SECTION 1
OVERVIEW OF STUDY

1.1 Objectives

The main purpose of this study is to apply the methods developed by the Brookshire et. al. (1979) for estimating benefits of air quality changes in Los Angeles to another area, namely the San Francisco Bay Area. In addition to comparing results in two geographic areas, certain modifications of the methods are tested here to see how they affect the conclusions obtained.

As in the Los Angeles study, this study includes two different methods for determination of benefits related to air quality changes. Both methods estimate willingness to pay for air quality changes. One method uses property value data to obtain benefit estimates from actual market transactions. Another method uses survey information; here, value information is obtained from self-report of behavior in a hypothetical situation.

Both of these methods involve some methodological and theoretical problems. The underlying philosophy behind this study, as in the Los Angeles study, is that by using several methods, each with some imperfections, a better estimate of the range of benefit values associated with air quality improvement is obtained.

In order to carry out a study of the Bay Area, the first step was to develop an understanding of the area, both in terms of air quality and socioeconomic characteristics. Section two contains a general description of air quality problems in the San Francisco Bay Area. In section three, we develop a taxonomy of air quality types and assign cities to each air quality type. Section four describes our sampling design based on a taxonomic study of cities, census tracts, and market areas; the same sample design was used for both the property value and survey studies. Section five contains the results of our property value study and section six presents its application to benefit measurement. Section seven gives the results of our survey and its use for benefit measurement. Section eight compares results of the property value and survey studies.

1.2 General Comparisons of the Bay Area with the Los Angeles Area

In making a comparative study of benefits of air quality improvements in San Francisco and Los Angeles, a priori we do not expect that results will be exactly comparable. A major cause for differences is due to differences in the two areas.

The principal difference between the two areas relevant for this study is air quality. Although oxidant pollution (or smog) is considered to be the major problem in both regions, the city of San Francisco has a less severe air pollution problem than Los Angeles. Los Angeles experiences significantly higher levels of particulate (TSP) and Nitrogen Dioxide (NO_2) while San Francisco suffers only minor localized problems with these and other pollutants. However, some cities in the region (San Jose and Los Gatos, for example) suffer from severe pollution problems. Differences in air quality result from meteorological, topographical and population concentration differences between the two areas. These differences are described in more detail in Section Two. Other differences between the San Francisco Bay Area and the Los Angeles area are due to socioeconomic and geographic factors. There are many distinct cities in the Bay Area. The six-county area studied here includes 73 incorporated cities. San Francisco and Oakland are large urban centers containing 22 percent of the area's population. Another city, San Jose, contains 15 percent of the area's population but is generally suburban in character. The remainder of the cities in the Bay Area are typically suburban but differ according to socioeconomic characteristics of the residents.

The main geographic features of the San Francisco area are that it is physically divided by the San Francisco Bay and ringed by mountains. Although there are major east-west access routes, travel between the East and West Bay areas is somewhat restricted. Thus the area may be hypothesized to contain at least two different market areas (the East Bay and West Bay).

There are other differences relevant for property value comparison between these two metropolitan areas, for example, the value of beach property as related to air pollution. In Southern California, the mild year-round climate encourages a variety of ocean related recreational activities. Beach front property is highly valued and has generally been densely developed. In the San Francisco Area, the bay is the most accessible body of water to major population centers; however the bay does not offer the same scenic or recreational experiences found along the coast of the Los Angeles area. In the Bay Area, ocean front property is located over the ridge of the Santa Cruz mountains and is less accessible to the major employment centers. As a result, much of the beach front property maintains a rural atmosphere and has good air quality.

Because of the differences between the two study areas, somewhat different statistical techniques and explanatory variables were used in this study; however results are still comparable. Sections Three, Four, and Five give the basis for statistical techniques and explanatory variables used here.

SECTION 2
AIR POLLUTANTS IN THE BAY AREA

The center of the San Francisco Bay Area is a large shallow basin ringed by. hills, stretching from southern Marin County to Santa Clara County. This basin tapers into a series of sheltered valleys including Santa Clara, Livermore and Napa. This topography gives the area great potential for trapping and accumulating air pollutants. Within the area, contaminants are emitted at a fairly constant rate throughout the year. The Bay Area is normally adequately ventilated to disperse most of the pollutants. However, pollution concentrations vary from day to day and season to season. During the summer and fall months, poor ventilation and warm weather fosters the development of photochemical oxidants. Other pollutants such as carbon monoxide, nitrogen dioxide and particulate reach their highest levels in fall and winter but not at sufficient levels to result in chronic problems. The area experiences sulfur dioxide problems only in northern Contra Costa County.

A comparison of the monitoring station data for the San Francisco Bay Area (Tables 1 and 2) and the Los Angeles Basin (Table 3) indicates the extent of the difference in air quality between the two regions. For instance, in 1977 the worst station in the San Francisco Area (Los Gates) exceeded the old Federal ozone standard (8 pphm) on 23 days. The worst station in Los Angeles area (Pasadena) exceeded the same standard on 195 days. Four out of seventeen stations in the Bay Area recorded no exceedances of the 8 pphm standard while the cleanest station in the Los Angeles Basin (Long Beach) reported 16 exceedances.

For other pollutant measures as well, the areas around Los Angeles experience far greater problems than San Francisco. The monitoring stations in the Los Angeles area record many more exceedances of the carbon monoxide standard. In addition, the average levels of nitrogen dioxide, total suspended particulate and sulfur dioxide are more than double that experienced in the Bay Area.

Visibility impairment from air pollution is also a far greater problem in Los Angeles. The Los Angeles area averaged 270 days with visibility less than 10 miles and with relative humidity less than 70 percent (based on 1977 and 1978 visibility readings from Ontario airport). This is almost double the number of such days experienced anywhere in the San Francisco area.

The major pollutants are discussed in detail below.

2.1 Nitrogen Dioxide

When substances burn at a high enough temperature, some of the nitrogen in the air will react forming reactive gases called nitrogen oxides. Nitrogen dioxide (NO_2), a poisonous brownish colored gas, is the most plentiful of these gases. Most of the nitrogen dioxide in the Bay

Table 1

AIR POLLUTION IN TNE SAN FRANCISCO BAY AREA
BY STATION AND CONTAMINANT (OZONE): 1977-78

Station	Highest Hourly Average Value (pphm)		Dally Maximum Hourly Average July-September concentrations (pphm)		Number of Days with High-hr. concentrations greater than 8 pphm.		Number of Deya with High-hr. concentrations greater than 12 pphm.	
	1977	1978	1977	1978	1977	1978	1977	1978
San Francisco	5	11	2.0	2.3	0	4	0	0
San Rafael	to	16	2.8	4.3	2	13	0	2
Richmond	8	14	2.4	4.0	0	11	0	1
Pittsburg	12	17	4.9	7.0	6	34	0	6
Concord	17	20	4.9	6.6	13	42	2	11
Walnut Creek	13	17	4.3	5.7	6	31	2	5
Oakland	7	1.1	1.7	2.7	0	5	0	0
San Leandro	10	16	2.9	4.3	3	12	0	2
Hayward	12	17	4.2	4.7	5	17	0	5
Fremont	9	19	3.2	5.7	2	38	o	10
Livermore	14	15	5.5	5.7	17	35	3	2
Alum Rock	12	20	5.3	6.9	15	57	0	17
San Jose	14	18	5.4	6.7	13	53	3	12
Gilroy	12	15	4.9	5.3	11	31	0	4
Loa Gates	14	23	5.8	8.7	23	64	3	22
Sunnyva ie	15	- -	4.2	- - -	11	- -	1	- -
Saratoga	- .	20	- - -	6.7	- -	38		7
Mountain View	14	15	4.4	5.3	8	16	1	1
Redwood City	14	12	3.2	2.7	3	6	1	0
Burlingame	7	14	3.0	3.0	0	5	0	2

