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Results from the 1991-92 Pilot Study of Wintertime PM_{10} in the San Francisco Bay Area

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INTRODUCTION

The Bay Area Air Quality Management District (BAAQMD, the District) encompasses an area of more than 14,000 km^2, as shown in Figure 1. The District is bounded on the west by the Pacific Ocean, to the east by the Mt. Hamilton and Diablo ranges, to the south by the Santa Cruz Mountains, and to the north by the northern reaches of the Sonoma and Napa Valleys. The San Joaquin Valley lies to the east of the BAAQMD, and major airflows between the two air basins occur at the Sacramento River delta, the Carquinez Straits, and Altamont Pass (elevation 304 m). The coastal mountains have nominal elevations of 500 m, though major peaks are much higher (Mount Diablo, 1173 m; Mt. Tamalpais, 783 m; Mt. Hamilton, 1328 m).

The BAAQMD manages air quality in Alameda, Contra Costa, Marin, San Francisco, San Mateo, Santa Clara and Napa Counties, in the southern part of Sonoma County, and in the southwestern portion of Solano County. More than six million people, approximately 20% of California's population, reside within this jurisdiction. Major industries and other areas of employment include tourism, government/defense, electronics manufacturing, software development, agriculture (vineyards, orchards, livestock), petroleum-refining, power generation, and steel manufacturing. Residences are often distant from employment opportunities, and 1,810 km of major controlled-access highways and bridges accommodate approximately 148 million vehicle miles traveled on a typical weekday. The District includes a diverse mixture of incomes, ethnic heritages, and lifestyles.

The BAAQMD started routine monitoring of ambient PM_{10} in November of 1984. Since then additional sites have been added, and the District now monitors PM_{10} at 14 sites. Exceedances of the federal 24-hour PM_{10} standard have been recorded at the San Jose, San Francisco, and Livermore sampling sites. Analysis of monitoring data since 1988 reveals that: 1) The federal 24-hour PM_{10} standard of 150 $\mu g/m^3$ is approached or exceeded only during the months of November, December, and January; 2) The federal annual standard of 50 $\mu g/m^3$ is not exceeded at any of the District monitoring sites; and 3) The highest PM_{10} levels occur in San Jose.

As a result of the PM_{10} exceedances, it is expected that the U.S. EPA will redesignate the Bay Area as non-attainment for PM_{10}, thereby requiring the submission of a State Implementation Plan (SIP).[1] The California Clean Air Act also specifies annual emissions reductions for the attainment of the state ozone standard, and it is possible that this might be extended to other state air quality standards in the future.

Elevated PM_{10} concentrations result from a combination of emissions, transport, transformation, and accumulation of pollutants. Previous studies showed that both primary and secondary particles cause high PM_{10} levels in the BAAQMD and other California cities.[2,3] Therefore, primary particles, sulfur dioxide, nitrogen dioxide, ammonia, and organic gas emissions must be related to transport and transformation to understand the causes of elevated PM_{10}.

A receptor model pilot study was conducted between 12/16/91 and 2/24/92 at two monitoring sites in San Jose to investigate the sources of PM_{10} and to determine the information needed to conduct additional PM_{10} studies in the Bay Area in order to develop emissions reduction strategies. The ambient chemical compositions and source apportionment results are presented in this paper.

EMISSIONS

Air pollution emission rates in the BAAQMD are comparable to those of California's San Joaquin Valley Air Basin (SJVAB), ranking second only to the South Coast Air Basin (SoCAB) among California's air basins.[4]

Alameda, Contra Costa, and Santa Clara Counties shown in Figure 1 account for the majority of all emissions, with 58% of TOG, 52% of ROG, 68% of NO_x, 68% of SO_2, 61% of CO, and 59% of PM_{10} emitted into the BAAQMD.[5] Re-entrained road dust is the largest emitter of primary PM_{10}, constituting 57% of the entire primary PM_{10} inventory. Construction and demolition activities are estimated to be the second most significant emitters of primary particles, 16% of the total, with the majority of emissions in the same three Counties. Primary particle emissions from on-road vehicle exhaust and residential wood combustion are less than 10% of total PM_{10} emissions.

Most of the BAAQMD point source emissions are located in Contra Costa County, which contains major refineries at Richmond and Benicia, a natural gas-fired power plant at Pittsburgh, and a steel mill at Antioch. Though these point sources are estimated to emit less than 5% of the primary PM_{10} in the BAAQMD, they are significant emitters of gaseous precursors of secondary PM_{10}. Forty-five percent of SO_2 emissions originate in Contra Costa County, with 60% of county-wide emissions originating from these point sources. Nearly 25% of District-wide SO_2 emissions originate from on-road motor vehicles, however. Over 50% of the District-wide NO_x originates from on-road motor vehicles with approximately 25% from area-wide fuel combustion. Less than 5% of total NO_x emissions originate in industrial point sources.

