently represent any significant danger to human health. Nevertheless, the sources of these compounds are somewhat perplexing.

The same seasonal patterns were displayed with the MRI data as Mason data. Winter experienced the most enriched months, while summer was generally the least enriched, which suggests that summer particulate is the most influenced by soil-related contributions.

The enrichment factor calculations and summary are presented below.

1. Both the crustal earth and local soil data showed the same general enrichment factors.
2. The soil comparisons exhibited lower values for enrichment factors than the Mason figures thereby indicating a higher background concentration of these elements than exist in the crustal earth.

3. Lead and cadmium were the most enriched elements. Arsenic, nickel, and zinc were the next most enriched elements, while aluminum, iron, and manganese were the least enriched.

4. Aluminum, iron, and manganese are probably from the soil since they have enrichment factors nearly equal to one.

5. Arsenic, nickel, and zinc are enriched but not to the degree of the other elements. The source is unclear but it could be a function of several sources.

6. Lead and cadmium are highly enriched suggesting that the vast majority of the lead and cadmium on the filters are not from soil, but some other source such as cars or refineries. The source of the cadmium is not known.

Factor Analysis

A multivariate method for source determination known as factor analysis, or principal component analysis, was applied in this paper. The factor analysis was applied to the meteorological and elemental data collected in the study. The use of principal components made it possible to study these component relationships to each other and other important variables. The factor analysis was used to extract information about a source's contribution to the particulate levels based on the variability of the elemental concentrations. If two or more elements originate from the same source, the variability of these elements, as measured by the elemental concentration on the filters, will have the same variability of the source; i.e., the variance on the high-volume sampler for these elements will have the same variance as the source. The object of the analysis is then to detect this common variability and imply source identification by comparing the elements with common variability to elements from a specific source(s).

The starting point for identifying these common sources of variability is the correlation matrix, which is analyzed such that a set of

initial factors are extracted (factors with common variance to one or more elements). The initial factors are then orthogonally rotated to obtain a solution that best explains all elements or combination of elements. For this analysis the principal compnent methodology was used to extract the initial factors. The reason for this selection is explained in the methodology chapter of the report.

To commence the analysis, a correlation matrix was constructed and analyzed for the elemental data. The matrix was prepared using a pair-wise correlation coefficient; that is, the correlation coefficient was calculated for each pair of variables regardless of the number of missing values in any other variables of the same day (case). Table 18 is the correlation matrix obtained for the elemental data. Note that vanadium was left off of the analysis since those data had essentially no variance because the values of the element were nearly always below the detectability of the measuring device. A close review of the cadmium and arsenic data revealed the same general pattern as vanadium. Almost all values reported for these two elements were near the detectability of the data. For this reason, all cadmium, arsenic, and vanadium data were not used in the final factor (principal component) analysis. It must be noted that data were obtained on both the membrane and high-volume filters on all elements. As was discussed in the Methodology chapter, the aluminum, iron, and zinc values were not reported on the high-volume sampler because of a high background level of the substance in the filter. In the case of nickel, there were less than 20 days data using the membrane filter. These data, therefore, were not coded onto the system. In addition, neither nitrate nor sulfate was analyzed on the membrane filter.

It was decided to use the membrane and high-volume data where possible since both types of sampling could yield different results. The high-volume filter is likely to measure larger particles than the membrane filter. It is possible, therefore, that each sampling device may be measuring different sources of the same element, if different sources do in fact exist.

Let us begin the analysis be first reviewing the results of the correlation matrix table (Table 18). The correlation between lead and lead-membrane is quite good; i.e., .83 which indicates that a relationship exists between the two devices. It would not be unreasonable to expect that lead measured by both methods are from the same source. One would also expect that both of these variables to be heavily loaded (highly correlated) with the same factor or principal component. The same cannot be said of manganese. The correlation of the high-volume and membrane manganese is .29, which is statistically signficant from zero at the 5% level but does not fit the linear model well since only a little over 8% of the data fits the model assumptions. Personal discussions with the Department of Health's laboratory staff indicated that no reasonable explanation exists as to the cause of this discrepency. An analysis done with National Bureau of Standards material indicated that the laboratory was able to recover between 72% and 89% of the total manganese on prepared filters. Given this situation the only probable reason for the difference is that the two samplers may have been measuring different size particles and hence different sources.

Table 18

Correlation Matrix
for
Central Park Element Data

	Mem. Aluminum	Mem. Iron	Mem. Zinc	Nickel	Copper	Nitrate	Sulfate	Lead	Mem. Copper	Mem. Lead	Mem. Mang.	Mang.
Aluminum (Mem.)	1.00	.97	.74	-.06	.37	.04	-.10	.30	.32	.45	.96	.25
Iron (Mem.)	.97	1.00	.72	-.07	.44	.01	-.11	.34	.35	.44	.98	.28
Zinc (Mem.)	.74	.72	1.00	.01	.39	.20	.13	.56	.28	.68	.77	.24
Nickel	-.06	-.07	.01	1.00	.06	.03	.03	.15	-.22	-.05	-.07	.14
Copper	.37	.44	.39	.06	1.00	-.02	-.01	.15	.51	.30	.48	.21
Nitrate	.04	.01	.20	.03	-.02	1.00	.66	.41	-.21	.40	.02	-.05
Sulfate	-.10	-.11	.13	.03	-.01	.66	1.00	.42	-.23	.28	-.10	.04
Lead	.30	.34	.56	.15	.15	.41	.42	1.00	-.10	.83	.36	.17
Copper (Mem.)	.32	.35	.28	-.22	.51	-.21	-.23	-.10	1.00	.10	.40	.43
Lead (Mem.)	.45	.44	.68	-.05	.30	.40	.28	.83	.10	1.00	.48	.15
Manganese (Mem.)	.96	.98	.77	-.07	.48	.02	-.10	.36	.40	.48	1.00	.29
Manganese	.25	.28	.24	.14	.21	-.05	.04	.17	.43	.15	.29	1.00

Mem. = sample gathered with membrane sampler

The same comparison with copper revealed a correlation coefficient somewhere between the two previously discussed values measuring .51. This indicates that a relationship exists between the two devices, but that only about 25% of the data fits the linear model well. The National Bureau of Standards comparison for this metal ranged from 82% to 98%, indicating good recovery. Personal discussion with the Department personnel and with the Anaconda Copper Co. in Butte, which has performed copper analysis on high-volume filters, indicates that it is not unusual for copper on a high-volume sampler to originate from the copper armature and brushes used in the motor. In any event, no quantitative explanation for the lack of good correlation is available. It was assumed that both samplers probably represent different sources but not totally independent sources.

The next step in the analysis was to choose an appropriate number of factors for the comparisons. The SPSS "FACTOR" program was used to generate a set of extracted factors. It was decided not to use any factor whose eigenvalue was less than 1.0. Table 19 below represent the 12 extracted factors and their eigenvalues.

As the reader can see from the table, only three factors had eigenvalues greater than one. Although the fourth factor was near an eigenvalue of one, it was not used since the factor failed to add any significant information.

The three factors were then rotated to obtain a terminal solution. The varimax method, as opposed to the quartimax and equimax method, is

Table 19

Factor Extraction for Elemental Data
Central Park

Factor #	Eigen Value	Percentage of Variance
1	4.629	38.6
2	2.479	20.7
3	1.485	12.4
4	.984	8.2
5	.711	5.9
6	.675	5.6
7	.359	3.0
8	.312	2.0
9	.240	1.8
10	.182	1.5
11	.028	.2
12	.016	.1

designed to simplify the columns (factors) of a factor matrix. This is done by maximizing the squared loadings (correlation coefficients) in each column. Table 20 yields the final solution of the factor analysis with the factor loadings presented.

The next step, and probably the most important, is to interpret the representation of the factors.

The first factor is heavily loaded with aluminum, iron, zinc, and manganese, which were all measured using the membrane sampler. The interpretation of this factor seems relatively easy. Aluminum and iron are two major constituents in soil and dust.[11] Manganese also may be an important and somewhat unique element to earth crustal material. Recall

Table 20

Factor Analysis Final Rotated Solution
Principal Components
Central Park

Factor Loadings
(Correlation)

	Filter	Factor 1	Factor 2	Factor 3
Aluminum	M	.936	.069	-.028
Iron	M	.946	.047	.020
Zinc	M	.813	.386	.015
Nickel	H	-.141	.073	.819
Copper	H	.543	-.057	.344
Nitrate	H	-.048	.799	-.091
Sulfate	H	-.184	.776	.076
Lead	H	.332	.778	.135
Copper	M	.517	-.370	.324
Lead	M	.402	.719	-.003
Manganese	M	.967	.070	.045
Manganese	H	.268	.013	.817

that in the enrichment factors section manganese displayed values between 1.7 and 4.6. Recall also that aluminum was used as a characteristic element for some of the analysis. Iron's enrichment factors ranaged from 1.4 to 2.9, which indicates that it is not enriched by sources other than the soil or crustal earth materials.

Factor 1's heavy loading with zinc is not as well explained. The source of the zinc seems to be more than just the soil, given the analy-

sis of the enrichment factors in the previous section; yet, the analysis of the principal components indicates that the aluminum and iron concentrations bear the same variation as zinc. This might be explained by the fact that it is difficult to separate soil, crustal earth, and road dust. The samples of road dust taken by MRI in the MAPS project indicates that the zinc concentrations on the road dust samples to be higher than the zinc concentrations in the soil (approximately 63% higher). As a comparison, the zinc concentrations taken at Colstrip[13] were only 11% lower than the soil concentrations by MRI in Billings. It also turns out that the aluminum and iron concentrations in most of the road dust samples were similar to the concentration of these same two elements in the soil of Colstrip samples. The greatest variation was approximately 17%, which occurred between Billings aluminum road dust and Billings soil.

It is concluded that Factor 1 represents the combination of soil, crustal earth materials, road dust, and so forth. This is a reasonable interpretation, since all heavily loaded elements are characteristic of all these sources. Not enough data variation was available to separate these sources further. Other techniques such as chemical mass balance need to be employed.

The second factor is heavily loaded with sulfate, nitrate, lead (both high-volume and membrane). There are two general sources of lead that can be found in Billings: 1) automobiles, and 2) refineries. It would seem that automobile emissions would be a likely candidate for this factor. It is a well established fact that lead is a unique constituent of automobile emissions. Measurements conducted by Little

and Wiffen[14] and others have suggested that the lead emitted from automobile exhaust is generally quite small in nature, usually less than 0.3 microns. The amount of lead emitted from the refineries is unknown and only suspected to be a cause of the lead values by virtue of their production of leaded gasoline. It is anticipated, naturally, that lead contributions will decline as the use of unleaded gasoline becomes more prevalent.

The source of sulfate and nitrate is likely to be from combustion and other high temperature burning sources. One would suspect that the major industries would be likely sources of sulfates by viture of the sulfur dioxide emitted. It is quite possible for sulfur dioxide to undergo several chemical reactions to become an aerosol.[15] The same holds true for the production of nitrates from oxides of nitrogen.[16] Automobiles emit a significant amount of nitrogen oxides[17] making them likely sources of nitrates. High temperature reactions may also aid in the production of nitrates from industrial sources. It is therefore suspected that factor 2 represents a combination of automobile exhaust and major industries.

Factor 3 is heavily loaded with nickel and manganese. The manganese and nickel were measured using the high-volume technique. The results of this factor are quite difficult to interpret. First, the manganese results at least in part are contradictory to the manganese membrane values in factor 1. Sources other than soil for manganese may be from the burning heavy fuel oil. Measurements by Mroz[18] and Cahill[19] tend to confirm the hypothesis. (The measurements were conducted with No. 6 oils, which would be burned only by major industries,

asphalt plants, and the like). The values for manganese, however, are quite low when compared to other elements such as iron, nickel, and zinc.

The loading with nickel is also difficult to explain. Again, the only likely high degree of nickel suspected in Billings air would be the burning of residual fuel oils. The case for nickel, because of its higher concentration, is stronger than manganese. Virtually no nickel can be found in automotive exhaust, soil, or road dust.[20] After careful review of the data avaialble on the composition of various sources of air pollution, no single explanation can account for this factor. The factor, therefore, was not interpreted. The factor was carried throughout the analysis only as a means of explaining some of the variance in the data.

The explanation of the factors are summarized below:

Factor 1: Aluminum, iron, zinc, and manganese (all membrane)
: Soil, road dust, crustal earth, and so forth.

Factor 2: Sulfate, nitrate, lead (all hi-vol), and lead (mem.)
: Automotive exhaust and/or major industry

Factor 3: Nickel and manganese (all hi-vol)
Unknown. Possibly residual fuel oils and/or asphalt plants.

The next step in the analysis was to calculate a value (factor score) for each case for which sufficient data exists. The SPSS computer package was used to generate factor score coefficients, which were then used to calculate factor scores for each factor for each day possible. The value for factor 1, for example, for day # i would be as follows:

factor 1 = (Aluminum)(Aluminum Factor Coefficient) + (Iron)(Iron Factor Coefficient)

+ . . . . + (Manganese)(Manganese Factor Coefficient)

where: aluminum = measured value of aluminum on day i
iron = measured value of iron for day i
.. ..
manganese = measured value for manganese for day i

If there were more than 6 missing values in any one day, the factor score was not calculated. If there were 6 or less, then the average value for each element was used to calculate a factor score, which in turn were coded onto the SPSS package such that further analysis could be conducted.