Table 2

AIR POLLUTION IN THE SAN FRANCISCO BAY AREA
BY STATION AND CONTAMINANT (CO, SO_2, NO_2, TSP): 1977-78

Station	Carbon Monoxide (CO)				Sulfur Dioxide (SO_2)		Nitrogen Dioxide (NO_2)		Total Suspended Particulates (TSP)	
	Highest 8hr. Average Value (ppm)		Number of Days exceeding 8hr. 9ppm Federal Standard		Highest 24hr. Average Value (pphm)		Hourly Average Concentration (ppm)		Annual Geometric Mean ($\mu g/m^3$)	
	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
San Francisco	8.9	9.4	0	1	3.5	2.4	3.5	4.0	41	42
San Rafael	1.9	9.1	0	1	1.3	1.1	2.6	2.6	3.4	40
Richmond	5.2	5.1	0	0	.5	1.2	2.6	2.5	51	52
Pittsburg	5.5	5.1	0	0	1.9	3.8	2.1	2.8	54	61
Concord	8.1	1.5	0	0	1.8	1.1	2.4	3.2	49	45
Oakland	7.0	9.9	0	1	---	---	2.4	4.0	--	--
Fremont	8.1	6.5	0	0	.3	.4	3.3	3.5	60	60
Livermore	5.9	6.2	0	u	.3	.4	3.2	3.1	68	64
San Jose	14.4	18.5	32	23	.6	.4	4.1	4.2	64	62
Gilroy	7.2	6.6	0	0	.7	.4	3.5	2.9	62	57
Sunnyvale	10.6	----	1	--	.1	---	4.2	---	45	--
Saratoga	----	5.1	. -	0	----	1.0	---	3.9	--	--
Redwood City	8.1	9.s	o	2	.5	.3	2.7	3.0	52	51
Burlingame	7.8	6.9	0	0	.1	2.8	2.7	3.3	34	39

Table 3

AIR POLIJJTION IN THE SOWN COAST AIR BASIN
BY STATION AND CONTAMINANT: 1971

Station	Ozone	Carbon Monoxide	Su lfer Dioxide	Nitrogen Dioxide	Total Suspended Particulates
	Number of Days with Nigh-hour concentration greater than 8pphm	Number of Days exceeding 8hr. 9ppm Federal Standard	Nighest 24hr. Average Value (pphm)	Hourly Average Concentrations (pphm)	Annual Geometric Mean (µg/m³)
Anaheim	46	29	9.0	5.8	106.8
Azusa	193	3	6.0	6.4	132.7
Burbank	160	82	10.0	1.5	-----
Costa Mesa	38	22	10.0	2.8	68.0
La Habra	94	15	12.0	5.5	107.3
Long Beach	16	43	13.0	1.2	-----
Los Angeles	147	48	9.0	8.7	121.5
Pasadena	195	23	7.0	B.9	110.0
Pomona	180	7	8.0	7.1	-----
Reseda	192	47	6.o	5.6	92.1
Riverside	168	0	12.0	5.6	123.9
San Bernardino	120	2	35.0	3.0	162.3
Whittier	98	30	18.0	7.3	162.3

Area is produced by automobile exhaust. On otherwise clear days, coloration effects of NO_2 will be a noticeable brown haze.

At low concentrations, NO_2 can irritate the lungs, impair breathing and cause eye irritation. At higher concentrations, NO_2 will increase the risk of lung ailments, pneumonia, bronchitis and lower resistance to respiratory infection. However, the principle harm resulting from NO_2 involves the role of the gas in the formation of photochemical oxidants.

The Federal standard (annual average of 5.0 pphm) has never been violated in the Bay Area. The state one-hour standard of 25 pphm has been exceeded in the period from 1975-78 at various locations in the area including San Francisco, San Jose, Fremont, and Sunnyvale. Generally, highest nitrogen dioxide levels are found in the Santa Clara Valley. A second peak in level of nitrogen dioxide occurs in the San Francisco/Oakland area. The accompanying isopleth map (Figure 1) indicates the extent of the NO problem in 1978. Hourly average 1977 and 1978 nitrogen dioxide concentrations are shown in Table 2.

2.2 Sulfur Dioxide

Sulfur dioxides are gases that come from the burning of fossil fuels and other industrial processes. Sulfur dioxide (SO_2) comprises the largest fraction of sulfur oxides. One the most noticeable impacts of SO_2 is the associated odor. Low levels of SO_2 can also damage vegetation and effect the health of animals. As the level of SO_2 increases, there is an obstruction in breathing and noticeable eye irritations for humans. Various research efforts also indicate a cause-effect relationship between SO_2 and morbidity and mortality.

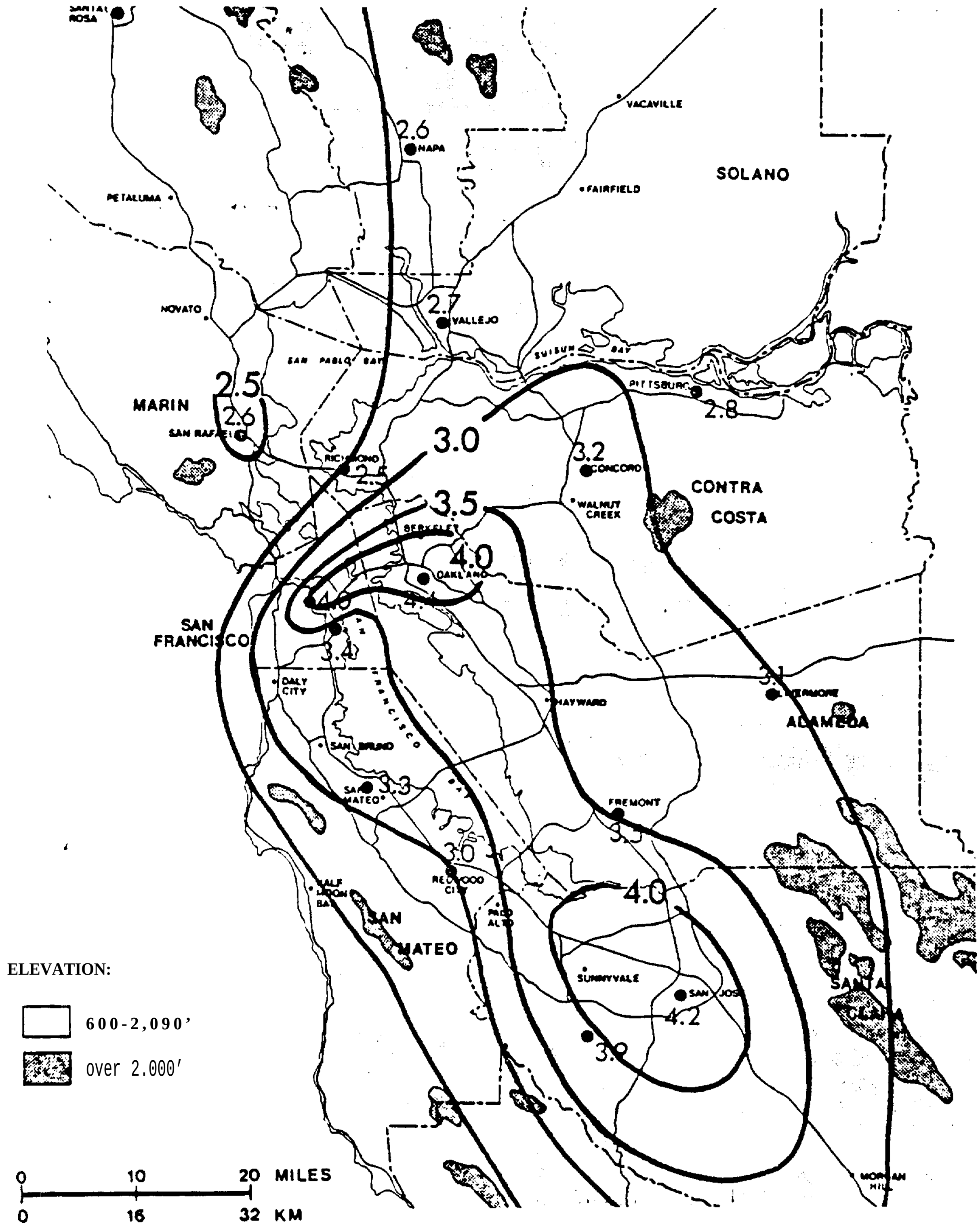
The Federal standard (annual average SO_2 of 30ppb) was not exceeded in the Bay Area in four-year period 1975-1978. During the same period, the state one-hour standard (300ppb) was exceeded on various occasions in San Francisco, Richmond, Burlingame, and Crockett. Table 2 indicates the highest 24 hour average SO_2 readings for 1977 and 1978 for Bay Area monitoring stations.