The 1992 BAAQMD emissions inventory is one of the best of its type; however it does not address temporal distributions for diurnally varying emissions, special circumstances (e.g., plant upsets, specific fires), and intermittent events (e.g., tilling, controlled burns, pesticide applications), which are most likely to affect the PM_{10} levels at sampling sites near a given source. The inventory does not include some of the source-types which might be important for primary PM_{10}, such as domestic cooking (e.g., charbroiling and frying) and agricultural ammonia emitters (e.g., livestock and fertilizing). Although the data in the emissions inventory provide a general appreciation of the major emitters, they are not sufficient to determine the major contributors to excessive PM_{10} levels, the chemical composition of PM_{10}, or the effects of emissions reductions on PM_{10} concentrations.

METEOROLOGY

The location and terrain of the San Francisco Bay Area influence the climate as much as synoptic weather conditions. There are many microclimates in the mountains, over the bays, and in the valleys which differ substantially from one area to another. It is not uncommon to find San Francisco blanketed with fog while the other areas a few miles away are sunny and cloudless.

A Pacific high pressure system, centered to the northwest and offshore of the BAAQMD, is the dominant feature during the summer. Onshore winds during the summer provide a cooling influence along the coast, while the latent heat in San Pablo and San Francisco Bays attenuates temperatures of their surroundings. Radiational heating in the valleys, especially the San Joaquin and Sacramento Valleys, creates lower pressure which augments the general flow from the eastern to western portions of the Districts. Ventilation is also enhanced by upslope flows during the day, countered by downslope flows at night.

During late fall, winter, and early spring, the Pacific High weakens and shifts southward. Upwelling ceases and storms are frequent. The majority of precipitation in the BAAQMD occurs from November through April. During rainstorms, inversions are weak and winds are moderate to vigorous. Between storms, however, the Pacific High induces subsidence inversions, below which temperatures are low and winds are sluggish. Water content in the air can be high and persistent fogs are intense and frequent, especially around the Bays. Surface wind measurements show outflows from California's Central Valley into the BAAQMD with weak onshore flows only in the afternoon. Daytime temperatures are fairly uniform at most locations in the BAAQMD, but nighttime temperatures vary substantially.

The wintertime conditions are those which are most conducive to the accumulation of primary PM_{10} and its precursors, to atmospheric transformations of gases to particles, and to transport from inland California to the BAAQMD.

MEASUREMENTS

Two 12-hour PM_{10} samples (0601 to 1800 PST, 1801 to 0600 PST next day) were collected daily using DRI modified Sequential Filter Samplers with Sierra Andersen SA 254I medium volume PM_{10} inlets at the San Jose - 4th Street (downtown commercial district) and West San Carlos (two and a half miles southwest of downtown San Jose) sites. PM_{10} mass concentrations were measured on nearly 150 samples, and 85 sample sets were selected for chemical analysis to represent high, median, and low PM_{10} concentrations.

Paved road dust samples adjacent to the San Jose and San Carlos sampling sites were collected. These samples were dried, sieved, and resuspended into PM_{10} size fractions, chemically analyzed, and composited to derive source profiles for geological material. Source profiles for additional geological material such as unpaved road dust and agricultural soil from the San Joaquin Valley were extracted from the California Air Resources Board Source Composition Library.[6-10] Source profiles for motor vehicle exhaust were obtained from the Phoenix Urban Haze Study.[11] Fireplace and woodstove profiles were taken from the SCENIC Denver Visibility Study.[12] These profiles are needed to apply the Chemical Mass Balance (CMB) source apportionment model.[13,14]

Source and receptor samples were analyzed for: 1) mass by gravimetry; 2) 40 elements by x-ray fluorescence; 3) water-soluble chloride, nitrate, and sulfate by ion chromatography; 4) water-soluble ammonium by automated colorimetry; 5) water-soluble sodium and potassium by atomic absorption spectrophotometry; and 6) organic and elemental carbon by thermal/optical reflectance. Ambient and source data are available in XBase (*.dbf) format on DOS-compatible floppy disks.

CHEMICAL COMPOSITIONS OF PM_{10}

During the pilot study, the San Carlos site recorded the highest 12-hour PM_{10} loadings (average $\pm$ standard deviation was 150.4 $\pm$ 7.6 $\mu g/m^3$) during the nighttime (1801-0600 PST) on 12/25/91, with the lowest concentration reported at the San Jose site (8.4 $\pm$ 1.0 $\mu g/m^3$) during the daytime (0601 - 1800 PST) on 1/12/92. The average PM_{10} concentrations were 68.4 $\pm$ 32.2 $\mu g/m^3$ at the San Jose Site, and 66.2 $\pm$ 32.4 $\mu g/m^3$ at the San Carlos site. Average PM_{10} chemical concentrations for the 36 samples at the San Jose site and 49 samples at the San Carlos site are reported in Tables I and II, respectively.

