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California Air Resources Board
on
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FURTHER INVESTIGATION OF AIR QUALITY
IN THE LAKE TAHOE BASIN

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EXECUTIVE SUMMARY

This study was designed to determine the air quality in the Lake Tahoe air basin and to address some of the questions raised by a 1977 study of air pollutants in the Tahoe area. The present study identified five major goals:

1. Identify the source(s) of sulfur aerosols in the Lake Tahoe basin
2. Determine the typical meteorological conditions in the basin during the summer and winter months
3. Collect enough samples in both summer and winter to provide a representative view of air quality in the basin
4. Collect samples at enough locations in the basin to determine the spatial distribution of aerosols
5. Collect precise information on traffic patterns in the basin in order to determine the automotive contribution to aerosol concentrations in the basin

The study plan was designed to meet these objectives, and included the following data gathering components:

1. Weekly particulate aerosol monitoring and daily intensive sampling of particulate aerosols in both summer and winter
2. Routine airplane over-flights and pilot balloon releases to provide meteorological data
3. Traffic volume counts to determine the traffic flow conditions in the basin
4. Review of emission inventory data for SO_2 in the basin

The data collected in the study suggest the following conclusions:

1. Lead aerosols are generated by vehicular traffic within the Lake Tahoe basin.
2. Fine soil-like aerosols are not enhanced by traffic within the basin.
3. Coarse soil-like aerosols are generated by vehicular traffic within the basin. In summer, the aerosols are generated primarily by traffic on unpaved roads. In winter, the aerosols are generated by traffic on major roadways following road sanding operations. The amounts of coarse soil-like aerosols generated by both mechanisms are comparable.
4. A significant fraction of the total suspended particulate concentration measured at Lake Tahoe is generated by vehicular traffic.
5. Transport from outside the basin is not a significant source of sulfur aerosols at Lake Tahoe. Furthermore, transport is not necessary to explain the measured concentrations of sulfur. Transformation of $\text{SO}_2 \rightarrow \text{SO}_4$ can fully explain measured concentrations of sulfur, based on basin-wide SO_2 emissions compiled by the ARB. The largest single source of SO_2 in the basin is on-road motor vehicles.
6. The atmosphere over the lake is typically characterized by an extremely stable layer approximately 100-200 meters deep, and an elevated inversion at an altitude of approximately 11,000 feet. The surface layer over land is somewhat deeper than over the lake, but was not measured in this study.

These conclusions all point to automotive traffic within the basin as the major source of particulate air pollution at Lake Tahoe. It follows that any increase or decrease in traffic in the Lake Tahoe area will result in an increase or decrease in all the major particulate air pollutants examined.

1. INTRODUCTION

Air quality in the Lake Tahoe basin has been the subject of concern and debate in recent years. Although the basin generally enjoys good visibility, occasionally a haze, commonly associated with populated urban areas, has been observed in the Tahoe basin. This haze has been observed with increasing frequency, especially during the summer months. In addition, violations of some air quality standards have been reported which place the Lake Tahoe basin in a non-attainment category.

In order to document the air quality in the Tahoe basin, a study sponsored by the Air Resources Board was conducted by the Air Quality Group at U.C. Davis in 1976-1977 (Cahill, 1977). The primary goal of this study was to investigate the sources of visibility degradation in the Tahoe basin. Study results indicated that automotive traffic was responsible for most of the aerosols in the South Lake Tahoe area. However, sulfur aerosols, a pollutant often responsible for visibility deterioration, did not correlate with traffic patterns. Furthermore, the source(s) of these aerosols could not be identified with the data available from the study. Results from the study did identify seasonal trends in aerosol concentrations. However, the data base for basin-wide spatial profiles was not large enough to provide conclusive evidence of the spatial distribution in aerosol concentrations. In addition, the significance of the spatial profiles was questioned on the basis of insufficient meteorological information. Despite these shortcomings, the study results suggested that aerosol concentrations in Lake Tahoe were comparable to other urban areas in California.

The present study was designed to address some of the questions raised by the 1977 study and to provide additional information for non-attainment planning. Five major goals were identified in the study. They were:

1. Identify the source(s) of sulfur aerosols in the Lake Tahoe basin.
2. Determine the typical meteorological conditions in the basin during the summer and winter months.

3. Collect enough samples in both summer and winter to provide a representative view of air quality in the basin.
4. Collect samples at enough locations in the basin to determine the spatial distribution of aerosols.
5. Collect precise information on traffic patterns in the basin in order to determine the automotive contribution to aerosol concentrations in the basin.

These objectives were accomplished by the study plan which included weekly monitoring and daily intensive sampling of particulates; routine airplane over-flights, and pilot balloon releases to provide meteorological information; and traffic counts which were used to determine the traffic flow conditions in the basin. In addition, emission inventory data were collected in order to aid in the identification of the sources of particulate sulfate in the basin.

2. MATERIALS AND METHODS

2.1. PARTICULATE SAMPLERS

Aerosol samples were collected by Davis stacked filter units (SFU) and by Sierra Instruments Multiday Impactors. The SFU, designed and evaluated by the UC Davis Air Quality Group, is shown in Figure 2.1.1. It consists of two filters in series upstream of a pump. The first filter (coarse stage) collects particles between about 2.5μ and 15μ . The second filter (fine stage) collects the particles which pass through the first filter, that is, particles below about 2.5μ . As shown in Figure 2.1.2, the particle collection properties of the SFU are similar to those of the human respiratory tracts. Also shown for comparison is the distribution of particles in a typical urban environment. The coarse stage of the SFU thus primarily collects particles from the coarse, or largely natural atmospheric mode which would be captured in the upper respiratory tract. The fine stage of the SFU primarily collects particles from the fine, or anthropogenic, mode which would be captured in the lungs and bronchial tubes.

The intake manifold is designed for 50% capture of 15μ aerodynamic diameter particles. The length is designed to provide uniform particle deposition on the first collection filter. The intake is typically located 1.6 m. above the ground.

Aerosol particles are collected on 47 mm filters mounted in a commercially available multiple filter holder. The coarse fraction corresponding to the upper respiratory tract is collected on an 8.0μ Nuclepore filter. Any efficient filter may be used for the second filter stage where fine particles corresponding to the lower respiratory tract are collected. To provide both gravimetric and total elemental analysis, a 0.4μ Nuclepore filter is used for the second filter stage.

The filter holder is connected to a 1/8 horsepower diaphragm air pump through an adjustable orifice. The orifice is designed to passively

Figure 2.1.1. Stacked Filter Unit

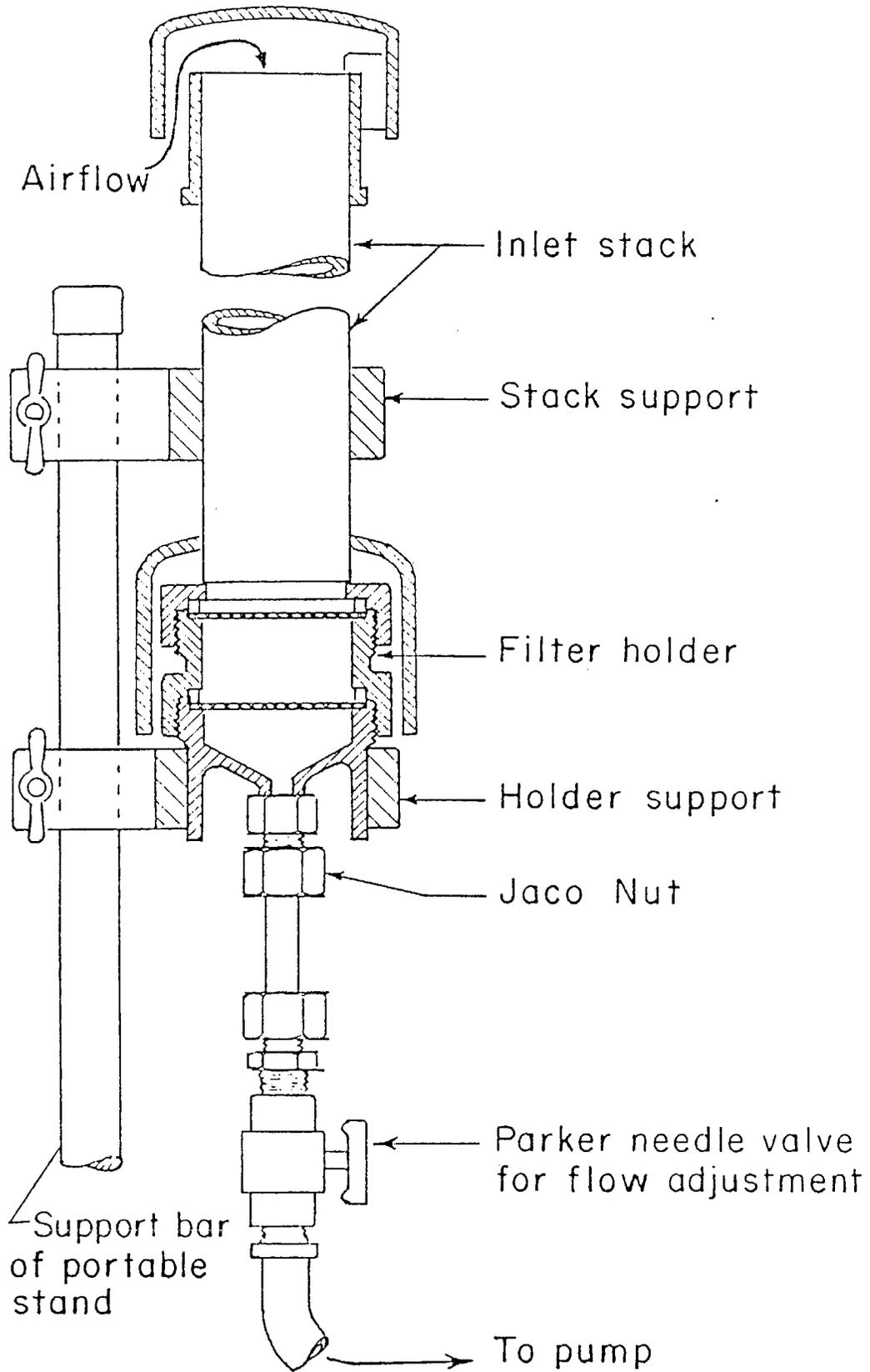
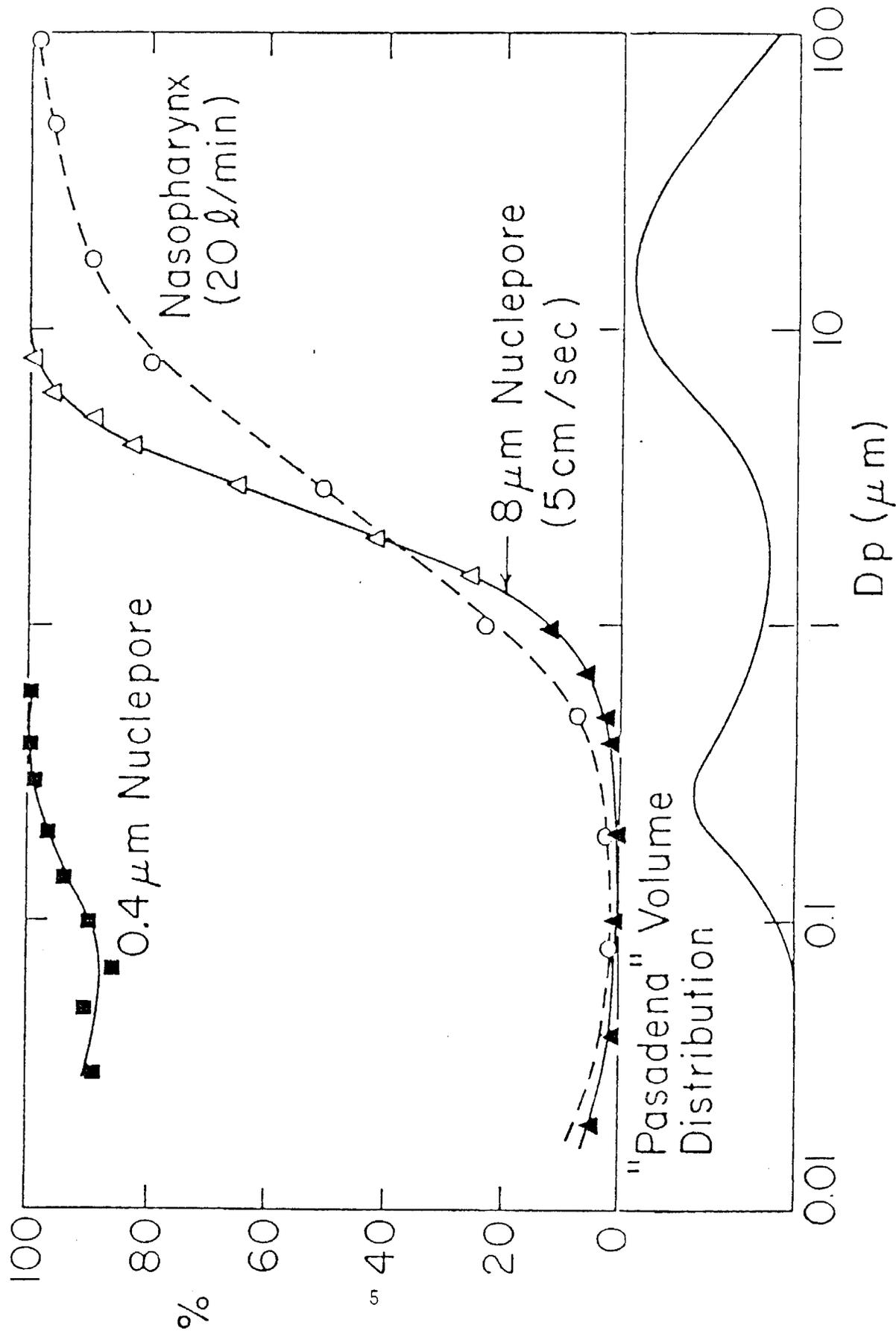


Figure 2.1.1.2

AEROSOL COLLECTION EFFICIENCY



correct for changes in flow due to filter loading by ballasting the pump which is capable of an 18 l/m flow with a pressure drop of 20 cm. Hg. The flow rate through the filters is measured periodically using a calibrated orifice upstream from the filters. The pressure drop across the orifice is measured by a magnehelic gauge which is calibrated for flow rate through the filters using a spirometer.

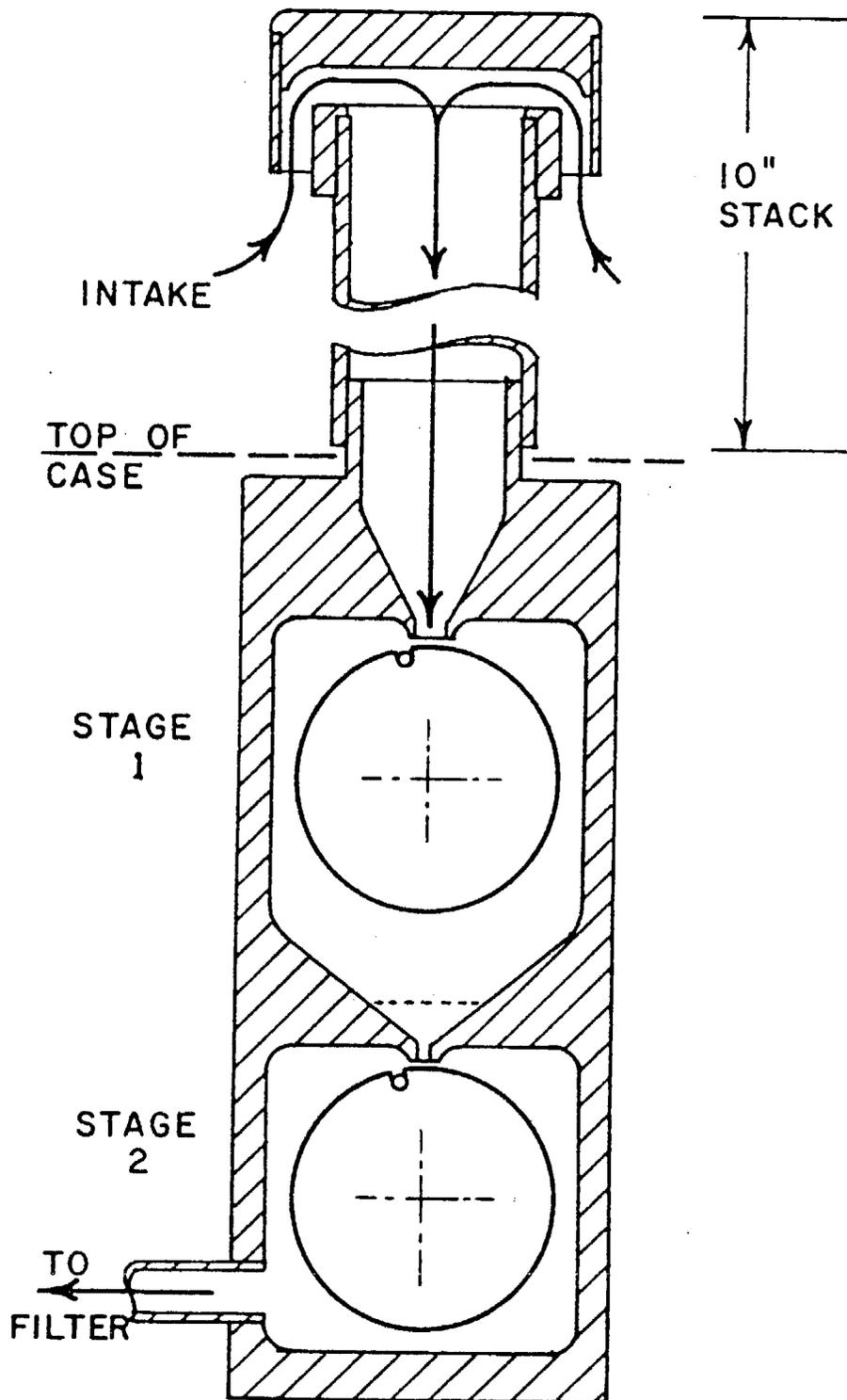
The aerodynamic diameter for 50% capture by the coarse stage varied from less than 2μ to 2.8μ , depending on the flow rate and on the pore diameter. For the summer, 1977, and winter, 1978, the cut point varied from 2.8μ for the weekly samples to 2.0μ for the twelve hour samples. The coarse filters used in July and August, 1978, were from a defective batch in which the pore diameters were somewhat smaller than 8μ , resulting in a 50% cut point of less than 2μ . This leads to a large uncertainty in the size segregation, but does not affect the total concentration of various elemental species obtained by summing the two stages. The coarse filters from this batch also contained a bromine contamination.

