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NATIONAL ASSESSMENT OF THE URBAN PARTICULATE PROBLEM

Volume X - Seattle Area

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Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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NATIONAL ASSESSMENT OF THE URBAN PARTICULATE PROBLEM

Volume X

Seattle, Washington

FINAL REPORT

by

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Contract No. 68-02-1376, Task Order No. 18

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Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

June 1976

This final report was furnished to the Environmental Protection Agency by the GCA/Technology Division in fulfillment of the requirements under Contract No. 68-02-1376, Task Order No. 18. The contents of this report are reproduced herein as received from the contractor. The opinions, findings and conclusions are those of the authors and not necessarily those of the Environmental Protection Agency.

FOREWORD

This document is part of a 16-volume report assessing the urban particulate problem, which was conducted by GCA/Technology Division for EPA.

This particular document is one of the 14 single city volumes that provide working summaries of data gathered in the 14 urban areas during 1974 to support an assessment of the general nature and extent of the TSP problem nationwide. No attempt was made to perform detailed or extensive analyses in each urban area. Rather, the city reports are intended as a collection of pertinent data which collectively form a profile of each urban area. This, in turn contributes to a comparative analysis of data among the 14 areas in an attempt to identify general patterns and factors relating to attainment of the TSP problem nationwide. Such an analysis has been made in Volume I of the study-National Assessment of the Urban Particulate Problem-National Assessment. The reader is referred to this volume as the summary document where the data is collectively analyzed.

This and the other 13 city reports are viewed primarily as working documents; thus, no effort was made to incorporate all the reviewer's comments into the text of the report. The comments were, however, considered during the preparation of Volume I and are included herein in order to alert the reader to different points of view. The 16 volumes comprising the overall study are as follows:

Volume	I	- National Assessment of the Urban Particulate Problem
Volume	II	- Particle Characterization
Volume	III	- Denver
Volume	IV	- Birmingham
Volume	V	- Baltimore
Volume	VI	- Philadelphia
Volume	VII	- Chattanooga
Volume	IX	- Oklahoma City
Volume	X	- Seattle
Volume	XI	- Cincinnati
Volume	XII	- Cleveland
Volume	XIII	- San Francisco
Volume	XIV	- Miami
Volume	XV	- St. Louis
Volume	XVI	- Providence

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GCA/Technology Division wishes to sincerely thank those persons and organizations who made significant contributions to this effort. On-going project supervision was provided by Thompson G. Pace of EPA's Control Programs Development Division. The case study in Seattle was greatly assisted by the cooperation and helpfulness of the staff of the Puget Sound Air Pollution Control Agency, particularly Milton Svoboda, Kay Saito, Ron Bisby, and Harry Walters. In addition, much guidance and information was obtained from Michael Schultz and George Hofer of EPA Region X.

EXECUTIVE SUMMARY

The report summarized herein presents the analyses of the particulate situation in the Seattle area conducted as part of the study for the national assessment of the problem of attainment or nonattainment of the National Ambient Air Quality Standards for particulates. Seattle represents a moderately industrialized area, with above average heating requirements and a definite rainy season, that has had some success in reducing emissions and particulate concentrations though not enough to attain the standards. Fugitive dust generated in the industrial valley during the dry season has been implicated as a major contributing source to the ambient levels of particulates in Seattle.

In addition to a discussion of this fugitive dust problem, analyses of the air quality levels, emissions, regulations, monitoring network, and meteorology, are included in this report. The major findings in each of these areas are summarized below in the order in which they appear in the text.

AIR QUALITY

The trends in TSP levels at several monitors have been primarily down during the past 8 years though an upturn has been noted in the past 2 years. Of those stations reporting a full year of data, the national primary annual air quality standard for particulates (75 $\mu g/m^3$) was exceeded at two stations in the industrial area of Seattle and the secondary annual standard (60 $\mu g/m^3$) was exceeded at another two sites — one in the industrial valley and one in the city. The highest annual geometric mean

was 105 $\mu g/m^3$ at a site in the industrial valley which is being considered for relocation back away from the road. Violations of the 24-hour standards occurred five times for the primary and 41 times for the secondary standard out of a total of almost 700 observations in 1974.

The spatial distribution of the TSP concentrations is related to the topographical characteristics of the region. The highest concentrations (60 to 105 $\mu g/m^3$) are centered in the industrial valley with the levels lower in the city (45 to 63 $\mu g/m^3$) and lowest in the residential areas out of the valley (35 $\mu g/m^3$).

EMISSIONS

The spatial distribution of emissions in the area varies widely from almost no major sources in the eastern part of the county to the densely industrialized Duwamish Valley. Local estimates of the impact of fugitive dust in the valley amount to almost a third of the major point sources in the area. Consistent data on yearly emission levels is not available to establish any correlation between TSP concentration and emissions. However, utilizing best available data, an estimate of 40 percent for the degree of reduction since 1969 was made. This estimated reduction was in agreement with that expected by EPA over a comparable period of time yet it was not paralleled by a similar improvement in air quality.

REGULATIONS AND SURVEILLANCE

The sources in the Seattle area are controlled by regulations from both the state's Department of Ecology (DOE) and the Puget Sound Air Pollution Control Agency (PSAPCA). The PSAPCA regulations are generally as stringent or more stringent than the DOE's regulations; however, the DOE has promulgated regulations for several types of industry. Surveillance of the sources is performed through the use of the permit system, visible emissions, and complaints. The majority of sources are determined to be in

compliance through theoretical calculations though some stack testing is done to determine compliance, especially with new construction.

NETWORK DESIGN

The network reviewed was found to be generally well-designed in terms of neighborhood selection and monitor siting. Monitors are spaced at intervals of about 1 mile from the mouth of the Duwamish Valley, where industrial emissions are concentrated, to the agricultural and residential areas to the south. This network is backed up by modeling and monitoring for wind speed and direction at numerous sites to better understand the wind flow in the complex topography.

The primary difficulty noted was that the monitors in the center city area (Public Safety Building, Food Circus) were located two to three times higher than the other monitors which were uniformly located at the more standard 15 to 25 feet above ground level. This increase in height is expected to result in lower readings and may therefore downplay the importance of planning in this area. In addition, there have been some relocations of monitors in the Duwamish Valley that have recorded high levels of TSP. While the movements of these monitors are probably appropriate, it was felt that some guidelines for documentation of these moves would be helpful.

METEOROLOGY AND CLIMATOLOGY

Numerous meteorological parameters were investigated for Seattle including the yearly and monthly variations in precipitation and space heating demands, the average wind speed and number of days of precipitation each month, and other ventilation characteristics of the region such as mixing height, inversions, and the movement of air masses through the region. While the seasonal pattern in space heating and various ventilation parameters (mixing height, inversion frequency) would tend to indicate higher

levels of particulates in the winter, the significant pattern of precipitation, with a definite rainy winter season and dry summer-fall, has an overwhelming influence on the seasonal pattern of TSP levels. On an areawide basis, the TSP concentration is 50 percent higher during the dry months than during the rainy season.

Precipitation has apparently also had an impact on the yearly levels of particulates. From 1969 to 1973 the improvement in air quality has been paralleled by increasing levels of precipitation. In 1973 and 1974, however, when the yearly precipitation decreased 25 percent, the TSP concentration increased. This trend was noticeable throughout Region X at rural, background sites. At these sites, the TSP levels noted a 5 $\mu g/m^3$ increase to 35 $\mu g/m^3$.

URBAN ACTIVITY

Insufficient data was available for an analysis of the possible impact on TSP levels due to the paving and conditioning of roads in the Duwamish Valley. Data from a DOE study underway to compare the effect of the location of a monitor with respect to a heavily traveled road was reviewed. Forty sets of paired measurements taken over the period from October 1974 to June 1975 indicated that the monitor located approximately 15 feet back from the road had values averaging over 60 percent higher than the concentration at the monitor located approximately 100 yards back from the road. Further analyses of this data have not indicated other expected relationships so it is undergoing additional study.

CONCLUSIONS

The results of this study indicated that significant reductions in the emissions from industry may be possible under a more stringent process weight rate regulation. However, the impact that such a regulation would have is not known at this stage due to insufficient information on the impact of the fugitive dust sources. In addition, the complexity of

the topography and meteorology of the area may call for other, less traditional control measures. The seasonal pattern of TSP may mean that controls for fugitive dust and/or seasonal controls on industry (fuel switching in the summer) would be most cost effective.

for existing and 0.05 gr/scr for new sources. Therefore, although the process weight regulation is less stringent than the others, the impact on emissions may not be much less. In addition, the effect of the process emissions relative to area source emissions and combustion sources is the important comparison to make to determine the impact of process on emissions air quality.

MONITORING

1. Third paragraph, page 37, reference fire station on 4th Avenue. In the Agency's opinion, inordinately high traffic from the Spokane Street viaduct running east-west and only 1000 feet south of the sensor and the six-lane road in front of the fire station (4th Avenue) combined with other traffic conditions were sufficient to bias the sensor by more than 25 percent with reentrained particulate during dry road conditions and S.W. winds. The viaduct is about 30 feet high.

2. Data from the monitor located at the Public Safety Building (discussed on pages xii and 37) can be used for showing trends in air quality even though it is located higher than the ideal height to represent people's respiration zone. The original objective of this monitor was to obtain data to assess air quality trends.

3. Attainment date for primary standard for suspended particulate matter is December 1973, not July 1975 as stated on page 51.

GENERAL

The inset map on page 2 (Figure 1) incorrectly shows the location of the AQCR in question. The region does not include areas west of Puget Sound.

SECTION I

STATEMENT OF THE PROBLEM

CHARACTERISTICS OF THE REGION

The Puget Sound Intrastate Air Quality Control Region (AQCR) encompasses the Counties of King, Kitsap, Pierce and Snohomish (Figure 1). It covers an area of about 6,300 square miles, extending roughly 60 miles east and west by 100 miles north and south and straddling the central part of Puget Sound, a large irregular mass of salt water containing numerous islands. On the east side of the AQCR is the 3000 to 6000 foot high Cascade Range, which effectively blocks the ventilation of the Puget Sound Lowlands in that direction. On the west side, the Olympic Mountains intercept a large part of the westerly rain-bearing winds. However, the winds can sweep freely north and south through the valley.

More than half of the population of the State of Washington resides in the AQCR yet the heavily forested eastern section of Snohomish, King, and Pierce Counties is largely uninhabited. All of the region's cities and most of the population are located along a narrow 20-mile wide lowland corridor, mainly on the east side of the Sound. This leads to the high urbanization of the area: 92 percent, 82 percent, 72 percent and 44 percent urbanized for King, Pierce, Snohomish, and Kitsap Counties, respectively. The region has two Standard Metropolitan Statistical Areas (SMSA's). The largest, ranking 22nd in the nation, is the Seattle-Everett SMSA with a population of 1.4 million; the Tacoma SMSA is much smaller with only 405,000 inhabitants. Both of these areas have had declining populations in the past several years.

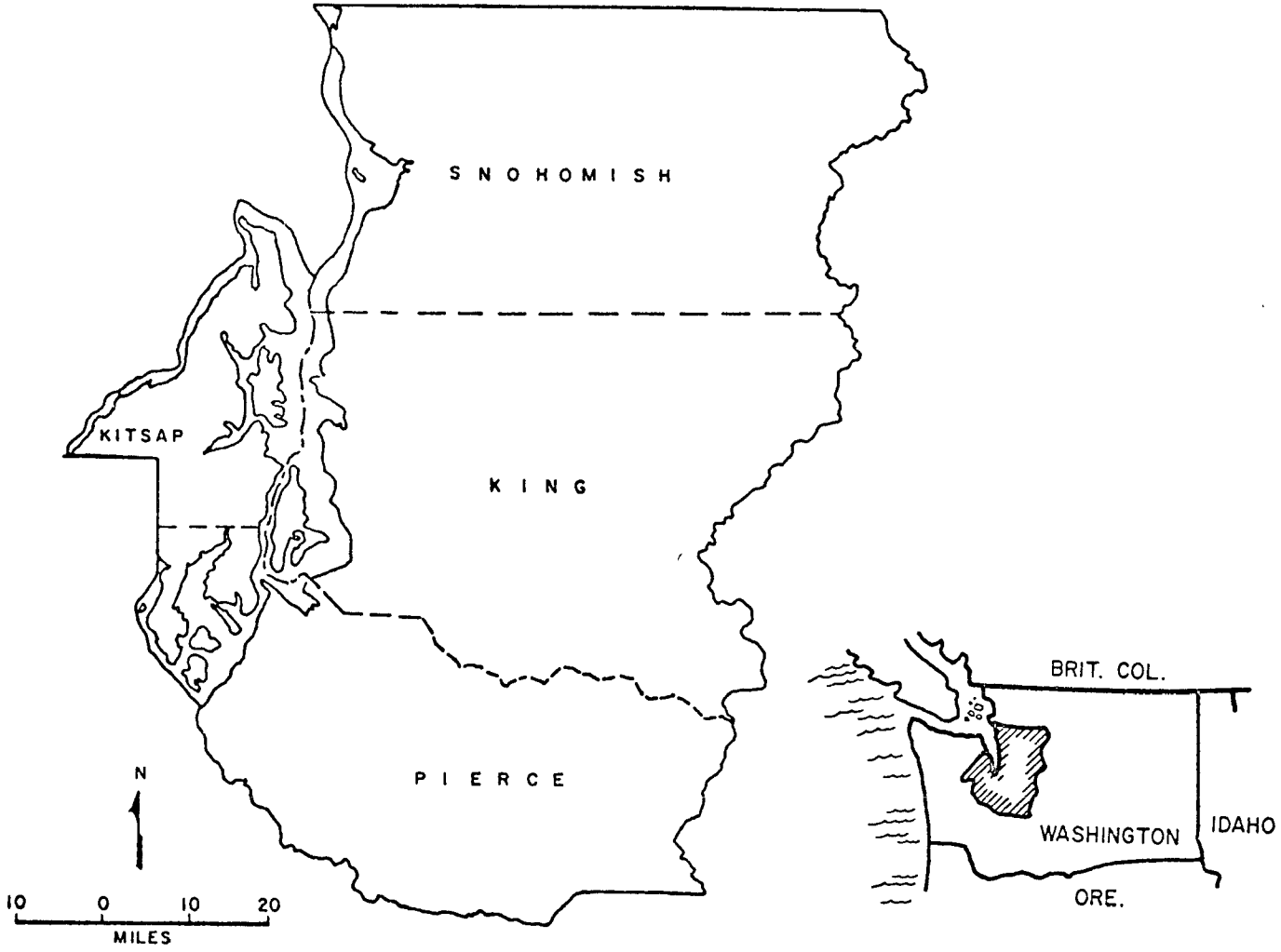

Figure 1. Puget Sound Intrastate Air Quality Control Region

The industry of the area is also located along this lowland area. The Puget Sound Region's economic structure is heavily oriented toward manufacturing and service activities in aerospace, shipbuilding, trade, transportation, and forest-related industries. While the Region's pollution problems are similar to those of many heavily-urbanized areas, sources especially noteworthy in the Seattle area include steel manufacturing, iron foundry, lumber mills, kraft pulp mills, two sulphite pulp mills, and various lumber, single and plywood mills. Figure 2 provides a graphical representation of the employment mix in the AQCR by 2-digit Standard Industrial Classification (SIC) code; this figure demonstrates the overwhelming influence of the transportation equipment industry on the employment in the area.

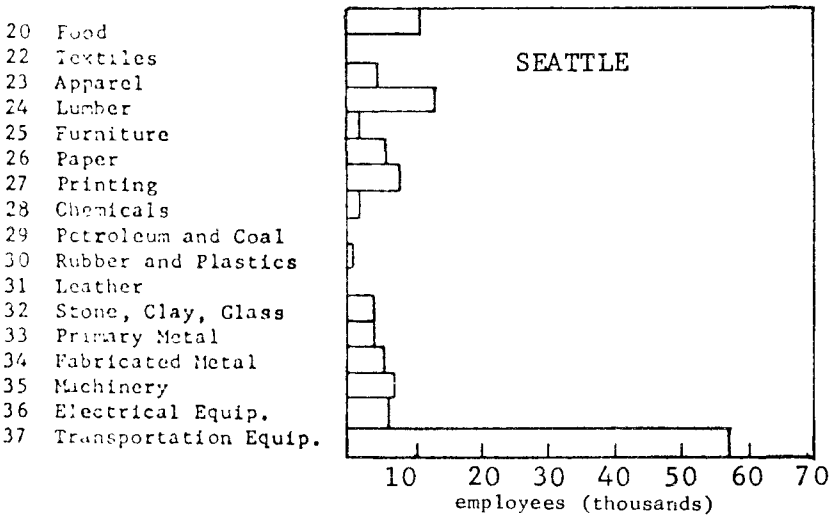

Figure 2. Manufacturing employment in the Puget Sound AQCR

The climate in the AQCR is predominately a mid-latitude, west coast, marine-type, with dry season and pleasant temperatures during the summer and rather mild but rainy winters. Precipitation averages less than 40 inches in the lowlands bordering Puget Sound, while 60 to 100 inches is common in the Cascade Mountains in the Region's eastern sector.

Some of the factors which influence the climate are: its location in the belt of the prevailing westerly winds, the distance and direction of the Pacific Ocean, the terrain, and the position and intensity of the semipermanent high and low pressure centers located over the north Pacific Ocean. The Cascade Mountains serve as an effective barrier in preventing the cold continental air in the winter and the warm air in the summer from reaching the Puget Sound lowlands. Most air masses reaching Puget Sound have their source regions over the Pacific Ocean; the maritime air has a moderating influence in both winter and summer. The prevailing wind is from the southwest in fall and winter, gradually shifting to northwest in late spring and summer.

Seattle has a relatively high number of expected episode days in a 5-year period with mixing heights less than 1000 meters and wind speeds less than 4 m/sec. Over this period, 18 different episodes lasting at least 2 days each may be expected to occur with the greatest number of episode-days in the autumn.[1] Table 1 presents mean ventilation characteristics for Seattle.

Table 1. VENTILATION CHARACTERISTICS FOR SEATTLE

	Annual		Winter		Spring		Summer		Autumn	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Mean mixing height (m)	705	1175	824	718	838	1577	576	1419	585	987
Mean wind speed through mixing layer (m/sec)	5.2	5.4	6.2	5.4	5.5	6.2	4.2	4.9	5.0	5.0
Median $\overline{X}/\overline{Q}$ for a 10-km city (sec/m)	10	10	10	10	10	10	11	10	11	10

AIR QUALITY PLANNING

The program of air pollution control in the State of Washington is a cooperative effort between the State agency, which is the Department of Ecology (DOE) and the various local agencies. The Washington Clean Air Act of 1967, as amended, places the primary responsibility for control of air pollution into the hands of local agencies. The first of the local agencies formed under this act was the Puget Sound Air Pollution Control Agency (PSAPCA). Prior to this, the City of Tacoma and the City of Seattle had separate programs. In July of 1967, King, Pierce, and Snohomish Counties formed a three-county agency with Kitsap County joining in January 1970.