Species which were sought but never found above their lower quantifiable limits (defined as three times the standard deviation of the average field blank) are: phosphorus (< 0.0285 $\mu g/m^3$), cobalt (< 0.0037 $\mu g/m^3$), gallium (< 0.0074 $\mu g/m^3$), arsenic (< 0.0085 $\mu g/m^3$), yttrium (< 0.0050 $\mu g/m^3$), palladium (< 0.0495 $\mu g/m^3$), silver (< 0.0576 $\mu g/m^3$), cadmium (< 0.0593 $\mu g/m^3$), indium (< 0.0679 $\mu g/m^3$), tin (< 0.0871 $\mu g/m^3$), antimony (< 0.0992 $\mu g/m^3$), lanthanum (< 0.4601 $\mu g/m^3$), gold (< 0.0122 $\mu g/m^3$), thallium (< 0.0094 $\mu g/m^3$), and uranium (< 0.0091 $\mu g/m^3$). Tables I and II show that organic carbon, elemental carbon, nitrate, sulfate, and ammonium are the most abundant chemical components of PM_{10}, and account for 69% of the average PM_{10} mass at the San Jose site, and 74% of the PM_{10} mass at the San Carlos site.

PM_{10} mass and chemical compositions are similar at the San Jose and San Carlos sites, as shown in Figure 2. The correlations between the observations is quite high, about 0.95. The median of the ratios of San Carlos to San Jose PM_{10} mass is 0.95, with 50% of the ratios falling between 0.85 and 0.99. The PM_{10} concentrations tend to be slightly lower at the San Carlos site. This can also be seen in the scatter plot (Figure 2), where most of the points lie below the one-to-one regression line.

Organic carbon concentrations rank highest among all chemical species with an average of 20 ± 10 $\mu g/m^3$, and account for more than 30% of the PM_{10} mass. These wintertime concentrations are 30% to 50% higher than the annual averages in South Coast[14] and in San Joaquin Valley[15] air basins. The average ratios of PM_{10} organic carbon (OC) to total carbon (TC, organic carbon (OC) plus elemental carbon (EC)) were 0.69 at the San Jose site and 0.70 at the San Carlos site. Elemental carbon originates primarily from direct emissions of particles, whereas organic carbon may originate from direct primary emissions and from atmospheric transformations of organic gases. The OC/TC ratio has been used to identify the presence of secondary organic aerosol when the OC/TC ratio is greater than 0.67 (i.e., OC/EC ratio > 2.0).[14,16,17] Secondary organic carbon is generally associated with photochemical transformations that are not deemed to be significant during winter months.

Nitrate concentrations rank second in average abundance and range from 0.5 to 28 $\mu g/m^3$, with an average of 11 ± 7 $\mu g/m^3$. They account for approximately 17% of the average PM_{10} mass, and are typical of annual averages reported in the South Coast[14] and San Joaquin Valley[15] air basins.

Relative proportions of soil-related species such as PM_{10} aluminum, silicon, potassium, calcium, titanium, and iron are also similar at the two sites and account for 8.5% of the PM_{10} mass. The average PM_{10} silicon concentration is 2.5 ± 3.9 $\mu g/m^3$ at both sites, which is similar to annual average crustal concentrations at South Coast urban sites.[19] These concentrations are 30% to 50% lower than those found in annual averages for the San Joaquin Valley, where geological material is one of the major PM_{10} source contributors. Average soluble potassium (K') is 0.67 ± 0.92 $\mu g/m^3$ at the San Jose site and 0.43 ± 0.41 $\mu g/m^3$ at the San Carlos site. The soluble potassium to total potassium (K'/K) ratio is 0.82 at the San Jose site and 0.53 at the San Carlos site. A large abundance of soluble potassium in total potassium is indicative of vegetative burning (e.g., woodstoves, fireplaces) in the wintertime.

SOURCE APPORTIONMENT

The CMB receptor model[13] was applied to this data set to estimate the source contributions to PM_{10} using the source profiles identified earlier. Aside from geological material, no source-specific source profiles were measured in this pilot study. The U.S. EPA application and validation protocol[14] was followed. Figures 3 summarizes the individual daytime and nighttime source contributions to PM_{10} at the two sites. Uncertainties for these apportionments are typically in the range of ± 15% to 25% for major contributors. These uncertainties should be examined when source contribution estimates are to be used quantitatively.

