FINAL REPORT

BASELINE METEOROLOGY AND AIR QUALITY IN THE UKIAH DISTRICT

SCIENCE APPLICATIONS, INC.

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BASELINE METEOROLOGY AND AIR QUALITY IN THE UKIAH DISTRICT

Submitted to:

Bureau of Land Management
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1. INTRODUCTION

This document provides baseline data on meteorology and air quality impacting BLM lands in California, and specifically, in the Ukiah District. Air quality considerations have become important factors in the establishment and execution of Federal land management policies. As with any resource, an assessment of current air quality and meteorological data must be performed to determine the present environmental baseline conditions.

BLM manages approximately 16.5 million acres in California as depicted in Figure 1-1. Figure 1-2 depicts BLM administered lands in the Ukiah District. Figure 1-2 is also provided as Overlay A. In addition, gridded township and range locations for the Ukiah District are provided on Figure 1-3. This map can be used directly with the color coded overlays provided for key parameters.

The purpose of this document is to provide information which can be used with other resource information to facilitate land use planning decisions for the Ukiah District.

The specific objectives of this work effort include the following:

- Describe the climatology, dispersion meteorology and air quality in the Ukiah District utilizing available historical data.
- Assess the emission sources which influence all BLM land areas in the Ukiah District.
- Assess past and present air quality and meteorological monitoring activities and provide monitoring recommendations for the Ukiah District.
- Provide a complete bibliography of available information and a glossary of all technical terms.

The above provides a brief synopsis of the objectives of this report. The document is intended for use by BLM personnel in all activities involved in the management of BLM administered lands.

This document uses a graphics intensive approach in the presentation of the meteorological and air quality baseline for BLM lands in the Ukiah District. The data base which has been used to develop this document comprises that available in published form from governmental, academic, and private institutions within the state. These sources of data are summarized in the appropriate sections for dispersion meteorology, climatology, air quality, and emissions.

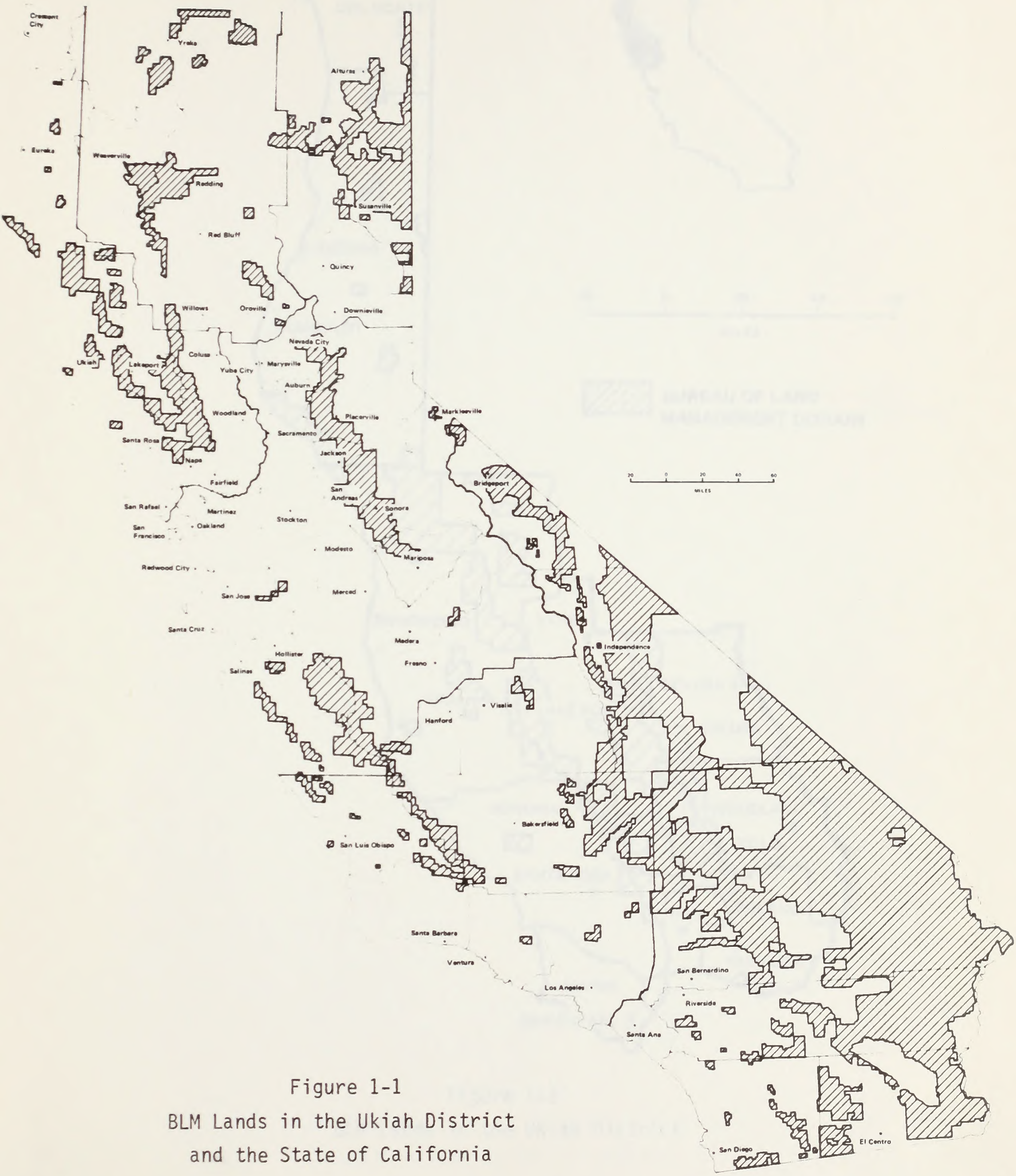


Figure 1-1
BLM Lands in the Ukiah District
and the State of California

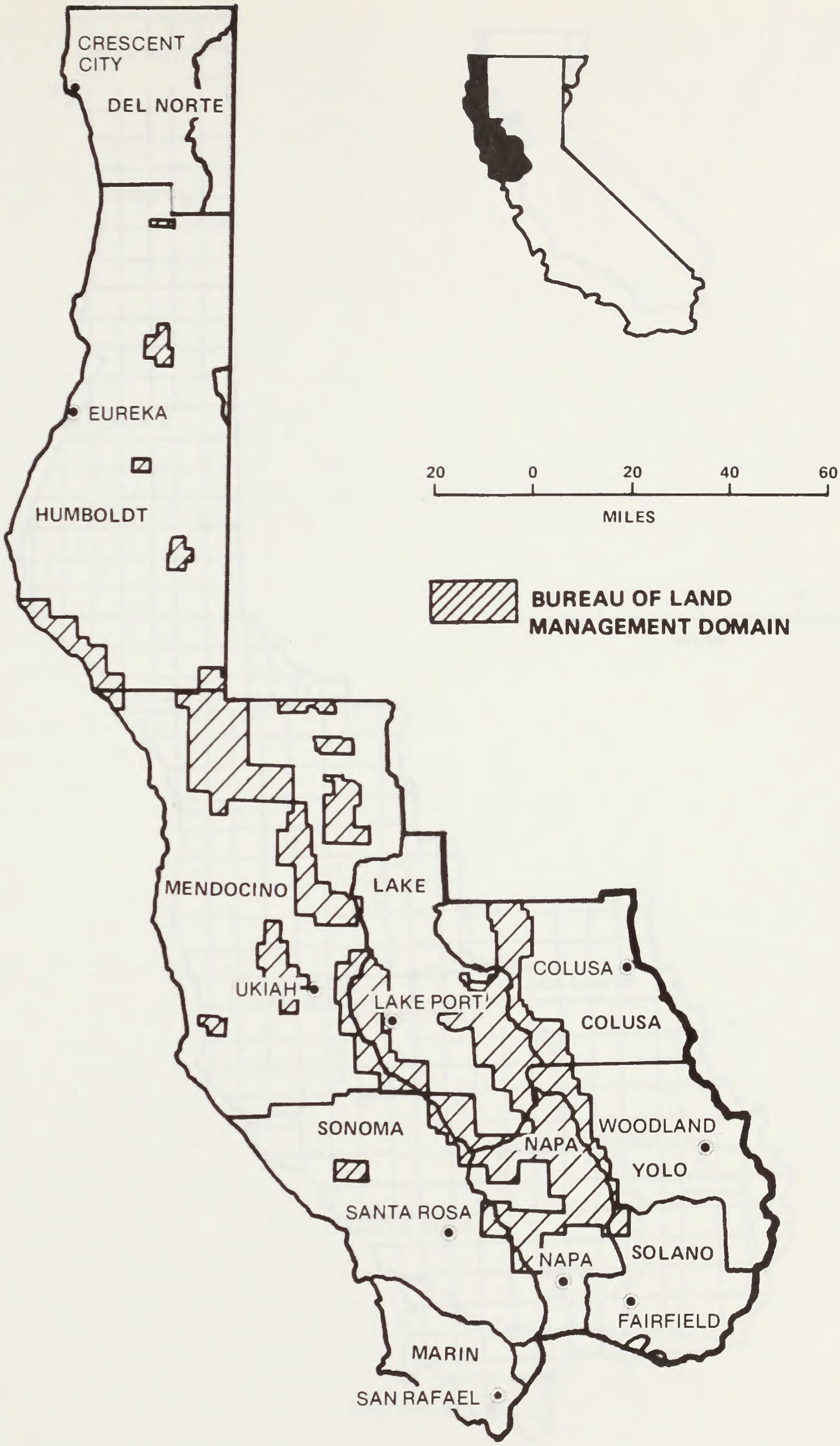


Figure 1-2
BLM Lands in the Ukiah District

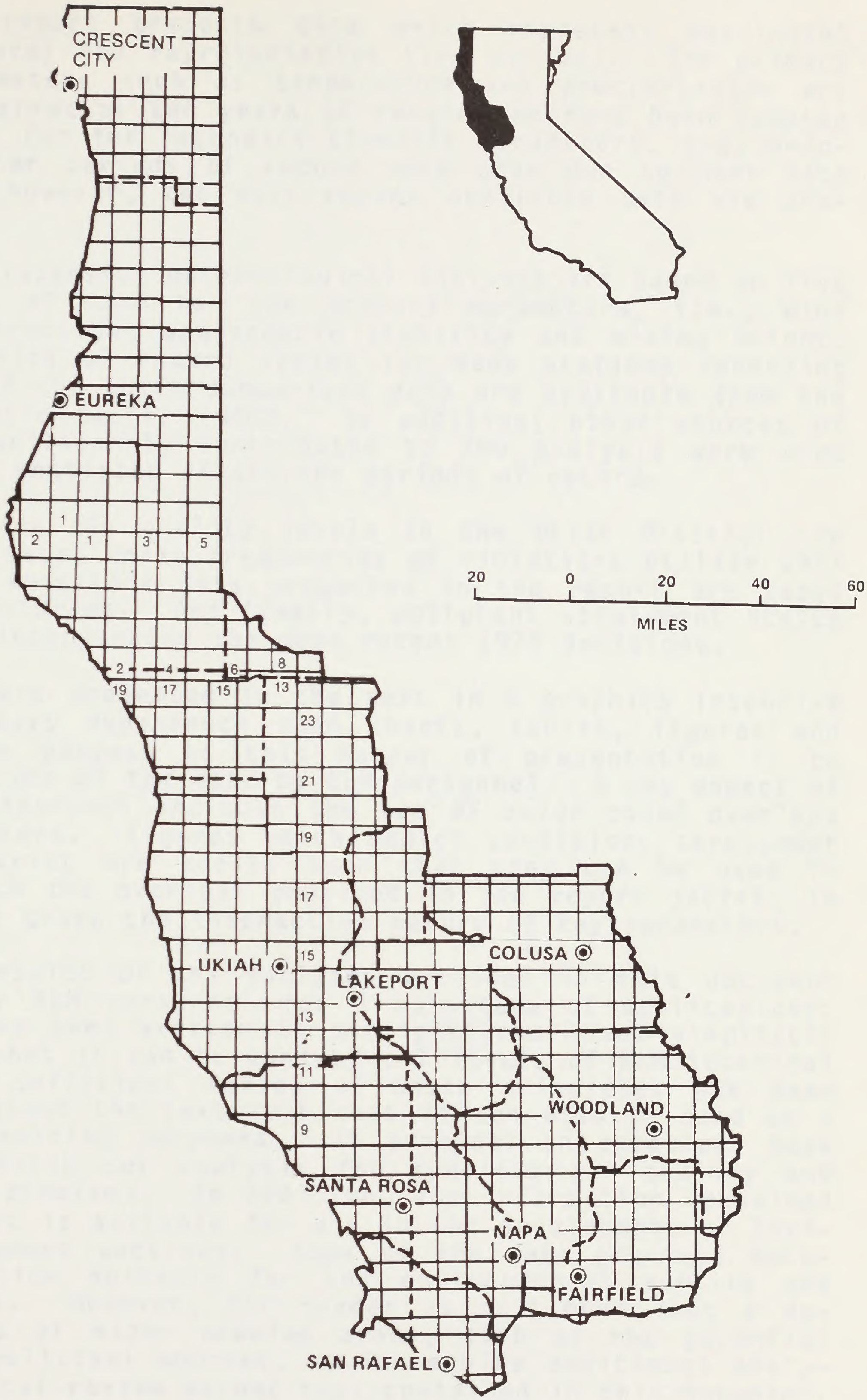


Figure 1-3
Gridded Township (N-S) and Range (E-W)
Locations in the Ukiah District

The report presents data which represent meaningful (i.e., long-term) and representative time periods. The primary climatic parameters such as temperature and precipitation are based on a minimum of ten years of record and have been updated through 1976. For the secondary climatic parameters, e.g. evaporation, shorter periods of record were used due to poor data availability; however, the most recent available data are presented.

The dispersion meteorological analyses are based on five or more years of data for the primary parameters, i.e., wind speed, wind direction, atmospheric stability and mixing height. The actual period of record varies for many stations depending upon the period for which summarized data are available from the National Climatic Center (NCC). In addition, other sources of data which significantly contributed to the analysis were used although these consisted of shorter periods of record.

Baseline air quality levels in the Ukiah District are based on 1975 data, while frequencies of violations utilize 1977 information. Emissions data presented in the report are based upon 1976 inventories. And finally, pollutant attainment status analyses have incorporated the most recent 1979 decisions.

Data are presented in the text in a graphics intensive manner with heavy dependence upon charts, tables, figures and overlays. The purpose of this manner of presentation is to facilitate the use of the data by BLM personnel. A key aspect of the graphical approach includes the use of color coded overlays for key parameters. Figures which depict conditions throughout the Ukiah District are scaled such that they can be used in conjunction with the overlays provided in the report jacket, in order to better grasp the interactive nature of key parameters.

The results of the analyses provided in this document can be used by BLM personnel for a multitude of applications. The document has been written in straightforward and simplistic language such that it can be used by all levels of BLM technical personnel. A sufficient review of basic principles has been provided throughout the text such that it can also be used as a handbook for training purposes. It provides an excellent base for making a first cut analysis for specific air quality and climatological problems. In addition, the information contained in this document is suitable for use in the development of Environmental Statement sections. Some of the data provides background information suitable for the environmental setting and impact sections. However, the reader is cautioned that a detailed analysis of major problem areas, such as the potential impact of new pollutant sources, would require additional analysis and analytical review beyond that contained in this document.

Finally, in addition to its uses as a training handbook and for use in Environmental Statements, this document can be used for overall planning purposes by BLM land managers. This is one of the major intents for publishing the document. It is felt that the information contained herein will provide suitable information on which one can base judgments relative to the optimum utilization of BLM lands in terms of such potential alternatives as agriculture, forest management and energy development, as these relate to the air resource.

This report is intended as an environmental baseline document suitable for use in the administration of BLM lands. Recommendations have been provided in the text concerning the need for additional data to adequately describe the environmental baseline, i.e., air quality and meteorology in certain portions of the Ukiah District. Monitoring would be required, as well as additional analyses, prior to making final decisions relative to major potential sources of air pollutants on BLM lands. Recommendations contained in this document for additional data collection and for additional analyses must be seriously considered by BLM planners during any final decision-making process. In addition, the information contained herein is current as of the publication date, but care must be taken while using the document, to ensure that all information and materials are up to date, particularly with regard to air quality regulations. For this reason, it is recommended that this document be updated on an annual basis by qualified technical personnel.

Separate reports have also been prepared for the Riverside, Redding, Susanville, Bakersfield and Folsom Districts. Reference should be made to the appropriate reports for air quality and meteorological baseline conditions for BLM lands outside of the Ukiah District in California.

2. PHYSICAL FEATURES

The following discussion provides a review of the major terrain and vegetation features in the Ukiah District. Ukiah is comprised of numerous terrain and vegetation types as indicated in the accompanying figures. Elevations range from sea level to over 7,000 feet above mean sea level (MSL) in the Siskiyou Mountains. Vegetation types range from marshlands to Douglas Fir.

The major vegetation types as classified by Durrenberger (1967) are depicted in Figure 2-1. This figure, illustrates the variety of vegetation types found in the coastal and interior mountainous regions. In coastal Northern California, vegetation types primarily include Douglas Fir, fir and plains grass. The mountainous portions of the Ukiah District are characterized by fir and woodlands. The Central Valley area is primarily characterized by plains grass and marshlands.

As indicated earlier, these vegetation types are distinctly influenced by terrain considerations. Figure 2-2 provides a review of major terrain features in the State of California. Figure 2-3 illustrates the Ukiah District terrain. This figure is also included as Overlay B.

The Ukiah District includes all or parts of eleven counties which comprise the northwestern portion of the State of California. The terrain of the District exhibits considerable variation ranging from the coastline of Marin, Sonoma, Mendocino, Humboldt and Del Norte Counties to the rugged terrain of the Coast Ranges. Elevations rapidly increases with inland distance from the Coast in all portions of the District with the exception of the extreme south. In the extreme northwest, elevations rapidly increase with rugged terrain in Del Norte and Siskiyou Counties, particularly in the Siskiyou, and further inland, and the Klamath Mountains. Some of the highest elevations in the District are located in Del Norte and Siskiyou Counties in the rugged terrain of the Six Rivers National Forest and further inland in the Siskiyou National Forest. Further south in Humboldt County the trend towards rugged terrain with inland progression increases, however, elevations do not rise as rapidly. Elevations in most of the Humboldt County are generally between two and four thousand feet.

The northwest is drained by several major river systems including the Klamath and the Eel Rivers. Further south the inland extent of the District increases and includes Mendocino, Lake, Colusa, Yolo, Solano, Napa, Sonoma and Marin Counties. The District coastal areas traverses the Coast Ranges and includes portions of the Sacramento Valley in Colusa, Yolo and Solano Counties. In Mendocino County, the trend exhibited further north continues with the terrain becoming fairly rugged with inland progression. However, elevations continue to decrease with most elevations between one and three thousand feet. A major valley

Figure 2-1
Major Vegetation Types
in California

Source: "Patterns on the Land" Robert W. Durrenberger

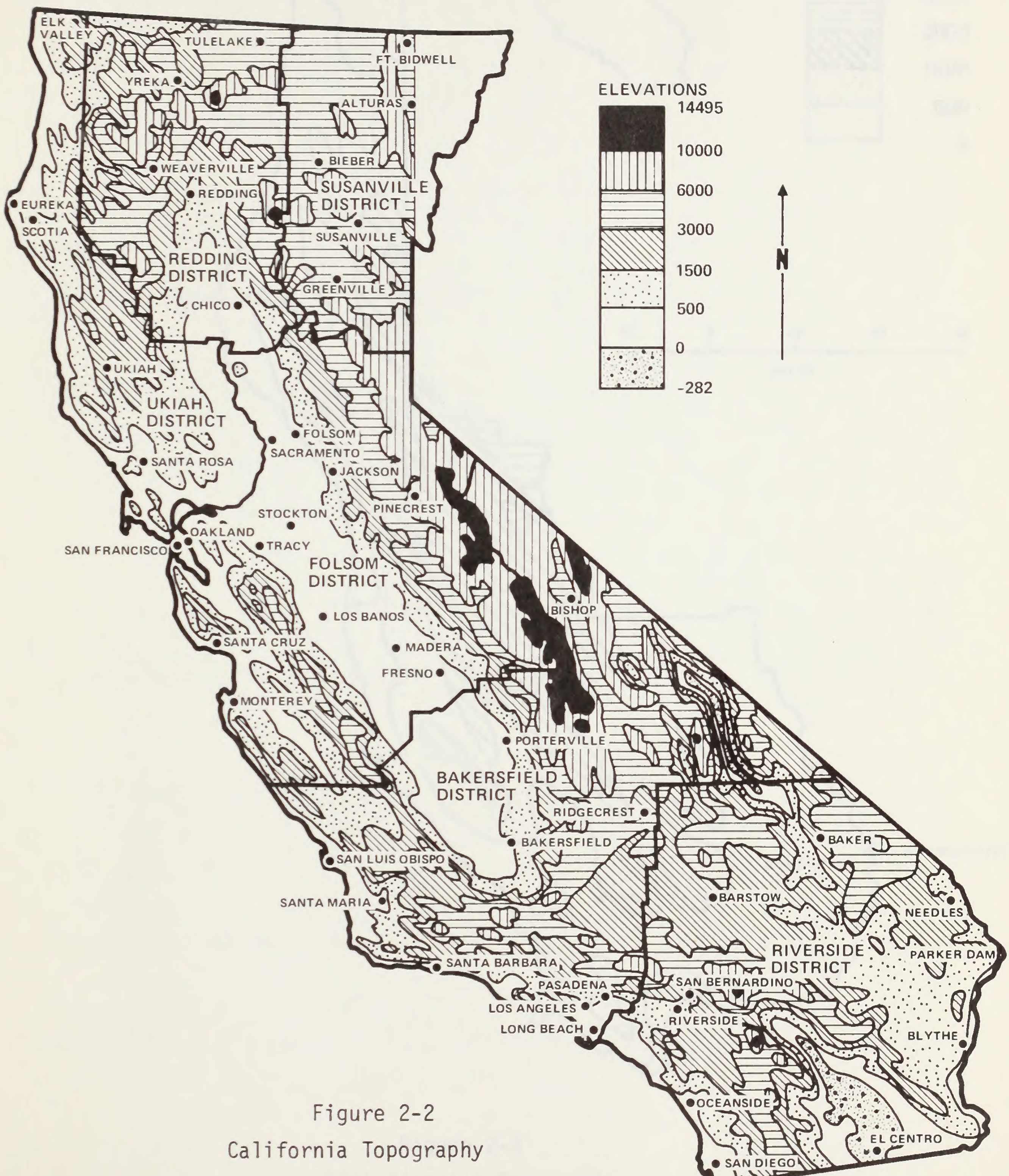


Figure 2-2
California Topography

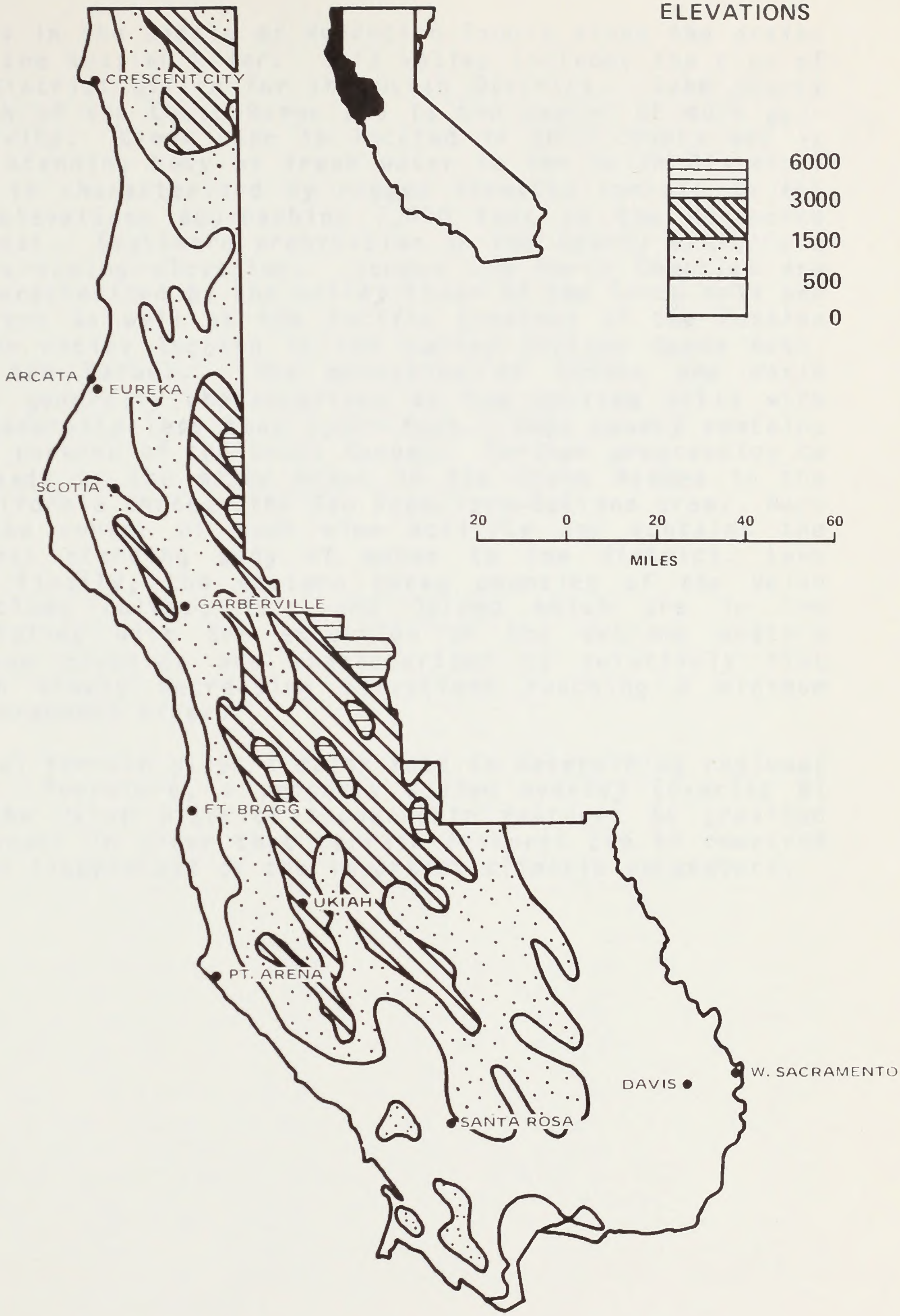


Figure 2-3
Ukiah District Topography

system exists in the middle of Mendocino County along the drainage flow of the Russian River. This valley includes the city of Ukiah, the district office for the Ukiah District. Lake County includes much of the Coast Range and is the center of much geothermal activity. Clear Lake is located in this county and is the largest standing body of fresh water in the Ukiah District. Lake County is characterized by rugged forested terrain in the north with elevations approaching 7,000 feet in the Mendocino National Forest. Southward progression in the County exhibits a generally decreasing elevation. Sonoma and Marin Counties are generally characterized by the valley floor of the Santa Rosa and Petaluma Rivers as well as the Pacific terminus of the Russian River. Major cities located in the valley include Santa Rosa, Novato and San Rafael. The mountains of Sonoma and Marin Counties are generally characterized as low rolling hills with elevations generally less than 2,000 feet. Napa county contains the southern portion of the Coast Ranges. Further progression to the south leads to the major break in the Coast Ranges in the State of California through the San Francisco-Oakland area. Napa Valley is the center of much wine activity and contains the second largest standing body of water in the district, Lake Berryessa. Finally, the eastern three counties of the Ukiah District include Colusa, Yolo and Solano which are in the Sacramento Valley with the exception of the extreme western areas. These counties are characterized by relatively flat terrain with slowly decreasing elevations reaching a minimum along the Sacramento River.

Local terrain plays a major role in determining regional climatology. Therefore, a properly scaled overlay (Overlay B) displaying the Ukiah District topographic features is provided with this report in order that terrain features can be compared with averages (isopleths) of the important climatic parameters.

BIBLIOGRAPHY

1. Durrenberger, Robert W., Patterns on the Land, National Press Books, Palo Alto, California, Second Printing, 1967.

3. CLIMATOLOGY

This section is designed to characterize the prevailing climate of the Ukiah District as well as to describe the physical processes that determine regional climate. Long-term manifestations of weather are best described by regional -and local analyses of the numerous climatic parameters, i.e., temperature, precipitation, winds, evaporation and evapotranspiration, sky conditions, dew point and humidity, pressure distributions, severe weather and many others. The following sections shall describe the various climatic statistics pertinent to the area.

Color coded overlays for selected key climatic summaries are provided to facilitate the correlation of the primary climatic variables in particular geographic areas. Much of the enclosed graphical material is properly scaled to the overlay dimensions.

3.1 PRINCIPLES OF CLIMATOLOGY

Energy

The energy expended in atmospheric processes is originally derived from the sun. This transfer of energy from the sun to the earth and its atmosphere is the result of radiational heat by electromagnetic waves. The radiation from the sun has its peak of energy transmission in the visible range (0.4 to 0.7 microns) of the electromagnetic spectrum but renergy in the ultraviolet and infrared regions as well. The greatest part of the sun's energy is emitted at wave lengths between 0.1 and 30 microns. Some of this radiation is reflected from the tops of clouds and from the land and water surfaces of the earth. The general term for this reflectivity is the albedo. For the earth and atmosphere as a whole, the albedo is 36 per cent for mean conditions of cloudiness over the earth. This reflectivity is greatest in the visible range of wavelengths. When light (or radiation) passes through a volume containing particles whose diameter is smaller than the wavelength of the light, scattering of a portion of this light takes place. Shorter wavelengths scatter most easily, which is the reason the scattered light from the sky appears blue. Sunlight, near sunrise and sunset, passes through a greater path-length of the atmosphere and appears more red because of the increased scattering of shorter wave lengths. Absorption of solar radiation by some of the gases in the atmosphere (notably water vapor) also takes place. Water vapor, although comprising only 3 per cent of the atmosphere, on the average absorbs about six times as much solar radiation as all other gases combined. Consequently, the amount of radiation received at the earth's surface is considerably less than that received above the atmosphere.

The earth also radiates energy in proportion to its temperature according to Planck's law. Because of the earth's temperature, the maximum emission is about 10 microns, which is in the infrared region of the spectrum. The gases of the atmosphere absorb some wave length regions of this radiation. Water vapor absorbs strongly between 5.5 and 7 microns and at greater than 27 microns but is essentially transparent from 8 to 13 microns. Carbon dioxide absorbs strongly between 13 and 17.5 microns. Because the atmosphere absorbs much more of the terrestrial radiation than solar radiation, some of the heat energy of the earth is conserved. This is the "greenhouse" effect.

Figure 3.1-1 shows the amount of solar radiation absorbed by the earth and atmosphere compared to the long wave radiation leaving the atmosphere as a function of latitude. The sine of the latitude is used as the abscissa to represent area. It can be seen that if there were no transfer of heat poleward, the equatorial regions would continue to gain heat and the polar regions would continue to cool. However, temperatures do remain nearly constant because of this poleward transfer of heat. The required transfer of heat across various latitudes is given in Table 3.1-1.

Table 3.1-1

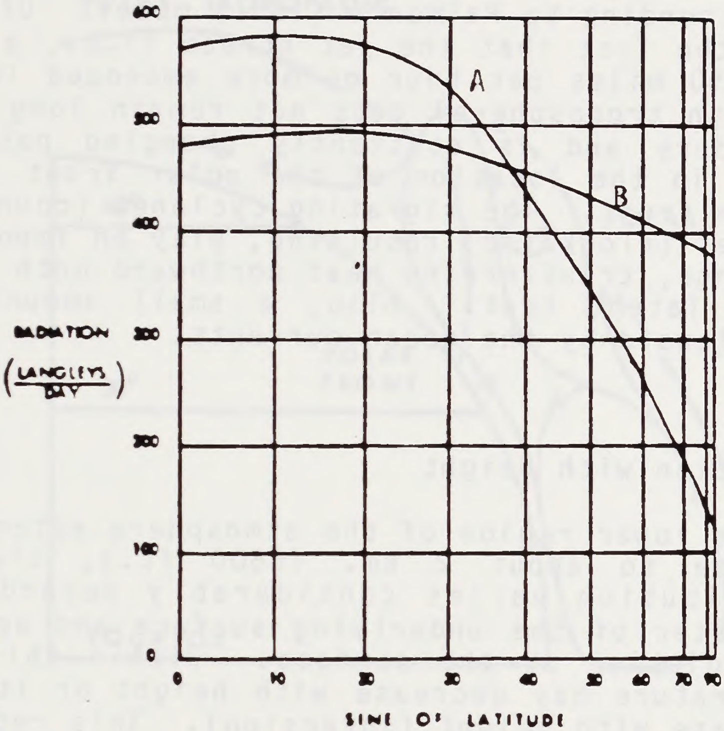
Required Flux of Heat Toward the Poles Across Latitudes (10^{19} calories per day) (1)

Latitude(^{o})	Flux
0	0
10	4.05
20	7.68
30	10.46
40	11.12
50	9.61
60	6.68
70	3.41
80	0.94
90	0

1. Source: H. G. Houghton, "On the Annual Heat Balance of the Northern Hemisphere."

The General Circulation

The previous section has indicated the necessity of transfer of heat from the warm equatorial regions to the cold polar regions in order to maintain the heat balance of the atmosphere. This thermal driving force is the main cause of atmospheric motion on the earth. The portion of the earth near the equator acts as a heat source and the polar regions as a heat sink. The atmosphere functions as a heat engine transforming the potential energy of heat difference between tropics and poles to kinetic energy of motion which transports heat poleward from source to sink.



A Solar Radiation Absorbed by Earth and Atmosphere

B Long Wave Radiation Leaving the Atmosphere

Figure 3.1-1

Global Radiation Balance

If the earth did not rotate, rising air above the equator would move poleward continually giving up some of its heat until the time it would sink and return toward the equator as a surface current. Since the earth does rotate, the Coriolis force deflects winds in the northern hemisphere to the right. Therefore flow from the tropics toward the poles become more westerly and flow from the poles toward the equator tends to become easterly. The result is that more of the motion is around the earth (zonal) with less than one-tenth of the motion between poles and equator. The meridional (along meridians, i.e., between poles and equator) circulation is broken into three cells shown in Figure 3.1-2 according to Palmen's (1951) model. Of considerable importance is the fact that the jet stream (i.e., a core of high winds usually 50 miles per hour or more embedded in the westerlies in the high troposphere) does not remain long in one position but meanders and is constantly changing position. This causes changes in the location of the polar front and perturbations along the front. The migrating cyclones (counterclockwise) and anticyclones (clockwise) resulting, play an important part in the heat exchange, transferring heat northward both as a sensible heat and also latent heat. Also, a small amount of heat is transferred poleward by the ocean currents.

Temperature

- Variation with Height

  In the lower region of the atmosphere extending from the surface to about 2 km. (6600 ft.), the temperature distribution varies considerably depending upon the character of the underlying surface and upon the amount of radiation at the surface. Within this region, the temperature may decrease with height or it may actually increase with height (inversion). This region, commonly called the lower troposphere, is the region of greatest interest in air pollution meteorology. The remainder of the troposphere is typified by a decrease of temperature with height on the order of 4 to 8°C per km. The stratosphere is a region with isothermal or slight inversion lapse rates. The layer of transition between the troposphere and stratosphere is called the tropopause. The tropopause varies in height from about 8 to 20 km (26,000 to 66,000 ft.), and is highest near the equator, lowest near the poles. Figure 3.1-3 and 3.1-4 indicate typical temperature variations with height for two latitudes for summer and winter in the troposphere and lower stratosphere.

  Above the stratosphere, the high atmosphere has several layers of differing characteristics. A rough indication of the variation of temperature with height including the high atmostphere is shown in Figure 3.1-5.

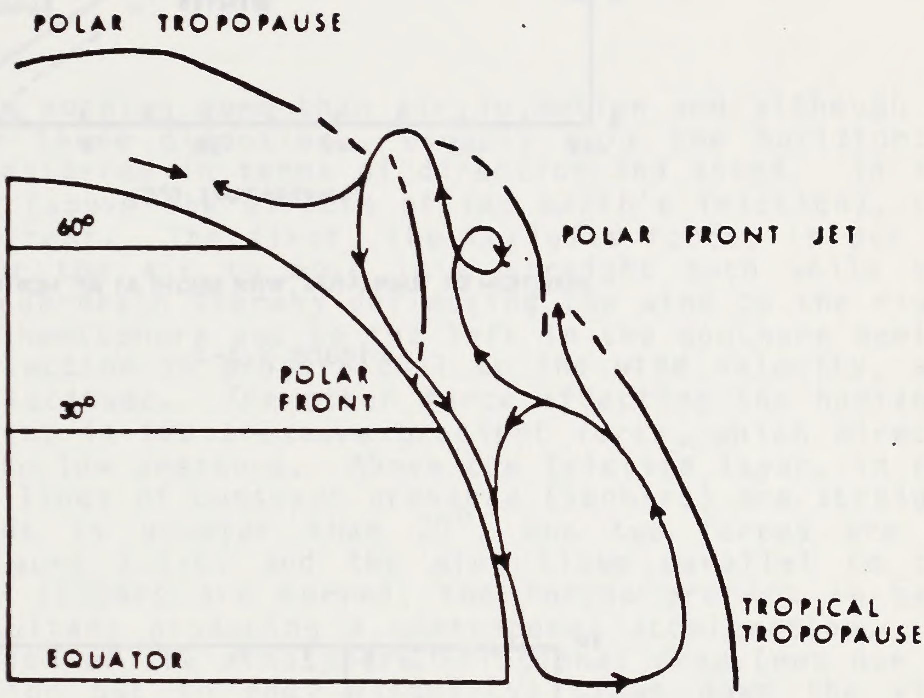
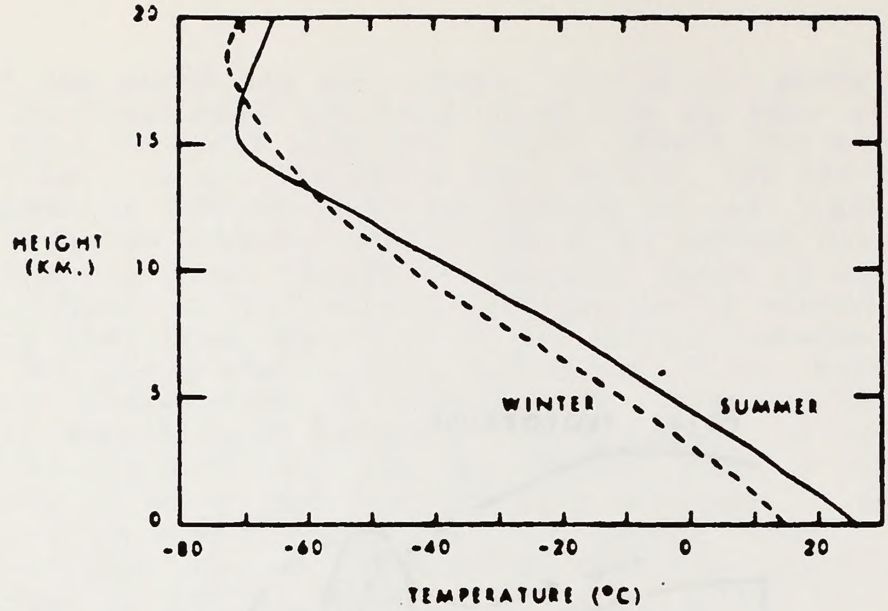


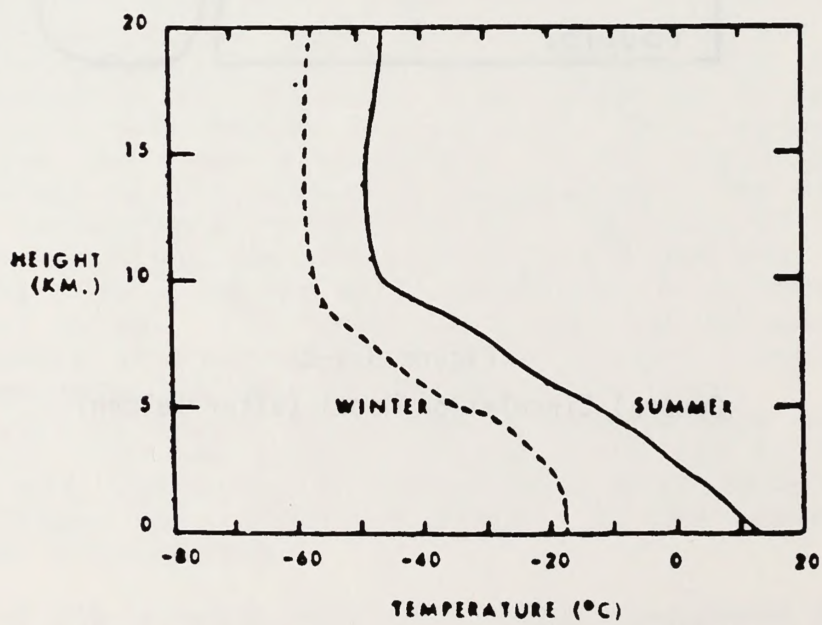
Figure 3.1-2

General Circulation Model (after Palmen)



VARIATION OF TEMPERATURE WITH HEIGHT AT 30° NORTH LATITUDE

Figure 3.1-3



VARIATION OF TEMPERATURE WITH HEIGHT AT 60° NORTH LATITUDE

Figure 3.1-4

• Horizontal Variation

Temperature also varies horizontally particularly with latitude, being colder near the poles and warmer near the equator. However, the influence of continents and oceans have considerable effects on modifying temperatures. The continents have more extreme temperatures (continental climate) becoming warmer in summer and colder in winter, whereas the oceans maintain a more moderate temperature (marine or maritime climate) year-round.