In addition to the coding of factor scores for the elemental data, it was decided to use the same approach with the meteorological data. A factor analysis identical to the one described was performed with the NWS meteorological data. The variables used were wind speed, precipitation index, visibility, temperature, dew point, stability, number of inches of snow on the ground, and relative humidity. The purpose of the analysis was the same; i.e., to reduce these variables into fewer easily understood variables. The same cut point for eigen values were used. Table 22 describes the final rotated factor loadings for this analysis.

As before, the purpose is to relate these factors to some physical property possibly relating to air pollution. The first factor is highly loaded with temperature, dew point, and negatively loaded with snow on the ground. A review of the correlation matrix (not presented) shows that dew point and temperature are highly correlated with a coefficient of .91. It appears that both dew point and temperature measure the same meteorological phenomena. Since snow on the ground is strongly

Table 21

Factor Analysis Final Rotated Solution
Principal Components
NWS
Factor Loadings (correlations)

	Factor 1	Factor 2	Factor 3
Wind Speed	-.191	-.246	.775
Precipitation Index	.184	.760	.275
Visibility	.432	-.712	.070
Temperature	.923	-.295	-.029
Dew Point	.935	.009	-.098
Stability	-.037	-.300	-.617
Snow on Ground	-.791	.100	.042
Relative Humidity	-.339	.801	-.138

negatively correlated, it would be appropriate to characterize factor 1 as an indicator of the temperature, or perhaps more generally of the seasons.

Factor 2 is highly loaded with precipitation index, relative humidity, and negatively with visibility. This factor is clearly an indicator of moisture.

Factor 3 is loaded with wind speed and negatively loaded against stability. Both of these variable to a large degree explain the amount of mixing or dispersion characteristics within the area. This factor is interpreted to represent the air's general dispersion characteristics. The negative correlation with stability is not surprising since large values for stability (i.e., 5 or 6) indicate a very stable atmosphere characterized generally by very low wind speeds.

As described in the factor analysis of the elemental data, factor scores were calculated and stored on the SPSS system for further analysis.

In order to be able to use the factor data more effectively, a number of statistical tests and comparisons were applied to the factor scores. The first of these comparisons was to calculate correlation information between the meteorological factors and the elemental factors. Table 22 describes the correlations between these two sets of variables.

Table 22

Correlation Coefficients
Element Factors versus Meteorological Factors

	Element Factor 1	Element Factor 2	Element Factor 3
Meteorological Factor 1	.391/ .00	-.266/ .00	.103/ .08
Meteorological Factor 2	-.322/ .00	.076/ .15	-.082/ .13
Meteorological Factor 3	-.086/ .12	-.364/ .00	.017/ .41

xxx/ .yy where: xxx = correlation coefficient
.yy = probability value
if the value is less than .05, then the slope is considered to be statistically different than zero.

Element factor 1 (soils, etc.) exhibits the most significant correlation with season/temperature. Since the value is positive, the warmer weather has the greatest impact on soils and so forth. As was described previously in this paper, that is the same type of relationship one would expect if soils and so forth were a major contributor to the TSP values. The soils factor is also negatively correlated with precipitation data, which is expected. The soils factor, however, does not show any significant relationship with stablity and wind speed. This suggests that the contribution of soil and road dust to the ambient air is not heavily related to the wind speed and atmospheric stability.

This is somewhat disconcerting, since one would expect higher winds to blow dust around and deposit it on the sampler. It appears from the data that the amount of dust resulting from this phenomena is not significant compared to other methods of causing the dust to become airborne, such as man's activities.

Element factor 2 (automobile and industry) shows a significant negative correlation with seasons (although not a strong one). This is easily explained when one considers that meteorological factors 1 and 3 are not unrelated. The most stable conditions occur in the winter and the least stable in the spring and summer. Therefore, the negative correlation may be a reflection of stability. It is assumed that industrial production levels are relatively constant throughout the season, while the automobile traffic undergoes a slight increase in the summer (approximately 11 percent based on 1977 and 1978 data). There seems to be no relationship between this factor and the precipitation factor, which should come as no surprise if one interprets the factor as industry and/or automobile exhaust. Production remains approximately the same regardless of wet weather; Table 15 indicated that no difference between automotive traffic on wet or dry days was evident. On the other hand, one notes a strong negative correlation between this factor and the stability factor, which would indicate that of the meteorological variables measured wind speed and stability have the most effect of particulate emissions from industry and automobiles. Of the three meteorological factors available, the one most likely to have the greatest effect on industry emission would be the factor best describing atmospheric mixing and/or stability. This is indeed the case.

Element factor 3, unknown, does not correlate well with any of the meteorological variables. If one were to assume that burning of residual oils were an explanation for this factor, it would be reasonable to assume that there ought to be a relationship with meteorological factor 3 and possibly 2. It appears, however, that this elemental factor is not explained by any of the meteorological factors with any degree of success.

One further analysis was performed by comparing Sundays with the rest of the days of the week. This comparison was carried out as described previously in this chapter. The results are found in Table 23 below.

Table 23

Sundays vs. Rest of the Week
Element Factors and Meteorological Factors
t-test

		Number	Mean	Standard Deviation	T Value	Sign. Level
Element Factor 1	Sunday	20	-.341	.395	-2.13	.034
	Rest of week	164	.047	.799		
Element Factor 2	Sunday	20	-.395	.527	-2.00	.050
	Rest of Week	164	.019	.904		
Element Factor 3	Sunday	20	-.067	.463	- .47	.64
	Rest of Week	165	.036	.964		
Met. Factor 1	Sunday	108	.037	.959	.09	.93
	Rest of Week	651	.028	.975		
Met. Factor 2	Sunday	108	-.101	.901	-1.27	.21
	Rest of Week	651	.030	1.008		
Met. Factor 3	Sunday	108	.006	.870	.07	.95
	Rest of Week	651	-.001	.918		

A comparison was done with the meteorological factors to assure that no difference existed, meteorologically speaking, between Sundays and the rest of the week. The data in the table above so indicate this fact.

The test indicates that the soil factor displays a statistically different mean on Sunday than the rest of the week. One would assume that there is no reason to expect the soil contribution by itself to be different from Sunday and the rest of the week. One must conclude that the reason for the difference must relate to man's activities. It further follows that man's activities are a major contributor to the soil factor. The test further indicates a difference between the automotive exhaust/industry factor and the days of the week, which may seem somewhat surprising since industry production is relatively constant. It follows that the automobile portion of this factor has a significant influence on the contribution. The final element factor showed no difference between Sundays and the rest of the week. It would appear that those activities that change from days of the week are not likely to be a cause of the third elemental factor.

The same type of analysis was also carried out by performing the wet day/dry day comparisons used previously in this chapter. The same cut-point of 5 (precipitation index) was used to define a wet and a dry day. A t-test was conducted as shown below in Table 24.

Element factor 1 displays a significant difference between the means of wet days as opposed to dry days, which is consistent with the notion that factor 1 represents soil or related materials. There is a definite decrease in the two values, nearly one-half of a standard

Table 24

Wet Day/Dry Day
Element Factors
t-test

		Number	Mean	Standard Deviation	T-Value	Sign. Level
Element Factor 1	Dry Day	119	.167	.846	4.01	.00
	Wet Day	65	-.293	.507		
Element Factor 2	Dry Day	119	.040	.865	1.39	.17
	Wet Day	65	-.148	.900		
Element Factor 3	Dry Day	119	.015	.689	-0.19	.85
	Wet Day	65	.042	1.248		

deviation, between the wet and dry days. Element factor 2 does not yield such a difference. This seems to indicate that precipitation does not affect the sources and concentratins of sulfate, nitrate, and lead. This appears consistent with Table 15, which showed that no difference was found with automobile traffic between a wet and dry day. No difference would be expected for industrial sources except what might occur from chemical or physical scrubbing or removal processes. These data seem to indicate that such processes are not significant. Element factor 3 also showed no significant change from wet and dry days, which is consistent with the other data for element 3 showing no relationship to meteorological or day-of-the-week activities.

The final analysis made with these factor scores is probably the most significant. The data from the factor scores were correlated with the ambient air monitoring data conducted at all of the Billings area monitors. A pairwise correlation was run between each element factor and the air monitoring data. Table 25 is a summary of the results of those correlations.

Table 25

Correlation Coefficients
Element Factors vs. Ambient Air Quality Data

	Element Factor 1	Element Factor 2	Element Factor 3
Central Park			
TSP	.648/ .00	.175/ .01	.184/ .01
Inhalable	.758/ .00	.144/ .08	-.022/ .42
Coarse	.744/ .00	-.021/ .42	-.028/ .39
Fine	.197/ .03	.433/ .00	-.010/ .46
Sulfur Dioxide	-.249/ .00	.778/ .00	-.013/ .44
Nitrogen Dioxide	.249/ .02	.210/ .04	-.116/ .17
City Hall TSP	.462/ .00	.344/ .00	-.033/ .49
KGHL TSP	.470/ .00	.496/ .00	-.049/ .34
Lockwood TSP	.676/ .00	.200/ .10	.003/ .49
Grand Ave. TSP	.405/ .00	.128/ .15	-.030/ .41

	Meteorological Factor 1	Meteorological Factor 2	Met. Factor 3
Central Park			
TSP	.511/ .00	-.467/ .00	-.140/ .00
Inhalable	.404/ .00	-.422/ .00	-.064 .23
Coarse	.449/ .00	-.415/ .00	-.002/ .49
Fine	-.033/ .36	-.108/ .11	-.174/ .02
Sulfur Dioxide	-.400/ .00	-.006/ .45	-.251/ .00
Nitrogen Dioxide	.172/ .00	-.258/ .00	-.304/ .00
City Hall TSP	.374/ .00	-.301/ .00	-.206/ .00
KGHL TSP	.112/ .00	-.275/ .00	-.166/ .01
Lockwood TSP	.263/ .11	-.345/ .00	-.115/ .16
Grand Ave. TSP	.285/ .01	-.279/ .00	-.086/ .19

xxx/.yy where: xxx = correlation coefficient
.yy = probability value that the slope is statistically different from zero. (i.e. that no relation exists)

As was the case in the previous such table, the meteorological values were calculated to test the authenticity of the meteorological factors. The TSP and small particulate data all exhibit a positive correlation with temperature and a negative correlation with precipitation. The analysis of the previous data using the precipitation index and so forth all exhibited this same trend. The sulfur dioxide and fine particulate data exhibited either no trend or a negative one when compared to the seasons. Again this matches previous such analyses. All of the ambient monitoring data exhibited a negative correlation with stability to varying degrees. This would be expected since one normally expects air pollution values to rise generally with worsening atmospheric stability. It would appear the wind direction has the greatest effect, since worsening stability classes correspond to larger values. These larger values should be indicated with a positive correlation coefficient. Since the values are negative, that is, higher air pollution levels corresponds to both lower stability classes and slower wind speeds, one presumes that wind speed is the overriding consideration or that stability classes have no effect.

Analysis of the elemental factors with the ambient air quality data yields some interesting insights. Note that all TSP sites exhibit a strong correlations coefficient with element factor 1. It would appear that all TSP sites are strongly influenced by factor 1 and therefore by soil, road dust, and the like. The same can be said for inhalable and coarse particulate at Central Park. One must be careful not to attach too much significance to the fact that the Central Park TSP, inhalable, and coarse data exhibit better correlations than do the other TSP sites.

Factor 1 was derived from the Central Park elemental analysis, and it would be expected that such relationships would be stronger at the site of measurement than at sites several blocks or miles away. Nevertheless, it appears quite reasonable to suggest that the soil, road dust, crustal earth materials, and so forth, are responsible for a major portion of the TSP, inhalable, and coarse particulate data at all Billings locations. This can be stated since both variables exhibit very similar patterns.

The analysis further shows that fine particulate, nitrogen dioxide, and sulfur dioxide are all significantly correlated to this same factor, but to different degrees and patterns. The fine particulate data seem to be related to factor 1, but to a much lesser degree and strength than the coarse or TSP particulates. The negative correlation with sulfur dioxide indicates that as the contributions from soil and the like increase, sulfur dioxide values decrease, and vice versa. This is logical when one keeps in mind that the maximum values for TSP and the like occur during the warmer months, while just the opposite occurs with sulfur dioxide. Although the relationship is statistically significant it is not of the same strength as the TSP, inhalable, and coarse particulate data. Just the opposite occurs with nitrogen dioxide as sulfur dioxide. The strength of the relationship is the same, but in the same direction as TSP. The increase in ozone during the summer also helps aid in the production of nitrogen dioxide.

It would be safe to conclude that element factor 1 is strongly

correlated with all particulate data, save the fine particulates. This factor explains the variance in the ambient air particulate data better than any other of the factors.

A review of the correlations between factor 2 and the ambient air quality data suggests that the Central Park fine particulate, sulfur dioxide, and KGHL TSP have the strongest ties to this factor. The correlation with sulfur dioxide is of particular importance since it relates itself to sulfate concentrations; this suggests that factor 2 is heavily related to the production of sulfur dioxide and hence to major industrial sources. Since the fine particulate is also related to this factor, a major share of the fine particulate data seen at Central Park is from automobiles and/or industry. All of the monitoring devices, except Central Park coarse, exhibited a positive relationship toward this factor. This indicates that the source of factor 2, that is, industry and automobile exhaust, also has an effect on all of the ambient monitors. Since the relationship is weaker than factor 1, it is assumed that factor 1 plays a more predominant role in the concentrations seen on the monitors as opposed to factor 2. It is of some interest that the KGHL site exhibited an approximately equal correlation with factor 1 and factor 2 (factor 2 was slightly higher), which suggests that both sources with relatively the same strength influence this monitor. This comes as somewhat of a surprise since the monitor is located several miles from the nearest industrial source. It might have been presupposed that factor 1 would have played the most significant role in explaining the variance at this site. Finally, it can be noted that nitrogen dioxide is positively correlated with factor 2. This

seems appropriate since automobiles and industry emit nitrogen oxides. The strength of the relationship is not as strong as one might expect, except that other factors such as sunlight, automotive exhaust, etc. also play an important role in nitrogen dioxide concentrations.