Summaries of CMB results at the San Jose and San Carlos sites are given by Fairley et al.[20] for: 1) primary geological material; 2) primary motor vehicle exhaust; 3) residential wood combustion; 4) primary vegetative burning; 5) primary marine-derived aerosol; 6) secondary ammonium sulfate; and 7) secondary ammonium nitrate. The percent mass explained was 100% (± 10%) in most cases, with these sources. PM_{10} concentrations and source contributions varied by a factor of five during the winter monitoring period.

A comparison of average PM_{10} source contributions at the San Jose and San Carlos sites is presented in Figure 4. The source contributions at the two sites are similar (within 1 to 2% of the measured PM_{10} mass). During the pilot study, the largest contributor to PM_{10} was residential wood combustion, which accounts for over 40% (29 $\mu g/m^3$ on average) of the PM_{10} mass. Primary geological material is the second largest contributor, and accounts for 18% (12 $\mu g/m^3$ on average) of the PM_{10} mass. Contributions from primary motor vehicle exhaust and secondary ammonium nitrate are also high, and account for 13% to 18% (9 to 13 $\mu g/m^3$ on average) of the PM_{10} mass.

Secondary ammonium sulfate contributions vary from 0 to 10 $\mu g/m^3$ with a typical value of 2 to 3 $\mu g/m^3$ (3% to 4% of PM_{10} mass). Primary marine-derived aerosol is generally detectable (< 1 $\mu g/m^3$), with a maximum of 3.3 $\mu g/m^3$ during the nighttime on 1/11/92 at the San Jose site.

Day/Night pairs were selected from the chemically analyzed samples. Day/Night comparisons of the average PM_{10} mass as well as their major source contributions are shown in Figure 5 for the two sites. On average, nighttime residential wood combustion contributions are nearly twice the daytime contributions. Primary motor vehicle exhaust contributions are 65% to 100% higher at night than during the day. PM_{10} source contributions from primary geological material and secondary ammonium nitrate are similar during day and night, however.

The increased residential wood combustion emissions on cold winter nights and motor vehicle exhaust emissions from morning and evening rush-hours coupled with lower wind speed and less mixing during nighttime resulted in higher PM_{10} at night.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The results of the wintertime pilot study conducted between 12/16/91 and 2/24/92 at the two sites in San Jose provide some insights for the future study of PM_{10} in the Bay Area. The major conclusions to be drawn from the measurement and modeling are as follows:

- The highest 12-hour PM_{10} concentration was 150.4 $\pm$ 7.6 $\mu g/m^3$ at the San Carlos site on 12/25/91 during nighttime (1801 to next day 0600 PST). Twelve-hour PM_{10} concentrations exceeded 100 $\mu g/m^3$ on 10% of the days during the pilot study. Nighttime concentrations are often substantially higher than daytime concentrations.

- Chemical analysis performed on the PM_{10} samples is sufficient for CMB receptor modeling.

- PM_{10} concentrations and source contributions are similar at the San Jose and San Carlos sites.

- Residential wood combustion is the largest contributor and accounts for 40% of the PM_{10} mass. Other major contributors are: primary geological material, primary motor vehicle exhaust, and secondary ammonium nitrate, -- each accounts for 15% to 20% of the average PM_{10} mass. Secondary ammonium sulfate and primary marine-derived aerosol contributions to PM_{10} are generally low, accounting for only a few percent of PM_{10}.

The pilot study identified the following needs for further understanding in a more comprehensive study:

- Area-specific source profiles for primary geological material, primary motor vehicle exhaust, and residential wood combustion should be acquired.

- Measurements of precursor gases for secondary aerosol such as ammonia and nitric acid are needed along with the PM_{10} measurements.

- Effects of transport and transformation meteorology on PM_{10} levels need to be further studied.

- Diurnal variations of PM_{10} mass and precursor gases can provide a better representation of the temporal distributions of PM_{10} in the Bay Area.

- More comprehensive spatial representation of PM_{10} distributions throughout the BAAQMD are essential.

- Discrepancies between the Bay Area emissions inventory and CMB receptor modeling results are evident. These discrepancies need to be resolved in order to formulate a District-wide emissions control strategy for PM_{10}.

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Table I. Summary statistics of PM_{10} at the San Jose site.