The Sierra Multiday Impactor was used to provide background monitoring samples. This sampler had previously been used at Park Avenue from October, 1975, through June, 1976. The Sierra Multiday Impactor collects samples in three size ranges by two rotating drums and an after filter (see Figure 2.1.3 for a diagram of the system). These size ranges are:

- Stage 1 (rotating impaction surface) about 15μ to 3.6μ .
The upper limit is set by the intake manifold.
- Stage 2 (rotating impaction surface) 3.6μ to 0.65μ
- Stage 3 (after filter) 0.65μ to 0.1μ .

The intake manifold is identical to that used on the SFU. The Multiday after filter and the fine SFU stage both used 0.4μ pore diameter Nuclepore, which has an efficiency of approximately 95%.

Figure 2.1.3



COMPARISONS OF SFU WITH OTHER SIZING SAMPLERS

Numerous comparisons of stacked filter units with other samplers have been made. Most of these studies were conducted during the early development of the SFU and do not include coating on the coarse filters. The tests were also conducted with a wide variety of sampler inlets with differing maximum particle size. Table 2.1.1 summarizes comparison tests involving SFU's. These tests were conducted by a variety of groups at several locations throughout the U.S. The results should be representative of the ambient conditions that would be experienced in other locations.

The Charleston 1977 study was the most extensive, covering sixteen 12-hour periods, 36 different samplers and 16 teams of investigators. The SFU's were operated by EPA-RTP (with 10 μ coarse stage) and by UCD (with 8 μ coarse stage at 2 and 5 l/min). Five virtual impactors were operated by EPA-RTP and by Lawrence Berkeley Laboratory. A multiday impactor was operated by UCD. Several total filters were included. The U.C. Davis SFU was the only particle sizing sampler which delivered data for all size ranges for all periods of the test.

In order to present the results of so many tests in a compact form, three variables will be used: soil (Si, Ca, Fe, Ti for Charleston), sulfur, and lead. The soil elements primarily occur as large particles, while sulfur and lead are primarily fine, anthropogenic, particles. Soil elements are sensitive to unit intakes, however.

Table 2.1.1 lists the total collection efficiency of the samplers (sum of stages) in the various tests. The results are given as a ratio of units or a ratio to mean or median of all samplers. The results for the UCD October, 1977 tests of SFU vs total filters are included. The conclusion is the same as in section 6.3, that no significant losses occur in the SFU.

Table 2.1.1. Comparisons of particle collection efficiency - all sizes summed.

REFERENCE	SITE	UNITS (for ratio)	RATIO OF OBSERVED MASSES			MASS
			Soils	Sulfur	Lead	
Parker et al.	Durham	SFU/VI	0.78	1.07	1.00	-
Ferek et al.	Los Alamos	SFU/VI	1.30	0.85	0.85	-
Ferek et al.	Tallahassee	SFU/TF	1.06	1.09	0.91	-
		SFU/MD	1.02	1.30	0.97	-
Camp et al.	Charleston	SFU/Mean	0.97 ± 0.17	0.94 ± 0.02	0.94 ± 0.04	0.95 ± 0.14
		SFU/Median	0.99	1.01	0.97	0.99
Cahill et al.	Davis	SFU/TF	1.06	1.01	0.90	0.99

SFU - Stacked Filter Unit

VI - Virtual Impactor

TF - Total Filter

MD - Multiday Impactor

In the Charleston study, one important result was that the SFU's, or Tandem filters, as the E.P.A. called them, although designed and operated by different groups, achieved comparable results during the study. The unit based upon the design of the Duke/EPA group (Parker et al, 1977) used 10 μ coarse filters and fluoropore fine filters, and operated at 8 l/min. The lower values associated with soils (Table 2.1.1) reflected the more severe intake restrictions used on UC Davis units and some EPA units. The differences in particle sizing (Table 2.1.2) include several effects, including intake restrictions, flow rates, intermediate cut points, shape of capture curve, and particle bounce, if any. The latter effect could occur since all coarse filters used in the study were uncoated. In addition, no mass measurements were taken on any of the SFU samplers, since techniques for weighing the samples had not been developed. The samples taken in the Charleston study were sent back to Davis for analysis via air freight, thus maintaining as close a comparison with common field practice as was possible.

Table 2.1.2. Comparisons of particle sizing efficiency, SFU vs. VI. Fraction of mass on fine stage.

SITE	YEAR	UNITS	SOIL	SULFUR	LEAD	REFERENCE OR COMMENT
Durham	1976	SFU: 12 μ , 12.7 cm/s	0.11	0.74	0.68	Parker et al (1977)
		VI	0.12	0.83	0.74	
Los Alamos	1976	SFU: 8 μ , 7.4 cm/s.	0.13	0.83	0.75	Ferek et al (1978)
		VI	0.15	0.90	0.83	
Charleston	1977	SFU: 12 μ , 12.7 cm/s.				Camp et al (1978)
		and 8 μ 7.4 cm/s.	0.25	0.92	0.81	
		VI: Sum of five	0.10	0.89	0.76	

2.2. ANALYTICAL SYSTEM

Particle Induced X-ray Emission Analysis

A diagram of the analytical system developed by the Air Quality Group is given in Figure 2.2.1. An 18 MeV alpha beam from the 76" isochronous cyclotron passes through remotely readable graphite collimators and impinges on a thin target which is mounted at an angle of 45° to the incoming beam. The target changer operates under realtime computer control. The beam spot is made uniform over the target by a magnetic deflection system. The beam which passes through the target is collected by a Faraday Cup which integrates to a precision of approximately 2% to give the total charge Q that passes through the sample. X-rays pass through an active filter and a 25μ Be window and are converted into electrical pulses by a $30\text{ mm}^2 \times 3\text{ mm}$ LN cooled Si (Li) detector and associated pulsed optical feedback circuitry. Data are accumulated in a PDP 15/40 computer with ND 2200 ADC's integral to the system.

The number of characteristic X-rays, N_Z , corresponding to some transition of element Z was correlated with the areal density $(\text{pt})_Z$ of the element present in the sample by $N_Z = A_Z (\text{pt})_Z Q$ where A_Z is constantly determined through use of gravimetric standards. Major effort has been expended in design of the electronics and beam handling in order to insure accuracy in the acquisition of the events comprising N_Z .

The average analysis required about 120 seconds of beam time. The minimum sensitivity for detection ranged from approximately 30 nanograms per square centimeter for the elements between calcium to bromine, to 100 nanograms for silicon, sulfur and lead, to 300 nanograms for sodium.

The elemental values were corrected for the absorption of the X-rays between the point of emission and the point where they leave the sample. The major correction is for particle size effects, produced by the absorption of X-rays before they leave the particle. The corrections for some elements are shown in Table 2.2.1. They are larger for the coarse stages of the two samplers. The second correction is for X-ray absorption

UCD-ARB AEROSOL ANALYSIS SYSTEM

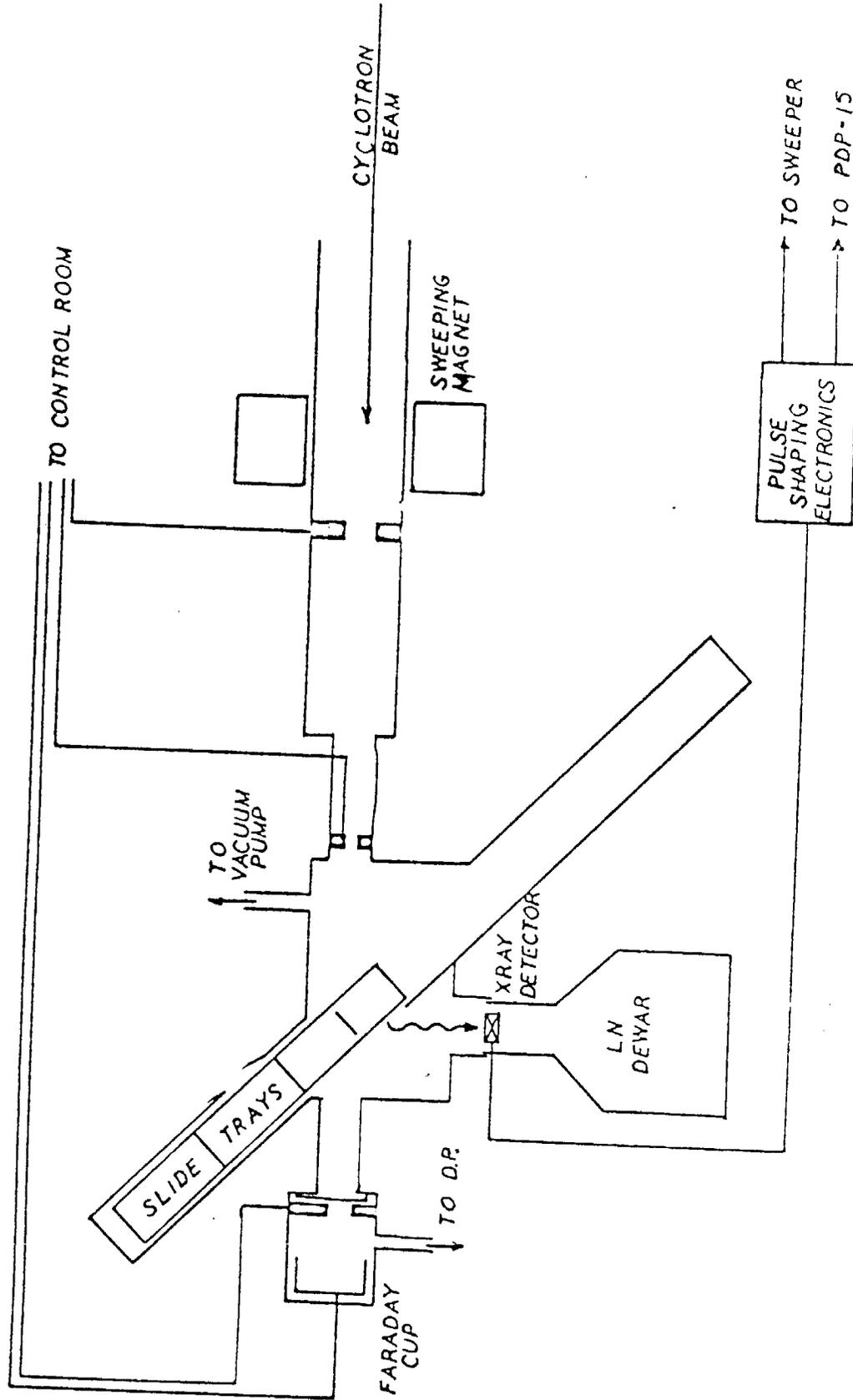


FIGURE 2.2.1

Table 2.2.1. Matrix Corrections

	Na	Al	Si	S	Cl	K	Ca	Fe	Br	Pb
SIZE										
SFU Coarse	2.66	2.25	1.66	1.28	1.36	1.14	1.14	1.08	1.04	1.05
SFU Fine	1.10	1.09	1.05	1.02	1.02	1.01	1.01	1.01	1.01	1.01
MULT - 1	2.88	2.37	1.70	1.31	1.39	1.15	1.15	1.08	1.05	1.07
MULT - 2	1.20	1.16	1.09	1.04	1.05	1.02	1.02	1.01	1.01	1.01
Loading										
100 $\mu\text{g}/\text{m}^3$	1.19	1.08	1.05	1.03	1.03	1.01	1.01	1.00	1.00	1.00
500 $\mu\text{g}/\text{m}^3$	2.17	1.41	1.28	1.14	1.13	1.07	1.07	1.01	1.01	1.00

by the deposit which lies on top of the particle containing the emitting atom. This correction, which depends on the thickness of the deposit, is applied only on the fine stages (below about 3 μ) of the samplers. In this case, the total correction is the product of the size and layer corrections.

At the beginning of every analysis run, several thin standard foils were analyzed in order to check the calibration of the system. A normalization factor, generally less than 10%, was introduced to correct for variations in ion beam energy.

As a further internal check of consistency, samples previously analyzed have been reanalyzed. Approximately fifty SFU samples were reanalyzed as part of a study for the state of Oregon. Large measured concentrations of soil-like particles on the coarse stage and sulfur and lead aerosols on the fine stage were reproduced to within 10%. Amounts from smaller measured concentrations were reproduced to within 20%. These numbers are within the nominal uncertainty of the system which is 10% plus statistical uncertainty.

The accuracy of the X-ray analysis system has been verified in three interlaboratory comparisons: in 1973 1975 and 1978. In the 1973 comparison, the ratio of UCD values to values of other laboratories for aluminum and heavier was

$$1.02 \pm 0.07 \quad (\text{Camp, 1973})$$

In the 1975 comparison, the ratio of UCD values to the reference values for three samples were:

$$\begin{array}{ll} 1.09 \pm 0.13 & \text{gravimetric solution standard} \\ 1.08 \pm 0.21 & \text{ground rock sample} \quad (\text{Camp et. al., 1975}) \\ 0.97 \pm 0.32 & \text{thick aerosol stack sample} \end{array}$$

One problem which became evident in the 1975 test was that corrections for finite particle size were both significant and hard to ascertain with uncontrolled samples. These problems were largely overcome in the third

intercomparison of 1978, in which only pre-sized fine particles were used. The 1978 intercomparison is summarized in Table 2.2.2. The table lists the mean ratio of the participant's measurement made by an independent referee (Camp et. al., 1978).

In summary, the absolute accuracy of $\pm 10\%$ quoted by the Analytical Services Division for statistically sound X-ray peaks appears realistic based upon impartial intercomparisons.

GRAVIMETRIC ANALYSIS

The total suspended particulate mass in both of the size ranges of the SFU was obtained by weighing each of the filters. The samples collected in summer, 1977, and winter, 1978, were measured with a standard Mettler mechanical balance. The samples collected in summer, 1978 were measured on a Cahn Model 25 electrobalance.

A precision test of SFU gravimetric mass measurements was made at UC Davis. All units were run on the roof of the Physics/Geology building, approximately 20 meters above the ground. Five units were operated on 3/6 and 3/7, and six units were operated on 3/8/79. The coarse filter was an Apiezon-coated 8.0μ Nuclepore. The fine filter was a 0.3μ Nuclepore. All filters were weighed on a Cahn 25 electrobalance. The test days were unusually warm, with highs in the mid-70's. Fog formed in the morning on 3/8/79. The results are shown in Table 2.2.3. As can be seen from the data in the table, a precision of approximately 5% for both the coarse and fine fractions of the SFU was achieved. Furthermore, the precision for the total mass was approximately 3%.

Table 2.2.2. PARTICIPANT RESULTS FROM ANALYTICAL
TECHNIQUE QUALITY CONTROL SAMPLES

	S	Ca	Ti	Fe	Cu	Zn	Se	Br	Pb	Mean
Cahill ^{a)}	1.01	1.41 ^{b)}	1.04	1.01	0.90	1.14	0.93	0.91	0.92	0.98 ^{c)}
UCD (3)	±.07	±.26	±.43	±.06	±.01	±.05	±.06	±.05	±.03	±.08
Dzubay	0.93	0.89	1.14	0.96	1.04	0.95	0.96	0.92	0.93	0.97
EPA (3)	±.04	±.06	±.13	±.05	±.13	±.06	±.14	±.05	±.02	±.08
Loo (30) ^{d)}	0.98 ^{d)}	1.27	1.33	0.98	1.02	1.10	0.87	1.16 ^{e)}	1.03	1.08
LBL	±.04	±.13	±.19	±.05	±.07	±.06	±.14	±.06	±.02	±.15
Hudson	0.89	1.06	1.01	0.94	1.33	1.12	(f)	0.92	0.84	1.01
FSU (3)	±.05	±.16	±.05	±.04	±.44	±.20		±.07	±.05	±.16
Rodes	1.06	-	-	-	-	-	-	-	1.03	-
EPA (2)	±.16								±.02	
Tanner	0.84									
BNL (3)	±.12									
Delumyea	0.76									
WU (3)	±.15									

Burton (EPA) and Mueller (ERT) did not report trace element concentrations.

- a) The number of reference samples measured is given in parenthesis.
b) The filters were temporarily exposed to a known source of calcium contamination (cement dust).
c) Mean value calculated without including calcium.
d) All 30 reference samples were originally from one of the automated dichotomous samplers. Only five could be compared with the referee results.
e) These bromine values were obtained early, then divided by the referees' results which were obtained later after an apparent bromine loss. See the Bromine Loss discussion below.
f) Selenium concentrations were too small to be accurately measured by PIXE.

Table 2.2.3. PRECISION TEST RESULTS

Gravimetric Analysis ($\mu\text{g}/\text{m}^3$)

<u>Day</u>	<u>Coarse Filter</u>	<u>Fine Filter</u>	<u>Sum</u>
3/6-3/7/79	17.0 \pm 1.2	31.4 \pm 1.9	48.4 \pm 2.5
3/7-3/8/79	12.7 \pm 0.5	19.0 \pm 0.9	31.7 \pm 0.6
3/8-3/9/79	16.4 \pm 0.7	14.7 \pm 0.6	31.1 \pm 0.6

Precision (%)

<u>Day</u>	<u>Coarse Filter</u>	<u>Fine Filter</u>	<u>Sum</u>
3/6-3/7/79	7.13	5.89	5.21
3/7-3/8/79	4.13	4.89	2.00
3/8-3/9/79	<u>3.97</u>	<u>4.36</u>	<u>1.92</u>
Average	5.07	5.05	3.04

2.3. DESCRIPTION OF THE PARTICULATE SAMPLING NETWORKS

The particulate sample collection networks used in this study were designed to provide information on several possible aerosol sources. Two weekly monitoring networks and three intensive sampling networks were employed. A description of each network follows.

2.3.1. BASIN WIDE MONITORING NETWORK

The summer/winter monitoring network was used to collect weekly integrated aerosol samples at eight stations around Lake Tahoe. The sites used for the summer, 1977 monitoring effort included: Sierra Ski Ranch (SS), Tata Lane (TT), Park Avenue (PK) and Nevada Beach (NB) in the South Lake Tahoe Area; Glenbrook (GB) on Tahoe's eastern shore; King's Beach (KB) and Tahoe City (TC) in the North Lake Tahoe area; and Sugar Pine Point (SP) on the western shore. The same sites were used for the winter, 1978 monitoring with the following exception: the Nevada Beach site was deleted and Incline Village (IN) was added. A list of the sampling sites with their identification number and period of record is given in Table 2.3.1. The location of the sampling sites is shown in Figure 2.3.1.