The final elemental factor, factor 3, exhibits a negative and consistently insignificant correlation with all ambient air monitoring, save Central Park TSP. It appears that factor 3 is not related to any of the ambient monitoring concentrations except perhaps TSP at Central Park. The lack of significance indicates either that the data themselves (i.e., factor 3) are randomly distributed, or the source of the data is not affected by the usual meteorology, season or day of the week. These results further serve to make it impossible to determine a physical explanation for this factor.

The data for this section on factor analysis can best be summarized as follows:

1. The arsenic, cadmium, nickel (membrane), and vanadium data did not exhibit a sufficient variance to warrant any valid analyses.

2. The remaining elements can be divided into three separate factors.
   Factor 1 is highly correlated with aluminum, iron, zinc, and manganese (membrane).
   Factor 2 is highly correlated with sulfate, nitrate, and lead (hi-vol and membrane).
   Factor 3 is highly correlated with nickel and manganese (hi-vol).

3. The three factor can be interpreted as follows:
   Factor 1 represents soil, road dust, crustal earth materials, and so forth.
   Factor 2 represent automotive exhaust and major industrial emissions.
   Factor 3 could not be interpreted with any degree of success. The only likely candidates seem to be the burning of residual oil or the production of asphalt and the like.

4. Meteorology can be represented by three factors also.
   Factor 1 is correlated with temperature, dew point, and netagively correlated with snow on the ground. This is interpreted to be related to the season and overall temperature.
   Factor 2 is correlated with precipitation, relative humidity, and negatively with visibility. This factor is interpreted to represent wet or precipitation conditions.
   Factor 3 is correlated with wind speed, and negatively correlated with stability classes. This is interpreted to represent the overall dispersion conditions of the local atmosphere.

5. Correlations between the two sets of factors yields:
   a. Positive correlations between element factor 1 and meteorological factor 1.
   b. Negative correlations between element factor 1 and meteorological factor 2, element factor 2 and meteorological factor 1, and element factor 2 and meteorological factor 3.

   These correlations indicate that (1) soils data increase as temperature increases, (2) soils data decrease as precipitation increases, (3) automobile/industry data decrease as temperature increases, and (4) automobile/industry data decreases as stability worsens or wind speed increases.

6. The soils data and the automobile/industry data exhibit a different set of means between Sunday and the rest of the week.

7. Only the soils data exhibits a different mean between wet and dry days.

8. The correlation between the elemental factors and the ambient data yields (1) factor 1 (soils) explains the most variance in the data for all particulate sites except Central Park fine, (2) sulfur dioxide and fine particulate are closely associated with factor 2, (3) the fine and coarse data are both associated with different factors, and (4) no relationship can be established for factor 3.

Footnotes

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Footnotes - Continued

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[10]B. H. O'Connor et al., "Use of Bromine Levels in Airborne Particulate Samples to Infer Vehicular Lead Concentrations in the Atmosphere," Atmospheric Environment 11, (June, 1977), pp. 635-638.

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[12]Philip Hopke, et al., "The Use of Multivariate Analysis to Identify Sources of Selected Elements in the Boston Urban Aerosol," Atmospheric Environment 10, (July, 1976), pp. 1015-1025.

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[14]P. Little, and R. D. Wiffen, "Emission and Deposition of Lead from Exhausts - II. Airborne Concentration, Particle Size and Deposition of Lead Near Roadways," pp. 1331-1341.

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Summary and Conclusions

The purpose of this paper was to present the results of an analysis of total and inhalable particulate air pollution in Billings, Montana. The analysis has taken the form of observing any relationships between the air monitoring data and meteorological or emission-related data. The analysis has taken many statistical forms from simple comparisons of the means to factor analysis.

The study analyzed ambient air quality data gathered in Billings under the Montana Air Pollution Study (MAPS) for the period 1978 through May 1980. Some air pollution monitoring systems existed prior to the MAPS project, with 1977 used as the starting year for these monitors. The ambient data consisted of total suspended particulate, inhalable particulate (particles less than 15 microns in size), coarse particulate (particles between 2.5 and 15 microns), fine particulate (particles less than 2.5 microns), sulfur dioxide, nitrogen dioxide, and 12 elements or compounds found on both the high-volume and membrane air samplers. The Central Park site, located in a residential portion of Billings, was the major site of analysis, since this site had most of the relevant instrumentation. High-volume sites located in the surrounding area also were used.

The majority of meteorological data used in the analysis was taken from the National Weather Service (NWS) located at Logan International Airport. It was decided to use these data, since NWS had the most complete meteorological record. A comparison was made between data collected at Central Park and the NWS data, located in Appendix A.

Since direct emission measurements were not taken during the MAPS project, other variables were chosen to represent emissions-related data. These data included vehicular traffic counts, day of the week, weekday/weekend, season, precipitation index, and elemental analysis of the filters. The variance observed among these variables provided clues as to the identity of the source of particulates.

The data were analyzed using various statistical techniques. The frequency distribution and monthly and seasonal variations were used to assist in the identification of a number of sources. The comparison of mean particulate values between days of the week and wet and dry days also yields important information relative to source contributions. These two methods can be used to determine the relative importance of man's activities on particulate counts from such things as automotive traffic, soil and road dust, and so forth. Enrichment factors were also used to determine which metals were likley to be enriched by some source other than the earth's crust or soil. Factor analysis, using principal components, also was a powerful tool used to identify sources of particulate. In this case, the elemental data gathered on the high-volume and membrane samplers were ordered to determine which elements were related to each other and which elements were independent of each other. It was assumed that unrelated elements are from independent sources.

The results of the frequency distribution indicated that most sites were probably being influenced by general or area sources. Only two sites failed the chi-square test for log-normality, indicating the

theory of general causes. The failure or success of passing the log-normality test is not in and of itself a clear indication of source identity, since several authors have suggested that the log-normal distribution is not the only distribution for stations influenced by many sources.

An observation of the data's monthly and seasonal variation indicates that the highest values for all sites occur in the summer, while the lowest values tend to occur in the winter. This observation is quite the opposite of typical air monitoring data, since the winter and fall offer periods of poorest dispersion characteristics. The coarse particulate had the same pattern, while the fine particulate showed no statistical difference between each measured month (ANOVA test). Since this distribution does not match the distribution for sulfur dioxide, a unique tracer for industrial sources, it is assumed that major industrial sources do not contribute significantly to the total or coarse particulate levels. This conclusion suggests only that the main "stack" emissions are not significant contributors and does not say anything about emissions that may vary from ancillary activities, such as shipping and receiving, office work, yard workers, and the like. The readings observed appear to be related to man's activities and associated with automotive traffic.

Proceeding one step further through comparison of mean values during Sundays and holidays with the mean values for the rest of the week, it was found that all sites in the area, save one, had particulate values lower on Sundays and holidays than the rest of the week. Only two TSP sites showed a statistical difference between the two (t-test); Central

Park and City Hall had the highest degree of variation, while Lockwood School and KGHL had the lowest variation. It was therefore assumed that outdoor recreational activities do not contribute much to particulate values, since days with their highest activities (Saturday and Sunday) are the days with the lowest particulate levels.

The same type of comparison was made between wet and dry days. A precipitation index was used to differentiate between a wet and a dry day. The ratio between the wet day and the dry day mean was between .41 and .72 for all particulates, except Central Park fines. It was concluded that this significant reduction in readings was responsible for a major portion of the total particulate levels, between 29% and 59%. At the same time the sulfur dioxide data (a tracer for industrial stack emissions) displayed no statistical difference between wet and dry days for all seasons combined. There was also no difference between traffic patterns from wet and dry days as measured in Great Falls and Missoula. It was therefore assumed that the same pattern holds true in Billings.

Enrichment factors were calculated for a number of the elemental data from the high-volume and membrane filters. Lead and cadmium displayed the greatest degree of enrichment, from sources other than the crustal earth or soil, arsenic, nickel, and zinc the next most enriched elements, with aluminum, iron, and manganese were the least enriched. The high degree of enrichment for lead and cadmium indicates that the source of these elements is not the solid or crustal earth. The arsenic, nickel, and zinc were enriched above normal levels, but they could have several sources of contribution, including the soil. The aluminum, iron, and manganese can be explained by contributions from the soil or a similar source.

The results of the factor analysis using the principal component method provided extremely interesting results. Three factors were extracted; two were identified. The first factor represented soil, road dust, and crustal earth material (by virtue of aluminum, iron, zinc, and manganese), while the second factor was interpreted to represent industrial emissions and automotive exhaust. The first factor displayed a positive correlation with temperature, while the second factor had a negative correlation. A comparison between Sundays and the rest of the week indicated that the first factor was closely associated with the observed TSP variations. The wet day/dry day comparisons also had the same distribution as the TSP data. A correlation between the factors and the ambient data revealed that the first factor was generally well correlated with the TSP and coarse particulate data. The second factor was associated with the fine particulate data and the sulfur dioxide values.

Based upon the information presented, it is concluded that the TSP values observed in the city of Billings are most closely associated with road dust, soil, and crustal earth materials. The relationship is borne out of the comparisons between wet and dry days, days of the week, enrichment factors, and principal component analyses. It is also concluded that the fine particulate data probably have major industrial and/or automotive exhaust as a major source.

Therefore, the control of TSP would best be accomplished through a program designed to limit dust and crustal earth-related sources. Since the rural site (KGHL) did not exhibit a strong dependence upon the soil-related factors (principal component 1), it can be concluded that the control of soil dust will not serve to improve air quality significantly. The control of road dust, however, would seem to make a concrete reduction in TSP levels observed in Billings.

The control of fine particulate, on the other hand, would not be as effectively controlled by the use of road dust suppression. It appears that the automotive/industrial component is most predominant in explaining the data variance. Further study, such as chemical mass balance, is necessary to make recommendations on effective control strategies.

Appendix A

Comparison between National Weather Service Meteorological Data and Central Park Meteorological Data

This appendix describes the comparison between the data gathered at the National Weather Service at the Logan International Airport and the data gathered at Central Park. The data is compared over the same paired time frames and in the same measuring units. The purpose of the comparisons was to see if it was valid to use the two data sets interchangeably. It was more desirable to use the Central Park data, except that this data was not as complete as the National Weather Service data. In addition, the National Weather Service (NWS) data offered more variables than the Central Park site such as visibility and station pressure.

There were only four variables measured at both NWS and Central park which could be compared. These variables are wind speed, wind direction, temperature, and dew point. A comparison of each variable follows.

Wind Speed

Wind speed was measured in meters per second at both sites. The Central Park data spanned from approximately August 1978 through April 1980 while the NWS data spanned April 1978 through April 1980. The data were compared only for equivalent pairs, that is data for which valid data were recorded for the same day. Table A-1 below is a tabulation of the data for each category of wind speed. The wind speed is rounded to the nearest whole meter per second. As the table clearly indicated, the wind speed at the Airport nearly always has more occurrances in higher

Table A-1

Central Park vs. NWS Wind Speed

Cross Tabulation

		National Weather Service												
		0	1	2	3	4	5	6	7	8	9	10	11	Row Total
Central Park	0	0	0	9	10	6	3	0	0	0	0	0	0	28
	1	0	0	6	34	42	29	7	4	1	1	1	1	125
	2	0	0	2	9	33	31	25	9	1	0	0	0	110
	3	0	0	0	1	2	10	15	7	13	5	1	0	54
	4	0	0	0	0	0	2	1	0	6	8	3	0	20
	5	0	0	0	0	0	0	1	0	1	2	2	1	7
	6	0	0	0	0	0	0	0	0	0	0	1	2	3
	Column Total	0	0	17	54	83	75	49	22	22	16	8	3	

Total = 347

Values = # of days matched
Units = meters/second

wind categories than the Central Park site. It would appear from the table, however, that there appears to be a relationship between the two parameters. The data was further reduced to obtain the following statistics.

Table A-2
Central Park vs. NWS Wind Speed
Summary Statistics

Number of Pairs of data = 347

Mean NWS Wind Speed = 5.10 meters/sec

Mean Central Park Speed = 1.84 meters/sec

Correlation Coefficient = .7329

Significance = .0000

Equation of Least Squares: Central park = (NWS)(-.441) - .406

The summary statistics indicate a true relationship between each other by virture of the significance level and the correlation coefficient. In addition the slope tend to indicate that the relationship is about 4.4 to 10. It appears, therefore, that the two parameters are related to each other and that the Billings Airport data generally reads slightly more than twice the values at Central Park. As long as only the variance in the data is being considered throughout the analysis, the use of either value should yield approximately the same results.

Wind Direction

Wind direction was measured as the predominant direction for the day using both the NWS and the Central Park data. The same 8 categories previously described was used in determining the predominant wind direction:

1 = north 2 = northeast 3 = east 4 = southeast

5 = south 6 = southwest 7 = west 8 = northwest

Since this data does not have the same ordering values as other variables, correlation analysis was not used. For example, a wind direction value of 8 does not mean that the direction has twice the weight as a direction of 4. The comparisons were limited to only analyzing the cross tabulations of the wind direction. The cross tabulations are listed in Table A-3.

