REPORT FOR CONSULTATION ON THE

SAN FRANCISCO BAY AREA

AIR QUALITY CONTROL REGION

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
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PREFACE

The Secretary, Department of Health, Education, and Welfare, is directed by the Air Quality Act of 1967 to designate "air quality control regions" to provide a basis for the establishment of air quality standards and the implementation of air quality control programs. In addition to listing the major factors to be considered in the development of region boundaries, the Act stipulates that the designation of a region shall be preceded by consultation with appropriate State and local authorities.

The National Air Pollution Control Administration, DHEW, has conducted a study of the San Francisco Bay Area, the results of which are presented in this report. The Region* boundaries proposed in this report reflect consideration of available and pertinent data; however, the boundaries remain subject to revisions suggested during consultation with State and local authorities. Formal designation of a Region will follow the consultation meeting. This report is intended to serve as background material for the consultation.

The Administration appreciates assistance received either directly during the course of this study or indirectly during previous activities in the San Francisco Bay Area from the California State Department of Public Health, Bay Area Air Pollution Control District, Association of Bay Area Governments and the San Francisco Bay Area Council.

*For the purposes of this report, the word region, when capitalized, will refer to the San Francisco Bay Area Air Quality Control Region. When not capitalized, unless otherwise noted, it will refer to air quality control regions in general.

INTRODUCTION

> "For the purpose of establishing ambient air quality standards pursuant to section 108, and for administrative and other purposes, the Secretary, after consultation with appropriate State and local authorities shall, to the extent feasible, within 18 months after the date of enactment of the Air Quality Act of 1967 designate air quality control regions based on jurisdictional boundaries, urban-industrial concentrations, and other factors including atmospheric areas necessary to provide adequate implementation of air quality standards. The Secretary may from time to time thereafter, as he determines necessary to protect the public health and welfare and after consultation with appropriate State and local authorities, revise the designation of such regions and designate additional air quality control regions. The Secretary shall immediately notify the Governor or Governors of the affected State or States of such designation."
>
> Section 107(a)(2), Air Quality Act of 1967

THE AIR QUALITY ACT

Air pollution in most of the Nation's urban areas is a regional problem. Consistent with the problem, the solution demands coordinated regional planning and regional effort. Beginning with the Section quoted above, in which the Secretary is required to designate air quality control regions, the Air Quality Act presents an approach to air pollution control involving closely coordinated efforts by Federal, State, and local governments, as shown in Figure 1. After the Secretary has (1) designated regions, (2) published air quality criteria, and (3) published corresponding documents on control technology and associated costs, the Governor(s) of the State(s) must file with the Secretary within 90 days a letter of intent, indicating that the State(s) will adopt within 180 days ambient air quality standards for the pollutants covered by the published criteria

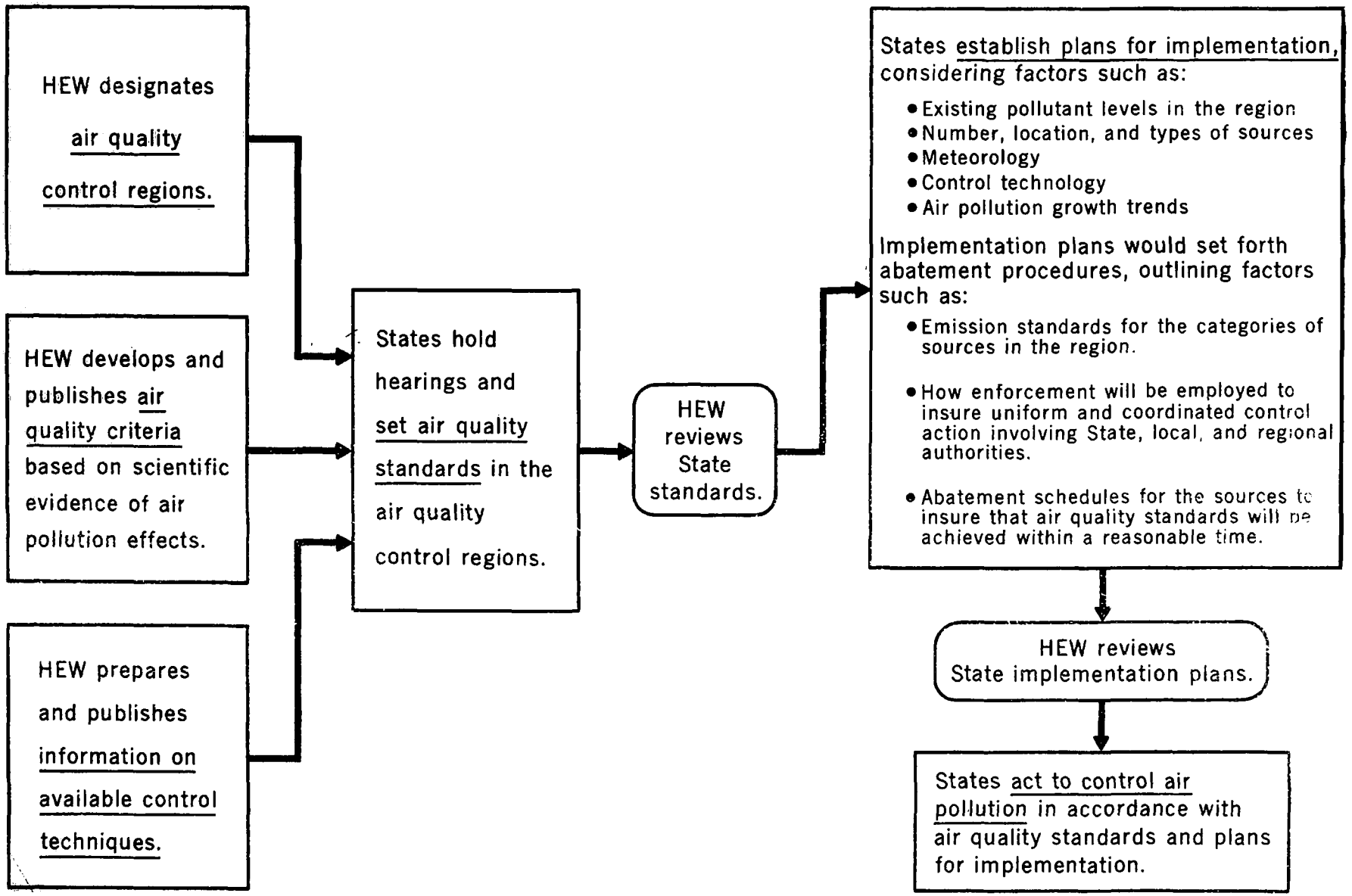

Figure 1. Flow diagram for State action to control air pollution on a regional basis.

and control technology documents and adopt within an additional 180 days plans for the implementation, maintenance, and enforcement of those standards in the designated air quality control regions.

The new Federal legislation provides for a regional attack on air pollution and, at the same time, allows latitude in the form which regional efforts may take. While the Secretary reserves approval authority, the State(s) involved in a designated region assumes the responsibility for developing standards and an implementation plan which includes administrative procedures for abatement and control. Informal cooperative arrangements with proper safeguards may be adequate in some regions, whereas in others, more formal arrangements, such as interstate compacts, may be selected. The objective in each instance will be to provide effective mechanisms for control on a regional basis.

PROCEDURE FOR DESIGNATION OF REGIONS

Figure 2 illustrates the procedures used by the National Air Pollution Control Administration for designating air quality control regions.

A preliminary delineation of the region is developed by bringing together two essentially separate studies - the "Evaluation of Urban Factors," and the "Evaluation of Engineering Factors."

The study of "Urban Factors" encompasses all considerations of a non-engineering nature. It reviews existing governmental jurisdictions, current air pollution control programs, present concentrations of population and industry, and expected patterns of growth. Other non-engineering factors are discussed when they are relevant. As a whole,

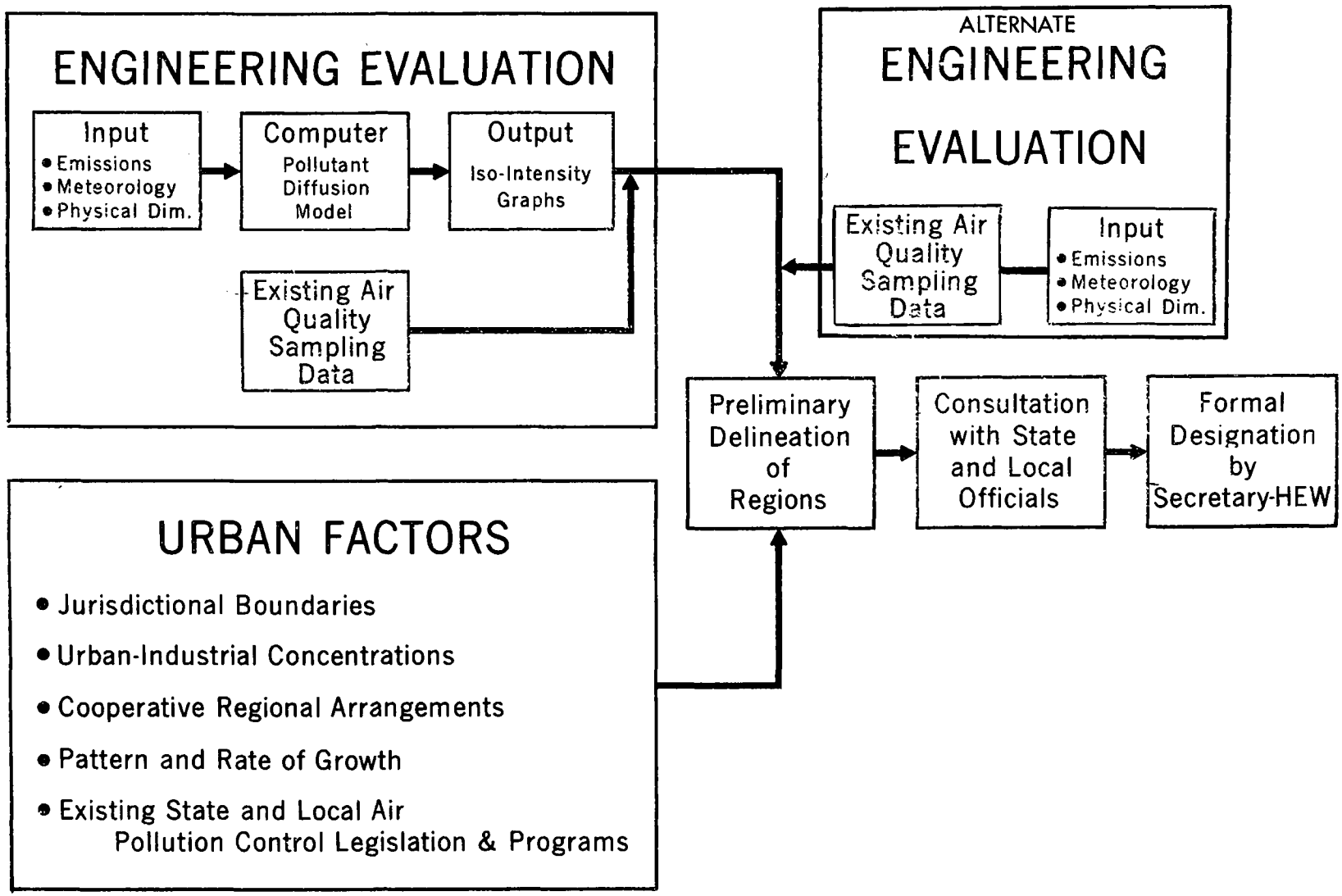

Figure 2. Flow diagram for the designation of air quality control regions.

the study of urban factors indicates how large an air quality control region must be in order to encompass expected growth. It also considers which group of governmental jurisdictions will most effectively administer a strong regional air quality control program.