During the summer, 1978, samples were collected for six consecutive weeks from August 12 to September 23. During the winter, 1978, samples were collected for seven consecutive weeks from January 20 to March 10.

2.3.2. SYNOPTIC MONITORING NETWORK

The synoptic monitoring network was operated from July 11 to August 15, 1978. A total of seventeen sites were included. Sites were located from Bodega Bay on the coast to Glenbrook on Tahoe's eastern shore. Figure 2.3.1 is a diagram of this monitoring network. These sites were chosen in order to determine the effect synoptic weather conditions have on particulate concentrations at Lake Tahoe. Samplers were operated for five weeks with a seven day integration period. Hence, the mean weekly concentration of aerosols was determined at each site. The sites included in

Table 2.3.1. Particulate Monitoring Stations

<u>LAKE TAHOE BASIN</u> <u>Weekly Monitoring</u>		<u>SYNOPTIC</u> <u>Weekly Monitoring</u>		<u>MULTIDAY</u> <u>Daily Monitoring</u>	
<u>Site #</u>	<u>Site Identification</u>	<u>Site #</u>	<u>Site Identification</u>	<u>Site#</u>	<u>Site Identification</u>
1	Sierra Ski Ranch	20	Bodega Bay ³	3	Park Avenue
2	Tata Lane	21	Middletown ³	8	Tahoe City
3	Park Avenue	22	Geysler Rock ⁴	9	Sugar Pine Point
4	Nevada Beach ¹	23	Sherman Island ³		
5	Glenbrook	24	Davis		
6	Incline Village ²	25	Marysville		
7	King's Beach	26	Placerville		
8	Tahoe City	27	Weimar		
9	Sugar Pine Point	28	Strawberry		
		29	Blue Canyon		
		30	Squaw Valley		
		1	Sierra Ski Ranch		
		3	Park Avenue		
		5	Glenbrook		
		7	King's Beach		
		8	Tahoe City		
		9	Sugar Pine Point		

PERIOD OF RECORD

August 12 - September 23, 1977

January 20 - March 10, 1978

1-August 12 - September 23, 1977

only

2-January 20 - March 10, 1978

only

July 11 - August 15, 1978

3-July 11 - August 8, 1978

only

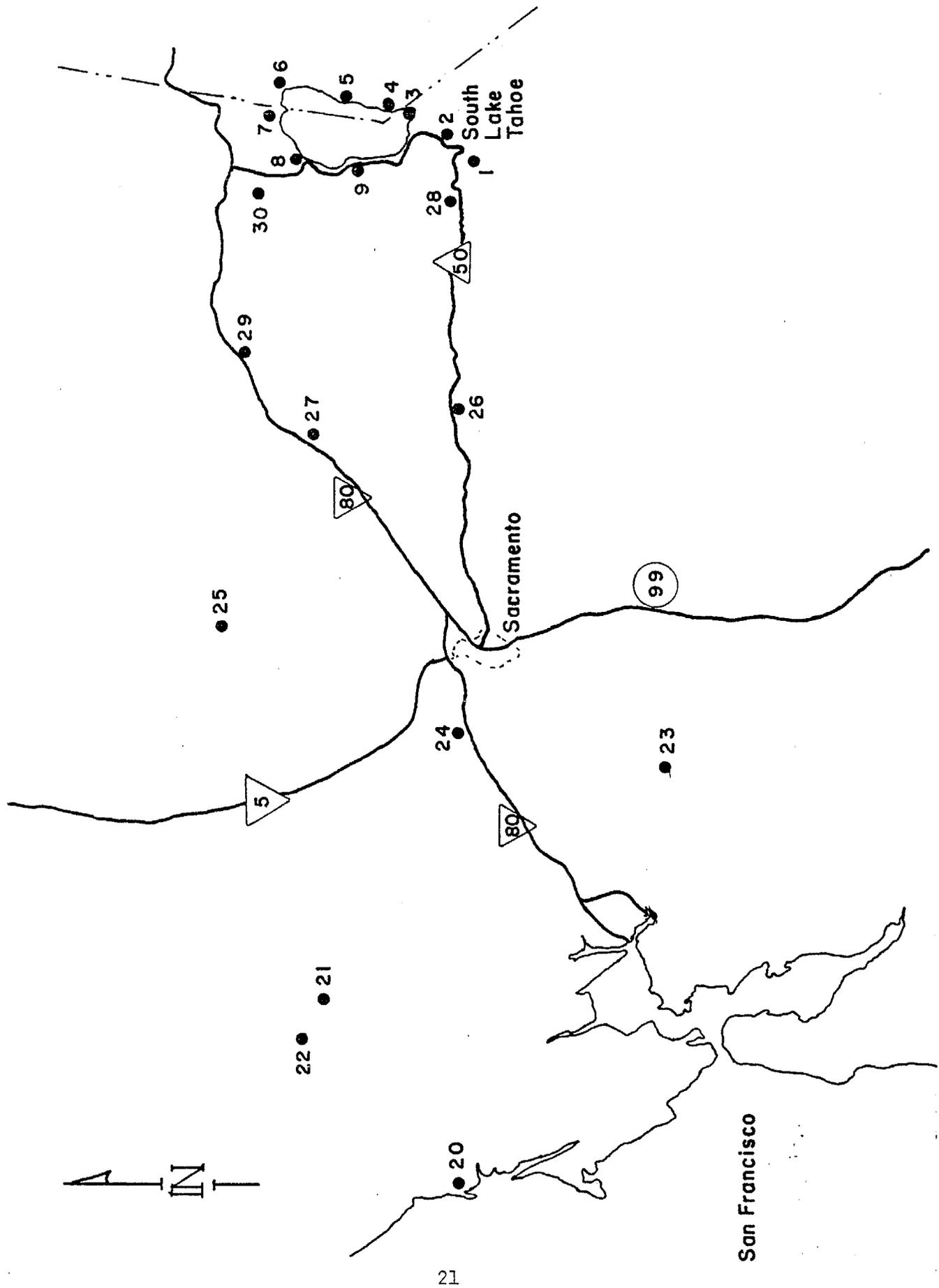
4-July 25 - August 8, 1978

only

August 22 - August 26,

1977

Figure 2.3.1



this network were: Bodega Bay on the California Coast; Middletown and Geysler Rock near Clear Lake; Sherman Island near the Carquinez Strait; Davis and Marysville in the Central Valley; Placerville and Weimar in the foothills; Blue Canyon, Strawberry and Sierra Ski Ranch in the Sierra; Squaw Valley; and Sugar Pine Point, Tahoe City, King's Beach, Glenbrook, and Park Avenue in the Tahoe basin. Table 2.3.1. lists the monitoring stations and the period of record.

2.3.3. DAILY AND DIURNAL SAMPLING NETWORKS

In order to determine the short term temporal variation in pollutants, two daily and three diurnal sampling networks were deployed. The diurnal networks were also used to determine small scale spatial variations in particulate pollutant concentrations. A description of these networks follows.

Ski Run Boulevard Network

On August 22 and 23, 1977, a network of seven stacked filter unit samplers was used to collect data on particulate concentrations in South Lake Tahoe. These sampling units were located along Ski Run Boulevard from the south shore of Lake Tahoe across U.S. Highway 50 to Saddle Road. The sampling network, shown in Figure 2.3.2, was designed to determine the temporal and spatial effect of Highway 50 on air quality in South Lake Tahoe. Samples were collected from 8 AM to 8 PM on August 22, and 8 PM August 22 to 8 AM August 23. These time periods correspond (roughly) to the diurnal changes in the wind field at South Lake Tahoe. Between 8 AM and 8 PM, upslope winds are the predominant flow conditions. From 8 PM to 8 AM, downslope drainage flow predominates. Table 2.3.2 includes a list of the stations operated for this network.

South Lake Tahoe Sampling Network

On August 23 and 24, 1977, eight samplers were operated in the South Lake Tahoe area. These samplers collected samples from 8 AM to 8 PM on August 23, and from 8 PM August 23 to 8 AM August 24. The sampling array

Figure 2.3.2

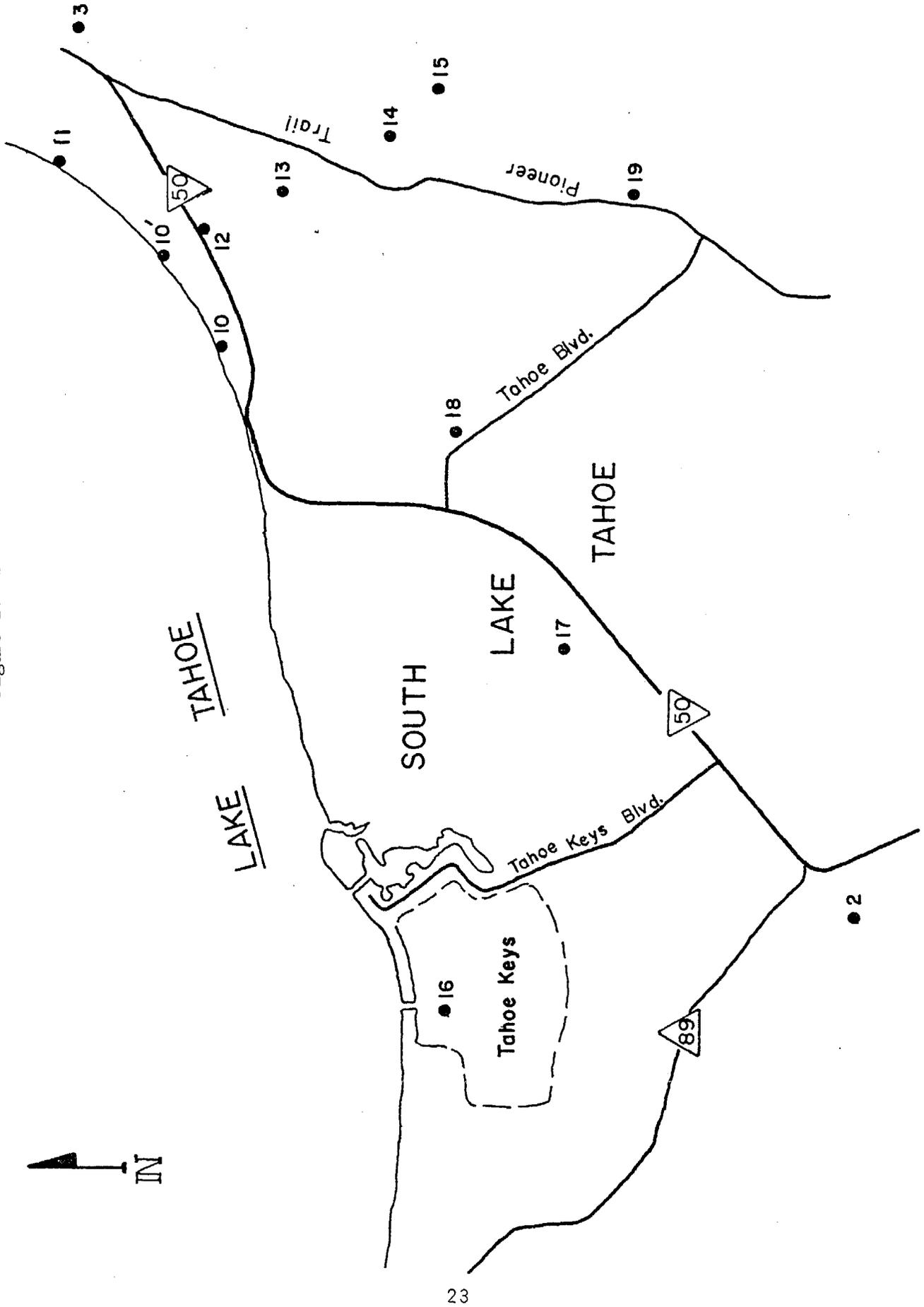


Table 2.3.2. Daily and Diurnal Sampling Sites

Ski Run Sampling Profile (Diurnal)		South Lake Tahoe Sampling Profile (Diurnal)		Basin Sampling Profile (Diurnal)		Synoptic Sampling Profile (Daily)	
Site #	Site Identification	Site #	Site Identification	Site #	Site Identification	Site #	Site Identification
10	Balbijou Lane	16	Aloha Lane	1	Sierra Ski Ranch ^{**+}	23	Sherman Island
11	Beach Road	2	Tata Lane	2	Tata Lane ^{**+}	24	Davis
12	U.S. Highway 50	17	Springwood Drive	3	Park Avenue ^{**+}	26	Placerville
13	Ski Haus Motel	18	So. Tahoe Sheriff's	4	Nevada Beach [*]	27	Weimar
14	Hansen's Motel	10	Balbijou Lane	5	Glenbrook ^{**+}	1	Sierra Ski Ranch
15	Saddle Road	19	Ralph Drive	6	Incline Village ⁺	3	Park Avenue
3	Park Avenue	3	Park Avenue	7	King's Beach ^{**+}	5	Glenbrook
		15	Saddle Road	8	Tahoe City ^{**+}	7	King's Beach
				9	Sugar Pine Point ^{**+}	8	Tahoe City
				10	Balbijou Lane ⁺	9	Sugar Pine Point
				15	Saddle Road ⁺	31	Lake Center
				18	South Tahoe Sheriff's ⁺		
				33	Incline Sheriff's ⁺		
				34	Cornelian Bay ⁺		
				35	Tahoe Keys ⁺		

Period of Record

August 22, 23, 1977

August 23, 24, 1977

*August 24-26, 1977

July 31 - August 3, 1978

+March 1, 1978

was designed to investigate the diurnal and local spatial variation in particulate concentrations in South Lake Tahoe. Sampler locations are listed in Table 2.3.2. and shown in Figure 2.3.2.

Basin Diurnal Sampling Network

From August 24 to August 26, 1977, eight samplers were operated at selected sites around Lake Tahoe. Twelve hour samples (8 AM to 8 PM and 8 PM to 8 AM) were collected at each site in order to determine the diurnal and spatial variation in particulate concentrations around Lake Tahoe. Table 2.3.2 includes a list of the sites for this study. The location of each site is shown in Figure 2.3.1.

On March 1, 1978, a similar network was operated on the same diurnal schedule. A list of these stations is given in Table 2.3.2 and their locations are shown in Figure 2.3.1.

Synoptic Daily Sampling Network

From July 31 to August 3, 1978, ten samplers were operated at locations ranging from Sherman Island, near the Carquinez Straits to Glenbrook on Lake Tahoe's eastern shore. These sites are listed in Table 2.3.2 and shown in Figure 2.3.1. Twenty-four hour samples were collected at each of these sites in order to determine the daily fluctuations in particulate concentrations.

These data were used in conjunction with weekly monitoring data at the same sites, to determine the effect of synoptic scale meteorology on particulate concentrations at Lake Tahoe.

2.4. METEOROLOGICAL DATA COLLECTION

2.4.1. AIRPLANE OVERFLIGHTS

The vertical temperature profile over the lake was measured on 18 separate occasions from August 24, 1977, to August 15, 1978. Six flights were made in the morning, while all other flights were made in mid-afternoon. The flight schedule is shown in Table 2.4.1.

A Cessna 172 was used for all flights. The temperature was measured with a YSI 44005 precision thermistor manufactured by Yellow Springs Instrument Company. The thermistor was taped to the leading edge of the wing strut, just under the wing. A digital ohmmeter was used to read the resistance, which was later converted to temperature.

The flight procedure was as follows. After take-off, the pilot was instructed to climb while flying to a point over the lake near Glenbrook. For the first seven flights, temperature was measured over the lake while flying a transect between Glenbrook and Meek's Bay. All subsequent measurements were made while flying a spiral over the lake near Glenbrook. The highest altitude measured on a particular flight was between 11,500 and 13,000 feet. This was determined in part by the capability of the aircraft on that day, in part by cloud cover, and in part by sample measurements taken while climbing. The first six flights descended to 250 feet above the lake surface. Subsequent flights routinely descended to fifty feet above the lake, and on several occasions lower. Temperature data and plots of potential temperature are included in the appendix. The surface layer and boundary layer heights for the flights are given in Table 2.4.2.

Temperature measurements made by the ARB on an ozone transport project were also examined for this study. These measurements were made daily from August 1, 1978, to September 4, 1978, at 0600 and 1500 over the Lake Tahoe Airport, and at 0630 and 1530 over the center of Lake Tahoe.

Table 2.4.1. Aircraft Overflights.

<u>DATE</u>	<u>TIME</u>	<u>MAXIMUM ALTITUDE (ASL)</u>	<u>MINIMUM ALTITUDE (ASL)</u>	<u>SURFACE TEMPERATURE</u>	<u>FLIGHT PATH*</u>
8/24/77	8:00	12,000	6,500	YES	1
8/24/77	15:00	12,000	6,500	YES	1
8/25/77	8:00	12,000	6,500	YES	1
8/25/77	15:00	12,000	6,500	YES	1
8/26/77	8:00	12,000	6,500	YES	1
8/26/77	15:00	12,500	6,400	YES	1
4/11/78	14:30	11,500	6,350	YES	1
7/11/78	13:00	12,500	6,300	NO	2
7/18/78	13:00	12,500	6,350	YES	2
7/25/78	13:00	12,000	6,300	YES	2
7/31/78	8:00	12,500	6,300	YES	2
7/31/78	14:00	12,500	6,270	YES	2
8/01/78	8:00	12,500	6,300	YES	2
8/01/78	14:30	13,000	6,300	YES	2
8/02/78	8:00	13,000	6,300	YES	2
8/02/78	14:00	13,000	6,280	NO	2
8/08/78	13:00	13,000	6,300	YES	2
8/15/78	13:45	12,500	6,300	YES	2

* 1. Transect Glenbrook to Meek's Bay

2. Spiral over the lake near Glenbrook

Lake elevation: 6,250 feet

Table 2.4.2. Surface Layer and Boundary Layer Heights

DATE	TIME	MORNING		TIME	AFTERNOON	
		SURFACE LAYER	BOUNDARY LAYER		SURFACE LAYER	BOUNDARY LAYER
8/24/77	8:00 AM	67 m	1,000 m	3:00 PM	67 m	1,470 m
8/25/77	8:00 AM	83 m	1,160 m	3:00 PM	83 m	1,300 m
8/26/77	8:00 AM	83 m	1,300 m	3:00 PM	83 m	1,730 m
4/11/78				2:30 PM	33 m	700 m
7/11/78				1:00 PM	50 m	1,600 m
7/18/78				1:00 PM	50 m	1,600 m
7/25/78				1:00 PM	50 m	1,600 m
7/31/78	8:00 AM	83 m	2,733 m	2:00 PM	33 m	1,300 m
8/01/78	8:00 AM	50 m	2,187 m	2:00 PM	33 m	1,600 m
8/02/78	8:00 AM	33 m	1,749 m	2:00 PM	33 m	1,600 m
8/08/78				1:30 PM	33 m	1,467 m
8/15/78				1:30 PM	17 m	1,433 m

2.4.2 UPPER WIND MEASUREMENTS

Pilot balloons were released at Tahoe City, South Lake Tahoe, Foresthill, and Placerville according to the schedule in Table 2.4.3. Each balloon was tracked by theodolite for 15-20 minutes, or until it was lost in clouds. The position was recorded every thirty seconds, and later reduced by computer to give an average wind vector over the thirty second height interval. Wind speed and direction data and plots are contained in Appendix B.