It can be noted from the table that there seems to be a relationship between each of the general categories. That is to say that majority of the matches tend to line up along the diaganol from the top left through the bottom right. The relationship, however, does not seem to match itself correctly within each category. For example, the Central Park site recorded the majority of the wind directions (59%) from the west, while the Airport data suggested that the majority of the wind direction was from the southwest (53%). The same pattern is generally observed for the north through east directions. When the Airport reports wind directions from the north or northeast, the Central Park sites tend to see the same directions as a northeast and east respectively. The data for the southeast, south, and northwest directions was insufficient to draw any conclusions.

In summary the wind direction measured at Central Park was generally rotated about 45° clockwise when compared to the Airport. This cannot be stated as an absolute, but appears to be the trend when compared against the available data. Reported directions from the southeast, south, and northwest were inconclusive.

Table A-3

Central Park vs. NWS Wind Direction
Cross Tabulations

NWS - Airport

Central Park	North	Northeast	East	Southeast	South	Southwest	West	Northwest	Row Total
North	2	1	0	0	0	1	1	2	7
Northeast	11	18	1	0	0	9	2	1	42
East	5	18	4	0	4	5	0	1	37
Southeast	0	0	7	3	1	3	0	0	14
South	0	0	0	0	0	0	0	0	0
Southwest	2	1	0	0	02	18	2	2	27
West	7	4	1	0	2	146	26	17	203
Northwest	1	0	0	0	0	2	6	8	17
Column Total	28	42	13	3	9	184	37	31	

Total = 347

Values = number of days matched

Temperature

The available temperature data from Central Park was quite limited. The coded data only spanned from October 1979 through April 1980. All comparisons, therefore, were made without the benefit of a summer season. The data was coded in degrees centigrade and reported to the nearest tenth of a degree. Table A-4 below lists the summary statistics for the comparison. The summary statistics are done in a pair-wise fashion as described in the wind speed comparisons.

Table A-4
Central Park vs. NWS Temperature
Degrees Centigrade
Summary Statistics

Number of Pairs of Data = 100

Mean Central Park Temperature = 0.66°C

Mean NWS Temperature = 2.68°C

Std. Dev. Central Park = 9.92

Std. Dev. NWS = 10.54

Mean Difference = -2.02

Correlation Coefficient = .936

Equation of Least Squares: Central park = (NWS)(.881) - 1.70

The summary statistics indicate a good relationship between the temperature measured at Central Park and the temperature measured at the Airport. It appears that the Airport consistently measures temperatures warmer than the valley floor. The correlation coefficient is a good indicator of the consistency of the relationship between the two values. It appears that the use of either variable in subsequent analysis would

have little impact upon the outcome as long as the variance of the values is being considered.

Dew Point

The same problem with limited data addressed above applies to the dew point comparison. Only 78 days of data were compared ranging from October 1979 to April 1980. The data were coded in degrees centigrade and reported to the nearest tenth of a degree. Table A-5 below lists the summary statistics for the comparison. The summary statistics are done in a pair wise fashion as described in the wind speed comparisons.

Table A-5
Central Park vs. NWS Dew Point
Degrees Centigrade
Summary Statistics

Number of pairs of data = 78

Mean Central Park Dew Point = -15.3

Mean NWS Dew Point = -3.2

Std. Dev. Central Park = 4.44

Std. Dev. NWS Dew Point = 4.25

Mean Difference = -12.1

Correlation Coefficient = .816

Equation of Least Squares: Central Park = (NWS)(.851) - 12.6

The data for dew point is somewhat surprising when compared to the temperature and wind speed data. There appears to be a good relationship between the two variables by virtue of the nearly identical standard deviations, correlation coefficient, and slope. What is disturbing is the degree of difference between the two values. Since

the Central Park site was located in a residential area on the valley floor, it would be reasonable to expect a warmer dew point, indicated more moist conditions, than the Airport which is located on an open plain above the valley. The data indicated quite the opposite. A review of the records indicates that only electronic checks were applied to the dew point indicated at Central Park. No dynamic calibrations were performed. This may indicate that although the dew point indicated at Central Park was operating correctly, perhaps the absolute value is incorrect. This could account for the difference. No other explanation seems reasonable.

In any event, there seems to be a good relationship between the two variables indicating that comparisons done with either variable would likely yield the same results as long as absolute values were not critical in the analysis.

Summary

This appendix has described some comparisons between meteorological data collected at Central Park and the National Weather Service (NWS) at Logan International Airport in Billings. The comparison was conducted with four variables, wind speed, wind direction, temperature, and dew point. The wind speed and direction data spanned approximately 18 months while the dew point and temperature data covered a period of 7 months.

The wind speed data indicated a good correlation between the two values. The wind speed data, however, was consistently faster at the Airport than on the valley floor. That is not a surprising conclusion,

since the Airport is located in a well ventilated area several hundred feet above the valley. The wind direction data also tended to exhibit a good relationship between the two sites. The data seems to indicate that the Central Park site measures wind approximately 45° rotated clockwise as opposed to the Airport. The dew point and temperature data exhibited a good correlaton between each site, but with different means. The mean difference was 12.1°C. The temperature difference is not unreasonable, but the difference in dew point is more than one would expect. The greater difference in dew point cannot be explained except by a possible calibration error.

In all cases, the relationship between the two appropriate variables and locations was good. Analysis performed with either variable would in all likelihood yield the same results as long as absolute values were not critical. The wind direction, on the other hand, tended to measure approximately 45° from each other.

Appendix B

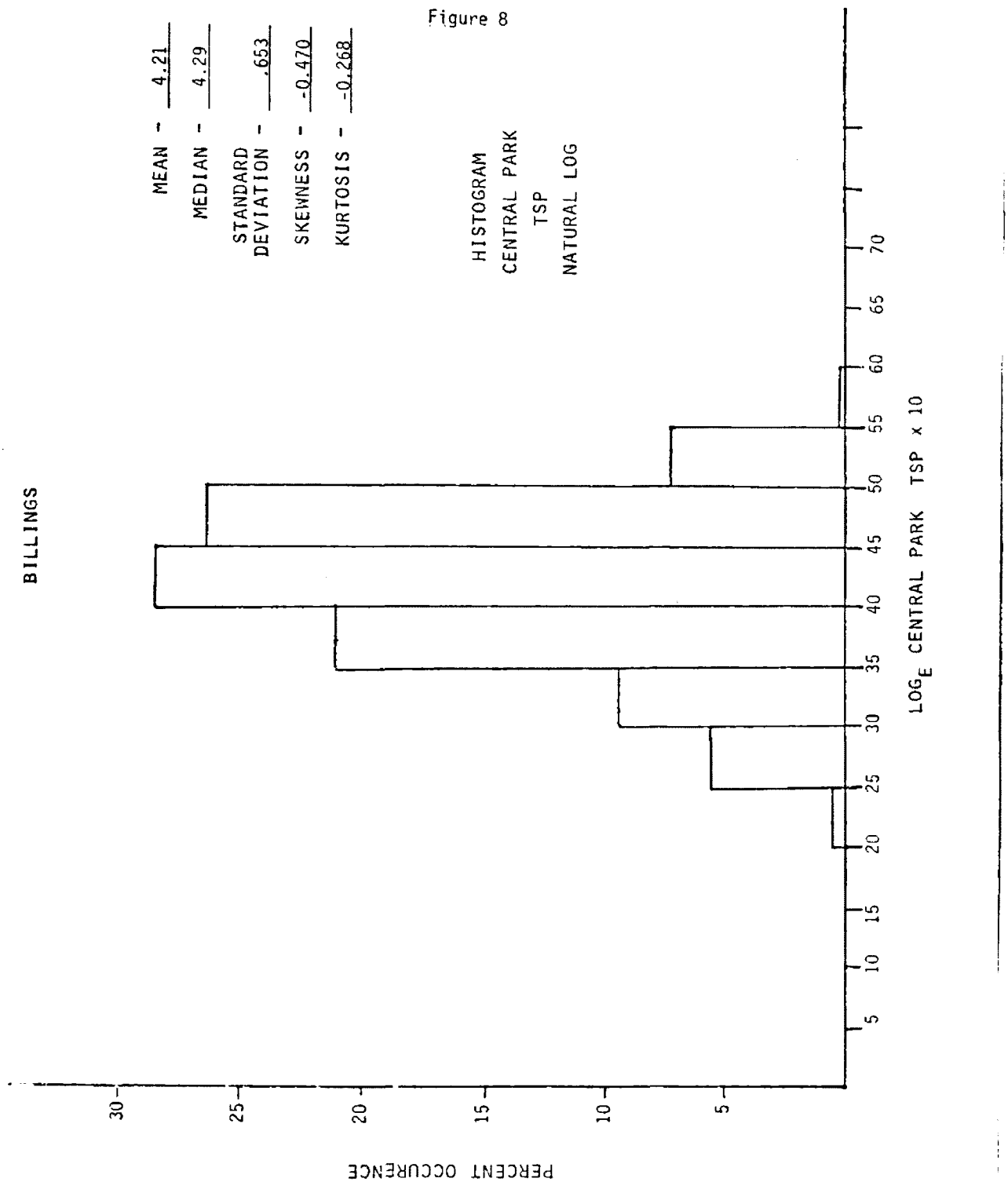
Particulate Distribution

This appendix is a compilation of the frequency distribution of the particulate data collected in Billings during the MAPS project. The following graphs include the frequency distribution for Central Park TSP, Central Park inhalable, Central Park coarse, Central Park fine, City Hall TSP, Grand Avenue School TSP, and Lockwood School TSP.

The distributions represent, to some degree, the log-normal distributions described in the results chapter of this paper. The values along the y-axis (ordinate) represent the frequency of occurrence in percent. The values along the x-axis (abscissa) are the particulate values expressed in a natural logarithm (base e). The values of the logarithm are multiplied by 10 to make the graph easier to read. As an example, the Central TSP graph shows that the TSP values whose natural logarithm lie between 4.0 and 4.5 occurs approximately 28 percent of the time.

The following graphs also display the mean, median, standard deviation, skewness, and kurtosis, all expressed in natural logarithm terms.