As the map of 1978 annual averages indicates (Figure 2), highest levels of sulfur dioxide occur in the vicinity of large oil refineries and chemical plants in Contra Costa County. SO_2 may become a more important factor in the Bay Area if there is a further shift from natural gas to fossil fuel burning.

2.3 Total Suspended Particulate

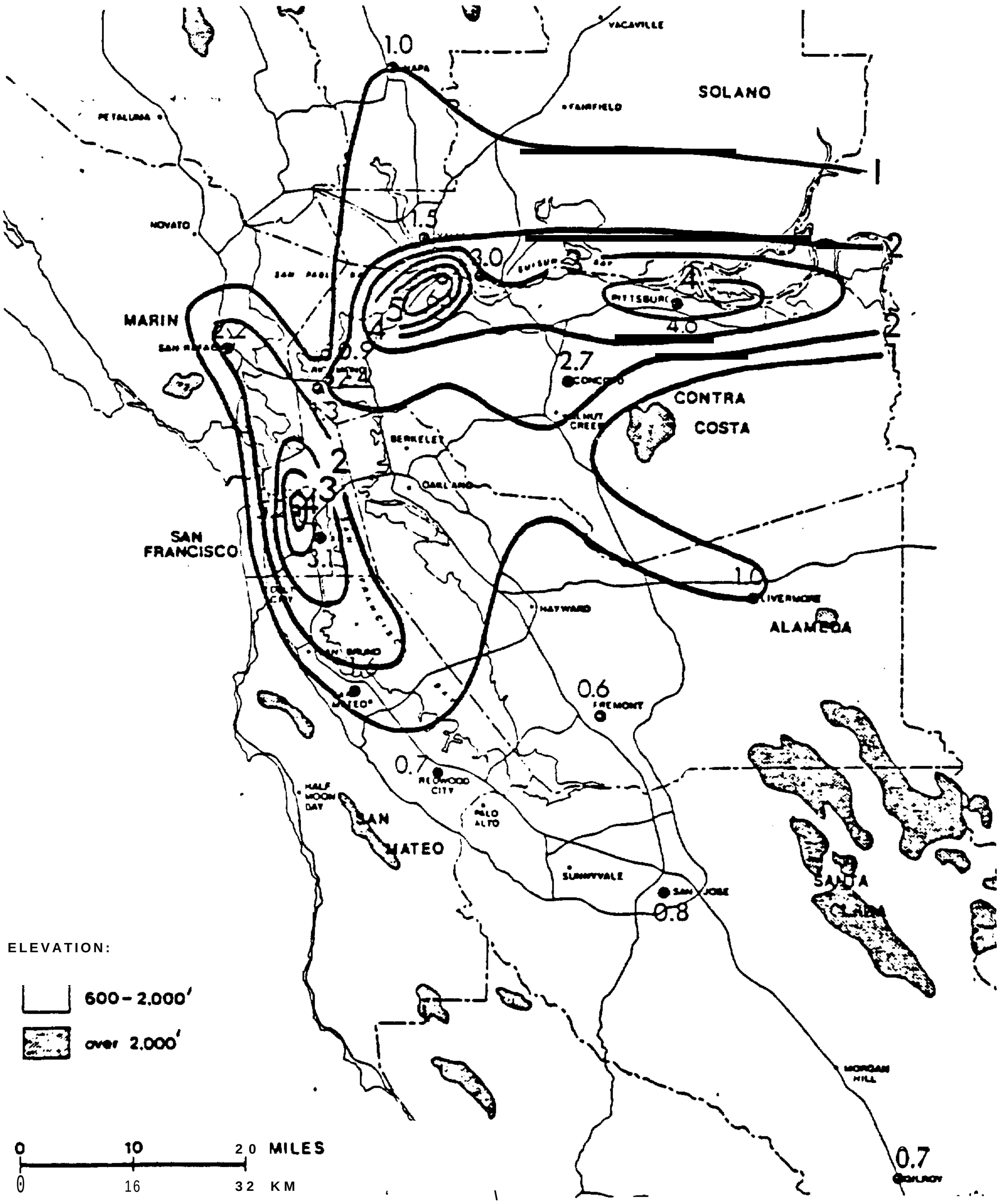
Total suspended particulate (TSP) are solid particles or liquid droplets small enough to remain suspended in the air. These particles include both irritating but non-toxic substances such as dust, soot, and smoke and other substances which may be highly toxic such as cadmium, beryllium., asbestos and lead. An estimated ten tons of lead are emitted daily in the Bay Area--principally as a by-product of automobile use. Problems associated with the other toxic particles are more localized in

Figure 1



1978 Annual Average Nitrogen Dioxide Values in Parts Per Hundred Million (pphm). Federal Standard is 5.0 pphm.

Figure 2



1978 Annual Averages of 24-Hour West Gaeke Sulfur Dioxide Values in Parts Per Billion (ppb). Federal Standard is 30 ppb.

nature as these substances can generally be associated with specific industries.

The harm associated with particulate may be physical (clogging the lung sacs) or chemical (changes in the human body caused by chemical reactions with toxic particles). The smaller the particles the more likely they are to reach the lungs and produce damage. Measurement of TSP concentration (using the Hi-Vol sampler technique) is a measure of weight without regard to the chemical composition or size of particulate; thus any violation of TSP standards gives only a rough indication of health hazard.

During the four-year period (1975-1979), particulate emissions averaged about 180 tons/day in the Bay Area. About 47 percent can be attributed to industrial or commercial sources and 27 percent to automotive vehicles. Other important sources involve aircraft and fuel combustion and natural factors such as wind blown dust.