2.4.3. SURFACE WIND MONITORING

A mechanical weather station manufactured by Meteorological Research Inc., was placed at the U.S. Coast Guard station at Lake Forest. It recorded continuously the wind speed, wind direction, and temperature at approximately eight meters above the lake surface from August 22, 1977, to September 22, 1977. The data were later reduced to obtain hourly average wind speed, direction, and temperature, as well as frequency tables of each parameter for each hour. These data are included in Appendix B.

Table 2.4.3. Pilot Balloon Releases

<u>TAHOE CITY</u>			<u>SOUTH LAKE TAHOE</u>			<u>FORESTHILL</u>			<u>PLACERVILLE</u>		
<u>Date</u>	<u>Time</u>	<u>Max.Alt. ASL</u>	<u>Date</u>	<u>Time</u>	<u>Max.Alt. ASL</u>	<u>Date</u>	<u>Time</u>	<u>Max.Alt. ASL</u>	<u>Date</u>	<u>Time</u>	<u>Max.Alt. ASL</u>
8/24/77	9:25	2,502 m	8/24/77	9:43	4,077	7/31/78	14:20	5,560	7/31/78	9:59	3,865
	9:44	2,502		12:25	3,614	8/01/78	14:00	4,634	8/01/78	10:10	4,421
	12:07	3,521		16:37	3,984		14:18	3,708	8/02/78	9:17	4,421
	12:20	3,799	8/25/78	9:33	2,873	8/02/78	13:47	4,634			
	14:30	2,317		10:01	3,428		14:12	4,634			
	14:40	3,706		12:01	3,521						
8/25/77	8:53	2,595		12:30	3,614						
	11:35	2,965		16:27	4,077						
	14:26	2,687	8/26/78	10:25	3,892						
8/26/77	8:57	3,892		11:00	4,633						
	11:46	2,595		12:04	4,540						
	11:57	3,151		14:30	3,892						
	14:30	4,633									
7/11/78	14:00	5,698									
7/18/78	13:05	5,559									
	13:35	4,633									

Table 2.4.3. Pilot Balloon Releases (continued)

<u>TAHOE CITY</u>		
<u>Date</u>	<u>Time</u>	<u>Maximum Altitude ASL</u>
7/31/78	8:25	5,096
	13:50	5,559
8/01/78	8:15	5,559
	14:00	5,559
8/02/78	8:05	5,559
	14:00	5,559
8/08/78	12:50	4,633

3. RESULTS AND DISCUSSION

The results of the present study of aerosol concentrations at Lake Tahoe indicate that most of Tahoe's aerosols are locally generated. The annual variation in aerosol concentrations at Tahoe appears to be quite different than at other urban sites in California. Furthermore, the source of the measured aerosols at Tahoe seems to be automotive traffic within the basin. The results and discussion section is divided into three parts which represent the three main areas of concern in terms of air quality at Lake Tahoe. The first section considers the seasonal variation in aerosols at Tahoe. The second deals with primary automotive pollutants in the Tahoe basin. The third section discusses secondary pollutants at Tahoe. In each section, we have incorporated data from all of the sampling and meteorological networks where applicable. In addition, we have attempted to address each of the objectives identified in this study within the three results sections. The complete data set for the study is included in Appendix B.

3.1. ANNUAL VARIATIONS OF S, Pb, Si, AND Cl

Daily particulate measurements were made with Multiday samplers at South Lake Tahoe (Park Avenue) between October, 1975, and June, 1976, and in July and August, 1978. These data provide information on annual variations of the various elemental species. The results obtained at South Lake Tahoe will be compared to those obtained at Sacramento in 1973-1974 and 1976-1977.

Four elements were selected for analysis, each providing a different source signature. Silicon is obtained primarily from soil, chlorine from salt, sulfur primarily from fossil fuels, and lead solely from automobiles. In general, there is no correlation between the daily concentrations of these four elements.

Silicon is primarily coarse, with 71% between 3.5μ and 15μ , 16% between 0.65μ and 3.5μ , and 13% smaller than 0.65μ . The size distributions for South Lake Tahoe and Sacramento are identical. The seasonal variation of the monthly mean concentrations of total silicon (all particles smaller than 15μ) is shown in Figure 3.1.1. In Sacramento, the silicon concentration is much larger in summer than in winter. This is due to the high soil moisture content in winter, which inhibits soil suspension into the atmosphere. In South Lake Tahoe, for 1975-76, the trend is reversed, and the maximum silicon concentrations occur in the winter, despite the fact that there is very little exposed soil during winter. The most likely source of winter silicon is from the sanding of the major roads. The silicon concentrations for the summer of 1978 are much larger than would be expected from the 1975-1976 concentrations. This may be due to construction projects in the vicinity of the Park Avenue site.

Chlorine is somewhat finer than silicon, with about one-third in each of the size regions of the Multiday sampler. The monthly mean total chlorine concentrations are shown in Figure 3.1.1. In Sacramento, the concentrations over a month are approximately constant except

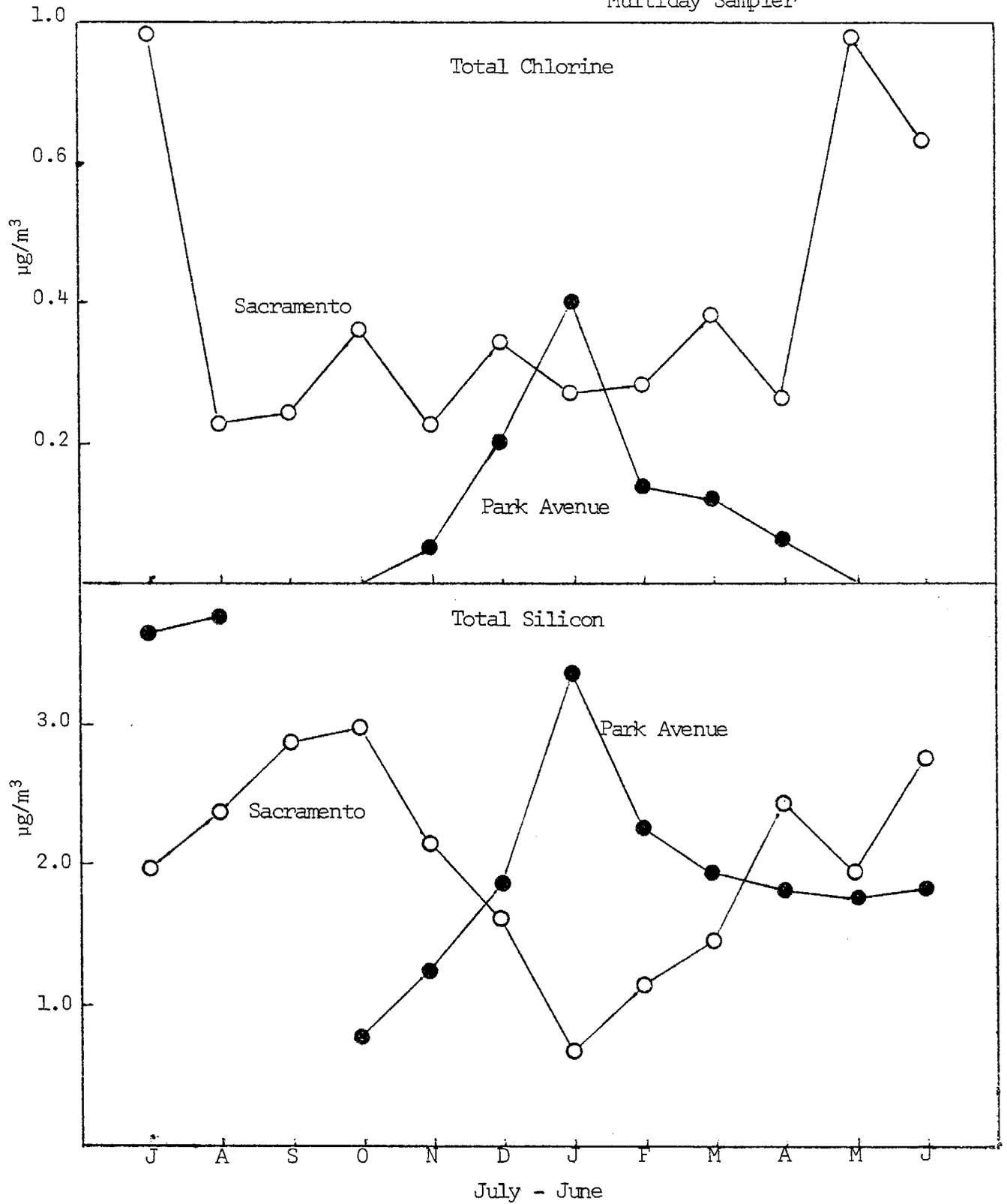
Figure 3.1.1

Monthly Mean Concentrations of Total Silicon and Total Chlorine
for South Lake Tahoe (Park Avenue) and Sacramento

Park Avenue: 10/75-6/76, 7/78-8/78

Sacramento: 6/73-12/74, 11/76-9/77

Multiday Sampler



for a peak from May through July, which is probably a result of marine air intrusion. In South Lake Tahoe, there is very little chlorine except in the winter. The lack of summer chlorine suggests that marine air is not a factor in the chlorine levels at Tahoe. The winter chlorine is probably produced by the salting of major roads. In the peak month of January, the chlorine is much more coarse (66% larger than 3.5μ) than in other months at South Lake Tahoe or than in any month at Sacramento.

Lead is primarily fine, with 75% smaller than 0.65μ , 16% between 0.65μ and 3.5μ , and 9% between 3.5μ and 15μ . The South Lake Tahoe size distribution is very close to that at Sacramento, or at other California urban sites. The pronounced fall-winter maximum exhibited in Sacramento is typical of California urban sites; however, it is much smaller at South Lake Tahoe (see Figure 3.1.2).

Sulfur is also primarily fine particles. At South Lake Tahoe and at Sacramento, 66% is smaller than 0.65μ . There is slightly more large sulfur particles (larger than 3.5μ) at South Lake Tahoe than at Sacramento (12 vs. 3%). In Sacramento, there is a summer maximum; for South Lake Tahoe, the data is inconclusive (see Figure 3.1.2). On the SFU's at Park Avenue, the concentration of total sulfur in summer is approximately twice that in winter.

The lead and sulfur concentrations in the summer of 1978 are both about one-half of that expected from the 1975-1976 data. On the other hand, Si is much larger than that expected from the earlier measurements. No explanation for these large shifts has been found.

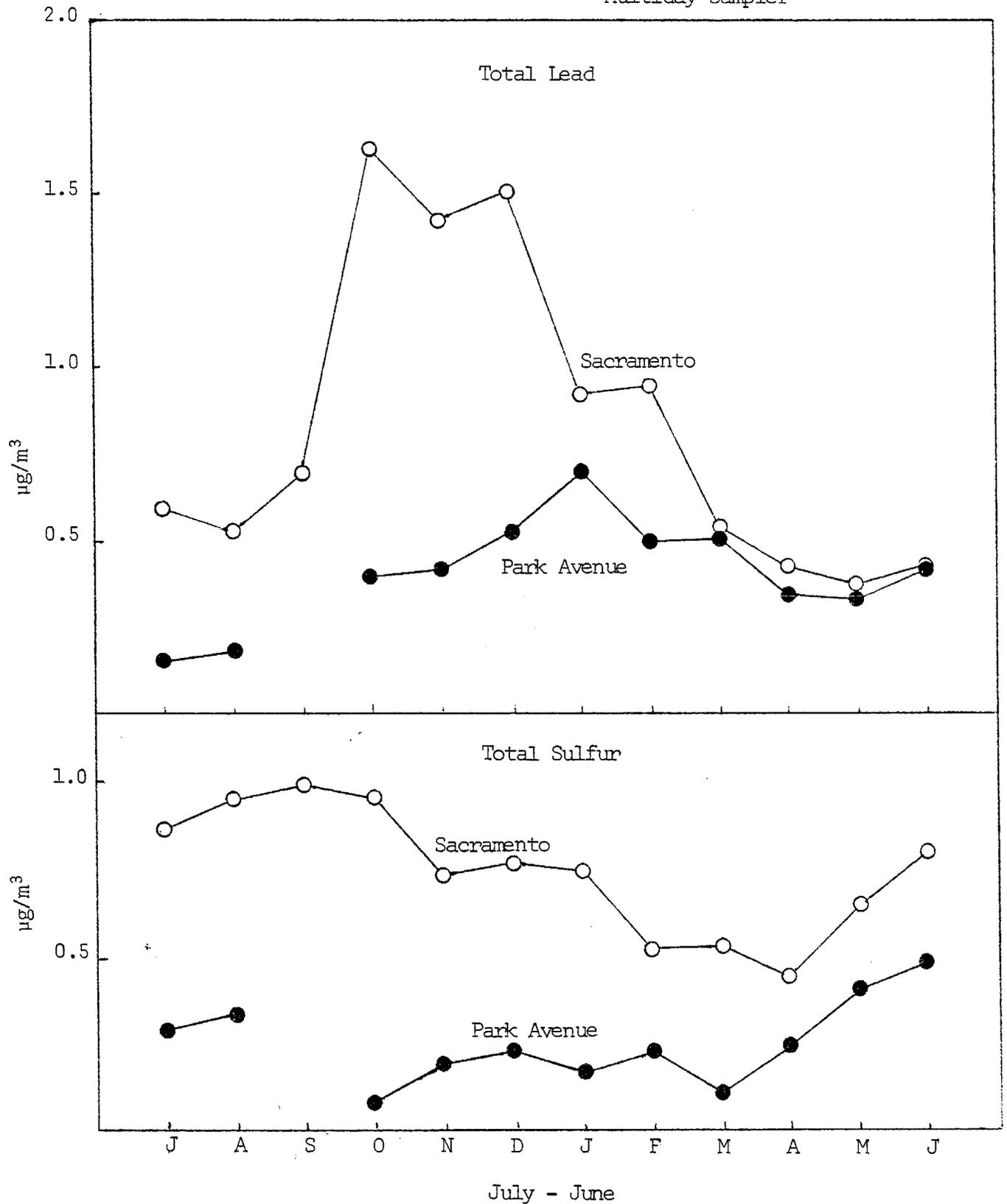
Figure 3.1.2

Monthly Mean Concentrations of Total Lead and Total Sulfur
for South Lake Tahoe (Park Avenue) and Sacramento

Park Avenue: 10/75-6/76, 7/78-8/78

Sacramento: 6/73-12/74, 11/76-9/77

Multiday Sampler



3.2. PRIMARY AUTOMOTIVE AEROSOLS IN LAKE TAHOE

The results from the 1976-1977 aerosol study at Lake Tahoe (Cahill et. al., 1977) indicated that many of Tahoe's aerosols were of local origin; and further, that automotive traffic in the basin was one of the prime contributors to the aerosol concentrations measured at Tahoe. However, only a limited amount of data was collected during the 1976-77 study. Furthermore, no information on traffic volume in the basin was collected, and therefore, the correlation of aerosols with traffic could not be computed. In the present study, we have extended the number of sampling days, included weekly monitoring of aerosols at several Tahoe locations, and have made traffic counts at many locations around the basin. Hence, it is now possible to directly relate measured ambient aerosol concentrations to traffic volumes at Lake Tahoe. The traffic counts used in the present study were taken during the summer, 1977, by the Air Quality Group in co-operation with the California Tahoe Regional Planning Agency and the California Department of Transportation.

The relationship between traffic count and total lead concentration is shown in Figure 3.2.1, and the best linear fit (least squares) for summer, 1977, winter, 1978, and summer, 1978, is included. The mean slope for this line is .007 with an intercept at approximately 40 ng/m^3 of lead. This suggests that the background lead concentration is less than 50 ng/m^3 . That is, a maximum of 50 ng/m^3 of lead is not generated locally. Approximately 72% of the variance in lead is explained by this relationship. A second illustration of the relationship between automotive traffic and the ambient lead concentration is shown in Figure 3.2.2. In this figure, the lead concentration (Pb) measured at eight sites within the Tahoe area is plotted. In addition, the traffic volume distribution (Tr) for 8/20-8/23, 1977, is shown along with the lead concentration (Pb²) for the same week that traffic counts were made. A similar graph of lead concentrations during the winter, 1978, is also shown. Both of these diagrams illustrate the relationship between local automotive traffic and the ambient lead concentration.