The Puget Sound AQCR was designated a Priority I region for all pollutants except SO_2 for which it was considered IA (the designation for NO_2 has been changed to Friority III). The implementation plan to meet the National Ambient Air Quality Standards (NAAQS) was completed by the Puget Sound Agency, in cooperation with the Department of Ecology, and submitted to EPA in January 1972. The state implementation plan (SIP) predicted that, under the then existing state regulations and Regulation I of the Puget Sound Air Pollution Control Agency, the particulate standards would be attained by July 1975. The analyses was based on projected emission levels given plant capacities, new plants, and growth in the region and using these emissions in the Martin-Tikvart atmospheric diffusion model. The SIP is currently approved for all pollutants except oxidants in the Puget Sound AQCR. However, the standards for particulates are not expected to be attained and the Puget Sound area is designated as a maintenance area solely for particulates.

AIR QUALITY SUMMARY

There were 34 monitoring stations operating in the four-county region during all or part of 1974; five of these are being run by the Washington

State Department of Ecology. These stations are distributed around the region with one station in a rural region east of Seattle and the rest reasonably distributed among the industrial, commercial, and residential sectors. As shown in Figure 3, the greatest density of stations is in the Seattle metropolitan area. The location of the stations and the types of monitors operated at each are given in Table 2. Of the 30 stations with hi-volume air samplers operating in 1974, 23 of them operated every month.

Two Seattle area stations have been monitoring particulate matter since February 1965, thereby accumulating 10 years of data. These samplers have operated on an intermittent schedule sampling continuously for 24 hours every third day from February 1965 through December 1968, every fourth day from January 1969 through December 1972, and every sixth day since January 1973. A total of 20 stations have acquired at least 4 years of data through the end of 1974.

An analysis technique which allows a reasonable determination of trends is the moving mean or average. As applied to suspended particulates, a 12-month moving geometric mean relates directly to the annual standard. This moving mean is calculated by computing the 12-month geometric mean for consecutive 12-month intervals and identifying each resultant value with the ending month for the particular 12-month interval. These values may be easily plotted on a graph to depict observed concentrations which relate directly to the annual standard. A variation of this technique of portraying a trend which requires more years of data is the calculation of the moving geometric mean in multiples of 12 months. For example, 24- and 36-month moving geometric means smooth out some of the year to year variations in meteorology and short-term changes in source emissions to more clearly depict the trend.

Data has been acquired continuously at the Public Safety Building (K001) in downtown Seattle since February 1965, and the 12-, 24- and 36-month

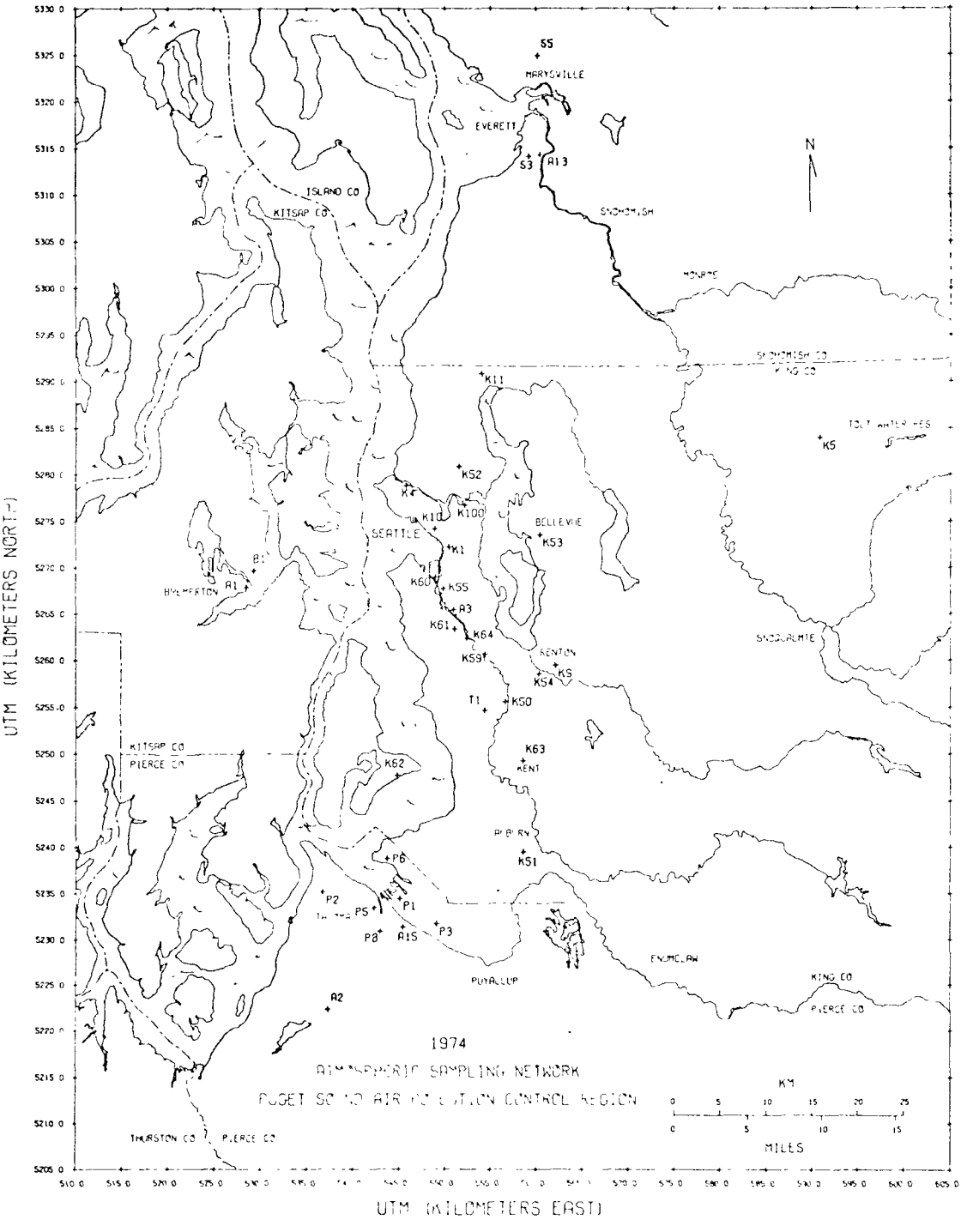

Figure 3. Location of monitoring sites in the Puget Sound AQCR[2]

Table 2. PUGET SOUND AIR POLLUTION CONTROL AGENCY ATMOSPHERIC SAMPLING NETWORK 1974

Sta. No.	Location	1	2	3	4	5	6	7	8
S 3	Medical-Dental Bldg., 2740 Colby Ave., Everett	x	x	x	x				
S 5	Tulalip Test Facility, Snohomish County	x		x	x				
K 1	Public Safety Bldg., 154 - 3rd Ave., Seattle	x							
K 4	U.S.G.S. Station, 2730 W. Commodore Way, Seattle	x							
K 5	Tolt River Watershed (East of Lake Joy)	x							
K 9	N.E. Dist. Health Center, 15015 S.W. 12th St., Renton	x							
K10	Food Circus Building, Seattle Center	x	x	x	x		x		
K11	Lake Forest Park Rsvr., N.E. 193rd & 46th Ave. N.E., Seattle				x				
K50	Southcenter, 401 Andover Park E., Tukwila	x	x	x	x				
K51	115 East Main St. & Auburn Ave., Auburn	x							
K52	Green Lake Rsvr., 12th Ave. N.E. 73rd, Seattle		x	x	x				
K53	Puget Power Bldg., 10604 N.E. 4th, Bellevue	x							
K54	Municipal Bldg., 200 Mill Ave. S., Renton	x							
K55	Duwamish, 4500 Blk. E. Marginal Way S., Seattle	x	x	x	x				
K59	Duwamish Valley, 12026 - 42nd Ave. S., King County	x							
K60	Harbor Island, 3400 - 13th Ave. S.W., Seattle	x							
K61	South Park, 723 S. Concord St., Seattle	x							
K62	S.W. 248th & 59th Ave. S.W., Maury Island		x	x	x				
K63	1234 North Central Ave., Kent	x	x	x	x			x	x
K64	10000 W. Marginal Way S.W., Seattle	x		x	x				
K100	NWS Urban Site, 2725 Montlake Blvd. E., Seattle				x				
T 1	McMicken Hts., S. 176th & 42nd Ave. S., King County	x	x	x	x	x	x		
P 1	Mann-Russell Electric, 1401 Thorne Road, Tacoma	x							
P 2	N. 26th & Pearl, Tacoma	x	x	x	x				
P 3	Fife Senior High School, 5616 - 20th E., Fife	x							
P 5	Hess Building, 901 Tacoma Ave., South, Tacoma	x							
P 6	Meeker Jr. H.S., 1520 - 51st St. N.E., Tacoma	x	x	x	x				
P 8	Willard Elem. School, S. 32nd & S. "D" St., Tacoma	x	x	x	x				
B 1	Dewey Jr. H.S., Perry Ave. & Holman St., Bremerton	x	x	x	x				
A13	Everett Ave. & Pine St., Everett	x							
A03	Duwamish, 6770 E. Marginal Way S., Seattle	x							
A15	Cascadia College, 2002 E. 28th St., Tacoma	x							
A02	112th St. S.W. & Loch Lea, Lakewood	x							
A01	City Hall, 239 - 4th St., Bremerton	x							

"A" Codes operated by Washington State Dept. of Ecology

TYPE OF SAMPLING

1. High-Volume Sampler
2. Sulfur Dioxide (SO_2)
3. Soiling Index (COH)
4. Wind Speed & Direction
5. Nitrogen Dioxide (NO_2)
6. Total Oxicant
7. Nepnelometer
8. Ozone

moving geometric means are plotted in Figure 4. The 12-month moving geometric mean plot shows short-term fluctuations, but also depicts a long-term downward trend which appears to level out at about the value of the annual standard. This long-term trend is even more evident in the 24- and 36-month moving geometric mean graphs.

The other Seattle area station with about 10 years of data is located at 2700 West Commodore Way in a commercial area. The 12-month moving geometric mean plot (Figure 5) indicates a long-term downward trend with values generally below the annual standard except for an upturn during 1973. In February 1974, a reversal of the short-term uptrend occurred and is sustained for the remainder of the year. The 24- and 36-month moving geometric mean graphs more clearly depict the long-term downward trend which appears to level off during the past 2 years.

Parallel to depicting levels of suspended particulates in the urban areas, it is important to document these concentrations in the nonurban regions. The Agency has operated a single station near the Tolt Water Reservoir in the foothills of the Cascade Mountains since November, 1966. The 12-, 24-, and 36-month moving geometric mean graphs (Figure 6) all depict a reasonably constant value of about 14 micrograms per cubic meter which is neither increasing nor decreasing. Evidently this station is not significantly affected by the urbanized areas in the Puget Sound region, and this value is considered to be an average background value for the air of the Puget Sound region.

In 1974, the majority of the AQCR was meeting both the primary and secondary annual standards. Of those stations reporting a full year of data, the national primary annual air quality standard for particulates (75 $\mu g/m^3$) was exceeded at two stations in the industrial area of Seattle and the secondary annual standard (60 $\mu g/m^3$) was also being exceeded at two other stations in Seattle and one in Tacoma. Figure 7 provides an isopleth map of the 1974 annual geometric means in the AQCR indicating the horizontal distribution of suspended particulates throughout the region. The

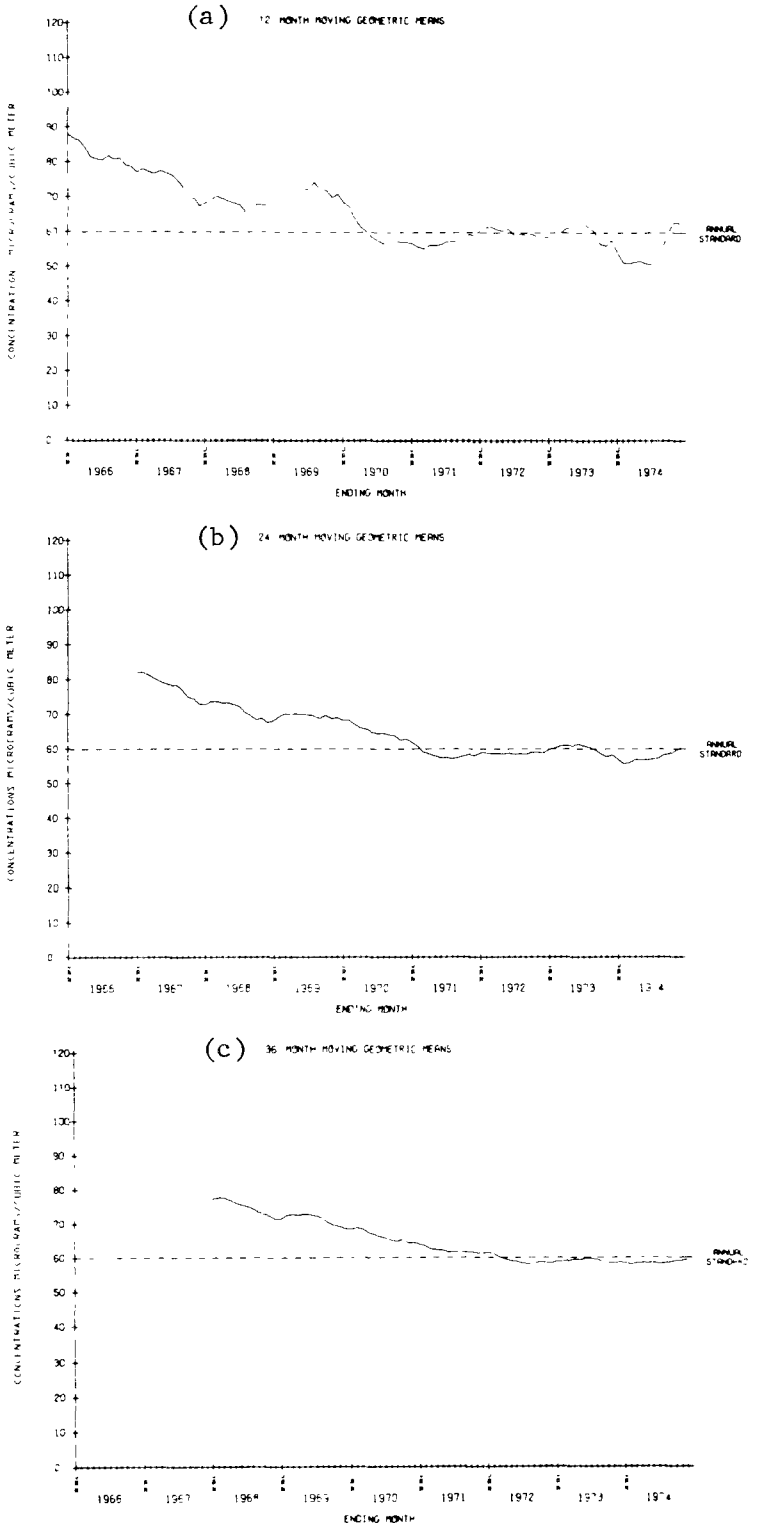

Figure 4. Trends in total suspended particulates at the Public Safety Building, Seattle[2]

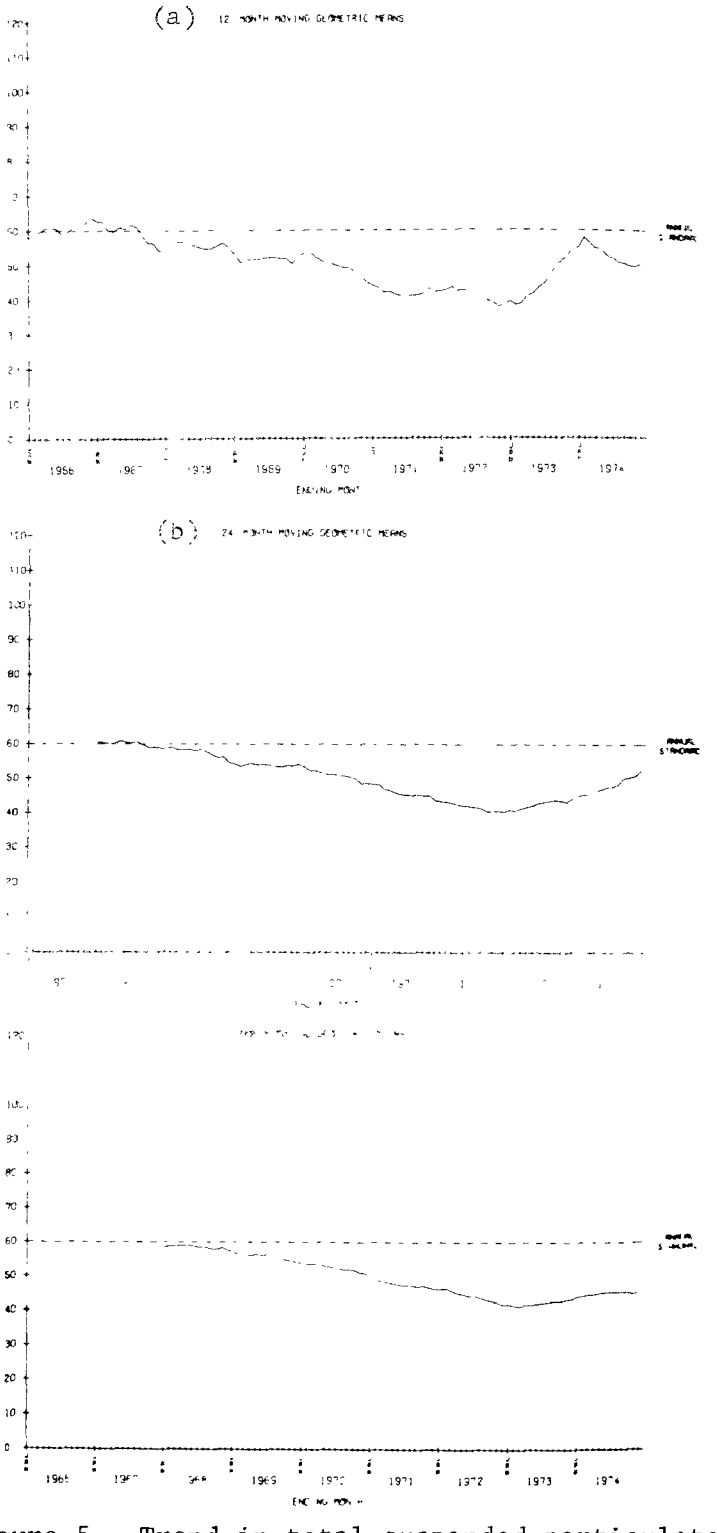

Figure 5. Trend in total suspended particulates at the USCG Station in Seattle[2]