Figure 8



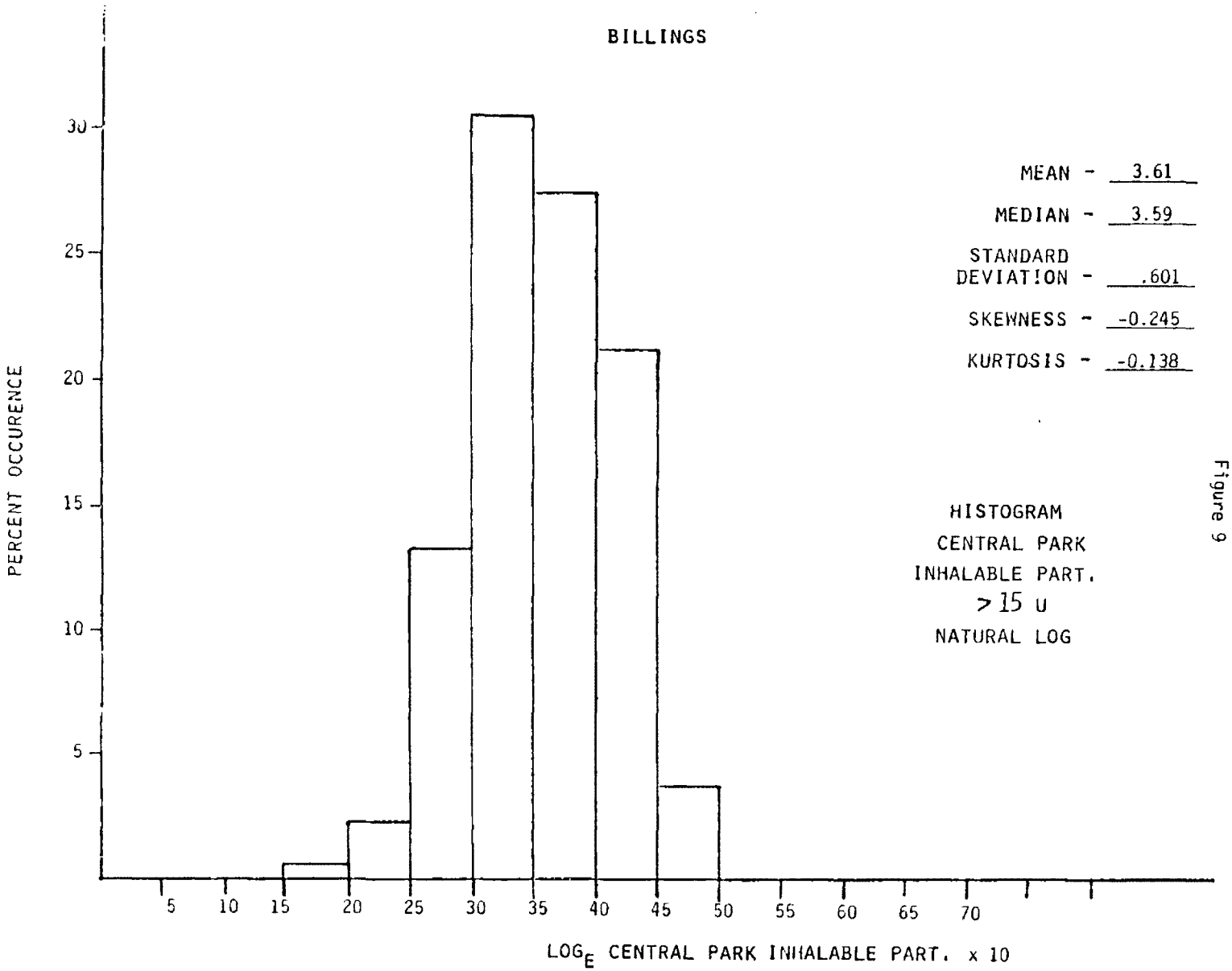
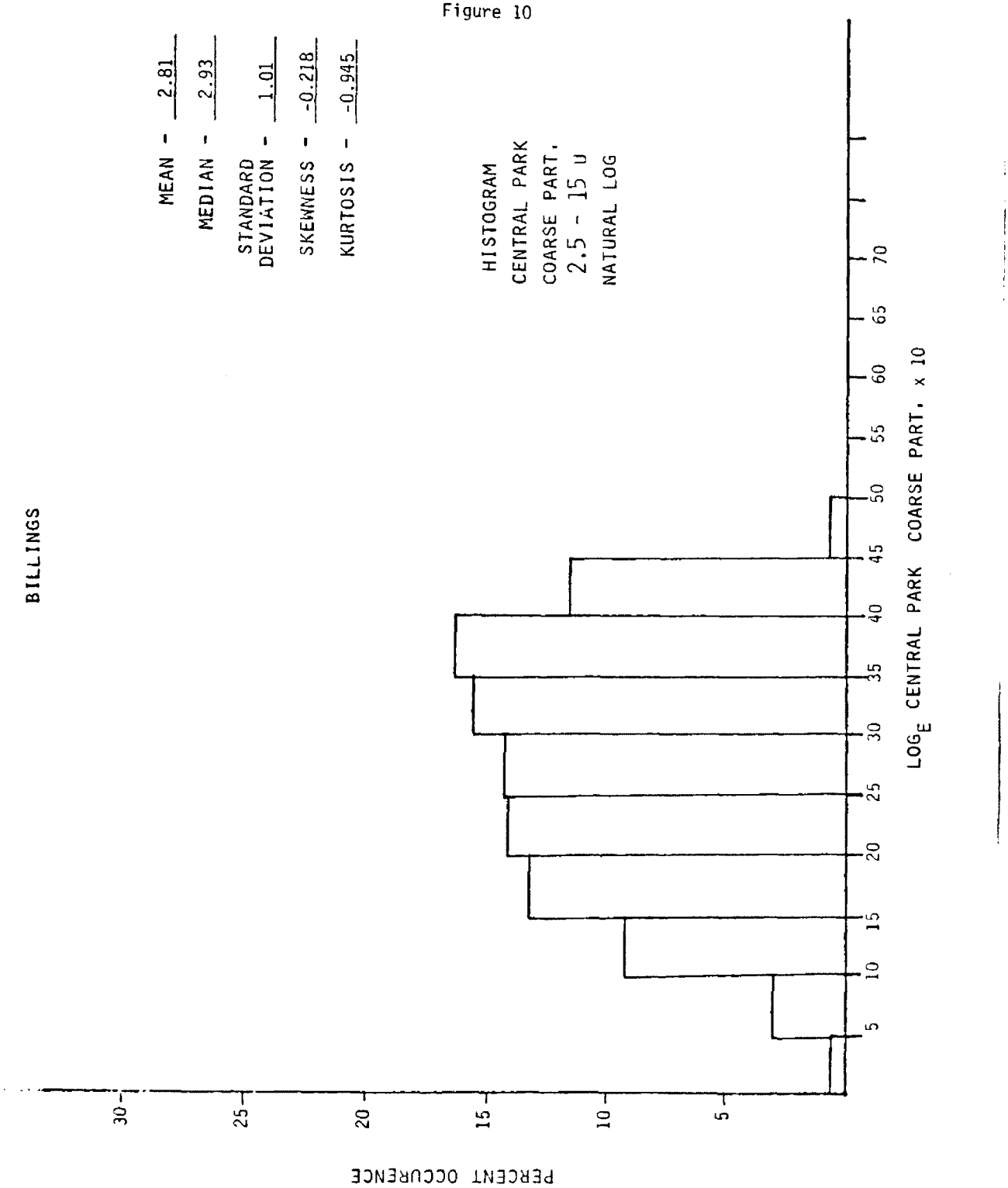