The study of "Engineering Factors" indicates the locations of air pollution sources, estimates of their emissions, and the geographic extent and behavior of air pollutant concentrations in the ambient air. Pollution concentrations in the ambient air are presented from air quality sampling data obtained from the local air pollution control agencies. The behavior and transport of air pollution within the proposed region are described in terms of meteorology characteristic to the Bay Area. This alternate study of engineering factors is a substitute for the diffusion model technique, a basic tool which projects theoretical air quality levels from meteorological and air pollutant emissions data. The diffusion model was not used because there is a wide geographic variation in terrain in the San Francisco Bay Area which produces a variety of meteorological conditions. Diverse meteorological situations obviate using an average seasonal or annual meteorological condition for the whole area for input to a general diffusion model. This alternative method of describing the behavior of air pollutants in the area in lieu of the diffusion model can also serve as a guide to the appropriate size of the air quality control region. As a whole, the engineering study indicates how large the air quality control region must be in order to encompass most pollution sources and most people and property affected by those sources.

The conclusions of the engineering study are combined with the results of the urban factors study to form the basis of an initial proposal for an air quality control region. As shown in figure 2, the proposal is then submitted for consultation with State and local officials. After reviewing the consultation record, the Secretary formally designates the region with a notice in the Federal Register and notifies the governors of the States affected by the designation.

The body of this report contains the proposal for the boundaries of the San Francisco Bay Area Air Quality Control Region and supporting studies on engineering and urban factors. The report itself is intended to serve as the background document for the formal consultation with appropriate State and local authorities.

THE PROPOSED REGION

Subject to the scheduled consultation, the Secretary, Department of Health, Education, and Welfare, proposes to designate an air quality control region for the San Francisco Bay Area consisting of the following jurisdictions:

Alameda County

Contra Costa County

Marin County

Napa County

San Francisco County

San Mateo County

Santa Clara County

Solano County

Sonoma County

As so proposed, the San Francisco Bay Area Air Quality Control Region would consist of the territorial area encompassed by the outermost boundaries of the above counties. The proposed region is illustrated in Figure 3.

DISCUSSION OF PROPOSAL

To be successful, an air quality control region should meet three basic conditions. First, its boundaries should encompass most pollution sources as well as most people and property affected by those sources. Second, the boundaries should encompass those locations where industrial and residential development will create significant air pollution problems in the near future. Third, the boundaries should be chosen in a way which is compatible with and even fosters unified and cooperative governmental

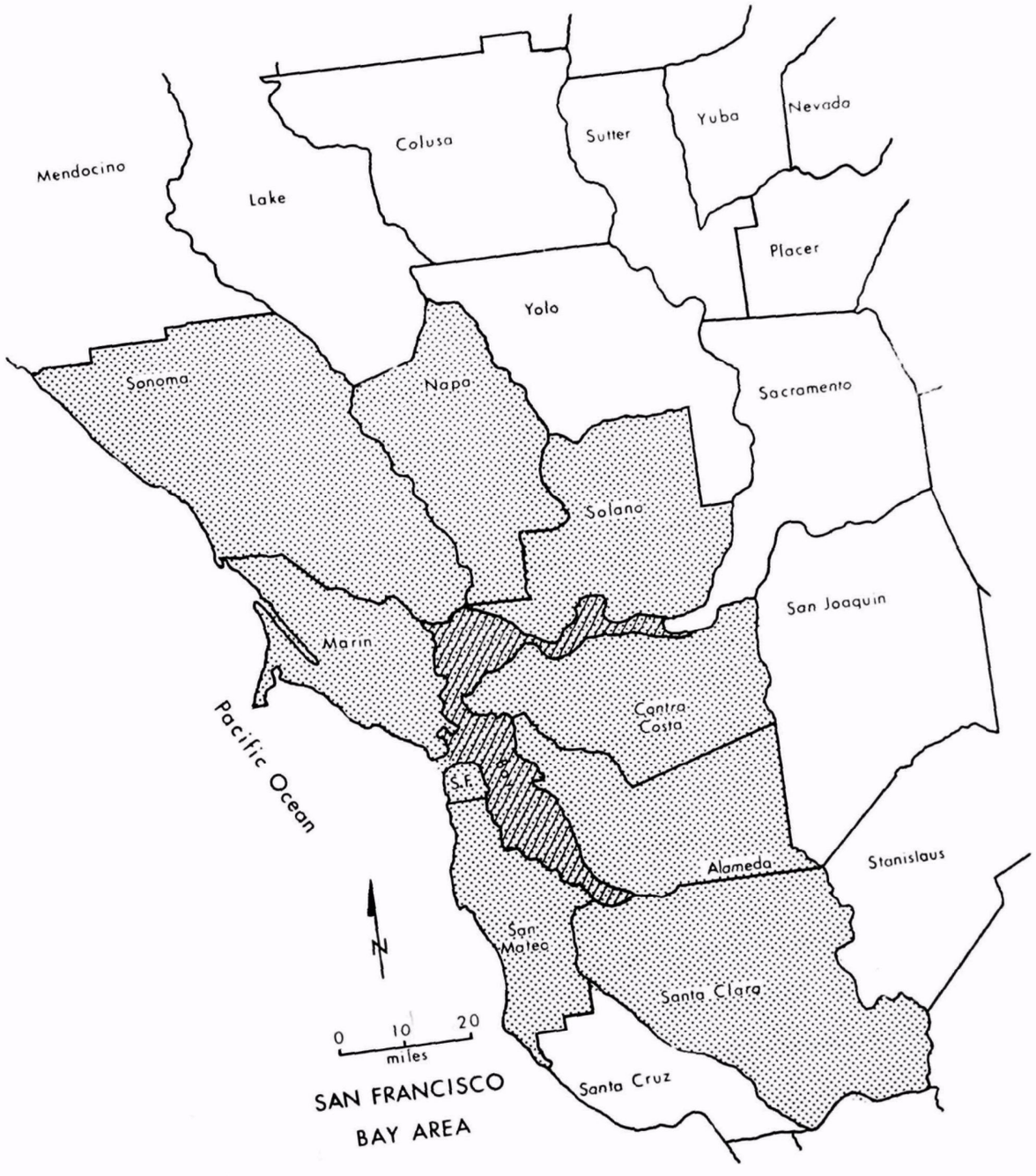

Figure 3. Proposed San Francisco Bay Area Air Quality Control Region.

administration of the air resource throughout the region.

The "Evaluation of Urban Factors" indicates that the present high densities of population and industrial activity, and hence the transportation arteries supporting them, are primarily centered in the southern five counties of Contra Costa, San Francisco, San Mateo, Alameda and Santa Clara. Substantial growth will continue in these counties , but highest rates of growth are projected for the counties of Marin, Sonoma, Napa, Solana, and Contra Costa.

The "Evaluation of Engineering Factors" indicates that at the present time most air pollution sources affecting the air quality of the San Francisco Bay Area are included within the boundaries of nine counties: Sonoma, Napa, Solana, Marin, Contra Costa, San Francisco, Alameda, San Mateo, and Santa Clara.

Engineering data show that air pollution is primarily emitted near the shoreline of the Bays and transported to portions of the nine county Bay area, primarily in the valleys of these counties which border on the San Francisco, San Pablo and Suisun Bays, (Figure 4). The data also indicates that under certain meteorological conditions some air pollution does travel from the San Pablo Bay area into the Sacramento Valley via the Carquinez Strait. Due to sufficient mixing and dilution of air pollutants as they enter the fringes or buffer zone between the San Francisco Bay Area and the Sacramento Valley, the air pollution impact on the latter does not appear significant for considering the portions of these Sacramento Valley counties for inclusion in the San Francisco Bay Area Air Quality Control Region.

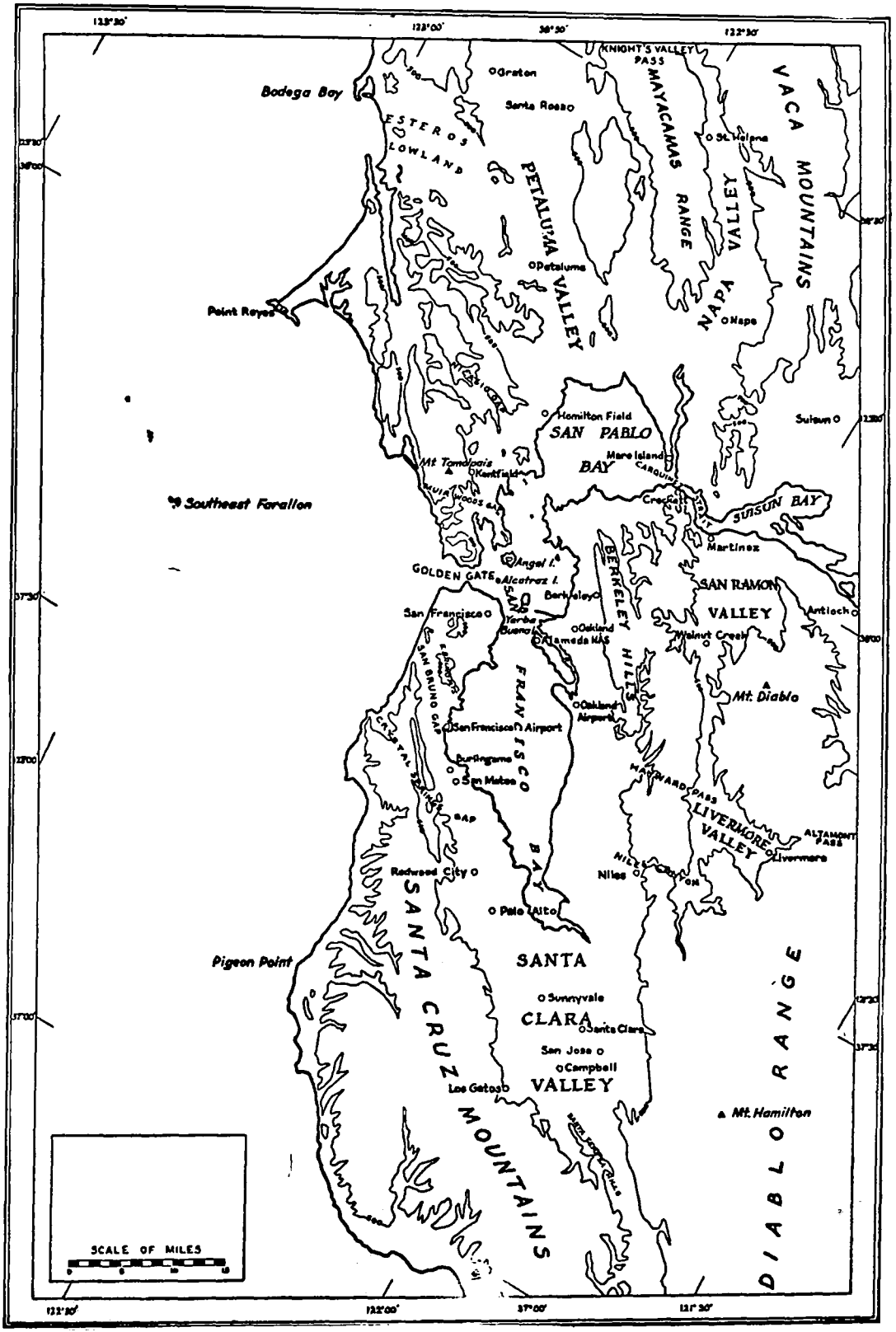

Figure 4. Topography of the San Francisco Bay Area. (Adapted from Patton[14])

As proposed, the Region boundaries are coterminous with the nine counties of the following: (1) the proposed expanded Bay Area Air Pollution Control District basin, (2) the Preliminary Regional Plan for the San Francisco Bay Region by the Association of Bay Area Governments, and (3) the Air Basin designated by the State of California Air Resources Board.

In view of these above observations, the San Francisco Bay Air Quality Control Region, consisting of the nine counties proposed herein, is considered to be the most cohesive and yet inclusive area within which an effective regional effort can be mounted to prevent and control air pollution in the urban area surrounding the San Francisco Bay. The remaining two sections of this report describe the initial evaluation of urban and engineering factors.

THE CONSULTATION

The purpose of the scheduled consultation with appropriate State and local officials is to receive comments and suggestions regarding this proposal. Comments of the appropriate State and local officials will be pertinent to the final disposition* of the proposal.