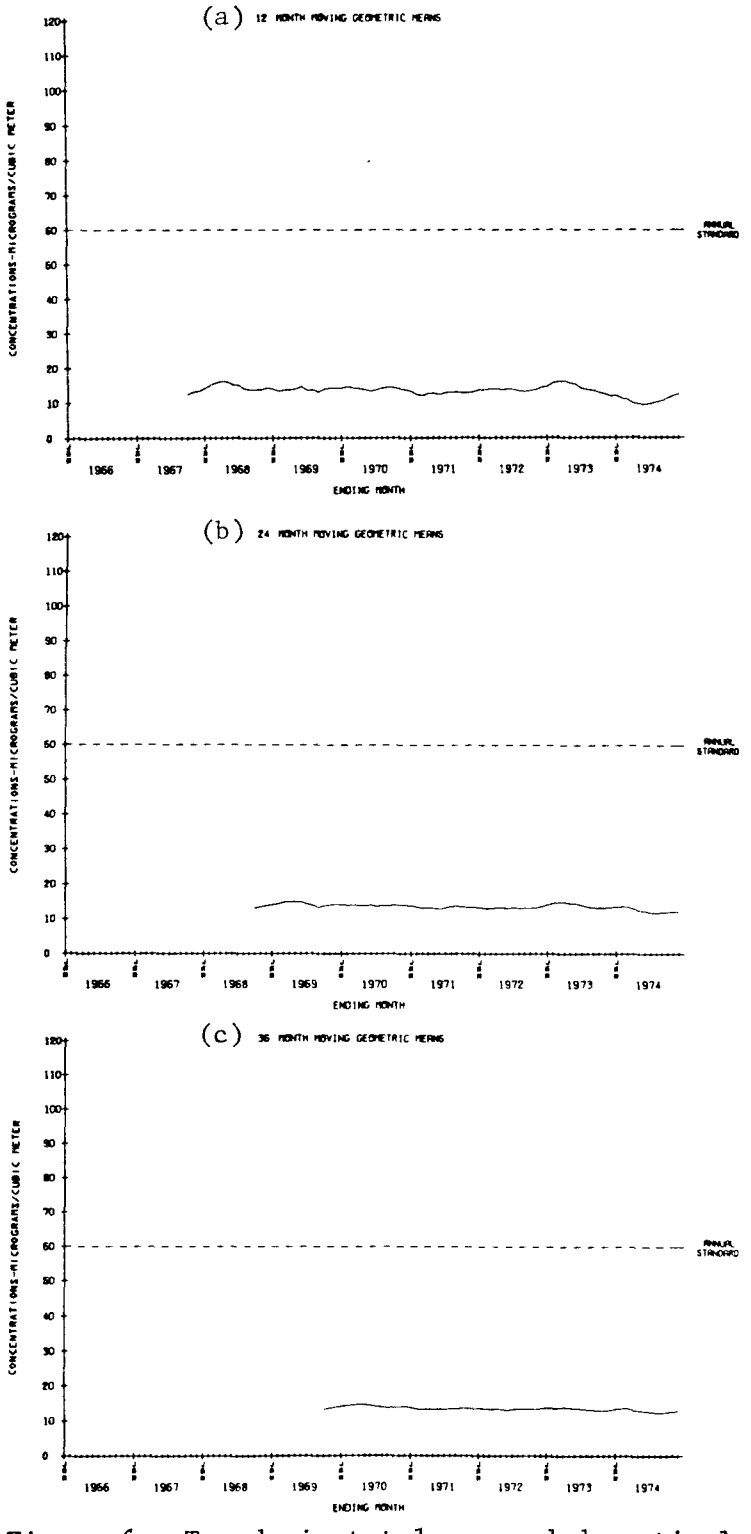

Figure 6. Trends in total suspended particulates at Tolt River Watershed, King County[2]

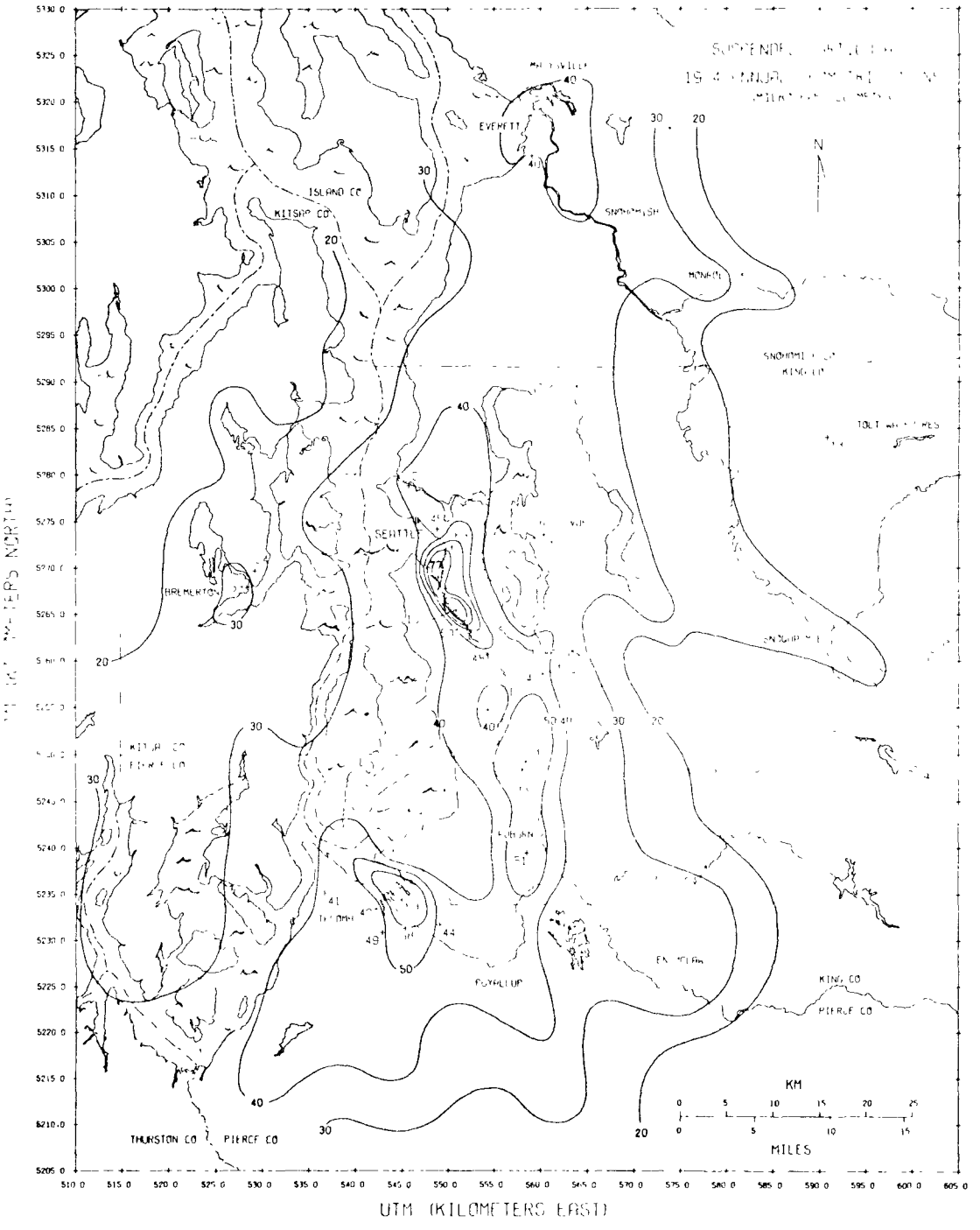

Figure 7. TSP annual geometric means at monitors and isopleths in the Puget Sound AQCR, 1974 ($\mu g/m^3$)

development of these annual average isopleth maps by the PSAPCS required the input of (1) measured air quality data, (2) meteorological conditions, (3) topographic influences, (4) demography of the area, and (5) the particulate emissions of all sources. This map indicates the problem of attainment of the annual standards is a matter of local influences as opposed to a regionwide problem.

Of the 1580 individual 24-hour samples taken in 1974, 67 (4.2 percent) of the samples violated the secondary 24-hour standard (150 $\mu g/m^3$). One station operated by the PSAPCA violated the primary 24-hour standard — (260 $\mu g/m^3$) once in 1974 and another station operated by the DOE in the same industrial area — the Duwamish valley in Seattle — is reported to have violated the primary standard four times in 1974. This DOE site, which also had the highest annual mean, is under study regarding its siting and will be discussed further under monitor siting in Section II of this report. Another DOE station in Tacoma is known to have violated the primary 24-hour standard at least once.

Table 3 summarizes the 1974 monitoring history of the monitoring stations in the AQCR, arranged by county and type of neighborhood in which the monitor is located. More detailed data on the stations visited in the course of the study are given in Section II.

Table 3. HISTORY OF TSP MONITORING SITES IN THE PUGET SOUND AQCR — 1974

Location	Area class	Geo. mean	Std. geo. dev.	Max.	Date	Number of observations: Exceeding secondary standard	Exceeding primary standard	Total
Tolt River Watershed	RUR	13	2.50	46	Jul 22			57
Tulalip Test Facility[a]	RUR	18	2.11	143	Oct 8			15
Everett & Pine, Everett[b*]	RES	43	2.05	123	Jan 5			19
Medical-Dental Bldg., Everett	COM	40	1.63	110	Oct 8			61
U.S.C.G. Station, Seattle	COM	50	1.61	159	Jan 11	2		61
Food Circus Bldg., Seattle Center	COM	45	1.51	97	Oct 26			59
Public Safety Bldg., Seattle	COM	63	1.66	229	Oct 8	3		62
Harbor Island, Seattle	IND	77	1.76	257	Sep 20	8		65
4500 Blk. E. Marg. Way S., Seattle	IND	68	1.76	264	Jan 8	6	1	65
6700 E. Marg. Way S., Seattle[*]	IND	105	1.97	320	Jan 5	18	4	58
South Park, Seattle[c]	RES	50	1.87	152	Oct 16			56
10000 W. Marg. Way S., Seattle[d]	IND	60	2.12	235	Oct 8	-		31
Duwamish Valley, King Co.	RES	48	1.82	147	Jan 8			61
Puget Power Bldg., Bellevue	COM	32	1.57	70	Jan 11			61
S.E. Dist. Health Center, Renton	SUB	33	1.82	92	Sep 20			60
Municipal Bldg., Renton	COM	43	1.64	119	Sep 20			61
Southcenter, Tukwila[e]	COM	36	1.56	80	Dec 31			11
McMicken Hts., King Co.	RES	35	1.71	122	Aug 9			55
1234 N. Central Ave., Kent[f]	COM	53	2.05	234	Sep 14	2		33
Main St. & Auburn Ave., Auburn	COM	51	1.63	136	Jan 5			61
Meeker Jr. H.S., Tacoma	RES	38	1.74	119	Jan 8			61
Mann-Russell Elec., Tacoma	IND	69	1.75	254	Aug 9	5		61
Fife Sr. H.S., Fife	COM	4[illegible]	2.05	147	Jan 8			61
Cascadia College, Tacoma[*]	RES	58	2.60	316	Jan 11	1[illegible]	h	54
Willard Elem. School, Tacoma	RES	49	2.14	173	Oct 8	4		61
Hess Bldg., Tacoma	COM	42	1.92	164	Oct 8	2		60
112th St. S.W. & Loch Lea, Lakewood[g*]	RES	38	2.04	122	Oct 8			37
N. 26th & Pearl, Tacoma	COM	41	2.15	131	Jan 11			60
City Hall, Bremerton	COM	33	1.52	66	Oct 17			53
Dewey Jr. H.S., Bremerton	RES	24	1.68	60	Oct 14			60
All-station totals						67	64	1,580

[*]Washington State Department of Ecology Stations.

[a]Site established 10/08/74

[b]Site discontinued 4/23/74

[c]Site established 2/16/74

[d]Site established 7/13/74

[e]Site established 11/07/74

[f]Site established 6/22/74

[g]Site established 5/29/74

[h]Data not available

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1. Holzworth, George C. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. U.S. Environmental Protection Agency. January, 1972. AP-101.

2. 1974 Air Quality Data Summary. Puget Sound Air Pollution Control Agency, Seattle, Washington. June 1975.

SECTION II

ANALYSES

This section presents the individual analyses that were performed on the data gathered for the study of the particulate problem in Seattle. It attempts to correlate various factors which are known to influence air quality with the measured ambient TSP concentrations. These factors include those that most often come under the jurisdiction of the air pollution control agency — emissions, regulations, and monitor siting — and other factors that are not usually or cannot be controlled — urban activity, meteorology, etc.

EMISSIONS

The Puget Sound Intrastate AQCR is a moderately industrialized area with most of the sources compacted into several localities. Data in the current National Emissions Data System (NEDS) for the area indicates that industrial processes contribute the largest share (44 percent) of the total inventoried particulate emissions and 67 percent of the total point source emissions. Inventoried area source emissions are approximately half the magnitude of particulate emissions from point sources.

In King County, the primary area for study under this effort, the industrial processes account for 77 percent of the point source emissions and 29 percent of the total inventoried particulate emissions. However, inventoried area sources contribute almost 70 percent more than point sources to the total particulate emissions in King County. Emissions from transportation sources represent 63 percent of these area source particulate emissions (see Table 4).

Table 4. NEDS PARTICULATE EMISSIONS FOR THE PUGET SOUND AQCR AND KING COUNTY (in tons per year)

	Puget Sound AQCR			King County			County percent of AQCR
	Point	Area	Total	Point	Area	Total	
Fuel combustion	(9,318)	(3,641)	(12,959)	(1,122)	(2,069)	(3,191)	(25)
External	9,318	3,641	12,959	1,122	2,069	3,191	25
Residential	–	1,728	1,728	–	1,110	1,110	64
Electrical	10	–	10	10	–	10	100
Industrial	7,240	936	8,176	1,013	402	1,415	17
C-I	2,068	976	3,044	99	558	657	22
Industrial process	(19,814)	–	(19,184)	(3,782)	–	(3,782)	(19)
Chemical	31	–	31	30	–	30	97
Food/Agricultural	1,279	–	1,279	858	–	858	67
Metals	4,682	–	4,682	–	–	–	0
Mineral	5,845	–	5,845	2,894	–	2,894	50
Petroleum	7,977	–	7,977	–	–	–	0
Solid waste disposal	(456)	(647)	(1,103)	(18)	(288)	(306)	(28)
Government	99	–	99	8	–	8	8
Residential	–	271	271	–	130	130	48
C-I	01	200	201	–	86	86	43
Industrial	356	176	532	10	72	82	15
Transportation	–	(9,035)	(9,035)	–	(5,187)	(5,187)	(57)
Gasoline	–	6,440	6,440	–	3,932	3,932	61
Diesel	–	1,633	1,633	–	812	812	50
Aircraft	–	539	5539	–	208	208	39
Vessels	–	423	423	–	235	235	56
Miscellaneous	–	1,973	1,973	–	719	719	36
Total	29,588	15,296	44,884	4,922	8,263	13,185	29
Percent of combined	65.9	34.0	100	37.3	62.7	100	

The spatial distribution of emissions in the AQCR is quite varied. Almost all sources lie in the valley along the Sound, the various inlets, and rivers in the area. Figure 8 locates the point sources in King County and provides an idea of the relative size of each source. As may be seen from this figure, the greatest density of point sources is along a river south of Seattle, an area known as the Duwamish Valley. Figure 9 identifies, by the dashed line, that area defined as the Duwamish Valley by PSAPCA and also provides a closer look at the location of sources in the Duwamish Valley area.

The wide variation in the degree of industrialization of the AQCR makes analysis of the emission levels difficult for levels reported at the AQCR or county level. A particular example of this is reflected in the emissions from fuel combustion. Table 5 provides a breakdown of the emissions from combustion based on fuel usage for the AQCR and King County as reported in NEDS. This table indicates that almost 55 percent of the emissions from fuel combustion in the AQCR are from the burning of wood and in King County this contribution is over 30 percent. However, these emissions are almost totally due to combustion occurring in the rural areas of the AQCR and county and are not of significance when considering the violation of the standards in the metropolitan areas. In the Seattle-Everett SMSA in 1970, based on the U.S. Census of Housing, 44 percent of dwelling units used distillate oil and the other units were evenly divided between gas and electricity usage with only 0.2 percent using coal.

The above NEDS data does not include any estimate of the emissions from possible fugitive dust sources. A calculation of the preliminary data supplied from the MRI study[1] of dirt roads, dirt air strips, construction, and agricultural tilling indicates that the fugitive dust emissions from these sources would be more than 22 times the total tonnage as the inventoried emissions, and, in King County by itself, the fugitive dust is over 30 times the total inventoried emissions (see Table 6). Almost