Species	Number > LOL[a]	Average Conc. ($\mu g/m^3$)	Standard Deviation ($\mu g/m^3$)	Percent[b] Mass (%)	Statistic Distributions ($\mu g/m^3$) Minimum	25th Percentile	Median	75th Percentile	Maximum
Mass	36	68.4300	32.1300	100.000	8.3800	41.1500	69.7000	88.8100	135.100
Chloride	36	0.7303	0.5525	1.067	0.0623	0.3061	0.6072	1.1154	2.600
Nitrate	36	11.3600	7.0400	16.601	0.4900	5.4900	11.3300	16.6400	28.470
Sulfate	36	2.5180	1.6860	3.680	0.4340	1.4670	1.9690	3.1120	7.955
Ammonium	36	4.0630	2.7330	5.937	0.1670	1.7480	4.1410	5.6880	9.924
Soluble Sodium	36	0.3839	0.2811	0.561	0.0877	0.2060	0.3014	0.4560	1.342
Potassium	36	0.6700	0.9160	0.979	0.1090	0.2690	0.4030	0.6480	4.575
Organic Carbon	36	20.2400	9.1900	29.578	5.3500	13.9300	18.7600	25.8600	39.280
Elemental Carbon	36	9.1600	4.4290	13.386	0.9340	5.8370	9.3590	12.1290	18.075
Aluminum	36	0.8117	0.3915	1.186	0.1685	0.4974	0.7890	1.1115	1.974
Silicon	36	2.6150	1.1910	3.821	0.5620	1.7280	2.5030	3.5800	5.742
Sulfur	36	1.2240	0.8970	1.789	0.2170	0.6470	0.9590	1.5520	4.420
Chlorine	34	0.8190	0.8170	1.197	0.0160	0.1860	0.5530	1.3430	3.399
Potassium	36	0.8200	0.3984	1.198	0.1598	0.4483	0.7945	1.0670	1.696
Calcium	36	0.6682	0.3189	0.976	0.1279	0.5003	0.5843	0.8750	1.552
Titanium	33	0.0614	0.0269	0.090	0.0114	0.0420	0.0620	0.0783	0.121
Vanadium	10	0.0049	0.0028	0.007	0.0000	0.0035	0.0048	0.0067	0.013
Chromium	13	0.0026	0.0022	0.004	0.0000	0.0008	0.0021	0.0043	0.009
Manganese	36	0.0137	0.0059	0.020	0.0024	0.0098	0.0133	0.0180	0.026
Iron	36	0.8358	0.3561	1.221	0.1585	0.5785	0.8576	1.1138	1.498
Nickel	35	0.0037	0.0017	0.005	0.0013	0.0022	0.0036	0.0047	0.008
Copper	36	0.0274	0.0110	0.040	0.0049	0.0214	0.0282	0.0347	0.046
Zinc	36	0.0742	0.0436	0.108	0.0110	0.0559	0.0715	0.0912	0.282
Selenium	27	0.0034	0.0025	0.005	0.0000	0.0011	0.0032	0.0050	0.011
Bromine	36	0.0131	0.0057	0.019	0.0026	0.0077	0.0129	0.0188	0.022
Rubidium	24	0.0015	0.0007	0.002	0.0000	0.0010	0.0015	0.0019	0.003
Strontium	36	0.0203	0.0231	0.030	0.0042	0.0080	0.0133	0.0185	0.112
Zirconium	11	0.0031	0.0093	0.004	0.0002	0.0009	0.0014	0.0022	0.057
Molybdenum	5	0.0016	0.0015	0.002	0.0000	0.0007	0.0014	0.0022	0.008
Tin	1	0.0051	0.0075	0.007	0.0000	0.0000	0.0014	0.0087	0.027
Barium	2	0.0268	0.0280	0.039	0.0000	0.0011	0.0226	0.0412	0.107
Lead	35	0.0398	0.0173	0.058	0.0040	0.0301	0.0373	0.0525	0.084

[a] Lower quantifiable limit is defined as three times the standard deviation of the average field blanks.
[b] Percent Mass is the average species concentrations as a percentage of average PM_{10} Mass.

Table II. Summary statistics of PM_{10} at the San Carlos site.