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*When air quality control region boundaries have been designated, a situation may develop involving a source of pollution on one side of the region boundary which affects in some real way air quality on the other side of the boundary. If adjustment of the boundary is not a practical way to alleviate the situation, relief should be found in the control implementation plan which follows the designation. The plan should contain provisions for the control of sources located close to but beyond the region boundaries. The level of control for such sources should depend, in part, upon the degree to which emissions from the source cause air quality levels to exceed the standards chosen for applications within the region.

EVALUATION OF URBAN FACTORS

INTRODUCTION

The evaluation of urban factors, (land use, population, transportation, and existing governmental organizations), is influenced by the regions main physical characteristics, the mountains surrounding the San Francisco Bay,* the valleys that tie these mountains to the San Francisco Bay, and the San Francisco Bay, the largest natural harbor in the world, covering 450 square miles. The nine counties, (Figure 5), that are tied into this physical relationship thus become economically and socially interrelated.

LAND USE

For necessary area-wide cooperation and coordination of policies, plans, and services, the Association of Bay Area Governments was created in 1961 to solve problems, formulate and implement regional development policies for those nine counties. Their work in regional planning reveals existing and future air pollution source and receptor areas. Industrial point sources are reflected in industrial zoning. Air pollution receptor areas are related to residential zoning. Mobile source distributions become meaningful from transportation planning. Industrial activity and projections of industrial development, are shown in Fig. 5 which shows land use, 1965, and permitted development for the San Francisco Bay Region.[1] Most industrial development will occur in a continuous band immediately surrounding the Bay. Substantial increases in industrial permitted development are planned along the shores of Contra Costa, Solano, and Alameda Counties, owing to excellent water and land transportation.[2] (The industrial zoning projected towards the

*The San Francisco Bay, San Pablo Bay, and Suisun Bay will be referred to in general as the San Francisco Bay.

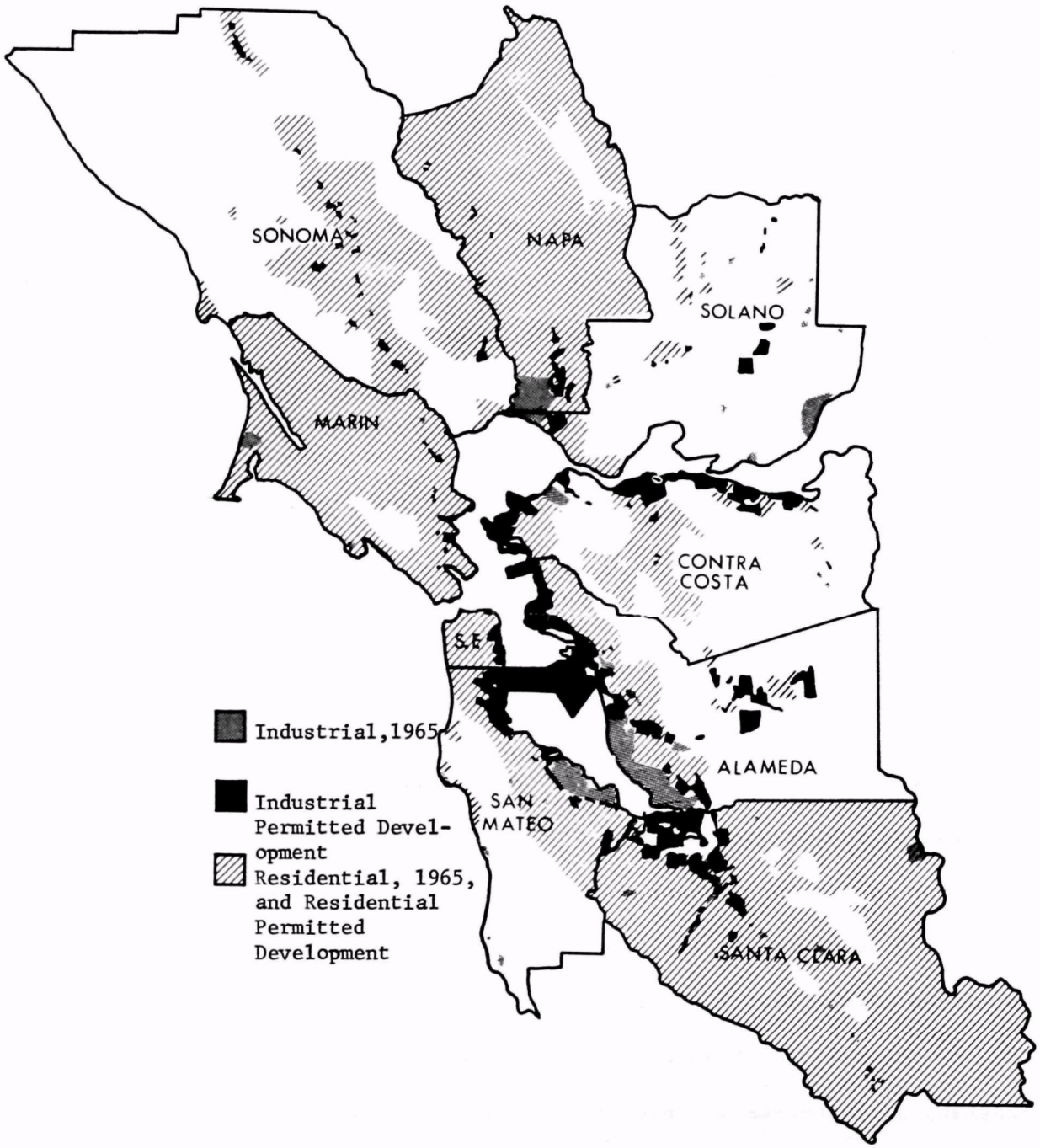

Figure 5. Land use, 1965, and permitted development for land area covered by the Preliminary Regional Plan for the San Francisco Bay Region. (Adapted from The Association of Bay Area Government's Preliminary Regional Plan [1])

Bay from San Mateo and Alameda counties is not an indication of projected heavy industrial development but rather a result of adjacent city zoning laws which define city boundaries extending to the county lines in waterfront areas.)

Contra Costa County is the site of heavy industrial activity within the nine county area with present and future developments showing substantial increases. Large oil refineries are located at Richmond, Oleum, Martinez, and Avon, with future developments in Hercules and Pittsburgh. Large metal and steel mills, chemical plants, wood product plants, transportation oriented plants, powerplants, and asphalt plants exist in the county or are scheduled for completion in the near future.

Solano County is primarily agricultural in nature. Two governmental installations, Travis Air Force Base, and Mare Island Navy Yard in addition to one of the best equipped industrial park developments, Benicia Industrial Park, are located in the county. This industrial park is California's largest port oriented industrial park, consisting of over 40 companies, and a large refinery.

Alameda County in 1965 ranked third among California counties in the number of manufacturing plants The manufacturing is not considered heavy industrial, with the food processing industry being the largest of the counties manufacturing economy, with production of transportation equipment, metal products and machinery following in that order. Extensive harbors, airport facilities, and highways provide the necessary routes of transportation to sustain this extensive manufacturing.[3]

The trend in manufacturing employment density by county[4] is shown in Fig. 6 indicating noticable increases in the northern counties of Sonoma, Solano, and Marin.

POPULATION

Population projections show that by 1990 close to 7.2 million persons will be living in the Bay Region.[1] Fig. 7 shows the 1960 population and projections for 1970 and 1990 by county. Substantial population increases will occur from 1960 to 1970 in Sonoma, Marin, Contra Costa, and Santa Clara counties with continued high population increases projected for Sonoma, Napa, Marin, and Contra Costa counties. The permitted development land use map, Fig. 5, shows the planned residential areas necessary to accommodate these projected population increases.

In summary, most counties will continue to grow at their present accelerated rates for the next 10 years. Starting in 1980 the bulk of new growth will shift to the north Bay counties including Contra Costa County.

TRANSPORTATION

The regional transportation plan, (Fig. 8), shows the major transportation arteries--mainly major highways, rapid transit routes, and shipping channels--interwoven in the nine county area. Dense highway, and rapid transit systems are located adjacent to the Bay to accomodate the concentrated industrial-commercial and shipping establishments. Standard freeways and special expressways are distributed in the outlying areas to accomodate residential developments. With the completion of the Bay Area Rapid Transit District (BARTD) system in 1972, and conversion of some

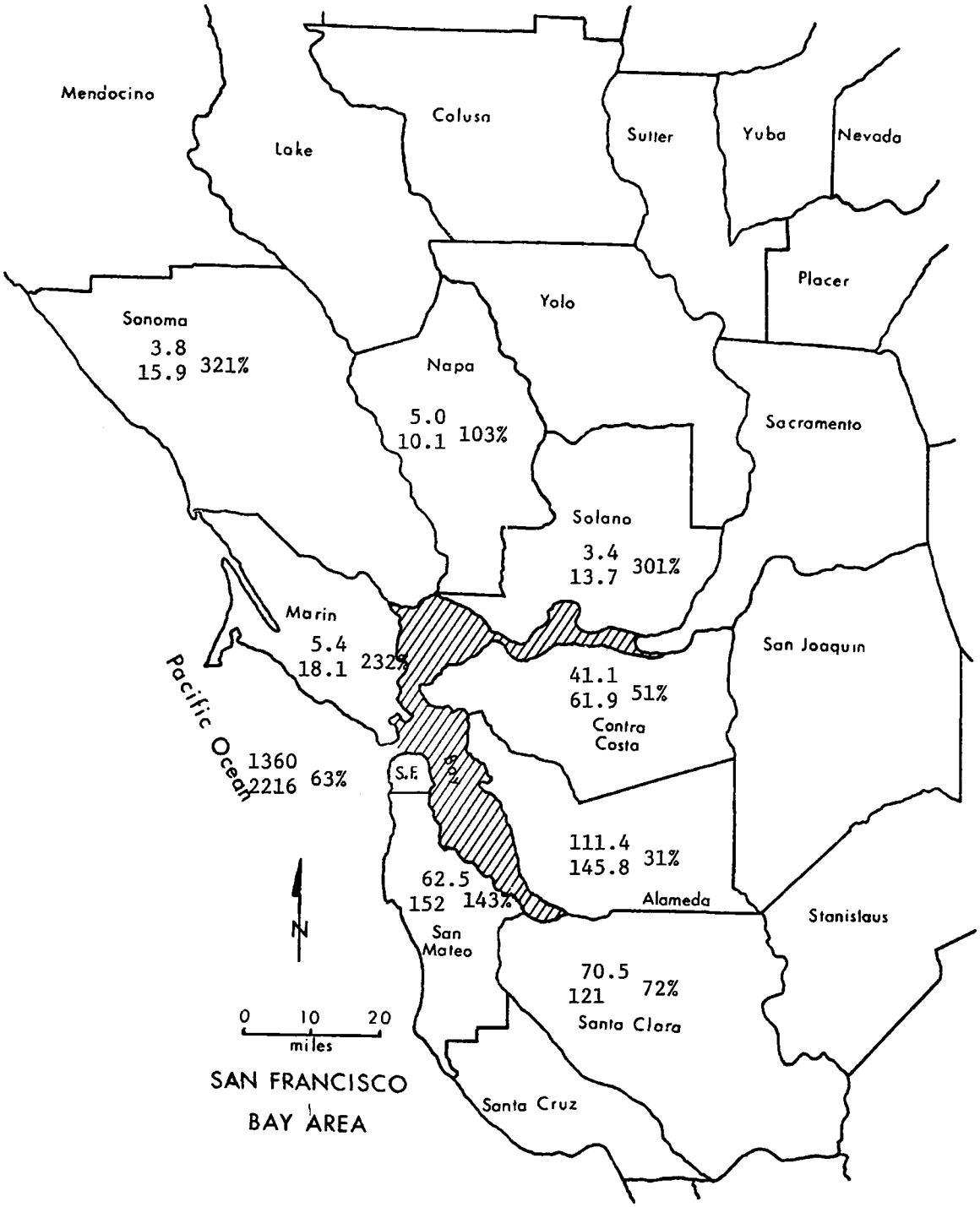

Figure 6. 1960 and 1990 manufacturing employment densities by county, (workers per square mile), and percent increase.