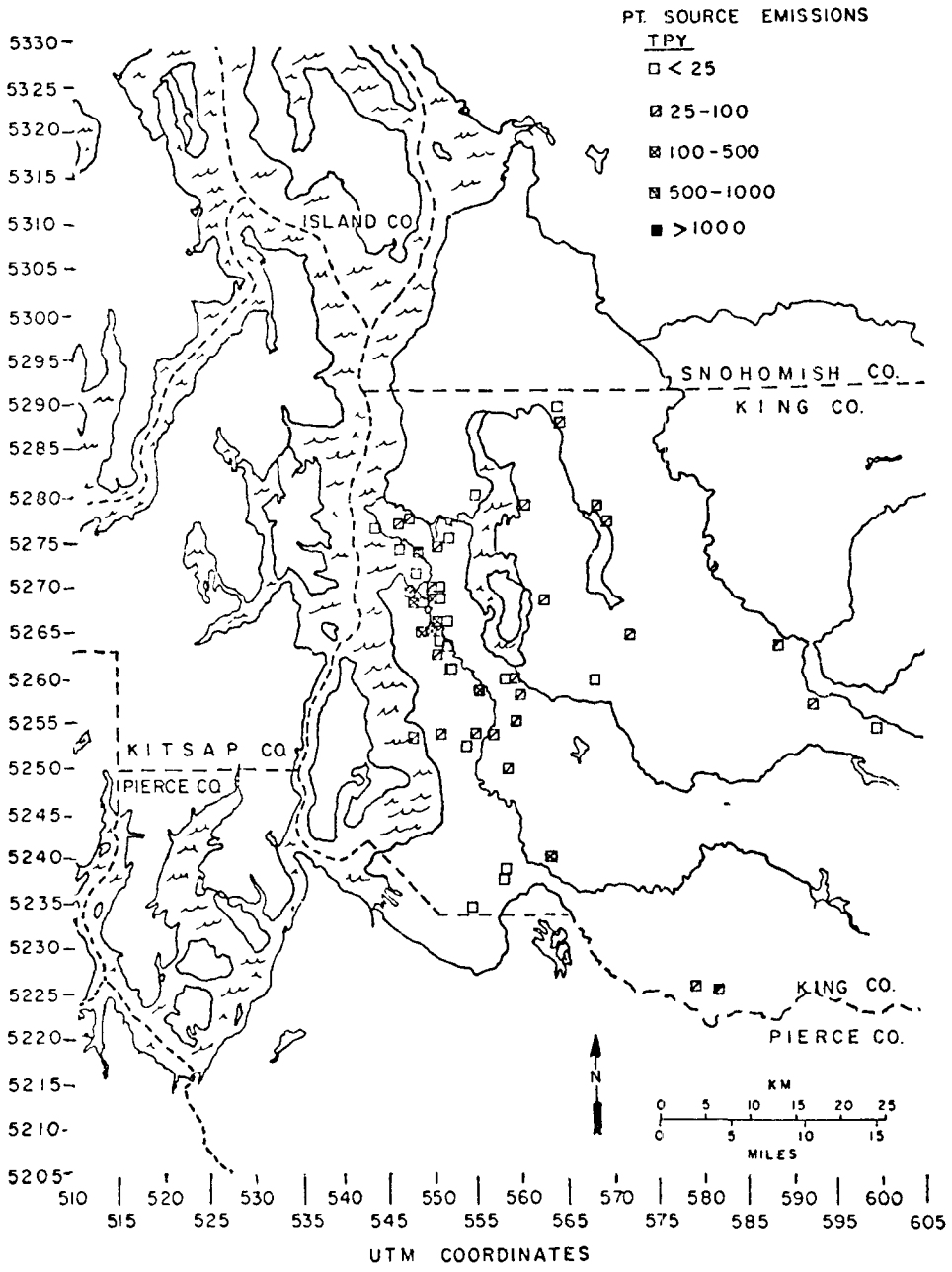


Figure 8. Location of point sources in King County

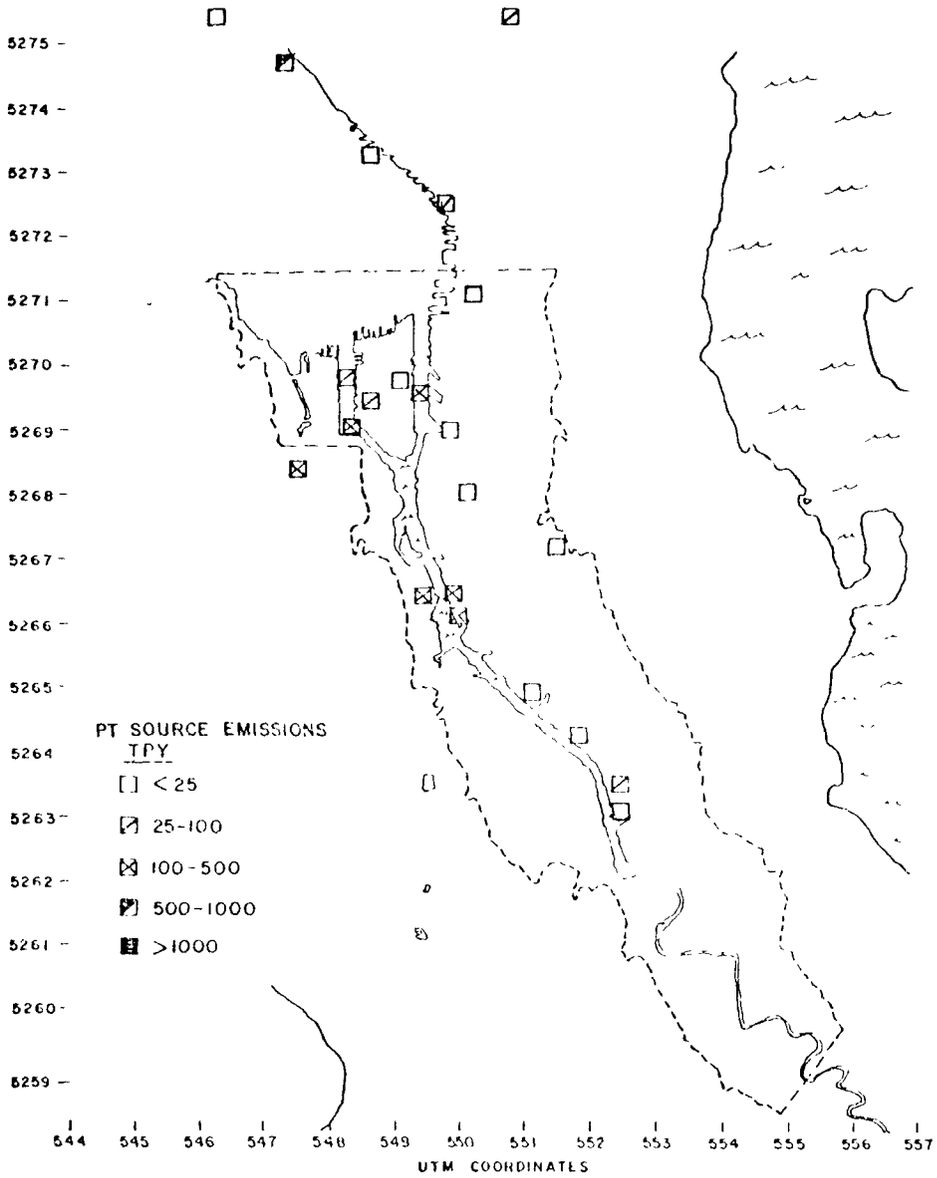


Figure 9. Location of point sources in the Duwamish Valley

Table 5. RATIO OF EMISSIONS FROM FUEL COMBUSTION BY FUEL TYPE TO TOTAL EMISSIONS DUE TO FUEL COMBUSTION, PUGET SOUND AQCR AND KING COUNTY[a]

Area	Source type	Fuel type					Total
		Bituminous coal	Residual oil	Distillate oil	Natural gas	Wood	
AQCR	Point	0.133	0.059	0.010	0.008	0.509	0.719
	Area	0.004	0.101	0.118	0.018	0.039	0.280
King County	Point	0	0.047	0.009	0.013	0.282	0.351
	Area	0.007	0.215	0.334	0.046	0.046	0.648

[a]From NEDS data

Table 6. FUGITIVE DUST EMISSIONS IN THE PUGET SOUND AQCR (in tons per year)[a]

County	Unpaved roads	Dirt air strips	Construction	Land tilling	Total	Percent of AQCR
King (0980)	196,765	44	204,680	39	401,528	40
Kitsap (1020)	110,625	40	13,072	20	123,757	12
Pierce (1560)	160,480	16	70,348	59	230,903	23
Snohomish (2000)	171,100	35	66,048	106	237,289	24
Total	638,970	135	354,148	224	993,477	100
Percent of total	64	< 1	36	< 1	100	

[a]From an MRI Study[1]

all of these emissions are contributed from unpaved roads (64 percent) and construction activity (36 percent).

The problem of fugitive dust in Seattle has been recognized and analyzed in several studies by J. W. Roberts. In a thesis prepared by Roberts in 1973[2], he developed an emission inventory for fugitive dust generated as a result of vehicular activity in the Duwamish Valley. In this study, Roberts attempted to identify not only those total emissions that may be expected to result from traffic on dusty paved roads and gravel roads but also the amount that would remain suspended for any period of time. Particulates less than 10 microns in diameter were defined as the suspended portion and, on average, this amounted to approximately 25 percent of the total emissions.

Table 7 details the emission inventory calculated by Roberts for the Duwamish Valley air basin with the grid numbers referring to the map in Figure 10 as given in his thesis. This table indicates that there is an estimated emission level of 2540 tons of particulates per year within this area due to traffic on paved gravel roads and that 655 tons of this would remain suspended. While the determination of this level may have some problems due to sampling directly behind a moving vehicle and it can be expected to vary greatly depending upon climatic and individual road conditions, the amount of "suspended" particulates generated is significant. It amounts to almost one-third of the emissions from the major point sources in the area and is emitted directly into the breathing zone without much dilution as occurs with emissions from stacks.

Due in part to this research and the recognition that these sources are contributing to the ambient air levels (and water pollution) in the area, some stabilization of roads (about 15 miles in 1974) and paving of parking lots has occurred in the Duwamish Valley. Unfortunately, this is a relatively recent and ongoing activity so that sufficient data is not available to establish an estimate of the impact on air quality that these programs are having.

Table 7. POLLUTION INVENTORY FOR DUSTY PAVED ROADS AND UNPAVED ROADS IN THE DUWAMISH VALLEY[2]

Grid	Dusty paved roads, emissions in t/y			Gravel roads, emissions in t/y			Total emissions, t/y	
	Miles road	Total particulate	Suspended particulate (< 10μ)	Miles road	Total particulate	Suspended particulate (< 10μ)	Total particulate	Suspended particulate (< 10μ)
11/18 D	4.6	26	5	1.2	76	21	102	26
11/19 C	9.4	53	11	4.4	176	48	229	59
11/19 D	11.9	68	14	1.0	218	60	286	74
12/18 A	14.6	83	17	0.1	4	1	87	18
12/18 B	11.9	68	14	4.7	435	119	503	133
12/18 C	18.2	103	21	0.8	67	18	170	39
12/18 D	11.0	62	13	1.2	101	28	163	41
12/19 A	7.8	44	9	2.4	224	61	268	70
12/19 B	4.3	24	5	2.2	644	176	668	181
13/18 A	8.4	48	10	0.2	16	4	64	14
Totals	102.4	579	119	18.2	1,961	536	2,540	655

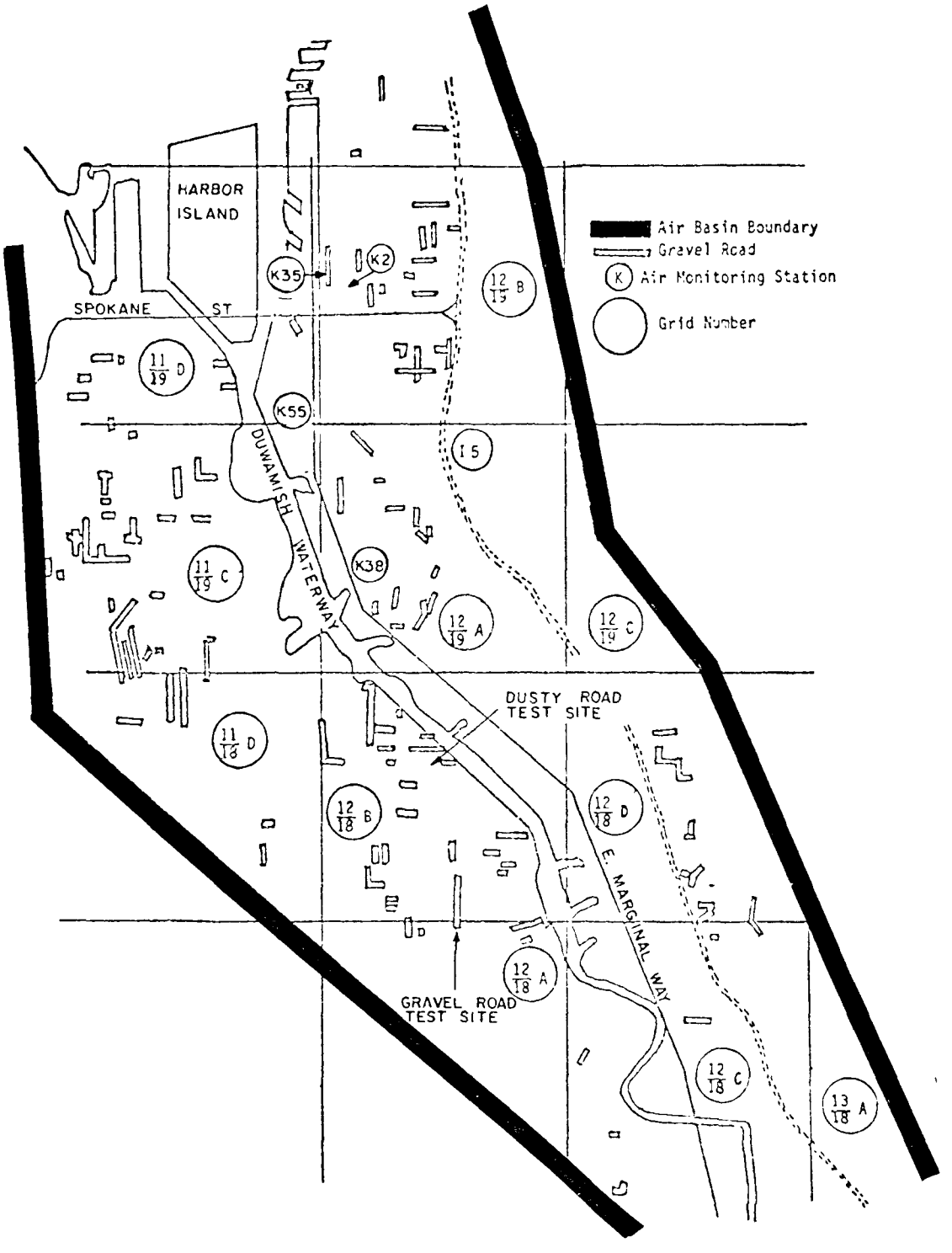


Figure 10. Duwamish Air Basin gravel road location

While no consistent set of data was available to establish any long-term trends in emissions from different source categories, annual emission inventories for King County for the years 1969 to 1972 had been compiled by the PSAPCA. (However, differences in emission factors and approaches to compiling the inventories have varied over this time and no attempt has been made to update previous inventories.) In addition, the EPA Region X office had compiled a 1973 inventory for a study of the King County area[3] and the NEDS data is supposedly representative of 1974 emissions. Therefore, utilizing these data bases, it is possible to develop an approximation of the trends in emissions over time.

Figure 11 provides a graph of the changes in these emission inventories for the major source categories and the total emissions (divided by two to fit on the graph). Emissions of approximately 1000 tons/year from dirt roads, included in the 1973 inventory, were excluded in the 1973 total to try to maintain consistency between the inventories. Despite the differences in the emission inventories, the magnitude of reduction of emissions is almost equivalent to the 40 percent reduction expected in the Region X report.[3] The major problem in establishing a trend is for the transportation category, however all other sources show a noticeable continuing downtrend. An average of annual TSP concentrations at three stations (USCG, Public Safety Building, Food Circus) is also plotted on this figure. This air quality plot indicates that, while improvements in air quality were noted in the early years, 1973 and 1974 have shown increasing levels at a time when emissions have continued to decrease. Possible factors relating to this discrepancy are investigated under the discussion of meteorology and climatology.

LEGAL AUTHORITY, REGULATIONS, AND SURVEILLANCE

The program of air pollution in control in the State of Washington is a cooperative effort between the state agency, which is the Department of Ecology (DOE) and the various local agencies. The Washington Clean Air

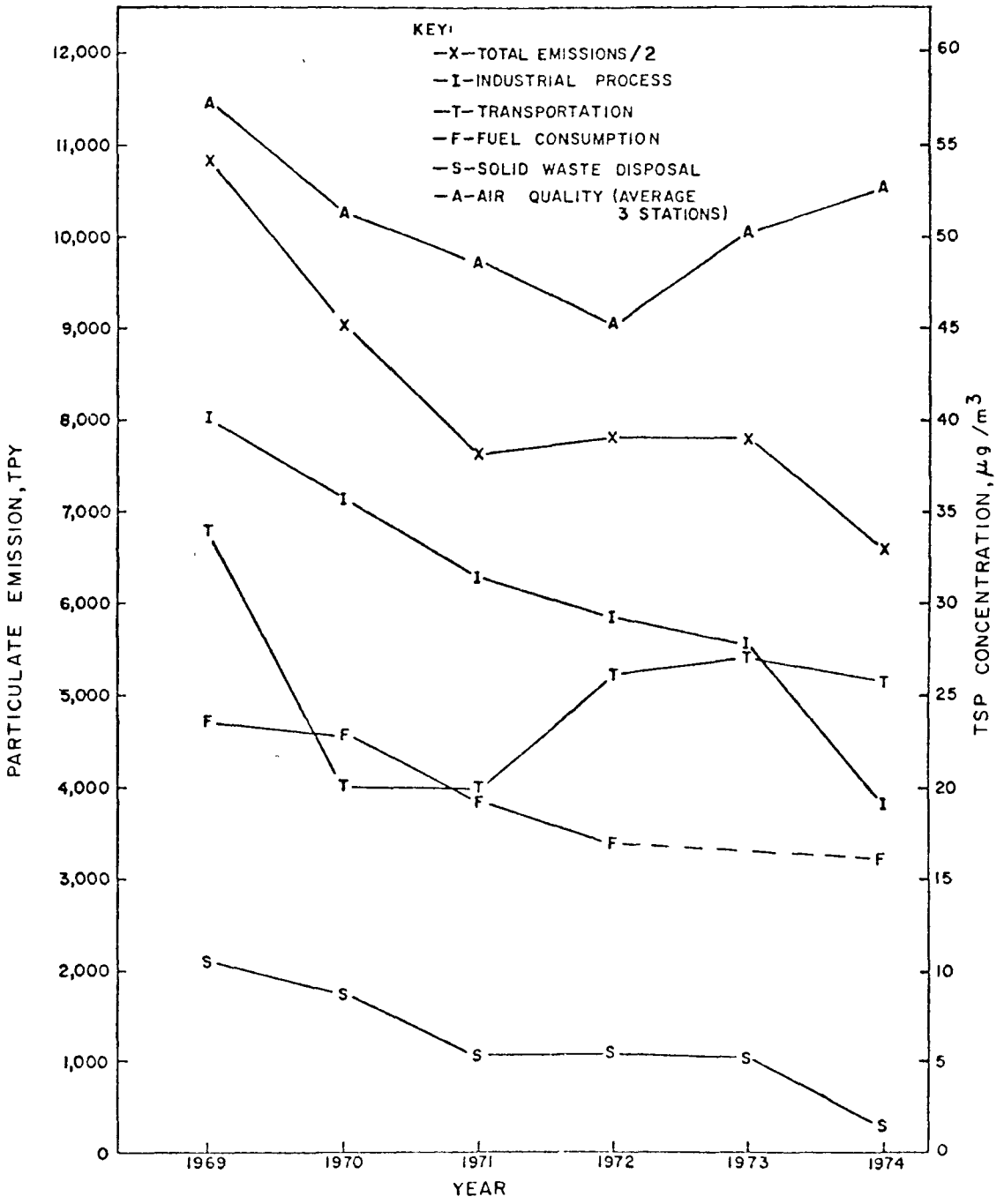


Figure 11. Particulate emission and TSP air quality trends in King County

Act of 1967 as amended in 1969 and 1970 and 1971 places the primary responsibility for control of air pollution into the hands of local agencies. The first of the local agencies formed under this act was the Puget Sound Air Pollution Control Agency (PSAPCA). Prior to this, the City of Tacoma and the City of Seattle had separate programs. In July of 1967, King, Pierce, and Snohomish Counties formed a three-county agency with Kitsap County joining in January 1970.

Regulations

The Department of Ecology is organized to provide technical advice and consultation for the local agencies and to assist them in their programs and planning. The state agency has also been granted the authority to set standards and assume jurisdiction for certain source categories if it is determined that these should be controlled on a uniform statewide basis. The State of Washington's air pollution regulations are applicable statewide unless the local regulation is more stringent, in which case the local regulation would be applied. Some areas under the direct jurisdiction of the state agency can be designated sensitive areas by the director, depending on present and predicted ambient air quality, population density, topographic and meteorological conditions and other factors. These areas would be subject to more stringent regulations.

The state's regulations include sections on compliance schedules, source registration, odors, fugitive dust, sulfur dioxide, hazardous substances, combustion and general process sources, as well as separate sections on the following sources: wigwam burners, asphalt batching, hog fuel boilers, orchard heaters, grain elevators and catalytic cracking units. There are separate regulations for primary aluminum plants, open burning, field burning, sulfite pulping, Kraft pulping, thermal power plants, chemical wood pulp mills, and suspended particulates.

The regulations which DOE has adopted for the ambient air quality standard is identical to the secondary National Ambient Air Quality Standards (NAAQS) for particulates with one exception of interest. Included in the standard is the possibility of variance from the standard in areas east of the Cascade Mountain Crest "in recognition of natural dust loading:"

(1) If concentrations, measured at approved background locations, exceed 30 micrograms per cubit meter of air on individual sample days, the concentration of suspended particulate matter measured at any primary air mass station shall not exceed 120 micrograms per cubic meter of air plus background as a maximum 24-hour concentration not to be exceeded more than once per year.

(2) If concentrations, measured at approved background locations, exceed 20 micrograms per cubic meter of air as an annual geometric mean, the concentration of suspended particulate matter at any primary air mass station shall not exceed 40 micrograms per cubic meter of air, plus background, as an annual geometric mean.

The ambient air quality standards for particulates that were promulgated by the PSAPCA under Regulation I are identical to those of the DOE; and, since the region is west of the Cascade Mountains, it has no exempted areas. However, an additional standard for particulate has been adopted which regulates the level of fallout based upon the area which is being measured:

(1) Ten grams per square meter per month (10 $g/m^2/mo$) in an industrial area; or

(2) Five grams per square meter per month (5 $g/m^2/mo$) in an industrial area if visual observations show a presence of wood waste and the volatile fraction of the sample exceeds 70 percent.