Winds

Wind is nothing more than air in motion and although it is a motion in three dimensions, usually only the horiztontal component is considered in terms of direction and speed. In the free atmosphere (above the effects of the earth's friction), two forces are important. The first, the Coriolis force, is due to the tendency for the air to move in a straight path while the earth rotates underneath thereby deflecting the wind to the right in the northern hemisphere and to the left in the southern hemisphere. The deflection is proportional to the wind velocity, and decreases with latitude. The other force affecting the horizontal wind component is the pressure gradient force, which directs flow from high to low pressure. Above the friction layer, in regions where the lines of constant pressure (isobars) are straight and the latitude is greater than 20^{o}, the two forces are in balance (See Figure 3.1-6) and the wind blows parallel to the isobars. Where isobars are curved, the forces are not in balance, their resultant producing a centripetal acceleration. In the lowest portion of the atmosphere frictional drag (not due to molecular friction but to eddy viscosity) slows down the wind speed, and because the Coriolis force is proportional to the wind speed, reduces the Coriolis force. The balance of forces under frictional flow is shown in Figure 3.1-7. It will be noted that under frictional flow the wind has a component across the isobars toward lower pressure.

Anticyclones and Cyclones

Migrating areas of high pressure (anticyclones) and low pressure (cyclones) and the fronts associated with the latter are responsible for the day to day changes in weather that occur over most of the mid-latitude regions of the earth. The low pressure systems in the atmospheric circulation are related to perturbations along the jet stream (the region of strongest horizontal temperature gradient in the upper troposphere and consequently the region of strongest winds) and form along frontal surfaces separating masses of air having different temperature and moisture characteristics. The evolution of a low pressure system is accompanied by the formation of a wave in the circulation pattern. This develops further into a warm front and a cold front both moving around the low in a counterclockwise (cyclonic)

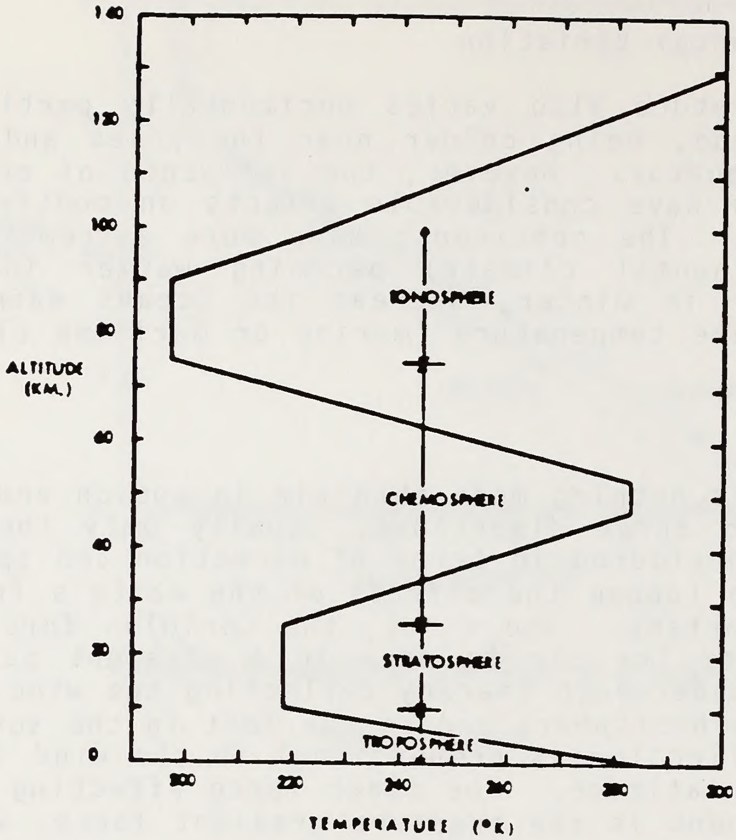


Figure 3.1-5

General Variation of Temperature with Height Throughout the Atmosphere

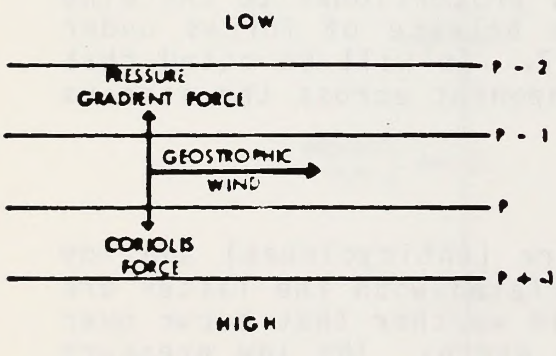


Figure 3.1-6

Balance of Forces in the Upper Atmosphere

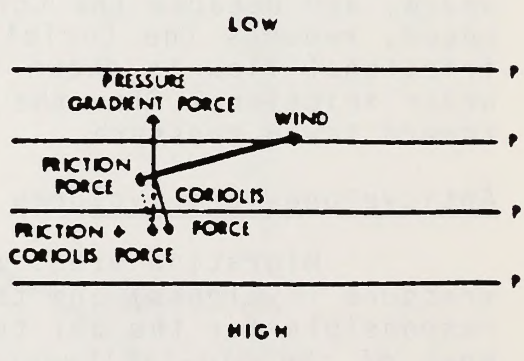


Figure 3.1-7

Balance of Forces in the Lower (Friction Layer) Atmosphere sense. The life cycle of a typical cyclone is shown in Figure 3.1-8. The cold front is a transition zone between warm and cold air. The cold air typically is moving toward and over the area previously occupied by warm air. Cold fronts generally have slopes from 1/50 to 1/150. Warm fronts separate advancing warm air from retreating cold air and have slopes on the order of 1/100 to 1/300 due to the effects of friction on the trailing edge of the front. Figure 3.1-9 illustrates a vertical cross section through both a warm and a cold front.

Air Masses

Air masses are frequently divided by frontal systems and are usually classified according to the source region of their recent history. Air masses are classified as maritime or continental to indicate origin over the ocean or land, and arctic, polar, or tropical depending principally on the latitude of origin. Air masses are modified by vertical motions and radiation upon the surfaces over which they move.

Condensation, Clouds, and Precipitation

Condensation of water vapor upon suitable condensation nuclei in the atmosphere causes clouds. (Table 3.1-2 indicates the relative sizes of different particles.) Large hygroscopic nuclei will condense water vapor upon them even before saturation is reached, as opposed to crystallization nuclei which promote the growth of ice crystals, at the expense of small water droplets within a supercooled cloud. Of course, only a small proportion of all clouds produce rain. It is necessary that droplets increase in size so that they will have appreciable fall velocity and also to prevent complete evaporation of the drops before they reach the ground. Table 3.1-3 indicates the distance of fall for different size drops before evaporation occurs. Growth of water droplets into rain drops large enough to fall is thought to originate predominately with the large condensation nuclei which grow larger as they fall through the cloud. The presence of an electric field in clouds generally promotes the growth of raindrops.

Table 3.1-2

Sizes of Particles

Particles	Size (microns)*
Small ions	less than 10^{-3}
Medium ions	10^{-3} to 5×10^{-2}
Large ions	5×10^{-2} to 2×10^{-1}
Aitken nuclei	5×10^{-2} to 2×10^{-1}
Smoke, haze, dust	10^{-1} to 2

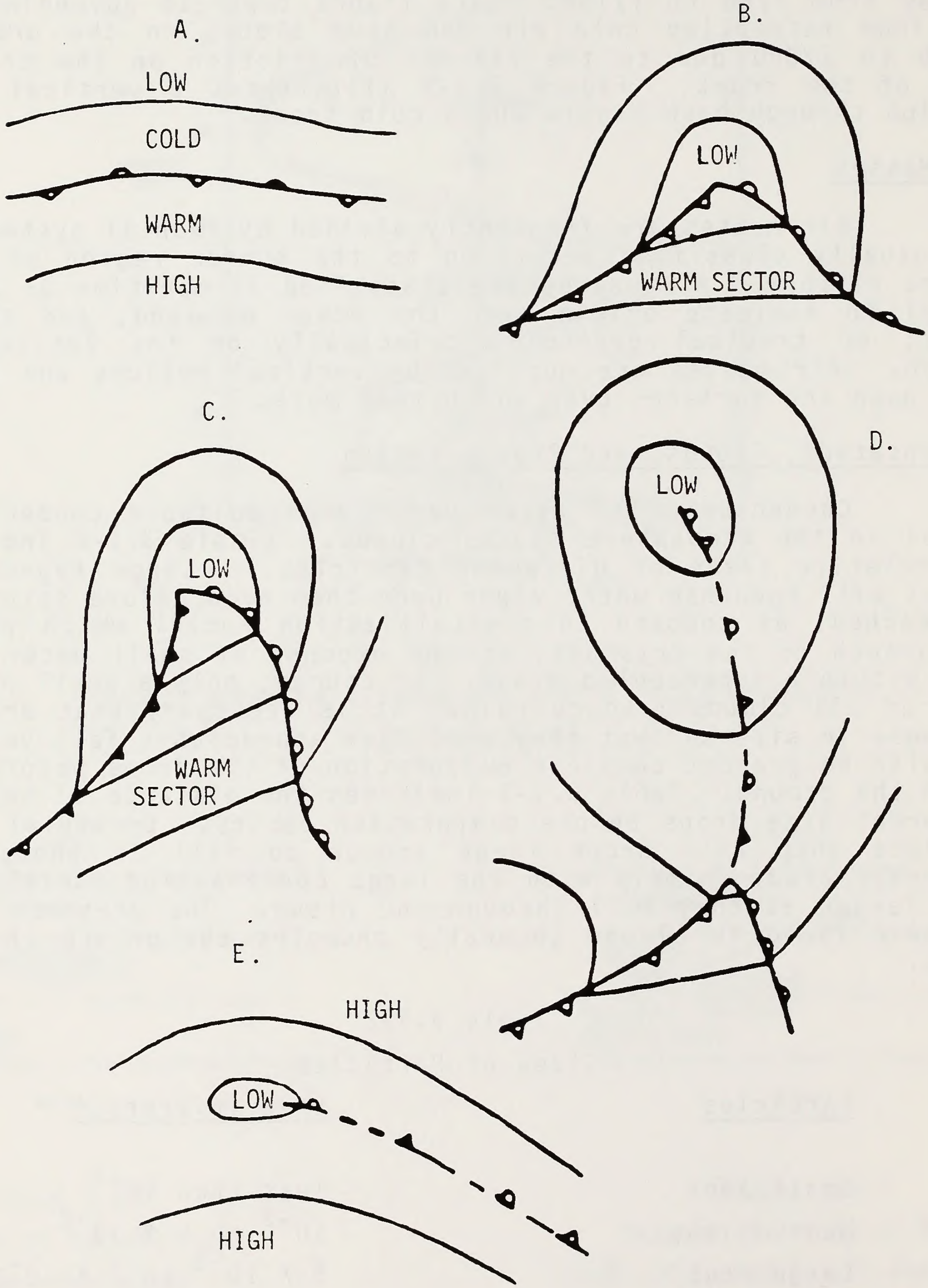
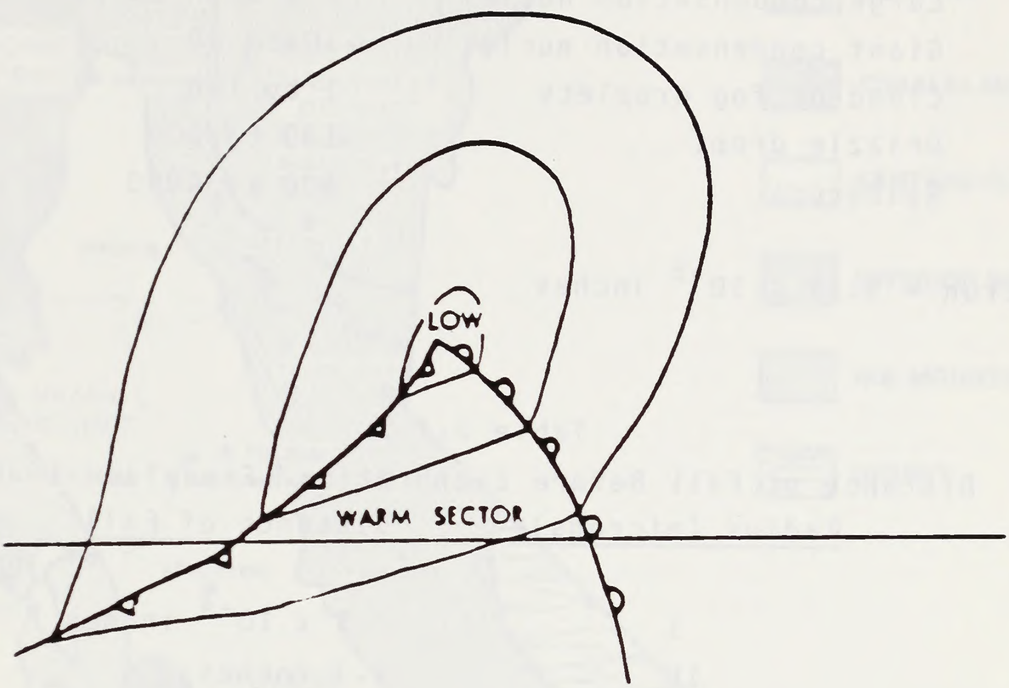
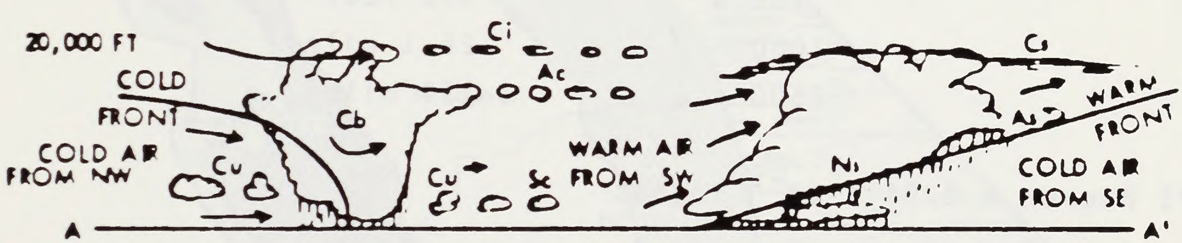


Figure 3.1-8
Idealized Development of a Low-Pressure (cyclone) System





Cross Section Through a Cold Front
and a Warm Front

Figure 3.1-9

Key:

Ci - Cirrus	Cb - Cumulonimbus
Cs - Cirrostratus	Ns - Nimbostratus
Cu - Cumulus	Sc - Stratocumulus
Ac - Altocumulus	As - Altostratus

Table 3.1-2 (cont'd)

Sizes of Particles

Particles	Size (microns)*
Large condensation nuclei	2×10^{-1} to 10
Giant condensation nuclei	10 to 30
Cloud or fog droplets	1 to 100
Drizzle drops	100 to 500
Raindrops	500 to 4000

*1 Micron = 3.94×10^{-5} inches

Table 3.1-3

Distance of Fall Before Evaporation (Findeison 1939)

Radius (microns)*	Distance of Fall
1	1.3×10^{-4} inches
10	1.3 inches
100	492 feet
1000	26.1 miles
2500	174 miles

*1 Micron = 3.94×10^{-5} inches

3.2 CLIMATIC ZONES

California encompasses a vast amount of territory and offers a wide variety of climate types, ranging from hot, arid desert climates to cold, moist mountain climates. It is therefore advantageous to present the climatic analysis in terms of climatic zones. Figure 3.2-1 depicts the general climatic zones for California in each of the six BLM districts. Overlay C presents the climatic zones for the Ukiah District. Regional topography as well as latitude plays a major role in the determination of the characteristic climate of the various California regions.

The Ukiah District is comprised of a complete cross-section of the various types of topographic features present in California as described in Section 2 and includes three of the

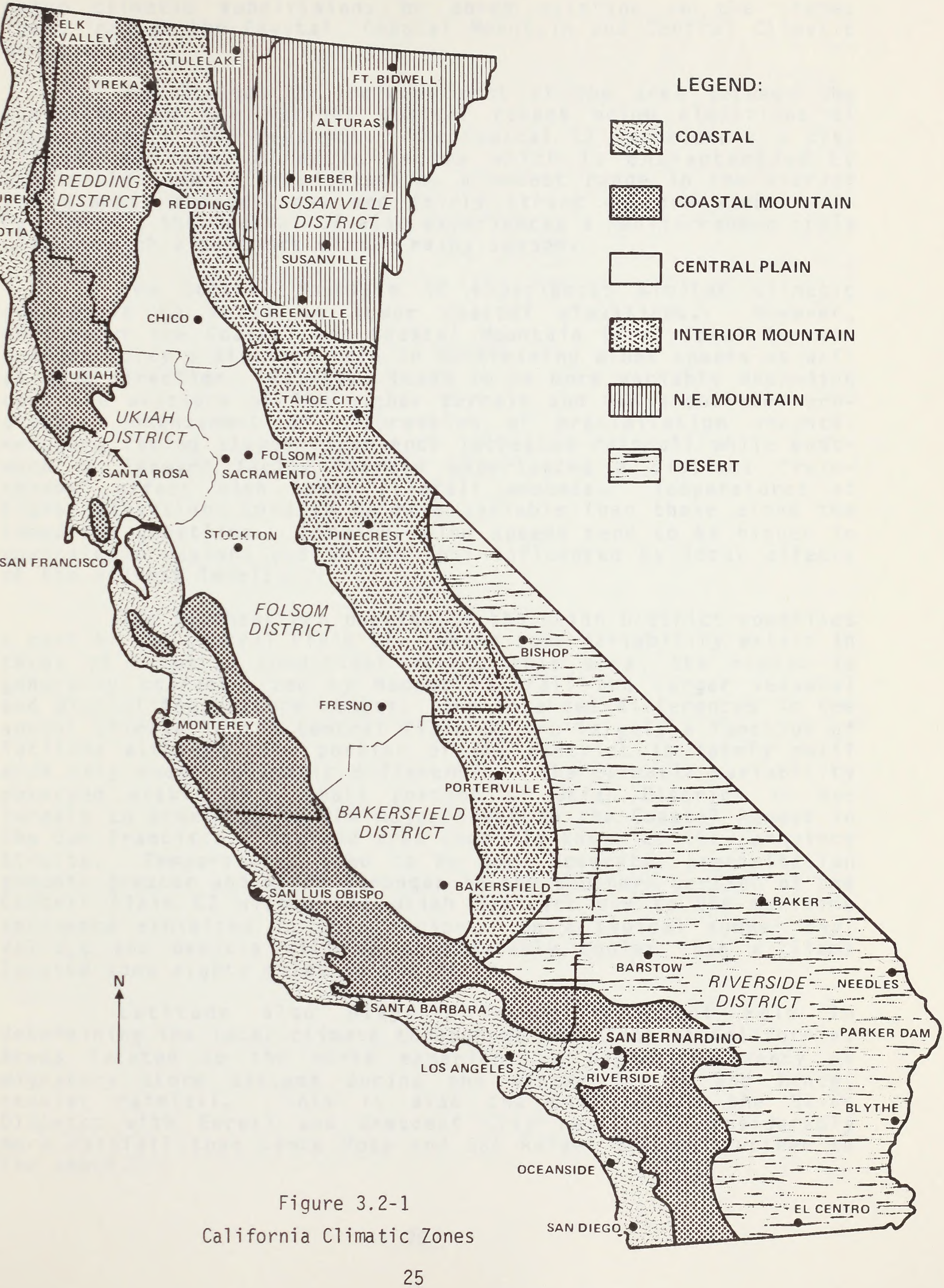


Figure 3.2-1
California Climatic Zones

major climatic subdivisions or zones existing in the State. These include the Coastal, Coastal Mountain and Central Climatic Zones (CZ).

The Coastal CZ includes most of the area between the coastline and the various coastal ranges below elevations of approximately 1500 feet MSL. The Coastal CZ experiences a distinctly maritime climatic regime which is characterized by substantial annual precipitation, a modest range in the average and diurnal temperatures and fairly strong onshore winds. In California, the Coastal CZ also experiences a Mediterranean style climate with a distinct winter rainy season.

The Coastal Mountain CZ experiences similar climatic conditions to those at lower coastal elevations. However, throughout the Coastal and Coastal Mountain CZ's, local terrain features play a distinct role in determining winds speeds as well as wind direction. Rainfall tends to be more variable depending upon the exposure of the higher terrain and the associated orographic enhancement or suppression of precipitation amounts. Westward facing slopes experience increased rainfall while eastward or leeward facing terrain experiences a distinct "rain-shadow" effect with lower rainfall amounts. Temperatures at higher elevations tend to be more variable than those along the immediate coastline. Finally, wind speeds tend to be higher in mountainous regions and become less influenced by local effects at the highest levels.

The southeastern portion of the Ukiah District comprises a part of the Central Plain CZ. While some variability exists in terms of climatic conditions across this area, the region is generally characterized by modest rainfall and larger seasonal and diurnal temperature ranges. The observed differences in the annual climate in the Central Plain CZ are largely a function of latitude although this portion of the district is fairly small with only modest climatic differences. The climatic variability observed within this small portion of Ukiah District is due largely to proximity to the major break in the Coastal Ranges in the San Francisco - Oakland area commonly known as the Carquince Straits. Temperatures tend to be more moderate, precipitation amounts greater and winds stronger in the southern portion of the Central Plain CZ within the Ukiah District due to the maritime influence exhibited in this region. On a typical summer day, Vallejo and Benicia will be considerably cooler than Williams located some eighty miles to the north.

Latitude also plays an very important role in determining the local climate throughout the State of California. Areas located to the north experience a higher frequency of migratory storm systems during the winter season and hence, heavier rainfall. This is also the case within the Ukiah District with Eureka and Crescent City receiving considerably more rainfall than Santa Rosa and San Rafael located further to the south.

3.3 SOURCES OF CLIMATOLOGICAL DATA

It is necessary in the consideration of most climatological problems to obtain meteorological information. Frequently, a special observational program must be initiated as will be discussed in more detail in Section 7. However, there are also many situations where current or past meteorological records from a Weather Service station will suffice. The following outline provides a brief insight into the types of observations taken at Weather Service stations and some of the summaries compiled from this data. The discussion also serves to describe the bulk of the published data sources used in the Ukiah District analysis. Many other data sources used in this report are noted in the bibliography as appropriate.

3.3.1 Observations and Records

Surface

- First Order Stations
  There are 100 Weather Bureau stations where 24 hourly observations are taken daily. The measurements taken are: dry bulb temperature and wet bulb temperature (from which dew point temperature and relative humdity are calculated), pressure, wind direction and speed, cloud cover and visibility. These observations are transmitted each hour on weather teletype circuits and are entered on a form with one day to each page. The original is sent to the National Climatic Center (NCC) in Asheville, North Carolina, and a duplicate is maintained in the station files. Each station also maintains a climatological record book where certain tabulations of monthly, daily, and hourly observations are recorded.

- Second Order Stations
  These stations usually take hourly observations similar to the first order stations above but not throughout the entire 24 hours of the day.

- Military Installations
  Many military installations, especially Air Force Bases, take hourly observations. These are transmitted on military teletype circuits and therefore not available for general use. No routine publications of these data is done. Records of observations are sent to NCC where special summaries can be made by use of punched cards.

- Supplementary Airways Reporting Stations
  These stations are located at smaller airports. Observations are not taken at regular intervals, usually being taken according to airline schedules. These observations are not published and are not available on punched cards. Original records, however, are sent to the NCC.

- Cooperative Stations
  There are about 10,000 of these stations manned, for the most part, by volunteer observers. The observations are taken once each day and consist generally of maximum and minimum temperatures and 24 hour rainfall. Observations are recorded on a form with one month to a page. The original is sent to NCC, a carbon sent to the state climatologist (prior to the termination of the State Climatologist Positions), and a carbon maintained at the station. A few cooperative stations have additional data on evaporation and wind. However, the wind observations are taken only a few inches off the ground and are of use mainly in connection with the evaporation measurements.

- Fire Weather Service Stations
  There are a number of special stations maintained during certain times of the year in forested regions where measurements of wind, relative humidity, and cloud cover are taken. These are generally not on punched cards nor are they summarized.

Upper Air

There are between 60 and 70 stations in the contiguous United States where upper air observations are taken twice daily (at 0000 GMT and 1200 GMT) by radiosonde balloon and radio direction-finding equipment. The measurements taken include temperature, pressure, relative humidity and wind speed and direction at several levels. These observations are transmitted to teletype and original records are sent to NCC where these data are published. Since these data are collected primarily to determine large scale meteorological patterns and have relatively little refinement in the lower 2 to 3 thousand feet of the atmosphere, they are of limited use in air pollution meteorology.

3.3.2 Climatological Data

There are a number of routine and special publications available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402, that are useful in air pollution evaluation. A number of these are listed in Price List 48, available from the Superintendent of Documents.

Routinely Prepared Data

- Daily Weather Maps - Weekly Series
  The charts in this 4-page, weekly publication are a continuation of the principal charts of the former Weather Bureau publication, "Daily Weather Map." All of the charts for 1 day are arranged on a single page after being copied. They are copies from operational weather maps prepared by the National Meteorological Center,

National Weather Service. The Surface Weather Map presents station data and the analysis for 7:00 a.m. EST.

The 500-Millibar Height Contour chart presents the height contours and isotherms of the 500-millibar surface at 7:00 a.m. EST.

The Highest and Lowest Temperatures chart presents the maximum and minimum values for the 24-hour period ending at 1:00 a.m., EST.

The Precipitation Areas and Amounts chart indicates by means of shading, areas that had precipitation during the 24 hour period ending at 1:00 a.m., EST.

- <u>Local Climatological Data (LCD)</u>
These data are published individually for each station and include 3 issues discussed below.

<u>Monthly Issue LCD</u>
This issue gives daily information on a number of meteorological variables and monthly means of temperature, heating degree days, pressure and precipitation. Also tabulated are observations at 3-Hourly Intervals (observations for each hour of the day were discontinued after December 31, 1964). This publication is usually available between the 10th and 15th of the following month.

<u>LCD Supplement (monthly)</u>
This issue is available for stations having 24 hourly observations daily until December 31, 1964 when publication was discontinued. For air pollution investigations, Tables B, E, F, and G would be of greatest interest (Frederick, 1964). The Supplement is usually available from 20 to 40 days after the end of the month.

<u>LCD with Comparative Data (annual)</u>
This issue, published annually, has a table of climatological data for the current year and a table of normals, means, and extremes for a longer period of record. This issue is usually available between 45 and 60 days after the end of the year.

- <u>Northern Hemisphere Data Tabulations</u>
This publication, issued daily, contains approximately 30 pages of surface synoptic observations and upper air observations. The surface data are for one hour only (1200 GCT). In this publication, the radisonde information is of principal interest in air pollution meteorology.

- <u>Climatological Data - National Summary</u>
This publication of approximately 50 pages, issued monthly, contains a narrative summary of weather

conditions, climatological data (similar to those given in each station's LCD) in both English and metric units, mean monthly radiosonde data, and solar radiation data. Also included are a number of maps of the United States showing spatial distribution of temperature, precipitation, solar radiation and winds. The mean radiosonde and solar radiation data are of main interest in this publication for air pollution meteorology.

- Climatological Data (by State)
  This summary, issued monthly and annually, contains data primarily on temperature and precipitation. This will provide only limited information to the air pollution meteorologist.

- Selected Climatic Maps
  This publication consists of 30 U.S. maps of various meteorological parameters such as: maximum and minimum temperature, heating and cooling degree days, precipitation, relative humidity, solar radiation, and surface wind roses for January and July together with the annual wind rose. Wind data are presented for 74 locations within the contiguous U.S. A list of the basic Climatic Maps from which the generalized maps of this publication are taken is included.

Summaries

- Summary of Hourly Observation
  This series of publications, Climatography of the United States, No. 82-, Decennial Census of United States Climate, has been prepared for over 100 Weather Bureau stations where 24 hourly observations are recorded. One issue is prepared for each station, and where the period of record is sufficient, the ten year period 1951 - 1960 has been considered. For other stations, the 5 year period 1956 - 1960 has been summarized. This series supersedes the series, "Climatography of the United States" No 30-, a 5 year summary published in 1956.

- Climatic Guide
  This series of climatological publications contains a wealth of climatological information useful to the air pollution meteorologist fortunate enough to have had one prepared for his city. Of major interest to air pollution meteorologists, are tables of wind frequencies, solar radiation and degree days.

- Climatic Summary of the United States-Supplement for 1931 - 1952.
  This summary, issued by state, contains tables of monthly and annual precipitation, snowfall, and temperature for stations within the state.

- <u>Terminal Forecasting Reference Manual</u>
  This manual, published by station, describes the weather conditions at the station, and contains information on local topography, visibility effects due to fog and smoke, ceiling, precipitation, special weather occurrences, and mean wind and visibility conditions. Numerous charts are included summarizing the above elements. Of special interest are surface wind roses by month and a wind rose chart related to restricted visibility conditions. A topographic and smoke source map for the station is included.

- <u>Key to Meteorological Records Documentation</u>
  This series of publications was established to provide guidance to those making use of observed data. A recent addition to this series No. 4.11, "Selective Guide to Published Climatic Data Sources prepared by U.S. Weather Bureau" (1969) is extremely useful to anyone contemplating use of climatic data.

  The series No. 1.1 title "Substation History" and issued by state contains information regarding history of station locations, type and exposure of measuring instruments, location of original meteorological records, where published, and dates of first and last observations.

3.4 TEMPERATURE

Temperature is a critical climatological parameter for land management activities. Temperature and related parameters, such as the length of the growing season, greatly influence the suitability of land areas for utilization in agriculture, forestry and grazing.

Ambient temperatures are determined by a multitude of factors, including the following:

- The intensity and duration of solar radiant energy
- The degree of depletion of this energy by reflection, scattering and absorption in the atmosphere
- The surface albedo
- The physical characteristics of the surface such as terrain types
- The local heat budget in terms of terrestrial and atmospheric radiation
- Heat exchanges involved in water phase changes
- Importation or advection of warm or cold air masses by horizontal air movement
- Transport of heat upward or downward by vertical air currents caused by natural convection and/or mechanical turbulence

In the United States, temperature is most commonly measured in degrees Fahrenheit (^{o}F), however, there is an increasing trend towards the use of degrees Centigrade (^{o}C). For this reason, temperature data and analyses presented in this report are in degrees Fahrenheit, with Table 3.4-1 providing a summary of temperature conversion information for aid in the usage of both systems.

Temperature data are available for numerous stations in California. For this reason, key stations have been used to represent the various climatic zones in the district in an effort to limit the amount of data analysis necessary to present the required information. Once again, the Ukiah District has been divided into three key climatic zones in which temperature is fairly homogeneous. For each of these regions, data from the selected key stations has been used to describe temperature characteristics. Data provided for each of the key stations includes monthly and annual means, mean maximum, mean minimum as well as the record high and low temperatures.

Figure 3.4-1 presents the three climatic zones superimposed on the district map with selected station locations for which temperature data are available. Tables 3.4-2 through 3.4-4 summarize the temperature statistics for these stations in each climatic zone. Section 3.2 briefly summarizes temperature and other climatic characteristics of each climatic zone.

Table 3.4-1

TEMPERATURE CONVERSIONS

Temperatures in this publication are given in degrees Fahrenheit (°F). The Celsius (C) temperature scale, also called Centigrade, is used in most countries of the world. A temperature conversion scale is shown on the left, note that the values coincide only at the -40 degree mark.

°F	°C	
212	100	Water Boils [1]
194	90	
176	80	
158	70	
140	60	
134	56.7	U.S. Record High [2]
122	50	
104	40	
86	30	
68	20	
50	10	
32	0	Water Freezes [1]
14	−10	
−4	−20	
−22	−30	
−40	−40	Scales Coincide
−58	−50	
−76	−60	
−94	−70	U.S. Record Low [3]
−112	−80	
−130	−90	
−148	−100	

The standard formulas to convert °F to °C and °C to °F are shown below:

°F = 9/5 °C + 32

°C = 5/9 (°F -32)

Atlernate, easy to remember conversion methods follow:

°F = 9/5 (°C + 40) -40

°C = 5/9 (°F + 40) -40

To use the alternate conversion formulas for converting from one scale to the other:

(a) add 40 to the value to be converted

(b) multiply that sum by the fraction:
(5/9 for °F to °C)
(9/5 for °C to °F)

(c) subtract 40 from the product

For example, to convert 68°F to °C:

(a) add 40: 68+40 = 108

(b) multiply the sum by 5/9 (°F to °C):
5/9x108 = 60

(c) subtract 40: 60-40 = 20

(d) answer: 68°F = 20°C

1. Under Standard Sea Level Pressure
2. Greenland Ranch, CA - July 10, 1913
3. Rogers Pass, Montana - January 20, 1954

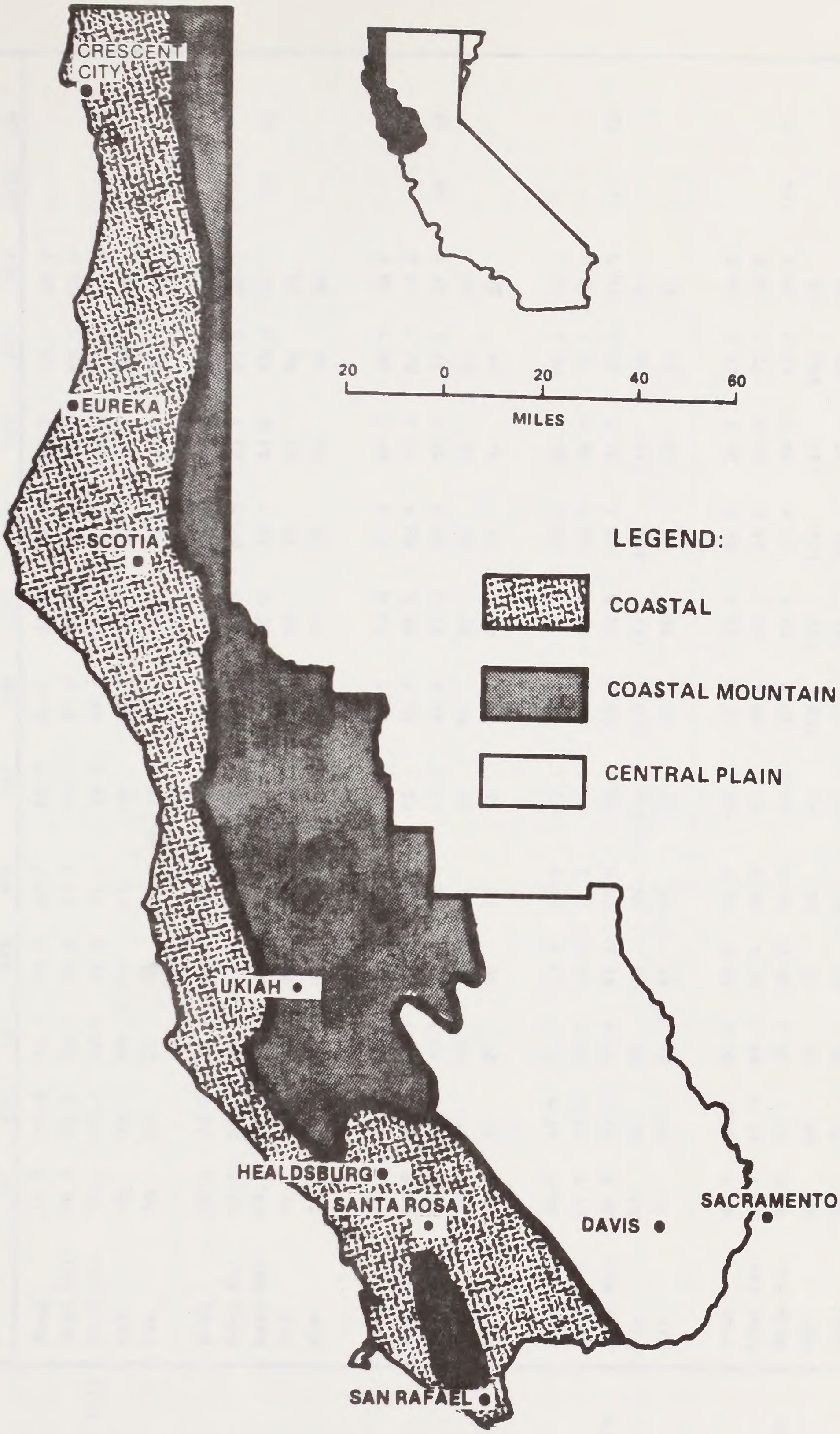


Figure 3.4-1
Temperature Stations for the Ukiah District

Table 3.4-2

Summarized Temperature (^{o}F) Data for

Selected Stations in the Coastal Climatic Zone

		DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	HIGH	LOW
	Mean.	47.7	46.8	48.5	48.3	49.4	52.7	56.3	57.9	58.9	58.3	55.1	52.7		
	Mean Max.	55.7	53.8	55.7	55.8	57.7	60.7	63.9	65.2	66.2	66.9	63.5	58.8		
Crescent City	Mean Min.	40.5	39.1	40.4	41.0	41.7	44.9	48.8	50.2	50.8	49.4	46.6	43.5	93	20
	Max.	70	74	78	72	81	92	93	76	91	93	89	76		
	Min.	20	22	27	26	30	32	37	40	41	38	34	29		
	Mean	48.0	46.9	48.6	48.5	48.9	51.8	54 4	56.1	57.1	56.3	54.2	51.6		
	Mean Max.	51.8	53.0	59.3	54.0	54.9	56.9	58.9	60.0	60.3	61.1	57.6	54.7		
Eureka	Mean Min.	44.2	41.0	41.3	43.0	43.9	47.0	50.0	51.2	52.1	51.0	48.0	45.1	83	21
	Max.	77	70	73	72	78	81	73	70	82	83	80	73		
	Min.	21	28	21	31	34	37	41	40	47	43	32	30		
	Mean.	47.5	46.6	48.6	48.8	50.5	54.5	57.7	59.9	61.0	60.3	56.7	52.0		
	Mean Max.	54.6	53.9	56.7	56.8	58.3	62.1	65.4	68.0	69.4	70.2	66.3	59.9		
Scotia	Mean Min.	40.3	39.2	40.5	40.7	42.8	46.8	49.9	51.8	52.3	50.3	47.1	43.9	98	19
	Max.	73	70	79	83	85	91	93	87	96	98	93	80		
	Min.	19	23	25	29	32	35	40	41	41	38	28	28		
	Mean.	48.0	47.5	51.7	53.7	57.4	63.1	68.4	70.7	70.5	69.1	63.1	54.5		
	Mean Max.	57.4	57.0	62.4	66.0	71.2	78.1	84.5	89.1	88.5	86.5	78.1	66.0		
Healdsburg	Mean Min.	38.6	37.9	40.8	41.5	43.8	48.1	52.2	52.3	52.5	51.7	48.0	42.9	116	19
	Max.	83	85	82	90	96	104	113	116	109	114	105	96		
	Min.	19	23	25	28	29	37	37	40	41	38	30	27		
	Mean.	47.1	46.4	50.4	52.0	55.3	60.2	65.0	67.4	67.6	66.7	61.3	53.0		
	Mean Max.	57.5	57.0	62.3	65.4	69.6	75.0	80.8	84.3	84.6	84.0	77.5	66.0		
Santa Rosa	Mean Min.	36.5	35.7	38.4	38.6	41.0	45.2	49.2	50.4	50.4	49.4	45.0	39.9	110	16
	Max.	83	85	83	88	93	100	109	110	104	110	102	92		
	Min.	16	21	23	26	29	34	37	41	41	37	30	23		
	Mean.	48	47	51	53	56	60	64	66	66	66	61	53		
	Mean Max.	55	54	59	62	67	71	77	79	79	79	73	63		
San Rafael	Mean Min.	40	39	42	43	45	48	51	52	52	52	49	43	106	23
	Max.	73	77	75	81	89	102	106	102	102	104	96	83		
	Min.	24	23	25	30	30	36	42	44	44	40	34	28		

Table 3.4-3

Summarized Temperature (^{o}F) Data for

Selected Stations in the Coastal Mountain Climatic Zone

		DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	HIGH	LOW
Ukiah	Mean.	46.8	46.3	50.0	51.6	55.7	62.0	68.3	73.9	73.1	69.8	61.5	52.4	115	13
	Mean Max.	57.5	57.0	62.0	64.8	70.4	78.0	85.4	93.6	92.5	89.3	78.8	64.9		
	Mean Min.	36.0	35.4	37.9	38.4	40.9	46.0	51.3	54.2	53.6	50.2	44.5	39.7		
	Max.	80	81	83	90	97	101	114	114	111	115	109	52		
	Min.	13	19	19	24	28	32	37	41	44	36	24	22		

Table 3.4-4

Summarized Temperature (^{o}F) Data for

Selected Stations in the Central Plain Climatic Zone

		DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	HIGH	LOW
	Mean.	45.7	45.0	50.0	52.9	57.7	64.6	70.9	74.4	73.2	70.6	63.1	52.9		
	Mean Max.	53.9	53.0	59.6	64.6	71.1	79.9	87.6	93.3	91.7	88.1	78.1	64.1		
Davis	Mean Min.	37.3	36.9	40.2	41.2	44.2	49.3	54.1	55.3	54.6	53.1	48.2	41.7	113	19
	Max.	76	77	76	85	93	102	110	113	109	110	100	87		
	Min.	21	19	26	26	29	35	40	44	44	40	30	24		
	Mean.	45.0	44.5	50.4	53.1	57.4	65.4	71.4	71.2	71.1	72.1	63.9	53.4		
	Mean Max.	53.8	53.2	59.2	64.5	71.3	79.1	86.7	92.8	91.3	87.5	77.3	63.5		
Sacramento	Mean Min.	33.8	37.4	40.5	42.1	45.3	50	55.0	58.0	57.0	55.3	49.5	42.2	115	20
	Max.	72	70	76	86	93	104	115	114	108	108	101	87		
	Min.	22	20	25	26	32	34	41	49	46	43	31	26		

3.4.1 Mean Temperature Distribution

The data presented in the figures and tables in this section provide generalized information for BLM lands located within each of the study regions. However, temperature is a variable which is subject to microclimatological effects and the actual temperature at a given location will depend upon several variables as previously indicated. The data show that variability among stations within a particular region is fairly modest and that the average values provided in the summary figures can be used with a good degree of confidence. Caution when using these values is warranted when the location of interest varies significantly from the elevation of the key stations or if a particular location experiences important micro-scale effects (e.g., anomalous ground cover conditions).