Figure 3.2.1

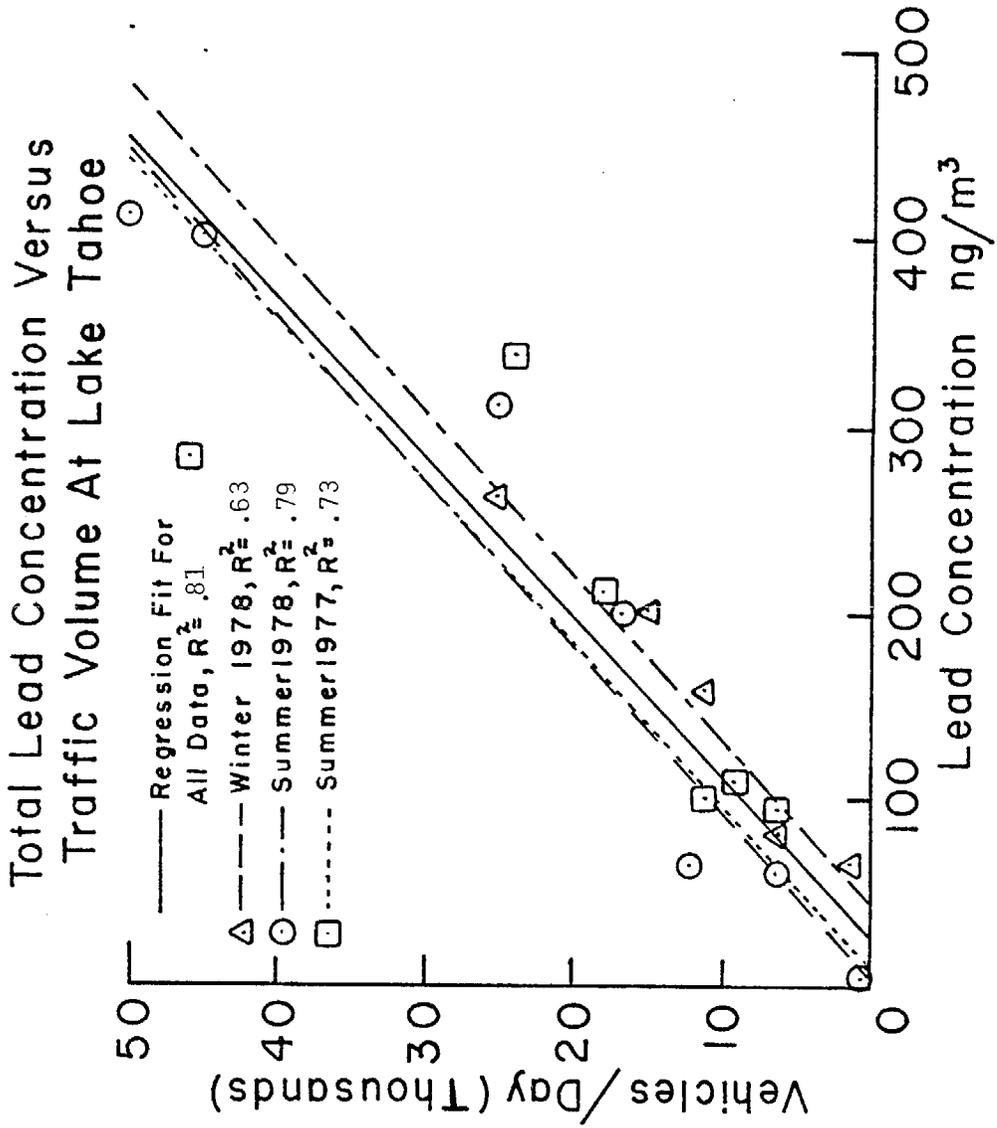
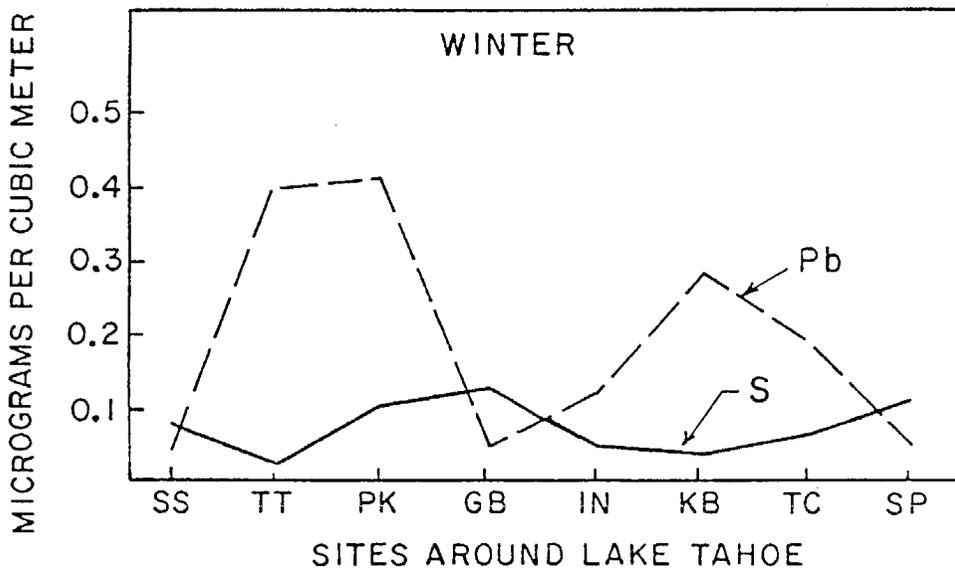
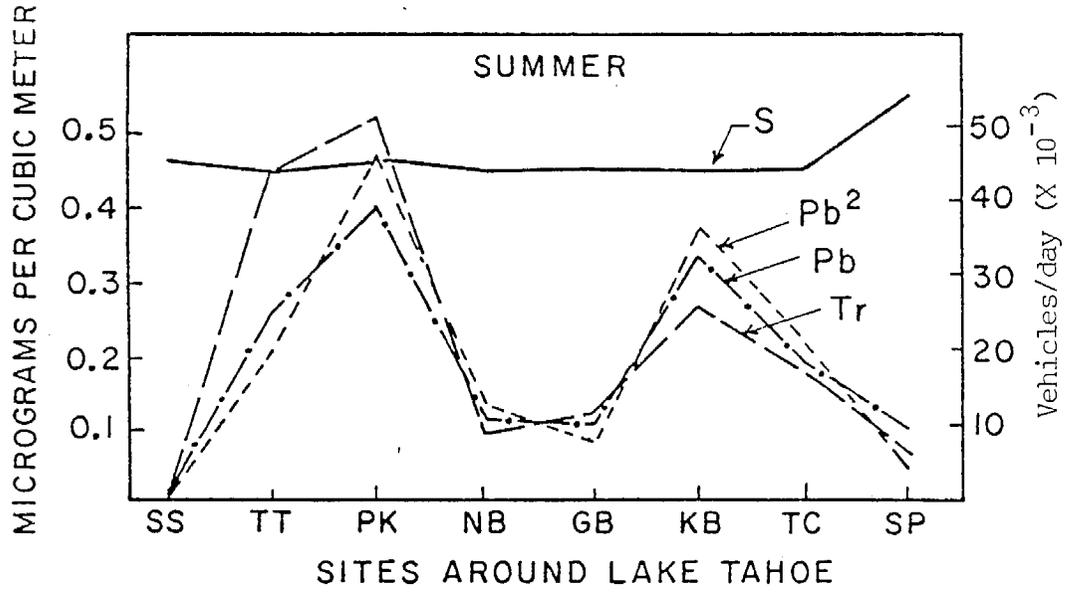


Figure 3.2.2. Total Lead Concentration Versus Traffic Volume at Lake Tahoe



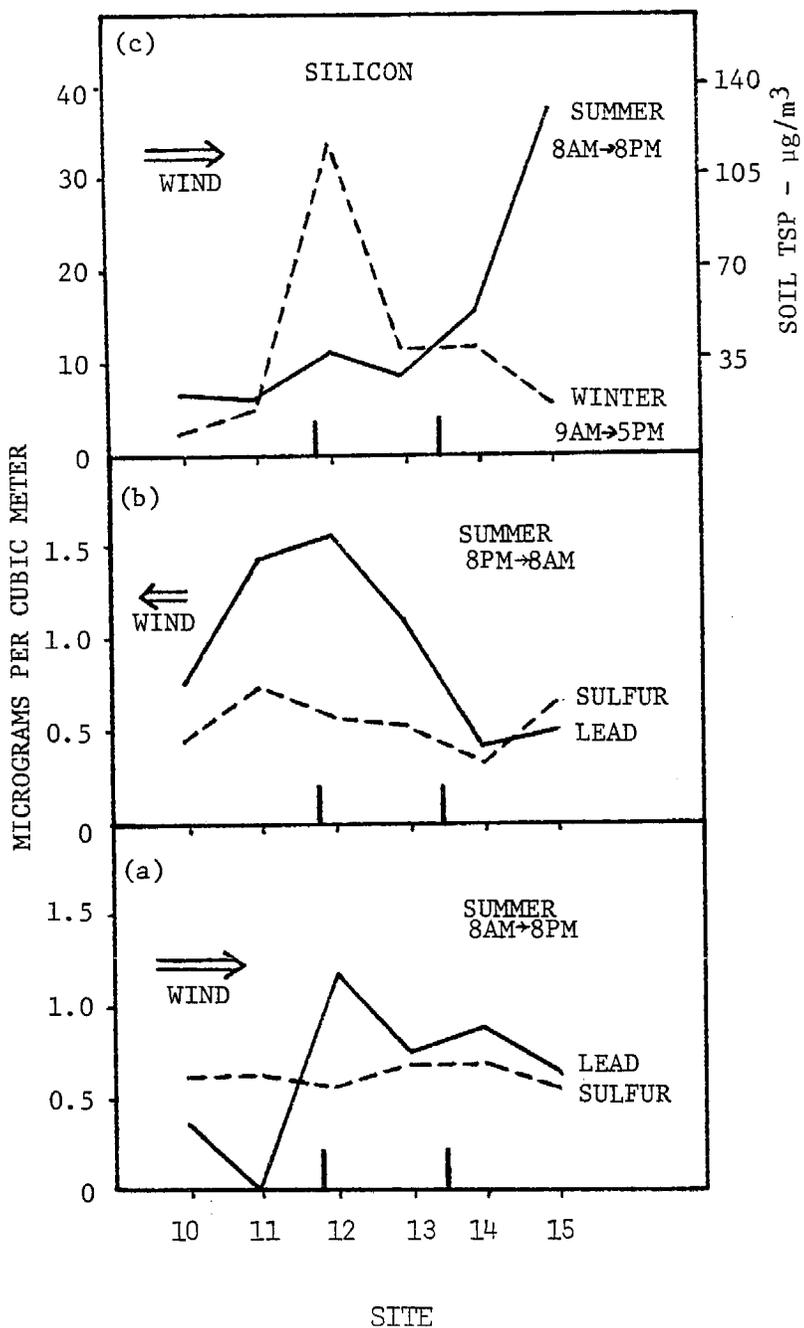
A smaller scale study conducted in South Lake Tahoe in August, 1977, was used to determine the sources of aerosols in the South Lake Tahoe area. The distribution of particulates across Highway 50 from the south shore of Lake Tahoe to the base of Heavenly Valley is shown in Figure 3.2.3. During the daylight hours (Figure 3.2.3a), the wind is predominantly from the lake, while during the night (Figure 3.2.3b), the wind blows downslope from the mountains. Highway 50 is located between sites 11 and 12, and Pioneer Trail is located between sites 13 and 14. An increase in lead concentrations is observed downwind of these major highways during the day. At night, when the wind shifts direction, the lead concentration drops at both sites upwind of Pioneer Trail, and rises at both sites downwind of Highway 50.

The results from the large and small scale spatial studies outlined above indicate that lead aerosols are locally generated in the Tahoe basin. Furthermore, Highway 50 appears to be the major source of lead aerosols in South Lake Tahoe.

Other Automotive Aerosols

The automotive contribution to ambient aerosol concentrations measured at Lake Tahoe is not necessarily limited to lead particulates. Other particulate aerosols such as silicon, may be generated by local automotive traffic. In order to determine the effect of automotive traffic on the total suspended particulate concentrations measured at Lake Tahoe, the basin monitoring data and the local spatial profile data were examined. The results from each of these data sets will be discussed below.

Figure 3.2.3



The spatial distribution of pollutants across Highway 50 in South Lake Tahoe. The vertical lines denote Highway 50 (between sites 11 and 12) and Pioneer Trail (between sites 13 and 14).

- (a) Daytime concentrations of lead and sulfur on 8/22/77.
- (b) Nighttime concentrations of lead and sulfur on 8/22/77 - 8/23/77.
- (c) Daytime silicon concentrations - summer (8/22/77) and winter (9/25/77), and estimated soil TSP.

Local Spatial Profiles of Aerosols

Direct measurements of particulate aerosols emitted by automobiles on Highway 50 in South Lake Tahoe were made in the winter of 1976 and have been reported in an earlier study (Cahill et. al. 1977). Similar measurements made as a part of the present study agree with the 1976, 1977 measurements. All of these measurements showed a strong relationship between Highway 50 and elevated silicon concentrations in South Lake Tahoe. Silicon, a tracer of soil, is shown in Figure 3.2.3(c) for summer and winter. During the summer, a high silicon concentration was observed at site 15 near a dirt road. During the winter, the road near site 15 is typically snow covered or frozen, and a low silicon concentration was measured. However, due to road sanding and salting operations in the winter, the silicon concentration near Highway 50 was almost as high as the concentration measured near dirt roads during the summer. In order to estimate the concentration of soil total suspended particulate (TSP) at Tahoe, it was assumed that all of the soil elements measured were in oxide form. The concentrations of these elements were converted to concentrations of their corresponding oxides, summed, and the ratio of the oxide total to elemental silicon was calculated. The ratio varied between 3.5 and 4.0. The conservative ratio of 3.5 was used as an estimate of soil TSP in Figure 3.2.3(c).

Based upon these data, the following conclusions can be drawn:

1. Automotive traffic on Highway 50 is a major source of coarse soil-like aerosols in South Lake Tahoe during the winter.
2. Automotive traffic on unpaved roads contributes significantly to coarse aerosol concentrations in the summer.

Basin-wide Monitoring of Aerosols

During the summer, 1977, winter, 1978, and summer, 1978, weekly monitoring of particulate aerosols at eight sites around the Tahoe basin was conducted. The strong relationship between soil-derived particulates (e.g. silicon) and automotive traffic was also indicated in these

seven day SFU samples. The correlation between total silicon and total lead aerosols measured at all sites in the basin for summer, 1977, winter, 1978, and summer, 1978, is 0.85. The mean ratio for total lead mass to total silicon mass is 0.06 with a standard deviation for each sample of 0.02. Moreover, the lead to silicon ratio does not change significantly from summer to winter or from site to site. (See Table 3.2.1). The consistency of this ratio coupled with the high correlation coefficient between total lead and total silicon and coarse lead and coarse silicon for both summer and winter months suggests that the soil aerosol contribution per automobile is nearly the same in winter (with snow and sand), as it is in summer. Furthermore, the automotive soil-like contribution appears to be constant from site to site around the basin.

Although total silicon appears to correlate well with traffic volume and lead concentrations, fine soil aerosols (including Si and Fe) do not appear to correlate with automotive traffic. Figure 3.2.4 is a graph of coarse Si, fine iron, and coarse iron versus basin site for summer, 1977. Figure 3.2.5 also includes coarse chlorine for winter, 1978. Both of these figures suggest that fine soil particles are not directly associated with automotive traffic at Tahoe, since they do not correlate well with coarse silicon or lead. It should be noted that fine soil particles do not constitute a significant portion of the total mass measured at Tahoe sites.

During the three monitoring studies (summer, 1977, winter, 1978, and summer, 1978), mass measurements of the coarse and fine aerosols collected by the SFU samplers were made. The results of these measurements are shown in Figures 3.2.6, 3.2.7, and 3.2.8. The results from these analyses are consistent with the elemental silicon measurements. That is, coarse aerosol mass is highly correlated with lead concentrations, while fine mass shows a poor correlation to measured lead concentrations.

Furthermore, since most of the aerosol mass is concentrated in the coarse particle mode, the total aerosol mass correlates well with the measured lead concentration. These data suggest that automotive

Table 3.2.1. Ratio of Total Lead to Total Silicon Concentrations
For Lake Tahoe Basin

	SUMMER 1977	WINTER 1978	SUMMER 1978	ALL SEASONS
Tata Lane	.06	.07	-	.06
Park Avenue	.06	.07	.05	.06
Nevada Beach	.04	-	-	-
Glenbrook	.05	.08	.07	.06
Incline Village	-	.06	-	-
King's Beach	.07	.05	.05	.06
Tahoe City	.07	.04	.04	.05
Sugar Pine Point	.05	.07	.04	.05
All sites	.06	.06	.05	.06