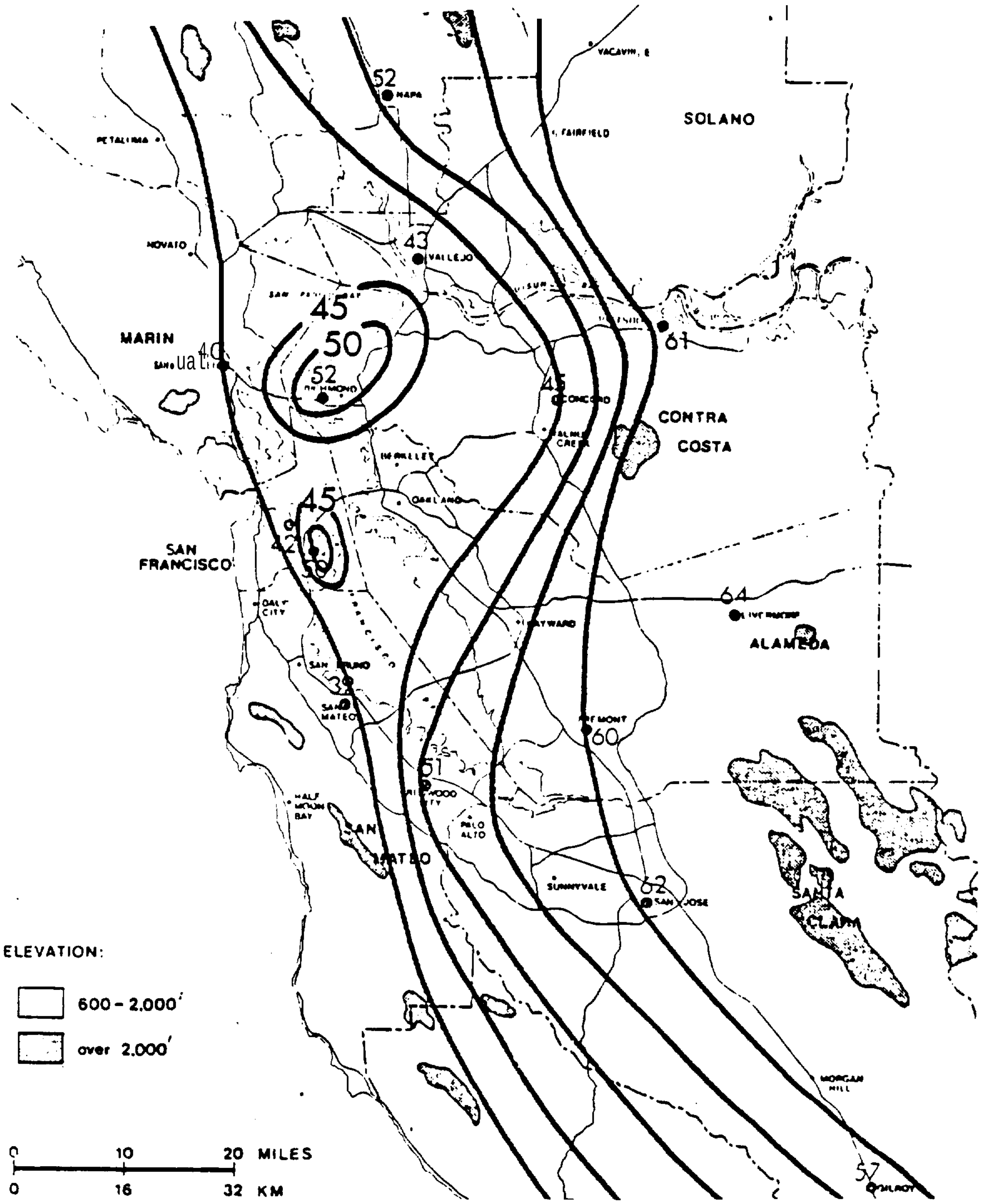
The isopleth map of 1978 TSP geometric means (Figure 3) indicates that TSP values get progressively worse as one moves inland. During the period from 1975-1978, Livermore exceeded the state 24 hour standard ($100 \mu g/m^3$) on 24 percent of the observed days. Other areas including Pittsburgh, Fremont, San Jose, and Gilroy exceeded the state air quality standard on at least 12 percent of the observed days. In terms of the annual geometric mean standard, only Livermore (in 1976) exceeded the Federal standard ($75 \mu g/m^3$) during the four-year period. The state annual standard ($60 \mu g/m^3$) was violated all four years in Livermore, three of the four years in San Jose and Fremont, and twice in Gilroy and Pittsburgh. Table 2 lists the 1977 and 1978 annual geometric means for individual monitoring stations in the Bay Area.

2.4 Photochemical Oxidants

Photochemical oxidant pollution is considered to be the major pollution problem in the Bay Area. The primary precursors of this form of air pollution are sunshine, nitrogen oxides, and numerous hydrocarbons. The primary source of these gases in the San Francisco Bay Area is the automobile. For instance, about 61% of the reactive organic gases and 46% of the nitrogen oxide gases come from cars and light duty trucks. These primary elements interact in the atmosphere to produce a host of undesirable secondary products known as oxidants. The major component of photochemical oxidants is ozone; other substances include peroxyaletyl nitrate, acrolein, nitric acid, and various sulfate compounds. The major health effects of photochemical oxidants include eye, nose, and throat irritation, difficulty in breathing for patients suffering from emphysema; other effects include visibility reduction and vegetation damage.

Photochemical oxidants (commonly known as “smog”) create the most widespread air pollution problem in the San Francisco Bay Area. After peaking in 1965, the oxidant levels have shown a downward trend. Days exceeding the Federal standard of 8 pphm (pre-1979 standard) averaged 131 in 1965-1969 and 85 in 1970-1974. In the four-year period 1975-1978,

Figure 3



1978 Total Suspended Particulate, in µg/m³ annual geometric means. (Federal primary standard is 75 µg/m³; State standard is 60 µg/m³.)

exceedances averaged 68 per year. However, the Bay Area did experience a sharp increase in the ozone levels in 1978. In the entire district, 96 days were in excess of the standard in 1978 compared with only 40 excess days in 1977. Table 1 shows the differences between the two years on a station by station basis.

The accompanying map (Figure 4) plots the three-year (1976-1978) annual average exceedences of the new Federal l-hour ozone standard (12 pphm). The San Jose area (centering in Los Gates) experiences the greatest problem with ozone. Another maximum centers on the Walnut Creek-Concord area. All areas to the east of the "l" isopleth are in violation of the national standard for photochemical oxidants since the Federal standard (12 pphm) is exceeded more than once per year.