Annual Average

Figure 3.4-2 provides the mean annual temperature distribution for the Ukiah District and also appears as Overlay D. The figure shows a modest 6°F range in mean annual temperature across the region from a low of 54°F along most of the northern coastal areas to a maximum of just over 60°F in the northeast portion of the Central Plains CZ. Temperatures are uniform along coastal locations showing the strong maritime influence of the Pacific Ocean on ambient temperatures in this area. Temperatures show very little variation with a gradual increase with inland progression in the southern portion of the District. The decreased influence of the Pacific Ocean in the Central Plain portion of the Ukiah District in the lee of the Coast Ranges is evident from the somewhat increased mean annual temperatures.

Mean maximum and mean minimum temperature data are summarized in Figures 3.4-3 through 3.4-5 for the three major climatic zones in the Ukiah District on a monthly basis. The influence of the Pacific Ocean on coastal and coastal mountain temperature characteristics can be noted with the figures which provide a comparison between the climatic zones. Coastal regions experience a modest 15°F temperature increase from winter to summer while Central Plain locations experience a 25°F difference.

Mean Maximum

During the months of December and January, maximum temperatures range from the low 50's°F at Eureka to the upper 50's°F at Ukiah and Santa Rosa (See Figure 3.4-4.) During the summer, temperatures show considerable variation ranging from the low 60's°F at Eureka to the low 90's°F at Ukiah, Davis and Sacramento. Maximum temperatures generally reach a peak in July and August in all areas except along the north coast where the maximum is generally shifted to August and September.

2.4.1 Mean Temperature Distribution

The data presented on the figures and tables in this section provide generalized information for BLM lands located within each of the study regions. However, temperature is a variable which is subject to distinct diurnal patterns and the actual temperature at a given location will depend upon several variables as previously mentioned. The data show that variability among stations within a particular region is fairly modest and thus the average values presented in the summary figures can be used with a good degree of confidence. Caution when using these values is warranted when the location of interest varies significantly from the conditions at the key stations which a particular region represents ([illegible], micro-scale effects [illegible] ground-level conditions).

Annual Patterns

Figure 2.4-1 presents the mean annual temperature distribution for each Utah District and also segments of [illegible]. The figure shows a general [illegible]°F range in mean annual temperature across the region from a low of [illegible]°F along much of the northern central area to a maximum of just over 60°F in the southwest portion of the [illegible]. Temperatures [illegible] central districts [illegible] the strong [illegible] influence of the [illegible] of ambient temperatures in this area. Temperatures then [illegible] with a gradual increase with [illegible] in the southern portion of the District. The [illegible] influence of the Pacific [illegible] in the central [illegible] portion of the [illegible] of the Great Basin [illegible] from the [illegible] mean annual temperatures.

Mean maximum and mean minimum temperature data are summarized in Figures 2.4-2 through 2.4-4 for each [illegible] on a monthly basis. The influence of [illegible] temperature [illegible] can be noted with the figures which provide a comparison between [illegible]. January [illegible] temperatures [illegible] while central [illegible] experienced a [illegible]°F difference.

Daily Maximum

During the months of December and January, maximum temperatures range from the low [illegible]°F at [illegible] in the upper [illegible]°F at [illegible] and [illegible] (see Figure 2.4-2). During the summer, temperatures show considerable variation ranging from the low [illegible]°F [illegible] to the [illegible]°F [illegible]. Maximum temperatures generally reach a peak in July and August in all areas except along the [illegible] where the maximum is generally shifted to August and September.

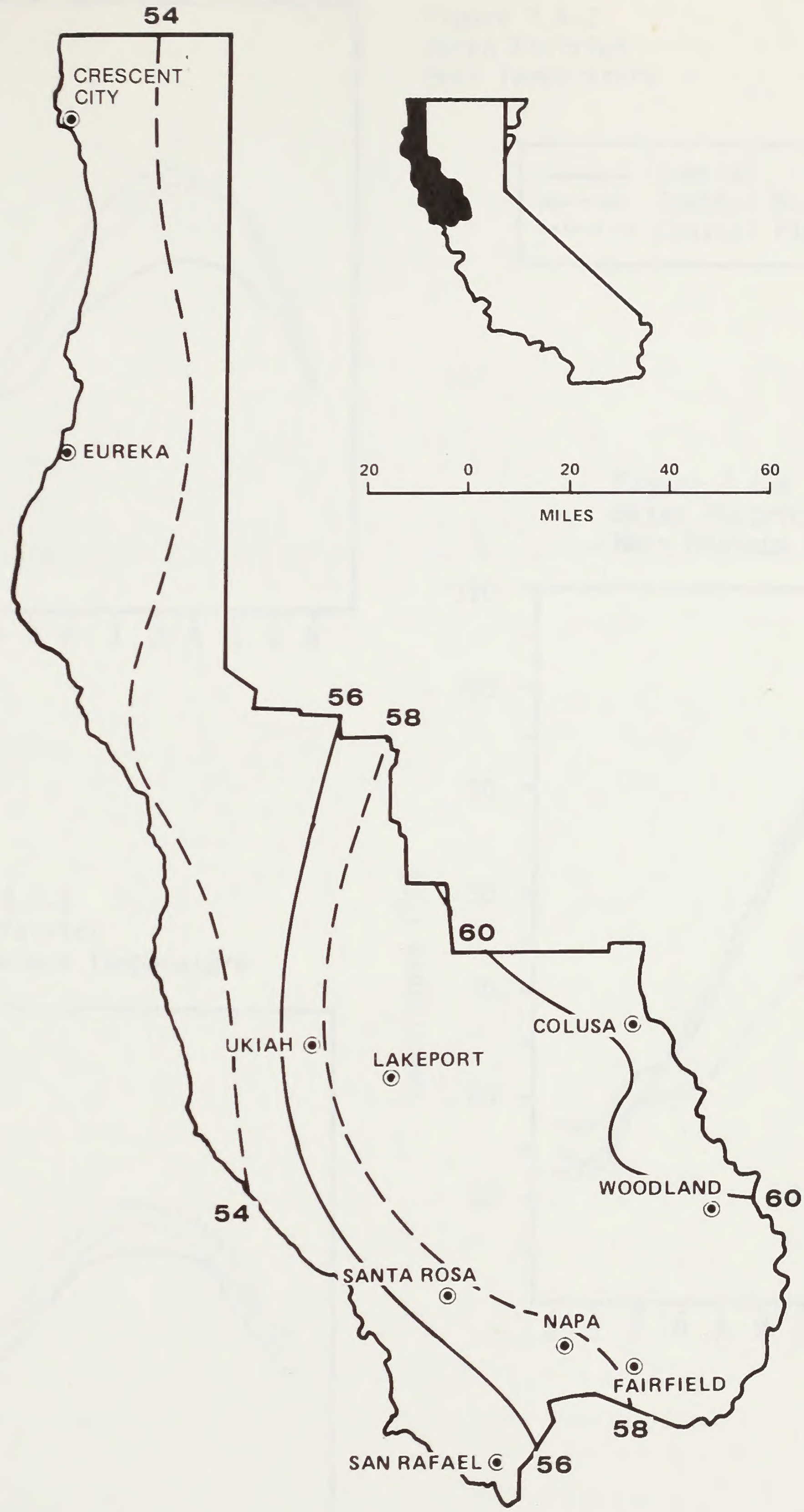


Figure 3.4-2
Mean Annual Temperature Contours (^oF) in the Ukiah District

Figure 3.4-3
Ukiah District
Mean Temperature

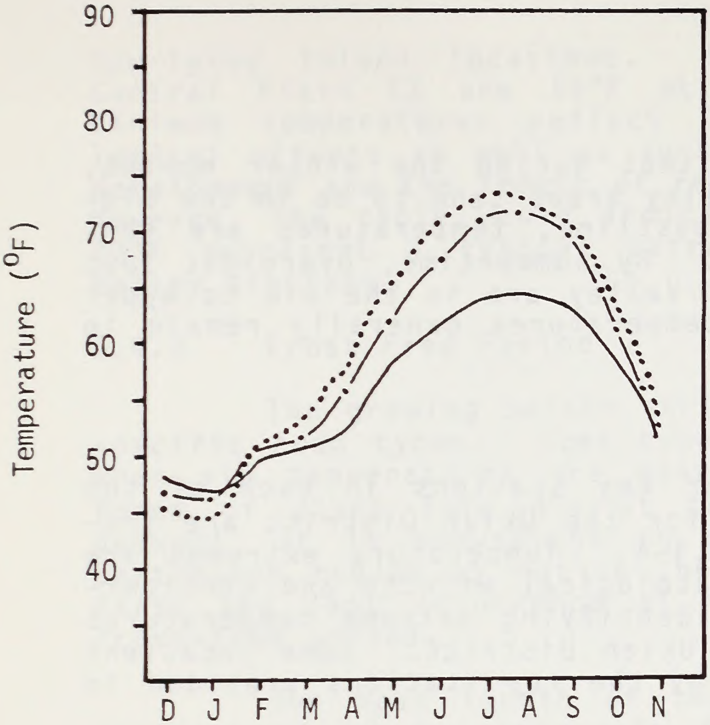


Figure 3.4-4
Ukiah District
Mean Maximum Temperature

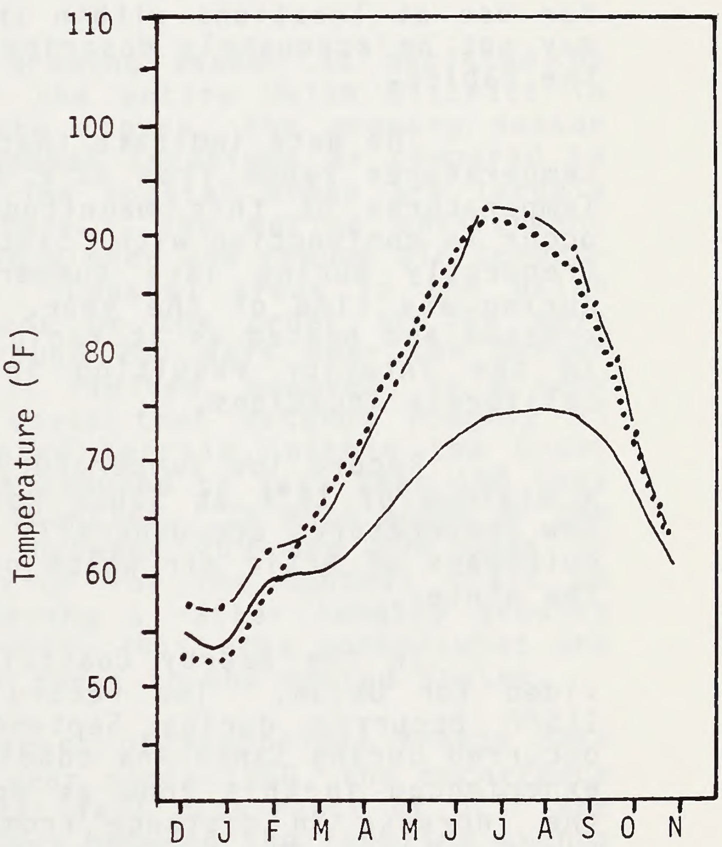
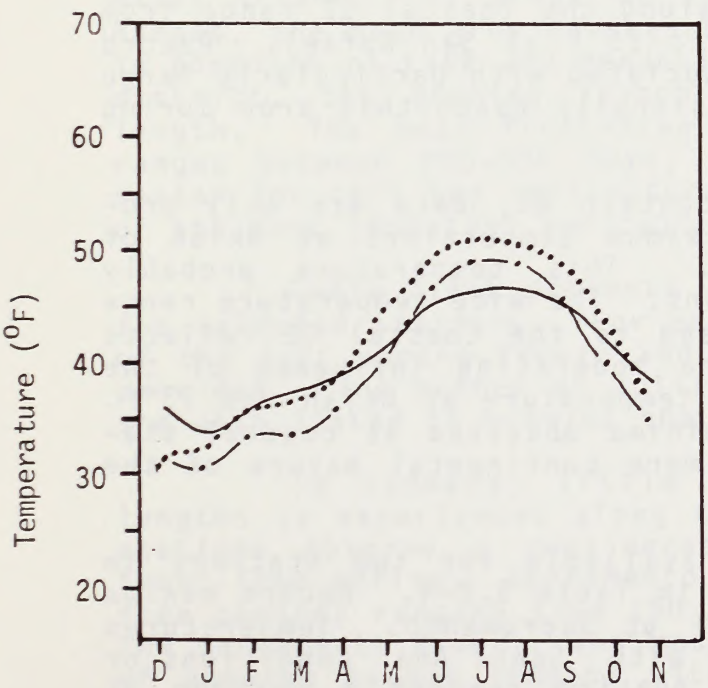


Figure 3.4-5
Ukiah District
Mean Minimum Temperature



Mean Minimum

Figure 3.4-5 indicates that during the winter months, minima in the mountainous and valley areas tend to be in the mid-30's°F. Along the immediate coastline, temperatures are generally in the low to mid-40's°F. By summertime, overnight lows in the mountains and the Central Valley are in the mid to upper 50's°F. Along the coastline, temperatures generally remain in the low 60's°F.

3.4.2 Temperature Extremes

Temperature extremes for key stations in each of the three climatic zones identified for the Ukiah District are provided in Tables 3.4-2 through 3.4-4. Temperature extremes are strongly influenced by microclimatological effects and considerable caution must be used when identifying extreme temperatures for use at locations within the Ukiah District. Some locations may not be adequately described by the key stations provided in the tables.

The data indicate that in the Coastal CZ, record maximum temperatures range from 83°F at Eureka to 116°F at Healdsburg. Temperatures of this magnitude at coastal locations generally occur in conjunction with "Santa Ana" conditions which occur most frequently during late summer and fall, but which can occur during any time of the year. During a Santa Ana, air is compressed and heated as it rapidly descends from higher elevations in the interior resulting in hot, dry conditions at coastal California locations.

Record low temperatures along the Coastal CZ range from a minimum of 16°F at Santa Rosa to 23°F at San Rafael. Record low temperatures are generally associated with particularly large outbreaks of Artic air which occasionally reach this area during the winter.

In the nearby Coastal Mountain CZ, data are only provided for Ukiah. The record maximum temperature at Ukiah of 115°F occurred during September. This temperature probably occurred during Santa Ana conditions. The wide temperature range experienced in this zone as opposed to the Coastal CZ reflects the increase in distance from the moderating influence of the Pacific Ocean. The record minimum temperature at Ukiah was 13°F. This is colder than the record minima observed at coastal stations, once again reflecting the more continental nature of the area.

Record temperatures are available for two stations in the Central Plain CZ as indicated in Table 3.2-4. Record maxima range from 113°F at Davis to 115°F at Sacramento. Temperatures of this magnitude can occur either with "Santa Ana" conditions or during late summer when surface heating reaches a maximum at low-lying inland locations. Record low temperatures in the Central Plain CZ are 19°F at Davis and 20°F at Sacramento. Minimum temperatures reflect local terrain and micrometeorological effects as well as such factors as the degree of urban development and the length of record available for the data base. However, the table would indicate that temperatures lower than 20°F represent a typical extreme minimum value at Sacramento Valley stations.

3.4.3 Frost-Free Period

The growing season varies considerably as a function of specific crop types. Some types of vegetation continue to grow when air temperatures are near freezing (32°F), whereas other forms of plant life die at temperatures above freezing. In general, it is convenient to define the growing season for a particular region by noting the mean number of days between the first and last occurrence of freezing temperatures, i.e., the frost-free period.

The mean length of the growing season is depicted by isolines of 50 day intervals for the entire Ukiah District in Figure 3.4-6. As indicated in the figure, the growing season length differs considerably at coastal locations as compared to regions located further inland. The coastal areas are largely influenced by nearby Pacific waters. The marine environment tends to warm ambient air masses in winter and reduce air temperatures during the summer months. Coastal areas in the Ukiah District experience growing seasons on the order of 300 days south of Eureka decreasing to around 200 days near the Oregon border. This maritime influence is limited, however, to a very narrow strip of land along the coast that extends roughly 10 miles inland. In areas of elevated terrain, within the Coast Ranges, the mean growing season is reduced to less than 150 days in portions of Lake and Mendocino Counties. In most areas of the district, the growing season is between 200 and 300 days in length. The mean frost-free period for the Central Plain CZ ranges between 250-300 days, offering a rather lengthy growing season for this key agricultural area. This area constitutes one of the most important agricultural zones in the United States.

Table 3.4-5 presents 16 years of historical freeze data for selected stations. For each year since 1960, the occurrence of the last spring freeze and first fall occurrence of 32°F are provided. The number of Julian days between the freezing events are also listed to provide the growing season length.

In summary, little difference in frost-free period lengths is experienced along the coast south of Eureka. Inland stations observe a considerable change in the length of the frost-free period. Sacramento Valley locations experience frost-free periods ranging from 250 days in the west to 300 days along the Sacramento River. The mountainous areas reveal a wide range of growing season lengths with growing seasons often less than 150 days at the higher elevations.

low-lying inland locations. Record low temperatures in the Central Valley are 11°F at Davis and 20°F at Sacramento. Minimum temperatures reflect local terrain and microclimatological effects as well as such factors as the degree of urban development and the length of record available for the data base. However, the table would indicate that temperatures [illegible] 15°F constitute a typical extreme minimum value of Sacramento Valley locations.

2.4.5.3 Frost-Free Period

The growing season varies considerably as a function of specific crop types. Some types of vegetation continue to grow even after [illegible] are near freezing (32°F), whereas other types of plant life die at temperatures above freezing. In [illegible], the mean number of days between the last and first occurrence of freezing temperatures (32°F) [illegible] frost-free period.

The mean length of the growing season is depicted as isolines of 30 day intervals for the entire Ukiah District on Figure 2.4-5. As indicated in the figure, the growing season length differs considerably [illegible] as compared to [illegible] interior valleys. The coastal areas are largely influenced by [illegible] air temperature [illegible] 270 days [illegible] 300 days [illegible] however, [illegible] along the coast [illegible] extends 10 miles inland. In areas of [illegible] terrain, within the local [illegible] growing season is less than 150 days [illegible] portions of Lake and Mendocino Counties [illegible]. The mean frost-free period for the Central Valley ranges between 250-300 days, offering a rather lengthy growing season for this key agricultural area. This area constitutes one of the most important agricultural areas in the United States.

Table 2.4-5 presents 10 years of [illegible] frost data for selected stations. For each year [illegible], the occurrence of the last spring freeze and first fall occurrence at 32°F are presented. The number of days between the freezing occurrences are also given to provide the growing season lengths.

In summary, [illegible] frost-free period length is experienced along the coast south of Eureka. Inland [illegible] a considerable change in the length of the frost-free period. [illegible] frost-free periods [illegible] 270 days [illegible] 300 days [illegible] less than 150 days at the higher elevations.

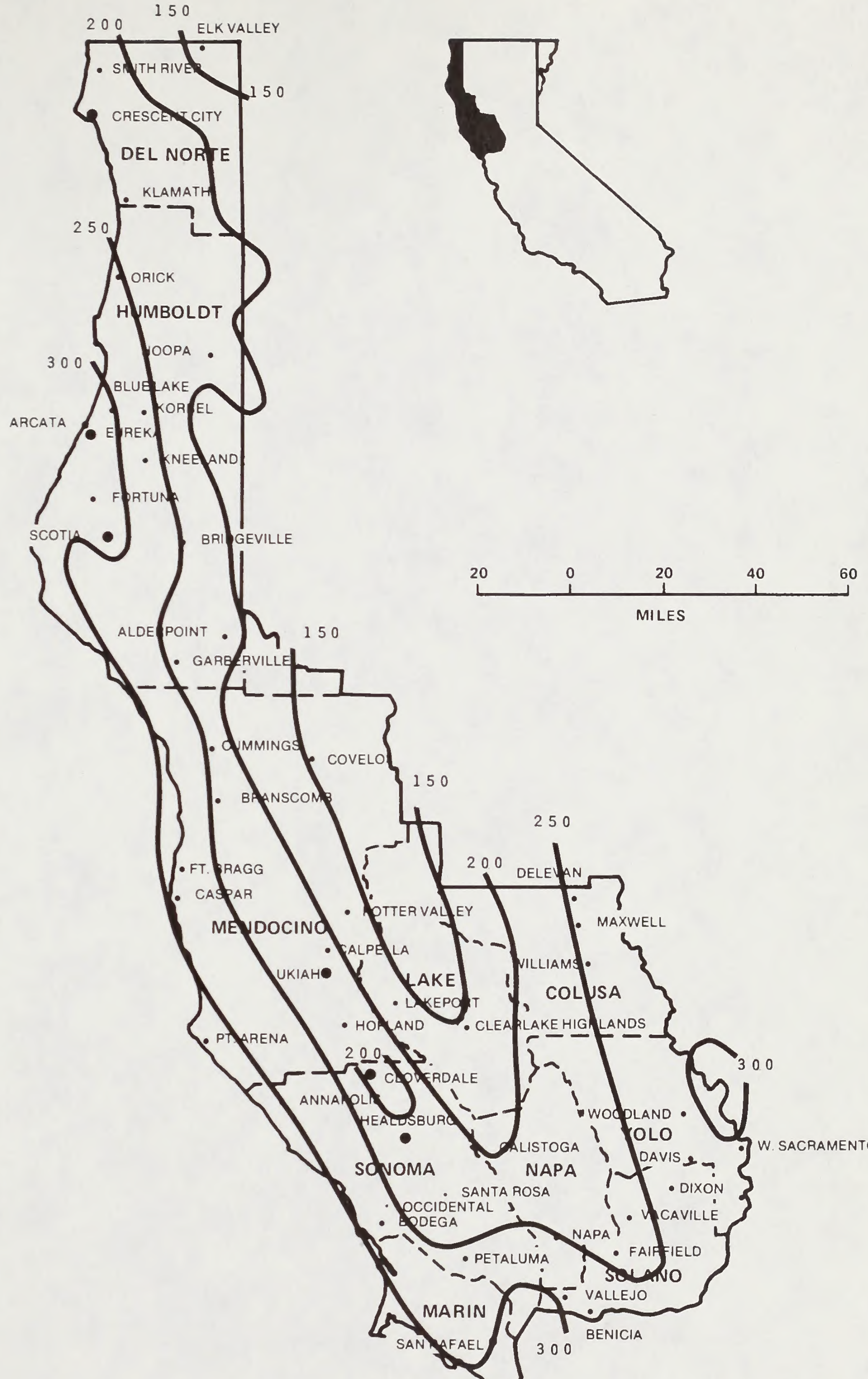


Figure 3.4-6
Ukiah District
Frost-Free Period or Length of Growing Season by 50-Day Intervals

Table 3.4-5

Ukiah District

Frost-Free Periods at Selected Stations

	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	Average
CRESCENT CITY IN																		
Last Spring 32°F	Mar 14	Mar 3	Feb 27	Mar 17	May 6	Mar 19	Mar 3	Mar 7	Apr 19	Mar 11	Jan 5	Apr 24	Mar 27	Jan 26	None	Apr 1	Apr 1	Apr 2
First Fall 32°F	Dec 5	Nov 20	Dec 26	Dec 13	Nov 14	Dec 16	Dec 27	Dec 13	Dec 20	Dec 27	Dec 26	Nov 16	Dec 5	None	None	Nov 18	Nov 30	Dec 11
Julian Days	266	262	302	271	192	272	299	281	245	291	355	206	253	-	-	231	243	275
EUREKA WSO C1																		
Last Spring 32°F	Jan 15	None	Feb 27	Jan 12	None	Jan 8	Mar 17	Jan 6	Jan 11	Jan 23	None	Feb 26	Feb 2	Jan 26	Feb 23	Feb 21	Mar 1	Jan 29
First Fall 32°F	None	Dec 11	Dec 24	None	Nov 14	Dec 16	Dec 27	Dec 13	Dec 19	None	Dec 19	Oct 29	Dec 5	None	Dec 23	Nov 18	None	Dec 15
Julian Days	-	-	300	-	-	343	285	341	343	-	-	245	307	-	303	270	-	320
SCOTIA																		
Last Spring 32°F	Mar 10	Jan 5	Mar 13	Jan 22	Mar 7	Jan 1	Mar 17	Mar 11	Jan 5	Mar 12	Feb 20	Apr 21	Feb 3	Jan 27	Mar 10	Mar 28	Apr 2	Feb 24
First Fall 32°F	Dec 6	Nov 16	Dec 24	None	Nov 15	Dec 15	Dec 27	Dec 13	Dec 20	None	Dec 19	Oct 28	Dec 5	None	Dec 23	Nov 18	Nov 27	Dec 10
Julian Days	271	315	286	-	253	349	285	277	350	-	302	190	306	-	288	235	239	289
FORT BRAGG																		
Last Spring 32°F	Jan 15	Jan 4	Mar 12	Jan 14	Mar 2	Feb 10	Mar 17	None	Apr 16	Mar 11	Jan 5	Mar 5	Feb 3	Jan 27	Feb 25	Apr 17	Mar 3	Feb 17
First Fall 32°F	None	Dec 11	Nov 29	None	Nov 14	Dec 16	Dec 27	Dec 13	Dec 20	None	Dec 19	Oct 29	Dec 5	Dec 2	Dec 23	Nov 18	None	Dec 12
Julian Days	-	341	262	-	257	310	285	-	248	-	348	238	306	309	301	215	-	298
SANTA ROSA																		
Last Spring 32°F	Apr 24	Apr 19	Mar 14	Apr 21	Apr 25	Apr 11	Mar 20	Apr 28	Feb 1	Mar 15	Apr 28	Apr 21	Mar 26	Mar 22	Mar 9	Apr 17	Apr 2	Apr 4
First Fall 32°F	Nov 27	Nov 14	Nov 29	Nov 22	Nov 13	Nov 26	Nov 23	Dec 1	Nov 28	Nov 17	Oct 27	Nov 6	Nov 23	Nov 4	Nov 26	Nov 11	Nov 28	Nov 19
Julian Days	217	209	260	215	202	229	248	217	301	247	182	199	240	227	262	208	240	229
SAN FRANCISCO																		
Last Spring 32°F	Jan 2	Jan 4	Jan 24	Jan 20	None	Jan 1	Mar 3	None	Jan 6	None	None	Jan 5	Jan 5	Jan 7	Jan 8	Jan 30	Jan 2	Jan 10
First Fall 32°F	None	None	Dec 25	None	None	Dec 17	Dec 28	Dec 15	Dec 21	None	None	None	Dec 5	None	Dec 25	None	None	Dec 28
Julian Days	364	361	335	345	366	351	300	349	350	365	365	360	335	358	351	335	364	350
HEALDSBURG																		
Last Spring 32°F	Feb 27	Jan 21	Feb 28	Mar 17	Feb 7	Jan 24	Mar 4	Mar 4	Jan 28	Mar 13	Jan 29	Mar 8	Feb 2	Jan 28	Mar 9	Feb 22	Mar 5	Feb 19
First Fall 32°F	Nov 27	Nov 16	Dec 24	Dec 7	Nov 15	Dec 15	Dec 27	Dec 1	Nov 28	Nov 18	Dec 19	Oct 29	Dec 5	None	Dec 19	Nov 29	Nov 26	Dec 4
Julian Days	274	299	299	265	282	326	298	272	305	250	324	235	307	-	285	280	268	288
DAVIS 2WSW EXP. FARM																		
Last Spring 32°F	Feb 27	Mar 7	Mar 10	Apr 21	Mar 25	Feb 24	Mar 4	Apr 1	Feb 1	Mar 15	Apr 28	Apr 21	Feb 3	Jan 28	Feb 24	Apr 17	Apr 2	Mar 15
First Fall 32°F	Nov 22	Oct 23	Nov 30	Nov 18	Nov 17	Dec 13	Nov 25	Nov 26	Nov 27	Nov 18	Dec 20	Nov 17	Nov 23	Nov 4	Nov 29	Nov 9	Nov 28	Nov 23
Julian Days	269	230	265	211	237	293	266	239	300	248	236	210	294	280	278	206	240	253

3.5 PRECIPITATION

Precipitation plays a very important role in the effective management of large land areas for agriculture, forest management, energy development or other pertinent interests. Precipitation is one of the most basic of climatological parameters and is best described in terms of seasonal and annual means and extremes coupled with a discussion of the type of precipitation experienced in a given area. A region can be prone to either general prolonged rainfall or precipitation occurrences in short, violent bursts, such as heavy showers or thunderstorms. The nature of the precipitation is almost equal in importance to the amount of precipitation in terms of the effectiveness of the moisture for interests such as agriculture. In addition, the type of precipitation (i.e., liquid vs. frozen) and the amount of each also plays an important role.

Precipitation results from the expansion and cooling of ascending air. Therefore, it is important to investigate and understand the atmospheric conditions that cause large masses of air to spontaneously rise. Three characteristic causes that can result in precipitation are:

- Convective lifting due to unstable atmospheric conditions
- Orographic or terrain-induced lifting of air masses
- Large scale atmospheric disturbances

The three are not mutually exclusive, and precipitation is generally not the result of just one type, but more often the joint action of several types of atmospheric lifting processes.

The following sections provide a detailed breakdown of precipitation amounts, types and frequencies. Seasonal and annual means and extremes are provided as well as rainfall intensity, and a detailed discussion on snowfall. More unusual types of precipitation such as hail are discussed in the section provided on severe weather.

3.5.1 Annual Distribution

Figure 3.5-1 presents a base map which includes the selected stations for which precipitation data are available. A climatic zone overlay (Overlay C) for the Ukiah District is suitable for use with the precipitation maps.

Precipitation in California and within the Ukiah District is primarily the result of the influence of maritime Pacific air and orographic influences imposed by the substantial terrain within the region. The neighboring Pacific Ocean serves as the major moisture source for precipitation in the district.

2.5 PRECIPITATION

Precipitation plays a very important role in the effective management of large land areas for agriculture, forest management, energy development or other pertinent interests. Precipitation is one of the most basic of climatological parameters and is most described in terms of seasonal and annual means and extremes coupled with a discussion of the type of precipitation experienced in a given area. A region can be arid in either general prolonged rainfall or precipitation occurrence in short, violent bursts, such as heavy showers or thunderstorms. The manner of the precipitation is almost equal in importance to the amount of precipitation in terms of the effectiveness of the moisture for uses such as agriculture. In addition, the type of precipitation (i.e., liquid vs. frozen) and the amount of each also plays an important role.

Precipitation results from the expansion and cooling of ascending air. Therefore, it is important to investigate and understand the atmospheric conditions that cause large volumes of air to simultaneously rise. Three characteristic causes that can result in precipitation are:

* Convective lifting due to unstable atmospheric conditions
* Orographic or terrain-induced lifting of air masses
* Large scale atmospheric disturbances

All three are mechanically exclusive, and precipitation is generally not the result of just one type, but more often the joint action of several types of atmospheric lifting processes.

The following sections provide a detailed discussion of precipitation amounts, types and frequencies. Seasonal and annual means and extremes are provided as well as variability and a detailed discussion of snowfall. More unusual types of precipitation such as hail are discussed in the section presented on severe weather.

2.5.1 Annual Distribution

Figure 2.5-1 presents a base map which includes the selected stations for which precipitation data are available. A climatic zone overlay (overlay 1) for the [illegible] Project is available for use with the precipitation maps.

Precipitation in California and western Oregon and Washington is primarily the result of the influence of maritime Pacific air and orographic influences exerted by the mountainous terrain within the region. The Pacific Ocean serves as the major moisture source for precipitation in the region.

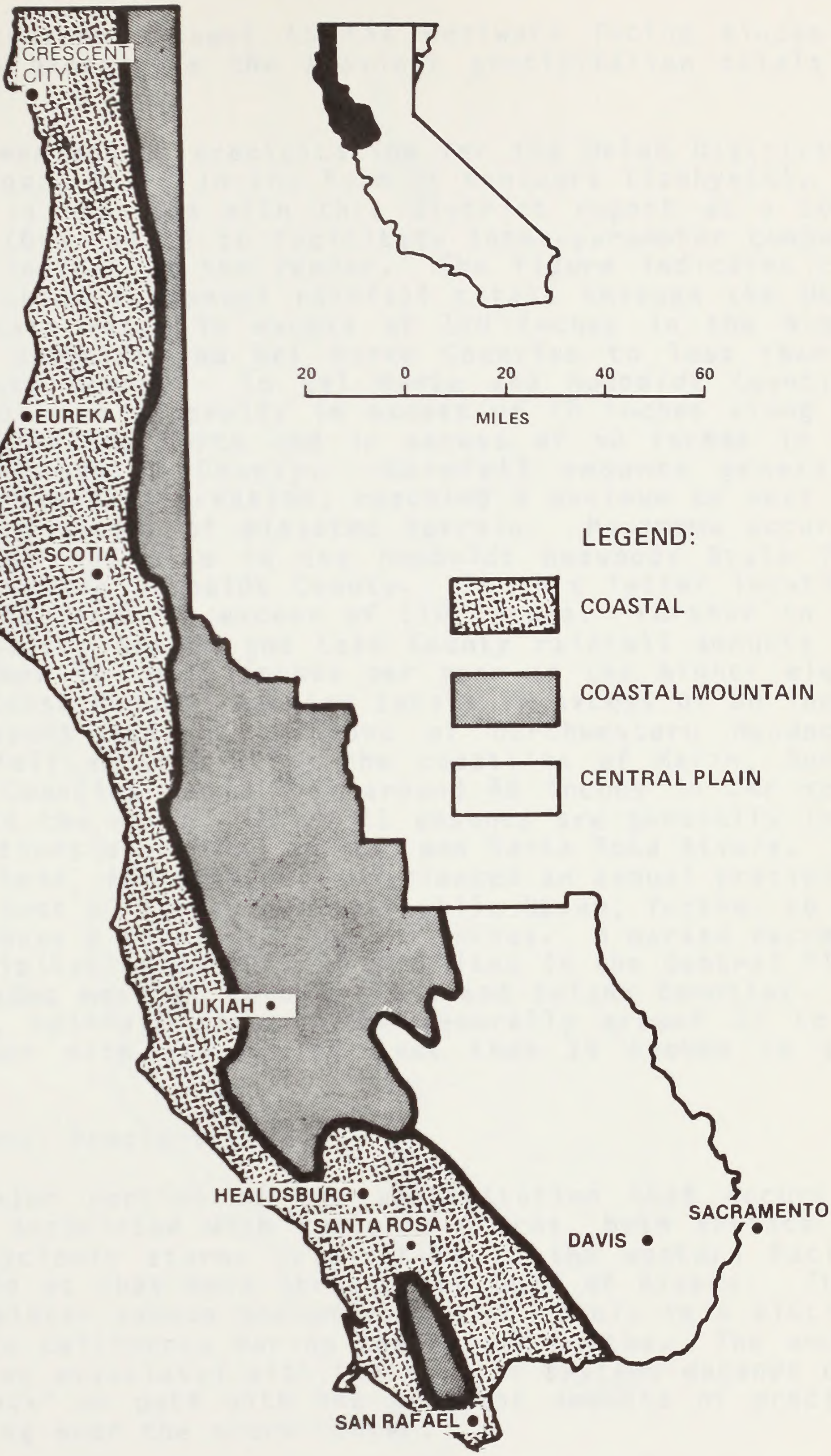


Figure 3.5-1

Selected Precipitation Stations for the Ukiah District

Therefore, locations closest to the westward facing slopes of higher terrain experience the heaviest precipitation totals in the district.

The mean annual precipitation for the Ukiah District is depicted on Figure 3.5-2 in the form of contours (isohyets). An identical map is provided with this district report as a color coded overlay (Overlay E) to facilitate inter-parameter comparisons and correlations by the reader. The figure indicates considerable variation in annual rainfall totals through the Ukiah District. Totals range in excess of 120 inches in the higher elevations of Humboldt and Del Norte Counties to less than 15 inches in Colusa County. In Del Norte and Humboldt Counties, rainfall amounts are generally in excess of 70 inches along the coast and the extreme north and in excess of 50 inches in the remainder of Humboldt County. Rainfall amounts generally increase with inland progression, reaching a maximum on west and southward facing slopes of elevated terrain. Maximums occur in Del Norte County and also in the Humboldt Redwoods State Park area of southwestern Humboldt County. In this latter location, rainfall amounts reach in excess of 110 inches. Further to the south in Mendocino, Sonoma and Lake County rainfall amounts are generally between 40 to 70 inches per year in the higher elevations of the Coast Ranges reaching totals in excess of 80 inches south of Lakeport and in portions of northwestern Mendocino County. Rainfall amounts along the coastline of Marin, Sonoma and Mendocino Counties range from around 40 inches in the south to 70 inches in the north. Rainfall amounts are generally lower in valley locations along the Russian and Santa Rosa Rivers. The city of Santa Rosa, for example, experiences an annual precipitation total of just 30 inches per year while Ukiah, further to the north, experiences a total of about 40 inches. A marked decrease in annual precipitation amounts is exhibited in the Central Plain CZ which includes most of Colusa, Yolo and Solano Counties. In these regions, rainfall amounts are generally around 15 to 20 inches per year with amounts of less than 15 inches in some locations.

3.5.2 Seasonal Precipitation

A major portion of the precipitation that occurs in California is associated with cyclonic storms, both surface and upper air. Cyclonic storms originating in the western Pacific are intensified as they move through the Gulf of Alaska. These storms are a winter season phenomenon which result in a distinct rainy season in California during the winter months. The amount of precipitation associated with these storm systems depends upon the "storm track" or path with the greatest amounts of precipitation occurring near the storm center.

Rainy season storms from the west can result in rain for prolonged periods when the storm-track becomes established across northern California. Rains may last for a week or more with only partial clearing between episodes. The actual amount of precipitherefore, interior climate) in the westward facing slopes of higher terrain experience the heaviest precipitation totals in the district.

The mean annual precipitation for the Union District is depicted on Figure 3.2-1 in the form of isohyets (inches). An additional isohyet with this district is given on a water based overlay (Overlay 1) to facilitate interesting smaller comparisons and correlations by the reader. The figure indicates considerable variation in annual rainfall totals through the Union District. Totals range in excess of 120 inches in the higher elevations of Humboldt and Del Norte Counties to less than 15 inches in Shasta County. In Del Norte and Humboldt Counties, rainfall amounts are generally in excess of 70 inches along the coast and the northern north and in excess of 90 inches in the remainder of Humboldt County. Rainfall amounts generally increase with inland progression, reaching a maximum on west and southwest facing slopes of elevated terrain. Extremes occur in Del Norte County and also in the Humboldt Redwoods State Park area of southeastern Humboldt County. In this latter location, rainfall amounts reach in excess of 110 inches. Further to the south in Mendocino, Sonoma and Lake County rainfall amounts are generally between 40 to 70 inches per year in the higher elevations of the Coast Ranges reaching totals in excess of 70 inches south of Lakeport and in portions of northeastern Mendocino County. Rainfall amounts along the coastline of Marin, Sonoma and Mendocino Counties range from around 30 inches in the south to 70 inches in the north. Rainfall amounts are generally lower in valley locations along the Russian and Santa Rosa Rivers. The city of Santa Rosa, for example, experiences an annual precipitation total of just 30 inches and Ukiah, 40 to 50, further to the north, experiences a total of about 40 inches. A marked decrease in annual precipitation amounts is experienced in the central area which includes most of Shasta, Yolo and Solano Counties. In these regions, rainfall amounts are generally around 15 to 20 inches per year with amounts of less than 15 inches in some locations.

3.2.2 Seasonal Precipitation

A major portion of the precipitation that occurs in California is associated with cyclonic storms, both surface and upper air. Cyclonic storms originating in the northern Pacific are intensified as they move through the belt of westerlies. These storms are a winter season phenomenon which results in a distinct rainy season in California during the winter months. The amount of precipitation associated with these storm systems depends upon the "storm track" or path with the greatest amounts of precipitation occurring near the storm center.