Figure 3.2.4

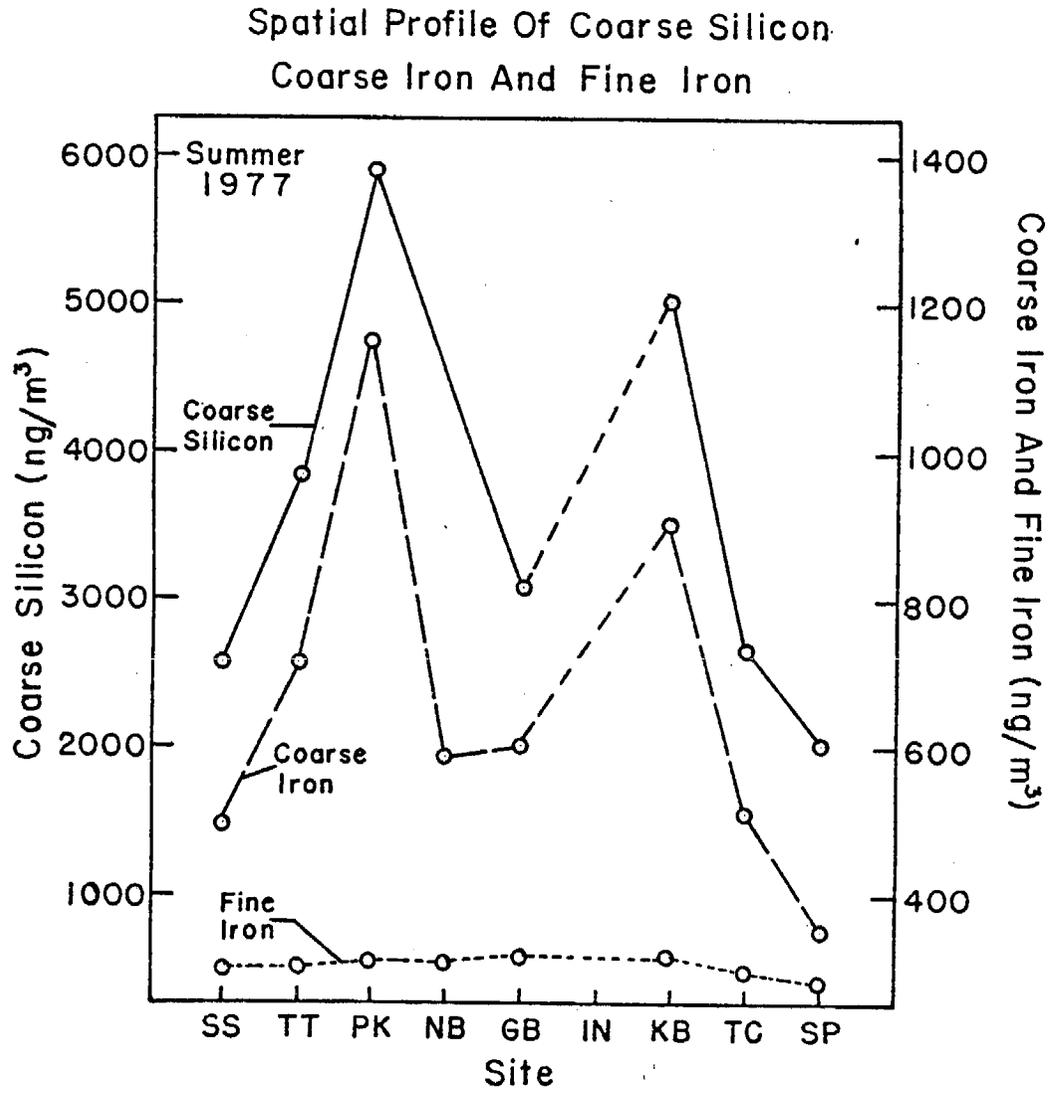


Figure 3.2.5

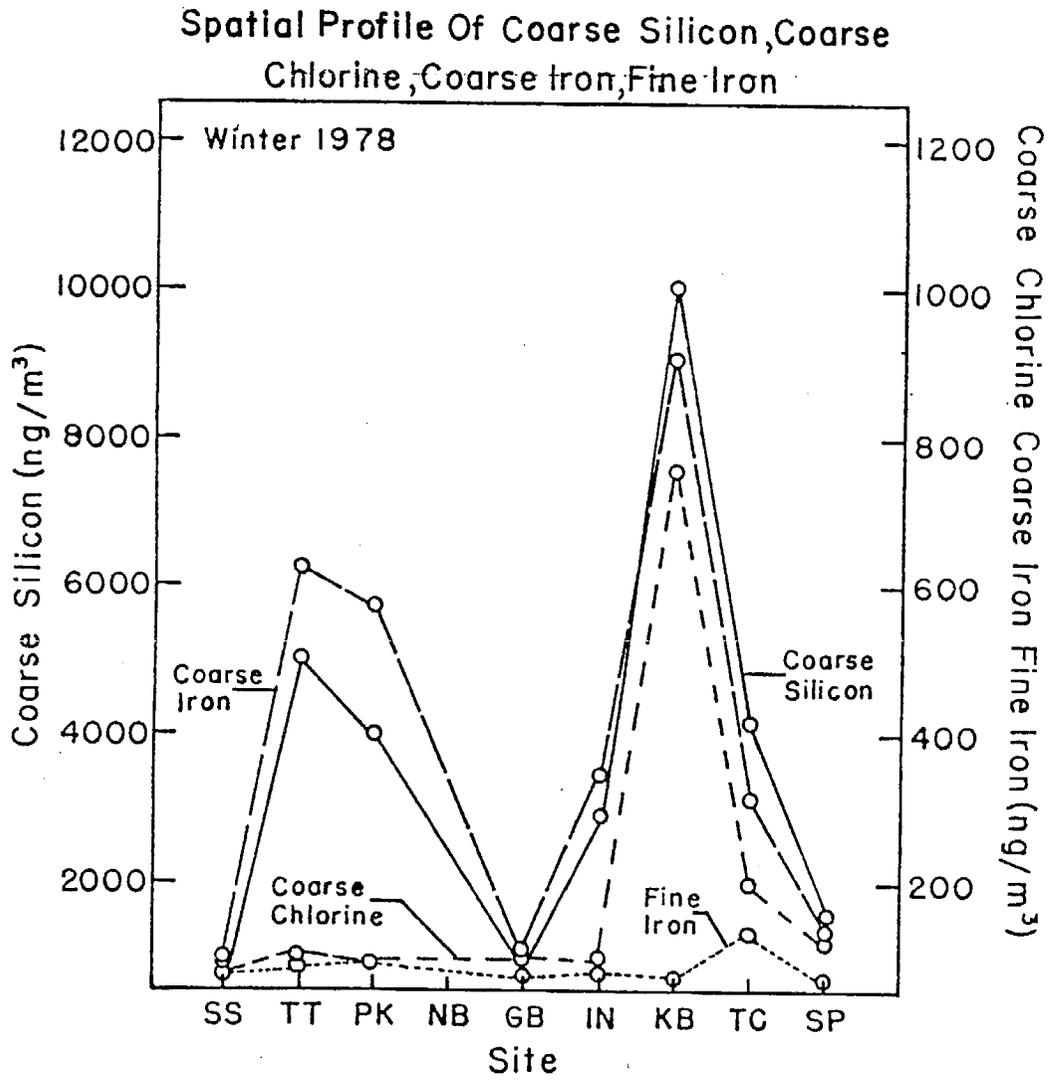


Figure 3.2.6

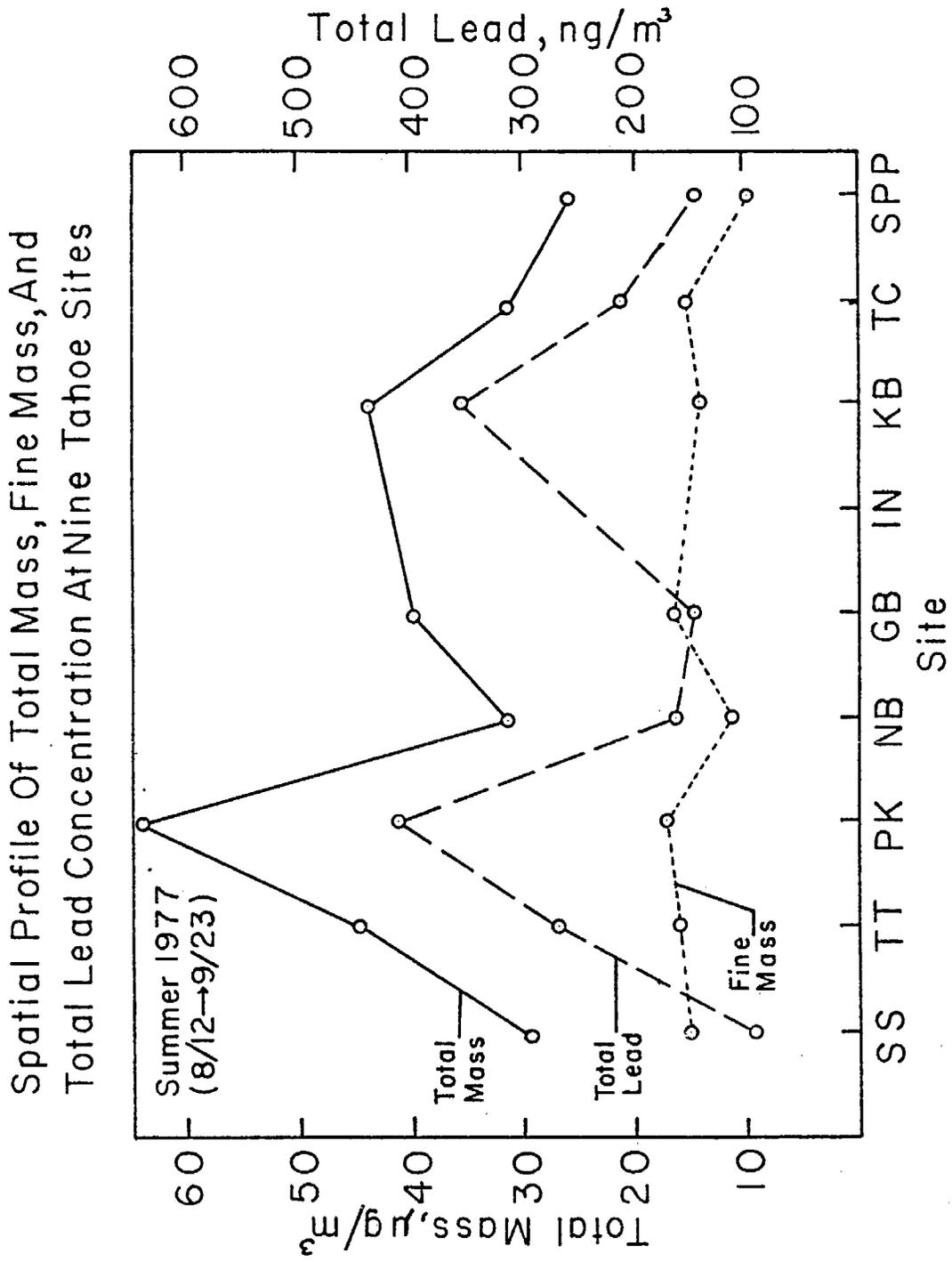


Figure 3.2.7

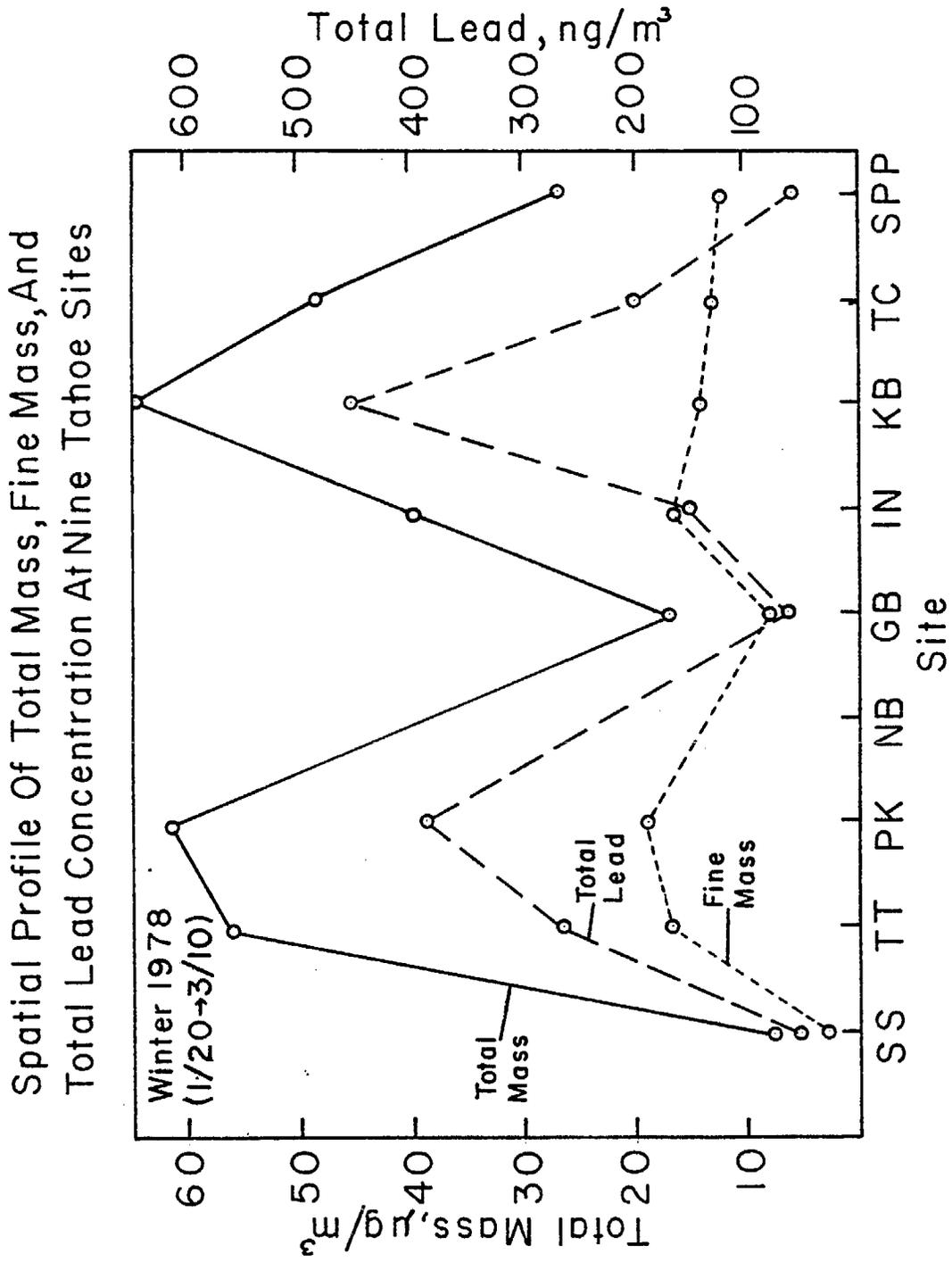
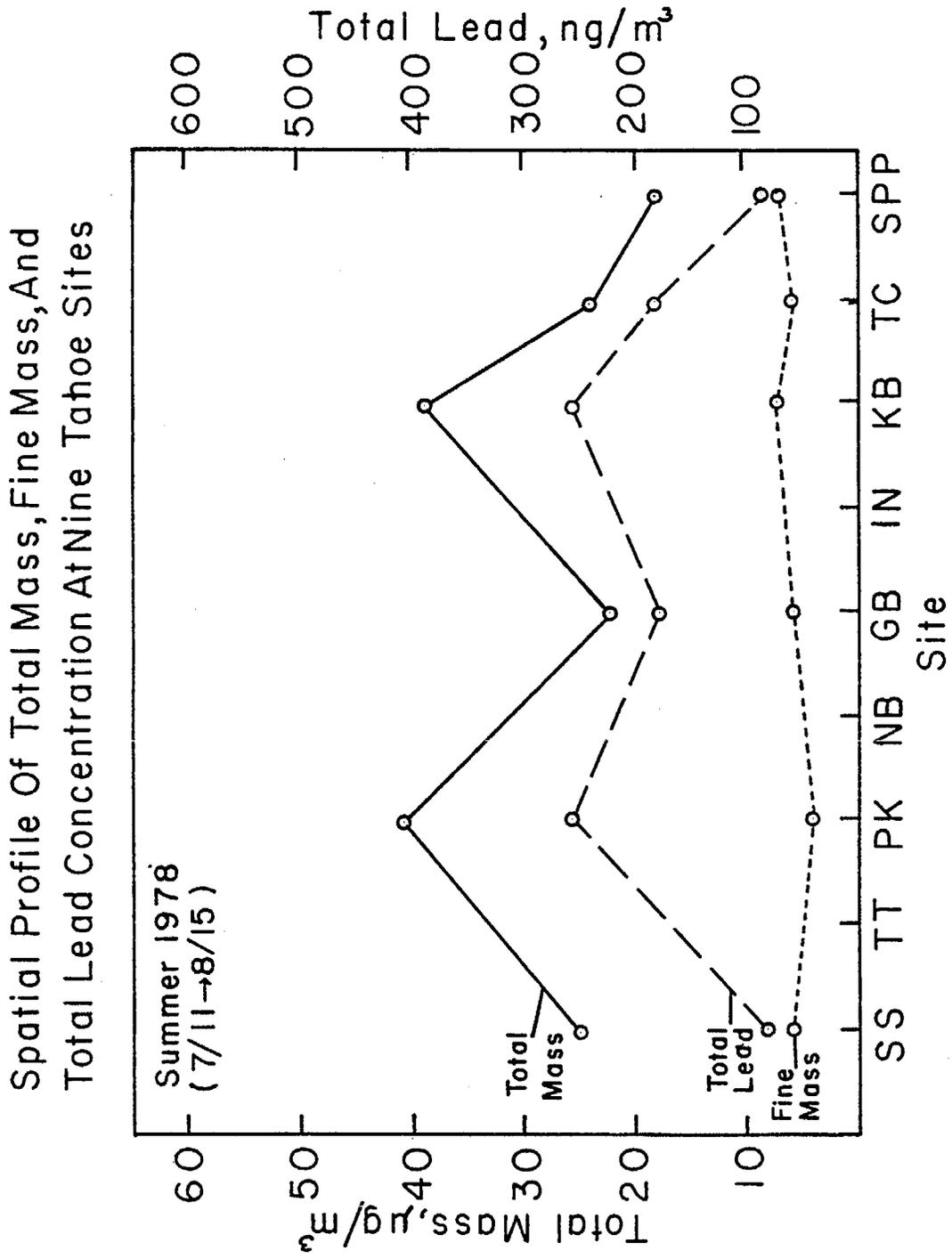


Figure 3.2.8



traffic within the Tahoe basin contributes significantly to the total suspended particulate concentrations.

The two analysis methods presented above (local spatial profile and basin wide monitoring of aerosols) suggest the following:

1. Lead aerosols are generated by automotive traffic within the basin.
2. Coarse soil-like aerosols are generated by automotive traffic within the basin.
3. Fine soil-like aerosols are not enhanced by automotive traffic at Tahoe.
4. Summer and winter aerosol concentrations appear to be affected in a similar fashion by automotive traffic.
5. A significant amount of the total suspended particulate concentration at Lake Tahoe is generated by automotive traffic.

Furthermore, based upon the above data, any increase in vehicular traffic at Tahoe will increase the total suspended particulate concentrations in the basin.

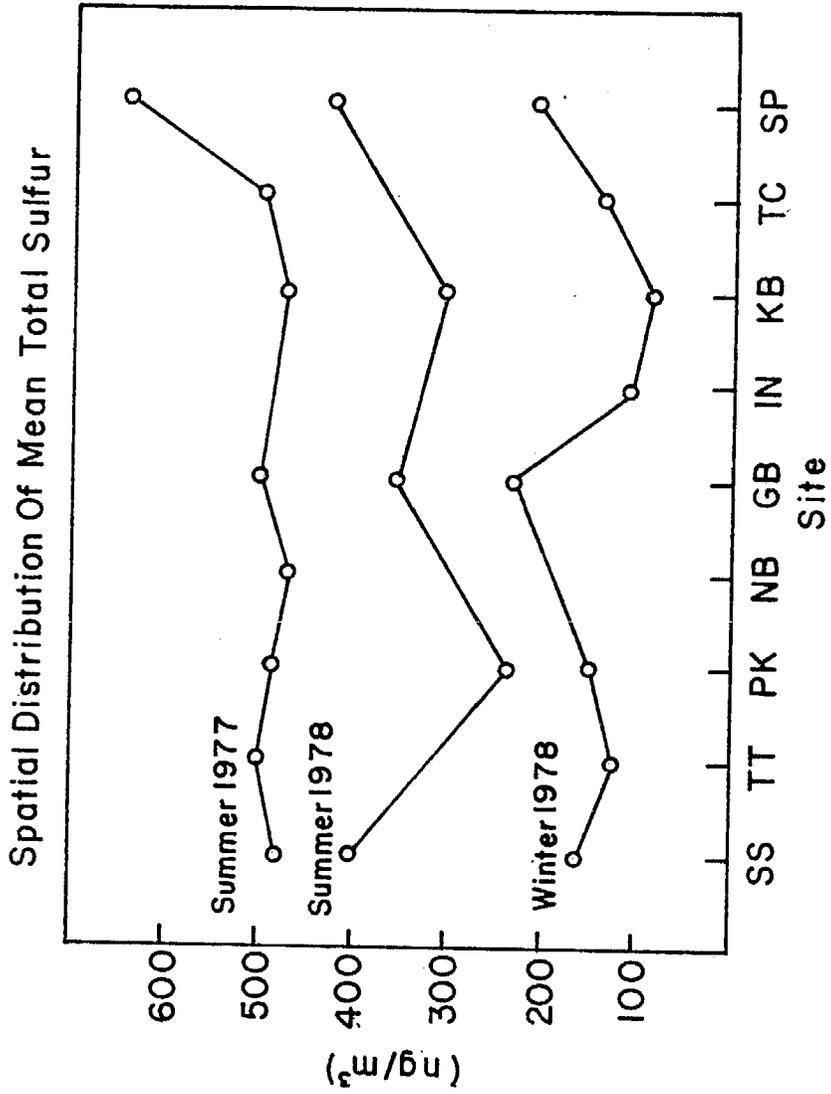
3.3. SECONDARY POLLUTANTS AT LAKE TAHOE

The results of the 1976-77 Lake Tahoe study indicated that the source of sulfur aerosols in the Tahoe basin was different from that of most other aerosols in the basin. Too little data was collected in that study, however, to be able to identify the source. One of the primary goals of this study was to collect a sufficient number of samples to identify the source of sulfur aerosols. The particulate monitoring network used in the present study provided enough data to characterize the sulfur particulate concentration at Tahoe.