Figure 9

Figure 10



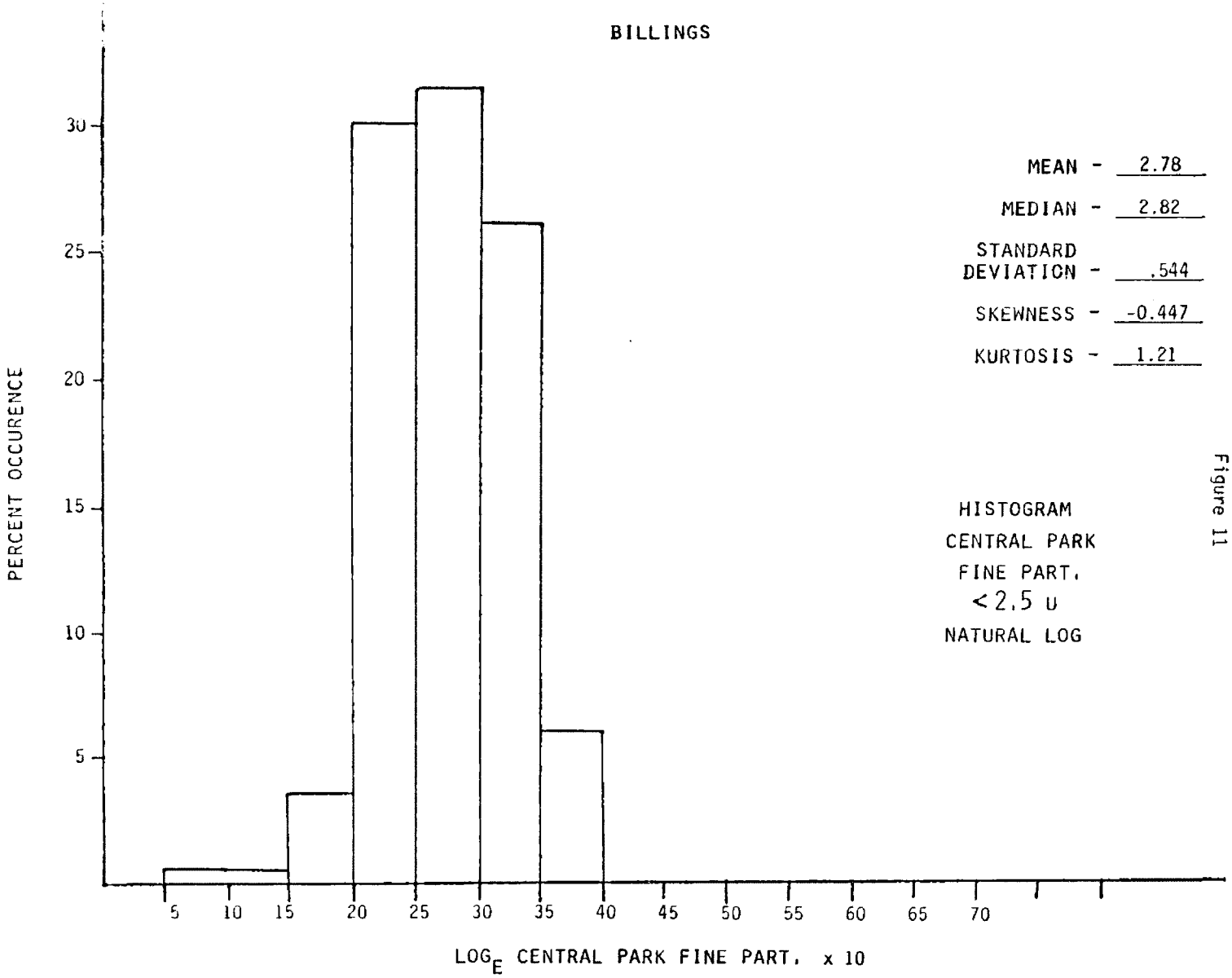


Figure 11

Figure 12

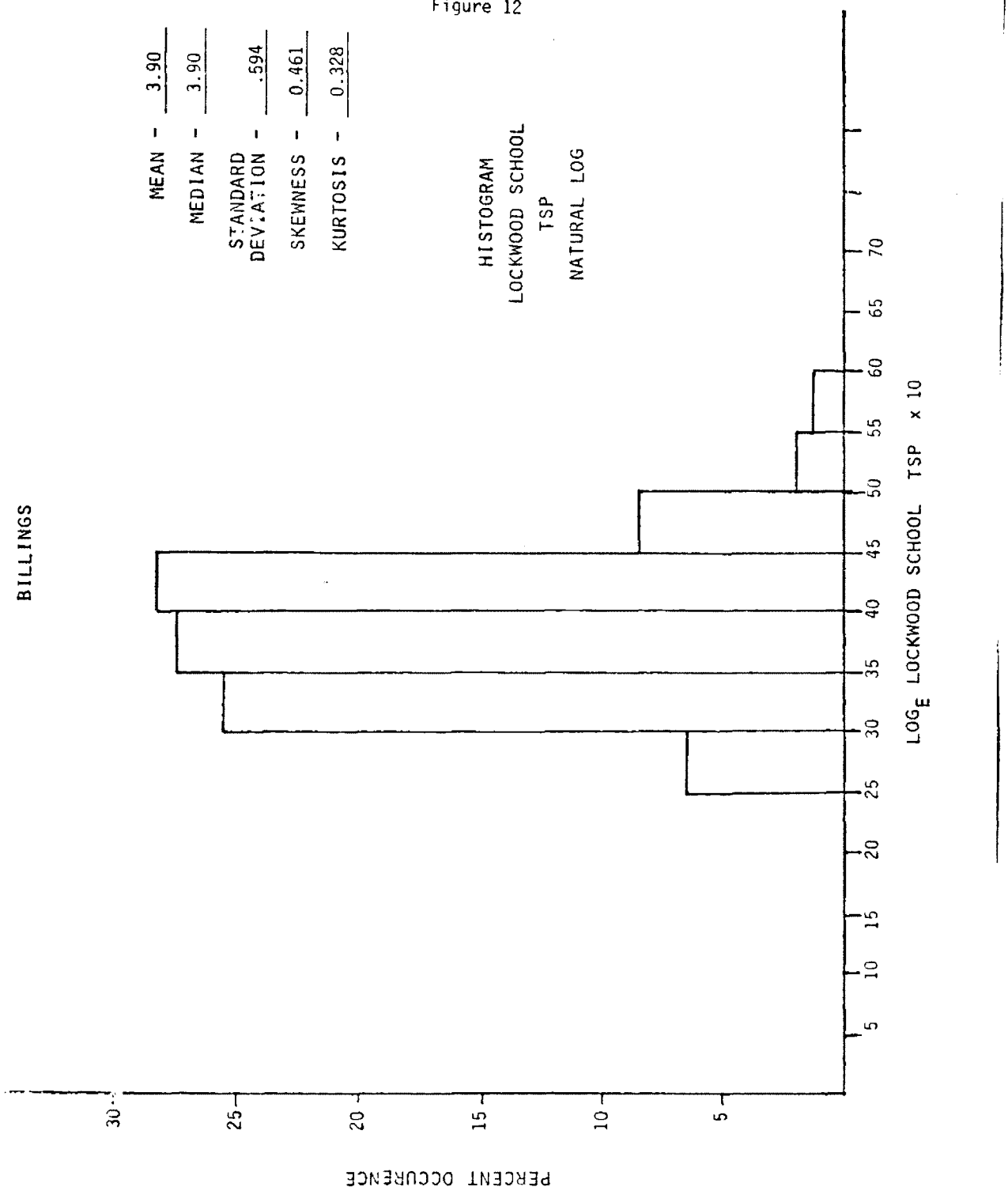


Figure 13

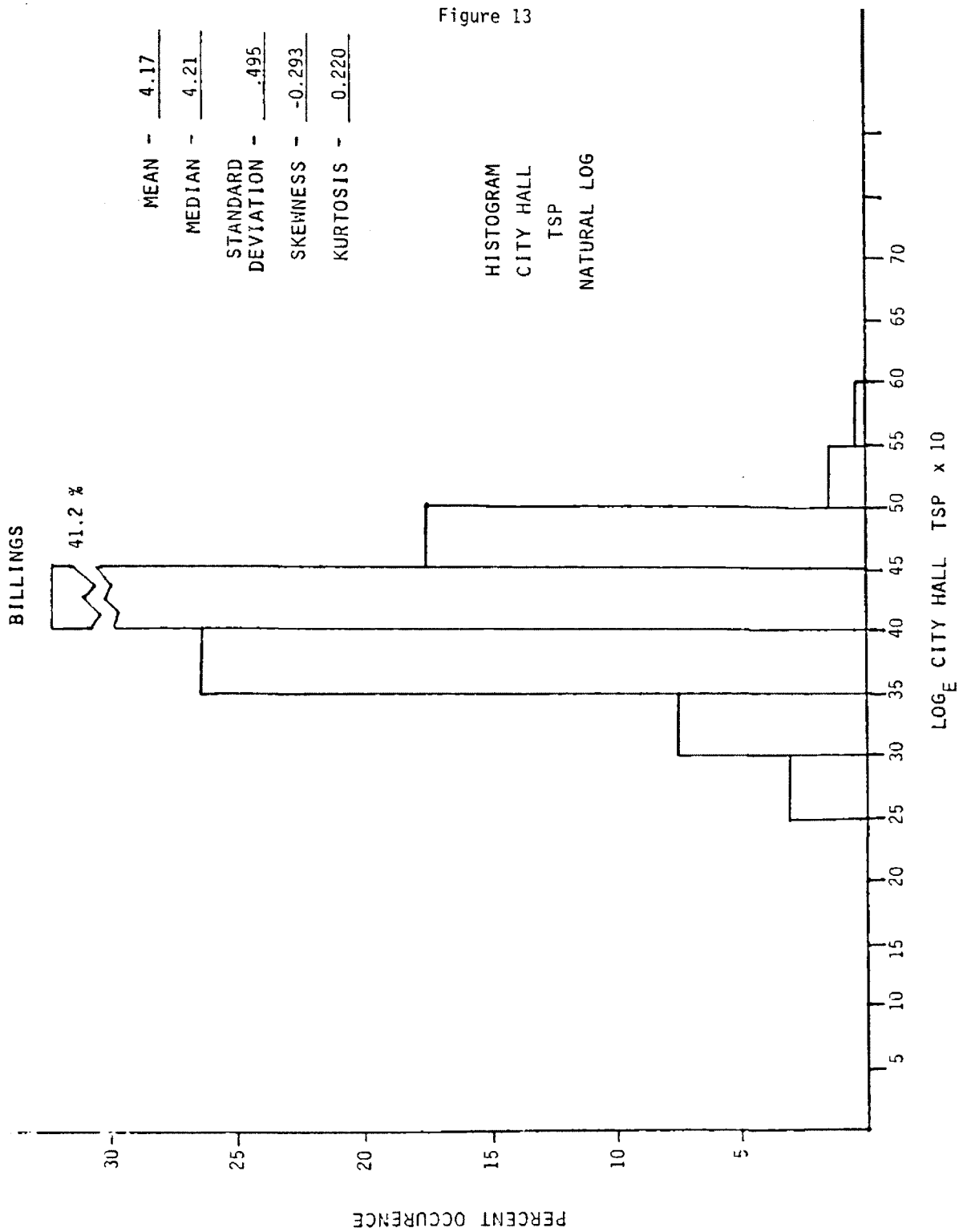
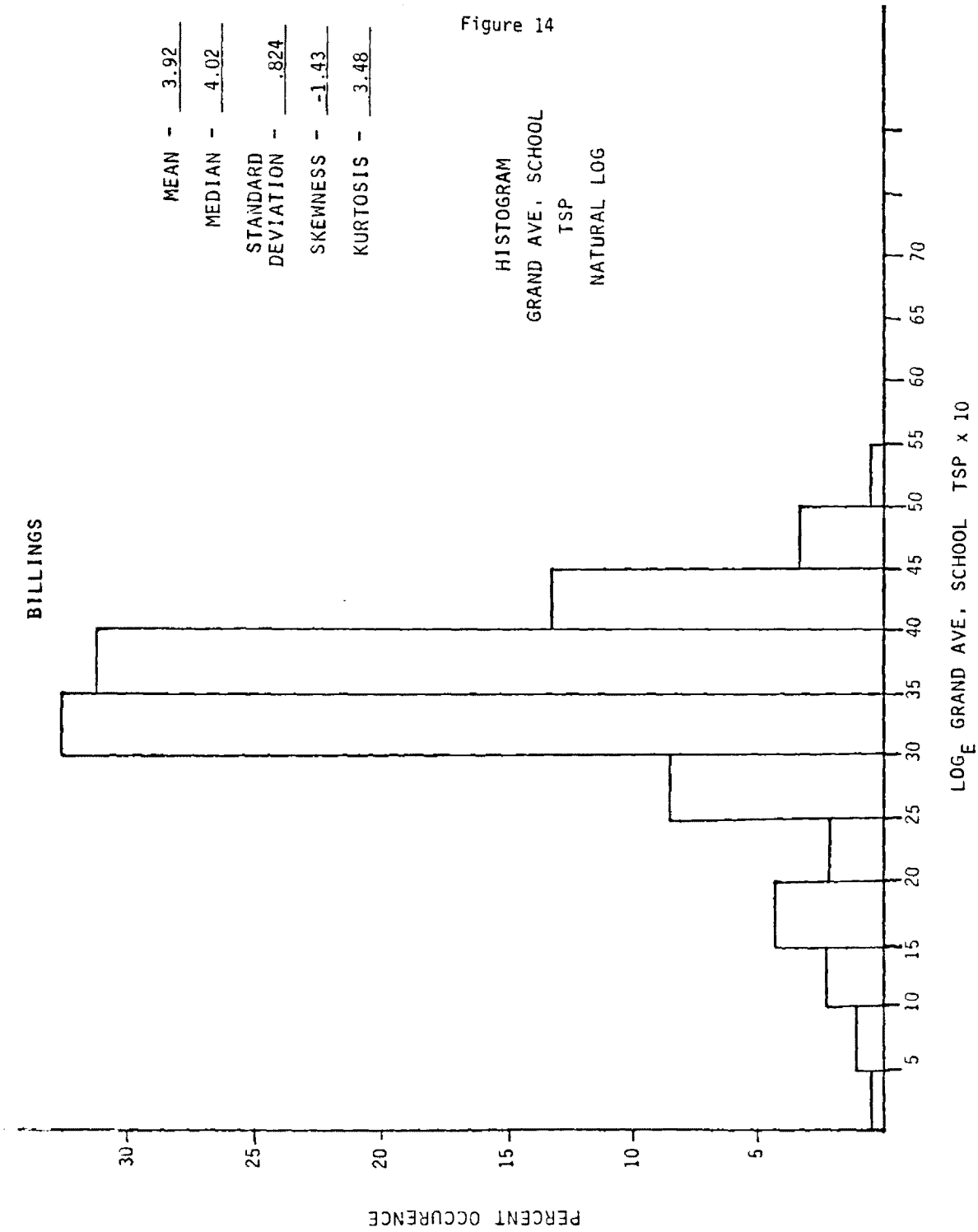


Figure 14



Appendix C
Chi-Square Test for Normality

The particulate data was tested to determine if the data maintained a log-normal frequency distribution. Graphs were drawn and displayed in Appendix B to assist in a visual interpretation of the distribution. To add some quantitative validity to any conclusions, it was decided to apply a statistical test to the data to determine if the data exhibited a log-normal distribution. That is to say that a statistical test was used to determine if the natural logarithm of the particulate data exhibited a normal distribution.

The appropriateness of the log-normal distribution was justified by the chi-square test for normality. The particulate data was normalized into a z-score form (z-score = (data value - mean)/standard deviation) and then categorized. The number of values occurring in each category was counted and compared against an expected value. The following categories were used:

Category #	Values
1	Lowest through -2.0
2	-2. through -1.5
3	-1.5 through -1.0
4	-1.0 through -0.5
5	-0.5 through 0.0
6	0.0 through 0.5
7	0.5 through 1.0
8	1.0 through 1.5
9	1.5 through 2.0
10	2.0 through highest value

These values were chosen because by normalizing the data to a z-score statistic, the value of 1 represents an approximate standard

deviation of one. In this way, the number of values for each category could be computed based on an ideal distribution of a mean zero and a standard deviation of one. Standard Z-tables were used to determine the expected values along with the number in the sample.

The chi-squared statistic is calculated using the following formula:

$$X^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

If the data perfectly matches a normal log-normal distribution then the chi-squared statistic would equal zero. If the distribution is not perfectly normal, then some other value would be expected. Using a probability value of 1%, the critical value of the chi-squared statistic is 21.7. Any chi-square statistic which exceeds 19.0 is assumed to have failed the test. If the distribution data were in fact a normal distribution, then there would only be about one chance in one hundred that the distribution would have been rejected as not being a log-normal distribution.

The following describes the results of the chi-square test:

	Central Park TSP		Central Park Inhalable	
Category	Actual Occurrences	Expected Occurrences	Actual Occurrences	Expected Occurrences
1	14	10.9	4	2.9
2	27	21.0	5	5.6
3	39	43.9	9	11.7
4	59	71.6	21	19.0
5	81	91.5	25	24.3
6	89	91.5	18	24.3
7	89	71.6	22	19.0
8	59	43.9	16	11.7
9	20	21.0	6	5.6
10	1	10.9	1	2.9
	Chi-squared = 25.1		Chi squared = 6.30	

Central Park
Coarse

Category	Actual Occurrences	Expected Occurrences
1	3	2.9
2	8	5.7
3	16	11.9
4	18	19.8
5	16	24.7
6	22	24.7
7	21	19.8
8	22	11.9
9	3	5.7
10	0	2.9

Chi-squared = 18.7

Central Park
Fine

Actual Occurrences	Expected Occurrences
3	2.9
2	5.7
14	11.9
25	19.8
16	24.7
27	24.7
24	19.8
10	11.9
5	5.7
3	2.9

Chi-squared = 9.3

City Hall
TSP

Category	Actual Occurrences	Expected Occurrences
1	10	4.3
2	8	8.4
3	9	17.5
4	25	28.5
5	37	36.4
6	40	36.4
7	34	28.5
8	18	17.5
9	7	8.4
10	2	4.3

Chi-squared = 15.0

Grand Avenue School
TSP

Actual Occurrences	Expected Occurrences
12	4.2
3	8.1
5	16.8
14	27.4
47	35.0
51	35.0
31	27.4
17	16.8
2	8.1
1	4.2

Chi-squared = 51.5

Lockwood School
TSP

Category	Actual Occurrences	Expected Occurrences
1	0	3.5
2	8	6.7
3	18	14.0
4	25	22.8
5	25	29.1
6	35	29.1
7	18	22.8
8	14	14.0
9	4	6.7
10	5	3.5

Chi-squared = 12.1

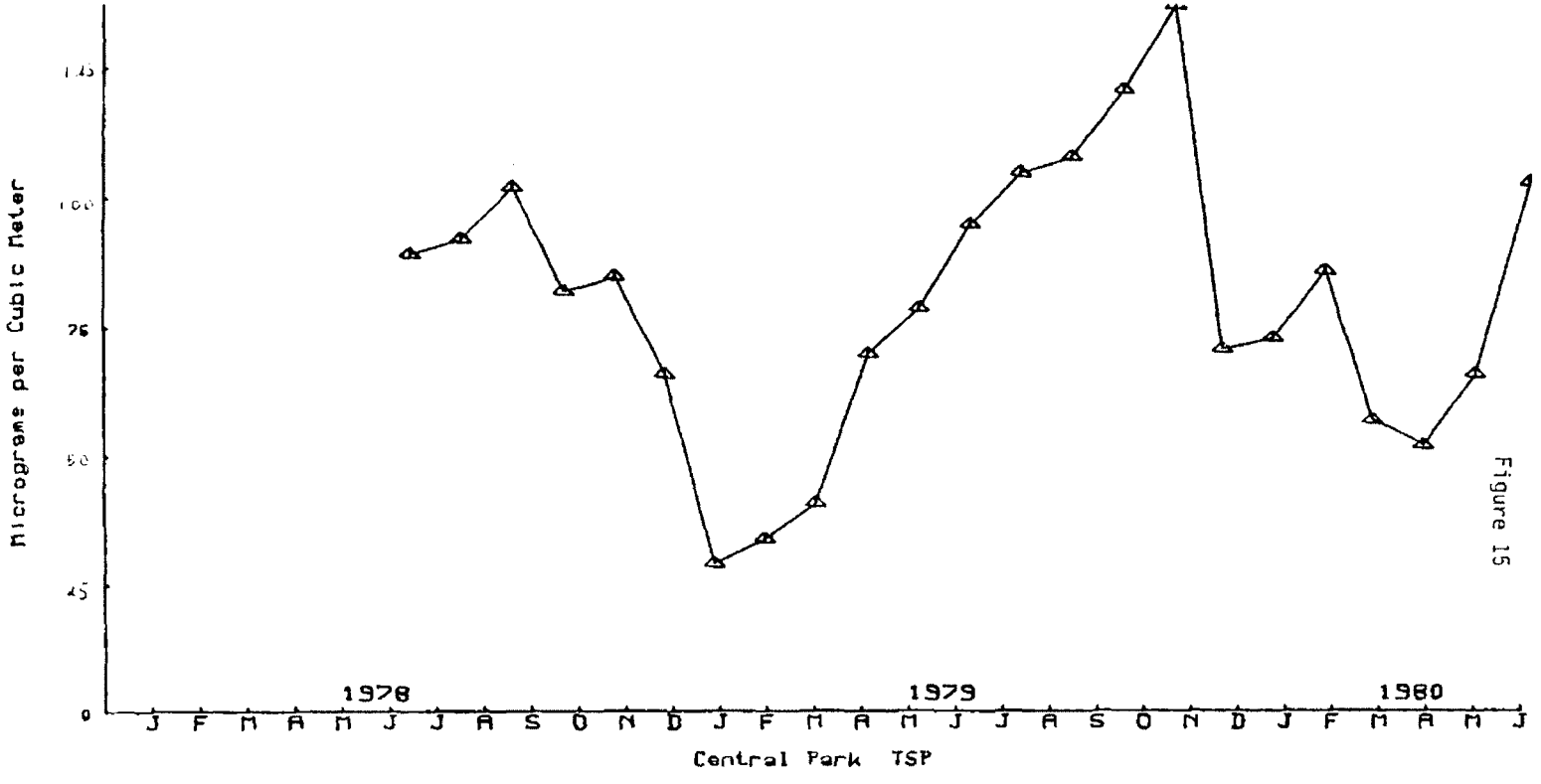
The chi-square results can be summarized in the following table:

Site	Chi-squared statistic	Critical value	Log-Normal?
Central Park TSP	25.1	21.7	No
Central Park Inhalable	6.3	21.7	Yes
Central Park Coarse	18.7	21.7	Yes
Central Park Fine	9.3	21.7	Yes
City Hall TSP	15.0	21.7	Yes
Grand Avenue School	51.5	21.7	No
Lockwood School	12.1	21.7	Yes

Only the Central Park TSP and the Grand Avenue sites failed the log-normal test using the chi-squared statistic. The interpretation of these tests is addressed in the results section of this paper.