Moving frontal storms from the west can result in rain for prolonged periods when the storm track traverses relatively across northern California. Rains may last for a week or more, with only partial clearing between episodes. The annual amount of precipi-

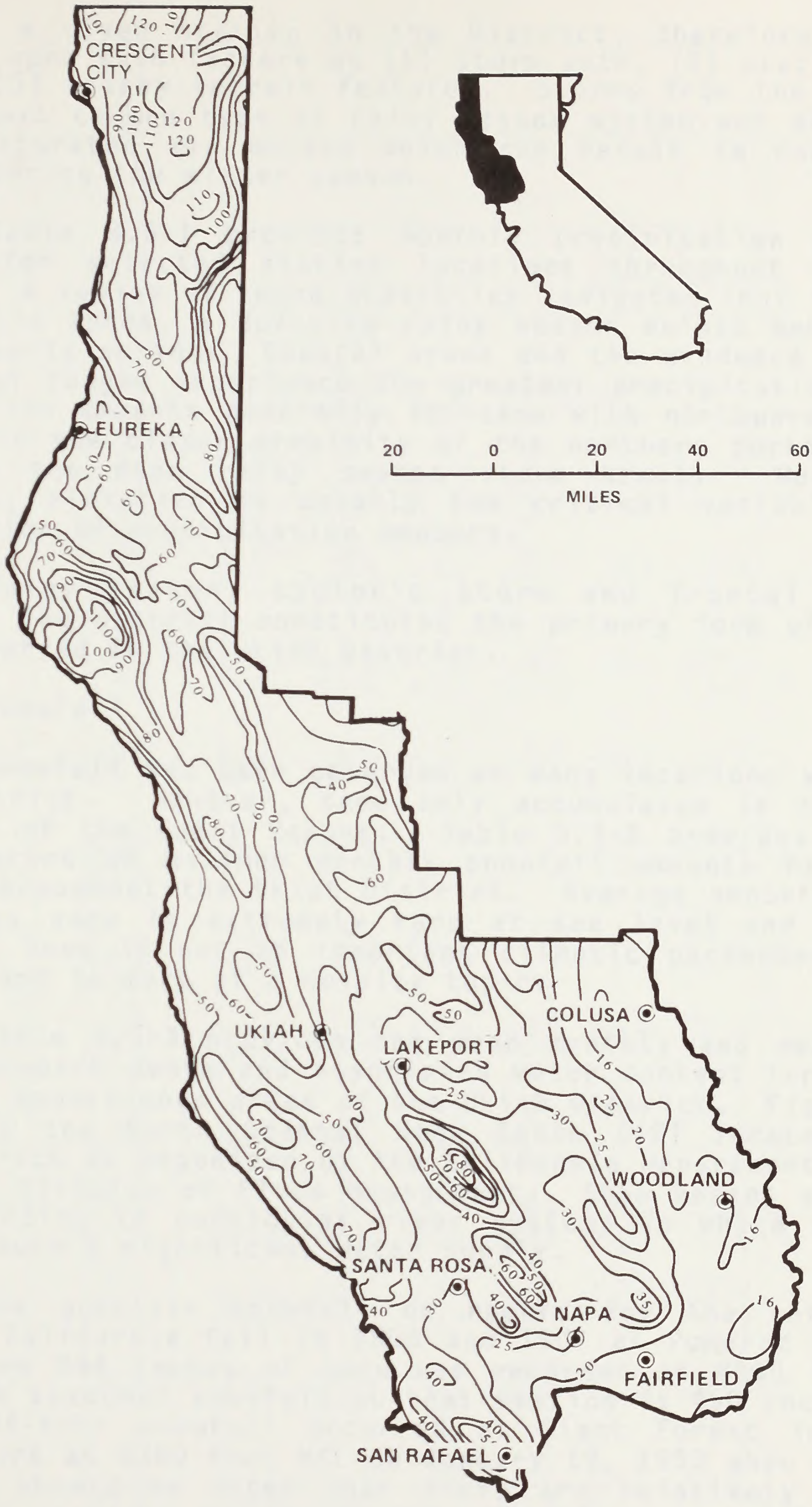


Figure 3.5-2

Mean Annual Precipitation (Inches) in the Ukiah District

tation at a given station in the District, therefore, will be dependent upon such factors as (1) storm path, (2) station elevation and (3) nearby terrain features. Storms from the northwest are the most common type of rainy season system and often bring heavily saturated air masses which can result in considerable flooding during the winter season.

Table 3.5-1 provides monthly precipitation means and extremes for selected station locations throughout the Ukiah District. A review of these statistics indicates that in each of the climatic zones, a definite rainy season exists between late fall and early spring. Coastal areas and the windward slopes of the coastal ranges experience the greatest precipitation totals. Precipitation amounts generally increase with northward progression due to the closer proximity of the northern portion of the region to the mean rainy season storm track. However, in California, elevation is usually the critical variable in the determination of precipitation amounts.

Rainy season, cyclonic storm and frontal activity throughout the district constitutes the primary form of precipitation observed in the Ukiah District.

3.5.3 Snowfall

Snowfall has been observed at many locations within the Ukiah District. However, snow only accumulates in the higher elevations of the Coast Ranges. Table 3.5-2 provides the historical record of maximum monthly snowfall amounts for various stations throughout the Ukiah District. Average amounts are not provided as snow is extremely rare at sea level and low-lying stations. Snow is not an important climatic parameter at such locations and is more of a novelty topic.

Table 3.5-3 provides the mean monthly and mean annual maximum snowpack depth and associated water content for stations within the mountainous areas of the Ukiah District. Figure 3.5-3 illustrates the North Coastal Snow Basin (#2) located in the Ukiah District as organized by the California Department of Water Resources, Division of Flood Management. Snow basins are determined according to particular river systems in which snow melt can contribute a significant water supply.

The greatest snowfall on record for the entire snow season in California fell in 1906 and 1907 at Pomerac in Alpine County where 884 inches of snow was recorded at 8000 feet MSL. The average seasonal snowfall at that station is 450 inches. The greatest 24-hour snowfall occurred at Giant Forest in Sequoia National Park at 6360 feet MSL on January 19, 1933 when 60 inches fell. It should be noted that there are relatively few snow observation stations in the Sierra, therefore, snowfall amounts in excess of these record amounts may have occurred.

Table 3.5-1

Ukiah Precipitation (Inches)

Monthly Means and Extremes

Station		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	
Crescent City	Mean	12.22	9.31	9.42	4.89	3.40	1.31	0.63	0.85	1.59	5.78	9.86	11.23	34.87	Coastal Zone
	Max	20.90	15.14	17.75	13.60	10.79	4.02	2.15	5.30	3.78	10.51	31.25	26.24	26.24	
	Min	1.72	2.08	1.11	0.76	0.29	0.00	0.00	0.01	0.00	1.06	2.69	0.46	0.00	
Eureka	Mean	7.15	6.16	5.26	5.76	1.78	0.68	0.11	0.27	0.24	1.28	5.49	6.34	39.70	
	Max	13.92	7.68	10.73	10.68	6.05	1.51	0.83	1.98	1.98	2.88	16.58	10.96	16.58	
	Min	1.68	1.20	1.23	0.14	0.06	T	0.00	0.00	T	T	1.72	0.52	0.00	
Scotia	Mean	10.21	7.71	6.45	3.53	1.39	0.52	0.06	0.36	0.70	2.90	7.13	9.57	50.17	
	Max	19.75	21.54	12.42	12.38	5.61	1.83	0.16	1.74	2.88	9.14	21.53	22.88	22.88	
	Min	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Healdsburg	Mean	10.20	6.56	4.59	2.78	0.55	0.30	0.08	0.27	0.47	2.47	6.05	7.92	42.23	
	Max	25.24	23.34	12.17	6.85	4.36	2.17	1.71	3.17	4.52	10.83	21.20	22.34	25.24	
	Min	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Santa Rosa	Mean	6.90	4.37	3.46	2.35	0.49	0.28	0.06	0.20	0.37	1.99	3.94	5.58	29.97	
	Max	15.89	11.94	6.87	6.72	3.93	1.94	1.61	1.68	3.16	9.47	13.23	17.89	17.89	
	Min	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
San Rafael	Mean	5.7	4.6	3.2	1.8	0.5	0.2	T	T	0.2	1.7	2.9	5.2	26.0	
	Max	3.6	3.2	2.3	2.8	0.8	1.8	T	0.1	2.3	3.9	3.3	3.9	3.9	
	Min	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Ukiah	Mean	8.86	5.90	4.55	2.42	0.75	0.27	0.07	0.22	0.38	1.98	5.26	7.62	38.35	Coastal Mountain Zone
	Max	23.52	19.49	9.96	.761	4.67	1.41	0.84	1.35	3.51	7.74	16.33	21.05	39.33	
	Min	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Davis 2WSW	Mean	3.90	2.64	1.86	1.25	0.34	0.14	0.03	0.06	0.21	1.01	2.21	3.08	16.74	Central Plain Zone
	Max	9.60	9.08	4.75	4.11	1.78	0.95	0.63	0.51	1.83	7.93	6.87	11.87	11.87	
	Min	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Sacramento	Mean	3.73	2.78	2.17	1.54	0.51	0.10	0.01	0.05	0.19	0.99	2.13	2.13	17.22	
	Max	8.50	8.77	5.62	4.76	3.13	0.63	0.79	0.65	1.61	7.51	7.41	12.60	12.60	
	Min	0.38	0.15	0.14	0.00	T	0.00	0.00	0.00	0.00	0.00	0.02	0.17	0.00	

Table 3.5-2

Ukiah District

Maximum Monthly Snowfall

Station	Month												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Scotia	1.3	0.3	1.0	0	0	0	0	0	0	0	0	2.5	2.5
Santa Rosa	0	0	0	6.5	0	0	0	0	0	0	0	0	6.5
Healdsburg	0.2	0	0.8	0	0	0	0	0	0	0	0	0	0.8
San Francisco	T	T	T	0	0	0	0	0	0	0	0	T	T
Ukiah	5.0	0	1.5	0	0	0	0	0	0	0	0	0	5.0
Davis	1.1	0.5	0	0	0	0	0	0	0	0	0	0	1.1
Sacramento	T	2.0	0	0	0	0	0	0	0	0	0	T	2.0

T = Trace (less than 0.01")

Table 3.5-3

Mean Snow Depth and Water Content (WC) in Inches at

Selected River-Snow Basin Stations in the Ukiah District

Basin	Course #	Lat. Deg	Lat. Min	Long. Deg	Long. Min	Mean Depth	Max. Annual WC	Jan Depth	Jan WC	Feb Depth	Feb WC	Mar Depth	Mar WC	Apr Depth	Apr WC	May Depth	May WC	# Years Depth	# Years WC	Elevation (feet)
North Coastal (2)	278	41	34.0	123	11.9	108.2	47.1	NA	NA	38.0	16.0	NA	NA	108.2	47.1	76.9	39.0	27	27	6200
North Coastal (2)	63	39	43.5	122	51.0	45.7	18.9	NA	NA	23.5	7.5	NA	NA	44.3	18.3	NA	NA	31	31	6000
North Coastal (2)	62	39	50.5	122	57.0	77.3	31.8	NA	NA	46.5	17.7	57.9	23.6	69.9	29.6	50.4	23.3	34	34	6200

Figure 3.5-3

Snow Basin Map

In the Ukiah District, at non-mountain stations, the maximum monthly snowfall occurred at Santa Rosa with an accumulation of 6.5 inches. At Ukiah, in Mendocino County, 5 inches of snow have occurred in January. Other monthly maximum snowfall data are presented in Table 3.5-2.

3.5.4 Precipitation Frequency

An analysis of rainfall intensity for selected areas offers added insight into regional precipitation characteristics. Rainfall frequency and intensity studies, sometimes referred to as pluvial indices, provide an understanding of the nature of precipitation and rainfall in a given region. Isopluvial maps facilitate an evaluation of rainfall intensity for particular areas over selected short-term time periods or intervals. Isohyet analyses coupled with isopluvial studies provide an indication of the nature of the precipitation means for the area, i.e., frequent light rains versus sporadic heavy rainstorms.

Appendix A provides isopluvial analyses for the Ukiah District as well as for the entire state of California. These figures provide information for the following return periods and rainfall duration times:

- 2 year-6 hour precipitation
- 5 year-6 hour precipitation
- 10 year-6 hour precipitation
- 25 year-6 hour precipitation
- 50 year-6 hour precipitation
- 100 year-6 hour precipitation
- 2 year-24 hour precipitation
- 5 year-24 hour precipitation
- 10 year-24 hour precipitation
- 25 year-24 hour precipitation
- 50 year-24 hour precipitation
- 100 year-24 hour precipitation

These maps present precipitation amounts received within designated time periods based on recurrence intervals of 2, 5, 10, 25, 50 or 100 years. For example, Figure A-1 provides isopluvials of precipitation amounts for a 6 hour period, experienced at least once in a 2 year time frame. The isoline intervals provided on these maps were designed to provide a reasonably complete description of isopluvial patterns in various regions of the state. Dashed intermediate lines are placed between the normal isopluvial intervals where a linear interpolation would lead to erroneous results.

Rainfall frequency values for selected key stations within the Ukiah District were obtained from the Appendix and summarized in Table 3.5-4. This table provides easy reference to pluvial indices for the climatic zones throughout the district. The tables and figures indicate that coastal and coastal mountain areas could expect the most intense rainfall amounts over a 6 or

Table 3.5-4

Pluvial Indices (in tenths of inches)

at Selected Stations in the Ukiah District

Time Frame	6 HOUR				24 HOUR			
Return Period	2 YR	10 YR	25 YR	50 YR	2 YR	10 YR	25 YR	50 YR
Station	Coastal							
Crescent City	22	30	34	36	45	65	80	80
Orick	20	27	30	33	45	68	75	85
Eureka	16.5	23	28	31	30	45	52	56
Bridgeville	20	26	30	32.5	47	65	75	80
Garberville	22	26	32	35	50	70	80	88
Ft. Bragg	17	21	25	29	34	45	50	55
Annapolis	27	36	40	43	60	80	95	95
Santa Rosa	18	23	26	27.5	34	45	50	60
Vallejo	14	19	21 x	22.5	25	33	45	45
	Coastal Mountain							
Ukiah	18	23	26	27.5	35	50	62	68
Cloverdale	24	30	38	38	50	72	79	90
Lakeport	14	18	20	22.5	30	44	52.5	60
	Coastal Plain							
Williams	12	16	17	19	20	27.5	32.5	36
Woodland	12	16	18.5	20	20	28	33	38
Dixon	14	20	24	27	24	35	42	45
Vacaville	16.5	22	27	29	32	47	55	62

24 hour period. At Annapolis, for example, rainfall could total as high as 6 to 10 inches in a single 24 hour period. At coastal and coastal mountain locations, 24-hour maxima are quite variable ranging between 4 and 8 inches slong the north coast and between 3 and 5 inches along the south coast. In the Sacramento Valley, maximum 24-hour values are generally betweed 2 and 4 inches. The isopluvial maps, as previously mentioned, strongly reflect the influence of topography on the nature of precipitation as evidenced by the values indicated in Table 3.5-4 for the District's mountainous areas.

3.6 PREVAILING WINDS

Wind is considered a primary climatic parameter since air flow characteristics directly affect ambient air moisture content and regional temperature levels. Seasonal and diurnal air flow patterns can promote periods of wet or dry weather as well as determine hot or cold climates. The prevailing winds are responsible for much of the climatic characteristics of an area and are deeply interrelated with other climatic parameters. The distribution of wind direction and wind speed are used to categorize this parameter.

Observations of wind direction are usually classified into the 16 cardinal compass directions using either a directional abbreviation or the heading in degrees. The degrees associated with each compass heading are listed in Table 3.6-1. Meteorological convention requires that the compass heading associated with a given wind observation is the direction from which the air is flowing. In other words, north or northerly winds mean that air is moving from north to south.

The following sections will describe wind on both an annual and seasonal basis. A primary tool used to graphically describe the prevailing wind conditions at a given station is known as a wind rose. As described in detail in Section 4.2.1, a wind rose is a plot of the frequency of winds from each of the sixteen cardinal directions. The diagram resembles a compass face with the length of the line drawn for each direction indicating the frequency of occurrence of flow from that direction for the indicated period of record.

3.6.1 Annual Wind Distribution

California lies within the zone of prevailing westerly winds and is situated on the east side of the Eastern Pacific semi-permanent high pressure center. Since general air flow patterns in the Northern Hemisphere are clockwise (anticyclonic) about high pressure centers, basic air flow over California is from the west and northwest. Figure 3.6-1 illustrates a typical pressure situation off the California coast and depicts the associated wind flow patterns. As the seasons progress, there exists considerable variation in this generalized scheme due to mesoscale (several hundred miles) and synoptic (thousands of miles) scale pressure distribution changes. Most importantly, several mountain chains within the state are responsible for deflecting the large scale flow. Except along the immediate coast, wind direction and speed is likely to be largely a function of local terrain and orographic effects rather than the prevailing circulation patterns observed in a hemispheric sense.

Figure 3.6-2 depicts various selected station locations in the Ukiah District for which reduced historical wind speed and direction data have been summarized. Annual wind roses are superimposed on this study map for selected key stations within

Table 3.6-1

Wind Direction Classification

Direction (Abbreviation)	Direction (Degrees)	Direction (Winds From)
N	348.75 - 11.25	North
NNE	11.25 - 33.75	North - Northeast
NE	33.75 - 56.25	Northeast
ENE	56.25 - 78.75	East - Northeast
E	78.75 - 101.25	East
ESE	101.25 - 123.75	East - Southeast
SE	123.75 - 146.25	Southeast
SSE	146.25 - 168.75	South - Southeast
S	168.75 - 191.25	South
SSW	191.25 - 213.75	South - Southwest
SW	213.75 - 236.25	Southwest
WSW	236.25 - 258.75	West - Southwest
W	258.75 - 281.25	West
WNW	281.25 - 303.75	West - Northwest
NW	303.75 - 326.25	Northwest
NNW	326.25 - 348.75	North - Northwest

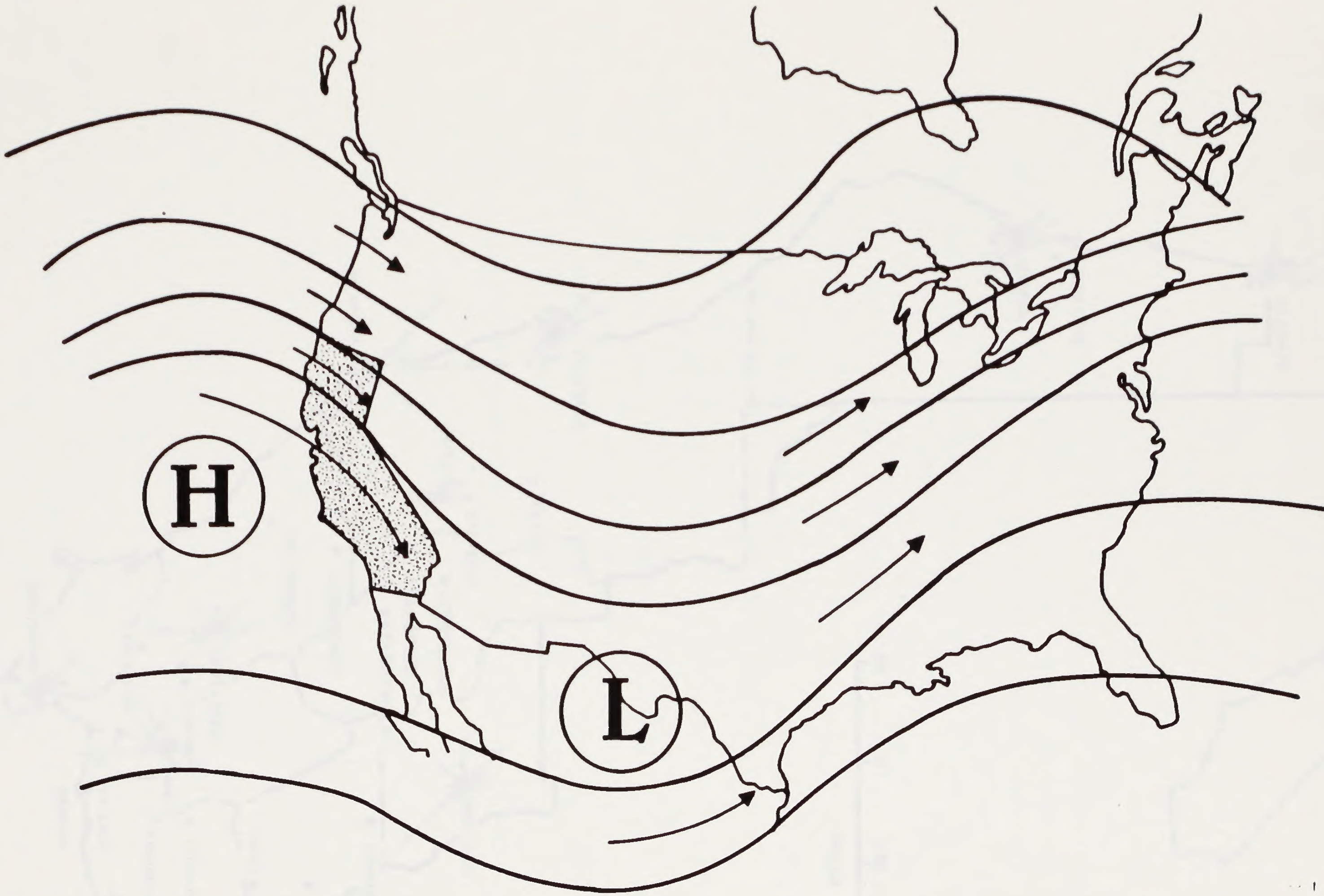


Figure 3.6-1
Prevailing Synoptic Scale Wind Flow Patterns Over California

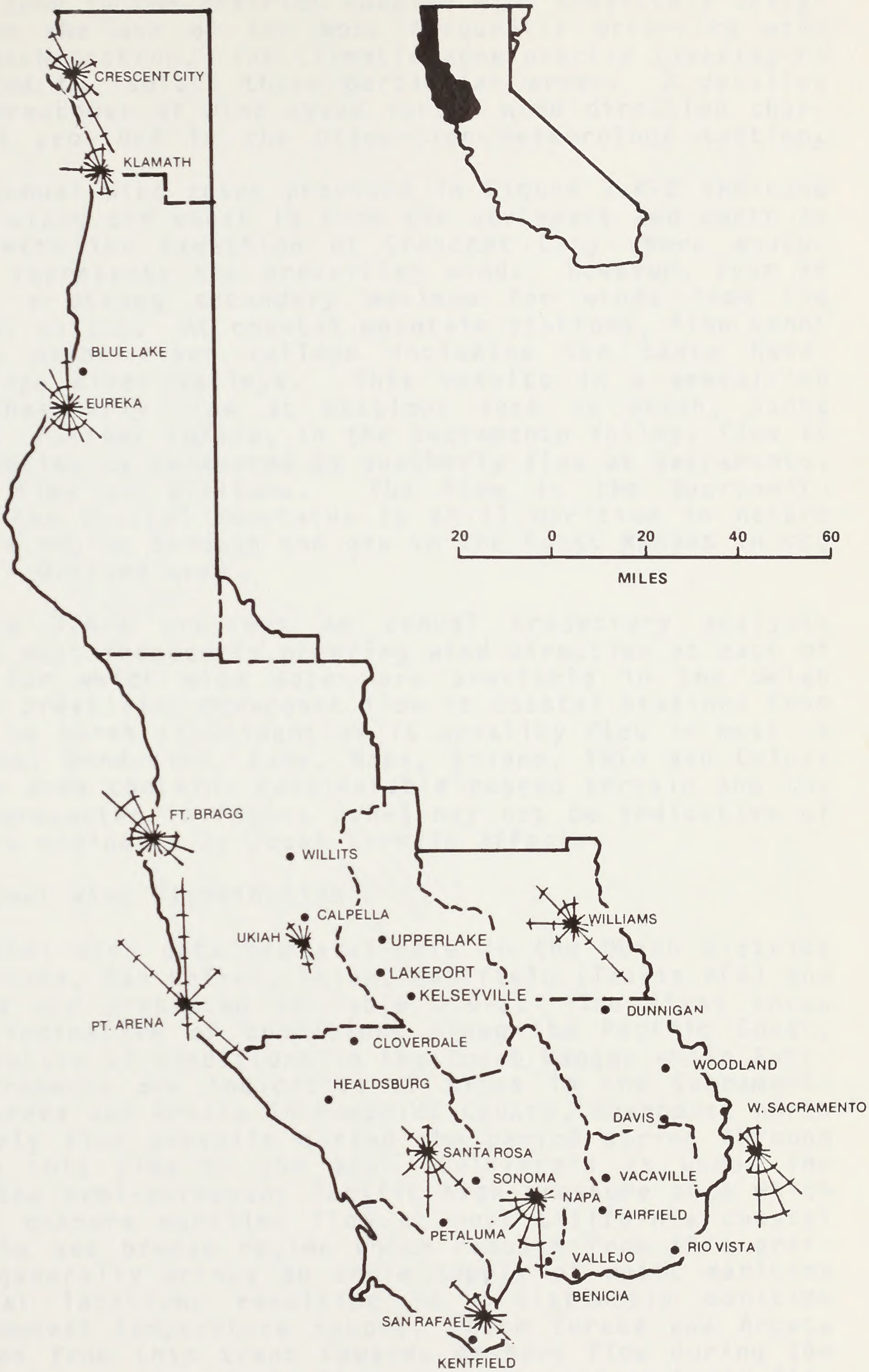


Figure 3.6-2
Annual Wind Roses at Selected Key Stations
in the Ukiah District

Note: Each Division on the Roses is Equal to an Annual Frequency of 5%.

Figure 3.4-3

Annual Wind Roses at Selected Key Stations in the Desert Region

Note: Each Division of the Roses is Equal to an Annual Frequency of 5%.

each climatic zone in the district coupled with trajectory analyses based upon the use of the most frequently occurring wind direction at each station. The climatic zone overlay (Overlay C) map may be used to isolate these particular areas. A detailed analysis and breakdown of wind speed versus wind direction characteristics is provided in the dispersion meteorology section.

The annual wind roses provided in Figure 3.6-2 indicate that the flow along the coast is from the northwest and north at all stations with the exception of Crescent City where southeasterly flow represents the prevailing wind. However, even at this station, a strong secondary maximum for winds from the north-northwest exists. At coastal mountain stations, flow tends to be up the major river valleys including the Santa Rosa, Russian and Napa River Valleys. This results in a prevailing south to southeasterly flow at stations such as Ukiah, Santa Rosa and Napa. Further inland, in the Sacramento Valley, flow is once again upvalley as evidenced by southerly flow at Sacramento, southeasterly flow at Williams. The flow in the Sacramento Valley and in the Coastal Mountains is still maritime in nature coming into the region through the gap in the Coast Ranges in the San Francisco - Oakland area.

Figure 3.6-3 provides an annual trajectory analysis based upon the most frequently occuring wind direction at each of the stations for which wind data were available in the Ukiah District. The prevailing downcoast flow at coastal stations from the northwest to north is evident as is upvalley flow in most of parts of Sonoma, Mendocino, Lake, Napa, Solano, Yolo and Colusa Counties. The area contains considerable rugged terrain and the wind flow as presented in Figure 3.6-3 may not be indicative of sites which are dominated by local terrain affects.

3.6.2 Seasonal Wind Distribution

Seasonal wind data are available in the Ukiah District for Eureka, Arcata, San Rafael, Ukiah, Fairfield (Travis AFB) and Sacramento and are presented in Table 3.6-2. The first three stations are indicative of conditions along the Pacific Coast. Ukiah is indicative of conditions in the Coast Ranges while Fairfield and Sacramento are indicative of sites in the Sacramento Valley. At Eureka and Arcata in Humboldt County, downcoast north to northwesterly flow prevails during the period spring through fall. During this time of the year, California is under the influence of the semi-permanent Pacific high pressure zone which results in an onshore maritime flow at most California coastal locations. The sea breeze regime which results from this pressure pattern generally brings an ample supply of moist maritime air to coastal locations resulting in a distinctly maritime climate with modest temperature ranges. Both Eureka and Arcata show deviations from this trend towards onshore flow during the winter months with southeasterly flow at Eureka and easterly flow at Arcata. During the winter months, drainage flow from inland each climatic zone in California, coupled with trajectory analyses based upon the use of the most frequently occurring wind direction at each station. The climatic zone overlay (overlay C) map may be used to assess these more major areas. A detailed analysis and breakdown of wind speed versus wind direction characteristics is provided in the dispersion meteorology section.

The annual wind roses provided in Figure 3.4-2 indicate that the flow along the coast is from the northwest and north at all stations with the exception of Crescent City where southeasterly flow represents the prevailing wind. However, even at this station, a strong secondary maximum for winds from the north-northwest exists. In coastal mountain locations, flow tends to follow the major valleys (including the Scott River, Russian and Hoopa valleys). This results in a prevailing south to southwesterly flow at stations such as Ukiah, Santa Rosa and Napa. Further inland, in the Sacramento Valley, flow in most areas is mainly evidenced by southerly flow at Sacramento, southeasterly flow at Williams. The flow in the Sacramento Valley and at the Coastal Mountains is still marine in nature flowing into the Valley through the gap in the coast ranges in the San Francisco - Oakland area.

Figure 3.4-3 provides an annual trajectory analysis based upon the most frequently occurring wind direction at each of the stations for which wind data were available in the Ukiah District. The prevailing downcoastal flow at coastal stations from the northwest to north is evident as is upvalley flow in most parts of Humboldt, Mendocino, Lake, Napa, Solano and Yolo Counties. The area contains considerable rugged terrain and the wind flow as presented in Figure 3.4-3 may not be indicative of areas which are influenced by local terrain effects.

3.4.2 Seasonal Wind Distribution

Seasonal wind data are available in the Ukiah District for Eureka, Arcata, Crescent City, Ukiah, Fairfield (Travis AFB) and Sacramento and are presented in Table 3.4-1. The first three represent the variation of conditions along the Pacific Coast, Ukiah is representative of conditions of the coast ranges while Fairfield and Sacramento are indicative of sites in the Sacramento Valley. At Eureka and Arcata in Humboldt County, a generally north to northwesterly flow prevails during the period spring through fall. During this time of the year, California is under the influence of the semi-permanent Pacific High pressure zone which results in a persistent northerly flow at most California coastal locations. The low pressure region which results from this pressure pattern typically brings an onshore supply of moist maritime air to coastal locations resulting in a relatively stable climate with modest temperature ranges. Both Eureka and Arcata show variations from this trend through southern flow during the winter months with southeasterly flow at Eureka and easterly flow at Arcata. During the winter months, offshore flow from inland

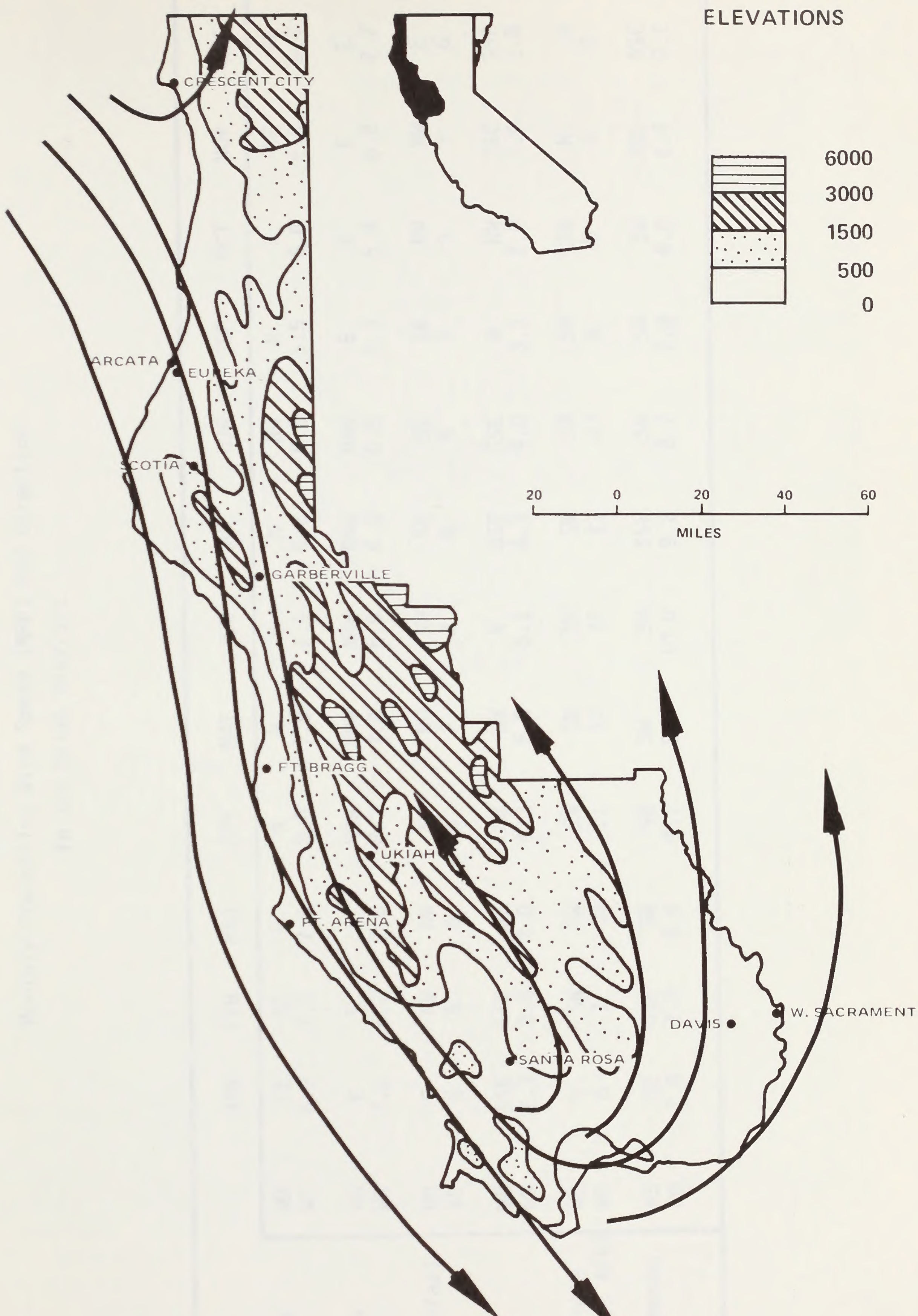


Figure 3.6-3
Trajectory Analyses for the Ukiah District

Table 3.6-2

Monthly Prevailing Wind Speed (MHP) and Direction in the Ukiah District

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Eureka	WD	SE	SE	N	N	N	N	N	NW	N	N	SE	SE
	WS	6.9	7.2	7.6	8.0	7.9	7.4	6.8	5.8	5.5	5.6	6.0	6.4
Arcata	WD	E	E	E	NNW	NNW	NNW	NNW	NNW	E	E	E	E
	WS	7.5	6.8	7.6	8.3	7.4	6.9	6.3	5.5	5.3	5.4	6.2	7.7
San Rafael	WD	E	NW	NW	NW	NW	NW	SE	SE	SE	NW	NW	E
	WS	6	6	6	6	7	7	6	6	5	5	5	6
Ukiah	WD	SSE	SSE	NW	NW	NW	N	SSE	SSE	N	NW	SSE	SSE
	WS	2.3	3.5	4.0	4.3	5.0	5.1	4.5	4.0	3.3	2.9	1.9	1.8
Fairfield	WS	N	SW	SW	SW	SW	SW	SW	SW	SW	SW	N	SW
(Travis AFB)	WD	6	7	10	11	13	15	13	11	8	5	5	8
Sacramento	WS	SE	SSE	SW	SW	SW	SW	SSW	SW	SW	SW	NNW	SSE
	WD	7.8	7.9	9.0	9.1	9.4	10.0	9.2	8.7	7.8	6.8	6.4	7.1

areas of substantial terrain tends to dominate the annual distribution. This offshore component is further supplemented by southeasterly and easterly flow in advance of migratory pressure systems during the rainy season months.

Further down the coast at San Rafael, the prevailing distribution is somewhat more erratic. Northwesterly flow dominates during most months but is absent during midwinter as well as during late summer and early fall. Once again, the northwesterly flow is indicative of the maritime sea breeze regime while southeasterly and easterly flow at San Rafael represents a combination of upvalley flow as well as outflow from the Central Valley of California.

Ukiah is representative of conditions at an inland valley location. Here, the trend is similar to that observed at San Rafael. South-southeasterly flow prevails during the winter months and during late summer while north and northwesterly flow dominates during other periods of the year. The northwesterly flow is indicative of the general down coastal flow observed in Northern California particularly during the summer months. The switch to south-southeasterly flow again occurs in late summer as surface heating becomes most intense and topographical influences dominate. This results in upvalley flow as warm air masses tend to move upslope. During the winter months, the south-southeasterly flow reflects the heavy influence of migratory storm systems which result in southerly and southeasterly flow on many occasions, particularly in Northern California.

Finally, Fairfield and Sacramento provide data indicative of conditions in the Sacramento Valley portion of the Ukiah District. Southwesterly flow dominates at Fairfield as maritime air moves inland through the Carquinez Straits. At Sacramento, southwesterly flow dominates during the summer as maritime air comes in through the Carquinez Straits and upvalley into the Sacramento Valley. During winter, southeasterly and south-southeasterly flow is evident as noted at most stations within the District.

At coastal and coastal mountain stations, wind speeds tend to be strongest during the period April through June. Down coastal flow is well established during this period resulting in brisk winds ranging from 5 knots at Ukiah to over 8 knots at Eureka and Arcata during April. Wind speeds tend to be lowest at these locations during the fall months. At Fairfield and Sacramento in the Sacramento Valley, wind speeds are clearly strongest during summer when the maritime influence of the sea breeze is strongest as air rushes through the San Francisco-Oakland area moving southward into the San Joachin Valley and northward into the Sacramento Valley. Wind speeds tend to be lowest in this area, once again, during the fall months.

3.7 EVAPORATION AND RELATED PARAMETERS

Evaporation is the physical process by which water is transformed from the liquid to the gaseous state. The rate of evaporation in a particular region is dependent upon many climatic parameters, but is primarily influenced by wind, temperature, relative humidity, sky conditions, precipitation and solar radiation.

Evapotranspiration is the process whereby water vapor is returned to the atmosphere both by living plants (transpiration) and from the earth's surface (evaporation). An assessment of regional evapotranspiration is important to the water and agricultural industries as it provides a complete picture of natural water demand for a given geographical area.

Solar radiation is the earth's principle source of energy. This energy is naturally dispersed in numerous forms such that much of the received solar energy is used to generate winds, heat air masses, as well as supply latent heat energy to the atmosphere by contributing to the rate of evaporation of large quantities of water into the atmosphere. Consequently, mean monthly and annual solar radiation levels for particular locations are often expressed in terms of equivalent evaporation units. The standard conversion of solar radiation units, as expressed in Langleys, to inches of evaporation, requires that 1 inch of evaporation be equivalent to 1486 Langleys.

3.7.1 Evaporation and Evapotranspiration

The California State Department of Water Resources has determined regional evaporative demand areas on the basis of similar monthly levels of evaporation and evapotranspiration rates. These areas are provided in Figure 3.7-1 for the entire state of California.

The Ukiah District includes three of the eleven statewide zones of similar evaporative demand. A contour map depicting areas of equal annual evaporative demand levels for the Ukiah District is provided as Figure 3.7-2. Note that a considerable gradient of evaporative demand exists. These rapid changes in regional evaporation rate are a result of the considerable difference between the nearby Pacific Ocean and the Sacramento Valley. Air masses along the coast experience modest temperature variations coupled with high relative humidity. These factors significantly limit the potential rate of evaporation since the ambient air has a diminished ability to hold additional water vapor. This is diammetrically opposed to the evaporative potential of the dry valley areas further east.