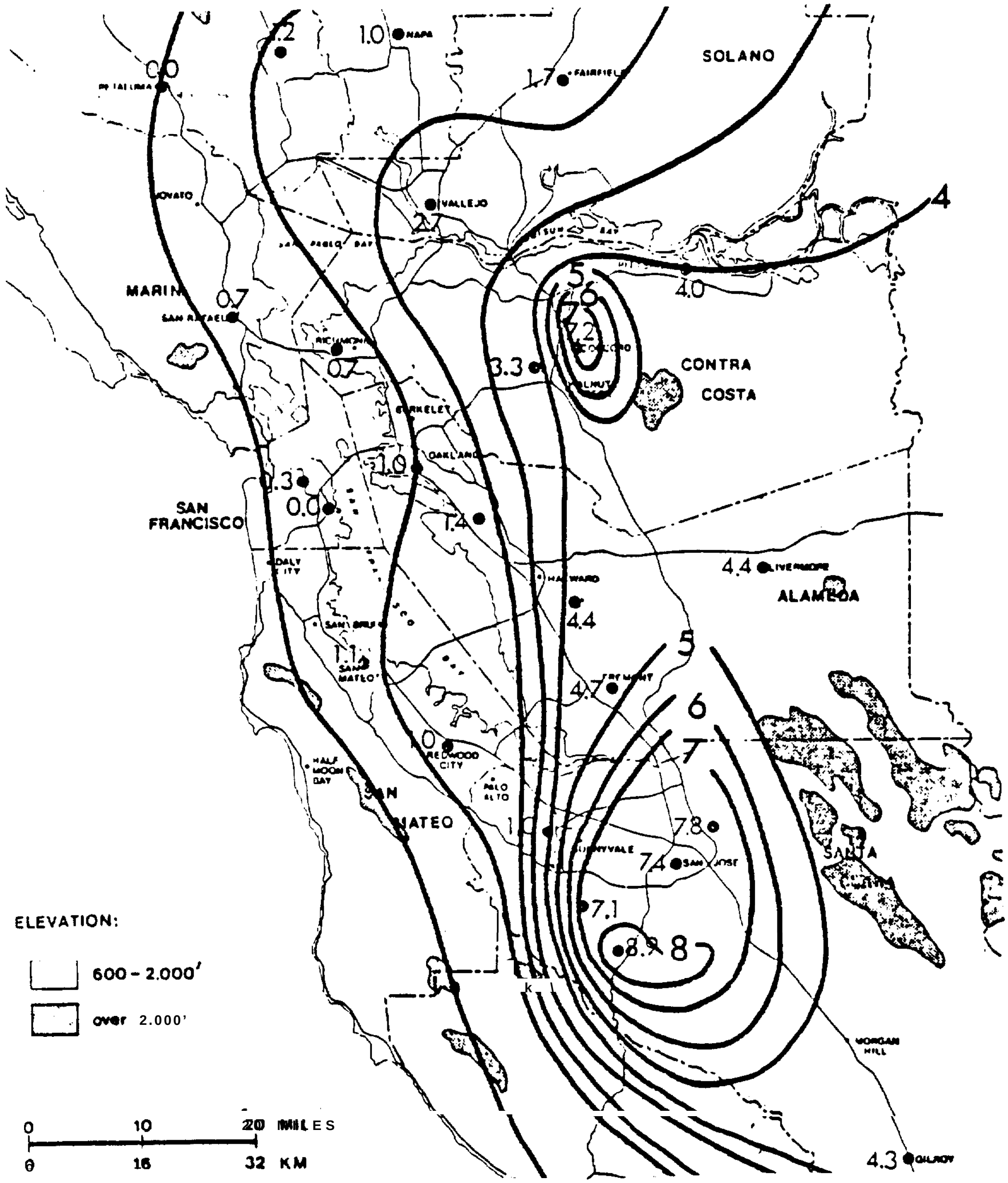
2.5 Carbon Monoxide

Carbon monoxide (CO) is a colorless, odorless, poisonous gas formed when carbon-containing fuel is not burned completely. About 95% of the Bay Area's carbon monoxide comes from automobiles. It is the most plentiful pollutant in the Bay Area; region-wide emissions were estimated to be about 4,300 tons per day in 1975.

If exposure to carbon monoxide is high enough, dizziness, unconsciousness and even death can result. Fortunately, carbon monoxide does not persist in the atmosphere for extended periods of time. It is converted by natural processes to harmless carbon dioxide. This conversion prevents a harmful buildup of CO in the general Bay Area.

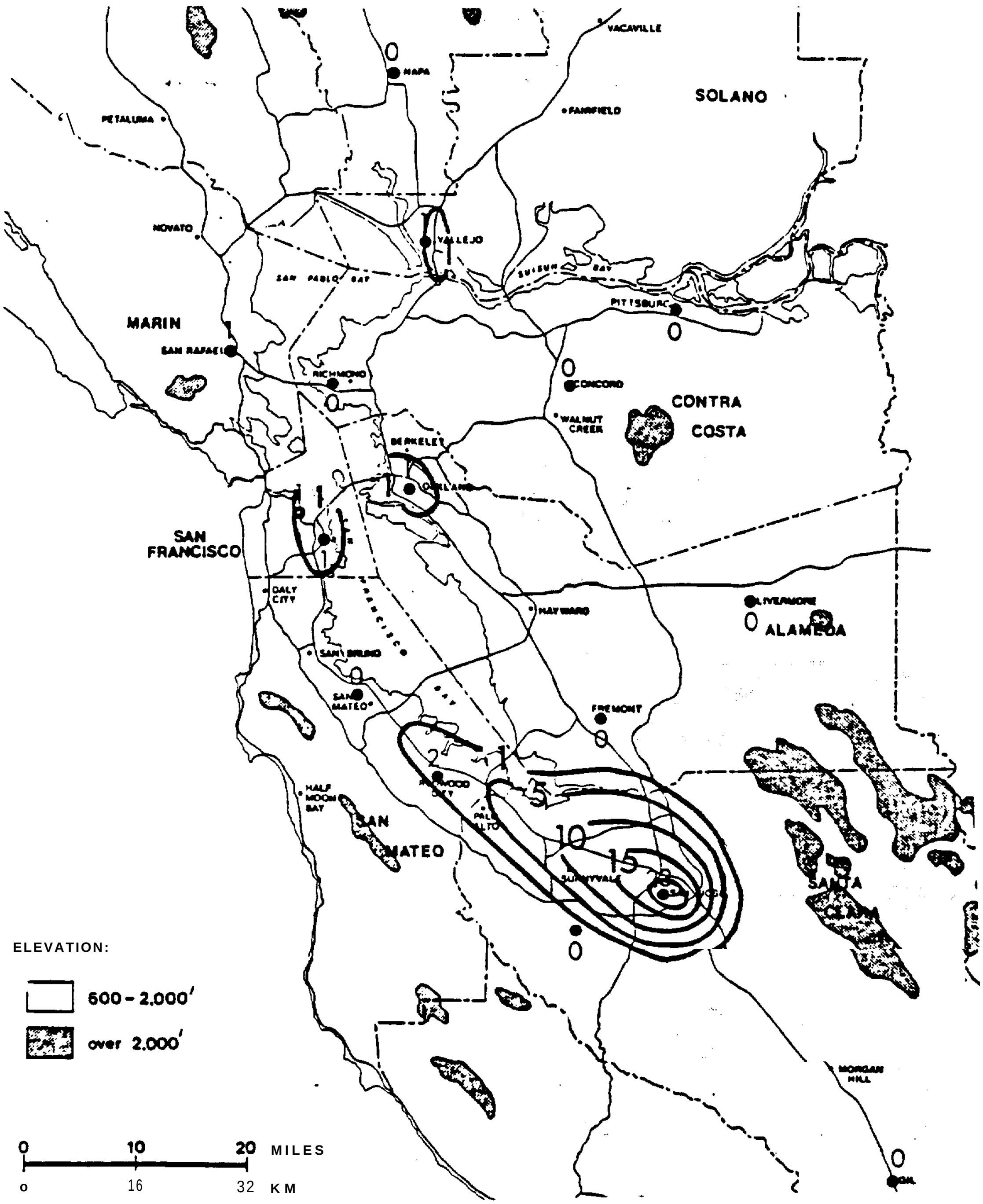
Carbon monoxide is a localized problem in the Bay Area. The main problem area is the Santa Clara Valley, centering on San Jose and extending northwest toward Sunnyvale. During the four-year period from 1975-1978, San Jose averaged 34 annual exceedences of the Federal eight-hour standard of 9 pphm. Sunnyvale and Redwood City averaged 6 and 4 exceedences respectively. A number of other areas also exceeded the Federal standard during this time period, e.g., San Francisco, San Rafael, Oakland, Fremont, and Burl ingame. The accompanying isopleth map (Figure 5) indicates the 1978 exceedences of the Federal standard. Table 2 presents 1977 and 1978 carbon monoxide data.

Figure 4



1978 Expected Annual **Exceedances** of Federal Ozone Standard, in days per year with a high hourly average exceeding .12 ppm, based on running 3-year average (1976-78).

Figure 5



1978 Annual Number of Days with Carbon Monoxide Exceeding Federal Standard (9 Parts Per Million for 8 Hours).

SECTION 3

AIR QUALITY MEASUREMENT AND CLASSIFICATION

Discussion in this section focuses on pollution measures used in this study. This section also describes how air quality measures were used to categorize cities in the bay area.

3.1 POLLUTION MEASURES TESTED IN THIS STUDY

Previous air pollution-property value studies have used various pollutant measures. Earlier studies generally used a measure of sulfur pollution or particulate [Ridker and Henning (1967), Anderson and Crocker (1971), Wieand (1973)]. Other studies have focused attention on mobile-source pollutants, namely oxidants, nitrogen oxides or hydrocarbons [Skov (1975), Harrison and Rubinfeld (1978), Nelson (1978), Brookshire (1979), Stonstelie and Portney (1980)].