(3) Five grams per square meter per month (5 $g/m^2/mo$) in residential and commercial area; or

(4) Three and one-half grams per square meter per month (3.5 $g/m^2/mo$) in residential and commercial areas if visual observations show the presence of wood waste and the volatile fraction of the sample exceeds 70 percent.

Regulation I includes general policy and implementation sections as well as rules governing ambient air quality and required control measures. It

regulates the sulfur content of fuel, odors, and emissions of sulfur oxides, particulates, and oxides. The general regulation adopted by the agency contains provisions requiring the registration of sources and a notification of construction to be filed for any new construction. The agency has the authority to deny construction upon finding that the new facility will result in a violation of the standards adopted by the agency.

As the controls adopted by the PSAPCA are generally equivalent to or more stringent than those of the DOE, they are the ones summarized below.

Open Burning — Open burning is restricted, depending on location, purpose, air pollution potential and the material to be burned. Small fires on residential property are generally allowed, provided that the material to be burned is not prohibited material and depending on the proximity of other structures.

Visible Emissions — After July 1, 1975, visible emissions cannot be darker than No. 1 on the Ringelmann chart (20 percent opacity) for periods greater than 3 minutes in any 60 minutes.

Refuse Burning — After June 30, 1975, emissions from incinerators are limited to 0.10 grains per standard cubic foot of exhaust gas, adjusted to 12 percent carbon dioxide. Incinerators must be of the multi-chambered design.

Fuel Burning — Emissions from equipment existing before the effective date of the regulations are limited to 0.10 grains per standard cubic foot of exhaust gas adjusted to 12 percent carbon dioxide. For equipment installed after 10 October 1973 emissions are limited to 0.05 grains per standard cubic foot. The emissions from existing fuel burning equipment using wood residue cannot exceed 0.20 grains per standard cubic foot; the emission standard for new facilities is 0.10 grains per standard cubic foot.

Manufacturing Processes — The allowable particulate emissions for manufacturing processes are presented graphically in Figure 12 on a process weight rate basis. The further restriction that emissions not exceed 0.10 grains per standard cubic foot for existing installations and 0.05 grains per standard cubic foot for new facilities is also applied.

Fugitive Dust — Reasonable precaution must be taken to prevent particulate matter from becoming airborne.

The plot of the PSAPCA general process regulation in Figure 12 is superimposed on a graph which represents the maximum and minimum controls currently being applied in the U.S.[4] The dashed lines in this figure represent the most (least) stringent of the regulations in each size category and, as such, do not reflect the controls in any one jurisdiction. The shaded area in this figure reflects the arithmetic mean, plus and minus one standard deviation, of the 14 cities reviewed under this study. This figure indicates that the process weight rate regulation for the Puget Sound AQCR is much less stringent than may be reasonably expected. In fact, the PSAPCA regulation for particulate emissions for industrial processes was the least stringent of the process weight rate regulations in the 14 cities studied for a process weight rate greater than 4000 pounds per hour.

Similar reviews were conducted for regulations governing fuel burning, incinerators, and fugitive dust. The PSAPCA regulation was converted to a pounds per 10^6 Btu rate and plotted in Figure 13 on which a relative stringency measure had been graphed. The emission standards for fuel burning equipment are more stringent than the average for facilities with less than 400 million Btu per hour heat input and somewhat less stringent, relatively, for the larger size ranges.

The regulations for visible emissions and incinerators were found to be comparable with most other areas with incinerator controls being perhaps a bit more stringent than average for the smaller sizes (< 100 tons per day).

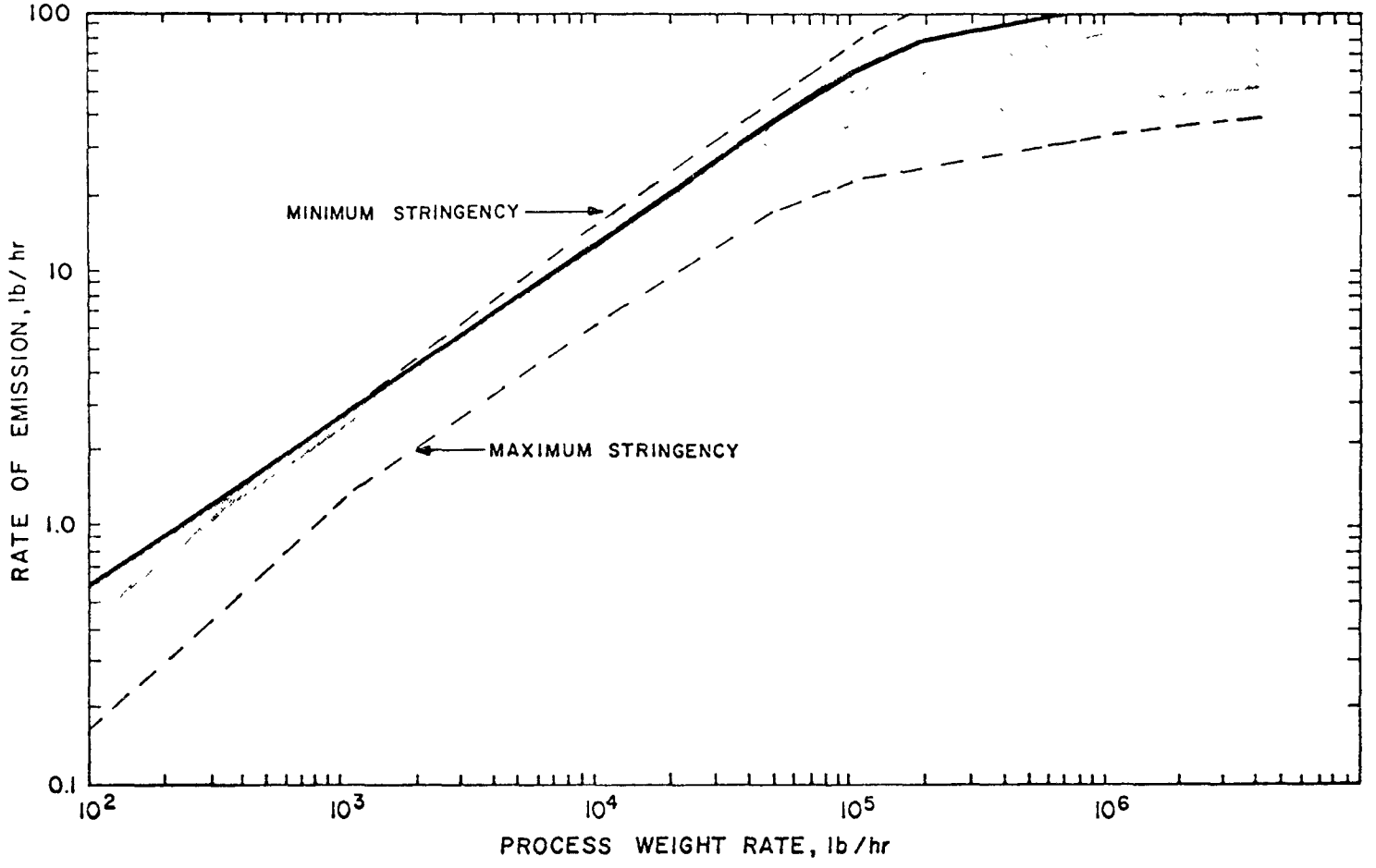


Figure 12. Comparison of stringency of the particulate emission regulation of PSAPCA with other controls nationwide — general processes

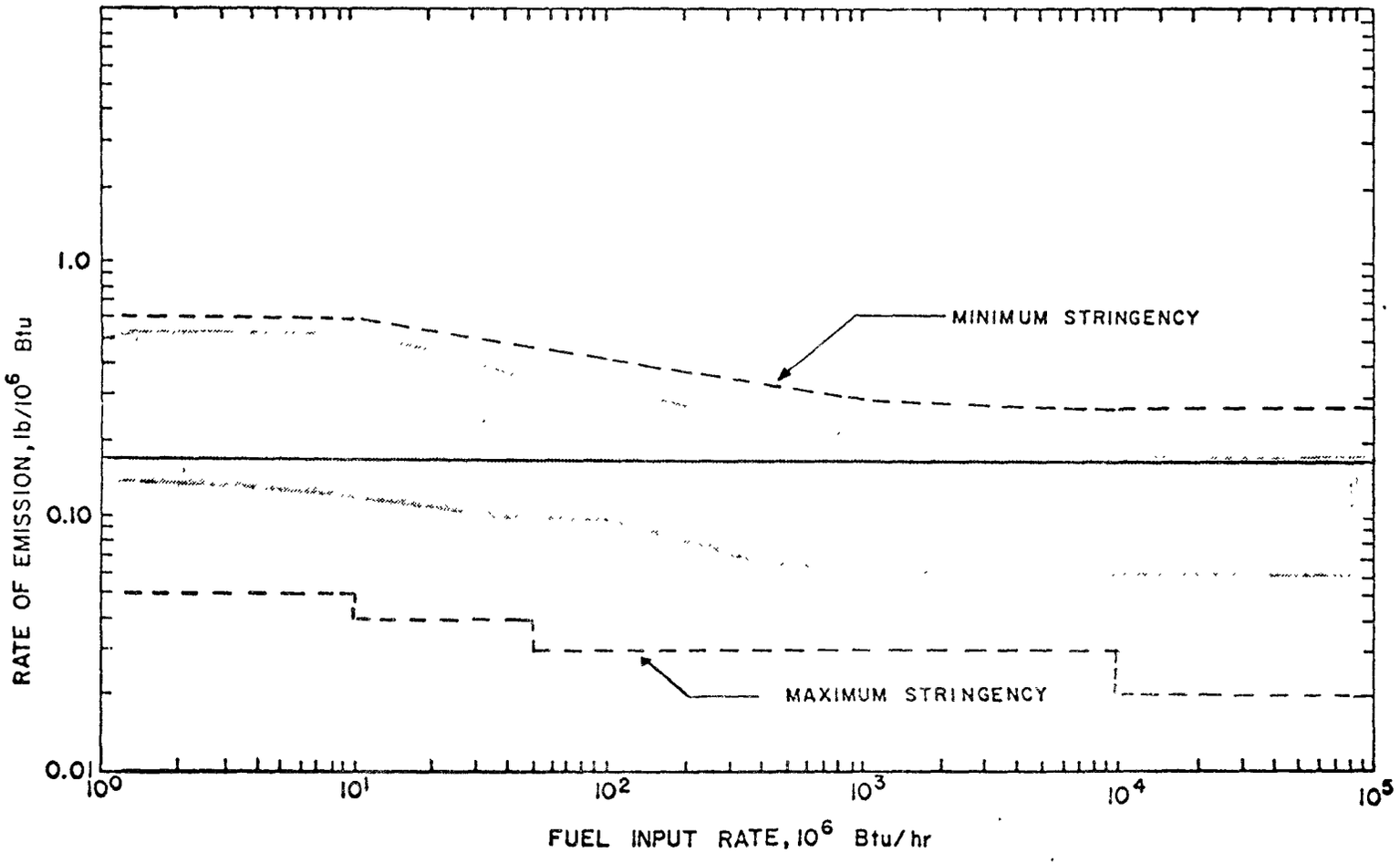


Figure 13. Comparison of stringency of the particulate emission regulation of PSAPCA with other controls nationwide — fuel burning

Surveillance Procedures

The surveillance of sources and enforcement of regulations in the Puget Sound AQCR are maintained by use of several techniques including inspection, registration of sources, notices of construction, and field surveys. The general program for enforcement by the PSAPCA is given below.[5]

Inspection

Field inspectors perform inspections on processes subject to regulation under Air Pollution Control regulations and standards. The types of inspections are:

1. Violation inspection
2. Follow-up and reinspection
3. Inventory inspection
4. Investigation of complaints
5. Miscellaneous inspections such as equipment breakdown, follow-up on variance conditions, compliance schedules, engineering final field reports, etc.

Complaints and inspection orders are relayed to field inspectors via two-way radio contact. The frequency of inspection depends upon the type. Complaints and visible emissions are investigated as soon as possible. Follow-up and reinspection on violations and variance conditions, status of compliance schedules, and inventory inspections are done on a scheduled basis. Each inspector conducts systematic coverage of his control area for optimum use of time.

Appropriate records of all types of inspections are made on appropriate forms and routed to source files. A file is initiated on the first contact with a source and maintained thereafter until retired for cause.

Violations

When evidence of a violation is established, a Notice of Violation is served in person by a field inspector or sent by certified mail, depending upon circumstances. The notice asks that the Agency be advised in writing within 10 days of the corrective action taken or to be taken to prevent continued or recurrent violations. If the source management fails to respond within the time specified, a second request for reply is

sent over the signature of the Supervising Inspector before resorting to one or more of the legal enforcement alternatives that are available. The most frequent legal action taken is issuance of a civil penalty.

Registration

Registration of active sources is accomplished on submission of one or more forms containing specific information regarding process equipment data, physical data, air pollution control equipment, combustion control devices, fuel used, fuel consumption and unit operation. Sources who do not respond when advised of the registration requirement are followed up in the field by air pollution inspectors.

Information obtained on the registration forms is entered onto load sheets for key-punching into computer cards, thereby creating a data bank from which emissions inventory, summaries, and other computer printouts can be generated at will.

Notices of Construction

Detailed plans and specifications submitted with Notices of Construction are reviewed by the Agency's engineers. Based upon plan evaluation the Agency will issue either an order or approval of an order to prevent construction. Failure to submit a Notice of Construction is a violation of Regulation I. In addition to the assurance that new sources will meet emission standards, a Notice of Construction system provides continuing help for the updating of source registration and emission inventory. Detailed information for this purpose is required to fulfill the Notice of Construction requirement.

Compliance Schedules

Compliance schedules are initiated by supervising inspectors on the recommendation of field inspectors. The air pollution source is supplied with a compliance schedule form and requested to submit the form by a fixed date. If the form is not submitted to the Agency on time and sufficient reason has not been presented, the supervising inspector recommends enforcement action.

On return of the compliance schedule form to the Agency, the supervising inspector forwards it to the Chief of Enforcement with recommendations. The Chief of Enforcement in turn forwards a copy of the schedule for Engineering review. On determining the proposed control methods are adequate for compliance and the completion dates are reasonable, the source is notified by letter that the compliance schedule is accepted, and that the Agency will not initiate legal action against the violator as long as the terms of the compliance schedule are met.

Variances

Applications for variances are made on forms supplied by the Agency and are accompanied by supporting data as required by the Board. Public notice of all hearings are placed in a newspaper officially designated by the Board and in a daily newspaper in the county from which the application is made. The Engineering Division studies the merits of the application and prepares a draft of staff recommendations to the Board. After hearing the applicant, the staff recommendations, and any other pertinent testimony, the Board directs its legal counsel to prepare a resolution containing the findings and decisions of the Board, for signature by the Chairman. This written notice of disposition is mailed to the applicant and made part of the record.

A review of the PSAPCA enforcement program indicated that it was quite an active program which apparently maintains complete and up-to-date files on most sources in the area. There are four inspectors in King County who visit each plant at least once per year to update the emission inventory. Twenty to thirty source tests are conducted each year to check compliance, often after construction of a new source. Within the last couple of years most major sources have come into compliance.

NETWORK DESIGN

Because of the widespread nature of the AQCR and the multitude of neighborhoods that would be involved, no analysis of the monitoring network (Figure 3) for the whole AQCR was attempted. Instead, attention was directed at the monitoring network operated by the PSAPCA in and around Seattle. The network reviewed was found to be fairly well designed in terms of neighborhood selection and monitor siting with the exceptions noted below.

From the standpoint of emissions, topography, and associated local meteorology, the area of maximum concern is the Duwamish valley. This has been confirmed both by monitoring and by modeling and the monitoring effort has accordingly been concentrated along the valley. Monitors are spaced at intervals of about 1 mile from the mouth of the valley where industrial

emissions are concentrated to the agricultural and residential areas to the south. It is felt that this area has an appropriate density of monitors.

The monitoring sites reviewed in the course of this study are grouped in Table 8 according to the predominant characteristic of the neighborhood of each. This table also provides the height of each monitor, its slant distance from the nearest major road, the geometric mean for each station, and summarizes the siting comments for each monitor.

The primary difficulty noted was that the monitors in the center city area (Public Safety Bldg., Food Circus) were located much higher above ground that the other monitors visited. This increased height has been shown to produce lower readings than would be measured if the monitors were located at the more standard 15 to 25 feet above ground level. While the stations were not inappropriately high according to guidelines, lower sites would have been more in line with the other monitors in the network.

In addition to the sites listed in Table 8, the location of a previous monitor that had been discontinued was reviewed. This site was also in the Duwamish valley at a fire station in the 3200 block of 4th Avenue and was recording the highest concentrations of any monitor in the period 1968 to 1970. In the preparation of the SIP, this site was deemed inappropriate because its values did not fit with the modeling results. The site visit did not indicate any major sources that may have been impacting on the monitor to cause the higher readings.

A similar situation is currently being studied at the DOE site on E. Marginal Way. This site recorded the highest TSP value (102 $\mu g/m^3$) in the Puget Sound AQCR and is being considered for relocation because of its high values which appear to result from its proximity to the heavily traveled road. The DOE is operating another monitor 100 yards back from the road for comparison purposes; to date, its values have averaged almost 40 percent lower than the site closer to the road.

Table 8. CHARACTERISTICS OF SEATTLE MONITOR SITES REVIEWED

Neighborhood	PSAPCA No.	Location	1974 annual geometric mean, $\mu g/m^3$	Height above ground, ft	Slant distance, ft	Siting comments
Residential	T1	McMicken Heights	35	15	30	Exposure good, only source would be residential home heating and traffic, on top of hill away from Duwamish Valley
	K59	Duwamish Fire Station	48	25	300	Exposure good, located in Duwamish Valley down from sources, almost rural surroundings
Commercial — Center City	K1	Public Service Building	63	80	85	Seven stories rise to the NNW of monitor, 4 foot parapet 12 feet from monitor, heavy traffic in area
	K10	Food Circus	45	70	120	On hill above city and Duwamish Valley, in park, expect high readings only during inversions
Industrial	K55	Duwamish Valley, 4500 Block E. Marginal	68	20	25	Openly located in industrial area, not source specific but probable influence from E. Marginal Way to east of monitor
	K60	Harbor Island	77	15	75	Well located in center of major industrial area, junky area to north, shipyards to east, cement plant to south, steel to SW
	K99	Duwamish Valley DOE site	105	15	25	Possible interference from low trees 5 feet above monitor to west, heavy traffic volume to west

Such movements of monitors which measure high levels of particulates raise some questions about the siting of monitors and the interpretation of the resulting citywide trends. While for most purposes monitors should not be located in areas heavily influenced by a single source, the relocation of those monitors recording high values may provide a picture of the TSP situation much less serious than actually exists. Though the moves may be totally appropriate, guidelines for a documentation of these siting decisions should be available.

METEOROLOGY AND CLIMATOLOGY

The general meteorology of the area appears to be one of the factors prominent in determining the TSP levels in Seattle. Numerous meteorological parameters were investigated for Seattle including the yearly and monthly variations in precipitation and space heating demands (degree days), the average wind speed and number of days of precipitation each month, and other ventilation characteristics of the region such as mixing height, inversions, and the movement of air masses through the region. Those factors which are known to be most influential for air quality levels — ventilation and precipitation — were found to be the same ones with the greatest seasonal variation. However, the analyses conducted indicated that the influence that precipitation has on the yearly and monthly TSP patterns in Seattle far outweighed any of the other meteorological factors. Therefore, the discussion below focuses primarily on precipitation and its impact after a short review of some of the other factors. Supporting data on the meteorological parameters are presented graphically in the appendix.