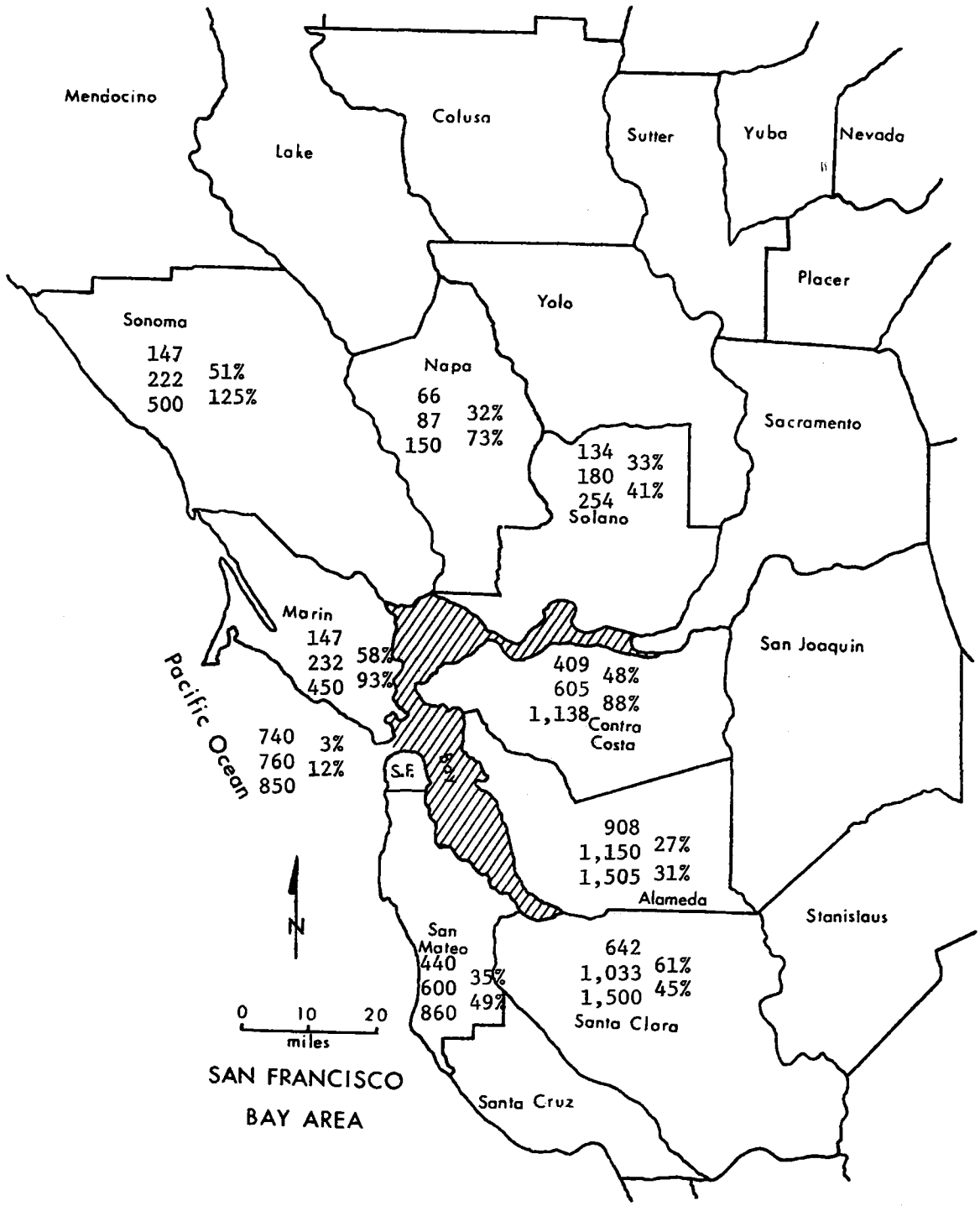

Figure 7. Population increases by county. (Values represent thousands of people for 1960, 1970, and 1990, and percent increase for intervals.)

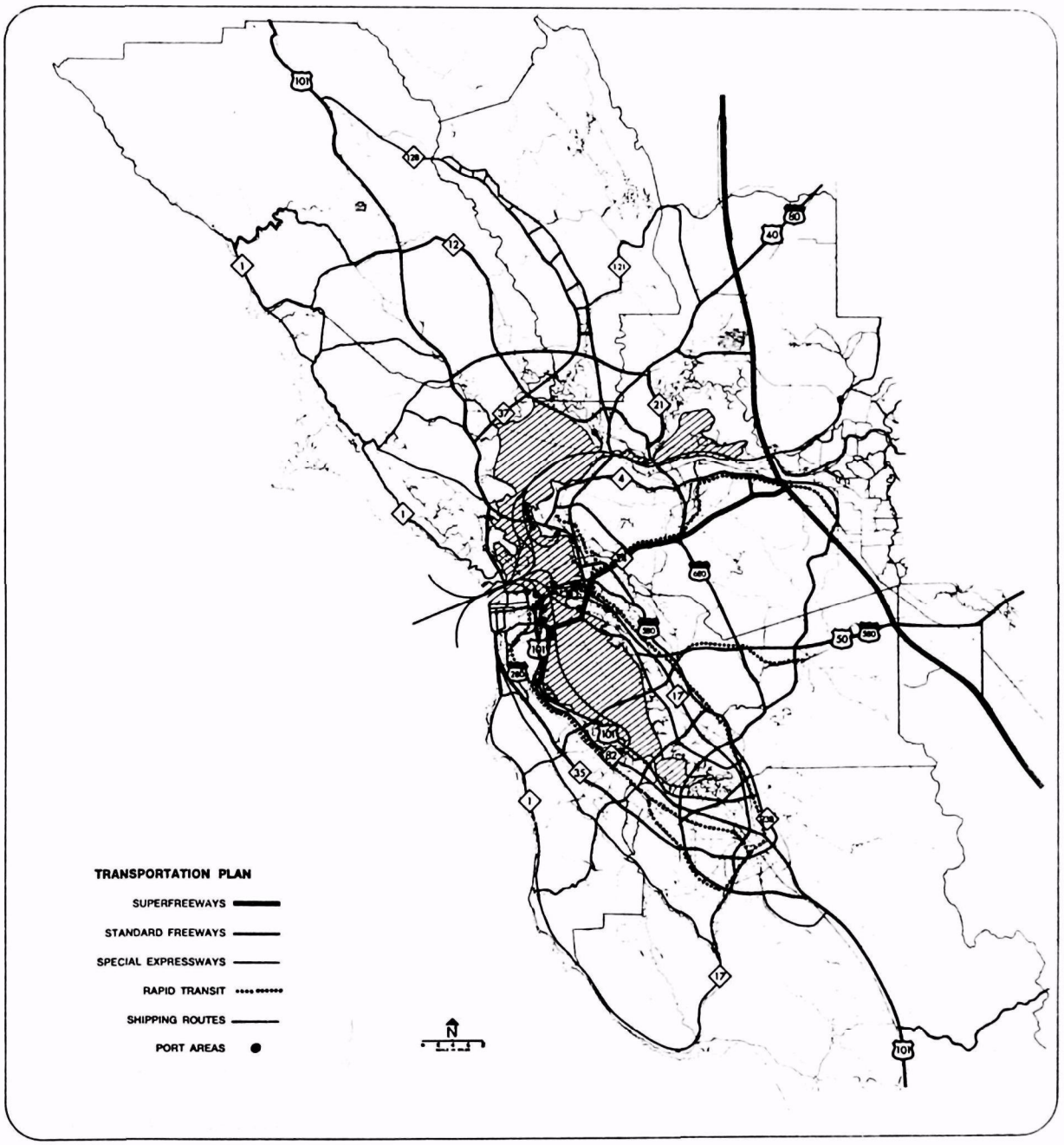

Figure 8. Transportation Plan for the San Francisco Bay Area. (Adapted from The Association of Bay Area Government's Preliminary Regional Plan[1])

existing railway systems to rapid transit in place of a comparable road improvement program, "at peak demand hours, all available major highway space will be fully used in the future."[1] This is noteworthy since the air pollution emissions estimated[5] for the Bay area show 75% of the carbon monoxide, 54% of the nitrogen oxides and 48% of the organic compounds, (the last two being the key photochemical pollutants), are emitted from motor vehicle exhaust.

EXISTING GOVERNMENTAL ORGANIZATIONS

Another important factor to consider for air quality control region boundaries is existing agencies or governmental units to administer an effective air quality control program. The Bay Area Air Pollution Control District (BAAPCD) presently consists of six counties, Alameda, Contra Costa, Marin, San Francisco, San Mateo, and Santa Clara. The law that originally established the BAAPCD in 1955 included three additional counties, Napa, Solano and Sonoma, which have not as yet become active in the BAAPCD. The California State Air Resources Board is considering their active membership in the BAAPCD.

The BAAPCD program has a present annual operating budget of $1,443,346 with $208,275 contributed by a Federal Air Pollution Control Program maintenance grant.

The jurisdiction of the Bay Area Air Pollution Control District is limited to stationary, rail, and sea transportation sources. Gasoline and diesel powered motor vehicles are the responsibility of the State of California Air Resources Board. Close cooperation exists between these two governmental bodies on this important air pollution problem.

This multicounty district is governed by a Board of Directors who receive assistance from a 20 man Advisory Council appointed by the Board, and operates on a performance standard basis rather than a permit system.

The BAAPCD presently employs 84 people in technical, clerical, and administrative positions. The enforcement Division consists of inspection (30 inspectors), engineering (inventory and compliance), source testing, statistical and agricultural sections The technical division embraces a library, a comprehensive laboratory, and an air analysis section consisting on six complete continuous air monitoring stations and 34 partial stations.[5]

In addition, the State of California Air Resources Board has recently approved the nine-county San Francisco Bay Area Basin, (Fig. 9), as one of eleven California Air Basins The basins were selected on the basis of homogenous air pollution problems, topography, meteorology, and population density, and were required by 1967 State Legislation in order that State Air Quality Standards can be set.