A comparison of annually averaged evaporative demand and evapotranspiration rates for different geographical areas can lead to ambiguous results. Annual evaporative totals for two areas may be similar, but monthly patterns of evaporation and

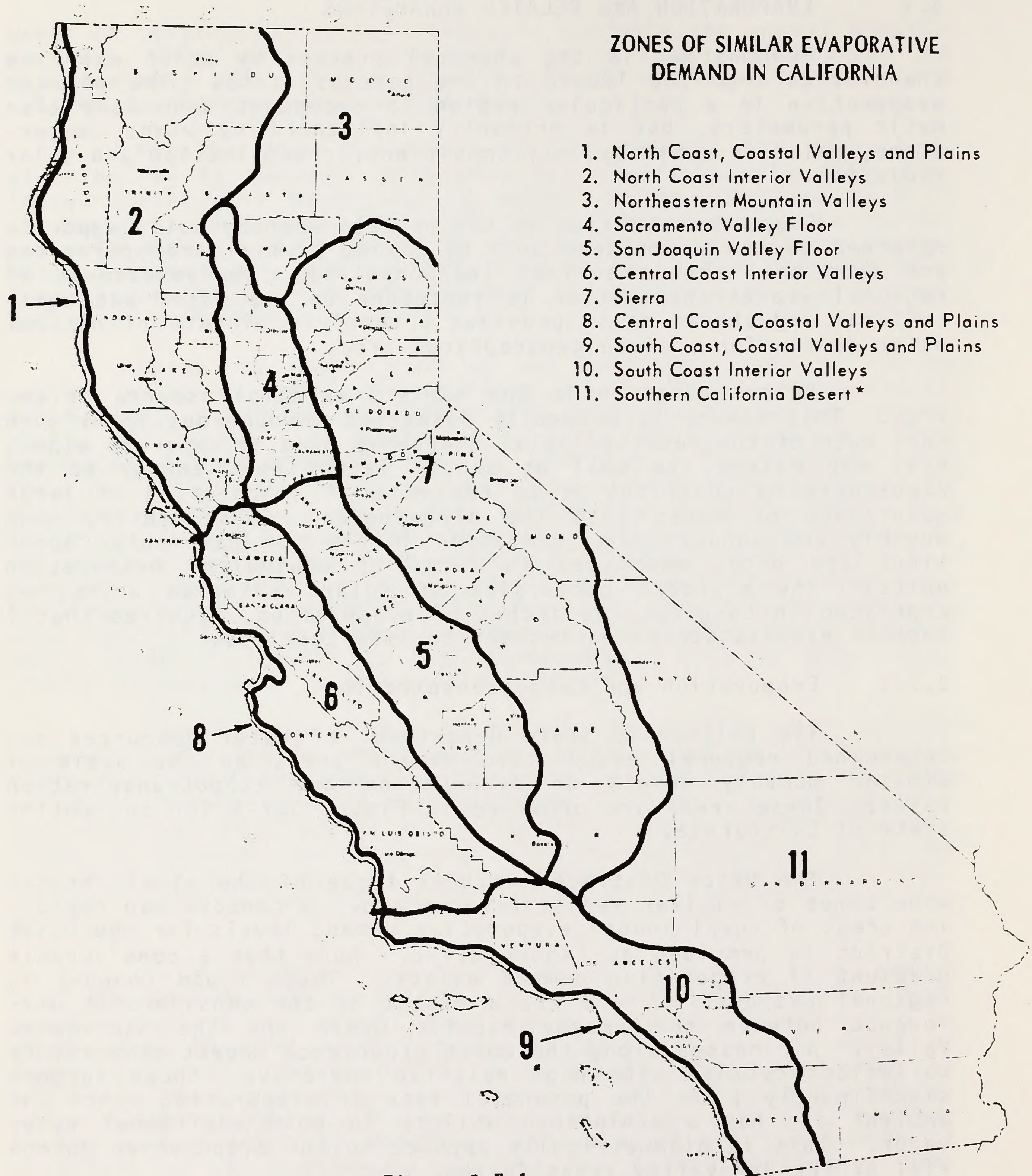


Figure 3.7-1

Source: "Vegetative Water Use in California, 1974", State of California Department of Water Resources

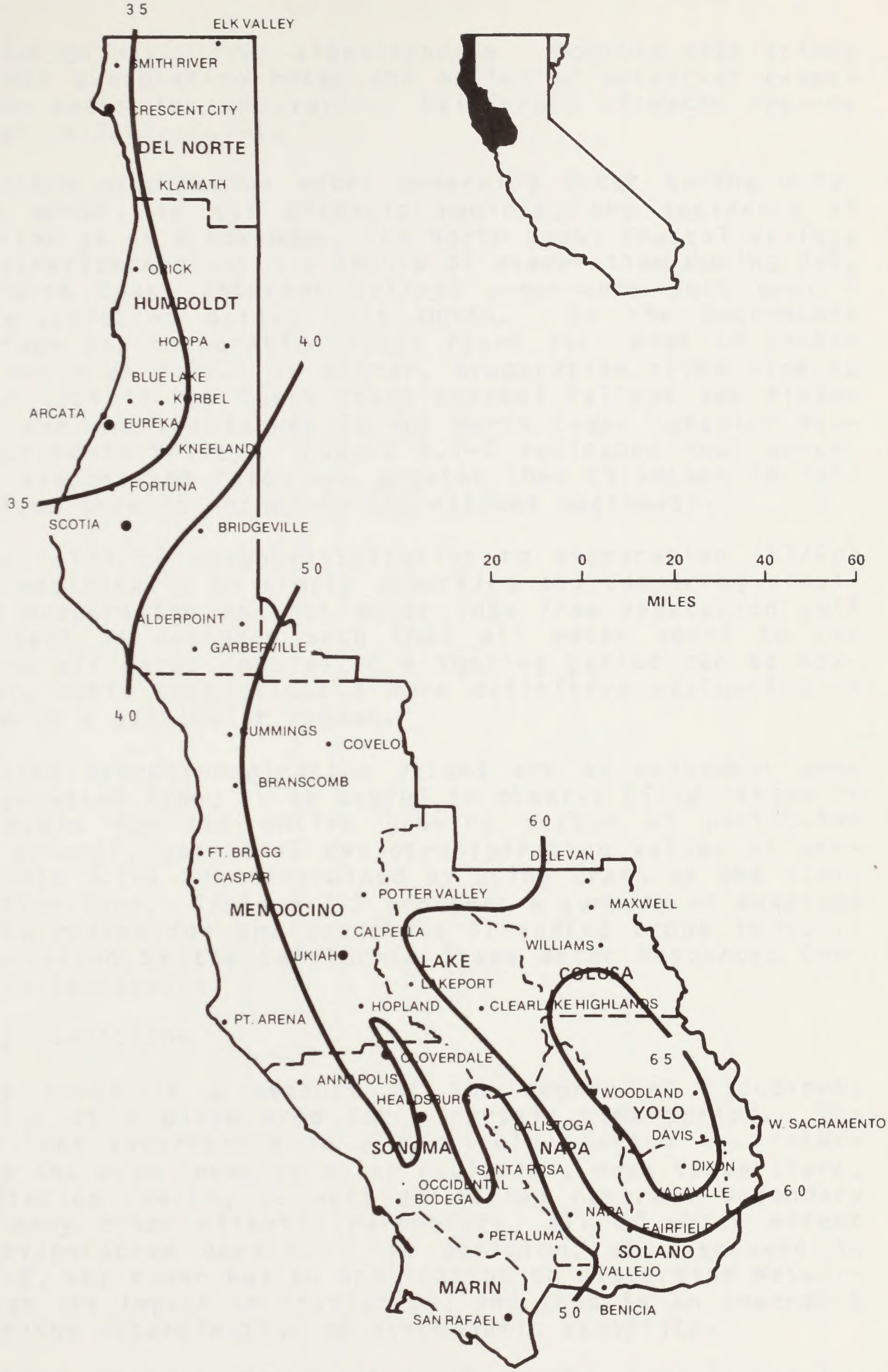


Figure 3.7-2
Annual Evaporative Demand
in the Ukiah District

Estimated from evaporation observed in non-irrigated environments adjusted to appropriate evaporation from Class "A" pans in irrigated pasture environments.

Figure [illegible]

Annual Evaporative Demand

in the [illegible] Districts

Estimated from [illegible]

[illegible]

evapotransiration may differ significantly. Monthly tabulations of average pan evaporation rates and estimated potential evapotranspiration rates for the various California climatic regions are presented in Table 3.7-1.

Maximum evaporation rates generally occur during July. During this month, in all climatic regions, the incidence of solar radiation is at a maximum. The North Coast Coastal Valleys and Plains experience about 4.5 inches of evaporation during July while the North Coast Interior Valleys experience just over 9 inches of evaporation during this month. In the Sacramento Valley, average pan evaporation rates reach just over 10 inches during the month of July. In winter, evaporation rates drop to less than an inch in the North Coast Coastal Valleys and Plains and between one and two inches in the North Coast Interior Valleys and Sacramento Valley. Figure 3.7-2 indicates that annual average pan evaporation rates are greater than 65 inches in Yolo County and less than 35 inches in the extreme northwest.

The ratio of evapotranspiration to evaporation (ET/Ep) is obtained empirically by simply observing and comparing simultaneous pan evaporation and net water loss from vegetation soil tanks (the tank is designed such that all water added to the apparatus and all water left after a testing period can be measured). This ratio thus allows a more definitive evaluation of water demand in a particular region.

Since evapotranspiration values are so dependent upon crop and vegetation type, it is useful to observe ET/Ep ratios on a monthly basis for the entire growing season of particular crops. In general, potential evapotranspiration values as presented in Table 3.7-1 are determined by using grass as the standard vegetation type. Table 3.7-2 provides a summary of observed monthly ET/Ep ratios for the principle irragated crops in California as provided by the California State Water Resources Control Board in Sacramento.

3.7.2 Sky Conditions

Sky cover is a measure of the degree of cloudiness characteristic of a given area for a certain time period. Sky cover conditions experienced in a particular region are interrelated with the mean incoming solar radiation, mean temperature, and precipitation levels, as well as having numerous secondary effects on many other climatic parameters, all of which effect the local evaporative demand. In addition, as discussed in Section 4.2-2, sky cover has an application to dispersion meteorology through its impact on insolation, and thus is an important parameter in the determination of atmospheric stability.

Clouds substantially insulate the surface from receiving large quantities of solar energy. Reflection and scattering of light energy from cloud tops and cloud interiors contribute significantly to the overall reduction of light received at

Table 3.7-1

Average Monthly Pan Evaporation Rate[1] and Estimated Potential Evapotranspiration[2], in the Ukiah District

Evaporation Region		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	March through October[3]	Annual Total
North Coast Coastal Valleys & Plains	EP	0.7	1.3	2.6	3.2	4.2	4.6	4.5	4.3	3.5	2.3	1.5	1.0	29.3	33.8
	ET	0.5	1.0	2.0	2.5	3.3	3.6	3.5	3.4	2.8	1.7	1.1	0.7	22.8	26.1
North Coast Interior Valleys	EP	1.2	1.6	3.1	4.4	6.4	7.6	9.1	8.0	6.0	3.6	1.6	1.0	48.2	64.0
	ET	0.8	1.2	2.4	3.4	5.0	5.9	7.1	6.2	4.6	2.7	2.3	0.7	37.3	41.2
Sacramento Valley	EP	1.5	2.4	3.9	5.7	7.5	9.3	10.1	8.6	6.8	4.6	2.2	1.4	56.5	64.0
	ET	1.1	1.8	3.0	4.4	5.8	7.3	7.9	6.7	5.2	3.4	1.6	1.0	43.7	49.2

(1) Evaporation from USWB - Class "A" Pans located in irrigated pasture environment.
(2) Potential ET = ET of grass.
(3) March through October is the principal growing season.

Table 3.7-2

Summary of Observed Monthly ET/Ep Ratios for Principal Irrigated Crops 1/

Crop	Location	Observer	Year	Active Growing Season	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Growing Season Average
Alfalfa (Hay)	Arvin 2.5NW	DWR	1959	Mar-Oct	-	-	-	0.64	0.52	0.64	0.63	0.70	0.90	0.71	1.04	1.12	-
			1960	"	-	-	-	-	-	0.77	0.64	0.81	0.67	0.63	-	-	-
			1963	"	1.00	0.88	0.72	0.73	0.78	0.73	0.86	0.90	0.85	0.91	0.70	1.00	0.81
			Average		1.00	0.88	0.72	0.69	0.64	0.71	0.71	0.80	0.81	0.75	0.88	1.17	0.73
	McArthur 4ESE	DWR	1960	Apr-Sep	-	-	-	-	-	0.64	0.81	0.97	0.86	0.95	-	-	-
			1961	"	-	-	0.28	0.83	0.87	0.77	-	0.86	0.85	0.51	0.33	0.14	-
			1962	"	-	-	-	0.74	0.92	0.72	0.61	0.61	1.06	-	-	-	0.75
			1963	"	-	-	-	-	0.98	0.88	0.90	0.79	0.77	0.79	1.63	-	-
			1964	"	-	-	-	0.67	1.27	0.52	0.68	0.85	0.71	1.18	-	-	0.78
			1965	"	-	0.70	0.69	0.41	0.85	0.90	0.80	0.96	1.19	-	-	-	0.87
			Average		-	0.70	0.52	0.69	0.98	0.74	0.76	0.83	0.91	0.87	0.83	0.14	0.82
Barley	Davis 2W (Grain Crop)	U.C.	1969-70	Nov-May	0.70	0.95	0.72	0.64	0.25	-	-	-	-	-	0.27	0.50	0.52
	Wasco 2W (Grain Crop)	DWR	1972	Feb-May	-	0.48	1.22	0.83	0.18	-	-	-	-	-	-	-	0.62
	Arvin 2.8NW (Winter Cover)	DWR	1966-67	Oct-Dec	-	-	-	-	-	-	-	-	-	0.12	0.90	0.95	0.46
Beans (Dry)	Davis 2W	U.C.	1968	Jul-Sep	-	-	-	-	-	-	0.42	0.85	0.43	-	-	-	0.56
Cantaloupes	Arvin 2.5S	DWR	1970	Mar 25-Jul 10	-	-	-	0.15	0.32	0.86	0.38	-	-	-	-	-	0.48
Castor Beans	Arvin 2.9NW	DWR	1970	May-Oct	0.49	0.28	0.32	0.06	0.14	0.67	1.01	0.95	0.78	0.69	0.39	0.44	0.71
Corn (Field)	Davis 2W	U.C.	Average 1970-71	Jun-Sep	-	-	-	-	0.12	0.48	0.89	0.84	0.50	-	-	-	0.62

1/ Ratios of observed evapotranspiration to evaporation from Class "A" pans in irrigated pasture, or comparable environments data collected by Department of Water Resources and/or cooperative agencies.
2/ Growing season ratios calculated from seasonal totals of ET and evaporation.

Source: "Vegetative Water Use in California, 1974", State of California Department of Water Resources

Table 3.7-2 (Continued)

Summary of Observed Monthly ET/Ep Ratios for Principal Irrigated Crops 1/

Crop	Location	Observer	Year	Active Growing Season	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Growing Season Average
Cotton	Arvin 2.5NW (Solid Plant)	DWR	1959	May-Oct	-	-	-	-	0.19	0.81	1.09	0.91	0.86	0.68	0.08	-	0.77
			1960	"	-	-	0.26	0.14	0.03	0.53	1.07	1.10	0.82	0.24	0.53	0.36	0.66
			1961	"	0.44	0.54	0.28	0.06	0.14	0.55	0.90	1.05	0.92	0.54	0.29	0.33	0.69
			Average		0.44	0.54	0.27	0.10	0.13	0.63	1.02	1.01	0.87	0.49	0.26	0.33	0.70
	Arvin 2.5NW (Skip 2 x 2)	DWR	1962	May-Oct	0.38	0.32	0.23	0.14	0.08	0.37	0.88	0.92	0.83	0.41	0.14	-	0.59
	Arvin 2.5NW (Skip 2 x 1)	DWR	1963	May-Oct	0.06	0.33	0.22	0.28	0.20	0.49	0.91	1.06	0.87	0.76	0.20	0.25	0.70
	Buttonwillow 2.5SE (Skip 2 x 2) (Fine textured soil)	DWR	1965	May-Oct	-	-	-	-	0.07	0.15	0.68	0.88	0.62	0.26	0.14	0.26	0.46
Deciduous Orchard	Arvin 3NNW (Plums)	DWR	1959	Apr-Oct	-	-	-	0.51	0.70	0.69	0.83	0.76	0.42	0.23	0.04	-	0.59
			1960	"	-	-	-	-	-	0.82	0.92	0.79	0.77	0.34	0.21	-	-
			1962	"	0.38	0.68	0.26	0.36	0.59	0.62	0.66	0.48	0.68	0.87	0.91	0.33	0.61
			1963	"	0.39	0.71	0.56	0.92	0.67	0.61	0.69	0.90	0.94	0.82	0.84	0.38	0.79
			1964	"	0.53	0.33	-	-	-	0.57	0.83	0.86	0.95	0.88	0.32	0.60	-
			Average		0.44	0.56	0.42	0.56	0.65	0.66	0.78	0.76	0.74	0.62	0.43	0.43	0.69
Grain Sorghum (Milo)	Bakersfield 9W	DWR	1971	Jul-Oct	-	-	-	-	-	-	0.26	0.91	0.82	0.40	-	-	0.58
Pasture (Improved) & Grass	Arvin 2.5NW (Grass)	DWR	1959-65 Average	Mar-Oct	0.50	0.72	0.82	0.75	0.81	0.74	0.82	0.88	0.88	0.90	0.81	0.69	0.82
	Davis 2W (Grass)	U.C.	1959-71 Average	"	0.79	0.75	0.70	0.73	0.77	0.78	0.79	0.79	0.74	0.68	0.64	0.73	0.76
	Davis 2W (Grass)	DWR	1959-60 Average	"	0.50	0.51	0.67	0.74	0.76	0.50	0.78	0.76	0.73	0.64	0.53	0.40	0.69
	Glenburn 0.3SE (Improved Pasture)	DWR	1964-66 Average	Apr-Sep	-	-	-	0.70	0.70	0.79	0.74	0.96	0.86	0.76	0.45	-	0.79
	Guadalupe 2NW (Improved Pasture)	SLOFC & DWR	1963-67 Average	Mar-Oct	0.77	0.81	0.78	0.82	0.78	0.69	0.77	0.85	0.84	0.87	0.87	0.79	0.79
	Lompoc 1N (Grass)	ARS	1968-70	"	0.44	0.75	0.80	0.69	0.73	0.64	0.75	0.69	0.55	0.67	0.69	0.50	0.69
	San Luis Obispo 1NW (Improved Pasture)	CSPC & DWR	1969-72 Average	"	0.92	0.84	0.74	0.59	0.76	0.62	0.72	0.59	0.71	0.63	0.82	0.82	0.67
	Soledad 3.5NW (Improved Pasture)	CDC & DWR	1963-70	"	0.75	0.79	0.77	0.77	0.71	0.68	0.75	0.82	0.75	0.78	0.82	0.64	0.75
	Thornton 2S (Improved Pasture)	DWR	1963-68	"	0.78	0.64	0.73	0.89	0.85	0.85	0.81	0.78	0.75	0.70	0.62	0.62	0.81

Table 3.7-2 (Continued)

Summary of Observed Monthly ET/Ep Ratios for Principal Irrigated Crops 1/

Crop	Location	Observer	Year	Active Growing Season	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Growing Season Average
Pasture (Native) (High Water Table	Alturas 2SE Meadow)	DWR	1959	Apr-Sep	-	-	-	0.94	0.98	1.14	1.06	1.05	0.96	0.78	-	-	1.03
			1960	"	-	-	-	0.67	0.81	0.82	1.09	1.12	1.02	0.97	-	1.33	0.95
			1961	"	0.17	0.47	0.74	0.78	1.00	1.00	1.19	0.96	1.12	1.00	-	-	1.02
			1962	"	-	-	0.35	0.72	0.76	0.86	0.96	0.98	0.95	0.77	0.69	0.60	0.88
			1963	"	0.42	0.36	0.48	0.59	0.61	0.98	0.81	0.89	0.89	0.83	-	-	0.82
			1964	"	-	-	-	0.56	0.66	0.86	0.93	0.99	0.89	0.86	-	-	0.85
			Average	"	0.44	0.40	0.56	0.75	0.80	0.94	1.00	1.00	0.96	0.85	0.69	0.88	0.93
Pasture (Native) (Continued)	Lookout 3S	DWR	1961	Apr-Sep	0.20	0.30	0.42	0.68	0.82	1.00	0.84	0.97	0.94	0.77	-	-	0.88
			1962	"	-	-	-	0.69	0.95	0.84	0.87	0.82	0.85	0.70	0.62	0.56	0.84
			1963	"	-	-	0.61	-	-	0.94	1.06	0.99	1.00	1.15	-	-	-
			Average	"	0.20	0.30	0.50	0.68	0.88	0.92	0.92	0.92	0.92	0.86	-	-	0.88
Potatoes	Arvin 2.8NW	DWR	1966	Apr-Jun	-	-	-	0.91	1.01	0.49	-	-	-	-	-	-	0.87
			1967	"	-	-	0.50	0.66	0.90	0.51	0.38	-	-	-	-	-	0.66
			Average	"	-	-	0.50	0.83	0.94	0.49	0.38	-	-	-	-	-	0.76
Sugar Beets	Arvin 2.5S	DWR	1966	Apr-Jul	-	-	-	0.68	1.01	1.02	0.68	-	-	-	-	-	0.86
	Davis 2W	U.C.	1965	Jul-Oct	-	-	-	-	-	-	0.41	0.92	0.88	0.88	0.57	-	0.66
			1966	Apr-Sep	-	-	-	0.17	0.36	0.86	0.93	0.83	0.91	-	-	-	0.64
Tomatoes	Arvin 2.5NW	DWR	1968	Apr-Jul	-	-	-	0.14	0.72	0.70	0.50	-	-	-	-	-	0.53
			1969	"	-	-	-	0.35	0.86	0.98	0.82	-	-	-	-	-	0.78
			Average	"	-	-	-	0.25	0.80	0.84	0.76	-	-	-	-	-	0.64
	Davis 2W	U.C.	1969		-	-	-	-	0.22	0.39	0.87	0.90	0.62	-	-	-	0.59
Vineyard	Arvin 1NW (Thompson Table Grapes)	DWR	1966	May-Oct	-	-	-	-	0.41	0.57	0.79	0.45	0.30	-	-	-	-
			1967	"	-	-	-	-	-	0.51	0.66	0.79	0.64	0.32	0.04	0.50	-
			1968	"	0.50	0.31	0.16	0.13	0.62	0.68	0.58	0.51	0.65	0.24	0.11	0.42	0.58
			1969	"	0.87	0.20	0.11	0.11	0.35	0.68	0.72	0.65	0.64	0.38	0.12	0.15	0.60
			Average	"	0.62	0.27	0.15	0.12	0.46	0.61	0.67	0.62	0.55	0.32	0.08	0.35	0.56

ground level. Generally, cloud cover is classified according to various categories. These categories include clear or cloudless sky conditions, mostly clear skies, partly cloudy conditions, mostly cloudy and cloudy conditions, or completely overcast skies. In order to make sky cover observations more definitive, these observations are defined in terms of categories using fractional units expressed in tenths of the sky covered by clouds (See Table 3.7-3).

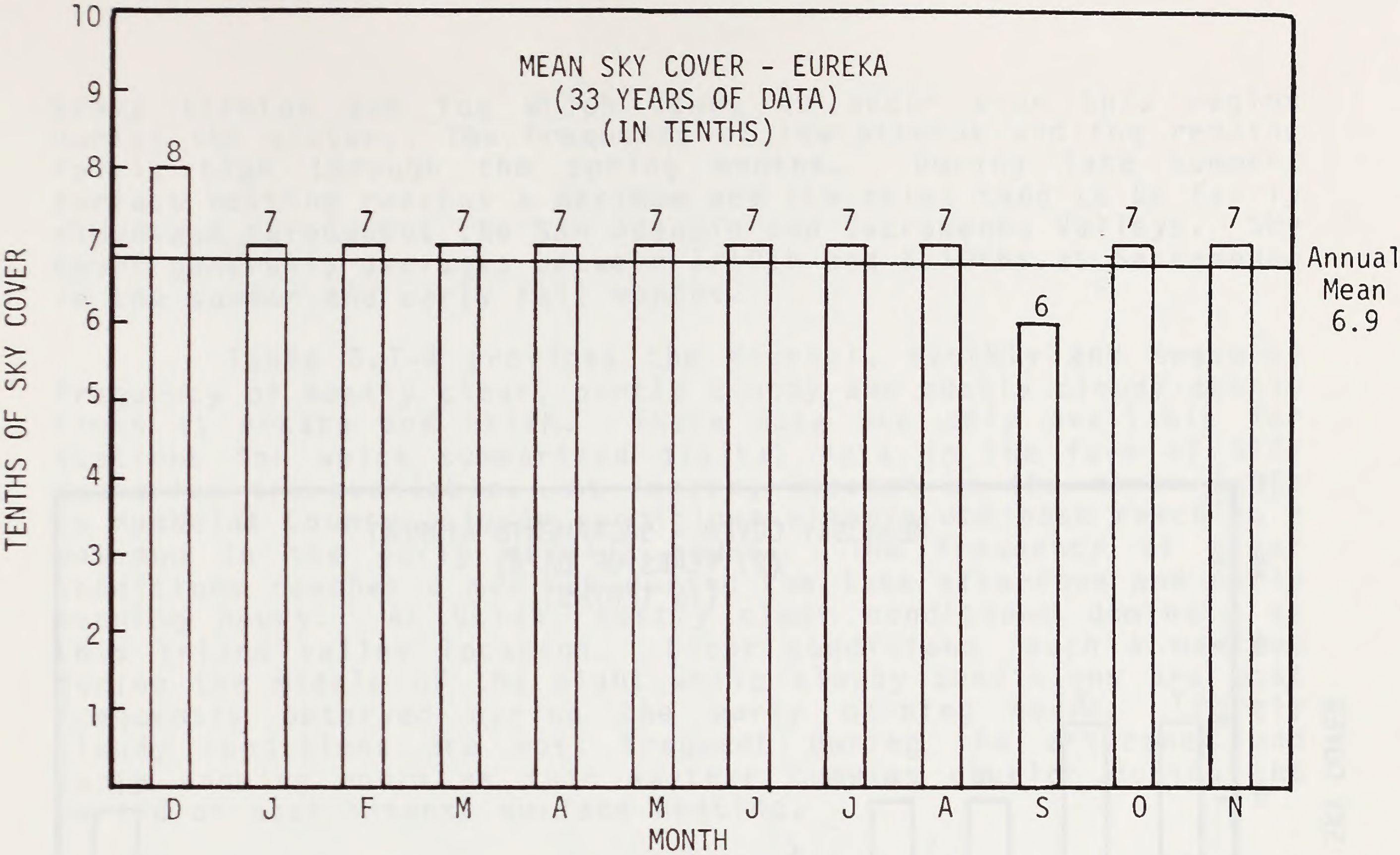
Table 3.7-3
Sky Cover Categories

Generalized Category	Sky Cover in Tenths
clear	0
mostly clear	0-3
partly cloudy	4-7
mostly cloudy	8-10
cloudy or complete overcast	10

Mean monthly and annual sky conditions at coastal and valley stations are provided in Figures 3.7-3 and 3.7-4. At Eureka, very little variation is evident as a function of the season of the year. The mean sky cover ranges from 6/10ths to 8/10ths with a maximum occurring during December and a minimum occurring during September. During all other months of the year, sky cover totals 7/10ths at Eureka. This station is heavily influenced by the maritime influx of air from the Pacific Ocean. Onshore flow dominates during all months of the year and fog and low stratus are quite common. The maximum for cloud cover during the winter represents the increased frequency of migratory low pressure systems during this month while the minimum in September reflects the generally good weather experienced throughout California during fall due to the presence of the semi-permanent eastern Pacific high pressure system.

Further down the coast at San Rafael, considerable variability is evident in the sky cover data ranging from 1/10th during August and September to a maximum of 6/10ths during December and January. The low frequency of cloudiness during the summer months is once again indicative of the improved sky cover conditions experienced at most California coastal stations during late summer. The high frequency of cloudiness during winter reflects the increased frequency of storm systems passing through the area. In addition, cloud cover remains fairly high through May, representing the influence of maritime air in this region during the spring months and the fairly high frequency of occurrence of low cloudiness and fog.

At Sacramento in the central plain climatic zone, conditions are similar to those experienced at San Rafael. Cloudiness reaches a peak in mid-winter with a minimum during late summer and early fall. The winter maximum reflects both the increased frequency of the passage of migratory storm systems as well as



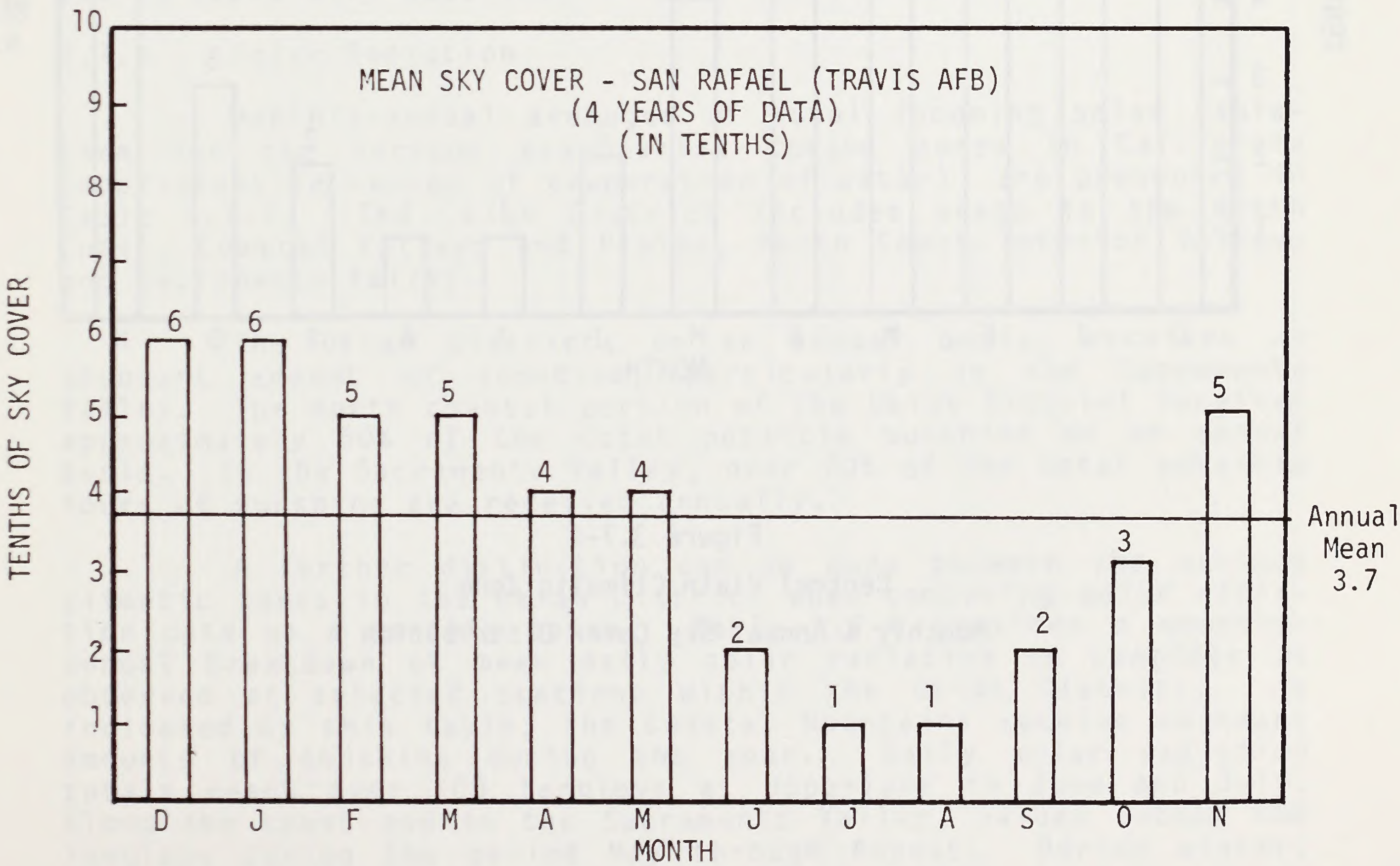


Figure 3.7-3

Coastal Climatic Zone

Monthly and Annual Sky Cover Distribution

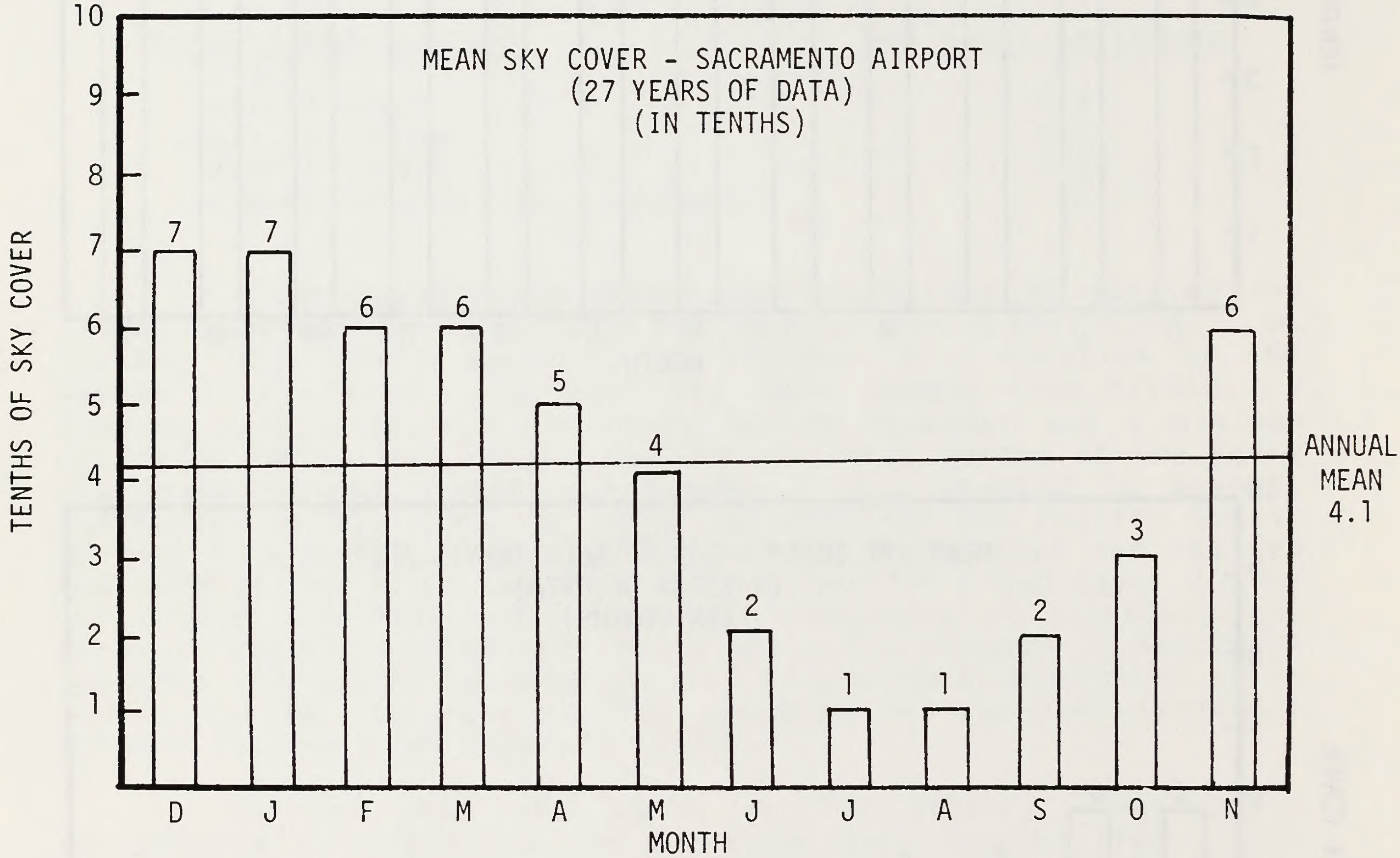


Figure 3.7-4

Central Plain Climatic Zone

Monthly & Annual Sky Cover Distribution

heavy stratus and fog which tends to occur over this region during the winter. The frequency of low stratus and fog remains fairly high through the spring months. During late summer, surface heating reaches a maximum and the skies tend to be fairly cloudless throughout the San Joaquin and Sacramento Valleys. Sky cover generally averages between 1/10th and 2/10ths at Sacramento in the summer and early fall months.

Table 3.7-4 provides the diurnal, monthly and seasonal frequency of mostly clear, partly cloudy and mostly cloudy conditions at Arcata and Ukiah. These data are only available for stations for which summarized digital data in the form of STAR summaries are available. At Arcata, located on the north coast in Humboldt County, cloudy conditions clearly dominate reaching a maximum in the early morning hours. The frequency of clear conditions reaches a maximum during the late afternoon and early evening hours. At Ukiah, mostly clear conditions dominate at this inland valley location. Clear conditions reach a maximum during the middle of the night while cloudy conditions are most frequently observed during the early morning hours. Partly cloudy conditions are most frequent during the afternoon and early evening hours as fair weather cumulus develop during the period of most intense surface heating.

The importance of sky cover as a parameter affecting atmospheric stability will be discussed further in Section 4.2.3 and is especially detailed in Table 4.2-4

3.7.3 Solar Radiation

Monthly-annual averages of total incoming solar radiation for the various evaporative demand zones in California (equivalent in inches of evaporation of water) are presented in Table 3.7-5. The Ukiah District includes areas in the North Coast, Coastal Valleys and Plains, North Coast Interior Valleys and Sacramento Valley.

The Ukiah District, on an annual basis, receives an abundant amount of sunshine, particularly in the Sacramento Valley. The north coastal portion of the Ukiah District receives approximately 50% of the total possible sunshine on an annual basis. In the Sacramento Valley, over 70% of the total possible hours of sunshine are received annually.

A further distinction can be made between the various climatic zones in the Ukiah District when comparing solar radiation data on a monthly basis. Table 3.7-6 provides a monthly-annual breakdown of mean daily solar radiation in Langleys as observed at selected stations within the Ukiah District. As indicated by this table, the Coastal Mountains receive abundant amounts of sunshine during the year. Daily solar radiation totals reach over 700 langleys at Upperlake in June and July. Along the coast and in the Sacramento Valley, values exceed 600 langleys during the period May through August. During winter, daily totals drop off to less than 200 langleys along the coast at some stations.

Table 3.7-4

Seasonal and Diurnal Frequencies (%)

of Sky Coverage Conditions in the Ukiah District

	Arcata			Ukiah		
Time	0-3	4-7	8-10	0-3	4-7	8-10
01	29.0	7.3	63.6	66.5	7.7	25.8
02	*	*	*	64.0	8.2	27.8
03	*	*	*	62.9	8.7	28.4
04	26.7	7.6	65.7	61.8	8.3	29.9
05	*	*	*	60.8	7.9	31.3
06	*	*	*	57.6	8.6	33.8
07	21.7	8.4	69.9	54.1	9.1	36.8
08	*	*	*	51.5	10.4	38.1
09	*	*	*	51.0	9.4	39.6
10	23.4	11.0	65.6	51.7	9.5	38.7
11	*	*	*	54.2	10.2	35.6
12	*	*	*	55.7	10.7	33.6
13	30.7	12.1	57.2	55.9	11.4	32.7
14	*	*	*	56.5	11.4	32.1
15	*	*	*	56.2	12.1	31.7
16	31.8	13.8	54.4	56.4	11.2	32.4
17	*	*	*	56.2	11.3	32.4
18	*	*	*	55.3	13.3	31.4
19	32.2	11.4	56.4	58.0	12.1	30.0
20	*	*	*	60.4	12.8	26.8
21	*	*	*	63.2	11.3	25.5
22	32.7	9.3	58.1	64.9	10.1	25.0
23	*	*	*	65.7	9.5	24.8
24	*	*	*	66.3	8.4	25.3
Month(s)						
DEC	22.3	10.8	66.9	38.0	13.0	49.0
JAN	26.4	9.6	64.0	35.9	11.5	52.6
FEB	16.0	10.3	73.8	39.6	9.9	50.5
WINTER	21.8	10.2	68.0	37.8	11.5	50.7
MAR	29.7	11.0	59.3	42.0	13.2	44.8
APR	33.6	12.3	54.1	49.8	14.3	36.0
MAY	24.0	12.1	63.9	55.7	11.6	32.7
SPRING	29.0	11.8	59.1	49.2	13.0	37.8
JUN	24.4	8.5	67.1	73.7	9.9	16.5
JUL	26.3	6.4	67.3	89.3	4.8	5.8
AUG	32.4	8.4	59.2	87.0	5.7	7.3
SUMMER	27.7	7.7	64.5	83.4	6.8	9.8
SEP	44.3	8.1	47.6	81.4	7.0	11.6
OCT	36.0	11.4	52.6	62.7	10.1	27.2
NOV	26.2	12.6	61.3	47.4	10.8	41.8
FALL	35.5	10.7	53.8	63.8	9.3	26.9

* No Dat

Table 3.7-5

Monthly Solar Radiation Summary for the Ukiah District

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	March through October	Annual Average
North Coast Coastal Valleys & Plains	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
North Coast Interior Valleys	4.7	5.1	8.3	11.1	13.3	13.8	14.9	12.9	9.6	7.7	4.3	3.3	91.6	109.0
Sacramento Valley	3.8	5.4	8.6	10.9	13.7	14.0	14.8	13.0	10.2	7.7	4.4	3.4	92.9	109.9

*Solar radiation expressed as equivalent inches (1486 Langleys = 1 inch E_p)

Table 3.7-6

Monthly Averages of Daily Solar Radiation for the Ukiah District (Langleys)

Station Name	Climate Zone	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL	Period of Record
Santa Rosa	Coastal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	588	421	245	N/A	N/A	N/A	1972-1973
San Rafael	Coastal	194	275	389	566	624	679	674	609	486	320	194	150	429	1970-1975
Napa	Coastal	170	239	307	457	536	605	591	535	434	272	138	123	367	1972-1975
Vallejo	Coastal	163	239	336	575	600	627	599	527	423	302	191	150	394	1972-1975
Upperlake 1SE	Coastal Mt.	223	311	420	570	625	705	725	653	559	418	256	172	470	1970-1973
Davis	Central Plain	173	243	386	524	629	685	688	616	501	347	220	155	431	1957-1976
Vacaville	Central Plain	N/A	N/A	N/A	N/A	645	674	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1976-1977

1 Langley = 6.45 cal/in^2

3.8 OTHER CLIMATIC PARAMETERS

This section presents analyses of various secondary climatic parameters. These parameters have considerable potential for short-term influence on BLM land use alternatives, but when considered on a long-term climatological basis, they are less significant in characterizing the climate than the parameters previously discussed. The particular climatic parameters reviewed in this section include:

- Dew Point and Relative Humidity
- Severe Weather
- Barometric Pressure
- Fog and Visibility
- Ocean Surface Temperatures

Variations of these particular climatic parameters are briefly discussed and variations within specific climatic zones of the Ukiah District are presented in the form of figures and tables. A complete bibliography is provided in the back as for previous sections.

3.8.1 Relative Humidity and Dew Point

Relative humidity and dew point temperature are discussed together in this section as they both represent measures of the available moisture in the atmosphere as a function of ambient air temperatures. Relative humidity describes the saturation moisture percentage of the atmosphere. More accurately, this parameter is defined by the ratio of the actual vapor pressure of air to the saturation vapor pressure of ambient air parcels. Dew point temperature represents the temperature to which a given parcel of air must be cooled, at constant pressure and water vapor content, in order for saturation to occur. For example, the dew point temperature is the temperature at which moisture condenses on grass and other exposed surfaces during the cool early morning hours. When this temperature is below freezing, it becomes the frost point temperature, i.e., the point at which frost will develop on exposed surfaces.

Dew point and relative humidity both provide a measure of the amount of moisture available in the atmosphere for condensation. However, care must be used in interpreting these parameters. For example, the higher the relative humidity, the higher the amount of moisture available for condensation. However, a low dew point does not necessarily mean low availability of moisture. The key criterion in interpreting dew point data is the difference between the dew point temperature and the ambient air temperature which is commonly known as the dew point depression. When this temperature difference is small, the amount of available moisture is high. When there is no difference, the atmosphere is saturated. Finally, when the dew point depression is large, the amount of available moisture in the atmosphere is quite small. In a great majority of normal atmospheric conditions, supersaturation does not occur; therefore, the dew point temperature should never be higher than the ambient air temperature.

Atmospheric moisture content also plays an important role in air quality. High moisture levels not only reduce visibility but can also enhance the formation of secondary air pollutants such as sulfates and nitrates, which can further reduce visibility.