The mean total sulfur concentrations for all weeks at each site for each of the weekly monitoring periods are depicted in Figure 3.3.1. In the summer of 1977, the mean total sulfur concentration was nearly uniform throughout the basin, except for a slightly higher value measured at Sugar Pine Point. In the winter of 1978, the mean sulfur concentrations were a factor of three lower than the previous summer, and some spatial variation was observed. The highest mean concentrations were recorded at Glenbrook and Sugar Pine Point; the lowest mean concentrations were on the north end of the lake. In the summer of 1978, the sulfur concentration showed spatial variation similar to that of the winter, but the concentration was, on the average, midway between the concentrations measured in the winter, 1978, and summer, 1977. The highest mean concentrations were recorded at Sierra Ski Ranch and at Sugar Pine Point.

The spatial pattern of sulfur concentration recorded in the summer of 1977 suggested that transport from outside the basin may be a significant source of sulfur within the basin. The elevated concentration measured at Sugar Pine Point during all three monitoring periods reinforced the hypothesis, further suggesting that the source is the Sacramento Valley. The spatial pattern recorded in the winter of 1978 indicates that some local generation of sulfur may exist in winter, but does not eliminate the possibility of summer transport from outside the basin. In any case, the locally generated concentrations are very low in the winter months. The spatial pattern recorded in the summer of 1978, however, was not consistent with sulfur transport from outside the basin. The measured concentrations were not uniform around the basin as they were in the summer of 1977, and they were higher than in the winter. Several other data suggested that transport may not be an important sulfur generating mechanism at Tahoe. The first indication that transport may not be important involves the results from an Air Resources Board study (Unger, 1978), which showed that ozone was not transported to Lake Tahoe from Sacramento. The second was an indication from the synoptic monitoring network that under transport conditions, sulfur levels were sometimes reduced at Lake Tahoe, not increased. The third was a calculation using an Air Resources Board

Figure 3.3.1



emissions inventory and assumptions concerning transformation and removal which indicated that SO₂ to sulfate conversion could account for the measured summer and winter sulfur concentration in the basin.

Air Resources Board Ozone Study

During the summer of 1978, the Air Resources Board conducted a study of ozone transport from the Sacramento area to Lake Tahoe. Ozone measurements were made approximately every twenty miles between Sacramento and Lake Tahoe. Other gases, including total hydrocarbons, non-methane hydrocarbons, SO₂, CO, and NO_x were sampled at some locations.

The data analysis indicated that ozone transport was limited to about the 4,000 foot level of the western slopes of the Sierra Nevada range. Above this elevation, turbulent mixing reduces the efficiency of ozone transport. Other gaseous and particulate pollutants would be affected in a similar manner. Hence, transport of airborne contaminants from the Sacramento area to the eastern slopes of the Sierra is unlikely.

Upper Air Transport Analysis

For each of the three monitoring periods, upper air charts were examined to determine whether or not transport conditions existed. Wind speed and direction at 850 mb and 500 mb were examined and each day was rated according to its transport possibilities. The days within each of the weekly monitoring periods were then averaged to obtain a weekly transport likelihood coefficient. These coefficients are presented in Table 3.3.1. The average sulfur concentration measured at five Lake Tahoe basin sites is also included in the table. The sulfur levels are not well correlated with the transport coefficients. The correlation coefficients range from $r^2 = .12$ to $r^2 = .22$. This data also suggests transport may not be an important sulfur generating mechanism at Tahoe.

Table 3.3.1. Transport Likelihood Coefficients and Sulfur Levels

	<u>500 mb</u>	<u>850 mb</u>	<u>Fine Sulfur</u>
8/12 - 8/19/77	-.13	.27	633 ng/m ³
8/19 - 8/26/77	.47	.40	530
8/26 - 9/02/77	.20	.07	209
9/02 - 9/09/77	.87	.13	406
9/09 - 9/16/77	.73	.27	517
9/16 - 9/23/77	.67	.40	307

	<u>500 mb</u>	<u>850 mb</u>	<u>Fine Sulfur</u>
1/20 - 1/27/78		-.93	59
1/27 - 2/03/78		.13	74
2/03 - 2/10/78		0	69
2/10 - 2/17/78		-.60	93
2/17 - 2/24/78		.67	138
2/24 - 3/03/78		0	278
3/03 - 3/10/78		0	165

	<u>500 mb</u>	<u>850 mb</u>	<u>Total Sulfur</u>
7/11 - 7/18/78	.33	.53	150
7/18 - 7/25/78	-.40	.13	370
7/25 - 8/01/78	-.40	-.20	537
8/01 - 8/08/78	-.80	-.67	350
8/08 - 8/15/78	.27	-.73	345

+1 = transport likely
 0 = transport uncertain
 -1 = transport unlikely

Emission Inventory and Sulfur Transformation Study

In an effort to explain the behavior of sulfur particulates on the basis of local sulfur generation, an emissions inventory for the Lake Tahoe basin prepared by the ARB was obtained from the Mountain Counties Air Pollution Control District. A summary of SO₂ emissions is listed in Table 3.3.2. A simple model of SO₂ to particulate sulfur transformation was developed to calculate expected sulfate concentrations based on the SO₂ emissions inventory. The SO₂ and sulfur particulate concentrations as a function of time can be expressed by the differential equations:

$$\frac{d(\text{SO}_2)}{dt} = \frac{E}{V} - (R_1 + T) (\text{SO}_2) \quad (1)$$

$$\frac{dS}{dt} = T \frac{\text{SO}_2}{2} - R_2 S \quad (2)$$

where: SO₂ = Sulfur dioxide concentration
S = Sulfur particulate concentration
E = Emission rate of SO₂
V = Mixed volume of the basin
R₁ = Removal rate for SO₂
T = Transformation rate for SO₂ to sulfate
R₂ = Removal rate for sulfur particulate

The factor of 2 in the first term on the right in equation (2) converts mass of SO₂ to mass of sulfur. If the concentrations vary slowly enough, the steady-state condition gives

$$\text{SO}_2 = \frac{E/V}{R_1 + T} \quad (3)$$

$$S = \frac{T}{R_2} \frac{\text{SO}_2}{2} = \frac{T}{2R_2} \frac{E/V}{R_1 + T} \quad (4)$$

Table 3.3.2. 1976 SO₂ Emissions (Tons/day)

<u>AREA SOURCES</u>	<u>WINTER</u>	<u>% OF TOTAL</u>	<u>SUMMER</u>	<u>% OF TOTAL</u>
Commercial & Industrial Fuel Combustion				
Distillates	.001	0.4	.00	0
Natural Gas	.001	0.4	.000	0
Residential Fuel Combustion				
Natural Gas	.002	0.7	.000	0
L P G	.006	2.2	.002	0.6
Distillates	.037	13.6	.010	2.9
Off-road Motor Vehicles				
Construction Equipment	.05	18.3	.05	14.5
Commercial Aircraft				
Air Carrier Turbos	<u>.02</u>	<u>7.3</u>	<u>.02</u>	<u>5.8</u>
 TOTAL AREA SOURCES	 .117	 42.9	 .082	 23.7
 <u>MOBILE SOURCES</u>				
Motor Vehicles				
Light Duty Passenger	.078	28.6	.132	38.2
Heavy Duty Truck	<u>.078</u>	<u>28.6</u>	<u>.132</u>	<u>38.2</u>
 TOTAL MOBILE SOURCES	 .156	 57.1	 .264	 76.3
 TOTAL EMISSIONS	 .273	 100.0	 .346	 100.0

The parameters used in the model are listed in Table 3.3.3. The following assumptions were used to calculate the parameters:

1. The emission rate was calculated from the emissions inventory for SO_2 .
2. In summer, the mixed layer over the lake is 100 m deep, and over land is 300 m deep. These figures were obtained from airplane over-flights. The lake surface area is 193 mi^2 or $500 \times 10^6 \text{ m}^2$, and the land surface area is 87 mi^2 or $225 \times 10^6 \text{ m}^2$. Thus, the mixed volume in summer is approximately $118 \times 10^9 \text{ m}^3$.
3. In winter, the mixed layer over the lake is 200 m deep, and over land is 75 m deep. Thus, the mixed volume in winter is approximately $117 \times 10^9 \text{ m}^3$.
4. The removal rates for SO_2 are estimated to be 0.04 hr^{-1} , summer, and 0.08 hr^{-1} , winter. Eliassen (1978) estimated dry removal of SO_2 as 0.04 hr^{-1} and wet removal (rain) as 0.14 hr^{-1} . The actual winter average removal rate is estimated to be less than 0.14 hr^{-1} , since it does not rain 100% of the time. The conservative estimate of 0.08 hr^{-1} was chosen for this calculation. A lower removal rate would increase the winter SO_2 and sulfur particulate concentrations.
5. Eggleton and Cox (1978) found transformation rates for $\text{SO}_2 \rightarrow \text{SO}_4 =$ in unpolluted atmospheres of $0.014 - .022 \text{ hr}^{-1}$ in summer, and $.002 - .011 \text{ hr}^{-1}$ in winter. Other researchers have found transformation rates in more polluted atmospheres to be on the order of $.03 - .05 \text{ hr}^{-1}$ or slightly higher. The more conservative rates from Eggleton and Cox (1978) were used for this model, since transformation rates at Tahoe should be lower than rates in polluted atmospheres.
6. The removal rate of sulfur particles was estimated to be 0.05 hr^{-1} in both summer and winter. This estimate is based on somewhat less than one day removal from the basin. Pollutant removal from the Los Angeles basin is on the order of one day. Since the Lake Tahoe basin is smaller than the Los Angeles basin, a shorter period was estimated.

Table 3.3.3. Parameter Values for Transformation Model

<u>PARAMETER</u>	<u>SUMMER VALUE</u>	<u>WINTER VALUE</u>
E	$13.1 \times 10^3 \text{ g/hr}$	$10.3 \times 10^3 \text{ g/hr}$
V	$118 \times 10^9 \text{ m}^3$	$117 \times 10^9 \text{ m}^3$
R_1	$.04 \text{ hr}^{-1}$	$.08 \text{ hr}^{-1}$
T	$.014 - .022 \text{ hr}^{-1}$	$.002 - .011 \text{ hr}^{-1}$
R_2	$.05 \text{ hr}^{-1}$	$.05 \text{ hr}^{-1}$

From the above assumptions, the calculated concentrations are:

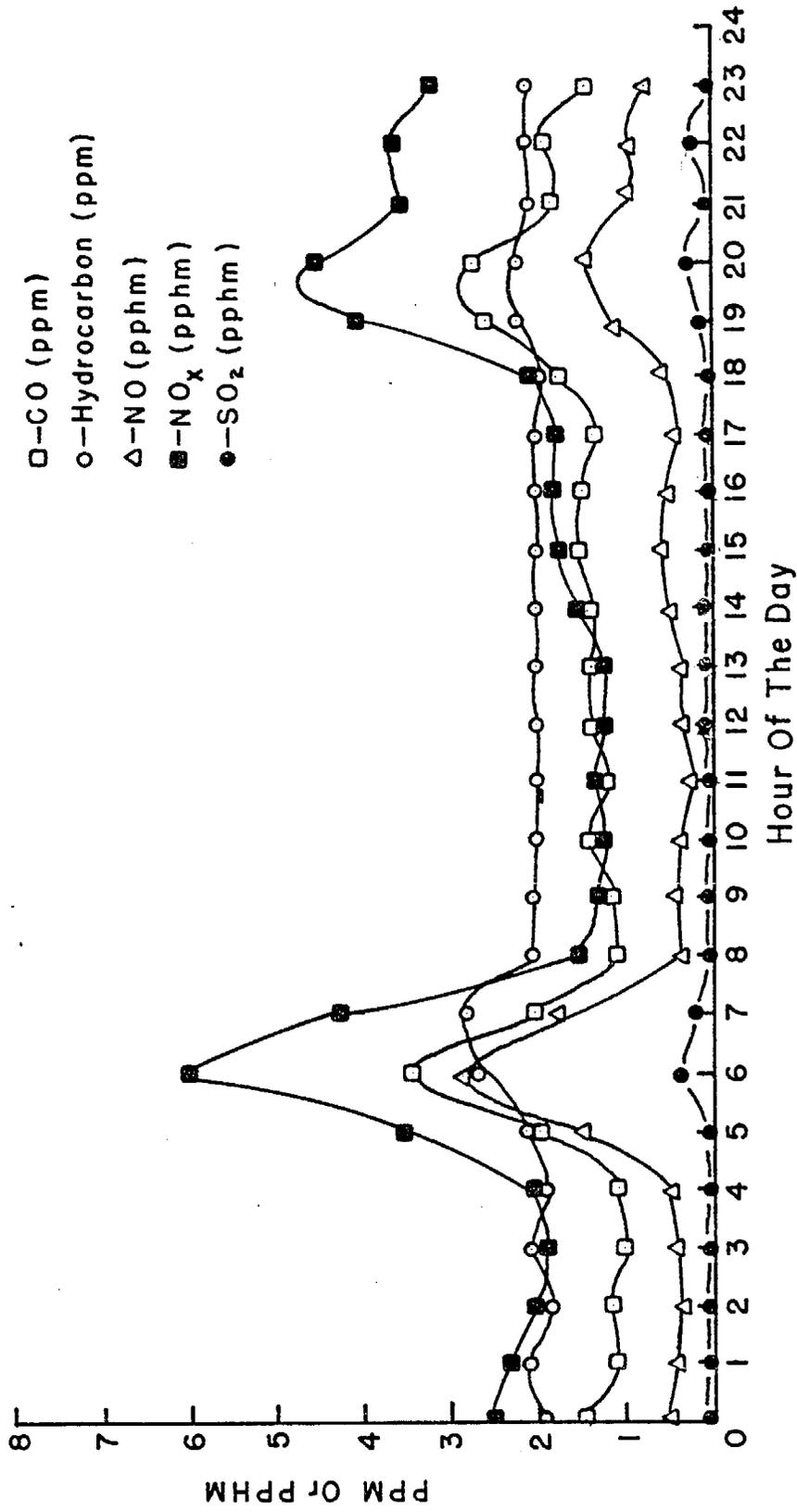
	<u>Summer</u>	<u>Winter</u>
SO ₂ (pphm)	0.79 - 0.69	0.41 - 0.37
S (ng/m ³)	288 - 394	22 - 106
Measured S (ng/m ³)	150 - 633	59 - 278

The calculated sulfur concentrations are in good agreement with the observed concentrations. Slight changes in any of the parameters could easily account for any differences noted. Sulfur dioxide is rarely measured at Lake Tahoe, since the sensitivity of the measuring instrument is 1 pphm. It is occasionally measured at Dunlap Street in South Lake Tahoe at 1 pphm during the peak pollution hours of 6:00 AM to 7:00 AM. (See Figure 3.3.2).

The conversion of SO₂ to sulfate can explain both the mean concentrations observed in the basin and the anomalous spatial pattern observed. The SO₂ gas may be mixed more or less completely throughout the basin before conversion takes place, resulting in a relatively uniform distribution of sulfur at points around the basin. The sampling sites at Glenbrook and Sugar Pine Point were located in the forest canopy, where stable atmospheric conditions nearly always exist. As sulfur particles settle into the stable atmosphere of the canopy, they are not effectively removed. Thus, it is possible for these two sites to record higher sulfur concentrations. Furthermore, the spatial pattern of sulfur across Highway 50 in South Lake Tahoe can be explained by the transformation mechanism in much the same way. Higher sulfur concentrations were measured near the lake, where stable temperature stratification also exists, and at the top of Ski Run Boulevard, in the forest canopy.

If sulfur transformation is the dominant source of sulfur particulate in the basin, and if it is desired to reduce the level of sulfur particulate, the SO₂ sources must be reduced. The major sources of SO₂ in the basin

Figure 3.3.2



by far are on-road motor vehicles, with off-road construction equipment a distant second (see Table 3.3.2). In winter, 57% of SO_2 emitted in the basin comes from on-road motor vehicles. In summer, the on-road vehicles account for 76% of SO_2 emitted.

The following conclusions regarding sulfate aerosols can be drawn from the above analysis:

1. Transport of sulfur aerosols into the Lake Tahoe basin from Sacramento (or other areas outside the basin) is not a significant source of sulfur aerosols measured in the basin.
2. Measured sulfur aerosol concentrations in the Lake Tahoe basin can be explained by $\text{SO}_2 \longrightarrow \text{SO}_4$ conversion, based on sulfur dioxide emissions within the basin.
3. On-road motor vehicle traffic is the major source of the SO_2 in the basin.
4. Increases in automotive traffic in the Tahoe basin is likely to increase sulfate concentrations at Tahoe - all other conditions being equal.