Generally the pollutant measures used have been physical measures (in terms of an annual geometric or arithmetic mean of density) derived from monitoring station data or isopleth maps based on monitoring station data. For example, Harrison and Rubinfeld (1978) and Smith (1978) used such pollution measures computed from a dispersion model. Other studies such as Stonstelie and Portney (1980) and Skov (1975) used some measure of exceedances of Federal standards as a pollution indicator. For example, Stonstelie and Portney used a measure of photochemical oxidants based on the number of days exceeding 10 pphm.

Table 4 indicates pollution measurements tested in this study. In this study, we use both exceedance and physical measures of pollution. Since there is annual variation in pollution levels due to natural conditions, we have used the average of two years (1977 and 1978) for all pollution measures.

Data from 17 monitoring stations were utilized in this study; only 12 of these stations have complete measurements for CO, TSP and ozone. With the assistance of the Bay Area Air Pollution Control District, each of the 73 cities in the study area was matched with the monitoring station which most closely reflects the level of a particular pollutant for that city. Table Al in the appendix gives the correspondence between the cities and monitoring stations. Monitoring station data was used directly without interpolation.

Table 4

POLLUTION MEASURES USED IN THIS STUDY

Pollutant Type	Variable Name	Definition
Ozone (O_3)	OZMAX	Average of Daily Maximun Values in pphm (July-September 1977-78)
	OZEX	Average Number of Days exceeding .08 ppm (1977-78)
	OZONE	OZMAX*OZEX
Total Suspended Particulate	TSPMN	Annual Geometric Mean in $\mu g/m^3$ (1977-78)
Health Index (PSI2)	PS12	Average 1977-78 PSI Value* (% Moderate Days + % Unhealthful Days + % Very Unhealthful Days)
Nitrogen Oxide (NO_2)	AVEN02	Average of Hourly Concentration in ppm (1977-78)
Visibility	PCTVIS	Percentage of Days Below 10 miles visibility (1977-78)
Carbon Monoxide (CO)	COHI	High 8 hour CO value

Measurement of ozone is more extensive than measurement of other pollutants; 17 stations monitor concentrations compared to 12 stations for all other pollutants. Three alternative measures of oxidant pollution were studied: the average of daily maximum summer values (OZMAX), days exceeding 8 pphm (OZEX) and a multiplicative measure (OZONE). OZONE takes into account both the exceedances of standards and the average summer oxidant value. Average annual values for TSP (TSPMN) and NO_2 (AVENO2) were also tested for the purpose of comparing the Bay area to the Los Angeles area.

3.2 CALCULATION OF HEALTH INDEX VALUES

Previous studies only used one pollution measure in a regression equation because of multicollinearity problems. Here, we also used a pollution measure which combines more than one pollutant according to their equivalence in terms of health effects.

The Environmental Protection Agency has developed a standardized health index (PSI) to provide nationwide uniformity in pollution measurement and to increase public awareness and understanding of air pollution. The Pollution Standards Index (PSI) converts concentrations of a combination of pollutants (SO_2, CO, O_3, NO_2 and TSP) into a number on a scale of 0 to 500. Intervals on this scale are related to increasing health effects due to increasing concentrations of the five major pollutants. The air pollution health categories and corresponding index value are "good" (0 to 50), "moderate" (50 to 100), "unhealthful" (100 to 200), "very unhealthful" (200 to 300) and "hazardous" (above 300). In general, the "good" and "moderate" ranges correspond to concentrations of each pollutant in which adverse health effects have not been generally observed. The PSI description chart (Table 5) indicates the general health effects observed at various index levels. In this study, we utilize the PSI measure as well as the individual pollutant measures discussed above.

According to the PSI index, the Los Angeles area experiences a far greater health problem associated with air pollution than does the San Francisco area. For example, in 1978, one city in the Los Angeles area (Pasadena) had 64 "good" health days, 138 "moderate" health days, 75 "unhealthful" days, 87 "very unhealthful" days and 2 "hazardous" days. By comparison, the worst area in the Bay (San Jose) had 160 "good" health days, 169 "moderate" health days, 29 "unhealthful" days and no "hazardous" health days.

In the San Francisco Bay Area calculation of the index is simplified because only three pollutants are relevant for determining the index: ozone, particulate and carbon monoxide. Nitrogen dioxide and sulfur dioxide are not utilized since the levels of NO and SO_2 experienced in the Bay Area fall almost exclusively in the "good" ?ategory. Table 6 shows the definition of the index for ranges of ozone, CO and TSP levels.

Calculation of the health index for each city required examining monitoring station data for each of the relevant pollutants. Each city was assigned a daily PSI rating by determining the "critical pollutant", i.e.,

Table 5

DEFINITION OF PSI INDEX
IN TERMS OF HEALTH EFFECTS

Index Value	PSI Descriptor	General Health Effects	Cautionary Statements
500		Premature death of ill ● d elderly. Healthy people will experience adverse symptoms that affect their normal activity.	All persons should reman in-doom, keeping windows and doors closed. All persons should minimize physical exertion and avoid traffic.
400	hazardous	Premature onset of certain diseases in addition to significant aggravation of symptoms and decreased exercise t olerance in healthy persons.	Elderly and persona with existing diseases should stay indoors and avoid physical ● xemon. General population should avoid outdoor activity.
300	very unhealthful	Significant aggravation of symp-tome and decreased exercised tolerance in persons with bean or lung disease with widespread symptoms in the healthy popula-tion.	Elderly and persons with existing bean or lung disease should stay indoors and reduce physical activity.
20	unhealthful	Mild aggravation of symptoms in susceptible persons, with irrita-tion symptoms in the health population.	Persons with existing heart or respiratory ailments should reduce physical exertion and out-door activity.
100	moderate		
50	good		
0			

PSI values descriptor words generalized health effects, and cautionary statements

Table 6

DEFINITION OF AIR QUALITY CATEGORIES

HEALTH[a]

	Ozone (O_3) (ppm) 1 Hour Max.	Carbon Monoxide (CO) (ppm) 8 Hour Max.	Total Suspended Particulate (TSP) ($\mu g/m^3$) 24 Hour Max.
Good Day	.00-.06	0.0-4.5	00-75
Moderate Day	.07-.12	4.6-9.0	76-259
Unhealthful Day	.13-.19	9.1-14.8	260-374
Very Unhealthful Day	.20-.40	14.9-29.6	375-624
Hazardous Day	greater than .40	greater than 29.6	greater than 624

VISIBILITY[b]

Non-Polluted Days	Days with visibility greater than 10 miles when the relative humidity was less than 70 percent.
Moderate Days	Days with visibility greater than or equal to 6 miles, but less than or equal to 10 miles when the relative humidity was less than 70 percent.
Poor Days	Days with visibility less than 6 miles when the relative humidity was less than 70 percent.

[a]Based on Pollutants Standard Index (PSI) as defined by the E.P.A.

[b]Total of moderate and poor visibilitydays corresponds to days exceeding the State visibility standard.

the pollutant with the highest index value for a given day[2]. For example, if on a given day CO falls into the "good" range and TSP and O_3 falls into the "moderate" range, then the day is assigned a "moderate" PSI rating. Table 7 illustrates how PSI values are derived for cities. Redwood City, for example, experienced 3 "moderate" O_3 days and 7 "moderate" CO days during the month of October. In this case the "moderate" O_3 days occurred on the same days as "moderate" CO days. Thus, according to this procedure, Redwood City experienced 24 "good" health days, 7 "moderate" health days and no "unhealthful" or very "unhealthful" days during October 1977.

Calculation of PSI for some cities required data from more than one monitoring station. Table A2 shows the resulting PSI days (based on 1977-78 monitoring station data) for all the cities in the Bay Area.