Summary tables and figures have been provided for the Ukiah District which present relative humidity and dew point temperature data on a diurnal, monthly, seasonal and annual basis. Relative humidity and dew point temperature data are generally available only for major first order stations; however, the data base for the Ukiah District is sufficient to provide regional long-term averages.

Figure 3.8-1 summarizes seasonal mean dew point temperature and relative humidity for the state of California. The data indicate that atmospheric moisture content is highest along the coastline, particularly in the extreme northwestern portion of the state. There is a tendency for moisture to flow in through the Bay Area and during the late fall, winter and early spring seasons, this moisture reaches the Central Valley. During other seasons of the year, most of the valley is significantly dryer than coastal locations as indicated by the figure. The southeast desert is the dryest portion of the state during all seasons.

In the Ukiah District, relative humidities tend to be highest in winter and lowest in summer. Detailed information on relative humidity is presented in Figures 3.8-2 - 3.8.4. Figure 3.8-5 provides a review of average dew point temperatures on a monthly basis at key first order stations. Finally, diurnal distributions of relative humidity and dew point at key stations are provided on a seasonal basis in Tables 3.8-1 and 3.8-2.

To summarize the data in the tables and figures, relative humidities remain fairly constant at a rather high level at the coastal locations throughout the year and are consistently lower in the Sacramento Valley. There is a strong moisture gradient between coastal and inland stations particularly during the warmer months.

3.8.2 Severe Weather

This section presents a basic summary of severe weather in the Ukiah District. The regional formation and statistical incidence of thunderstorms, tornadoes, hail and ice are discussed in this section. The damaging effects of these abnormal weather features are also reviewed. In comparison with other areas of the country, thunderstorms, tornadoes, hail and ice occur relatively infrequently in most portions of the state.

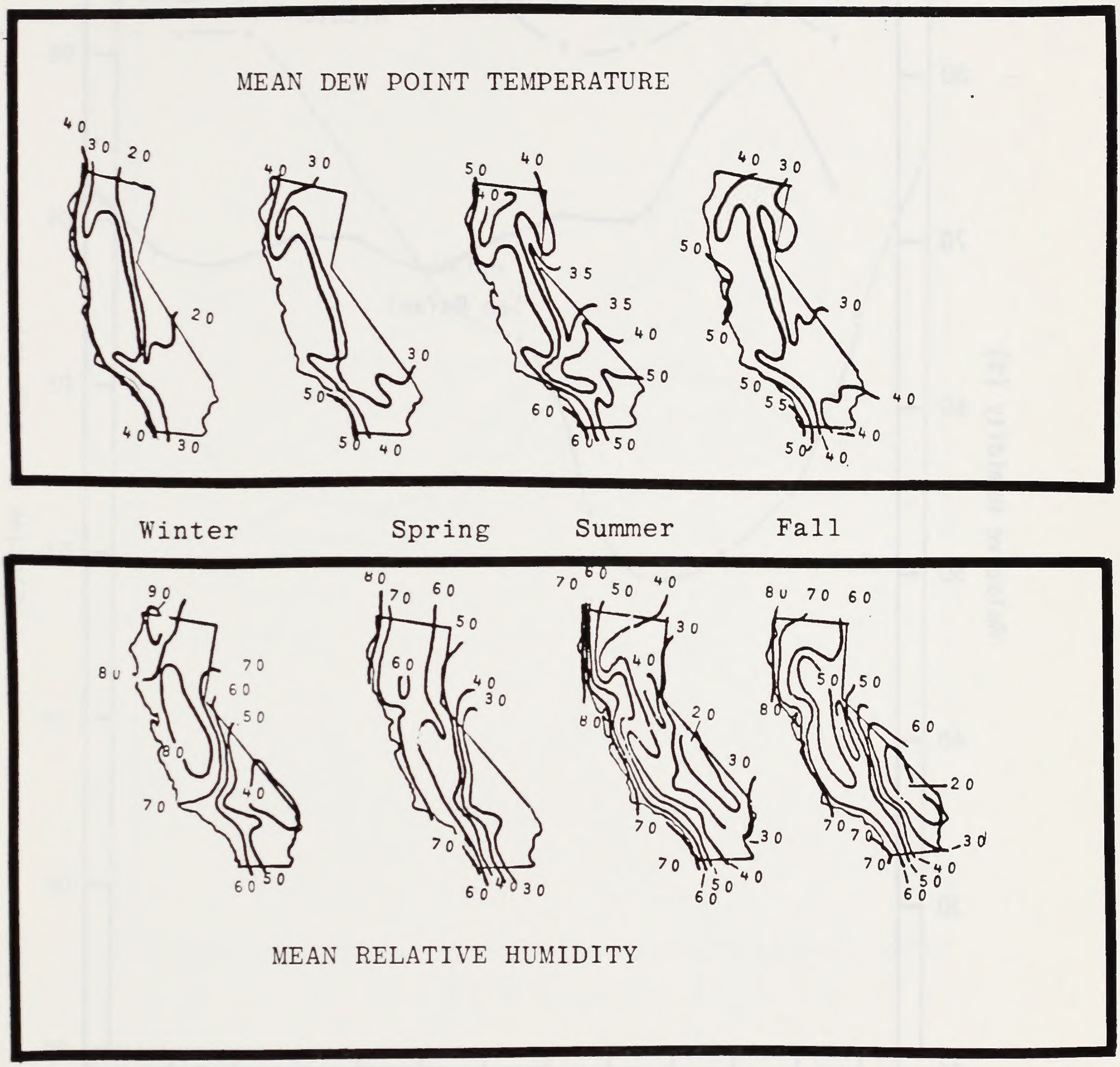


Figure 3.8-1
Mean Seasonal Dew Point (^{O}F)
and Relative Humidity (%) in California

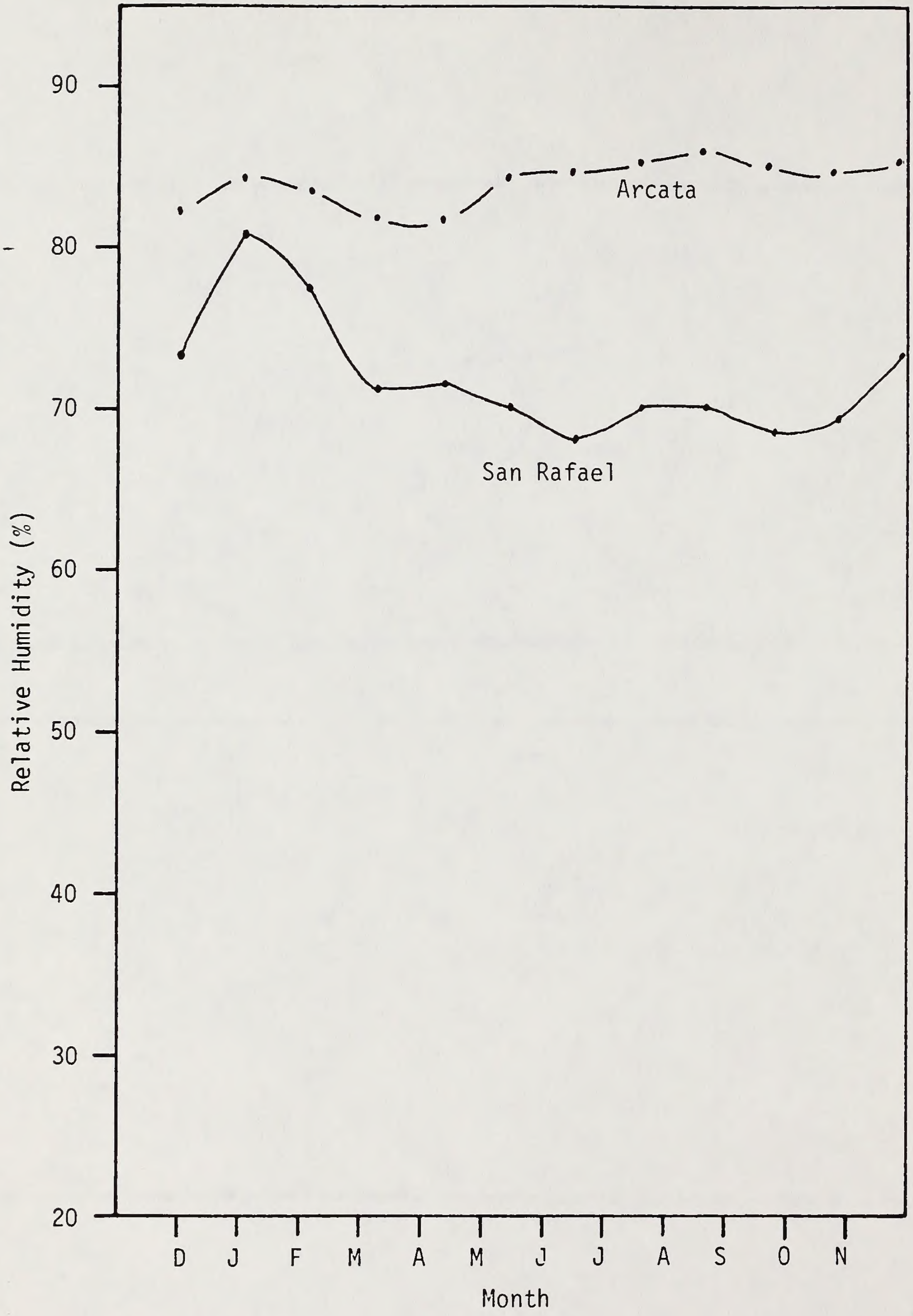


Figure 3.8-2
Coastal Climatic Zone Monthly-Annual Humidity
Distribution in the Ukiah District

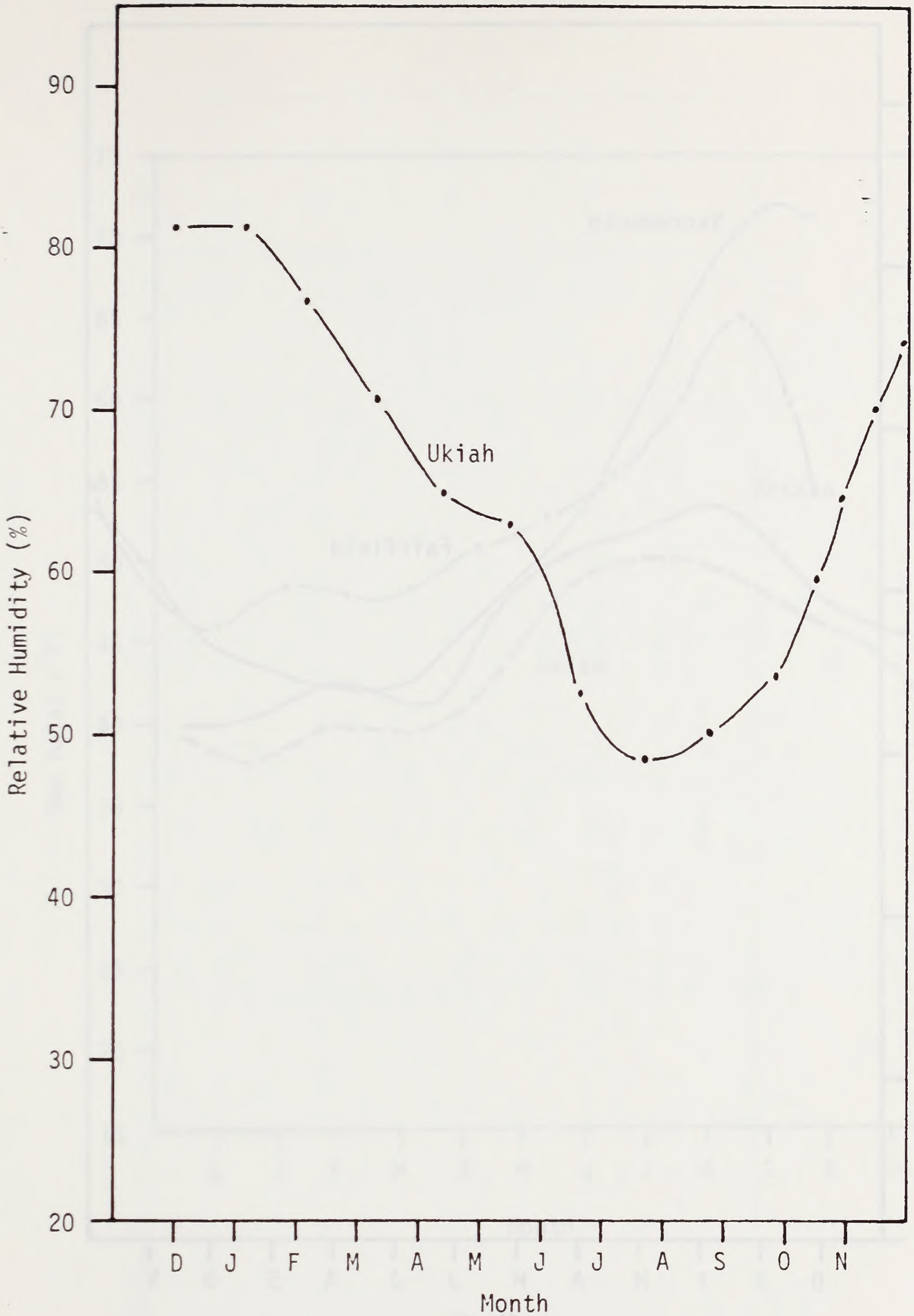


Figure 3.8-3

Coastal Mountain Climatic Zone Monthly-Annual Humidity Distribution in the Ukiah District

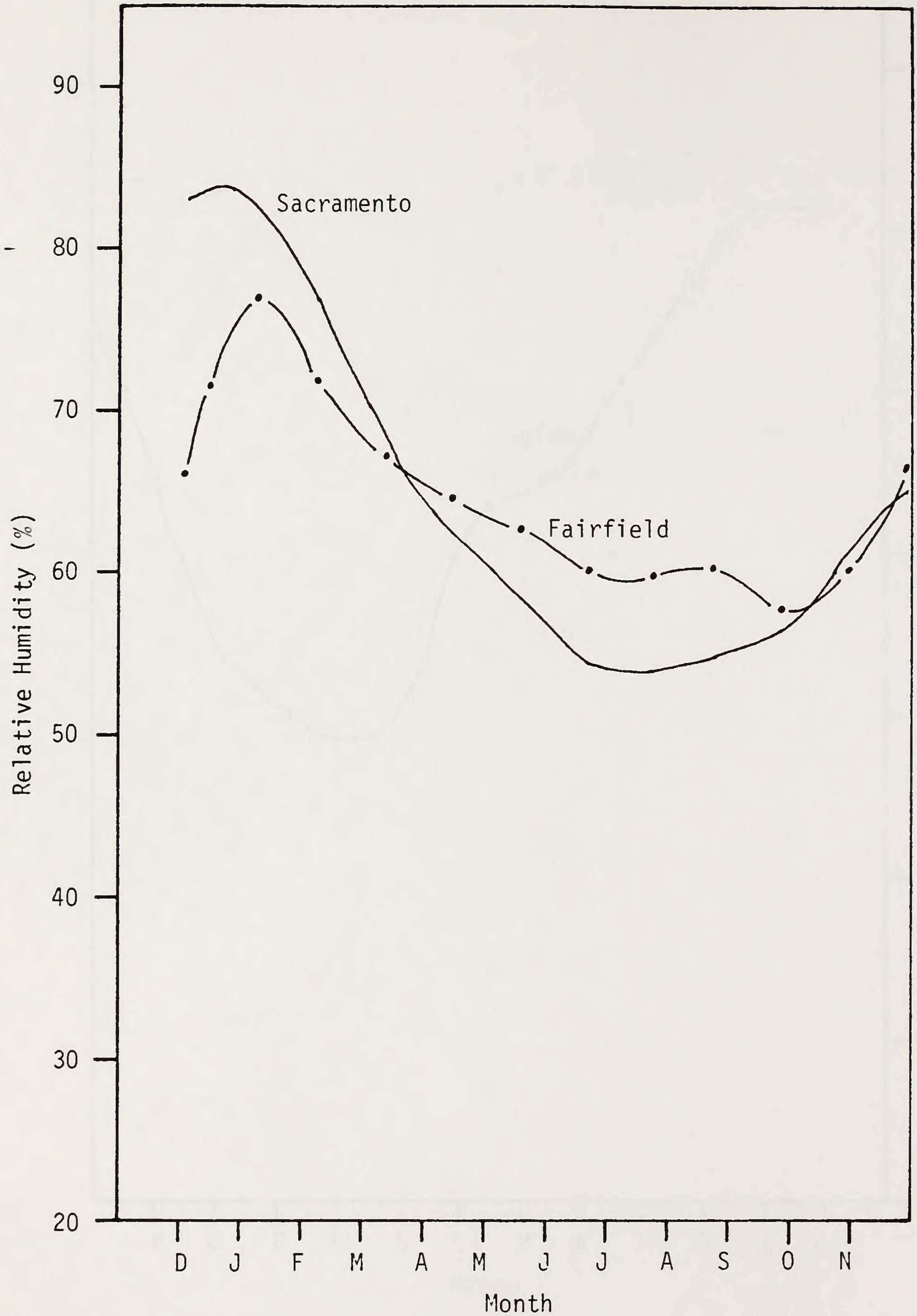


Figure 3.8-4
Central Plain Climatic Zone Monthly-Annual Humidity
Distribution in the Ukiah District

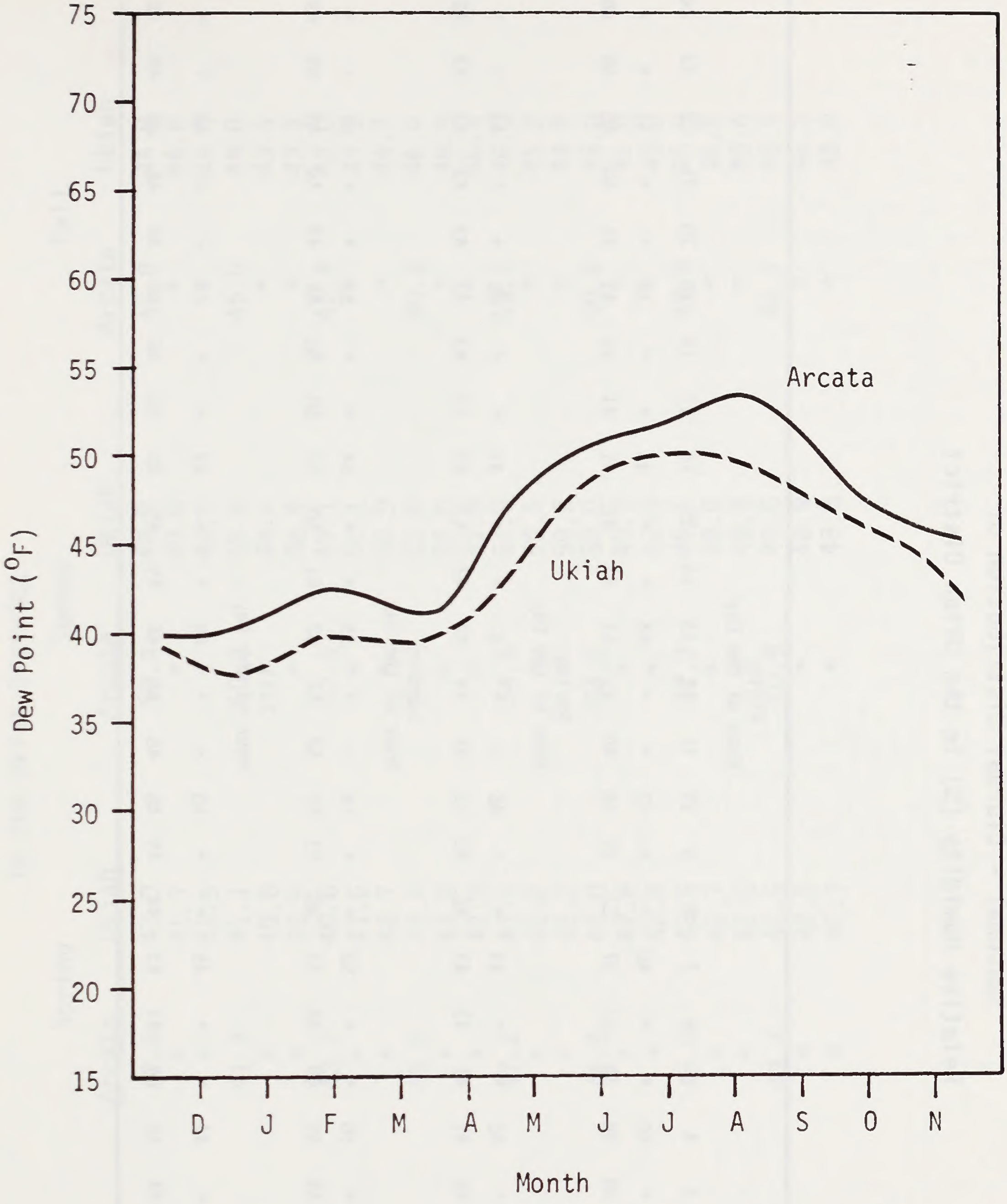


Figure 3.8-5
Ukiah District
Monthly-Annual Dew Point Temperature

Table 3.8-1

Seasonal - Diurnal Distribution of

Relative Humidity (%) in the Ukiah District

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Winter – Hour of the Day																								
Arcata	40	*	*	40	*	*	40	*	*	42	*	*	44	*	*	44	*	*	42	*	*	41	*	*
Ukiah	39	39	38	38	38	37	37	37	37	38	40	41	41	41	41	41	41	41	41	41	40	40	40	40
Spring – Hour of the Day																								
Arcata	42	*	*	42	*	*	43	*	*	46	*	*	47	*	*	47	*	*	45	*	*	43	*	*
Ukiah	42	42	42	41	41	41	41	42	43	43	44	44	44	43	43	43	43	43	43	43	43	43	43	42
Summer – Hour of the Day																								
Arcata	50	*	*	50	*	*	52	*	*	54	*	*	55	*	*	54	*	*	53	*	*	41	*	*
Ukiah	49	49	49	49	49	48	49	50	51	52	52	52	52	51	50	50	50	50	49	49	49	49	49	49
Fall – Hour of the Day																								
Arcata	45	*	*	44	*	*	45	*	*	48	*	*	49	*	*	49	*	*	47	*	*	46	*	*
Ukiah	45	45	44	44	44	43	43	44	45	46	46	46	46	45	45	45	46	46	46	46	46	46	45	45

* No Data

Table 3.8-2

Seasonal - Diurnal Distribution of Dew Point Temperature (^{o}F)

in the Ukiah District

	Winter		Spring		Summer		Fall	
Hr.	Arcata	Ukiah	Arcata	Ukiah	Arcata	Ukiah	Arcata	Ukiah
1	40.1	39.0	42.4	42.0	50.4	48.9	45.8	44.9
2	*	38.6	*	41.7	*	49.0	*	44.6
3	*	38.2	*	41.5	*	48.9	*	44.3
4	39.5	37.8	41.7	41.1	50.1	48.8	45.0	44.0
5	*	37.5	*	40.8	*	48.6	*	43.6
6	*	37.1	*	40.5	*	48.4	*	43.3
7	38.9	36.8	42.7	40.6	52.1	49.1	45.4	43.0
8	*	36.6	*	41.6	*	50.1	*	43.5
9	*	37.0	*	42.7	*	50.9	*	44.7
10	42.1	38.3	45.9	43.4	53.8	51.6	50.1	46.0
11	*	39.9	*	43.8	*	52.0	*	46.4
12	*	40.8	*	43.9	*	51.9	*	46.4
13	43.6	41.0	47.2	43.7	54.6	51.5	50.7	46.0
14	*	40.9	*	43.2	*	50.5	*	45.2
15	*	40.8	*	43.2	*	50.2	*	44.9
16	43.6	41.0	46.5	43.0	54.1	50.0	50.5	45.0
17	*	41.3	*	42.8	*	49.5	*	45.6
18	*	41.2	*	42.8	*	49.3	*	45.8
19	42.2	41.0	45.0	42.9	52.7	49.1	48.4	45.9
20	*	40.7	*	42.7	*	49.0	*	45.8
21	*	40.5	*	42.6	*	48.8	*	45.6
22	40.9	40.2	43.4	42.6	50.9	49.0	46.7	45.5
23	*	39.7	*	42.5	*	48.9	*	45.2
24	*	39.4	*	42.3	*	48.8	*	45.0

*No Data

Thunderstorms

Thunderstorms are rare along the coast and have no well defined season. On the other hand, thunderstorms developing over the interior mountains are severe on occasion and occur primarily during summer. Most of the thunderstorms that occur in the Ukiah District cause little, if any, damage. The storms usually are accompanied by brief gusts of wind, heavy rain and lightning as well as some small hail. Large hail, strong winds and a funnel cloud or tornado are quite rare. Flash flooding comprises the primary source of damage associated with summer thunderstorms.

Winter thunderstorms generally occur in conjunction with rapidly moving cold fronts that pass over the district. Advancing frontal systems can promote considerable instability aloft which contributes to thunderstorm development. Summer thunderstorms develop over mountainous and desert areas as strong surface heating effects couple with moist maritime air and, in the mountians, forced orographic lifting.

Isolines of the annual mean number of thunderstorm days are depicted on a national scale in Figure 3.8-6. Generally, the Ukiah District experiences 5-10 thunderstorm days per year. Considerable data resolution is lacking on Figure 3.8-6 and the distribution does not reflect the higher incidence of thunderstorm days that can be experienced in the mountainous areas. Isolated thunderstorm activity, as observed on radar over mountain areas, averages as high as 50 to 60 days per year at some locations. Lightning strikes resulting from these thunderstorms can cause dry brush to ignite and promote forest fires. Detailed data for selected stations in the Ukiah District are presented in Table 3.8-3.

Table 3.8-3
Mean Number of Thunderstorm Days

Station	Winter	Spring	Summer	Fall	Annual
Arcata	2.0	4.0	2.0	1.0	4.0
Eureka	3.0	0.8	0.8	1.5	6.1
San Francisco	0.8	0.8	0.8	0.8	3.2
Ukiah	2.0	5.0	17.0	6.0	30.0
Sacramento	0.5	2.3	0.8	1.5	5.1

Tornadoes

Tornadoes and funnel clouds are associated with severe thunderstorms. They develop when just the right conditions of moisture, atmospheric stability, and winds are present. Tornadoes frequently form within thunderstorms that have organized into lines. Frequently, but not always, these "squall lines" are

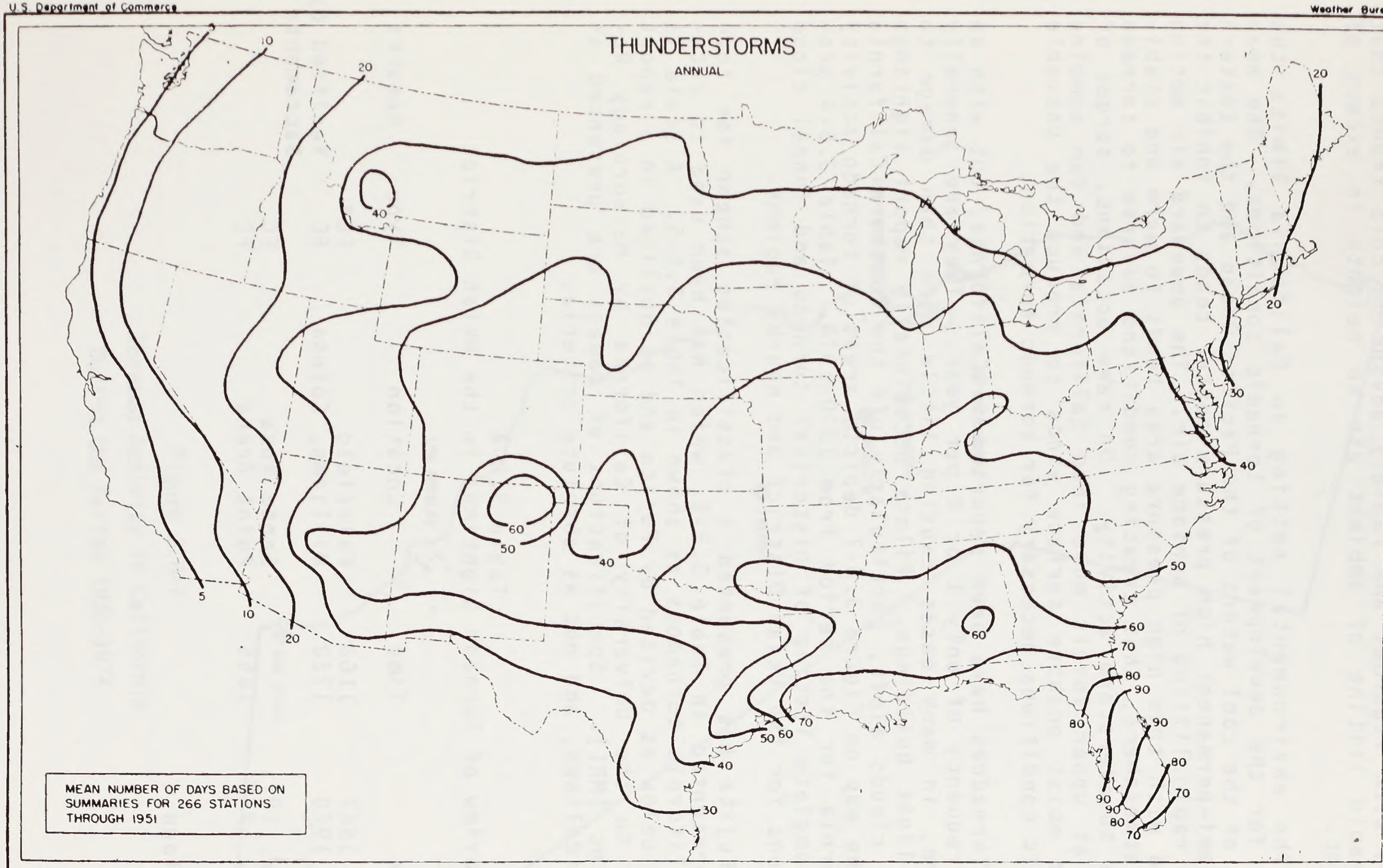


Figure 3.8-6

Mean Number of Thunderstorm Days in the United States associated with vigorous and rapidly advancing cold fronts that promote rapid lifting of ambient air to heights in excess of 60,000 feet.

The environmental setting in California limits the potential for the development of tornadic conditions. The near proximity of the cool waters of the Pacific Ocean and the Eastern Pacific semi-permanent high pressure center tends to inhibit the necessary rapid lifting of surface air. The downward air motion associated with this high pressure area tends to warm and stabilize the atmosphere, thus creating conditions adverse to tornado or severe thunderstorm activity. On rare occasions, surges of cold air at upper levels move into California and can combine with warm moist onshore surface winds to produce the unstable atmospheric conditions necessary for tornado formation.

Tornadoes have been reported in California, but with an average frequency of only 1 or 2 per year. They are generally not severe, in many cases causing little more than damage to trees or light buildings. Pilots occasionally report sightings of funnel clouds aloft, particularly off the southern California coast. The map on Figure 3.8-7 depicts areas of tornado activity in California for the period from 1930-1974. Table 3.8-4 provides a complete listing of historical tornado and funnel cloud observations for the Ukiah District and nearby regions.

Fujita has presented a classification scheme for tornadoes, presented in Table 3.8-5, which has been used to categorize California tornadoes as shown in Table 3.8-5. A scale is presented below as devised by Fujita and as outlined in a report submitted to the University of California by Meteorology Research, Inc (MRI). Specifications of damage are presented as visual guidelines, and not as absolute criteria.

Table 3.8-4
Review of Tornado Sightings in the Ukiah District

Date	Time	Location	Type	Remarks
April 19, 1967	1108	Fairfield	FC*	
April 27, 1970	1720	Williams, Colusa	FC	Verified by Sacramento Radar
January 12, 1971		Santa Rosa	FC	
August 25, 1973	1655	Point Arena	FC	

*Funnel Cloud

Figure 3.8-7
Tornado Activity in California
During the Period 1930-1974

Table 3.8-5
Fujita Tornado Classification Scheme

(F0) GALE TORNADO, Light Damage
40-72 mph
Some damage to chimneys and TV antennae; breaks twigs off trees; pushes trees over.

(F1) WEAK TORNADO, Moderate Damage
73-112 mph
Peels surface off roofs; windows broken; light trailer houses overturned; some trees uprooted or snapped; automobiles pushed off the road.

(F2) STRONG TORNADO, Considerable Damage
113-157 mph
Roofs torn off frame houses leaving only strong walls upright; trailer houses destroyed; large trees snapped or uprooted; railroad box cars derailed; light object missiles generated; cars blown off highway.

(F3) SEVERE TORNADO, Severe Damage
158-206 mph
Roofs and some walls torn off frame houses; trains derailed or overturned; steel framed hangar-warehouse type structures torn; cars lifted off the ground.

(F4) DEVASTATING TORNADO, Devastating Damage
207-260 mph
Whole frame houses leveled, leaving piles of debris; steel structures badly damaged; small flying objects debark trees; cars and trains thrown or rolled considerable distances, large missiles generated.

(F5) INCREDIBLE TORNADO, Incredible Damage
261-318 mph
whole frame houses tossed off foundations; automobile-sized missiles generated; incredible phenomena can occur.

(F6) 319-379 mph

(F7) 380-445 mph

(F8) 446-513 mph

(F9) 514-585 mph

(F10) 586-659 mph

(F11) 660-737 mph

(F12) 738-818 mph

Photographs and eyewitness accounts of the larger tornadoes have been used to compile the various classifications. Table 3.8-6 presents a summary of the historical intensities of California tornadoes.

Table 3.8-6

Historical Intensity Of California Tornadoes
Based Upon the Fujita Classification Scheme

Class	No. of Storms	Percentage (%) of Observations
F0	8	16.7
F1	32	66.7
F2	8	16.7
F3 or worse	0	0.0

<u>Hail</u>

Hail results from the formation of spheres of irregular chips of ice which are produced by convective activity in storm clouds, such as in cumulonimbus types. Thunderstorms which are characterized by strong updrafts, high water content, large cloud drop sizes, and great vertical height extent offer great potential for hail and ice formation. Hail sizes can range from that of a few millimeters in diameter to sizes on the order of several centimeters. Table 3.8-7 presents the incidence of hail and sleet seasonally and annually at several selected stations in the Ukiah District.

Table 3.8-7

Mean Number of Days With Hail/Sleet or Ice

Station	Winter	Spring	Summer	Fall	Annual
Arcata	1.0	0.0	0.0	0.0	1.0
Ukiah	1.0	0.0	0.0	0.0	1.0

3.8.3 Atmospheric Pressure

Atmospheric pressure, as a climatic parameter, has little direct effect on the ambient environment but acts as a climatic control parameter, such that slight variations in atmospheric pressure can induce remarkable variations in general weather conditions. Pressure gradients regulate wind, and wind is a major determinant of regional air temperature and moisture conditions. This also provides a connection between pressure and dispersion meteorology and ambient air quality. In addition, pressure systems are often positively correlated with pollutant levels. For example, the semi-permanent eastern Pacific High Pressure system permits the buildup of high pollutant levels in Southern California during summer.

Atmospheric pressure is defined as the force exerted by the atmosphere upon a unit surface area as a consequence of gravitational attraction on all air molecules. Hence, atmospheric pressure is a measure of the total weight of air situated above an area in question.

Pressure is defined in dimensions of force per unit area, such as dynes per square centimeter (dynes/cm^2), pounds per square inch (lbs/in^2), or newtons per square meter (N/m^2). Meteorologists often refer to the dynes/cm^2 ratio as millibars (mb), such that, 1 mb equals 1,000 dynes/cm^2.

Pressure measurements are at times expressed in terms of standards. The average global mean sea level pressure has been determined to be 1,013.25 mb (14.7 lbs/in^2). This value of pressure is often referred to as 1 Standard Atmosphere (Atm). Similarly, the pressure level of approximately 506 mb (7.35 lbs/in^2)is referred to as 0.5 Atm.

Atmospheric pressure values are often expressed in terms of equivalents. Since the atmosphere exerts a force or weight per unit area, it therefore counter-balances an equivalent weight. A column of air one square inch in cross-sectional area extending from sea level to the top of the atmosphere weighs approximately 14.7 pounds. This weight can be balanced by a column of mercury having the same cross-sectional area extending vertically 29.92 inches or 760 millimeters. Therefore, pressure values can be referred to in units of inches (in) or millimeters of mercury (mmHg) with the understanding that these values represent the atmospheric mass that supports a vertical column of mercury so many inches or millimeters long. As atmospheric pressure changes in an area, the air mass above that region changes, and likewise, its ability to counter-balance the weight of the previously described column of mercury.

Table 3.8-8 provides the conversion factors necessary to transform pressure values into various conventional pressure units and equivalents. An example demonstrating how to use these factors is provided below the table.

Figures 3.8-8 through 3.8-11 provide a representive cross-section of the mean seasonal pressure contours on a national scale. General atmospheric flow can be estimated by assuming that winds move nearly parallel to isobars (lines of equal pressure values). In the northern hemisphere, winds blow clockwise (anticyclonic) around the high pressure centers and counterclockwise (cyclonic) about low pressure centers.

During the winter months, a high pressure center is generally situated to the northeast of California and the semi-permanent Eastern Pacific high pressure system is depressed well

Table 3.8-8

Pressure Conversion Factors

	UNITS (B)					
UNITS (A)	POUNDS/IN^2	DYNES/CM^2	MILLIBARS	ATMOSPHERES	INCHES OF MERCURY	MILLIMETERS OF MERCURY
POUNDS/IN^2	1.000	$6.902\text{x}10^{4}$	$6.902\text{x}10^{1}$	$6.812\text{x}10^{2}$	2.038	$5.177\text{x}10^{1}$
DYNES/CM^2	$1.449\text{x}10^{-5}$	1.000	$1.000\text{x}10^{-3}$	$9.870\text{x}10^{-7}$	$2.953\text{x}10^{-5}$	$7.501\text{x}10^{-4}$
MILLIBARS	$1.449\text{x}10^{-2}$	$1.000\text{x}10^{3}$	1.000	$9.870\text{x}10^{-4}$	$2.953.10^{-2}$	$7.501\text{x}10^{-4}$
ATMOSPHERES	$1.468\text{x}10^{1}$	$1.013\text{x}10^{6}$	$1.013\text{x}10^{3}$	1.000	$2.992\text{x}10^{1}$	$7.600\text{x}10^{2}$
INCHES OF MERCURY	$4.906\text{x}10^{-1}$	$3.386\text{x}10^{4}$	$3.386\text{x}10^{1}$	$3.342\text{x}10^{-2}$	1.000	$2.540\text{x}10^{1}$
MILLIMETERS OF MERCURY	$1.932.10^{-2}$	$1.333\text{x}10^{3}$	1.333	$1.316\text{x}10^{-3}$	$3.937\text{x}10^{-2}$	1.000

* Multipy pressure in (A) units by appropriate factor to transform into (B) units (i.e. 14.68 LBS/IN^2 x 6.902x10 = 1013.2 mb).