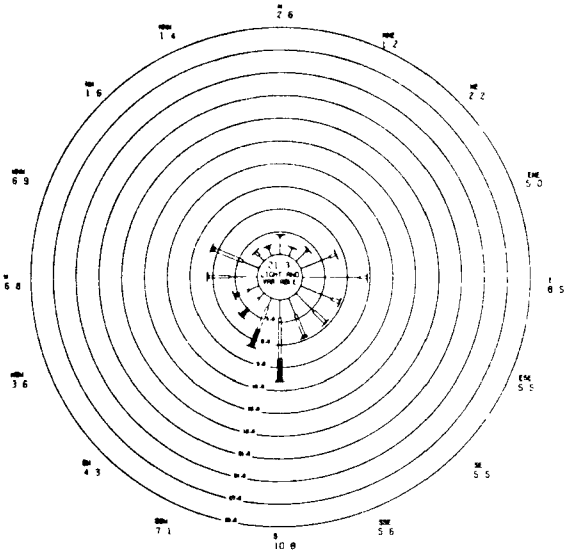
Ventilation Characteristics

The topography of the region significantly affects the climatology and meteorology, having its major effect on the ventilation. The middle-latitude west coast climate of the Seattle-Tacoma area is modified by the imposing barrier of the Cascade Range on the east and to a lesser

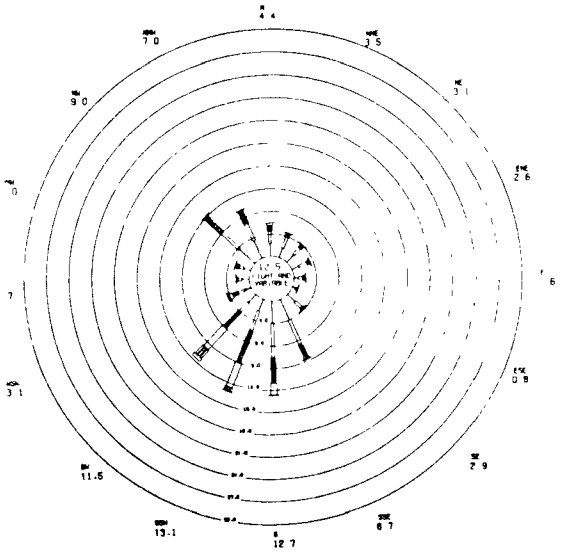
extent by the comparatively short Olympic Range to the west and northwest. The Cascades are very effective in excluding continental influences from the Seattle-Tacoma area, particularly in keeping cold air from draining westward during the winter. Occasionally the pressure distribution will result in a southward flow of cold air from Canada west of the Cascades and it is only under these conditions that extremely cold weather strikes the southern Puget Sound area. Since the southern end of the Puget Sound trough is open to the southwest winds generated by storms moving in off the ocean, the prevalent wind for the storm season of the winter and spring months is southwest. The trough of the Puget Sound is also open to the north allowing for strong winds from the northerly quarter during occasionally severe winter storms. During the summer months, the relatively light winds are influenced by the land- and sea-breeze effects as well as the channeling of the topography.

The wide variations in wind speed and direction that occur at different sites in the area can best be seen by looking at some of the wind roses at several sites operated by the PSAPCA. Wind roses at three sites around Seattle are given in Figure 14. In these roses, representing 1974 winds, each spoke points in the direction from which the wind blows. The length of each segment of a spoke indicates the relative frequency of winds of different speeds. Using the scale located to the lower right of the figure, these lengths may be converted to percentages of the total observations. The percentage frequency of winds from any given direction (without regard to speed) is expressed numerically beneath that direction on the perimeter of the roses. The percentage frequency of light and variable winds (winds less than 1.5 knots) is shown in the center of the rose.

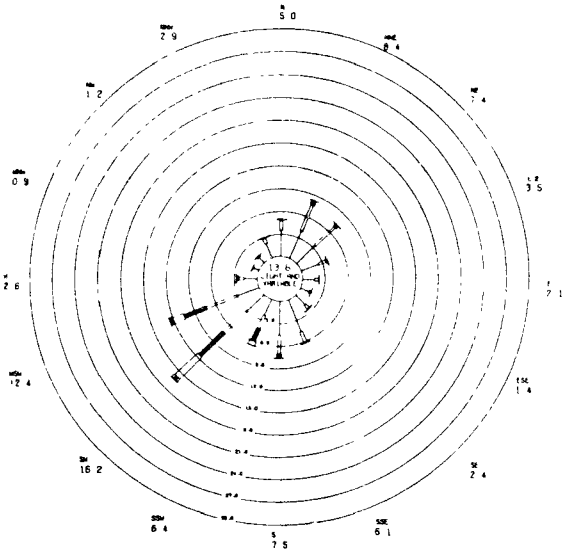
These roses indicate that, within 20 kilometers, one may expect to find significantly different wind patterns. Of particular interest is the high percentage of light and variable wind conditions. Such conditions are often associated with poor mixing and resulting high levels of particulates For example, on many summer days light north winds pass over Elliot Bay



(a) NWS Urban Site, Station No. K100



(b) Duwamish Valley, 4500 Blk. E.Marg. Way, Station No. 55



(c) McMicken Heights, Station No. T1

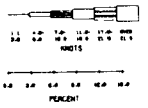


Figure 14. Wind roses at three sites around Seattle

into the Duwamish Valley and the air cooled by the water causes warmer air to rise. In such a manner a thermal lid is placed on the dispersion of air pollution. This condition compounds the effect of normal nighttime radiation inversions that occur during the same period of the year. The winds at the mouth of the Valley near Harbor Island are influenced by air currents from the Sound and this fact makes the Valley difficult to model.

For any given wind speed, the greater the mixing height, the greater the volume of air available to dilute the pollutants and therefore to lower their concentrations. The maximum vertical depth of the atmosphere available in any day for the mixing of polluted air usually occurs in the afternoon following the period of maximum surface heating and is known as the maximum mixing height. The minimum mixing height is associated with minimum surface temperatures and usually occurs at or around sunrise. From the data that was given in Table 1, it is apparent that this pattern of higher afternoon mixing heights is not followed in Seattle during the winter months. Instead, the afternoon mixing height is almost 13 percent lower than that calculated for the morning. In addition, the percentage of frequency of low-level inversions is higher in the winter and fall than during other seasons and the persistence of these inversions is also much greater (see Table 9).

While both of these conditions (inversions and mixing heights) would tend toward increased concentrations of particulates in the winter, such a trend is not seen due to the fact that the majority of precipitation also occurs during this time.

Table 9. PERCENTAGE OF FREQUENCY OF LOW-LEVEL INVERSION[a] (SEATTLE-TACOMA INTERNATIONAL AIRPORT)

Season	4 p.m.	7 p.m.	4 a.m.	7 a.m.
Fall	9	19	69	32
Winter	24	13	63	31
Spring	0	6	54	30
Summer	1	3	57	19

[a]Hosler, Charles R., 1961: Low-level inversion frequency in the Contiguous United States. Monthly Weather Review, vol. 89, Sept., 1961, 319-339

Precipitation

Precipitation is normally considered to be the meteorological parameter which has the maximum impact on air quality levels, aside from ventilation rate. It helps to clean the air of particulates through washout and rainout and can suppress the rise of pollution levels by wetting down particulates that would be resuspended if dry or even washing particulates off the streets into sewer systems if the rain is heavy enough. The expected relationship is one of inverse correlation with the pollutant concentration. Seattle has a well defined seasonal pattern of precipitation with as much as eight times the precipitation in the winter months than in the summer months on a normal basis. In 1974, this trend was even more pronounced with only 0.01 inch of precipitation recorded in August and 7.78 inches in January.

Because of the expected inverse relationship between TSP concentration and precipitation, Figure 15 provides an inverse graph of the precipitation during 1974 by dividing the average monthly (annual/12) by the actual monthly precipitation in 1974. Overlayed on this graph is a plot of the average monthly geometric mean for all the monitors in King County that operated for the full year. This countywide average is utilized to discount major influences that certain activities may have on individual sites.

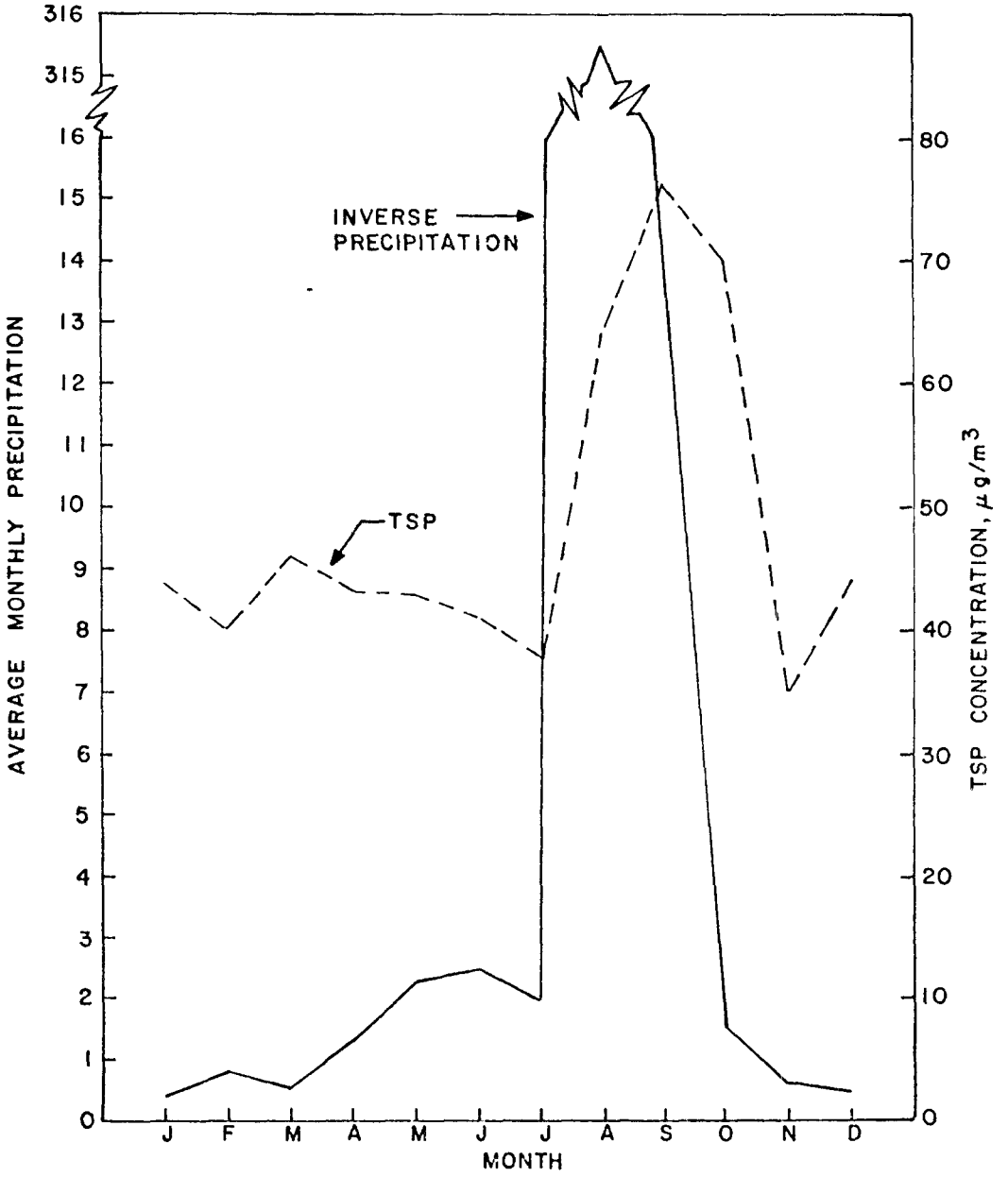


Figure 15. Monthly inverse precipitation — 1974, Seattle

The degree to which the inverse precipitation graph and the TSP concentration rise and fall together provides an indication of the correlation of the two parameters. The most pronounced characteristic of the precipitation plot is closely paralleled by the seasonal pattern in TSP.

This correlation must be considered even more significant since all other meteorological parameters (except for average monthly windspeed) would tend to indicate a pattern with higher TSP levels in the winter than in the summer. The fact that the pattern is not as closely paralleled during the rainier season may be partially explained by other meteorological factors such as ventilation characteristics. In addition, the daily pattern of precipitation may be used to better understand the impact that rainfall has on TSP levels. While Figure 15 would indicate that the rainfall in October was a sufficient amount to have a lower average TSP concentration for that month, almost all of the precipitation in October 1974 occurred within the last 4 days of the month and the other significant rainfall that month came in a downpour lasting about 5 hours on 1 day.

Just as precipitation has an impact on the short-term seasonal pattern of TSP concentrations, it can also affect the longer-term annual trends if the total level of precipitation varies significantly from year to year. In recent years in Seattle, the precipitation has fluctuated more than 20 percent on either side of the normal amount. This has led to differences of as much as 50 percent between 2 consecutive years. Again to provide an easier comparison of the correlation between the two parameters, a graph of the inverse (normal/yearly) precipitation and TSP levels measured at the NASN station on the Public Safety Building in Seattle between 1957 and 1974 is plotted in Figure 16. While there are obvious discrepancies in the correlation, this figure indicates that the precipitation has been having a measurable impact on the TSP concentration on a yearly basis. Of particular interest is the correlation in the most recent years which may be one explanation for the rise in TSP levels at a time when more sources were coming into compliance with the PSAPCA regulations.

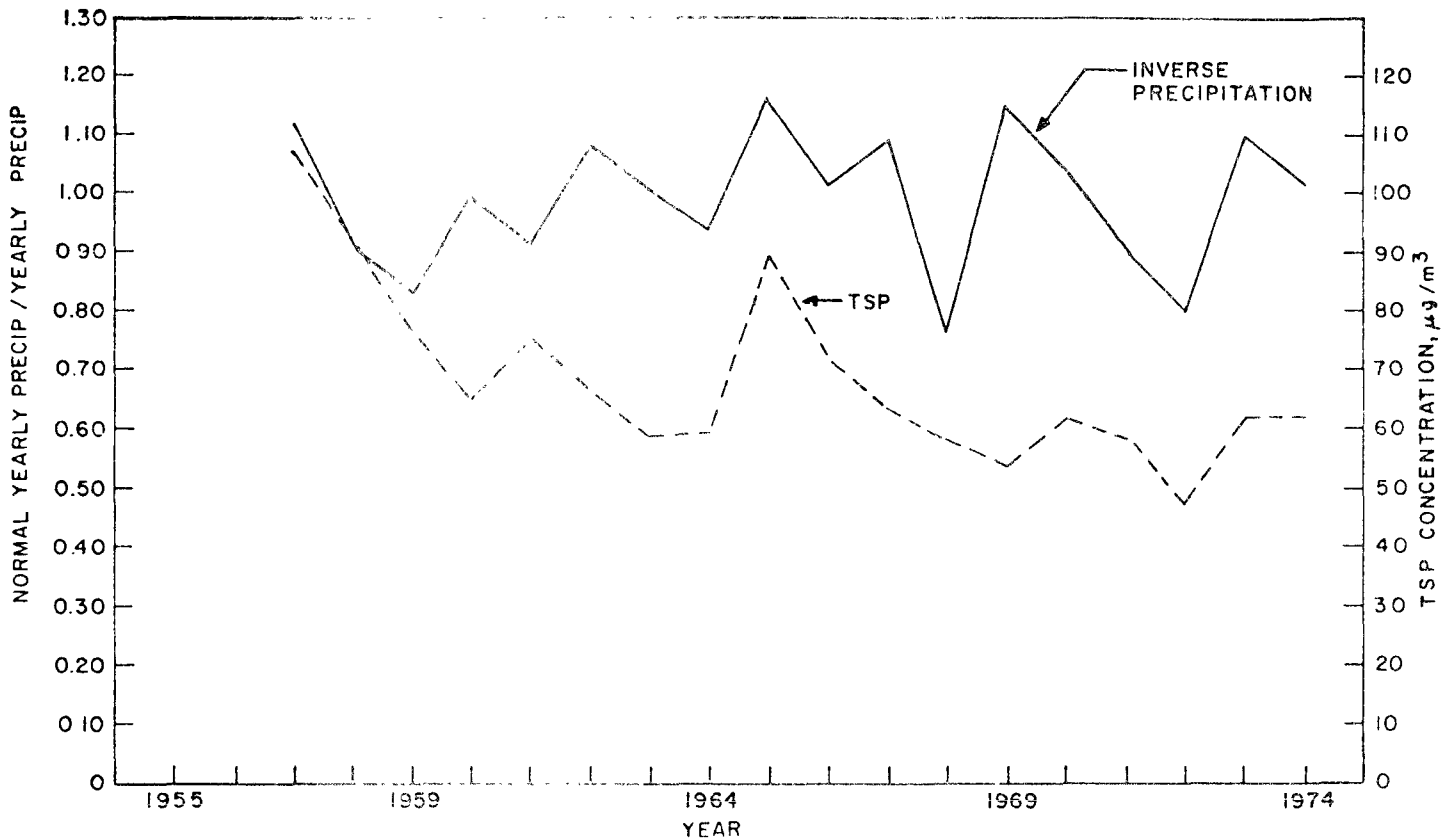


Figure 16. Normal/yearly precipitation and TSP concentration in Seattle, 1957 to 1974

URBAN ACTIVITY

Beyond industrial activity, fuel combustion, and other traditional pollution sources, it is increasingly apparent that in many locations other urban activities, such as routine traffic and construction and demolition activities, are a more major part of urban pollution problems than had been previously recognized. The primary area of interest in Seattle, because of published reports on the subject, was the problem of fugitive dust in the Duwamish Valley. It had been expected that data would be available on changes in concentration due to paving and road stabilization measures. However, this activity had not been completed and was too recent to have established any trends in TSP levels.

The other source of data that was identified for analysis of urban activity was the comparative study of the impact of the proximity of monitors to a heavily traveled street being conducted by the DOE. One of the hi-vols was located on top of an instrument shelter (height — 15 feet) immediately adjacent to E. Marginal Way, while the second hi-vol was located at the same height on top of a flat-roofed, one-story building set back approximately 100 meters from the street. The closer instrument shelter has a hedge-row of trees between the street and the monitor that provides some screening of street-generated particulates. Apart from this row of trees, there are no significant obstructions or local sources between the street and the second hi-vol.

Forty sets of paired measurements taken over the period from October 1974 to June 1975 are available for analysis. On 37 of the observation days, concentrations adjacent to the street exceeded those measured 100 meters from the street, with geometric mean concentrations at the two locations being 89 and 55 $\mu g/m^3$ respectively. These paired observations are plotted in Figure 17 to demonstrate the degree to which the monitor closest to the street is measuring higher levels.