Species	Number > LOL[a]	Average Conc. (μg/m³)	Standard Deviation (μg/m³)	Percent[b] Mass (%)	Statistic Distributions (μg/m³) Minimum	25th Percentile	Median	75th Percentile	Maximum
Mass	49	66.2000	100.000	32.3500	11.8900	41.8100	64.7900	88.4600	150.380
Chloride	49	0.7429	0.6410	1.182	0.0182	0.2065	0.5283	1.1777	2.640
Nitrate	49	10.8190	6.6870	17.219	0.5590	4.6470	10.4390	17.0150	26.061
Sulfate	49	2.3400	1.6480	3.724	0.3610	1.1400	1.9090	2.6960	7.455
Ammonium	49	3.9130	2.5840	6.228	0.1580	1.5020	4.0490	6.0250	8.802
Soluble Sodium	49	0.3170	0.2293	0.505	0.0753	0.1606	0.2011	0.4268	0.999
Potassium	49	0.4334	0.4093	0.690	0.0803	0.1772	0.3665	0.5498	2.633
Organic Carbon	49	20.7900	10.6300	33.089	6.0300	12.3000	19.0400	26.0900	53.300
Elemental Carbon	49	8.7760	4.4690	13.968	0.6730	4.9140	8.4480	11.9670	18.130
Aluminum	49	0.6682	0.3639	1.064	0.1747	0.3904	0.6441	0.9093	1.998
Silicon	49	2.4910	1.1860	3.965	0.7200	1.5530	2.3360	3.3490	6.466
Sulfur	49	1.1630	0.8620	1.851	0.1470	0.5890	0.9240	1.4490	4.444
Chlorine	47	0.8340	0.9180	1.327	0.0140	0.1390	0.3160	1.2990	3.846
Potassium	49	0.8051	0.4716	1.281	0.1505	0.4207	0.7401	1.0144	2.046
Calcium	49	0.5424	0.2673	0.863	0.1714	0.3632	0.5236	0.7092	1.437
Titanium	43	0.0682	0.0767	0.109	0.0090	0.0340	0.0555	0.0708	0.476
Vanadium	11	0.0062	0.0067	0.010	0.0000	0.0016	0.0045	0.0089	0.036
Chromium	4	0.0014	0.0025	0.002	0.0000	0.0000	0.0000	0.0019	0.013
Manganese	49	0.0116	0.0052	0.018	0.0025	0.0074	0.0115	0.0153	0.026
Iron	49	0.7371	0.3164	1.173	0.1713	0.4930	0.7577	0.9342	1.601
Nickel	33	0.0024	0.0014	0.004	0.0000	0.0014	0.0023	0.0034	0.006
Copper	49	0.0288	0.0162	0.046	0.0052	0.0178	0.0262	0.0362	0.072
Zinc	49	0.0602	0.0257	0.096	0.0134	0.0384	0.0637	0.0793	0.108
Selenium	28	0.0030	0.0023	0.005	0.0000	0.0012	0.0029	0.0043	0.009
Bromine	48	0.0129	0.0089	0.021	0.0008	0.0065	0.0111	0.0170	0.049
Rubidium	18	0.0015	0.0007	0.002	0.0003	0.0010	0.0015	0.0019	0.003
Strontium	48	0.0079	0.0090	0.013	0.0018	0.0038	0.0057	0.0076	0.057
Yttrium	2	0.0007	0.0008	0.001	0.0000	0.0002	0.0005	0.0009	0.004
Zirconium	3	0.0015	0.0008	0.002	0.0001	0.0010	0.0014	0.0019	0.003
Molybdenum	1	0.0012	0.0010	0.002	0.0000	0.0005	0.0013	0.0019	0.004
Lead	48	0.0313	0.0147	0.050	0.0041	0.0198	0.0305	0.0415	0.063

[a] Lower quantifiable limit is defined as three times the standard deviation of the average field blanks.
[b] Percent Mass is the average species concentrations as a percentage of average PM_{10} Mass.