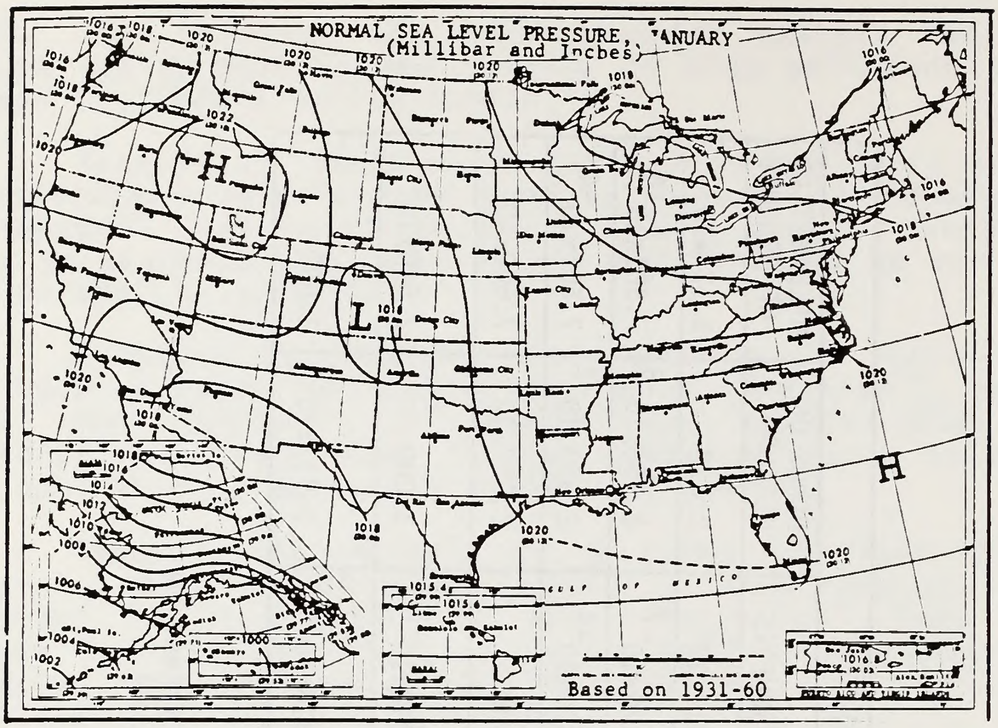


Figure 3.8-8
Mean Winter (January) Pressure Distribution
in the United States

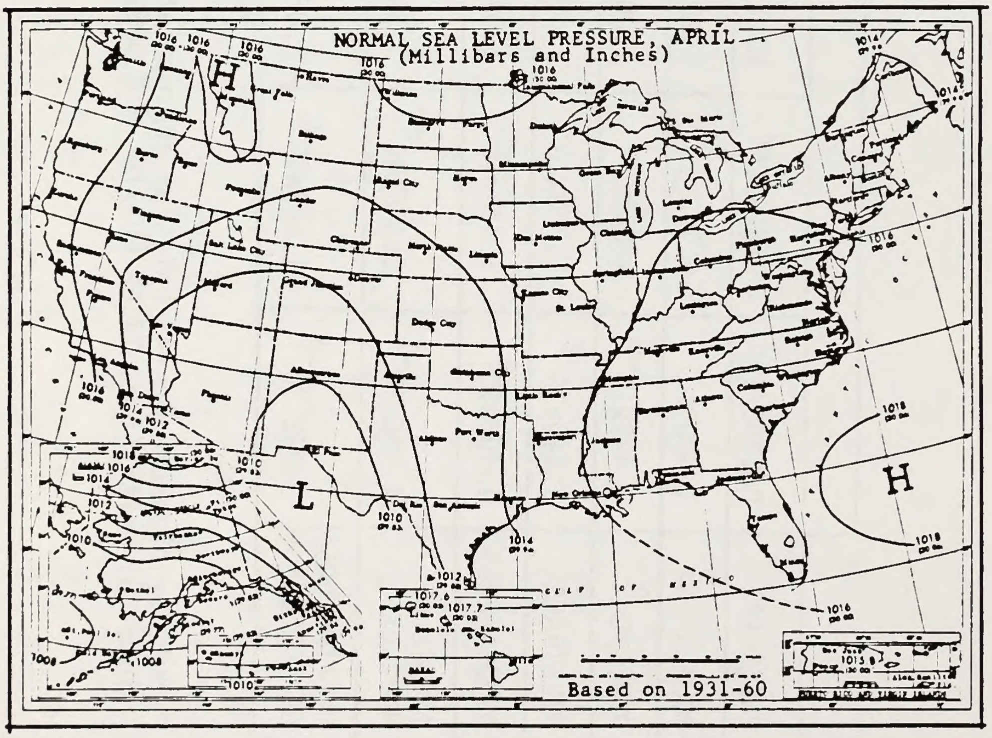


Figure 3.8-9
Mean Spring (April) Pressure Distribution
in the United States

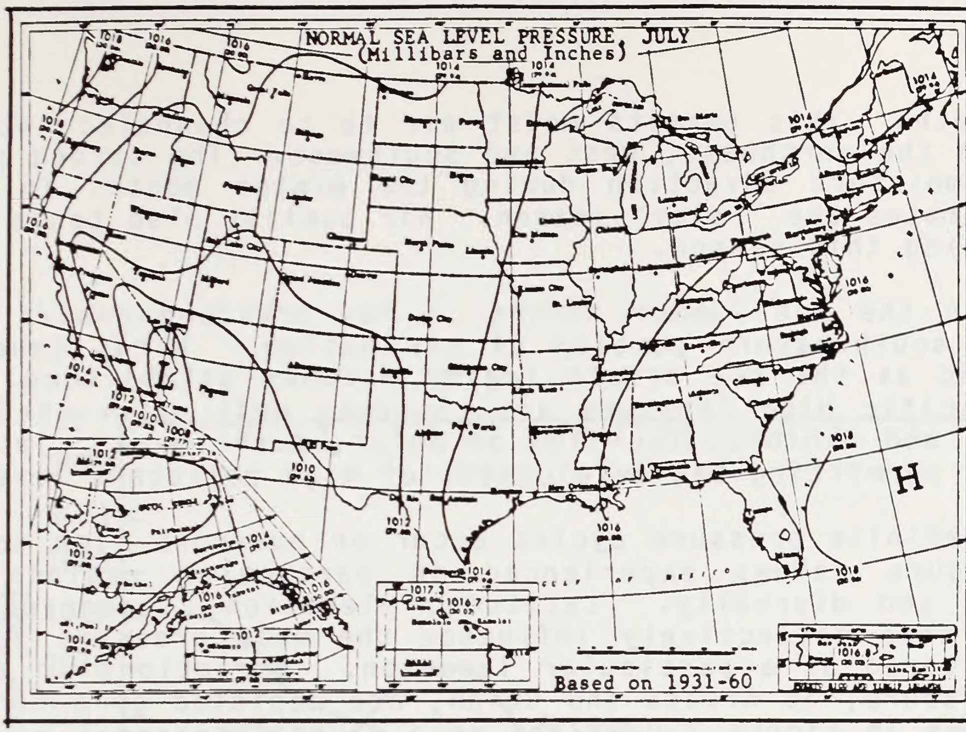


Figure 3.8-10

Mean Summer (July) Pressure Distribution
in the United States

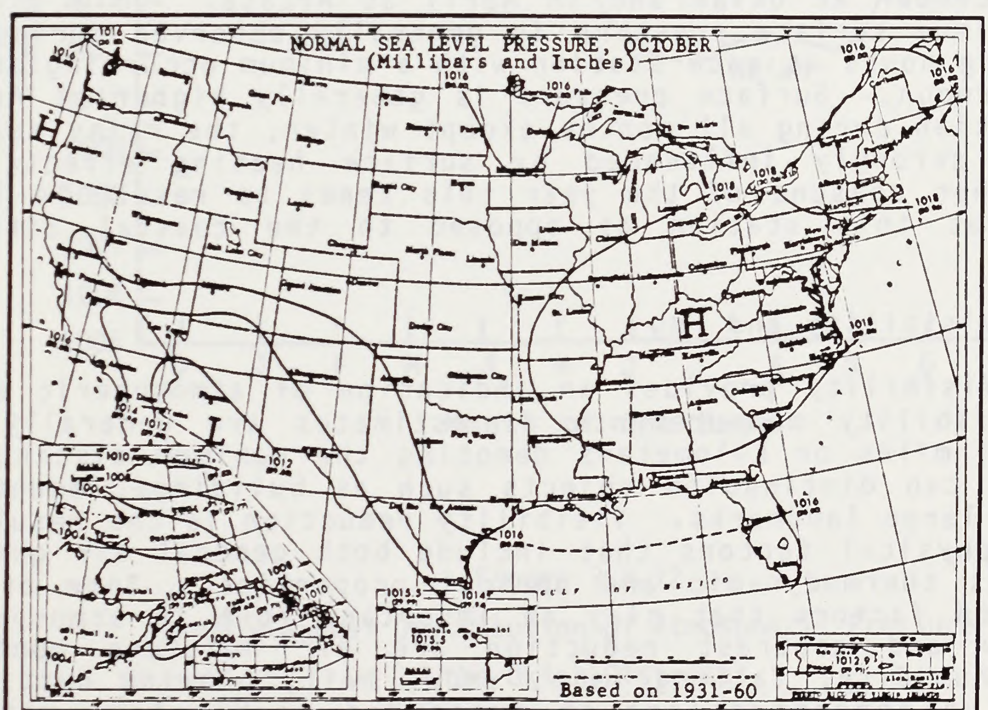


Figure 3.8-11

Mean Fall (October) Pressure Distribution
in the United States

to the south. This permits moist air to be channeled into the state from the northwest, west and southwest. The strong potential for moisture advection during the winter months in California promotes the "rainy" season. Air quality also tends to be better during this season.

In the hot summer months, a low pressure center dominates the southwestern portion of the nation. Winds generally flow inland as the sea breeze regime becomes established. The Eastern Pacific High Pressure area becomes well entrenched over California and inhibits the flow of moist, maritime air into the area, thus permitting the development of high pollutant levels.

Definite pressure cycles occur on numerous time scales. Mean pressure values experienced in particular regions vary seasonally and diurnally. Latitude, elevation, topography and surface albedo collectively influence the mean pressure tendencies registered at a particular location. Variations in atmospheric pressure, at Arcata and Ukiah, are depicted on a monthly-annual basis in Figure 3.8-12 and on a diurnal-seasonal basis in Figure 3.8-13. The monthly seasonal distribution indicates that barometric pressure reaches a seasonal maximum in spring at Arcata and in winter in Ukiah. At many stations throughout the United States winter is the traditional season of maximum high pressure, however, at Arcata the frequent passage of migratory storm systems prohibits this. Highest surface pressure occurs during December at Ukiah and in April at Arcata. On a diurnal basis maximum surface pressure is generally observed during the mid-morning hours at each station with a minimum occurring during late afternoon. Surface pressure is generally higher at Arcata than at Ukiah during all months except winter, the rainy season. Ukiah is strongly influenced by surface heating effects and during other seasons of the year this tends to result in lower pressure at this station as opposed to the coastal site of Arcata.

3.8.4 Visibility and Fog

Visibility provides an indication of atmospheric clarity. Visibility measurements or estimates are generally expressed in miles or kilometers denoting the maximum distance at which one can distinguish objects such as buildings, mountains and other large landmarks. Visibility reduction is the result of numerous physical factors that include both general air quality as well as thermodynamic and optical properties. Some of the more common factors that play an important role in atmospheric visibility and contrast reduction are air moisture content, relative humidity, falling rain, snow, hail, blowing dust, sea spray, high concentrations of suspended particulate matter, sulfates, oxides of nitrogen, and smoke.

Tables 3.8-9 and 3.8-10 present monthly, seasonal and annual percentage frequency distributions of visibility for Ukiah and Arcata in the Ukiah District. The data represent

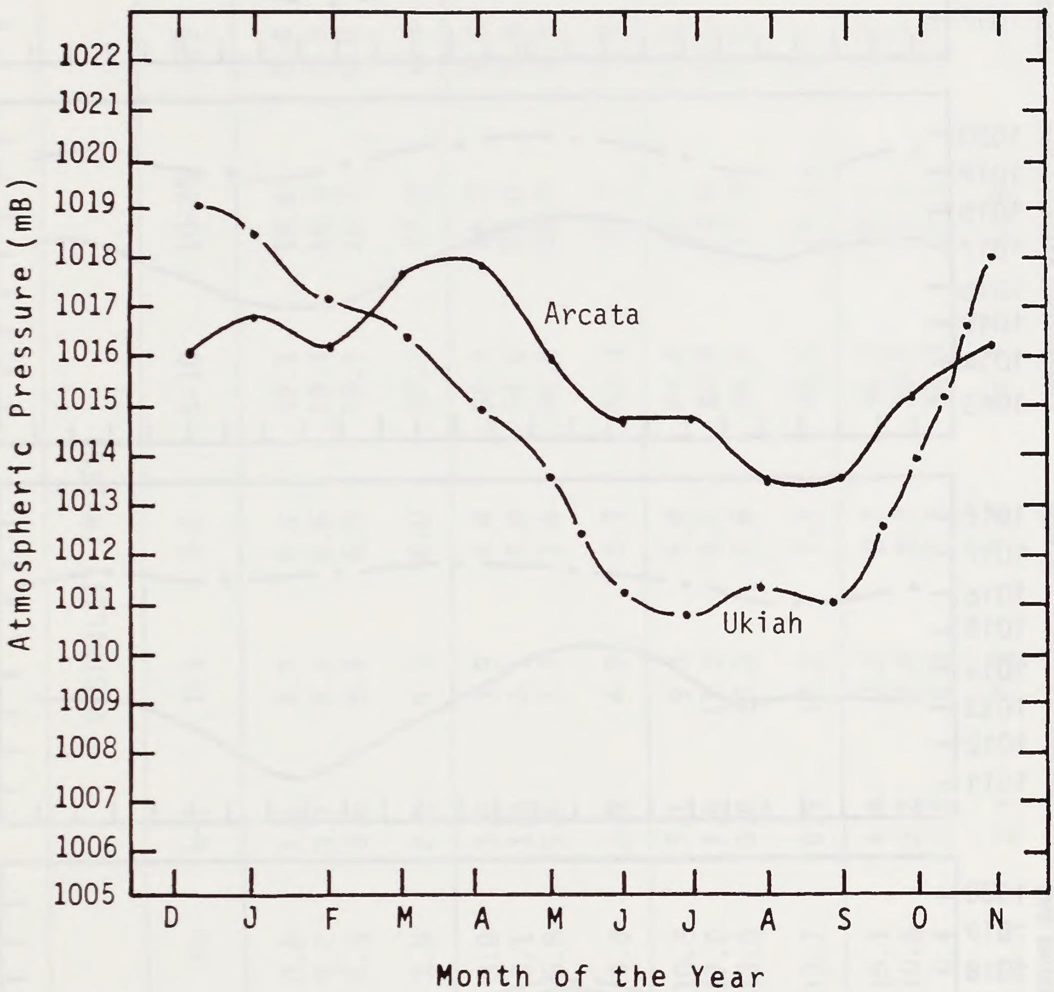


Figure 3.8-12
Monthly-Annual Distribution of Atmospheric Pressure in the Ukiah District

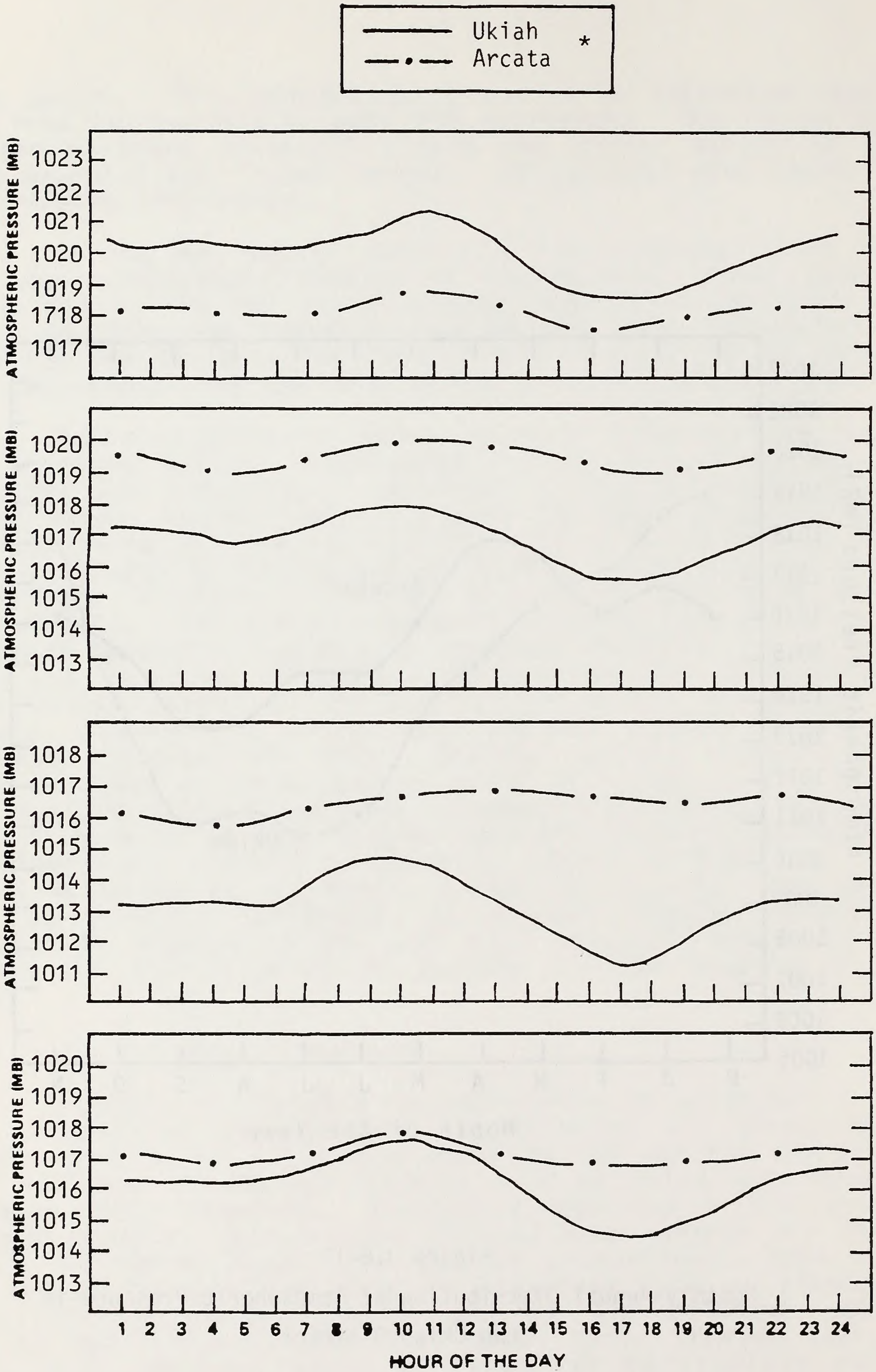


Figure 3.8-13

Diurnal-Seasonal Pressure Variations in the Ukiah District

*Analyses based on 8 obs/day

Table 3.8-9

Frequency (%) of Selected Visibility Categories at Arcata, California for the Period 1968-1972

PERIOD	VISIBILITY (MILES)						
	<¼	¼-1	1-3	3-5	5-10	10-25	>25
DEC	0.6	1.6	4.3	5.4	69.1	18.6	0.4
JAN	5.2	3.7	8.3	6.6	59.4	16.3	0.5
FEB	6.3	3.6	6.4	6.0	59.1	18.7	0.0
WINTER	3.9	2.9	6.3	6.0	62.7	17.8	0.3
MAR	3.0	3.0	3.9	4.4	58.9	26.3	0.6
APR	3.1	1.8	3.1	3.8	54.8	32.8	0.8
MAY	6.8	5.6	7.7	7.6	46.4	25.9	0.1
SPRING	4.3	3.5	4.9	5.3	53.3	28.3	0.5
JUN	10.3	7.1	9.3	6.8	44.8	21.7	0.0
JUL	17.0	7.9	11.3	8.0	40.9	14.8	0.2
AUG	13.6	5.8	10.0	7.6	44.9	17.9	0.2
SUMMER	13.7	6.9	10.2	7.5	43.5	18.1	0.1
SEP	15.1	4.4	7.2	8.2	46.3	18.7	0.2
OCT	10.8	3.2	7.9	8.3	50.2	19.5	0.1
NOV	6.4	3.3	6.8	7.2	58.8	17.5	0.0
FALL	10.8	3.7	7.3	7.9	51.7	18.6	0.1

Table 3.8-10

Frequency (%) of Selected Visibility Categories at Ukiah, California for the Period 1955-1964

PERIOD	VISIBILITY (MILES)					
	<¼	¼-1	1-3	3-5	5-10	10-25	>25
DEC	10.1	4.2	11.2	8.8	30.9	30.6	4.2
JAN	8.6	3.8	8.7	7.1	34.2	32.2	5.4
FEB	2.3	1.4	5.0	5.9	31.5	45.0	8.9
WINTER	7.2	3.2	8.4	7.3	32.2	35.6	6.1
MAR	0.8	0.6	2.7	4.6	22.3	56.1	12.9
APR	0.3	0.2	1.3	1.9	13.8	64.4	18.1
MAY	0.3	0.2	0.9	1.6	12.2	63.6	21.2
SPRING	0.5	0.4	1.6	2.7	16.1	61.3	17.4
JUN	0.1	0.1	0.3	0.8	8.8	64.2	25.8
JUL	0.1	0.0	0.2	0.7	7.4	68.9	22.7
AUG	0.0	0.1	0.3	1.7	9.3	71.2	17.4
SUMMER	0.0	0.1	0.3	1.1	8.5	68.2	21.9
SEP	0.1	0.1	1.0	2.1	15.2	68.6	13.0
OCT	1.1	1.2	3.4	4.0	22.8	58.6	8.8
NOV	5.2	2.3	7.1	8.0	33.9	37.1	6.4
FALL	2.1	1.2	3.9	4.7	24.0	54.7	9.4

observations of visual range by trained NWS observers at major airport locations. The data indicate that the frequency of significantly reduced visibilities is greatest at Arcata due largely to higher moisture levels. Visibility is generally between 5 and 10 miles during all seasons. The frequency of significantly reduced visibility is greatest between June and October at Arcata when fog and stratus frequently occur. At Ukiah, visibilities are generally between 10 and 25 miles. Poorest visibility occurs in winter when fog occurs most frequently.

In the mountains, visibility is extremely variable. Data is very scarce and the BLM is participating in programs geared to determine visibility on federally-administered lands. The data presented in Tables 3.8-9 through 3.8-10 is not felt to be indicative of conditions in rural, mountainous locations.

Air quality can be determined from visibility observations at particular locations within the district. By eliminating moisture influences on atmospheric clarity, the remaining reduction in visibility is largely due to suspended to air contaminants. Table 3.8-11 presents the number of hours during a representative five year period that substantial visibility reduction occurred due to non-moisture effects at Arcata and Ukiah. The criteria denoting a visibility violation in California was used to develop this table. A violation occurs when visibility is less than 10 miles and the relative humidity is less than 70 percent. Once again, data are not available for much of the mountainous areas in the district.

Table 3.8-11 indicates that at Arcata violations of the California visibility standard occur primarily during the fall and winter months when stagnation episodes occur. At Ukiah, summer and fall provide the maximum frequency of violations of the standard. Photochemical processes occur most actively during this season resulting in visibility impairment at Ukiah. The frequency of violations is generally greater at Ukiah then at Arcata which is greatly impacted by the onshore flow of clean, maritime Pacific air.

<u>Fog</u>

Considerable visibility reduction is directly related to ambient moisture levels. Table 3.8-12 presents the mean number of days that visibility is less than one-quarter mile due to the presence of heavy fog.

Table 3.8-12 indicates that the frequency of fog is greatest during the winter months at all stations with the exception of Arcata. At Eureka, San Francisco, Ukiah, and Sacramento the frequency of fog reaches a maximum during the December - January time frame when the passage of migratory storm systems reaches a maximum. The frequency of fog during the winter months increases with northward progression along the coast. Arcata

Table 3.8-11

Total Hours Violating the California Visibility Standard*

in the Ukiah District

ARCATA

YEAR	DEC	JAN	FEB	WINTER	MAR	APR	MAY	SPRING	JUN	JUL	AUG	SUMMER	SEP	OCT	NOV	FALL	POS OBS
1968	18	23	23	64	23	10	3	36	4	5	6	15	11	11	5	27	2918
1969	30	8	31	69	22	15	8	45	6	15	7	28	16	20	14	50	2916
1970	3	31	24	58	15	6	3	24	7	15	13	35	18	9	11	38	2920
1971	17	6	8	31	3	2	2	7	0	3	9	12	7	4	16	27	2920
1972	43	13	10	66	5	11	0	16	0	3	2	5	1	11	16	28	2920

UKIAH

YEAR	DEC	JAN	FEB	WINTER	MAR	APR	MAY	SPRING	JUN	JUL	AUG	SUMMER	SEP	OCT	NOV	FALL	POS OBS
1955	24	66	53	143	42	22	58	122	58	58	154	270	105	74	58	237	8755
1956	57	7	41	105	44	26	22	92	34	48	17	99	34	58	147	239	8750
1957	53	32	26	111	20	44	37	101	63	71	86	220	73	31	41	145	8743
1958	86	23	7	116	19	16	26	61	20	59	54	133	90	112	66	268	8753
1959	141	42	35	219	15	23	15	53	14	79	79	172	26	69	235	330	8758
1960	31	27	24	83	7	4	5	16	28	28	38	94	55	66	25	146	8759
1961	15	69	19	103	10	11	2	23	35	40	66	141	71	103	64	238	8760
1962	9	31	14	54	13	10	3	26	14	21	33	68	54	13	20	87	8755
1963	36	26	6	68	13	35	20	68	22	34	62	118	58	42	10	110	8750
1964	0	16	30	46	18	10	18	46	19	14	14	47	37	49	9	95	7707

Table 3.8-12

Mean Number of Days with Visibility Less than ¼ Mile
Due to Heavy Fog in the Ukiah District

	J	F	M	A	M	J	J	A	S	O	N	D	Annual	# of Years
Eureka	12	7	2	*	*	0	0	*	*	1	6	11	40	27
Arcata	5	6	3	3	7	10	17	14	15	11	6	1	98	5
San Francisco Airport	4	3	*	*	*	*	*	*	1	2	3	4	17	39
Ukiah	9	2	1	*	*	*	*	0	*	1	5	10	29	10
Sacramento	10	6	2	*	*	0	10	*	*	2	6	9	35	28

* Less than one-half

shows a maximum frequency of heavy fog during the summer and fall months, with heavy fog being not uncommon during any month of the year.

Fog, is associated with moist, cool, surface air masses at the point of saturation. Fog can be classified into numerous types according to the physical processes responsible for its development. Fog types that are common in the Ukiah District include:

- Radiational
- Advection
- Frontal

A very common type of land fog often experienced in the mountian valleys known as radiational or surface inversion fog, is produced by the radiational cooling of relatively shallow layers of calm, humid air, overlying a chilled land surface. This type of fog development requires certain nighttime conditions which include:

- Stable surface air
- Light or calm winds
- Clear skies

Stable surface conditions inhibit vertical diffusion of fog formed at the surface. Light winds promote radiational fog development by limiting mixing. Cloudless skies promote fog since they allow rapid heat loss from the surface thus permitting the ground to cool rapidly, even below surface air temperatures.

Radiational fog occurs in low-lying areas as cool, dense air drains into valleys and low-lying regions. Often, hilly areas will remain clear while adjacent lowlands are foggy. Radiational or ground fog deepens from the ground upward at night and is dissipated during the day by the warming sunlight from the top downward.

Advection fog, unlike radiational fog, requires considerable air movement to promote formation. It simply requires that warm moist air masses be moved over cold surfaces and this most commonly occurs over ocean and coastal locations during summer. During this period, pressure gradients between oceanic and inland air masses are at a maximum, thus promoting inland movement (sea breeze). At coastal locations, warm moist air is channelled over and mixed with cold, moist, surface maritime air. Condensation of water vapor in the ambient air is promoted, thus forming fog. This type of coastal sea fog is most commonly observed during the summer months.

The frequency of occurrence of fog by month in the Ukiah District is presented in Figure 3.8-14. The figure provides fog frequency at selected key stations in of the Ukiah District.

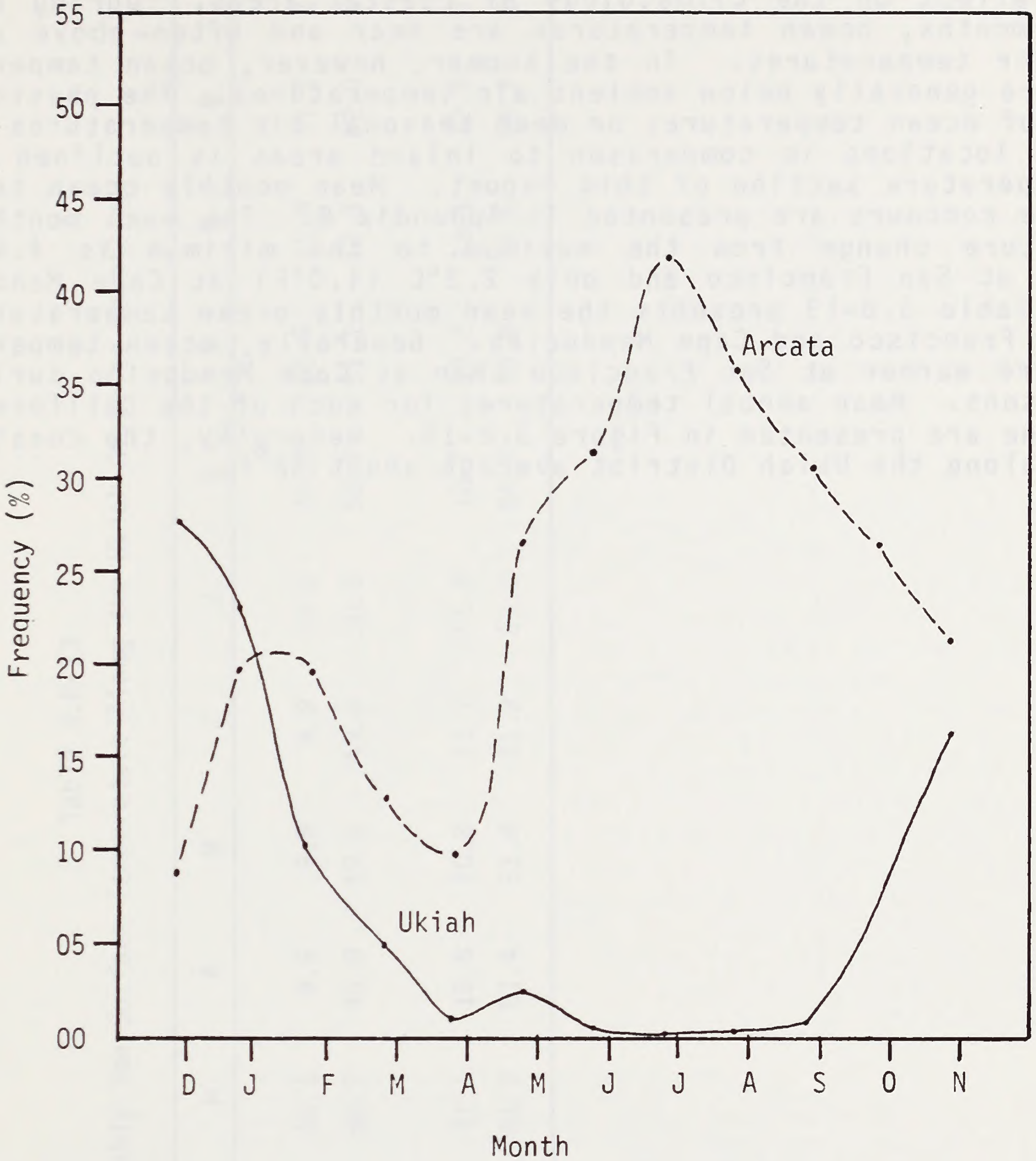


Figure 3.8-14
Frequency of Fog Development in the
Ukiah District

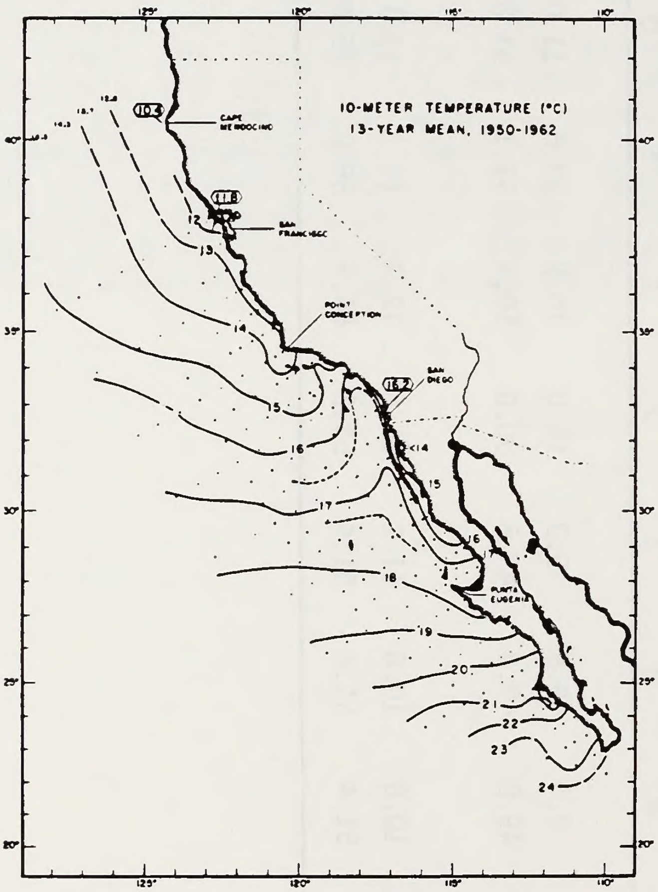
3.8.5 Ocean Temperatures

Seasonal variations of ocean temperatures have a definite effect on the climatology of coastal areas. During the winter months, ocean temperatures are near and often above ambient air temperatures. In the summer, however, ocean temperatures are generally below ambient air temperatures. The physical effect of ocean temperatures on mean seasonal air temperatures at coastal locations in comparison to inland areas is outlined in the temperature section of this report. Mean monthly ocean temperature contours are presented in Appendix B. The mean monthly temperature change from the maximum to the minimum is 4.4°C (7.9°F) at San Francisco and only 2.2°C (4.0°F) at Cape Mendocino. Table 3.8-13 presents the mean monthly ocean temperatures for San Francisco and Cape Mendocino. Generally, ocean temperatures are warmer at San Francisco than at Cape Mendocino during all seasons. Mean annual temperatures for much of the California coastline are presented in Figure 3.8-15. Generally, the coastal waters along the Ukiah District average about 52°F.

Table 3.8-13

Mean Monthly Sea Surface Temperature Along the Ukiah District Coastline

	J	F	M	A	M	J	J	A	S	O	N	D
Cape Mendocino												
°C	10.8	10.4	10.1	9.9	9.9	9.9	10.0	10.2	10.6	11.0	11.2	11.2
°F	51.4	50.7	50.2	49.8	49.8	49.8	50.0	50.4	51.1	51.8	52.0	52.0
San Francisco												
°C	11.6	11.4	11.1	10.8	10.8	11.1	11.8	12.7	13.2	13.1	12.6	12.0
°F	52.9	52.5	51.9	51.4	51.4	51.9	53.2	54.7	55.8	55.6	54.7	53.6



Ten-meter temperature (°C);* 13-year mean, 1950–62. Interval: 1° C. In this and other figures thin, short-dashed lines show half intervals and thick, long dashes show continuation of standard-interval isopleths into regions of infrequent sampling. Boxed values refer to shore stations.

Figure 3.8-15

$*{}^{o}C = \frac{5}{9}\ ({}^{o}F-32)$

3.9 URBAN EFFECT UPON METEOROLOGIC PARAMETERS

There is hardly a meteorologic element that can be named that is not influenced to some extent by cities. It is, however, difficult to separate urban effects from microclimatologic effects since very few measurements have been made with the specific aim of comparing urban and non-urban measurements. There are several causes for the differences between urban and open country climates. One of these is the alteration of the surface, e.g., the change from meadow, forest or swamp to buildings and streets of concrete, brick, steel, and asphalt. Not only does this cause changes in reception and reflection of solar radiation and evaporation, but also in the roughness of the surface over which the wind moves. Another change involves the production of a sizable quantity of heat due to combustion processes carried out in the city and the addition of material to the atmosphere in the form of dusts, gases, and vapors which change the atmosphere's composition in the vicinity of cities.

Temperature

The comparison of temperatures within cities with those outside reveal that city temperatures, especially at time of minimum, are higher (Mitchell, 1961). Also during the period right after sunset, the city temperature does not cool as rapidly as does the country air due to heat content of buildings and radiation between buildings, rather than toward the sky. Between sunrise and noon, urban and non-urban temperatures are nearly the same (Landsberg, 1956). The influence of the city extends in the vertical on the order of three times the height of the buildings (Duckworth and Sandberg, 1954). The average heat island effect over New York City extends to 300 meters (≈1000 feet) and has been observed as high as 500 meters (≈1650 feet) (Bernstein, 1968). Also, the change of temperature with height is quite different over the city, especially at night. In the open country, radiation inversions form frequently, whereas in the city, isothermal or neutral conditions frequently exist through the night with a radiation inversion layer above the city (DeMarrais, 1961).

Since temperatures in the city are warmer than those of the surrounding countryside, the city's heating requirements are less by as much as 10%. Variations between city and country temperatures are extremely noticeable at northern latitudes when the countryside is covered with snow which has melted in the city.

Humidity

Lower relative humidities exist in cities partly due to higher temperatures, but also because of lower absolute humidity. Although little is available in the way of measurements, it is felt that lower absolute humidities are a consequence of the rapid runoff of precipitation in the cities. Also, the existance of little vegetation in the urban environment reduces moisture received from evapotranspiration processes (Landsberg, 1956).

Precipitation

Precipitation is one of the most variable meteorological elements and, because of this, it is difficult to establish significant differences between urban and non-urban areas. However, numerous studies have been made which show either greater precipitation amounts and/or greater frequency of precipitation within cities. Schmauss in 1927 showed 11 percent increase of days with small amounts of precipitation occurring in Munich compared to stations outside the city. Bolgolepow in 1928 reported an increase in precipitation of 10 percent in Moscow compared to a country station for 17 years of record. Ashworth in 1929 noted the increase of average annual precipitation over 3 decades amounting to 13 percent. He also noted less increase for Sundays than for weekdays. Wiegel in 1938 using a 35 year record, noted a 5 percent increase in precipitation, as well as a 12 to 18 percent increase in the number of days with precipitation for the Ruhr area of Germany. These references are all reported in Landsberg (1956). Landsberg also reports a study for Tulsa where topographical effects are at a minimum and the urban area is confined to a rather definite area. In addition to a precipitation increase within the city over a 70 year period, there was an increase of 7 percent in the city compared to surroundings for a 14 year period.

Two more recent studies by Changnon (1961a, 1961b) indicate there may be some urban effect upon precipitaiton over Chicago and the moderate-sized communities of Champaign, and Urbana, Illinois.

The principal suspected causes of the increase of precipitation over cities is the increase of condensation nuclei over cities due to air pollutants and the increased turbulence caused by increased surface roughness. Although water vapor is added to the air from combustion sources, this is not expected to add significantly to the amount of precipitable water or to evoke a major effect.

Snow

Precipitation in the form of snow indicates to some extent the influence of temperature in the urban area. Kossner in 1917 and Maurain in 1947 indicated greater frequencies of snowfall outside as compared to within Berlin and Paris, respectively. On the other hand, Kratzer in 1937 in Munich reported occurrances of snow within the city when none occured in the surroundings, and Keinle in Mannheim, a heavy industry location, reported that snow fell from a fog and stratus layer on two successive days in January 1949 while none fell outside the urban area. It is probable that this was due to air pollutants furnishing condensation nuclei for supercooled water vapor. These references appear in Landsberg (1956) who also estimates a 5% average decrease in snowfall for urban areas (Landsberg, 1968).

Cloudiness

From climatological records there seems to have been a slight increase in cloudiness over the years but this has been so slight (less than 1/10 of mean sky cover) that for so subjective a measure as sky cover this may not be significant. Any increase may be primarily due to city fogs, as increases in early morning cloud cover seems to be greatest. Nearly all large cities show a decrease in the number of clear days over that obseved in adjacent rural areas. The primary effects may be expected to be due to addition of condensation nuclei by air pollution and the release of additional water vapor. Kratzer in 1937 in Munich indicated an 8 percent increase in summer cloudiness compared to a 3 percent increase in winter cloudiness over the city (Landsberg, 1956). This may indicate that surface roughness and therefore, increasing turbulence, may play a part in the formation of cumulus type summer clouds.

Wind

Because of the general increase of the size of the roughness elements in the city over that in the rural areas, wind speeds are decreased within the city. Also the frequency of calms is increased on the order of 5 to 20 percent (Landsberg, 1956). Recently, Pooler (1961) has shown that under conditions of light stable flow, an inflow of air toward the center of the city of Louisville occurs (heat island effect). In addition to the decrease of wind speed in cities, there is of course channeling of the wind in the canyons formed by alternating streets and groups of buildings.

Radiation

The decrease of solar radiation within cities as compared to rural areas is on the order of 15 to 20 percent. This is due to the absorption, reflection, and scattering of particles in the atmosphere, and the absorption of gases. These particles and gases are primarily the result of air pollution. The radiation most affected is the ultraviolet with the infrared being least affected. This is important because of the bactericidal effect of ultraviolet radiation.

Recently, McCormick (1960) has begun measuring of the attenuation of the solar beam at 0.5 micron wave length in order to have an objective measure of the entire pollution layer. In terms of duration of sunshine, Landsberg (1968), shows a decrease in the range of 5-15% in urban areas. Randerson (1970) has showed an average of 23% loss in intensity of light attributed to pollution in Houston, Texas.

Visual Range

The decrease of visibility in urban areas is probably the most noticeable of meteorological differences between urban and rural areas. Comparisons between hourly observations of visibility at city locations and at rural locations (Landsberg, 1956) have shown higher frequencies of fog, smoke, and low visibilities than in neighboring rural areas.

Holzworth and Maga (1960) analyzed visibility measurements from California locations to determine if trends which might be caused by increases in air pollution were noticeable. Results indicated that several cities showed trends toward lowering visibilities. Other showed lowering visibilities until efforts at controlling certain pollutants were made, after which no trend was discernible.

3.10 GENERAL ASSISTANCE IN CLIMATIC PROBLEMS

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Local U.S. National Weather Service Office

A wealth of meteorological informaiton and experience is available at the local city or airport Weather Service Office pertaining to local climatology, pecularities in local micrometeorological conditions including topographic effects, and exposure and operating characteristics of meteorological instruments.

Contract Work

Many universities do contract work for private organizations and for government agencies on meteorological problems.

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3.11 GLOSSARY OF TERMS

Abscissa	The Horizontal coordinate or axis of any graph; usually denoted by X.
Absorption	The process in which incident radiant energy is retained by a substance.
Advection	The process of transport of an atmospheric property solely by the mass motion (i.e., wind) of the atmosphere.
Air Pollution Meteorology	That aspect of meteorology concerned with atmospheric dispersion characteristics.
Aitken Nuclei	The microscopic particles in the atmosphere which serve as condensation nuclei for droplet growth. These nuclei are both liquid and solid with diameters of tens of microns or smaller.
Albedo	A measure of the part of the incoming solar radiation which is reflected from the earth and the atmosphere.
Annual Moisture Deficit	The moisture deficit of a month is the potential evapotranspiration less the rainfall and stored soil water. The sum of the appropriate months is the annual moisture deficit.
Anticyclone	Movements of air traveling in a clockwise direction (in the northern Hemisphere). Since anticyclone circulation and relative high atmospheric pressure usually coexist, the terms anticyclone and high pressure are often used interchangeably.
Attentuation	The process by which energy decreases with increasing distance from the energy source
Ceiling	The height of the lowest layer of clouds or other obscuring phenomena (e.g., dust). During clear weather, the ceiling in unlimited. With fog, the ceiling is obscured.
Centripetal Acceleration	Acceleration on a particle moving in a curved path, directed toward the center of curvature of the path.
Climate	The average condition of the weather at a place over a period of years as exhibited by temperature, wind velocity, and precipitation.