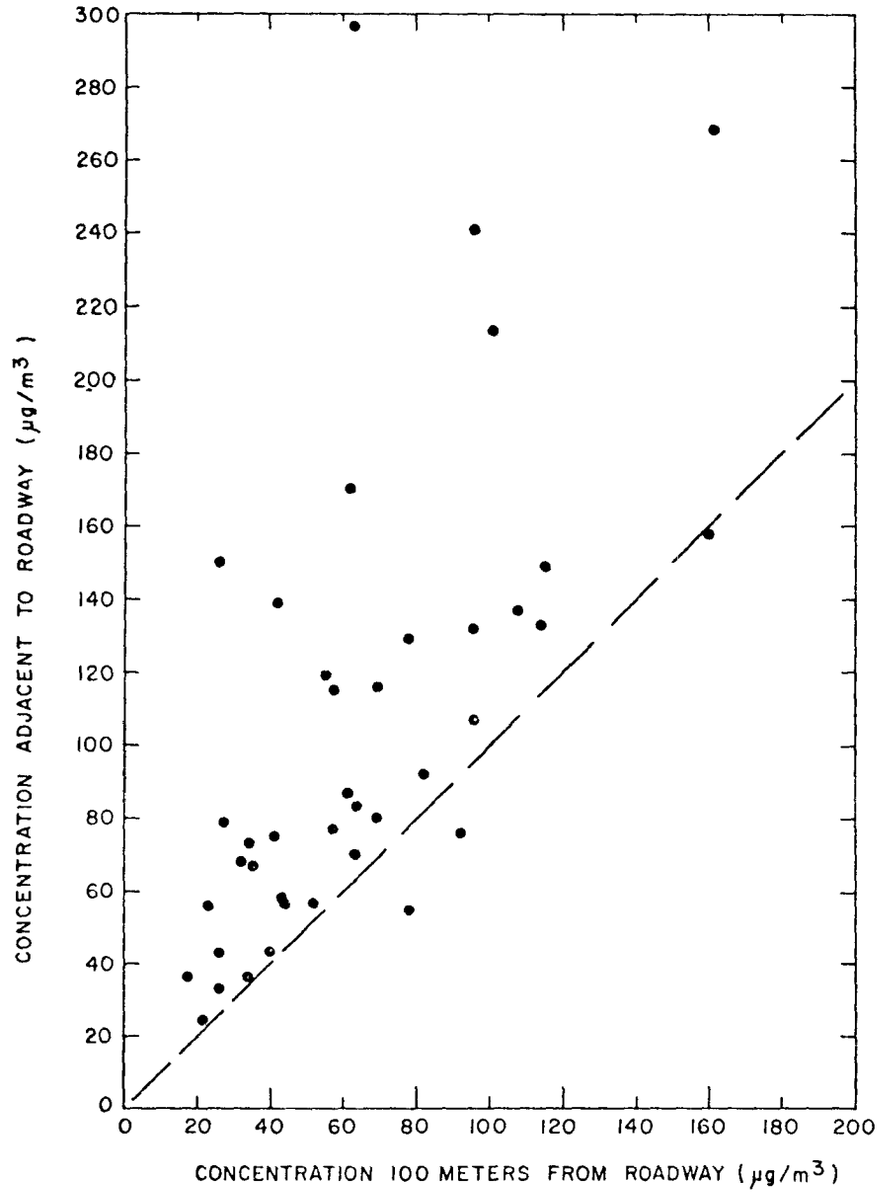


Figure 17. Comparison of TSP levels at two sites near E. Marginal Way, Seattle

While this data alone tends to indicate that the road is acting as a significant source, other analyses, including correlation with precipitation, wind speed, and wind direction, failed to indicate any of the effects expected if the road were actually a source. The lack of such effects is not conclusive evidence that the road is not the major cause of the increased values noted but rather that further data and consideration is needed. This is being pursued for the final report for this project.

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4. Martin, W. and A. C. Stern. The World's Air Quality Management Standards. Volume II: The Air Quality Management Standards of the United States. U.S. EPA, October 1974. EPA-650/9-75-001-b.

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SECTION III

CONCLUSIONS

Both the primary and secondary standards for total suspended particulate are exceeded in the Duwamish-Harbor Island area of Seattle, and did not meet the 1975 attainment date as required by the State Implementation Plan. The portion exceeding the primary standards extends from the south end of Boeing Field to the northern portion of Harbor Island. The area exceeding the secondary standards extends farther south than Boeing Field, and on the north includes the Seattle Central Business District. This is a relatively localized problem in terms of King County as a whole, resulting from the high density of large sources in an adverse topographical setting.

According to the analyses in the EPA King County study[1] which assumed a 25 $\mu g/m^3$ influence from particulate from outside the area, the following estimated emission reductions would be necessary for standard attainment in the vicinity of the following stations.

	Primary	Secondary
Duwamish	35 percent	54 percent
Harbor Island	4 percent	33 percent
Municipal Building	—	8 percent

Also according to this study, the Compliance Data System (CDS) projects that by 1977 these necessary reductions will not be achieved. By that date, an additional point source emission reduction of only 24 percent is anticipated in the Duwamish area. The analysis of the regulations

given in Section II of this report tends to indicate that there is still potential for reducing emissions through more stringent regulations, especially process weight rate, without becoming unreasonable. Tightening of the process weight regulation to the studywide average stringency would result in as much as 40 percent less emissions from major sources.

Meteorology has been a complicating element in any planning for attainment strategies. The season pattern in precipitation is such that the controls are primarily needed to keep down the elevated levels in the dry summer-fall season as opposed to the winter when additional emissions from space heating would be expected to raise the TSP levels. Because of this seasonal variation, the most appropriate, cost-effective strategies may not be those relating to traditional control of industrial point sources. Rather, it may be more reasonable to put emphasis on the control of fugitive dust emissions during the several months of the year that the problem is prominent. Further study in this area is obviously warranted.

Precipitation may also have been a confusing factor in the review of progress to date. Between 1969 and 1972, precipitation would have impacted on the TSP levels to the extent that a downward trend was established. Since 1972, however, the precipitation has decreased and TSP levels have risen — an unexpected occurrence given decreasing emissions. (The TSP trend plot given in this report is considered more pertinent than the one in the PSAPCA Air Quality Data Summary because a consistent set of monitors was used for establishing an average.)

With respect to these problems in the study of the area, the PSAPCA appears to have recognized them and is currently attempting to determine the relative contributions of fugitive dust and industrial emissions to the high particulate levels observed along the Duwamish Valley. The agency has devoted more than the normal amount of effort and resources in the monitoring and modeling of the area. In addition, the enforcement division has an active, well-structured program. As in most areas of the

county, further work is needed in tracking emissions from different facilities on a year-by-year and even a seasonal basis. The work underway at the PSAPCA directed at the computerization of the emission inventory for cross-referencing between years should be most helpful in this regard. The apparent lack of data on the spatial distribution of area sources needs to be resolved. Studies undertaken by Roberts, Boeing, and others have helped to provide much of the understanding of the problem area.

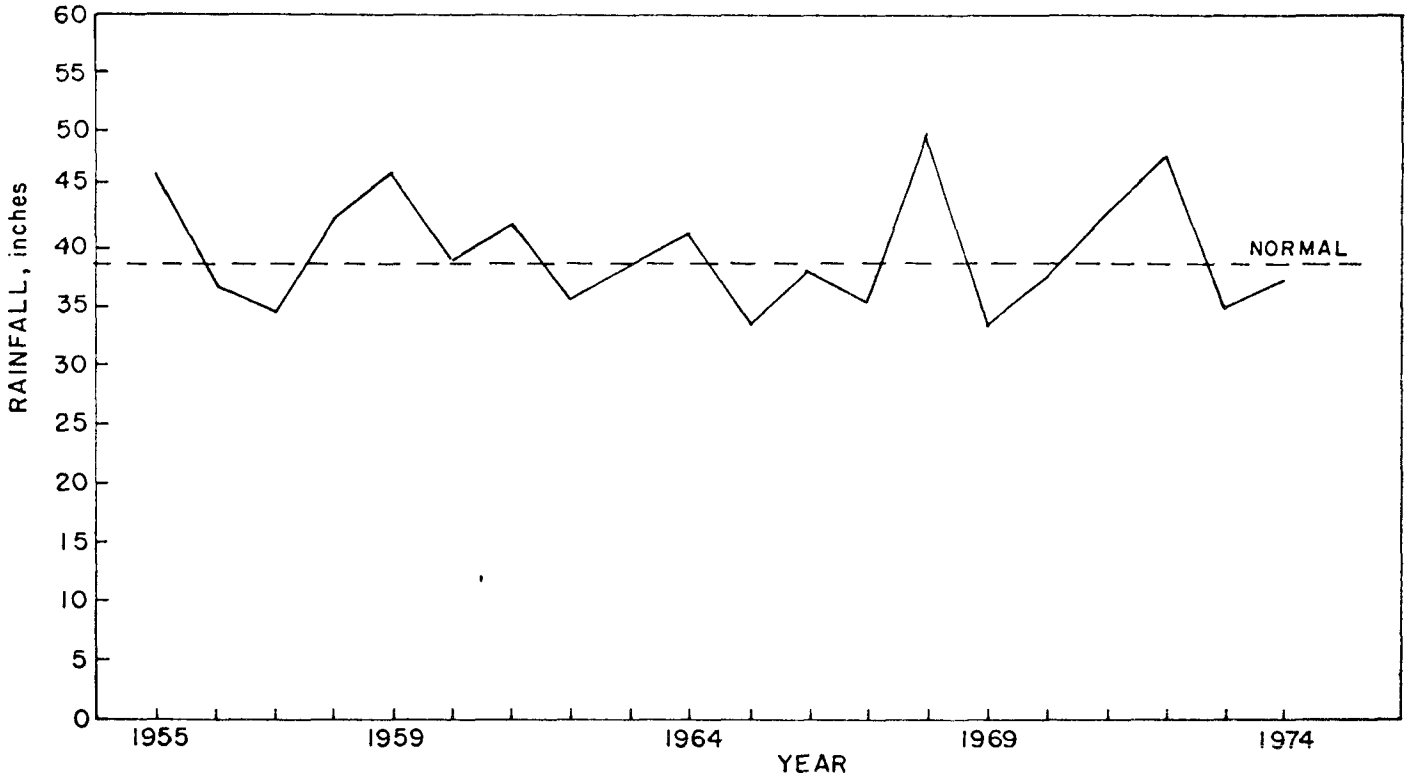

Figure A-1. Yearly rainfall in Seattle

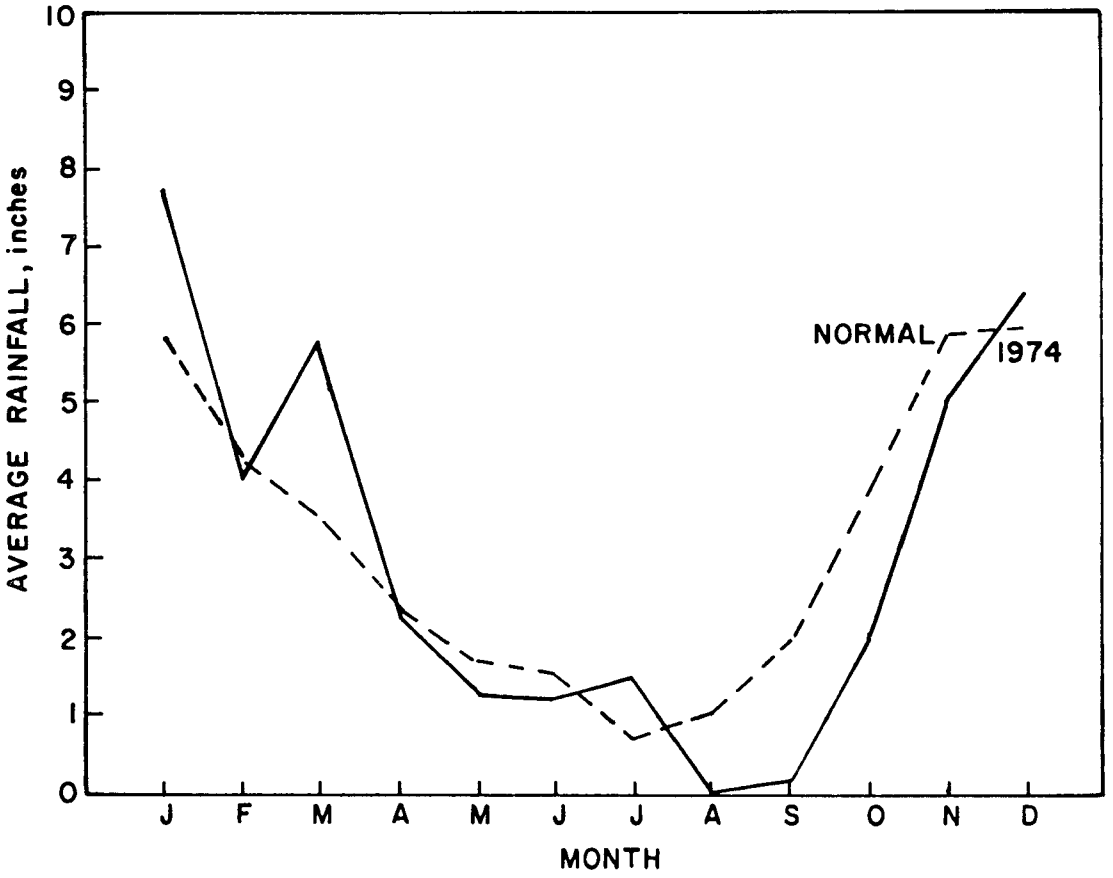

Figure A-2. Monthly rainfall in Seattle

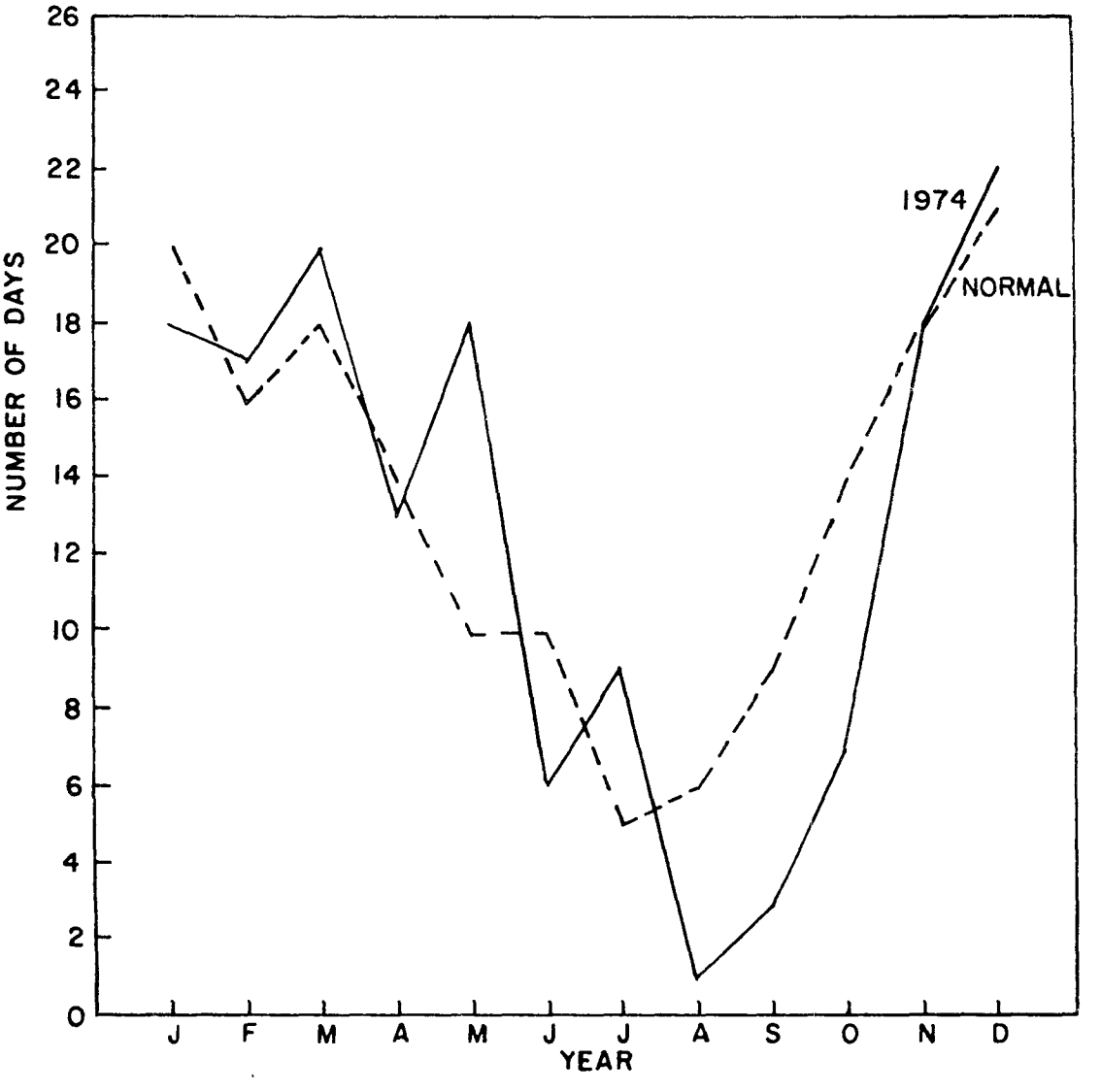

Figure A-3. Monthly number of days of rain in Seattle

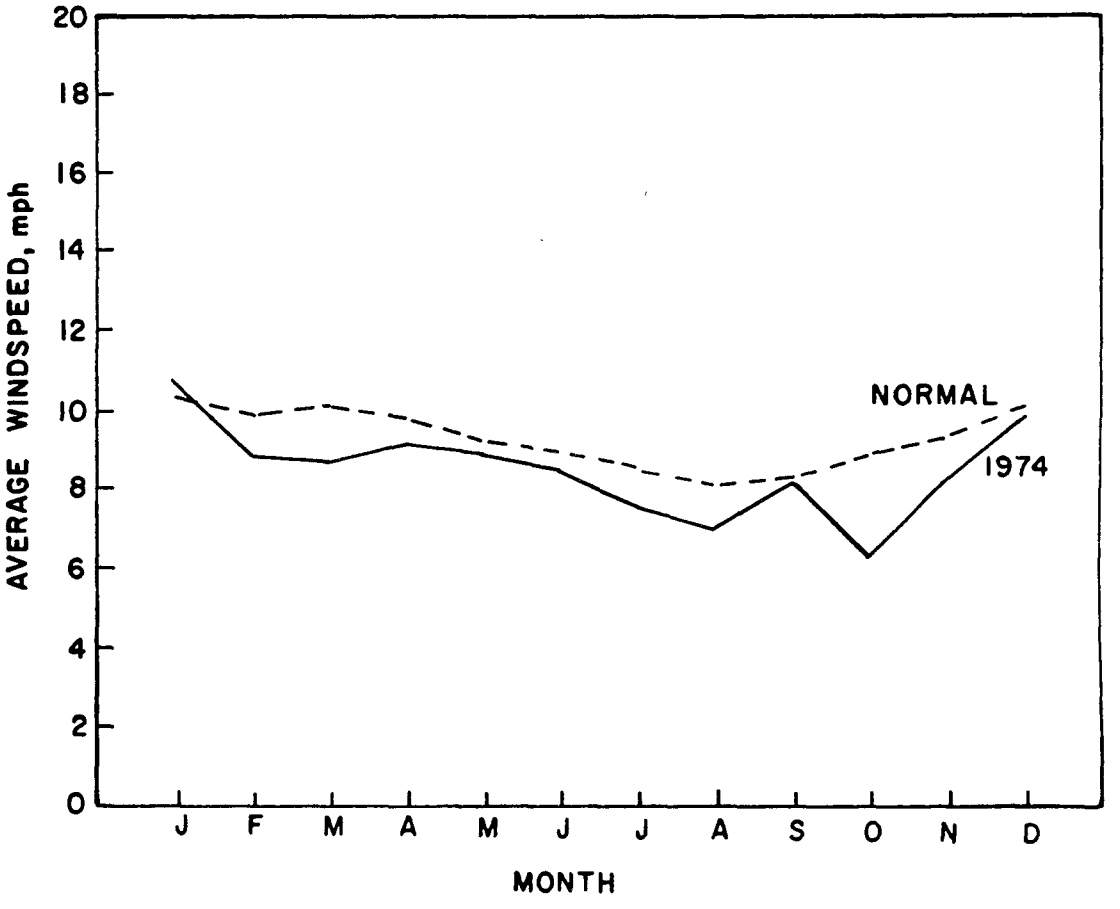

Figure A-6. Monthly wind speed in Seattle

APPENDIX B

PARTICLE CHARACTERIZATION

For most of the study cities members of the GCA study team acquired hi-vol filters from the 1974 filter banks of the cognizant local agencies. In addition, several filter samples for 1974 and selected earlier years were obtained from state and federal filter banks. Although some filters underwent chemical and/or detailed physical analysis, the principal purpose of obtaining filters was to utilize optical microscopy to identify each of the constituents that comprised more than five percent of the particulate mass. The selected filters, which were representative of several different site types and TSP levels within each study area, were returned to a clean room at GCA/Technology Division and carefully inspected for artifacts and evidence of sampler or filter malfunctions.