STATE OF CALIFORNIA

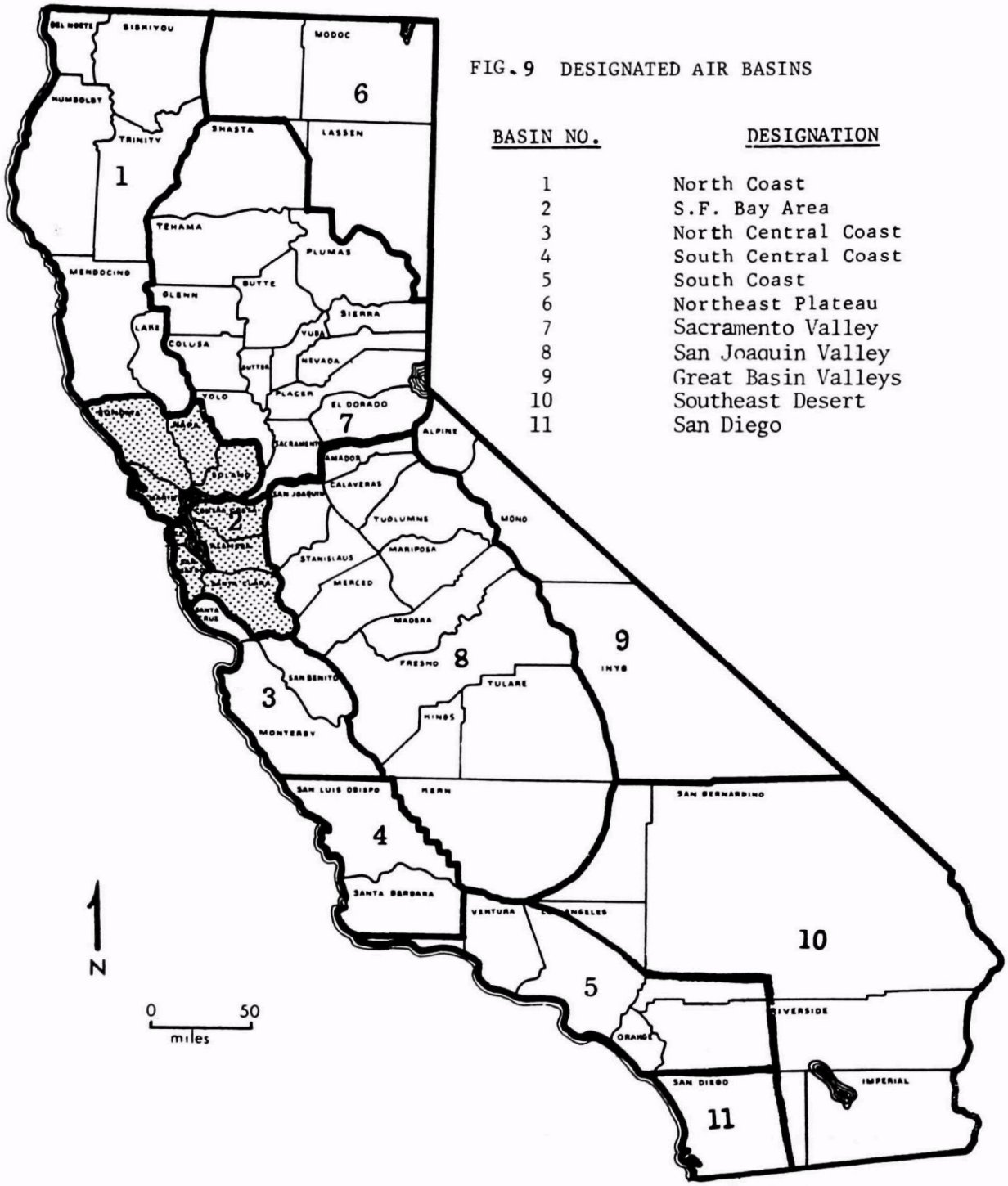

FIG. 9 DESIGNATED AIR BASINS

BASIN NO.	DESIGNATION
1	North Coast
2	S.F. Bay Area
3	North Central Coast
4	South Central Coast
5	South Coast
6	Northeast Plateau
7	Sacramento Valley
8	San Joaquin Valley
9	Great Basin Valleys
10	Southeast Desert
11	San Diego

EVALUATION OF ENGINEERING FACTORS

Introduction

The standard procedure for defining air quality control regions has been to apply a diffusion model[6]. The model is used with appropriate emission inventory and meteorological data to estimate air pollution distribution patterns for various pollutants. The use of the model is restricted to areas where the terrain is essentially level, and marked land-sea contrasts do not exist, (reflecting homogenous meteorological conditions). The model (without considerable refinement) could not be applied to the San Francisco Bay area. An alternate procedure, relating qualitatively emission source information, air quality data, and meteorological descriptions, (air flow patterns, mixing depths, and diffusion potential), was used for the purpose of determining a logical air quality control region boundary.

Most of the discussion in this evaluation is concerned with the nine counties, (Sonoma, Napa, Marin, Solano, Contra Costa, Alameda, Santa Clara, San Mateo, and San Francisco). In those cases in which a statement applies in general or to a substantial majority of the nine counties ~~re~~ferences are made to the Bay Area.

Emissions Inventory

Table 1 shows the distribution by pollutant of the major air pollution emissions, (compiled by the BAAPCD), in tons per day by county for the nine county area. Table 2 breaks down these emissions into source categories for the original six county Bay Area Air Pollution Control District.[5] 1967 estimates indicate about 12,000 tons per day are emitted from the nine county area with Santa Clara, Contra Costa and Alameda Counties

TABLE 1. BAY AREA AIR POLLUTION EMISSIONS BY TYPE, AND BY COUNTY, 1967[5]

	Pollutants in Tons/day					
	Particulates	Organics	Nitrogen Oxides	Sulfur Oxides	Carbon Monoxide	Total
San Mateo	31	257	51	4	890	1233
Santa Clara	52	612	92	8	1869	2633
San Francisco	23	267	76	16	923	1305
Alameda	43	549	106	12	1564	2274
Marin	5	84	17	2	305	413
Contra Costa	56	390	172	387	1352	2357
Napa	8	65	8	2	191	274
Solano	28	179	29	45	523	804
Sonoma	34	177	25	2	544	782
Area Total	280	2580	576	478	8161	12075

TABLE 2 - AIR POLLUTION EMISSIONS IN THE BAY AREA AIR POLLUTION CONTROL DISTRICT - 1967[5]

TONS PER DAY

Source Category	Particu-lates	Organic Compounds	Nitrogen Oxides	Sulfur Oxides	Carbon Monoxide
Petroleum	2.4	187	9.4	57	443
Chemical	30	28	0.7	78	8
Metallurgical & Mineral	26	2.5	7.6	75	0.6
Organic Solvent Users	5.8	327	0.1	--	--
Combustion	27	55	186	182	0.8
Incineration	29	301	1.0	1.6	678
Agriculture	18	186	0.1	0.5	447
Ships & Railroads	6.7	6.1	7.7	9.5	2.2
Aircraft	8.8	8.3	6.9	--	35
Tractors & Const. Equipment	19	31	16	5.1	68
Sub-Total--District Jurisdiction	172	1132	235	409	1683
Highway Motor Vehicles	38	1027	279	20	5220
Grand Total	210	2159	514	429	6903

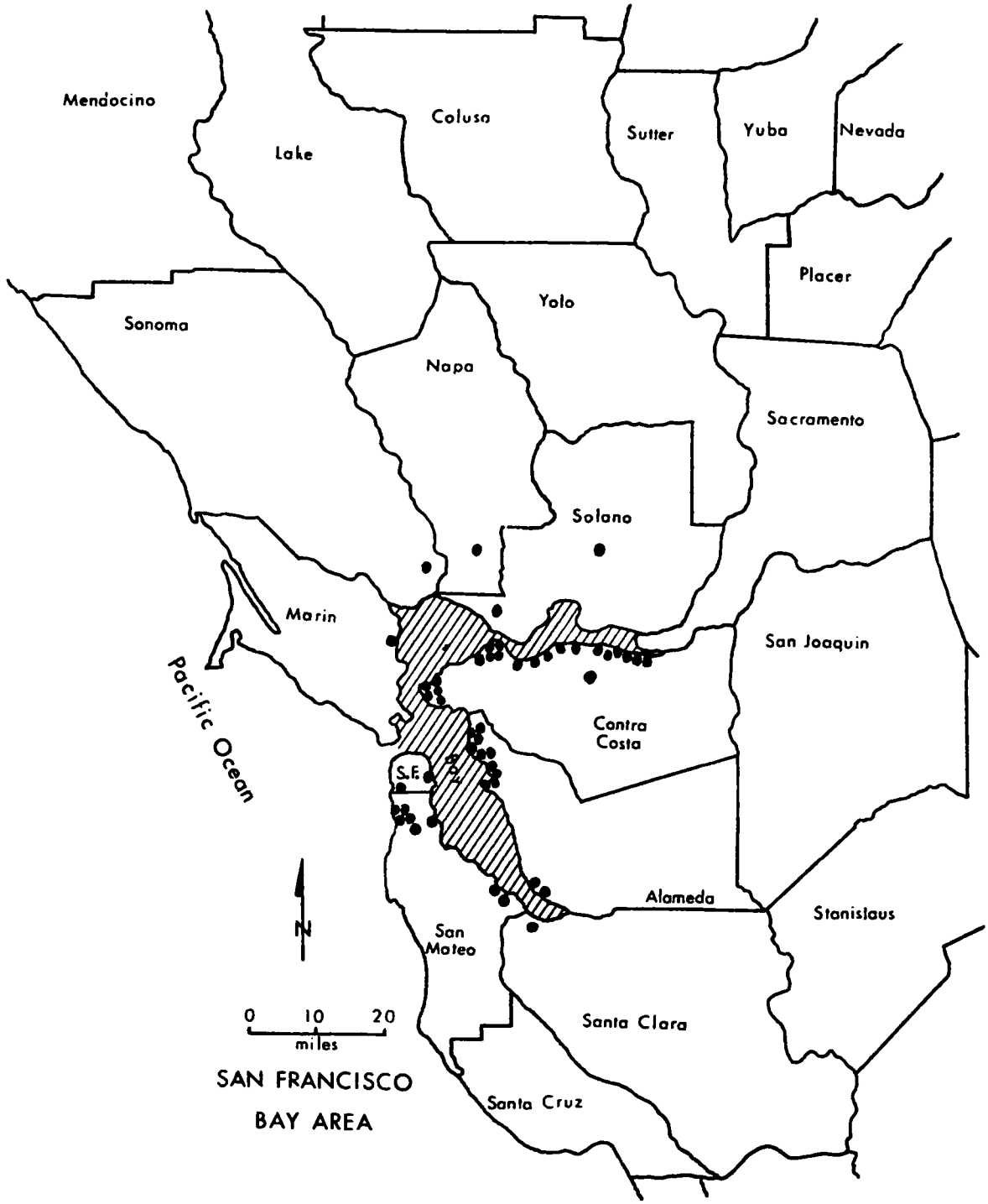

Figure 10. Major Point sources in the San Francisco Bay Area.

contributing slightly over 60 percent of the total emissions. The dense distribution of freeways and expressways,[1] (fig. 8), and major point sources, (fig. 10), immediately surrounding the San Francisco Bay indicate that the majority of air pollution from each county is emitted from locations near the San Francisco Bay.

Air Quality and Meteorological Description

The study of air quality levels and a description of its behavior in the atmosphere above the San Francisco Bay Area is necessary to determine the magnitude and the geographic extent of the air pollution problem. This type of evaluation should provide the necessary insight to assist in the determination of the air quality control region boundaries.

Terrain features and land-sea breeze contrasts play very important roles in the frequently observed air stagnation conditions, air flow patterns, mixing depths, and diffusion potentials, and thus directly affect the air pollution concentrations and distributions in the San Francisco Bay Area.

One frequently-used measurement of the concentration of photochemical air pollution is total oxidant.* Notable oxidant concentrations are prevalent in San Francisco Bay Area. In the presence of ultraviolet light, hydro-carbons and oxides of nitrogen, the latter two, products of the automobile exhaust, react to form photochemical air pollution.

Many meteorological factors directly affect the development and accumulation of oxidants. Sunshine and temperature in particular affect

*Total oxidant is defined as the total of all substances that are capable of oxidizing the iodide ion to iodine under certain specified conditions. The concentration of total oxidant is approximately correlated with the eye-irritating characteristic of photochemical smog.

photochemical development, whereas temperature inversions and wind speed affect pollutant accumulation in the local atmosphere. Ventilation index values, based on the hourly rate of available air flow through an arbitrary cross wind area under an inversion lid, have been computed regularly for the BAAPCD since 1962." July, August and September are consistently the months with most restricted ventilation, resulting from persistent maritime inversions which limit the vertical pollutant dilution.[7] Invariably, the low ventilation indexes coincide with high oxidant values.

Figure 11 shows a 1967 seasonal average, (July-September), of daily one-hour maximum, (computed from monthly averages of daily one-hour maximum values), concentrations of oxidant for nine BAAPCD stations and the surrounding stations. Table 3 presents the number of adverse oxidant days by county from 1963-1967. Adverse is defined by the California State Department of Health as days when readings of .15 parts oxidant per million parts of air, (by the potassium iodide method), or higher, are attained for one hour or longer. Adverse is considered the level at which there will be sensory irritation, damage to vegetation, reduction in visibility or similar effects.[8] It is evident that significant oxidant levels do exist in the valley portions of the present six county BAAPCD. Although there are no recorded values of oxidant in the three northern counties (Sonoma, Napa, and Solano), their valleys are condusive to air stagnations and the photochemical smog reaction. Because these valleys complete the air basin shared by the valleys of the Southern six counties, there is undoubtedly potential for exchanges of air pollution within this basin. This will be discussed in the following section.

TABLE 3.