PS12 is derived from multiplying the annual average PSI for a city by the percent of "nonhealthy" days ("moderate", "unhealthful" and "very unhealthful" days). The average PSI is computed as the percent of days of a given type ("good", "moderate", "unhealthful", "very unhealthful" and "hazardous") times the mid-value of the corresponding health index: (25, 75, 150, 250 and 400).

3.3 MEASUREMENT OF VISUAL QUALITY

3.3.1 Alternative Visibility Measures

Probably the most directly perceived effect of air pollution is visual impairment. However, the relationship between such impairment and physical measurements is less easy to define than in the case of health. Studies of visual quality have defined visual impairment as related to limitations in visual range, change in coloration of the sky, and change in contrast of perceived objects. Necessary for such impairment is the presence of atmospheric particles that reflect, scatter, or absorb light. Complicating the definition and measurement of visual pollution is the fact that fog and dust are natural causes of impairment. Such natural effects may be further compounded in the presence of man-caused particulate contamination.

A recent Los Angeles study (Flachsbart and Phillips, 1979) attempted to correlate human perceptions of visual quality (measured in terms of the percent of people believing the air to be smoggy) to physical measurements. Prevailing visibility (based on visual range) was shown to be more highly correlated to perceptions of smogginess than the other physical measures used.

Visual range is defined as the distance an observer can see an "ideal object" against the horizon. As required for National Weather Service observations, prevailing visibility is defined as the greatest visual range which is attained or surpassed around at least half of the horizon circle, but not necessarily in continuous sectors.

An indirect method of estimating visual range may be obtained by using the Koschmeider equation (Latimer, 1978):

Table 7

PSI TABULATION FOR MONITORING STATIONS
October 1977

STATION	OZONE (1 HR. PPM)			TSP (24 HR. $\mu G/M^3$)			CO (8 HR.PPM)			PSI		
	GOOD	MODERATE	UNHEALTHFUL	GOOD	MODERATE	UNHEALTHFUL	GOOD	NODESATE	UNHEALTHFUL	GOOD	MODERATE	UNHEALTHFUL
San Francisco	31	0	0	31	0	0	25	6	0	25	6	0
San Rafael	28	3	0	31	0	0	18	13	0	18	13	0
Richmond	31	0	0	25	6	0	31	0	0	25	6	0
Pittsburg	25	6	0	13	18	0	31	0	0	10	21	0
Concord	26	5	0	31	0	0	24	7	0	22	9	0
Walnut Creek	22	9	0									
Oakland	31	0	0				31	0	0			
San Leandro	30	1	0									
Hayward	26	5	0									
Fremont	21	4	0	13	18	0	24	7	0	11	20	0
Livermore	24	7	0	13	18	0	24	7	0	10	21	0
Alum Rock	24	7	0									
San Jose	23	8	0	13	18	0	19	11	1	11	19	1
Gilroy	24	7	0	0	31	0	31	0	0	0	31	0
Los Gatos	21	4	0									
Sunnyvale	26	5	0	31	0	0	27	4	0	24	7	0
Mountain View	25	6	0									
Redwood City	2a	3	0	31	0	0	24	7	0	24	7	0
Burlingame	31	0	0	31	0	0	22	9	0	22	9	0

$$r_v = \frac{K}{b_{ext}}$$

where r_v is the visual range and b_{ext} is the extinction coefficient. This measure can be directly obtained using an integrating nephlometer (Waggoner, 1976). Nephlometer readings are currently being made infrequently only at a limited number of sites. Thus visual range can not be estimated for any site in the Bay Area.

An alternative used in the Merkhofer, et. al. (1978) study is to calculate the extinction coefficient from a change in concentration 'of particles.

An alternative approach involves the use of a measure of particulate pollution as a surrogate for visibility impairment. According to the Bay Area Air Pollution Control District (BAAPCD), the California 24-hour standard for TSP of 100 $\mu g/m^3$ was based on a visibility restriction to less than 10 miles. However, BAAPCD studies for one region of the Bay Area indicate that high TSP values cannot be associated with visibility days under 10 miles (see BAAPCD Information Bulletin May 11, 1977).

Another widely used measure of particulate is the coefficient of haze (COH) or soiling index. This measurement is based on optical density. Sample air is drawn through an automatic sampler every two hours. Suspended particulate collected by the sampler cause a decrease in light transmission. This decrease in light transmission is reported in terms of a COH value per 1,000 linear feet of air samples. Based on a study of 1975 data for Santa Clara, days with COH greater than 1.5 had risibilities restricted to less than 10 miles 86% of the time. In addition this study reported that COH is better related to the public perception of polluted air than TSP (see BAAPCD Information Bulletin May 11, 1977).

There is no State or Federal standard for COH. However, according to the California Air Resources Board, COH units less than 1.0 indicate relatively clear air while a COH greater than 2.0 represents dirty air. Daily readings are available for 16 stations in the Bay area. COH cannot be directly related to visual range.

3.3.2 Measures Used in this Study

As the results of the work by Flachsbart (1979) indicate, prevailing visibility (or visual range) is most highly related to perceptions of smogginess. Although there is a potential problem of lack of enough sites to represent variation in visual quality, visibility readings from airports were used because of their availability. Based on airport readings visual quality in the Bay Area was rated in terms of the number of days when prevailing visibility was "poor", "moderate" or "good", similar to the procedures used to measure quality in terms of health standards (see Table 6 for definitions)

The state air quality standard for pollution-related visibility impairment is that when prevailing visibility is below ten miles with humidity less than 70 percent, the standard is exceeded. It is believed that such reduced risibilities are due to man-made particulate. The Bay Area Air Pollution Control District (BAAPCD) has categorized visibility readings into three categories: O-6 miles, 6-10 miles and greater than 10 miles. Visibility readings below 6 miles are designated to be "poor", 6-10 mile readings are "moderate" and visibility readings greater than 10 miles are "good".[3] (These definitions were consistent with the photographs representing polluted and clear days used for the survey.)

Visibility data coupled with humidity data is available for only four airports: Moffit Field (Sunnyvale), Travis AFB (Fairfield), San Francisco Airport (Millbrae) and Oakland Airport (Oakland). Visibility readings are also available from six other smaller airports in the area; however these airports do not take humidity readings and use of their data would require making assumptions about humidity readings.

Table 8 shows visibility readings for the four stations with visibility and humidity data. The areas represented by Travis AFB (Fairfield) experience the least frequent occurrence of "moderate" and "poor" visibility days. The Santa Clara region (as depicted by Moffit Field) has the most frequent occurrence of "moderate" and "poor" visibility readings. The data for the San Francisco and Oakland airports indicate that visibility is very similar in both of these areas. San Francisco and Oakland have fewer air-pollution visibility impaired days than Santa Clara but more than Fairfield.

Based on discussions with the Bay Area Air Pollution Control District and the National Weather Service, the cities in the Bay Area were assigned the visibility reading from the stations most representative of the visibility in each area. It was judged that Travis AFB (Fairfield) best defines visibility in northern Marin and eastern Contra Costa Counties; Oakland airport defines visibility patterns in the East Bay stretching from Richmond to Hayward in addition to the Livermore Valley and southern Santa Clara County. Moffit Field (Sunnyvale) typifies visibility in northern Santa Clara and southern Alameda Counties. The area stretching from southern Marin County (Belvedere, Sausalito, etc.) to Redwood City is represented by visibility data from the San Francisco Airport.