Appendix D

Monthly Mean Versus Air Concentration



Monthly Mean vs Total Suspended Particulate
Micrograms per Cubic Meter
Central Park
January 1978 - June 1980

BILLINGS SOURCE APPORTIONMENT STUDY

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Figure 15

Figure 16

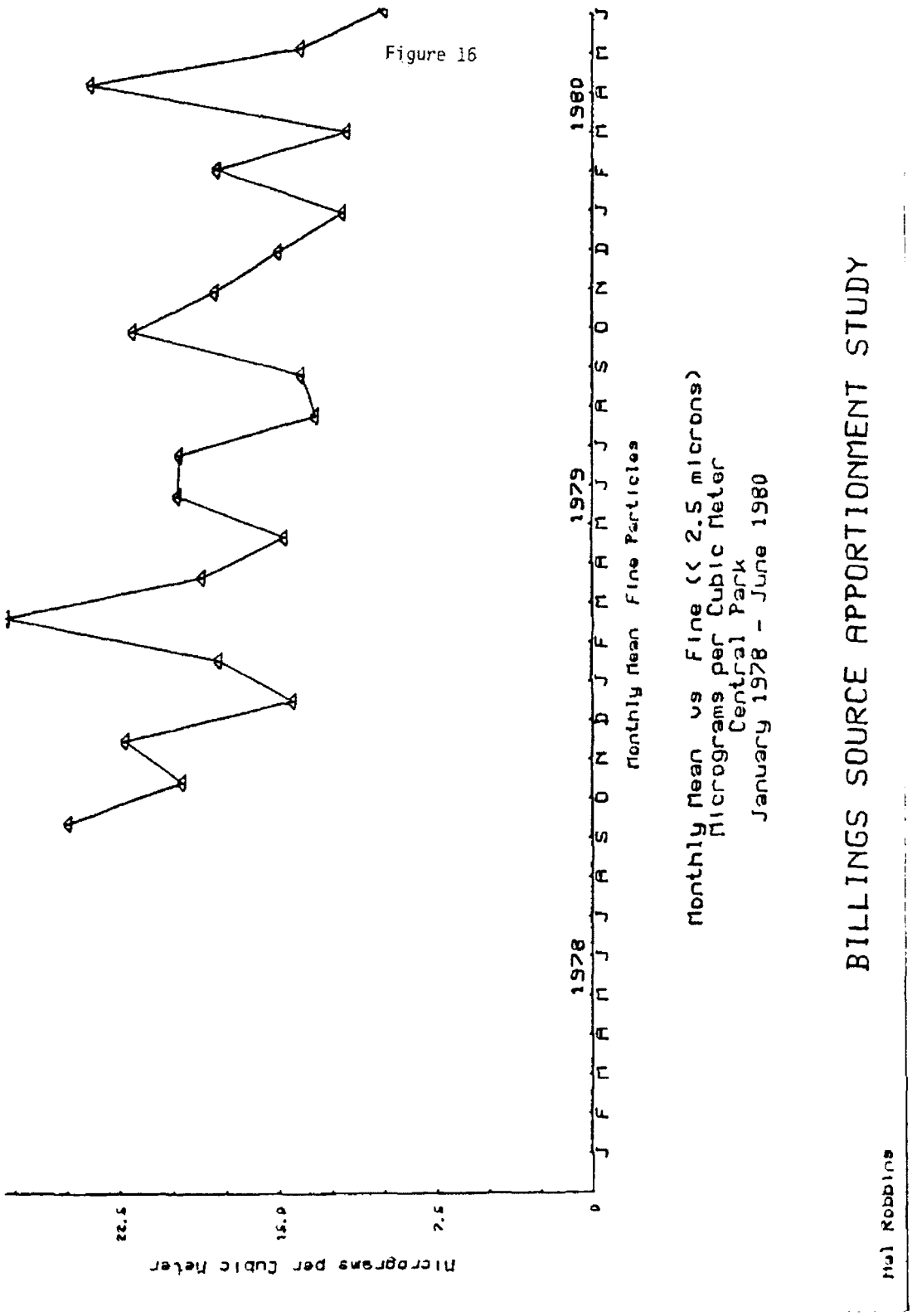


Figure 17

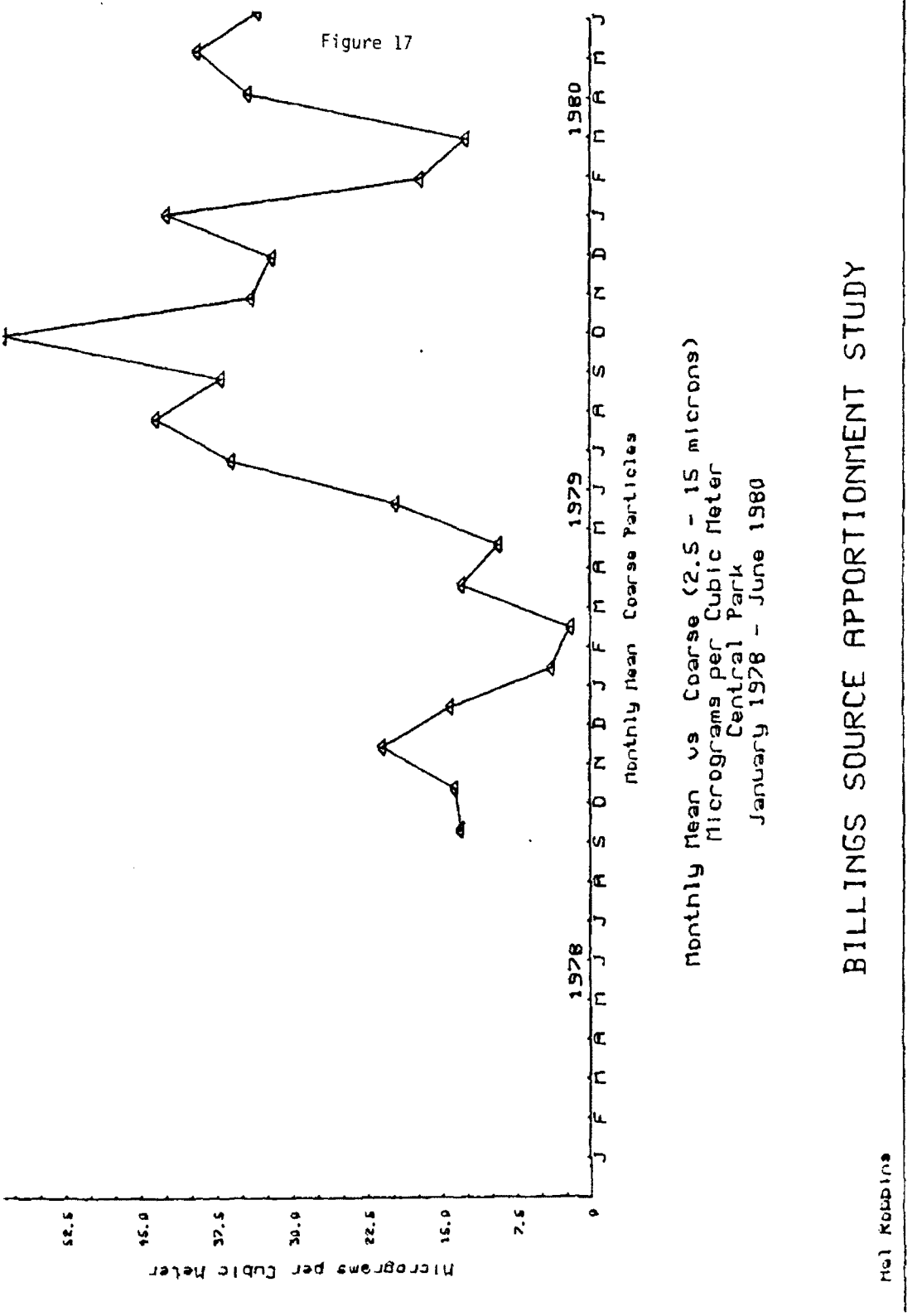
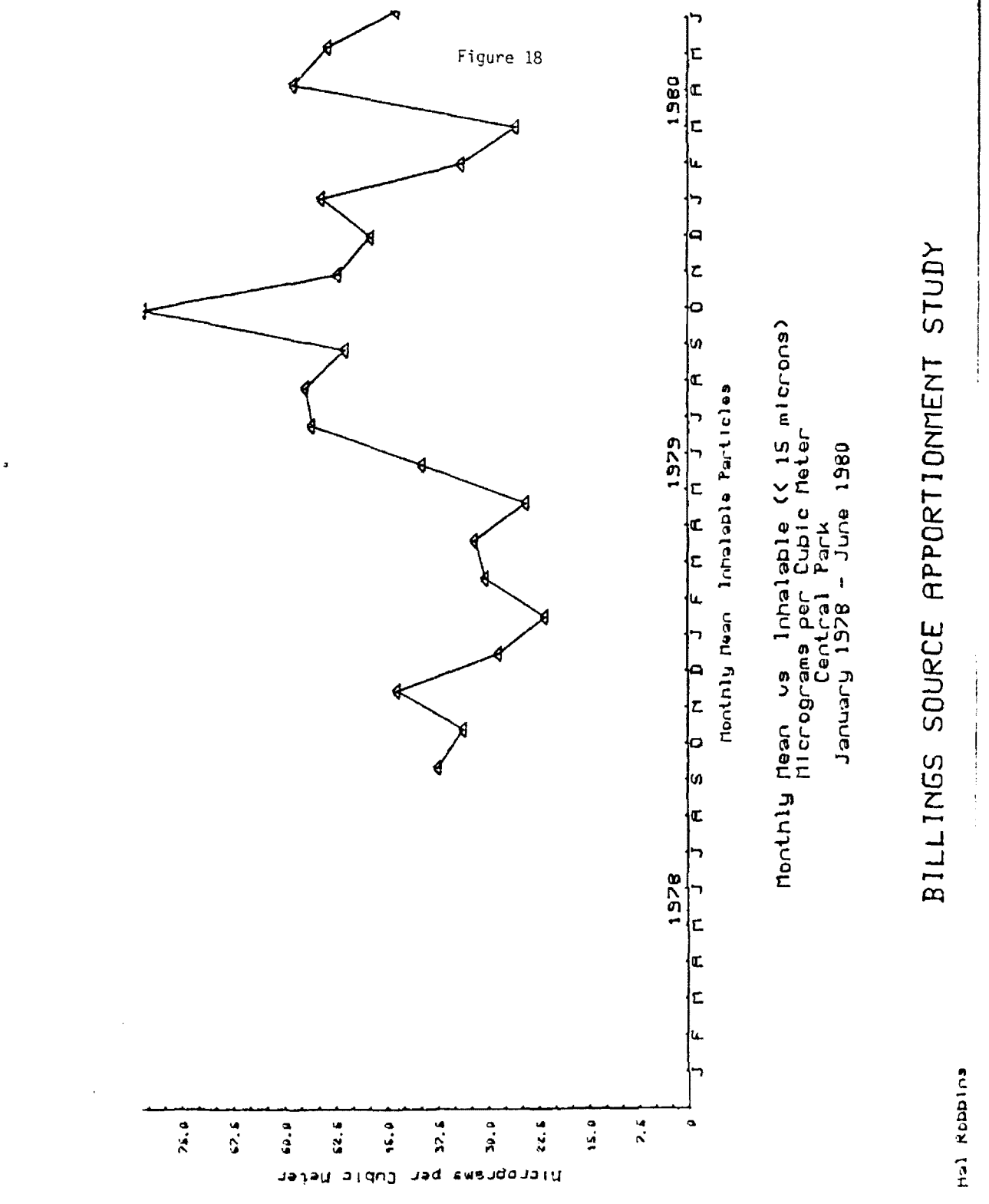
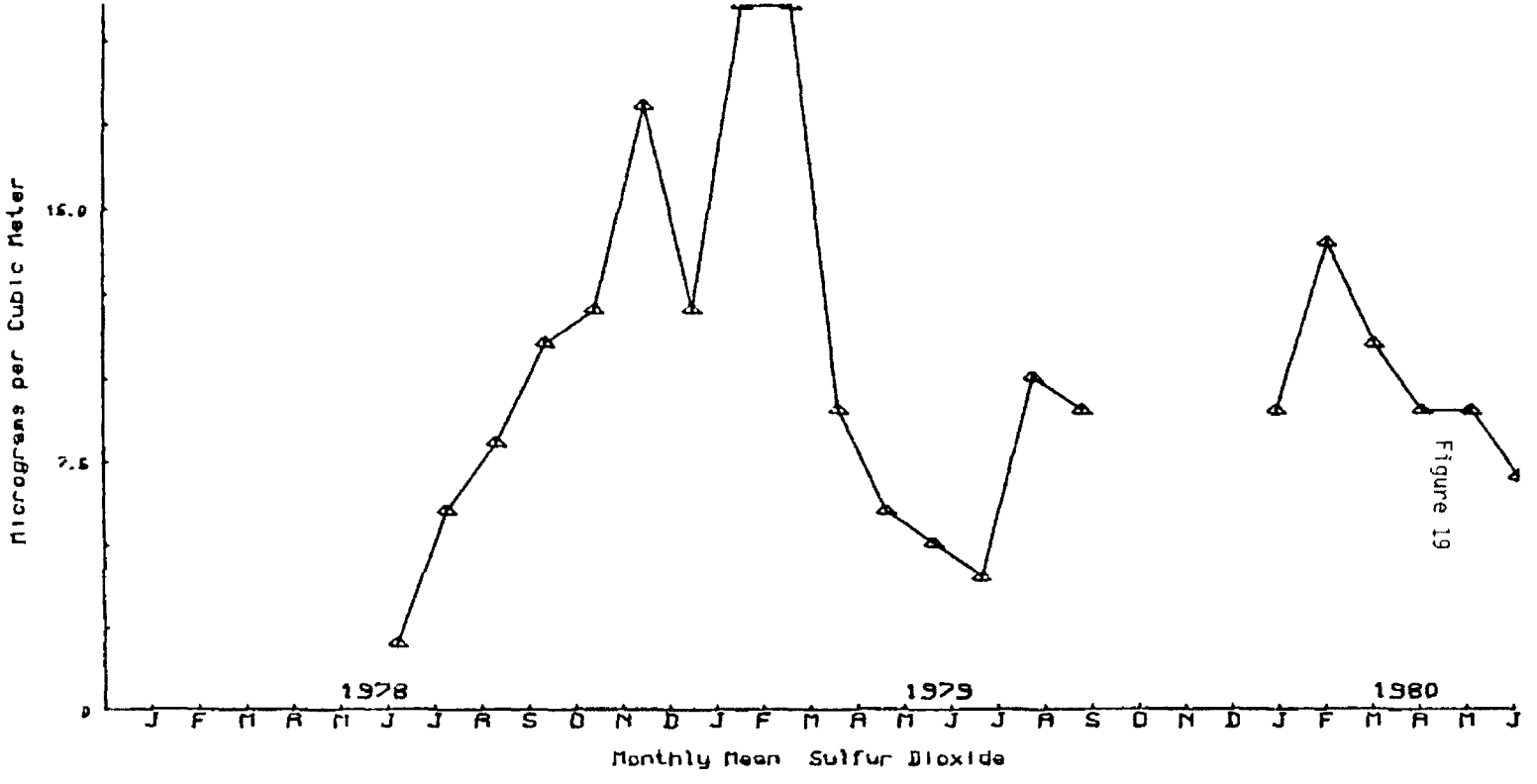