NUMBER OF ADVERSE OXIDANT DAYS BY COUNTY, 1963-1967[5]

COUNTY	1963	1964	1965	1966	1967
Alameda	17	26	27	14	14
Contra Costa	5	4	11	8	17
Marin	2	1	4	3	4
San Francisco	3	11	4	2	3
San Mateo	8	10	23	12	15
Santa Clara	22	13	34	16	19

Since the automobile is the number one source of pollutants in the District[9], the annual distribution of carbon monoxide concentrations is presented in figure 12, (values are also computed from monthly averages of the highest average hour per day). Higher CO concentrations are related to areas of dense traffic routes, figure 8, page 22.

Suspended particulate levels show a 1967 annual average of 97 $\mu g/m^3$ for Oakland, 76 $\mu g/m^3$ for San Francisco, and 75 $\mu g/m^3$ for San Jose.

Visibility restriction* due to air pollutants from the Oakland airport show increased number of days in the late fall and early winter where the visibility was 6 miles or less (Table 4).

*Visibility restriction is defined by visibility of 6 miles or less with relative humidity below 70%.

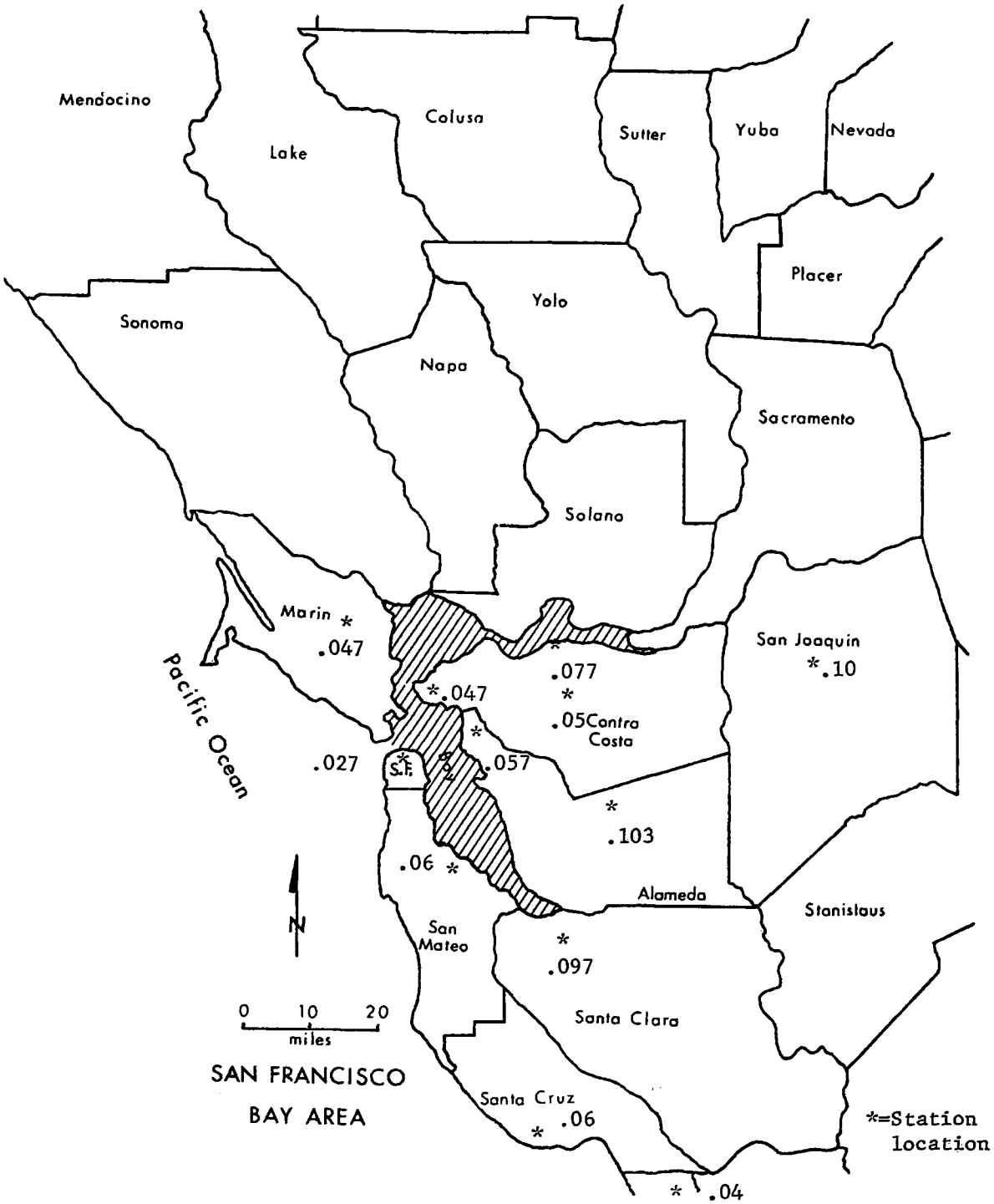

Figure 11. Seasonal (July-Sept) oxidant (KI) concentrations, PPM, (seasonal average of daily one-hour maximum concentrations).

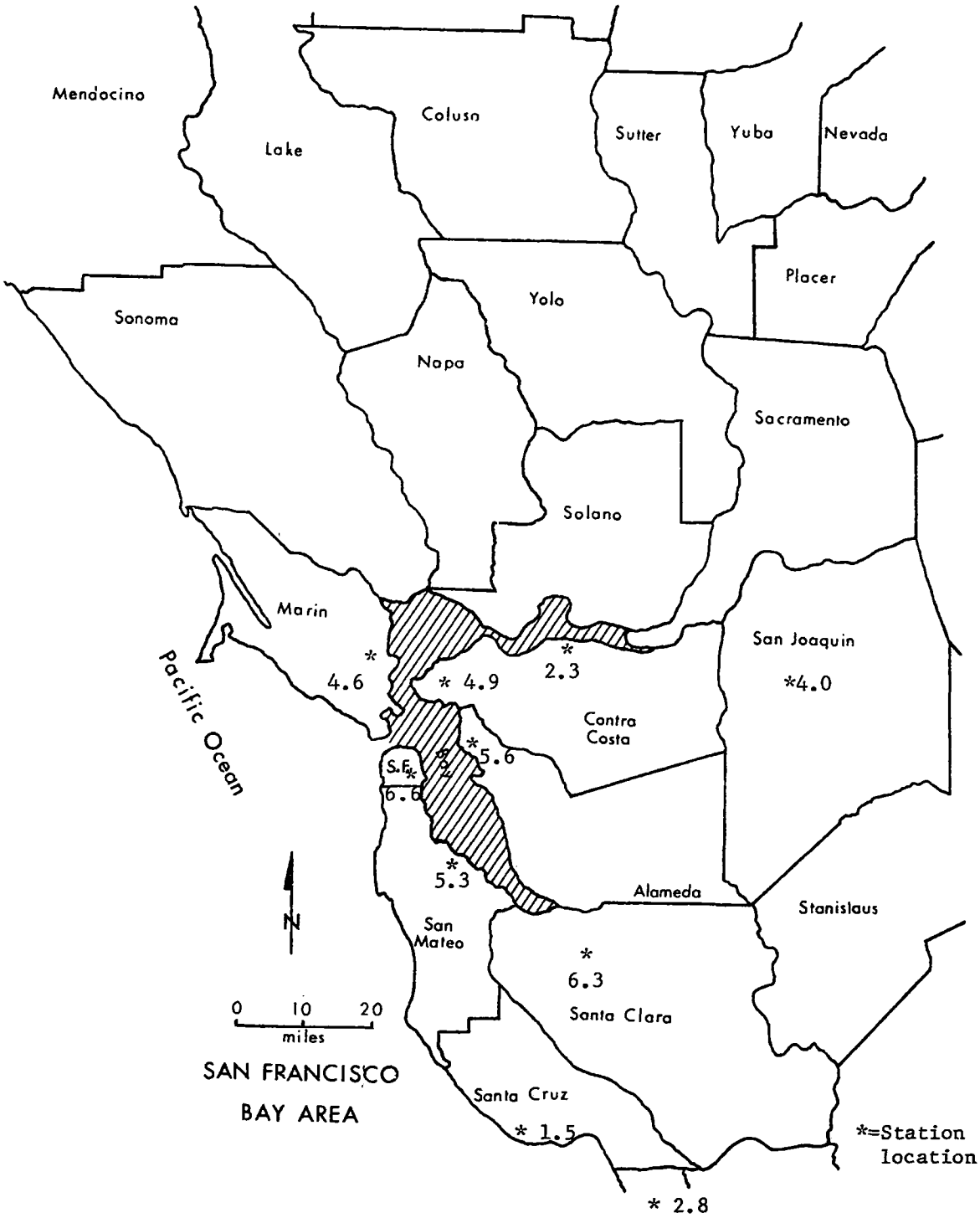

Figure 12. Mean annual carbon monoxide concentrations, PPM, (yearly average of daily one-hour maximum concentrations).

Table 4. Number of days/month when visibility is 6 miles or less.
(Aug, 1967-July, 1968)

Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
3	5	10	14	4	12	4	6	3	1	0	3

Air Flow Patterns and Mixing Depths

Topography plays a major role in directing or restricting air flow and hence the transport of pollutants in the San Francisco Bay Area. Since most of the air pollution sources and receptors are located in the lowland areas around San Francisco and San Pablo Bays, the Carquinez Strait and in the Petaluma, San Ramon, Livermore and Santa Clara Valleys, the major concern is how air flows from one of these sections to another or possibly outside of the general area.

Trajectory analyses has frequently used by meteorologists to demonstrate how air moves from one area to another. A number of reports deal with air flow patterns of the San Francisco area and general vicinity.[12-20] In general these reports support one another in their descriptions of air flow patterns. However, no single report is complete or detailed enough to form a basis for this report.

The San Francisco area experiences seasonal and diurnal variations in air flow the greatest seasonal difference is between winter and summer and the most marked diurnal variation occurs in winter. The autumn and spring are transitional periods during which the changes between seasonal extremes of prevailing flow patterns occur gradually.

Figures 13 and 14 (which are taken from Root 15), present the prevailing daytime air flows which accompany the two most common meteorological conditions in summer. Winds may approach the San Francisco area from any direction but the vast majority have a westerly component. The air is channeled through the passes and straits and along the sides of mountains as it penetrates the coast at (1) the Esteros Lowland, (2) the Golden Gate Pass, (3) the San Bruno Gap and (4) the Crystal Springs Gap (See Figure 4). Even though there is considerable exchange of air and thus pollutants between the portions of the nine counties tied into the San Francisco and San Pablo Bays, only a limited amount of the incoming air at the surface along the coast remains at the surface in its travel to the Central Valley (the Valley east of the Vaca Mountains and Diablo Range). Most of the air moves upslope on the west sides of the mountains and remains aloft as it passes over the Central Valley. The only coastal air that readily flows into the Central Valley at the surface and thus capable of transporting pollutants at ground level, is restricted by the topography to the circuitous route through the Golden Gate Pass and then the Carquinez Strait. Thus some of the air from the Bay Area moves into western Sacramento and San Joaquin Counties in the Great Central Valley via this route. A greater area is considered in a Stanford Research Institute report[18] and the indication is that very little air moves out of nine county Bay areas to the north or south.