3.4 CLASSIFICATION OF AIR QUALITY IN BAY AREA

3.4.1 Classification of Visibility Types

Because there are only four available visibility monitoring stations, it is difficult to assign some cities to airport monitoring stations with confidence. Because of limited data, we classified cities in the Bay Area into only two types, "very good" visibility and "not as good" visibility. Zone 1 is the area of best visibility with more than 90% of the days not visually polluted; it includes most of Contra Costa and Marin Counties. Zone 2 includes Santa Clara, San Mateo, San Francisco, Alameda Counties and the remainder of the Bay Area not included in Zone 1; less than 80% of the days are not visually polluted for this area.

Table 8

Visibility
By Airport Visibility Site and Categories

Airport Visibility Site	Non-Polluted Visibility % of observations with visibility greater than 10 miles when the relative humidity was less than 70 percent		Moderate Visibility % of observations with visibility greater than or equal to 6 miles but less than or equal to 10 miles when the relative humidity was less than 70 percent		Poor Visibility % of observations with visibility less than 6 miles when the relative humidity was less than 70 percent	
	1977	1978	1977	1978	1977	1978
Travis A. F.B., Fairfield	90.6	89.9	5.0	6.0	4.4	4.1
Oakland Airport, Oakland	80.8	76.8	14.7	16.4	4.5	6.8
San Francisco Airport, Millbrae	17.4	74.5	18.5	18.2	4.1	7.2
Moffet Field, Sunnyvale	37.0	51.2	48.4	37.5	14.6	11.3

3.4.2 Classification of Health Types

Based on exceedances of "good" health days from the PSI data, cities in the area were grouped into 3 health categories. Cities in the best health quality area are characterized by less than 100 "moderate" PSI days and no more than 1 "unhealthful" day per year. Intermediate health quality cities have more than 100 "moderate" PSI days and up to 5 "unhealthful" days and 1 "very unhealthful" day. Cities in the worst health quality areas all have more than 130 "moderate" PSI days. In addition these areas have more than 12 "unhealthful" days and up to 7 "very unhealthful" days.

3.4.3 Combination of Health and Visibility Typology

Figure 6 illustrates the definition of air quality types (A,B,C,D,E) according to the PSI health and visibility categories. Table 9 assigns Bay Area cities to air quality categories. No city falls into a fair health-good visibility category. As can be expected, the areas experiencing the highest levels of the pollutants making up the PSI index generally are in the area with visibility problems.

3.5 AREAS WITH UNCERTAINTY IN AIR QUALITY DATA

In the six counties of the Bay Area, only 12 monitoring stations have complete data for all relevant pollution measures. Thus, air quality in certain cities in the Bay Area cannot be well represented by monitoring station data. Either these cities are not in close proximity to the nearest station or there are other problems regarding the representativeness of the nearest station for air quality in the area.[4] The following cities fall into this category,

Brentwood	Martinez
Clayton	Moraga
Daly City	Novato
Half Moon Bay	Pacifica
Lafayette	Pinole
Los Altos	

In addition to these cities, there were census tracts in which the air quality data was felt to be uncertain; these were census tracts located where there is a large change in air quality over a small area as shown by the narrowness of the isopleths (Figures 1-5). As the map of annual exceedances of the Federal Ozone Standard indicates (Figure 4), isopleths are very close together in northwestern Santa Clara County between Palo Alto and Sunnyvale and near Concord.[5] The air quality of the remaining census tracts ("pool" tracts) was believed to be well represented by the monitoring station data.

3.6 CORRELATION OF POLLUTION MEASURES

As the correlation matrix (Table 10) indicates, the three alternative measures of oxidant pollution (OZMAX, OZEX, and OZONE) are highly correlated with each other; the correlation coefficient between the variables is on the order of 0.9. All the measures of ozone are also highly correlated with the measure of TSP (TSPMN). This can be expected from the general topology and meteorology of the area. Generally the

Figure 6

Air Quality Types

Health Days	Visibility Davs: > 90% Good (Fairfield Reading)	Visibility Davs: < 80% Good (SF-Oak-SJ Reading)
<100 Moderate 0-1 Unhealthy 0 V. Unhealthy	A	B
> 100 Moderate 2-5 Unhealthy 0-1 V. Unhealthy	C	D
> 130 Moderate > 12 Unhealthy 2-7 V. Unhealthy		E

'Table 9

HEALTH-VISIBILITY TYPOLOGY FOR BAY AREA CITIES

Area A	Area B	Area C	Area D	Area E
Good Health Good Visibility	Good Health Fair Visibility	Moderate Health Good Visibility	Moderate Health Fair Visibility	Fair Health Fair Visibility
Corte Madera	Albany	Antioch	Atherton	Campbell
Fairfax	Alameda	Brentwood	Belmont	Los Gates
Hercules	Belvedere	Clayton	Cupertino	Milpitas
Larkspur	Berkeley	Concrod	Fremont	Monte Sereno
Mill Valley	Brisbane	Lafayette	Gilroy	Santa Clara
Moraga	Burlingame	Martinez	Hayward	San Jose
Pinole	Daly City	Novato	Livermore	
	El Cerrito	Pittsburg	Los Altos	
	Emeryville	Pleasant Hill	Los Altos Hills	
	Foster City	Ross	Menlo Park	
	Hillsborough	San Anselmo	Morgan Hill	
	Half Moon Bay	San Rafael	Mountain View	
	Millbrae	Walnut Creek	Neward	
	Oakland		Palo Alto	
	Pacifica		Pleasanton	
	Piedmont		Portola Valley	
	San Bruno		Redwood City	
	San Francisco		San Carlos	
	San Leandro		Saratoga	
	San Mateo		Sunnyvale	
	San Pablo		Union City	
	Sausalito		Woodside	
	South San Francisco			
	Tiburon			

Table [illegible]

Pollution Correlation Matrix [a]

	OZMAX	OZEX	OZONE	COHI	TSPMN	AVENO2	AVESO2	PCTPSI	PSI2	PCTVIS	TEMPTURE
OZMAX	1.000										
OZEX	.967	[illegible]000									
OZONE	.953	.991	1.000								
COHI	.548	.648	.652	1.000							
TSPMN	.708	.710	650	.565	1.000						
AVENO2	.488	.623	.642	.[illegible]64	.369	[illegible]					
AVESO2	-.493	- 447	-.393	-.2[illegible]	- 628	[illegible]84	1.000				
PCTPSI	759	.832	.828	.930	.684	722	-.362	[illegible]0			
PSI2	.850	.875	85	.842	.822	.645	-.491	.938	[illegible]		
PCTVIS	.428	.494	.509	.656	.420	.634	-.305	.619	.632	1.000	
TEMPTURE	.702	.631	.614	.275	.486	.032	-.595	4[illegible]5	.583	.244	1.000

[a] using data from "pool" tracts

inland areas (San Jose, Concord, Livermore etc.) experience the greatest ozone problem, higher temperatures and the highest levels of suspended particulate. Thus, temperature and the pollution measures are also correlated. The measure of NO (AVENO2) is not as highly correlated with the various ozone measures or the measure of TSP. SO_2 is negatively correlated with pollution measures except for NO_2. The visibility measure has the highest correlation with PS12 and carbon monoxide (COHI).

Since the PSI index measure (PSI2) is determined by a combination of pollution measures (CO, TSP and O_3), one expects there to be a relationship between the index and the individual measures. The simple correlation between PS12 and the alternative ozone measures is about .70; .69 between PS12 and TSPMN; and .62 between PS12 and AVEN02.

In addition to spatial correlation of pollutants, there is also temporal correlation. The temporal correlation of pollutants is illustrated using pollution data for a sample monitoring station shown in Figure 7 for San Jose. NO_2, TSP and CO appear to be seasonally correlated while SO_2 and O_3 do not. Figure 7 shows that ozone values tend to be higher in the summer months while TSP, CO and NO_2 readings are higher in the winter months. Temporal correlation does not enter our analysis since we use annual averages.

Figure 7

TEMPORAL CORRELATION

(978 Mean Value for San Jose)