Each filter was then assigned a randomly generated five digit number which served as the only identifier for the filter sample so that each analyst had no information concerning the city, site, TSP loading or probable local sources associated with the sample. Furthermore, the use of two laboratories for the microscopy, coupled with the randomly generated identifying numbers, permitted a fairly comprehensive quality control program in the form of blind replicate analyses. Since both laboratories utilized more than one analyst, these procedures resulted in as many as four microscopists observing samples from the same filter and, in some cases, the same analyst examining replicate samples from the same filter as many as three times.

The resuls of this quality control effort, which are presented in Volumes I and II, warn against relying very heavily on the results of any one filter analysis. However, the random match-up between analyst and filter sample should minimize systematic bias in composited results.

Twenty-three filters from six sites were selected for analysis in Seattle and the meteorological data from the Seattle-Tacoma Airport for the selected sampling days are summarized in Table B-1. To gain some insight into the contribution of secondary particulates, much of which is too small to be observed by the microscopists, the annual average sulfate and nitrate concentrations for the NASN site are shown in Table B-2. The results for each of the filters submitted for routine analysis are presented in Table B-3. The results for the filters at each site have been averaged to give a composite of the particulate composition as shown in Table B-4. Six filters underwent replicate analyses, and the results are presented in Table B-5.

The composite particulate characterization for all filters from Seattle that underwent routine analysis, presented in Table B-6, shows that minerals predominat but not to as great a degree as observed in many study cities. Only three cities had lower average percent minerals than Seattle. Quartz was the major mineral constituent observed (over half of the mineral content) followed by lesser but nearly equal amounts of feldspars and calcite. The DOE site, which recorded the highest TSP levels in 1974, showed somewhat larger than average amounts of minerals presumably because of its proximity to the highway.

The site with the lowest average percent minerals was the Public Safety Building (K-1) which seems to be consistent with the high sampler location (80 feet above ground). Oddly, this site also recorded the highest levels of rubber, an observation apparently inconsistent with the sampler location.

Table B-1. METEOROLOGICAL DATA ON SELECTED SAMPLING DAYS (SEATTLE-TACOMA AIRPORT)

Date	Precipitation, in.		Wind speed, mph		Wind direction, deg	
	Day of obs.	Preceding day	Average	Resultant	3-hour obs.	Resultant
6/10/74	0	0	8.1	6.6	20, 10, 350, 250 360, 310, 350, 20	360
6/28/74	0	t	5.6	3.2	120, 160, 200, 250 210, 240, C, 330	220
7/22/74	0	0	8.9	8.2	200, 160, 190, 220 220, 230, 230, 240	210
9/14/74	0	0	3.5	2.3	C, C, 300, 260 270, 290, C, 30	300
9/26/74	t	0	8.5	2.9	180, 130, 170, 220 160, 320, 340, 100	170
10/08/74	0	0	4.6	4.6	20, 10, 330, 10 290, 290, 30, C	350

Note: C = Calm
t = Trace

Table B-2. ANNUAL AVERAGE CONCENTRATION OF SULFATE AND NITRATE IONS AT THE SEATTLE, WASHINGTON NASN SITE NO. 491840001 ($\mu g/m^3$)

Year	Sulfate		Nitrate	
	Arithmetic mean	Geometric mean	Arithmetic mean	Geometric mean
1972	6.27	6.02	1.56	1.22
1973	6.69	6.53	2.36	2.09
1974	8.40[a]	8.19[a]	2.15[a]	1.94[a]

[a]Indicates insufficient data for statistically valid year.

Table B-3a. RESULTS OF FILTER ANALYSES FOR SELECTED SITES IN SEATTLE AND VICINITY (PUBLIC SAFETY BLDG. — NO. K-1 AND 6770 E. MARGINAL WAY — NO. K-99)

Site	Public Safety Bldg. — No. K-1									6770 E. Marginal Way — No. K-99								
Date	10 June 1974			14 Sept. 1974			26 Sept. 1974			22 July 1974			14 Sept. 1974			26 Sept. 1974		
TSP (g/m^3)	54			117			126			101			115			163		
Components	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm
Minerals	(3)			(3)			(6-)			(6)	<1-30	8	(8)	<1-45	14	(9-)	1-46	10
Quartz	1-	10-40	25	1+	5-40	20	2+	5-60	30	5+			6+			6		
Calcite							1	2-35	20				1-			1-		
Feldspars	2	5-40	25	1	2-50	20	1+	2-50	20							1		
Hematite							1-	1-15	7				1-			1		
Mica																		
Other													1-					
Combustion Products	(3-)			(6)			(3)			(0+)			(2)	<1-60	2	(1-)	<1-20	2
Soot:																		
Oil	2	5-100	25	2+	25-75	35	1-	5-75	35				2					
Coal																		
Glassy fly ash																		
Incinerator fly ash	1-	5-40	15	4-	50-300	150	2+	2-80	30									
Burned wood																		
Burned paper																		
Magnetite																		
Biological Material	(0+)			(0+)			(0+)			(2)		500	(0+)			(0+)		
Pollen																		
Spores																		
Paper																		
Starch																		
Misc. plant tissue																		
Leaf trichomer										2								
Miscellaneous	(4)			(1)			(1+)			(2)	5-90	28	(0+)			(1)	5-54	30
Iron or steel																		
Rubber	4	20-100	40	1	25-100	50	1+	10-150	60	2						1		

Table B-3b. RESULTS OF FILTER ANALYSES FOR SELECTED SITES IN SEATTLE AND VICINITY (HARBOR ISLAND — NO. K-60)

Date	10 June 1974			28 June 1974			22 July 1974			14 Sept. 1974			26 Sept. 1974			8 October 1974		
TSP ($\mu g/m^3$)	136			86			68			118			138			180		
Components	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm
Minerals	(7+)			(5+)			(7)			(3+)			(3+)			(8)		
Quartz	4+	5-75	40	3+	5-100	40	3+	5-50	35	1	5-50	20	1	5-25	15	4	<1-100	3
Calcite	1	5-30	20	1-	2-50	30	1+	2-40	20	1	2-60	25	1	5-40	20	2	<1-100	3
Feldspars	1	2-40	20	1	5-100	40	1	2-60	30	1	2-40	20	1	2-60	30			
hematite	1	1-30	10	1-	1-75	20	1	1-20	8	1-	2-15	10				1+	<1-60	0.5
Mica																		
Combustion Products	(2+)			(2+)			(2+)			(5)			(5+)			(1+)		
Soot:																		
Oil	1	40-60	50	1-	2-70	30	1-	15-75	40	1+	15-50	30	1-	15-55	30	1	<1-60	0.5
Coal	1	20-75	50	1	5-75	35	1	10-70	50	1-	5-70	30				1-		
Glassy fly ash																		
Incinerator fly ash	1-	2-70	30	1-	1-100	30				3	1-50	30	4+	1-60	30			
Burned wood																		
Burned paper																		
Magnetite				1-	5-70	20	1-	15-30	25				1-	5-30	20			
Biological Material	(0+)			(0+)			(0+)			(0+)			(0+)			(0+)		
Pollen																		
Spores																		
Paper																		
Starch																		
Misc. plant tissue																		
Miscellaneous	(0+)			(2+)			(1-)			(1)			(1)			(1-)		
Iron or steel																		
Rubber				1	25-75	40	1-			1	15-120	60	1	20-100	70	1-	<1-100	30
Silicate glass				1+	10-200	75												

Table B-3c. RESULTS OF FILTER ANALYSES FOR SELECTED SITES IN SEATTLE AND VICINITY (DUWAMISH VALLEY — NO. K-59)

Date	10 June 1974			28 June 1974			22 July 1974			14 Sept. 1974			26 Sept. 1974			8 October 1974		
TSP ($\mu g/m^3$)	66			45			27			90			62			110		
Components	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm
Minerals	(4)			(7-)			(4)			(6)			(5+)			(8-)		
Quartz	2	2-45	20	5	5-50	20	2	5-25	15	4	5-50	35	2+	10-60	45	4+	<1-	2
Calcite	1-	2-30	15	1	2-40	20	1-			1-	5-35	20	1	5-30	25	1+	<1-	2
Feldspars	1	5-50	25	1-	2-50	20	2-	2-35	20	1	5-50	25	1+	5-50	35	1-		
Hematite																1	<1-20	0.5
Mica																		
Combustion Products	(3-)			(2)			(4+)			(3)			(3)			(2)		
Soot:																		
Oil	1-	5-30	15	1+	10-100	30	1	5-30	20	1	20-50	30				1	<1-60	0.5
Coal				1-	5-80	30	1	5-50	25	1+	5-60	30	2	5-50	25	1	<1-50	10
Fine soot							1+	<1-2	<1									
Glassy fly ash																		
Incinerator fly ash	2	2-75	30				1-	5-50	30	1-	5-75	30	1-	5-100	50			
Burned wood																		
Burned paper																		
Magnetite																		
Biological Material	(2+)			(0+)			(1)			(0+)			(1-)			(0+)		
Pollen	2	20-50	25															
Spores																		
Paper																		
Starch																		
Misc. plant tissue																		
Miscellaneous	(1)			(1)			(1)			(1)			(1+)			(0+)		
Iron or steel																		
Rubber	1	10-70	40	1	40-150	70	1	20-100	60	1	10-90	35	(1+)	10-100	50			

Table B-3d. RESULTS OF FILTER ANALYSES FOR SELECTED SITES IN SEATTLE AND VICINITY (FOOD CIRCUS — NO. K-10 AND USCG STATION — NO. K-4)

Site	Food Circus — No. K-10												USCG Station — No. K-4		
Date	28 June 1974			22 July 1974			14 Sept. 1974			8 October 1974			8 October 1974		
TSP ($\mu g/m^3$)	39			41			78			95			90		
Components	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm	Quantity, tenths	Size range, μm	Avg. size, μm
Minerals	(5+)			(5)			(8)	1-60	6	(8-)			(9+)		
Quartz	1	5-35	15	2+	10-50	25	6			5	<1-80	1	6+	<1-70	2
Calcite	1	2-20	8	1-	2-15	8	1-			1+	<1-80	1	1+	<1-40	2
Feldspars	3	1-50	20	2	2-60	25							1-		
Hematite							1+			1	<1-15	0.5	1	<1-30	0.1
Mica															
Other							1-								
Combustion Products	(3+)			(3+)			(2)	<1-30		(2)			(1-)		
Soot:															
Oil	1	10-40	25	1+	10-100	25	1			1+	<1-60				
Coal	2	5-70	30							1-			1-		
Soot							1-								
Glassy fly ash							1-								
Incinerator fly ash	1-	40-70	50	1+	5-100	30									
Burned wood															
Burned paper															
Magnetite															
Biological Material	(1-)			(1-)			(0+)			(0+)			(0+)		
Pollen															
Spores															
Paper															
Starch															
Misc. plant tissue															
Miscellaneous	(1)			(1)			(1-)			(0+)			(0+)		
Iron or steel															
Rubber	1	20-200	60	1	30-150										

Table B-4. COMPOSITE SUMMARY OF FILTER ANALYSES FOR SELECTED SITES IN SEATTLE AND VICINITY

Site	Public Safety Bldg. — No. K-1		Harbor Island No. K-60		Duwamish Valley No. K-59		Food Circus No. K-10		6770 E. Marginal Way — No. K-99		USCG Station No. K-4
No. of filters	3		6		6		4		3		1
	Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent		Quantity, percent
Components	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range	—
Minerals	(39)	30-56	(57)	33-78	(56)	41-76	(65)	51-78	(75)	60-87	(96)
Quartz	15	7-23	30	12-45	33	18-50	37	12-61	60	54-65	65
Calcite	5	2-12	11	8-20	9	5-15	9	5-15	4	1-7	15
Feldspars	15	12-20	9	3-12	10	4-16	13	0-28	3	0-8	4
Hematite	3	2-6	7	1-15	4	1-12	5	tr-10	5	2-9	12
Mica	<1	0-1	<1	0-1	<1	0-1	<1	0-1			<1
Coal			tr	0-tr							
Other							1		3	<1-4	
Combustion Products	(39)	27-62	(33)	17-55	(29)	22-43	(27)	18-34	(8)	1-20	(4)
Soot:											
Oil	17	5-25	9	5-15	9	2-15	12	8-15	7	0-20	
Coal			7	0-12	11	0-20	7	0-22			4
Very fine	<1	0-1	<1	0-1	3	0-16	<1	0-1			
Soot							1	0-5	1	0-1	
Glassy fly ash			<1	0-2	<1	0-2	1	0-4	tr	0-tr	<1
Incinerator fly ash	22	6-37	14	0-45	7	<1-20	5	0-14			<1
Burned wood			<1	0-tr							<1
Burned paper			<1	0-tr	tr	0-tr	<1	0-1			<1
Magnetite			3	0-6	tr	0-tr	<1	0-1			
Biological Material	(1)	tr-2	(1)	(tr-3)	(6)	tr-24	(2)	<1-5	(6)	<1-18	(<1)
Pollen	tr	0-tr	<1	0-1	4	0-20	1	tr-2	tr	0-tr	
Spores			tr	0-tr	<1	0-2	tr	0-tr	tr	0-tr	<1
Paper	1	0-2	<1	0-2	1	0-3	<1	0-1	tr	0-tr	<1
Starch	tr	0-tr	<1	0-2	<1	0-1	<1	0-1	tr	0-tr	
Misc. plant	tr	0-tr	tr	0-tr	1	0-2	1	0-1	tr	0-tr	<1
Leaf trichomer									6	0-18	
Miscellaneous	(21)	8-40	(9)	0-27	(9)	2-15	(6)	1-13	(11)	2-21	(<1)
Iron or steel			<1		<1	0-tr			1	0-2	<1
Rubber	21	8-40	7	tr-12	9	2-15	6	1-13	10	<1-20	
Silicate glass			2	0-15							
Other			<1	0-2							

Table B-5. RESULTS OF REPLICATE ANALYSES OF SEATTLE FILTERS

Site	Public Safety Bldg. – No. K-1							USCG Station No. K-4		Harbor Island No. K-60		6770 E. Marginal Way – No. K-99	
Date	10 June 1974		14 Sept.1974		26 Sept. 1974			8 October 1974		8 October 1974		22 July 1974	
TSP ($\mu g/m^3$)	54		117		126			90		180		101	
Laboratory	A	B	A	A	A	A	B	A	B	A	A	A	A
Analysis	1	1	1	2	1	2	1	1	1	1	2	1	2
Components													
Minerals	(31)	(27)	(30)	(69)	(56)	(84)	(23)	(96)	(56)	(78)	(77)	(60)	(72)
Quartz	7		14	30	23	50		65		40	51	54	67
Calcite	12		2	25	12	20		15		20	8	1	2
Feldspars	20		12	4	14	4		4		3			
Hematite	2		2	10	6	10		12		15	18	2	3
Mica			tr		1	<1		<1					
Other						<1						3	
Combustion Products	(27)	(72)	(62)	(21)	(29)	(6)	(77)	(4)	(44)	(17)	(21)	(1)	(8)
Soot:													
Oil	20	46	25	15	5	6	23	4	14	10	18		
Coal				2		<1				4	3		
V.v.fine Soot	1											1	8
Glassy fly ash		26		3		<1	54	<1	30	2	<1		
Incinerator fly ash	6		37		24			<1		1			
Burned wood				1		<1		<1		<1			
Burned paper								<1		<1			
Magnetite													
Biological Material	(2)	(1)	(<1)	(<1)	(<1)	(<1)	(<1)	(<1)	(<1)	(<1)	(<1)	(18)	(8)
Pollen	tr			tr	tr	tr				tr		tr	
Spores				tr		tr		tr		tr		tr	
Paper	2			tr		tr		tr		tr			3
Starch			tr	tr							tr	tr	
Misc. plant tissues	tr			tr	tr	tr		tr		tr	tr		
Leaf trichomer												18	5
Miscellaneous	(40)	(<1)	(8)	(10)	(15)	(10)	(<1)	(<1)	(<1)	(5)	(<1)	(21)	(12)
Iron or steel				tr		tr		tr		tr	tr	1	<1
Rubber	40		8	10	15	10				5		20	12

Table B-6. CITYWIDE COMPOSITE SUMMARY OF FILTER ANALYSES IN SEATTLE

No. of filters	23	
	Quantity, percent	
Components	Average	Range
Minerals	(60)	30-96
Quartz	35	7-65
Calcite	9	1-20
Feldspars	10	0-28
Hematite	5	1-15
Mica	<1	
Other	1	0-4
Combustion Products	(27)	1-62
Soot:		
Oil	10	0-25
Coal	6	0-22
Misc. soot	1	0-16
Glassy fly ash	<1	
Incinerator fly ash	9	0-45
Burned wood	<1	
Burned paper	<1	
Magnetite	1	0-6
Carbon black		
Other		
Biological Material	(3)	tr-24
Pollen	1	0-20
Spores	<1	0-2
Paper	1	0-3
Starch	<1	0-2
Misc. plant tissue	<1	0-2
Leaf trichomer	1	0-18
Miscellaneous	(10)	<1-40
Iron or steel	<1	0-2
Rubber	10	0-40
Other	<1	0-15

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16. ABSTRACT

This document is one volume of a sixteen-volume report presenting an overall assessment of the particulate problem, which was conducted by GCA/Technology Division for EPA.

This particular document is one of fourteen single-area volumes that provide working summaries of data gathered in the fourteen urban areas studied. These city reports primarily provide documentation and background information for Volume I of the study - National Assessment of the Particulate Problem - Final Report. Volume I should be considered the primary output of the report.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Particulate Matter Total Suspended Particulate Emission Sources Control Methods Air Quality Measurements	Optical Microscopy Secondary Particulates Fuel Combustion Process Emissions Fugitive Emissions Fugitive Dust Monitor Siting Meteorology	

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