In another area, it appears that passage through the Golden Gate, San Francisco Bay, Hayward Pass and Livermore Valley would bring air to the Central Valley at the surface. Passage out from the Livermore Valley is through a pass (Altamont) at an elevation of 750 feet, thus little,

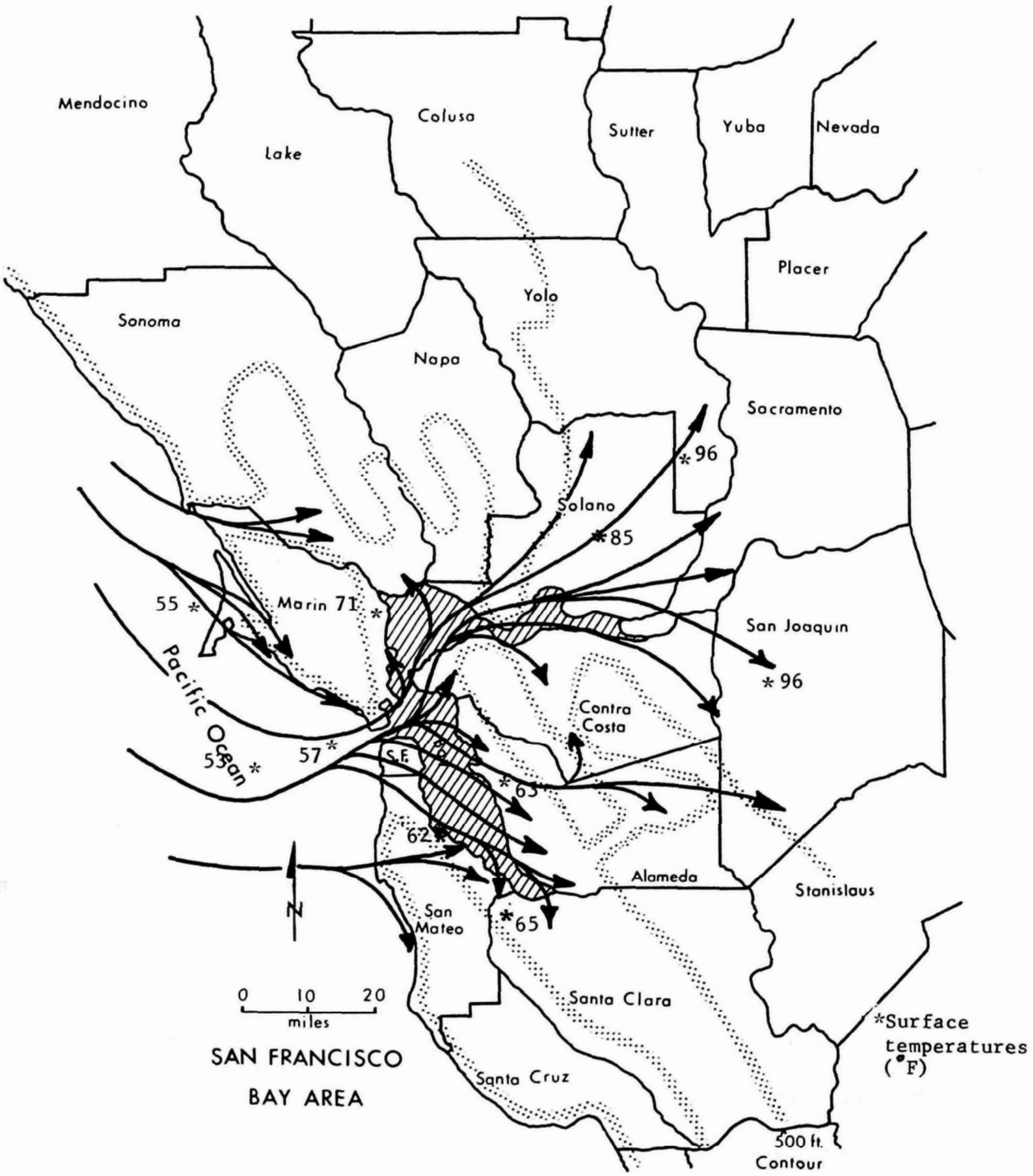

Figure 13. Generalized afternoon flow pattern of marine air in the San Francisco Bay Area under typical summer conditions. The observed temperatures at 1630 PST are entered to illustrate the cooling effect of the sea breeze. (adapted from Root[15])

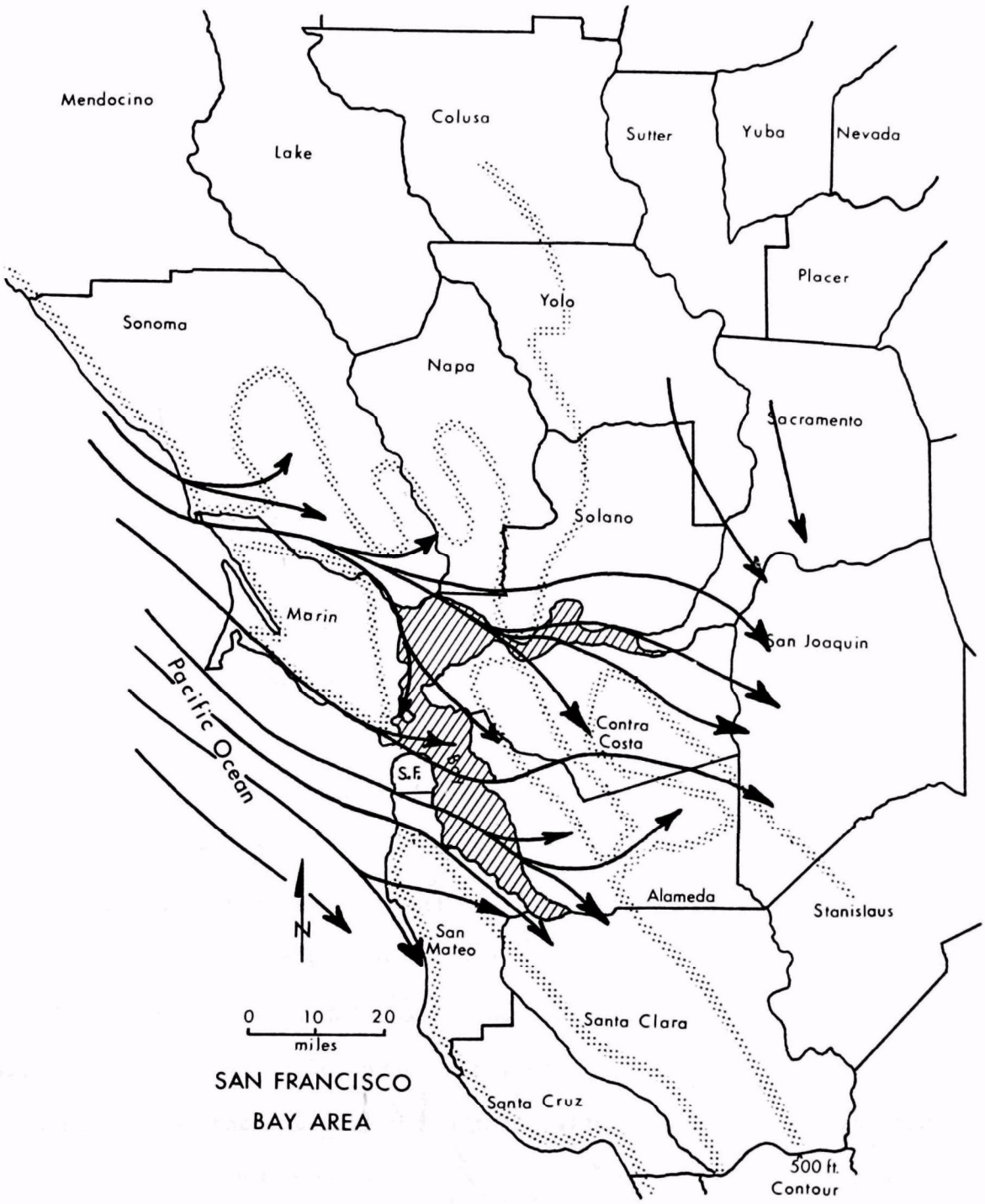

Figure 14. Generalized afternoon flow pattern in the San Francisco Bay Area under conditions of strong northwesterly flow. (adapted from Root[15])

if any, of the flow gets down to the central valley floor on the eastern side of the Diablo Range.

Land and sea breeze effects are also important due to their air pollutant transport capability. In many coastal locations throughout the world a land breeze (flow from land to sea) occurs at night. That this is not the case in the San Francisco area in summer is well documented.[13, 15, 17]

Frenzel concludes, "any land-breeze effect is only to reduce the nighttime velocity but not to reverse the direction." Thus the nocturnal air flows are similar to those which occur in the daytime. The main difference is that the volume of air moved from sea to land is reduced.

In the daytime in winter there is often an onshore flow. Root (1960) notes, ". . .the driving northwest winds diminish and the prevailing onshore flow is reduced to a gentle breeze...". The flow is similar to that shown in figure 13 except that the volume of air moved is reduced markedly. Smalley (1957) found that in the daytime in winter, flows from all four quadrants frequently move into the San Francisco area; these flows are readily channeled through the passes and straits and along the sides of mountains. These variations of flow imposed by topography have little effect in altering the mutual dependence of the individual counties for air quality; all the counties of the Bay Area use and reuse much of the same air.

The nighttime flows in winter, as typified in Figure 15, show air movements that would be expected with land breezes (flow from land to sea) superimposed on nocturnal mountain (flow downvalley in mountainous or hilly terrain) winds. These flows are practically the reverse of

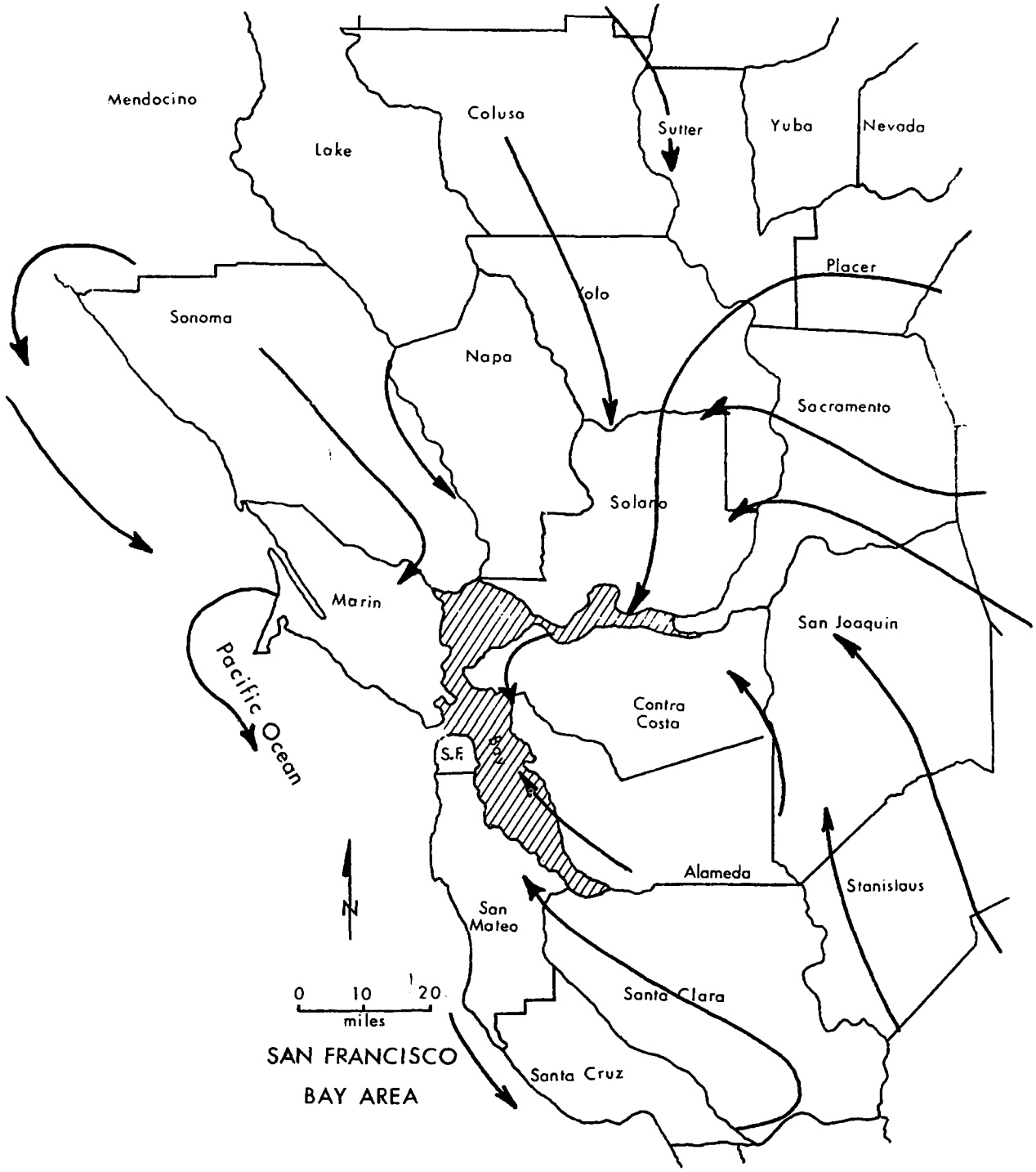

Figure 15 . Predominant January mean circulation of the surface winds. (adapted from SRI[18])

those which occur during typical summer conditions (see figure 13). The flow patterns also indicate that some air from Sacramento and San Joaquin Counties flows into Contra Costa County.