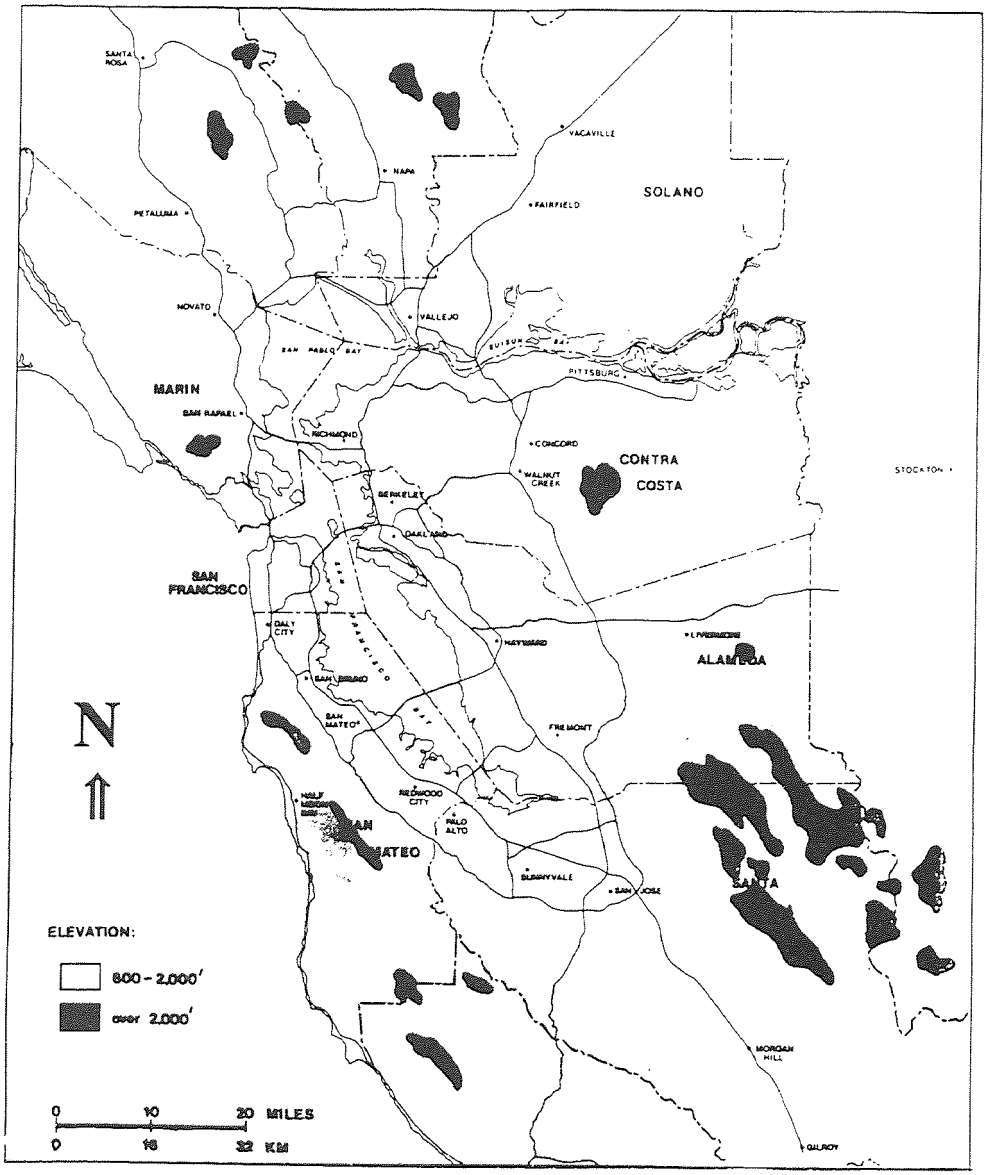


Figure 1. Map of Bay Area Air Quality Management District.

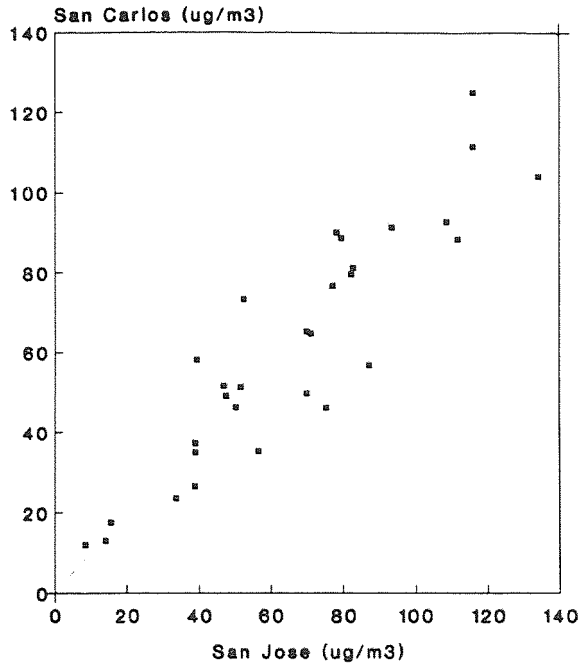
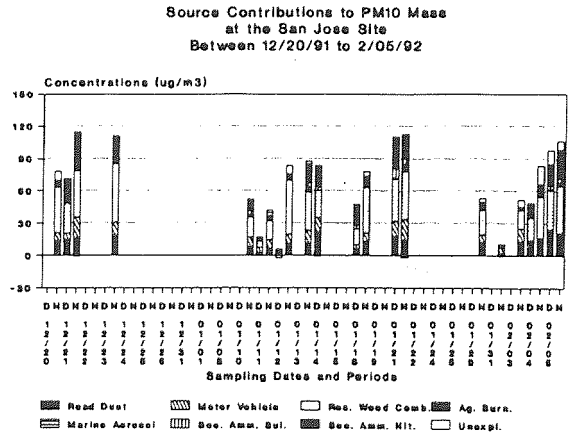


Figure 2. Comparison of 24-hour average PM_{10} mass concentrations at the San Jose and San Carlos sites (two 12-hour observations were sometimes used to compare with the 24-hour observations as one of the samplers was not sequencing properly).