Figure 18





Monthly Mean vs Sulfur Dioxide
Parts Per Billion (Volume)
Central Park
January 1978 - June 1980

Figure 19

BILLINGS SOURCE APPORTIONMENT STUDY

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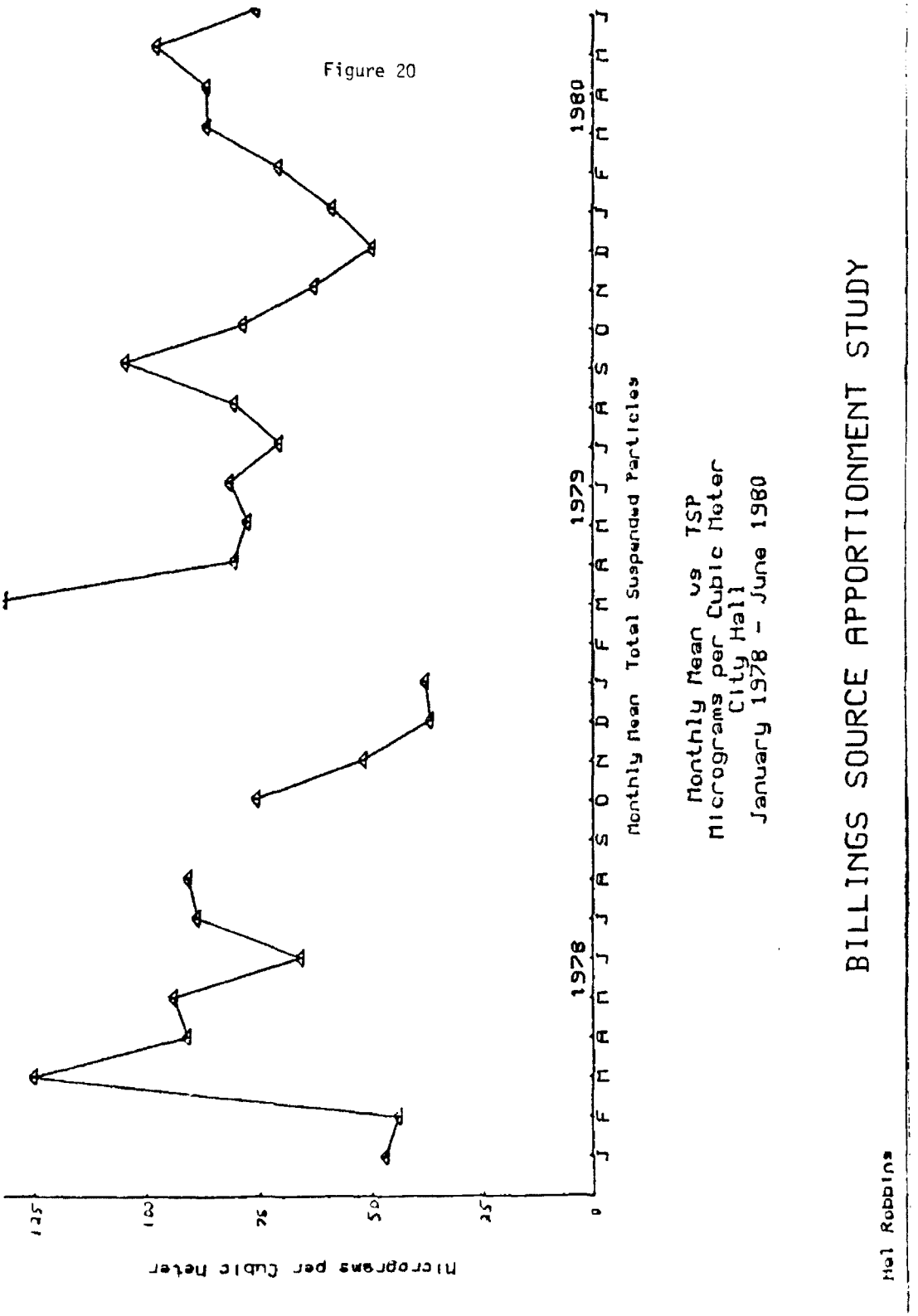
Figure 20



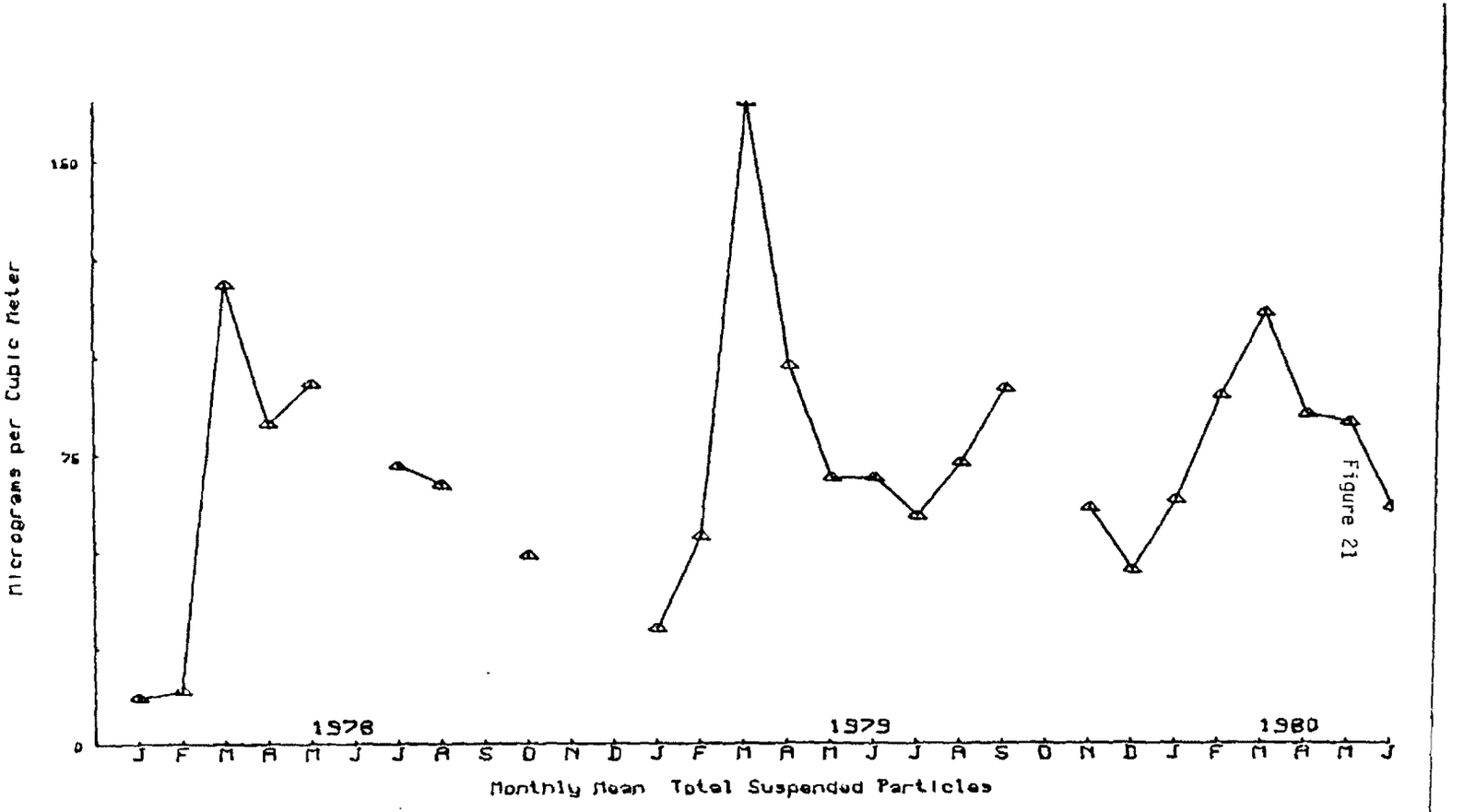


Figure 21

Monthly Mean vs TSP
Micrograms per Cubic Meter
Grand Avenue School
January 1978 - June 1980

BILLINGS SOURCE APPORTIONMENT STUDY

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Appendix E

Breakdown

by

Day of Week with Air Pollutant

and by

Season

All Seasons Combined

Site	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Central Park TSP	68	81	77	79	88	96	80
Central Park Inh.	39	40	45	39	56	48	44
Central Park Coarse	24	24	22	23	36	30	23
Central Park Fine	14	16	23	17	22	18	20
Central Park SO_2	10	11	11	12	11	12	11
Central Park O_3	22	20	20	20	21	20	21
City Hall TSP	62	69	75	73	73	83	74
Lockwood School TSP	61	63	64	48	60	66	55
Grand Ave. TSP	57	74	56	64	65	76	62
KGHL TSP	43	44	44	44	40	41	46
			Winter				
Central Park TSP	40	47	52	47	65	56	48
Central Park Inh.	*	*	*	*	*	*	*
Central Park Coarse	*	*	*	*	*	*	*
Central Park Fine	*	*	*	*	*	*	*
Central Park SO2	14	14	15	15	14	16	14
Central Park O_3	16	15	15	16	19	17	13
City Hall TSP	39	58	42	49	47	75	67
Lockwood School TSP	39	58	32	49	52	58	45
Grand Ave. TSP	39	58	32	49	52	58	45
KGHL TSP	27	36	35	29	34	34	40
			Spring				
Central Park TSP	71	79	69	79	75	119	82
Central Park Inh.	*	*	*	*	*	*	*
Central Park Coarse	*	*	*	*	*	*	*
Central Park Fine	*	*	*	*	*	*	*
Central Park SO_2	8	8	7	6	6	9	6
Central Park O_3	27	28	26	27	27	23	28
City Hall TSP	83	87	96	86	90	107	73
Lockwood School TSP	60	61	66	44	*	60	*
Grand Ave. TSP	82	109	76	86	87	106	68
KGHL TSP	55	56	44	48	31	41	37

Summer

Site	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Central Park TSP	85	111	106	105	110	117	89
Central Park Inhalable	*	*	65	*	*	58	41
Central Park Coarse	*	*	34	*	*	46	28
Central Park Fine	*	*	30	*	*	12	13
Central Park SO_2	6	7	*	*	*	7	6
Central Park O_3	30	27	29	29	27	28	30
City Hall TSP	55	56	93	75	78	76	72
Lockwood School TSP	*	71	68	57	66	75	58
Grand Ave. School TSP	51	51	72	70	67	61	58
KGHL TSP	41	42	56	45	53	45	45

Fall

Central Park TSP	72	92	80	86	95	95	101
Central Park Inhalable	49	49	48	38	67	44	64
Central Park Coarse	31	33	25	20	47	29	35
Central Park Fine	18	16	23	18	20	16	29
Central Park SO_2	11	11	13	18	15	15	14
Central Park O_3	16	15	14	13	14	13	16
City Hall TSP	71	75	6	81	69	64	*
Lockwood School TSP	*	77	*	56	89	*	*
Grand Ave. School TSP	58	*	49	46	48	*	*
KGHl TsP	52	38	42	59	41	48	69

Note 1: All particulate values are in micrograms per cubic meter

Note 2: Values are not reported if there are less than five occurrences within the appropriate category

Note 3: Values for sulfur dioxide and ozone are reported in parts per billion (volume)

Note 4: All reported values are an arithmetic mean