Mixing depth, the vertical distance through which convective and/or mechanical mixing of the air readily occurs, is one parameter used to assess the air pollution potential of an area. Table 5 shows mean mixing depth values considered representative of the San Francisco Bay Area.[18] These values and particularly those of the afternoon are markedly lower than the national average,[21, 22] and indicate there is restricted vertical mixing, or a limited volume of air available for dilution, compared to many other sections of the country. Together with frequent light wind speeds, these data indicate a relatively high pollution potential for the Bay Area.

Table 5. Mixing Depths (meters)*, Oakland, California.

	Summer	Winter	Annual**
Morning	515	386	517
Afternoon	643	649	781
Average***	579	518	649

*1 meter=3.28 feet
** four seasons
*** of morning and afternoon

Terrain and maritime influences have a marked effect on the vertical temperature distribution, and, therefore, the thermal stability of the area. As an example, Figure 16 shows the spatial variation in the height of the inversion which existed on a summer day when the inversion base was low. The base is lowest over the Bay, rises over the land, and generally is higher over the higher terrain.

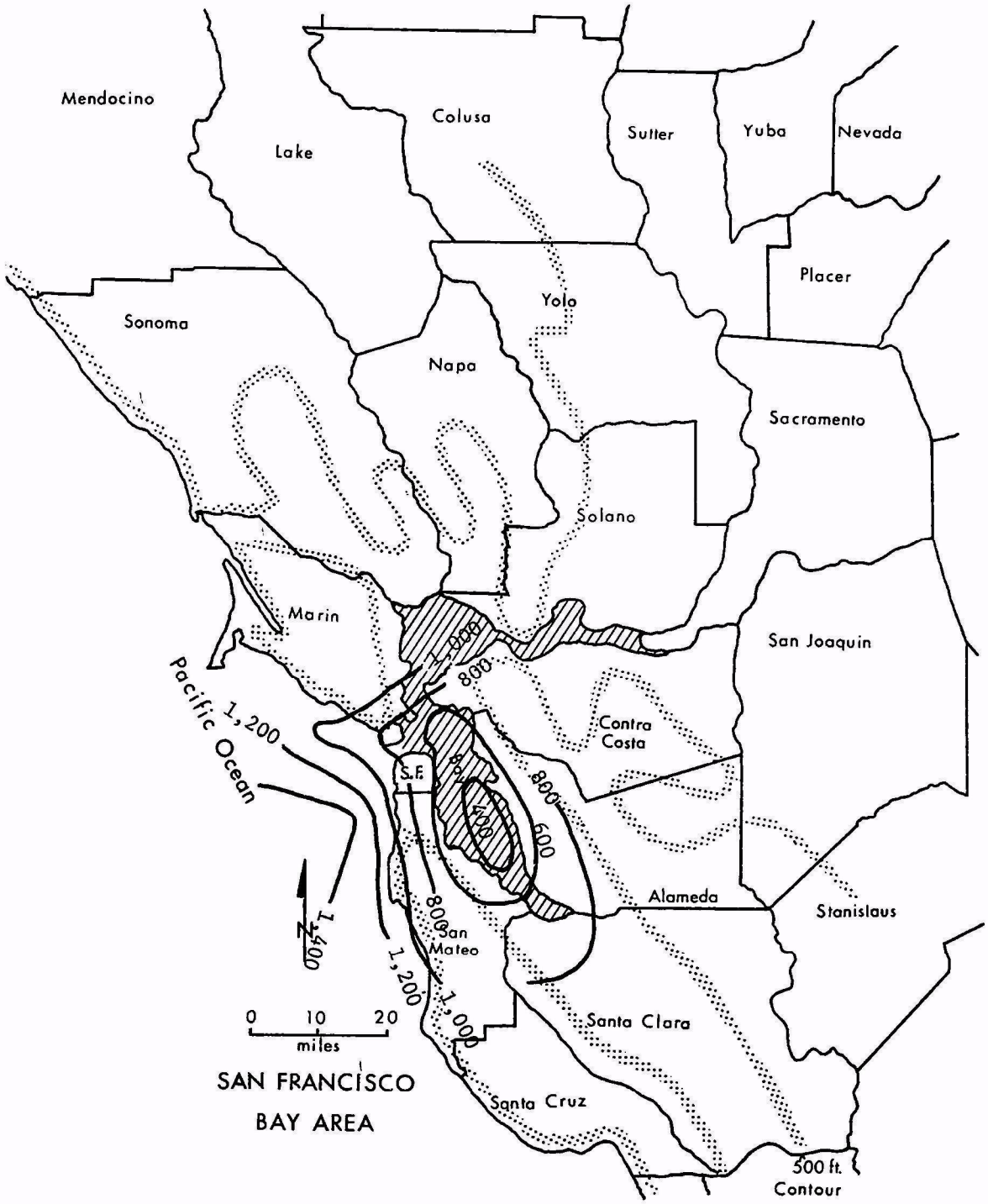

Figure 16. Inversion base topography (feet), 0700-0900 PST, 16 Aug. 1966. (Constructed from airplane soundings and radiosondes.) (adapted from Miller[23]).

Diffusion Potential

In a tracer study conducted by the Bay Area APCD,[24] it was found that, "pollutants released in any part of the Bay Area may travel to virtually any other part under suitable meteorological conditions." An additional conclusion was that measurable concentrations of the material released could be detected 50 to 60 miles from their release point.

Slade[25] found that dilution over a large body of water is markedly less than over land so that the water separation of counties by the Bay affords little benefit in regards to air pollution potential.

Prevailing air flow patterns over the Bay Area indicate that very little pollution originating in the Area is transported out of the region to the north or south. However, since some of the surface air from the Bay Area moves out into San Joaquin and Sacramento Counties through the Carquinez Strait, an analysis of the dilution climate of the Central Valley region is offered. Table 6 shows average afternoon mixing depths for Oakland and Fresno, which are considered representative of the Central Valley.[18] The indication is that there is considerably greater vertical mixing in the Central Valley in all seasons but winter.

Table 6. Afternoon Mixing Depths (Meters) Fresno and Oakland.

Season	Fresno	Oakland
Winter	618	649
Spring	1767	1087
Summer	1765	643
Autumn	1221	745

Fosberg and Schroeder[12] noted that Bay Area air penetrated to Sacramento and San Joaquin counties but that it was rapidly modified as it preceded eastward and could only be recognized by its dew point temperatures even in western sections. Patton[14] showed that an air mass starting just west of the Golden Gate at noon or midnight, during the summer, would take approximately eight hours to get to the Central Valley at the surface. The net result of the long travel time and increased dispersion over the inland area during the convective daytime period results in relatively good dilution of Bay Area pollutants by the time they reach the Central Valley area.

In winter the flow is usually from San Joaquin and Sacramento counties. However, this flow is generally weak and seldom persists for an extended period, so there is only a limited possibility of pollution in high concentrations moving from the Central Valley into the eastern Bay Area.

Conclusion

On the basis of this evaluation, it is concluded that practically all of the receptors that could be affected by high concentrations of pollutants from the Bay Area are contained within the nine counties. These nine counties are the logical, meteorologic boundary for the San Francisco Bay Air Quality Control Region.

REFERENCES

1. "Preliminary Regional Plan for the San Francisco Bay Region." Association of Bay Area Governments; Berkeley, California. November, 1966. 52 pp.
2. "San Francisco Bay Area Deep Water Channel and Inland Ports." Conway Research, Inc. Industrial Development; San Francisco, California. November, 1966. 52 pp.
3. Salitone, Edward V. and Evelyn D. Salitone. "California Information Almanac. Past Present Future." Doubleday Company, Inc., Garden City, New York, 1965. 624 pp.
4. Bay Area Facts. San Francisco Bay Area Council, San Francisco, California. January, 1968. 4 pp.
5. "Air Pollution and the San Francisco Bay Area." Bay Area Air Pollution Control District, San Francisco, California. July, 1968. 25 pp.
6. Martin, D. O. and J. A. Tikvart, "A General Atmospheric Diffusion Model for Estimating the Effects of One or More Sources on Air Quality" Paper (no. 68-148) presented at Annual Meeting, Air Pollution Control Association, St. Paul, Minnesota, 1968. 46 pp.
7. "Oxidant Smog Experience in the San Francisco Bay Area, 1962-1967." Bay Area Air Pollution Control District, Information Bulletin, February, 1968. 13 pp.
8. "California Standards for Ambient Air Quality and Motor Vehicle Exhaust." California State Department of Public Health; Berkley, California. September, 1963. 25 pp.

9. "Source Inventory Summary, 1964." Bay Area Air Pollution Control District, San Francisco, California. July, 1965. 12 pp.

10. Clean Air Quarterly. Bureau of Air Sanitation. State Department of Health, 11:2:19-20, 1967; 11:2:23-24, 1967; 11:2:27-28; 12:1:28-29; Berkley, California

11. "Contaminant and Weather Summary", Bay Area Air Pollution Control District, San Francisco, California, (monthly report), August, 1967 to July, 1968.

12. Fosberg, M. A. and M. J. Schroeder. "Marine Air Penetration in Central California." Journal of Applied Meteorology, 5:5:573-589, 1966.

13. Frenzel, C. W. "Diurnal Wind Variations in Central California. Journal of Applied Meteorology 1:3:405-412, 1962.

14. Patton, C. P. "Climatology of Summer Fogs in the San Francisco Bay Area." University of California Publication in Geography, 10:113-200, 1956.

15. Root, H. E. "San Francisco, the Air-Conditioned City. Weatherwise, 13:47-52, 1960.

16. Schultz, H. B., N. B. Akesson, and W. E. Yates. "The Delayed "Sea Breezes" in the Sacramento Valley and the Resulting Favorable Conditions for Application of Pesticides." Bulletin of the American Meteorological Society, 42:10:679-687, 1961.

17. Smalley, C. L. "A survey of air flow patterns in the San Francisco Bay Area." Preliminary Report. U. S. Weather Bureau, International Airport, San Francisco. March 1, 1957. (unpublished).

18. "The Use of Meteorological Data in Large Scale Air Pollution Surveys," SRI Report for State of California, Bureau of Air Sanitation, Berkley, California, 1958. 110 pp.

19. Williams, W. A. and R. E. DeMandel. "Land-sea boundary effects on small circulation." Report #2, San Jose State College Meteorology Department, State, 1966 97 pp.

20. Fitzwater, M. D. "The Summer Diurnal Influx of Marine Air into the Sacramento Valley." PhD thesis, University of California at Davis, 1966. 148 pp.

21. Holzworth, G. C. "Mixing Depths, Wind Speeds and Air Pollution Potential for Selected Locations in the United States." Journal of Applied Meteorology, 6:6:pp., Dec. 1967.

22. Hosler, C. R., "1963-4 Climatological Estimates of Diffusion Conditions in the United States." Nuclear Safety, 5:2:184-192, Winter year.

23. Miller, A. "Wind Profiles in West Coast Temperature Inversions" Report No. 4, San Jose State College Meteorology Department, State, 1968. 57 pp.

24. Callaghan, D. J. Memorandum to Sam Della Maggiore, Chairman and Members of the Board of Directors, Bay Area Air Pollution District on the subject "Tracer Trail Program." August 7, 1968. 21 pp.

25. Slade, D. H. "Atmospheric Dispersion over Chesapeake Bay", Monthly Weather Review 90:6:217-224, 1962.

* U. S. GOVERNMENT PRINTING OFFICE : 1969 3[illegible]-8[illegible] (5007)