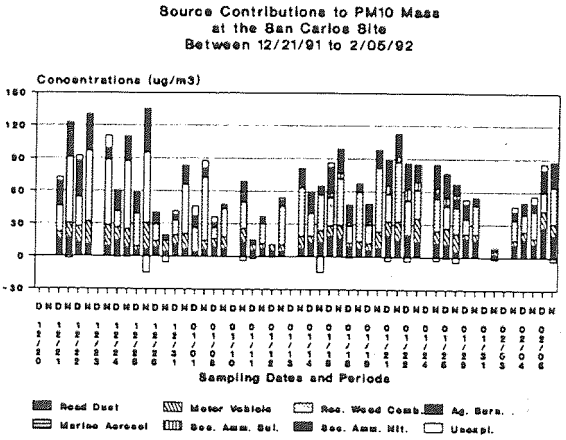


Figure 3. PM_{10} source contribution estimates at the San Jose and San Carlos sites.

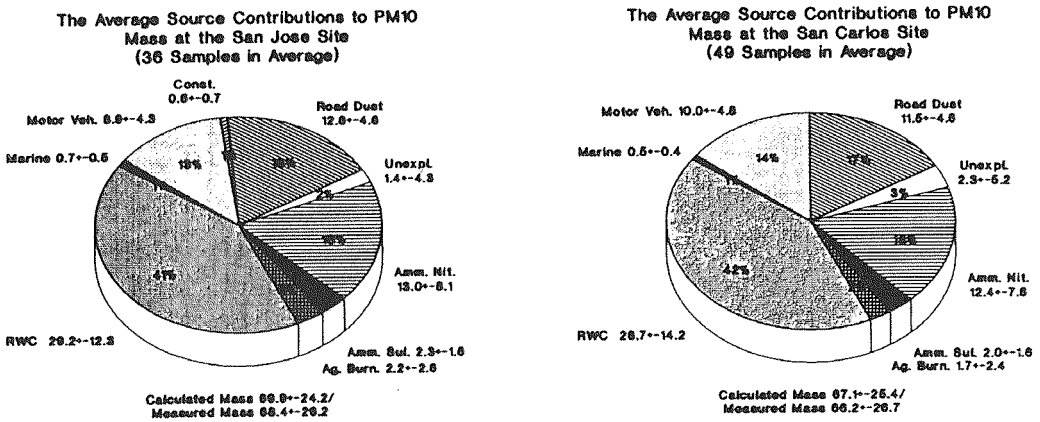


Figure 4. Calculated source contributions to wintertime PM_{10} at the San Jose and San Carlos sites.

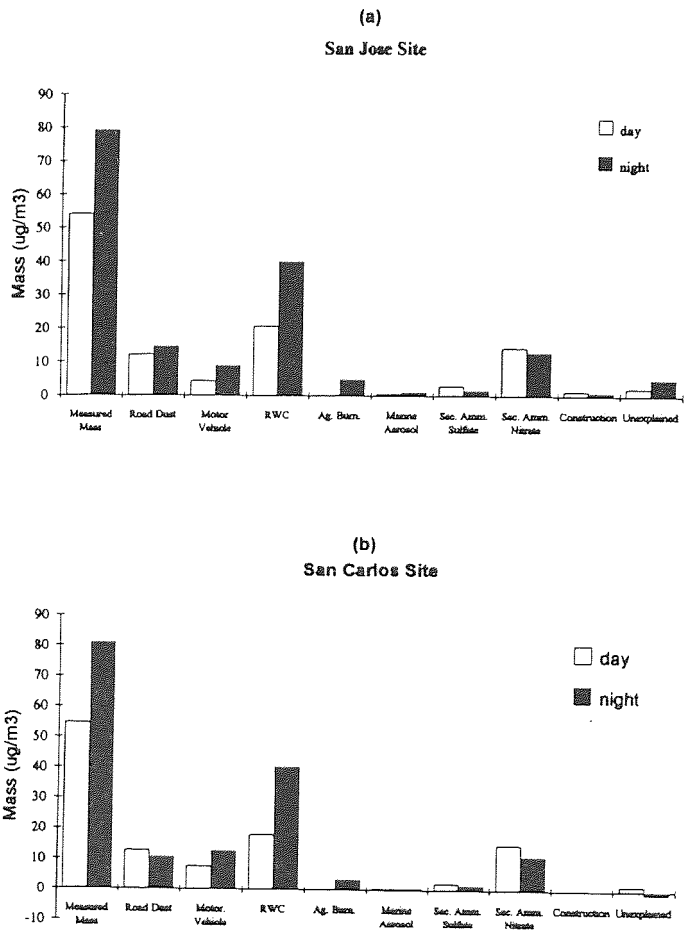


Figure 5. Day (0601-1800 PST) / Night (1801-0600 PST) comparisons of PM10 source contributions based on 7 Day/Night pairs at the San Jose site and 20 Day/Night pairs at the San Carlos site.