CONCLUSIONS

The analysis of data collected in this study leads to the following conclusions:

1. Lead aerosols are generated by vehicular traffic within the Lake Tahoe basin.
2. Fine soil-like aerosols are not enhanced by traffic within the basin.
3. Coarse soil-like aerosols are generated by vehicular traffic within the basin. In summer, the aerosols are generated primarily by traffic on unpaved roads. In winter, the aerosols are generated by traffic on major roadways following road sanding operations. The amounts of coarse soil-like aerosols generated by both mechanisms are comparable.
4. A significant fraction of the total suspended particulate concentration measured at Lake Tahoe is generated by vehicular traffic.
5. Transport from outside the basin is not a significant source of sulfur aerosols at Lake Tahoe. Furthermore, transport is not necessary to explain the measured concentrations of sulfur. Transformation of $\text{SO}_2 \longrightarrow \text{SO}_4 =$ can fully explain measured concentrations of sulfur, based on basin-wide SO_2 emissions compiled by the ARB. The largest single source of SO_2 in the basin is on-road motor vehicles.
6. The atmosphere over the lake is typically characterized by an extremely stable layer approximately 100-200 meters deep, and an elevated inversion at an altitude of approximately 11,000 feet. The surface layer over land is

somewhat deeper than over the lake, but was not measured in this study.

These conclusions all point to automotive traffic within the basin as the major source of particulate air pollution at Lake Tahoe. It follows that any increase or decrease in traffic in the Lake Tahoe area will result in an increase or decrease in all the major particulate air pollutants examined.

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APPENDIX A: "Spatial Distribution of Primary Automotive
Pollutants at Lake Tahoe"

T.A. Cahill, L.L. Ashbaugh, J.B. Barone, P.J. Feeney

SPATIAL DISTRIBUTION OF PRIMARY AUTOMOTIVE POLLUTANTS AT LAKE TAHOE

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1. INTRODUCTION

"The crystal clarity of Tahoe's atmosphere is so pronounced that often trees, houses, canyons and high mountain meadows on the Nevada shore appear to be focused in a powerful telescope when the sun drops behind the western Sierra with minuteness of detail standing out in bold relief"

Unfortunately this statement, taken from E.B. Scott's "The Saga of Lake Tahoe" (1957) is no longer typical of air quality in the Tahoe basin. In fact, substantial concern over air quality degradation in the Tahoe area has been expressed by numerous individuals and agencies. Both geographic and climatologic conditions at Lake Tahoe make the basin particularly susceptible to air pollution accumulation. The primary factors which enhance air pollution at Tahoe include the deep bowl shape of the basin, the frequent occurrences of temperature inversions and the intensity of solar radiation at the basin's high altitude.

The recreational and scenic value of Lake Tahoe makes a high level of air quality particularly desirable. The primary concern in the Tahoe basin with regard to air quality is

atmospheric visibility. Although the basin is only 30 miles long, many times during the year visibility is so poor that the mountains across the Lake are not clearly visible.

The causes of visibility degrading processes are not yet fully understood. However, evidence from other California cities suggests that fine sulfur aerosols are causally linked to poor visibility (Barone, 1978). In addition, this study indicated that site specific variables such as silicon (a soil tracer) and nitrogen dioxide (an automotive pollutant) can also be important visibility limiting pollutants. The importance of sulfur and soil aerosols and automotive pollutants such as nitrogen dioxide on visibility in the Tahoe basin is, as yet, unknown.

A second concern in the Tahoe basin is the relatively high level of atmospheric contaminants such as carbon monoxide, nitrogen dioxides, and lead. Table 1 compares the mean values of atmospheric pollutants at several Tahoe stations with the values observed in four California air basins. These results are quite unexpected and suggest that air quality in the Tahoe basin is comparable to other non-industrial communities in California.

Two possible sources have been implicated

TABLE 1*

POLLUTANT	Lake Tahoe	Monterey	Sacramento	Bay Area	Los Angeles
Oxidant (ppm)	0.065	0.041	0.094	0.047	0.160
Carbon Monoxide (ppm)	2.7	1.5	1.8	2.9	4.5
Hydrocarbons (ppm)	3.5	2.7	2.8	2.6	4.2
Nitrogen Dioxide (ppm)	0.024	0.014	0.038	0.039	0.082
Lead (10^{-6} g/m ³)	0.395	0.22	0.42	0.41	2.30

* All data for Lake Tahoe taken from "Air Quality in the Tahoe Basin, Summer, 1973, California Air Resources Board, March, 1974. Comparison values for other sites taken from "California Air Quality Data, July, 1973.

counts were made within 200 meters of the sampling instrument. At Nevada Beach and Glenbrook, the counts were made within 1 kilometer of the sampling site on the most heavily traveled nearby road (Highway 50 or 89). The sampler at Sierra Ski Rance was located approximately two miles from Highway 50 (the most heavily traveled nearby roadway). The sample site elevation was 350 meters higher than Highway 50 which effectively isolated this site from the highway. Therefore daily vehicle counts were assumed to be zero.

3. DATA COLLECTION AND ANALYSIS

Aerosol samples were collected by means of two-stage stacked filter unit (SFU) samplers (Cahill et al., 1977). These samplers consist of an 8.0µm pore diameter and a 0.4µm pore diameter Nuclepore filter in series. Aerosols are collected in two size ranges: 3.5-20µm on Stage 1, and 0-3.5µm on Stage 2. The weekly integrated monitoring samples were collected at 2 lpm, and the 12-hour samples were collected at 20 lpm. Experiments conducted by the Air Quality Group indicated little change in cut point for flow rates from 2-20 lpm.

The samples collected were analyzed for elemental content by particle induced x-ray emission (PIXE) at the Crocker Nuclear Laboratory Isochronous Cyclotron (Flocchini et al., 1976). Elements sodium through uranium were determined with minimum detectable limits ranging from a few nanograms per square centimeter to, when interferences were present, several hundred nanograms per square centimeter.

4. RESULTS AND DISCUSSION

Although analysis of aerosol samples indicate that numerous elements are present in the Tahoe urban atmosphere, only three representative elements have been included in this analysis. These elements, silicon, sulfur and lead, are representative of three distinct source types. Silicon is usually considered to be a tracer of soil aerosols. Lead, and to some extent bromine, is often used as an indicator of automotive pollutants, including carbon monoxide, hydrocarbons, and oxides of nitrogen. Sulfur is normally associated with combustion sources such as fossil fuel burning power generating facilities.

The basin spatial distributions of lead and sulfur are shown in Figures 3 and 4 for the summer and winter sampling periods, respectively. The data in Figure 3 includes six weeks of sampling data, while Figure 4 includes four weeks of data. Also included in Figure 3 is the spatial distribution of lead for week 2 (Pb²), which is quite similar to the six week average for lead (Pb), and traffic counts for week 2 (Tr). The lead distribution closely follows the traffic volume distribution, indicating that the source of lead particulate within the basin is of local origin. The summer sulfur levels, however, are virtually constant around the basin, indicating no correlation with traffic volume. The winter sulfur levels (Figure 4) are lower than the summer levels by a factor of 5 to 10, and show some spatial variation. Once again, no correlation

with traffic volume (as indicated by lead levels) is observed. This evidence suggests an alternative source, perhaps outside the basin, is responsible for sulfur aerosols within the basin.

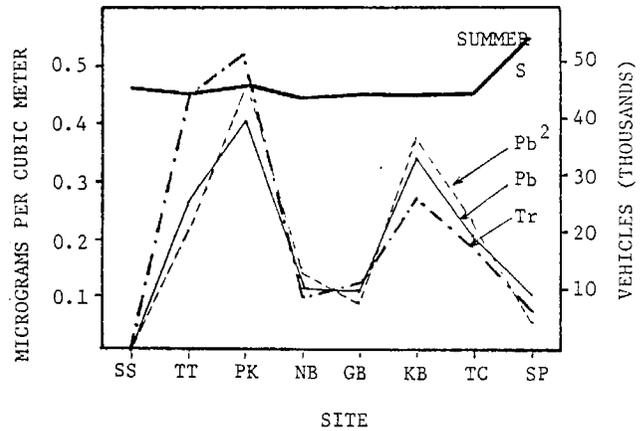


Figure 3. Spatial distribution of lead, sulfur, and traffic in the Lake Tahoe Basin. The symbols represent: S-mean sulfur concentration 8/12/77-9/23/77; Pb²-mean lead concentration 8/19/77-8/26/77; Pb-mean lead concentration 8/12/77-9/23/77; Tr-Traffic volume 8/20/77-8/23/77.

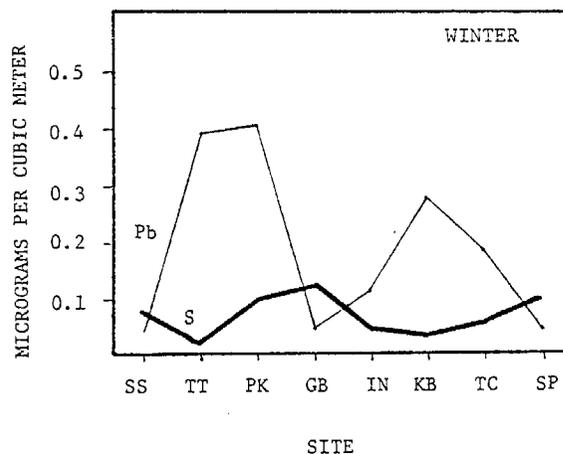


Figure 4. Spatial distribution of the mean lead and sulfur concentrations in the Lake Tahoe Basin 1/20/78-2/17/78.

The temporal distributions of lead and sulfur particulate within the Lake Tahoe basin during the summer are shown in Figure 5. Sulfur containing particulates in Sacramento (SULFUR^S) for the same period are also shown. The lead concentration in the Lake Tahoe basin is nearly constant over the six week period. The sulfur

aerosol concentration, on the other hand, varies by a factor of two. Sulfur aerosols in the Sacramento area exhibit a similar temporal variation to that observed at Lake Tahoe. The temporal variation of lead particulates in the Sacramento area is not plotted. However temporal variations in the lead concentration at Sacramento are quite different from those observed at Lake Tahoe. The combination of a uniform spatial distribution of sulfur in the Tahoe basin, coupled with the temporal correlation of sulfur at Tahoe and Sacramento during the summer suggests that sulfur is transported from the Sacramento Valley to the Tahoe basin during the summer months. During the winter, sulfur concentrations are reduced to twenty per cent of their summer values. The winter concentration of sulfur aerosols varies spatially suggesting that these aerosols may be locally generated. This hypothesis is supported by two other data. During the winter, sulfur aerosols in the Sacramento Valley are primarily intermediate size particles (.65-3.6 μ m), while during the summer it has been shown that sulfur aerosols in the valley are predominately fine particles (.1-.65 μ m) (Flocchini, et al. 1978). Therefore winter sulfur aerosols are less likely to be transported into the basin since losses due to settling are more likely during the winter. A second important difference between summer and winter is the magnitude of the winds on the western slope of the Sierra Nevada Range. During the summer upslope winds are much stronger than they are during the winter, hence transport is more likely to occur during the summer. The reduced probability of transport during the winter coupled with a deeper winter time mixed layer in the basin may account for the lower sulfur concentrations measured.

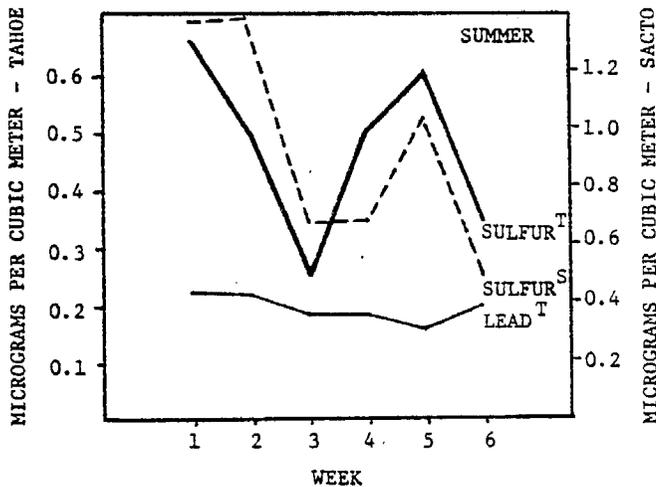


Figure 5. Temporal profile of mean sulfur and lead concentrations at Lake Tahoe and mean sulfur concentrations at Sacramento 8/12/77-9/23/77. The superscript T denotes the concentration averaged over all sites at Lake Tahoe. The superscript S denotes the mean concentration at Sacramento.

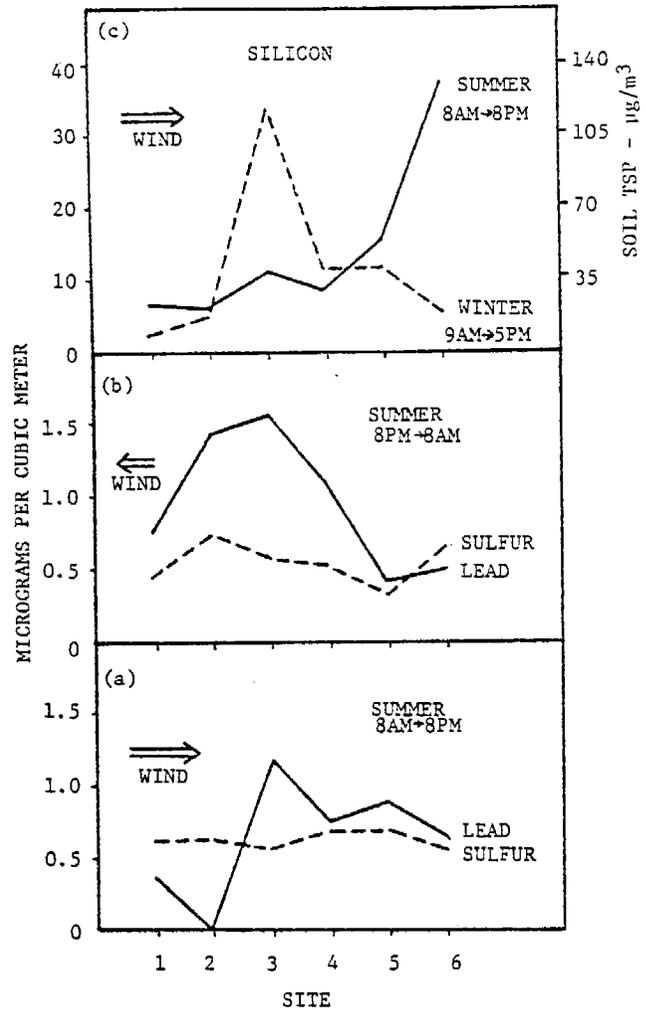


Figure 6. The spatial distribution of pollutants across Highway 50 in South Lake Tahoe. Highway 50 is located between sites 2 and 3. (a) Daytime concentrations of lead and sulfur on 8/22/77. (b) Nighttime concentrations of lead and sulfur on 8/22/77-8/23/77. (c) Daytime silicon concentrations in summer (8/22/77) and winter (9/25/77), and estimated soil TSP.

The distribution of particulates across Highway 50 from the south shore of Lake Tahoe to the base of Heavenly Valley is shown in Figure 6. During the daylight hours (Figure 6a), the wind is predominantly from the lake, while during the night (Figure 6b), the wind blows downslope from the mountains. Highway 50 is located between sites 2 and 3, and Pioneer Trail is located between sites 4 and 5. An increase in lead concentrations is observed downwind of these major highways during the day. At night, when the wind shifts direction, the lead concentration drops at both sites upwind of Pioneer Trail, and rises at both sites downwind of Highway 50. Sulfur again shows no relationship to highway traffic. Silicon, a tracer of soil, is shown in

Figure 6(c) for summer and winter. During the summer, a high silicon concentration is observed at site 6, near a dirt road. During the winter, the road near site 6 is typically snow covered or frozen, and a low silicon concentration is recorded. However, due to road sanding and salting operations in the winter, the silicon concentration near Highway 50 is almost as high as the concentration recorded near dirt roads during the summer. In order to estimate the concentration of soil total suspended particulate (TSP) at Tahoe, it was assumed that all of the soil elements measured were in oxide form. The concentrations of these elements were converted to concentrations of their corresponding oxides, summed, and the ratio of the oxide total to elemental silicon was calculated. The ratio varied between 3.5 and 4.0. The conservative ratio of 3.5 was used as an estimate of soil TSP in Figure 6(c).

The spatial distributions of lead and sulfur across South Lake Tahoe are shown in Figure 7. Lead concentrations are fairly uniform at night, but increase and vary spatially during the day when traffic volume increases. Sulfur concentrations are somewhat higher at night and do not exhibit the spatial variation observed with lead.

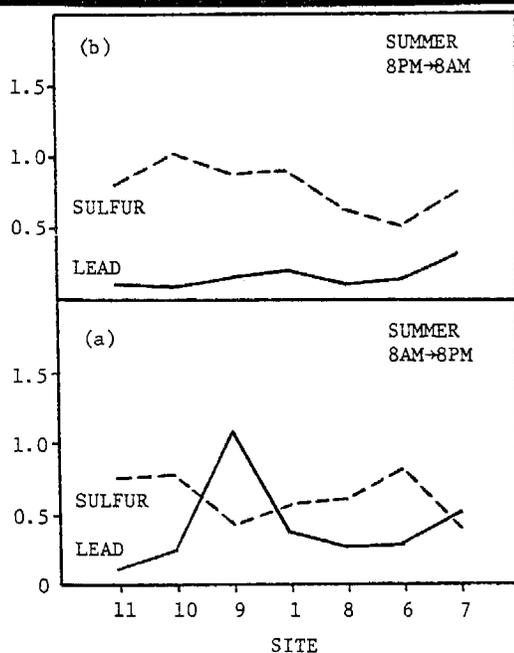


Figure 7. Spatial distributions of lead and sulfur concentrations across South Lake Tahoe. (a) Daytime concentrations on 8/23/77. (b) Nighttime concentrations on 8/23/77-8/24/77.

5. CONCLUSIONS

The following conclusions can be drawn from the above analysis:

1. Lead particulates are generated within the basin in both summer and winter. The spatial distribution of these aerosols demonstrates that they are traffic-derived.
2. During the winter, silicon aerosols are generated by traffic along major thoroughfares. During the summer, however, most silicon is generated by traffic on secondary unpaved roadways. The magnitude of the silicon concentration generated by each of these processes is similar. Significant TSP concentrations result from these processes.
3. Most of the sulfur aerosols present in the basin during the summer are due to transport from the Sacramento Valley. During the winter, the sulfur is locally generated, but at a concentration that is less than ten per cent of the summer sulfur concentration. The winter sulfur aerosol is not derived from traffic.

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