Compressional Heating	The disturbance of a fluid (e.g., air) such that the pressure and density and, therefore temperature, increase in the direction of motion.
Condensation	The physical process by which a vapor becomes a liquid or a solid.
Condensation Nuclei	A particle, either liquid or solid, upon which condensation of water vapor begins in the atmosphere.
Continental Climate	The climate that is characteristic of the interior of a land mass. It is marked bylarge annual, daily and day to day ranges of temperature, humidity and precipitation.
Convection	In general, mass motions within a fluid (e.g., air) resulting in transport and mixing of the properties of that fluid.
Cooling Degree	A form of degree day used to estimate the Days energy requirements for air conditioning or refrigeration. One cooling degree-day is given for each degree that the daily mean temperature deports above a base of 75°F.
Coriolis Force	A deflective force resulting from the earth's rotation; it acts to the right of wind direction in the Northern Hemisphere and to the left in the Southern Hemisphere.
Crystallization	A particle which serves as a nucleus in the formation of ice crystals in the atmosphere.
Cumulonimbus	A principal cloud type, exceptionally dense and vertically developed, occurring either as isolated clouds or as a line or wall of clouds with separated upper portions.
Cumulus	A principal cloud type in the form of individual, detached elements which are generally dense and possess sharp non-fibrous outlines.
Cyclones	Movements of air traveling in a counterclockwise direction (in the northern Hemisphere). Since cyclonic circulation and relative low atmospheric pressure usually coexist, the terms clclone and low pressure system often are used interchangeably.
Cyclonic Storms	Large storm systems (50 to 900 miles in diameter or more) characterized by air rotating around a center of low pressure. More common

in winter than summer. Rainfall and snowfall associated with such storms may be light, but may persist for two to three days or longer.

Dew Point — The temperature to which air must be cooled in order for saturation to occur.

Dew Point Depression — The difference between the air temperature and the dew point.

Divergence — The expansion or spreading out of a vector field (e.g., velocity field).

Dry Bulb Temperature — The ambient temperature of the air as measured by a dry-bulb thermometer.

Eddy Viscosity — The turbulent transfer of momentum by eddies (a glob of fluid with a fluid mass that has a life history of its own) giving rise to fluid friction.

Electromagnetic Spectrum — The ordered array of all known electromagnetic radiations, extending from the shortest cosmic rays, through gamma rays, x-rays, ultraviolet light, visible/light, infrared radiation, and including microwave and all other lengths of radio energy.

Electromagnetic Waves — Energy propagated through space or through material media in the form of an advancing disturbance in electric and magnetic fields existing in space.

Evaporation — The physical process by which a liquid or solid is transformed to the gaseous state.

Evapo-transpiration — The combined processes by which water is transferred from the surface of the earth to the atmosphere; evaporation of liquid or solid water plus transpiration from plants.

Exposure — The general surroundings of a site, with special reference to its openness to winds and sunshine.

Fall Velocity — That limited velocity attained by a body freely falling in air when the resisting force is equal to the gravitational force.

First Order Stations — A meteorological station at which automatic records and hourly readings of weather elements are made.

Free Atmosphere	That portion of the earth's atmosphere, above the planetary boundary layer, in which the effects of the earths surface friction on the air motion are negligible.
Friction Layer	The term is interchangeable with planetary boundary layer and surface boundary layer and refers to the layer between the surface and the free atmosphere.
Frictional Drag	The frictional impedence offered by air to the motion of bodies passing through it.
Front	In meteorology, generally, the interface or transition zone between two air masses of different density.
Frost-Free Period	The frost-free period refers to the length of the growing season as determined by the number of days between the last frost (i.e., 32°F) in spring and the first frost in fall.
Fujita Scale	A scale baed upon maximum wind speed to define the intensity of a tornado.
Gradient	The rate of change of a parameter as a function of distance.
Greenhouse Effect	The heating effect exerted by the atmosphere upon the earth by virtue of the fact that the atmosphere absorbs and reemits infrared radiation.
Growing Season	Generally, the period of the year during which the temperature of cultivated vegetation remains sufficiently high to allow plant growth (Usually synonymous with Frost-Free Period).
Heat Island	The accumulation of heat by large, man-made structures such as cities, resulting in considerable differences in temperature in comparison with surrounding areas, particularly at night.
Heating Degree	A form of degree-day used as an indication Day of fuel consumption; in the United States, one heating degree day is given for each degree that the daily mean temperature departs below a base of 65°F.
Hygroscopic Nuclei	Nuclei with a marked ability to accelerate the condensation of water vapor.

Infrared (Radiation)	Electromagnetic radiation lying in the wave-length interval between visible radiation (light) and microwave radiation.
Inversion	An increase in temperature with height--a reversal of the normal decrease with height in the troposhpere; may also be applied to other meteorological properties.
Ions	In atmospheric electricity, any of several types of electrically charged submicroscopic particles normally found in the atmosphere.
Isobars	Lines of equal or constant pressure.
Isohyet	A line drawn through geographical points recording equal amounts of precipitation during a given time period or for a particular storm.
Isothermal	Of equal or constant temperature, with respect to either space or time; more commonly, temperature with height; a zero lapse rate.
Jet Stream	Relatively strong winds concentrated in a narrow stream in the atmosphere.
Julian Days	A calendar system based upon the sequantial numbering of each day of the year up to 365 with no monthly delineation.
Killing Frost	The frost sufficiently severe to damage the vegetation of an area. For the purpose of this report, when temperatures are 28°F or less.
Kinetic Energy	The energy which a body possesses as a consequence of its motion.
Lake Evaporation	Evaporation from a lake large enough and deep enough so that evaporation from most of its surface is unaffected by the temperature of the surrounding and underlying land.
Langley	Unit of energy per unit area commonly employed in radiation. One Langley is equal to one gram - calorie per square centimeter. The unit was named in honor of the American scientist, Samuel P. Langley (1834-1906) who made many contributions to the knowledge of solar radiation.
Lapse Rate	The decrease of an atmospheric variable (commonly, temperature) with height.

Latent Heat	The amount of heat absorbed (converted to Kinetic Energy) during the processes of change of liquid water to water vapor, ice to water vapor, or ice to liquid water; or the amount released during the reverse processes. Four such processes are condensation, fusion, sublimation and vaporization.
Leeward	The downwind side of an obstacle.
Marine (also Maritime)	A regional climate which is under the predominant influence of the sea. A marine climate is characterized by small diurnal and annual ranges in temperature.
Mechanical	Turbulence due to the roughness of the surface over which the air is passing.
Mediterranean Climate	A type of climate characterized by hot, dry, sunny summers and a winter rainy season.
Meridional	Longitudinal; northerly or southerly; opposed to zonal.
Meso Scale	That portion of meteorology which deals with atmospheric phenomena on a scale larger than that of micrometeorology but smaller than the cyclonic scale (≈5 to 50 miles).
Micrometeorology (also, Microclimatology)	That portion of the science that deals with the observation and exploration of the smallest scale physical and dynamic occurrences within the atmosphere.
Moisture Deficit	The moisture deficit of a month is the potential evapotranspiration less the rainfall and stored soil water.
Molecular Friction	Whenever the surface of one molecule slides over that of another, each molecule exerts a frictional force on the other, parallel to the surfaces.
Norther	A strong, very dry, dusty, northerly wind which blows in late spring, summer and early fall in the Valley of California or in the West Coast when pressure is high over the mountains to the north.
Orographic Lifting	The lifting of an air current caused by its passage up and over mountains.
Palmen's Model	A model describing the general meridional circulation of the earth's atmosphere broken into three cells.

Pan Evaporation — The standard way to measure evaporation of water by using small pans exposed to the atmosphere. The standard Class A land pan is four feet in diameter and ten inches deep, raised six inches from the ground so that air can circulate around it.

Parameter — In general, any quantity that is not an independent variable. The term is often used in meteorology to describe almost any meteorological or climatological quantity or element.

Perturbation — Any departure introduced into an assumed steady state of a system.

Planck's Law — An expression for the variation of monochromatic emittance as a function of wavelength of black-body radiation at a given temperature. It is the most fundamental of the radiation laws.

Pluvial Indices — An index showing the amount of precipitation falling in one day, or other specified period, that is likely to be equalled or exceeded at a given place only once in a given return period (often, 100 years).

Polar Front — The semi-permanent, semi-continuous front separating air masses of tropical and polar origins.

Potential Energy — The energy which a body possesses as a consequence of its position in the field of gravity.

Potential Evapotranspiration — Combined evaporation from the soil surface and transpiration from plants when the water supply in the ground is unlimited.

Pressure Gradient Force — The force due to differences in pressure within a fluid mass (e.g., air).

Radiational Fog — A major type of fog, produced over a land area where radiational cooling reduces the air temperature to or below its dew-point.

Radiosonde — A balloon-borne instrument for the simultaneous measurement and transmission of meteorological data.

Rainfall Frequency — The number of times during a specific period of years that precipitation of a certain magnitude or greater, occurs or will occur at stations.

Snow Pack	The amount of annual accumulation of snow at higher elevations in the Western United States, usually expressed in terms of average water equivalent.
Solar Insolation	The total radiant energy from the sun incident on a unit area of a horizontal plane located at the surface of the earth.
Solar Radiation	The total electromagnetic radiation emitted by the sun.
Squall Line	Any non-frontal line or narrow band of active thunderstorms.
Stagnation Episodes	Periods of poor atmospheric ventilation resulting in the potential for substantial pollutant levels.
Standard Atmosphere	A hypothetical vertical distribution of atmospheric temepratature, pressure and density, which by international agreement is taken to be representative of the global atmosphere (59°F and 29.92 in. of mercury at sea level).
Storm Track	The path followed by a center of low atmospheric pressure.
Stratosphere	The atmospheric layer above the tropopause, average altitude of base and top, 7 and 22 miles respectively; a very stable layer characterized by low moisture content and absence of clouds.
Stratus	A principal cloud type in the form of a gray layer with a rather uniform base.
Supercooled	The reduction of temperature of any liquid below the melting point of that substance's solid phase; that is, cooling beyond its nominal freezing point.
Supersaturation	In meteorology, the condition existing in a given portion of the atmosphere, when the relative humidity is greater than 100 percent.
Synoptic	In general, pertaining to or affording an overall view. In meteorology, it refers to the use of meterological data obtained simultaneously over a wide area for the purpose of presenting a comprehensive and nearly instantaneous picture of the state of the atmosphere.

Synoptic Scale	Weather patterns associated with high and low pressure systems in the lower troposphere, i.e., large scale.
Terrestrial Radiation	(also called earth radiation, eradiation) The total infrared radiation emitted from the earth's surface.
Thermal Buoyancy	Buoyancy attributable to a local increase in temperature.
Transpiration	The process by which water in plants is transferred as water vapor to the atmosphere.
Tropopause	The transition zone between the troposphere and stratosphere, usually characterized by an abrupt change of lapse rate.
Troposphere	That portion of the atmosphere from the earth's surface to the tropopause; that is, the lowest 6 to 12 miles of the atmosphere. The troposphere is characterized by decreasing temperature with height and by appreciable water vapor.
Tule Fog	A persistent, dense fog common in the Central Valley of California.
Turbulence	A state of fluid flow in which the instantaneous velocities exhibit irregular and apparently random fluctuations so that in practice only statistical properties can be recognized and subjected to analysis.
Ultraviolet (radiation)	Electromagnetic radiation of shorter wavelength than visible light but longer than x-rays.
Water Equivalent	The liquid water present within a sample of snow.
Wavelength	In general, the mean distance between maxima of a roughly periodic pattern (e.g., light).
Weather	The state of the atmosphere mainly with respect to its effects upon life and human activities. As distinguished from climate, weather consists of the short term (minutes to months) variations of the atmosphere. Popularly, weather is thought of in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility and wind.

Wet Bulb Temperature	The temperature measured by a wet, muslim-covered bulb thermometer. The temperature an air parcel would have if cooled adiabatically to saturation at constant pressure by evaporation of water into it.
Wind Roses	Diagrams designed to show the distribution of wind speed and direction experienced at a given location over a considerable period. The most common form consists of a circle from which 8 or 16 lines emanate, one for each compass point. The length of the line is proportional to the frequency of wind from that direction; the frequency of calms is entered in the center.
Zonal	Latitudinal; easterly or westerly; opposed to meridional.

4. DISPERSION METEOROLOGY

4.1 INTRODUCTION

An understanding of the dispersion potential of a region is essential in determining the impact of both existing and proposed sources of ground level and elevated emissions of pollutants. Areas that are plagued with poor dispersion conditions for extended periods of time are apt to suffer stringent limitations on land use and industrial development. Under such poor dispersion conditions, seemingly insignificant sources of pollution can result in excessive concentrations over large areas. As discussed in Section 6, The Clean Air Act Amendments of 1977 impose strict regulatory requirements on new sources of air pollution in areas with high ambient pollutant concentrations.

The dispersion potential within the Ukiah District has been developed through the maximum utilization of available data. The following sections describe the dispersion meteorology of the Ukiah District in terms of the following analyses:

- Data Sources
- Prevailing Winds
- Atmospheric Stability
- Mixing Heights and Inversions
- Typical and Worst-Case Conditions
- Air Basins
- Fire Weather
- General Dispersion Modeling

Surface data suitable for use in the analysis of the Ukiah District dispersion meteorology are derived primarily from the National Weather Service (NWS) first-order meteorological stations. The availability of mixing height, inversion and winds aloft data is limited to those stations that take routine measurements of upper air winds and temperatures. There are no NWS station of this type in the District. However, upper air winds and temperature data are also available at other sites as part of a program being conducted by the California Air Resources Board (CARB). Additional data from lower-order NWS or other governmental and special interest stations have been reviewed and included where they provide additional significant information regarding the characterization of the dispersion meteorology of the Ukiah District.

Section 4.2 provides a review of the general principles of dispersion meteorology. Sources of data which have been used to describe the dispersion potential of the Ukiah District are discussed in Section 4.3. The discussion then turns to a review of specific dispersion parameters including prevailing winds, atmospheric stability, mixing heights, and inversions in Sections 4.4 through 4.6, respectively. More detailed analyses are then provided, including a review of typical and worst-case conditions for a variety of potential sources in Section 4.7. The air basin analysis approach to dispersion meteorology is outlined in Section 4.8. Section 4.9 provides a discussion of the impact of dispersion meteorology on burn conditions while section 4.10 describes concepts of air quality modeling including suggestions as to the manner in which the data presented in this document should be interfaced with appropriate models. Finally, Section 4.11 provides a review of sources of assistance to BLM personnel encountering problems in dispersion meteorology while Section 4.12 provides a glossary of terms.

4.2 PRINCIPLES OF DISPERSION METEOROLOGY

Dispersion meteorology provides an evaluation of the capability of the atmosphere to disperse airborne effluents in a given geographical region. That capability depends largely on the critical meteorological parameters wind speed and direction, atmospheric stability and mixing height. The topography of the region also plays an important role.

The air pollution cycle can be considered to consist of three phases: the release of air pollutants at the source, the transport and diffusion in the atmosphere, and the reception of air pollutants in reduced concentrations by humans, plants, animals, or inanimate objects. The major influence of meteorology occurs during the diffusion and transport phase. The motions of the atmoshphere which may be highly variable in four dimensions, are responsible for the transport and diffusion of air pollutants.

Although the distribution of a cloud of pollutant material with time will depend on the summation of all motions of all sizes and periods acting upon the cloud, it is convenient to first consider some mean atmospheric motions over periods on the order of an hour.

The following sections discuss (1) the principles of turbulence and diffusion, (2) the key dispersion parameters, (3) the role of topography in diffusion and (4) atmospheric chemistry. Modeling is discussed in detail in Section 4.9 while instrumentation is reviewed in Section 7.

4.2.1 Principles of Turbulence and Diffusion

When a small concentrated puff of gaseous pollutant is released into the atmosphere, it tends to expand in size due to the dynamic action of the atmosphere. In so doing, the concentration of the gaseous pollutant is decreased because the same amount of pollutant is now contained within a larger volume. This natural process of high concentrations spreading out to lower concentrations is the process of diffusion.

Atmospheric diffusion is ultimately accomplished by the wind induced movement of pollutants, but the character of the source of pollution requires that this action of the wind be taken into account in different ways. These sources can be conveniently grouped into three classes: point sources, line sources, and area sources. In practice, the first two classes must be further divided into instantaneous and continuous sources.

The instantaneous point source is essentially a "puff" of material created or ejected in a relatively short time, as by a nuclear explosion, the sudden rupture of a chlorine tank, or the bursting of a tear-gas shell. The wind of immediate importance is, of course, that occurring at the place and time at which the pollutant is created. Since the wind is highly variable, the initial direction of movement of the puff is also variable and difficult to predict; a soap-bubble pipe and five minutes' close observation of the initial travel of successive bubbles will convincingly demonstrate the difficulty of predicting the exact trajectory of the next bubble. In addition, dilution of a puff source is a very strong function of time after its release. At first, the small-scale fluctuations of the wind cause it to grow rather slowly and the larger-scale wind variations simply carry it along on erratic paths. But as the puff grows, larger-scale motions can get a "hold" on it to tear it apart and dilute it more rapidly. Thus, the unique feature of the instantaneous point source is its increasing dispersion rate with time, hence, the necessity to consider successively larger scales of meterorological phenomena in calculating its spread.

Continuous point sources (the smoke plume from a factory chimney, the pall from a burning dump) are the most familiar, the most conspicuous, and the most studied of all pollution sources. The meteorology of the continuous source must take into account the time changes of the wind at the point of emission. The behavior of a plume from a factory chimney is very much like that of water from a hose being played back and forth across a lawn. It is evident that if the hose is steady, the same area will be continually exposed to the water. But if the hose (wind) moves back and forth in an arc, the water (pollution) will be distributed over a wider area, hence the concentration will be less. For a truly continuous source, there are other changes of great importance - primarily the diurnal and seasonal cycles.

The isolated line source is less common, and therefore, of less general interest, with two important exceptions - heavily traveled highways, and the swath of chemicals emitted by crop-dusting apparatus. In both these examples, if the line of pollutant is uniform and is long enough, the dispersion of the pollution must be attained in only two dimensions, along the wind and in the vertical. If the line source is a continuous one, as might be the case of a freeway in rush hours, spreading in the downwind direction becomes ineffective (at a particular downwind location), so that only the vertical dimension is left to provide dilution. This behavior of the continuous line source has been exploited by meteorologists in field experiments with controlled tracers to permit the detailed study of vertical diffusion, uncomplicated by effects in the other two coordinates.

The area source can vary enormously in size. It may be distributed over several square miles, as in an industrial park, over tens or hundreds of square miles, as in a city, or over thousands of square miles, exemplified by the almost continuous strip city (the "megalopolis" or "megapolitan area") along the eastern seaboard of the United States. These area sources usually include combinations of all the single-source configurations.

A large city will include many thousands of home chimneys, thousands of factories and shops, hundreds of miles of streets, open dumps, burning leaves, evaporating fumes from gasoline storage or from cleaning plants and paint factories, and everywhere the automobile. The weather problem of the city area source becomes, in the aggregate, quite different from that of a single source. Here we are concerned not with the increasing rate of wind dispersion with increasing scale, or with the behavior of wind with time at a single point, but rather with the replenishment rate of the air over the city. We must consider the total movement of a large volume of air as it "ventilates" the city. Anything that reduces this ventilation rate, whether it be the confining effect of surrounding mountains or the reduced velocities of a slow-moving anticyclone, is of concern.

In the construction of cities man has modified the weather as will be discussed in more detail in Section 4.2.6. The volume of effluent injected into the air has reduced the solar radiation. The absorption characteristics of cement and asphalt instead of grass and trees create urban "heat islands." These effects must be considered in the meteorology of urban air pollution. The urban heat island effect is discussed in more detail in Section 3.9

The atmosphere disperses pollutants because it is in constant mostion, and this motion is always turbulent to some degree. There is, as yet, no fully accepted definition of turbulence, but empirically it can be described as random (three-dimensional) flow. The understanding of turbulent diffusion in the atmosphere has progressed largely through empirical treatments of controlled tracer experiments. The current tendency is to deal with turbulence through statistical concepts derived from aerodynamics and fluid dynamics, in contrast to earlier theories which centered around a virtual-diffusivity concept. In the practical application of computing pollution concentrations, the common practice is to employ the statistical method for distances to perhaps 150 kilometers (93 miles) from the source, and equations based on virtual-diffusivity ("K") theory for longer distances, particularly for calculations on a hemispheric or global scale.

Vertical Turbulent Diffusion

To all intents and purposes rapid atmospheric diffusion in the vertical is always bounded: on the bottom by the surface of the earth and at the top by the tropopause. The tropopause - the demarcation between the troposphere, where temperature decreases with altitude, and the stratosphere, where the temperature is relatively constant or increases with altitude - is lowest over the poles, at about 5 miles, and highest in the tropics, at about 12 miles. The full depth of the troposphere is available for vertical dispersion. However, utilization of this total vertical dimension can take place at very different rates, depending on the thermally driven vertical wind. These rates are intimately related to the vertical temperature profile. On the average (and if we neglect the effects of the phase change of water in the air), enhanced turbulence is associated with a drop in temperature with height of 10°C per kilometer (29°F per mile) or greater (this is the dry adiabatic rate as discussed in Section 4.2.3). If the temperature change with height is at a lesser rate, turbulence tends to be decreased, and if the temperature increases with height (an "inversion"), turbulence is very much reduced.

The temperature profiles particularly over land, show a large diurnal variation as seen in Figure 4.2-1. Shortly after sunrise, the heating of the land surface by the sun results in rapid warming of the air near the surface; the reduced density of this air causes it to rise rapidly. Cooler air from aloft replaces the rising air "bubble," to be warmed and rise in turn. This vigorous vertical interchange creates a "super-adiabatic" lapse rate - a temperature decrease of more than 29°F per vertical mile - and vertical displacements are accelerated. The depth of this well-mixed layer depends on the intensity of solar radiation and the radiation characteristics of the underlying surface. Over the deserts, this vigorous mixing may extend well above 2 miles, while over forested lake country, the layer may be only from three to seven hundred feet thick. Obviously, this effect is highly dependent on season; in winter, the lesser insolation and unfavorable radiation characteristics of snow cover greatly inhibit vertical turbulence.

In contrast, with clear or partly cloudy skies the temperature profile at night is drastically changed by the rapid radiational cooling of the ground and the subsequent cooling of the layers of air near the surface. This creates an "inversion" of the daytime temperature profile, since there is now an increase in temperature with height. In such a situation the density differences rapidly dampen out vertical motions, which tends to reduce vertical turbulence, and stabilize the atmosphere.

Two other temperature configurations, on very different scales, have important effects on vertical turbulence and the dilution of air pollution. At the smaller end of the scale, the heat capacity of urban areas and, to a lesser extent, the heat generated by fuel consumption act to modify the temperature profile. The effect is most evident at night, when the heat stored by day in the buildings and streets warms the air and prevents the formation of the surface-based temperature inversions typical of rural areas. Over cities, it is rare to find inversions in the lowest 300 feet; the city influence is usually evident 700 to 1000 feet above the surface. The effect is a function of city size and building density, but not enough observations are yet available to provide any precise quantitative relations. Although the effect even for the largest cities is probably insignificant above three thousand feet, this locally produced vertical mixing is quite important. Pollution, instead

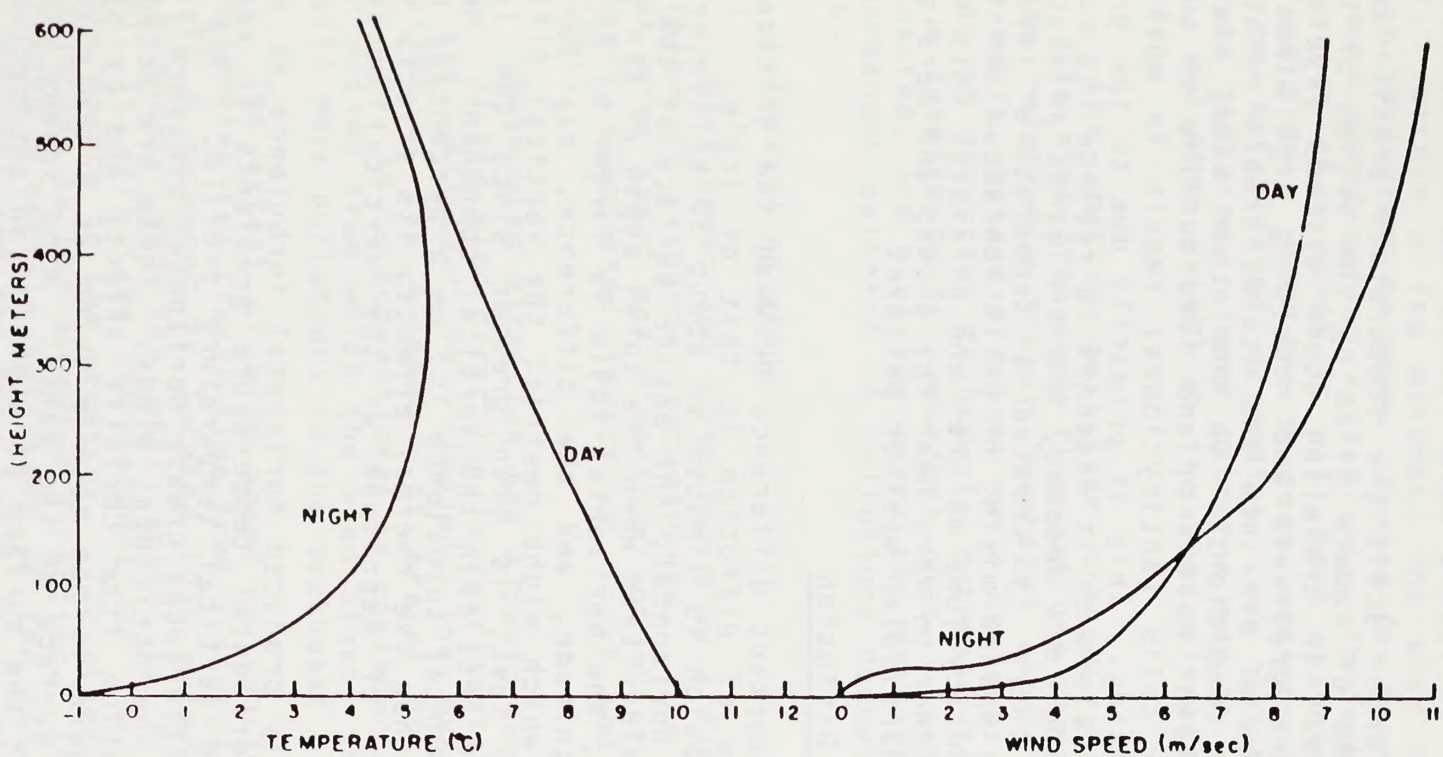

Figure 4.2-1

Diurnal Variation of Temperature and Wind Speed of being confined to a narrow layer near the height of emission, perhaps only 300 feet in thickness, can be freely diluted in more than double the volume of air, the concentrations being reduced by a similar factor.

On a much larger scale the temperature profile can be changed over thousands of square miles by the action of large-scale weather systems. In traveling storm systems (cyclones), the increased pressure gradients and resulting high winds, together with the inflow of air into the storm, create relatively good vertical mixing conditions. On the other hand, the flat pressure patterns, slower movement, and slow outflow of surface air in high-pressure cells (anticyclones) result in much less favorable vertical mixing. This is primarily due to the gradual subsidence of the air aloft as it descends to replace the outflow at the surface. During this descent, the air warms adiabatically, and eventually there is created a temperature inversion aloft, inhibiting the upward mixing of pollution above the inversion level. As the anticyclone matures and persists, this subsidence inversion may lower to very near the ground and persist for the duration of the particular weather pattern.

Horizontal Turbulent Diffusion

The most important difference between the vertical and horizontal dimensions of diffusion is that of scale. In the vertical, rapid diffusion is limited to about 10 kilometers (6 miles). But in the horizontal, the entire surface of the globe is eventually available. Even when the total depth of the troposphere is considered, the horizontal scale is larger by at least three orders of magnitude, and the difference, say during a nocturnal inversion which might restrict the vertical diffusion to within a hundred feet, is even greater since the lateral turbulence is reduced less than the vertical component. Mechanically produced horizontal turbulence is, on a percentage basis, much less important than the thermal effects; its effects are of about the same order of magnitude as the vertical mechanical effects.

The thermally produced horizontal turbulence is not so neatly related to horizontal temperature gradients as vertical turbulence is to the vertical temperature profile. The horizontal temperature differences create horizontal pressure fields, which in turn drive the horizontal winds. These are acted upon by the earth's rotation (the Coriolis effect) and by surface friction, so that there is not such a thing as a truly steady-state wind near the surface of the earth. Wind speeds may vary from nearly zero near the surface at night in an anticyclone, to 200 miles per hour under the driving force of the intense pressure gradient of a hurricane. The importance of this variation, even though in air pollution we are concerned with much more modest ranges, is that for continuous sources the concentration is inversely proportional to the wind speed.

The variation of turbulence in the lateral direction is perhaps the most important factor of all and certainly one of the most interesting. In practice, this can best be represented by the changes in horizontal wind direction illustrated in Figure 4.2-2. Within a few minutes, the wind may fluctuate rapidly through 90 degrees or more. Over a few hours it may shift, still with much short-period variability, through 180 degrees, and in the course of a month it will have changed through 360 degrees numerous times. Over the seasons, preferred directional patterns will be established depending upon latitude and large-scale pressure patterns. These patterns may be very stable over many years, and thus establish the wind climatology of a particular location.

The emitted pollution travels with this ever-varying wind. The high-frequency fluctuations spread out the pollutant, and the relatively steady "average" direction carries it off - for example, toward a suburb or a business district. A gradual turning of direction transports material toward new targets and gives a respite to the previous ones. Every few days the cycle is repeated, and over the years the prevailing winds can create semipermanent patterns of pollutions downwind from factories or cities.

4.2.2 Prevailing Winds

Wind speed and direction play a fundamental role in the dispersion of airborne contaminants. The following paragraphs discuss wind speed and direction and other wind characteristics and their associated impact on local and regional dispersion potential.

Mean wind direction has a basic impact on air pollutant levels. If the wind direction is representative of the height at which the pollutant is released, the mean direction will be indicative of the direciton of travel of the pollutants. In meteorology, it is conventional to consider the wind direction as the direction from which the wind blows, therefore, a northwest wind will move pollutants to the southeast of the source.

The effect of wind speed is two-fold. The wind speed will determine the travel time from a source to a given receptor, e.g., if a receptor is located 1000 meters (3281 ft) downwind from a source and the wind speed is 5 meters/second (16.4 ft/sec), it will take 260 seconds for the pollutants to travel from the source to the receptor. The other effect of wind speed is a dilution in the downwind direction. If a continuous source is emitting a certain pollutant at the rate of 10 grams/second (1.3 lbs/min) and the wind speed is 1 meter/second (2.2 mph) then in a downwind length of the plume of 1 meter (3.3 feet) will be contained 10 grams (0.02 lbs) of pollutant since 1 meter (3.3 feet) of air moves past the source each second. Next, consider that the conditions of emission are the same but the wind speed is 5 meters/second (11 mph). In this case, since 5 meters (16.4

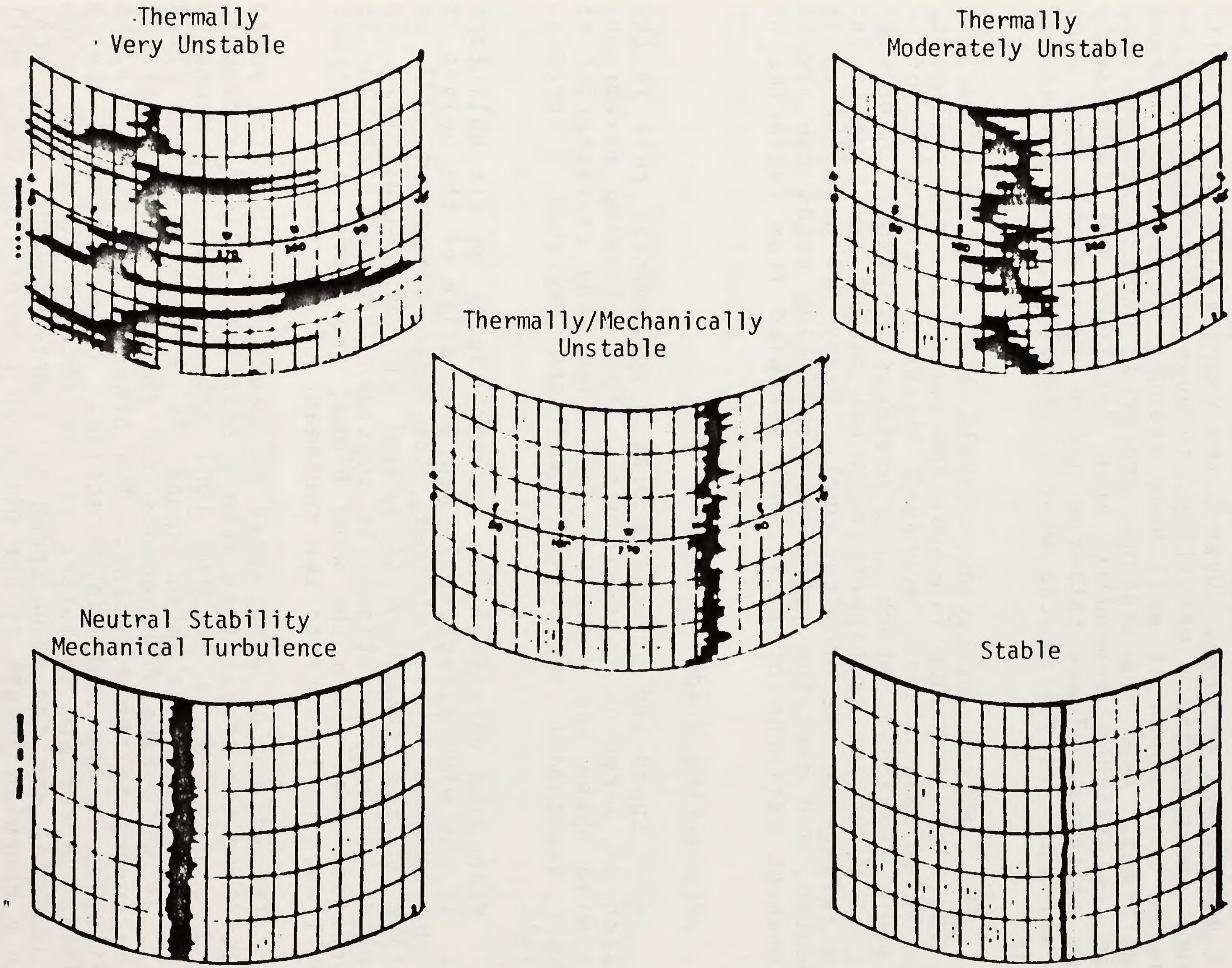

Figure 4.2-2

Gustiness Classification

feet) of air moves past the source each second, each meter of plume length contains 2 grams (0.04 lbs) of pollutant. Therefore, it can be seen that the dilution of air pollutants released form a source is proportional to the wind speed. This may be restated in another form: The concentration of air pollutants is inversely proportional to wind speed.

Wind speed is generally found to increase with height above the ground and wind direction to veer (turn clockwise) with height (in the northern hemisphere at extratropical latitudes) due to the effects of friction with the earth's surface. The amount of these increases in speed and veering in direction are quite variable, and to a great degree, related to the roughness of the surface and the stability of the atmosphere.

In the preceding paragraphs, consideration of only the mean speed and direction of wind has been made. Of course, there are deviations from these means. There are velocity components in all directions creating vertical motions as well as horizontal ones. These random motions of widely different scales and periods are essentially responsible for the movement and diffusion of pollutants about the mean downwind path. These motions, commonly called eddys, are considered as atmospheric turbulence. If the scale of a turbulent motion, i.e., the size of an eddy, is larger than the size of the pollutant plume in its vicinity, the eddy will move that portion of the plume. If an eddy is smaller than the plume, its effect will be to diffuse or spread out the plume. This diffusion caused by the eddy motion is widely variable, but even when this duffusion is at the minimum, it is roughly three orders of magnitude greater than the diffusion by molecular action alone.

During the daytime, solar heating causes turbulence to be at a maximum and vertical motions to be strongest. This causes the maximum amount of momentum exchange between various levels in the atmosphere. Because of this, the variation of wind speed with height is least during the daytime. Also, the amount of veering with height is least (on the order of 15^{o} to 20^{o} over average terrain). The thickness of the friction layer will also be greatest during the day due to the vertical exchange.

At night, the vertical motions are least and the effect of friction is not felt through as deep a layer as during the day. The surface speed over average terrain is much less than the free atmosphere wind (on the order of 1/4 to 1/3 that of the 1000 meter (3281 feet) wind) and the amount of veering with height may be on the order of 40^{o} to 45^{o}. Figure 4.2-3 shows the diurnal variation of wind speed at two different levels on a meteorological tower (Singer and Raynor, 1957).

Wind data are generally only available in terms of speed and direction. Turbulence data are considerably more sophisticated and are generally only available as a result of specialized, site-specific data gathering programs. Such data are only

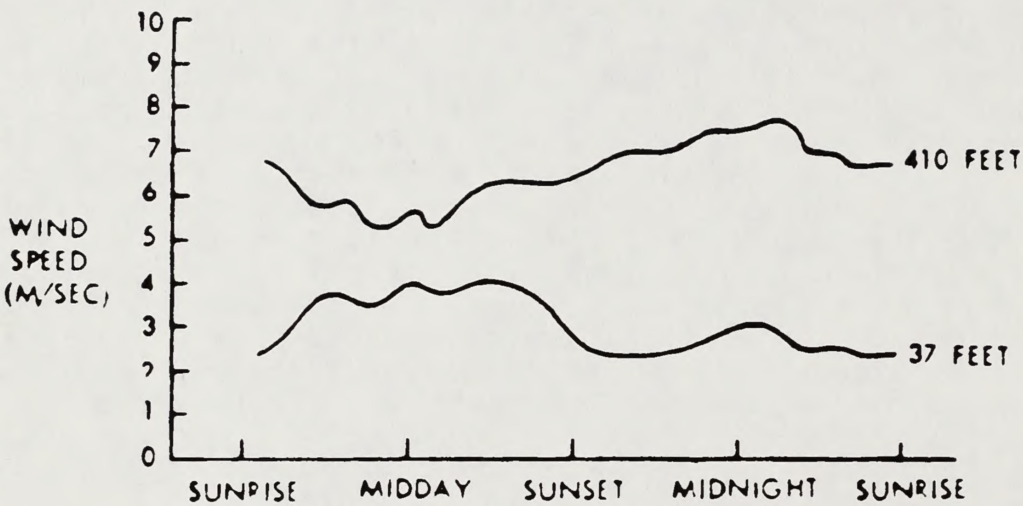

Figure 4.2-3
Diurnal Variations in Wind Speed
As a Function of Height (1)

(1) Data from Meteorological Tower
Brookhaven National Laboratory
April 1950-March 1952

used in very detailed modeling analyses. The bulk of the modeling analyses conducted for the air pollution industry require only basic wind data for speed and direction. This latter type of data are generally summarized in the form of wind roses. These may be viewed in Figure 4.4-1.

A wind rose is defined in the Glossary of Meteorology as, "Any one of a class of diagrams designed to show the distribution of wind direction experienced at a given location over a considerable period; it thus shows the prevailing wind direction. The most common form consists of a circle from which eight or sixteen lines emanate, one for each compass point. The length of each line is proportional to the frequency of wind from that direction; and the frequency of calm conditions is entered in the center. Many variations exist. Some indicate the range of wind speeds from each direction; some relate wind direction with other weather occurrences." Wind roses may be constructed for data from a given time period such as a particular month or may be for a particular time of day or season from a number of years of data. In constructing or interpreting wind roses, it is necessary to keep in mind the meteorological convention that wind direction refers to the direction from which the wind is blowing. A line or bar extending to the north on a wind rose indicates the frequency of winds blowing from the north, not the frequency of winds blowing toward the north. Some of the specialized wind roses that may be constructed are precipitation wind roses, stability wind roses, and pollution wind roses. The latter two require additional data than are generally available at standard Weather Bureau stations. An informative article on the history and variants of wind roses has been published by Court (1963).

Prior to January 1964, the surface wind direction was reported by U.S. Weather Bureau stations as one of the 16 directional points corresponding to the mariner's compass card or compass rose, on which each direciton is equivalent to a 22 1/2 sector of a 360^{o} circle. Table 4.2-1 illustrates, in the form of a frequency table of wind direction versus wind speed groups, the data essential to the development of a 16-point wind rose. It is an example of summaries of hourly observations published monthly until January 1964 in the Local Climatological Data (LCD) Supplement. Frequencies are totaled by direction and wind speed group. A quick look at this wind rose indicates the highest directional frequency is from the ENE and the highest speed frequency is the 8 to 12 mph column. Average speeds have been computed for each direction.

When wind roses are employed to summarize climatological data involving long periods of record, percentage frequencies are favored over numerical totals for tabular presentation since the number of observations in any one cell can become quite large. Moreover, wind rose diagrams can be drafted directly from tabular data if percentages are available. Table 4.2-2 presents 10 years of hourly wind data observed at New Orleans Moisant International

Table 4.2-1

A Typical Tabular 16 Point Wind Rose

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED										AVERAGE SPEED	
	KNOTS 0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	40 Over	TOTAL	KNOTS	M.P.H.
	M.P.H. 0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 Over			
N	8	13	15	18	12	3				69	10.8	12.4
NNE	1	16	28	30	7	1				83	10.2	11.7
NE	7	34	36	5						82	6.7	7.7
ENE	11	51	46	5						113	6.3	7.3
E	6	19	14	4						43	6.4	7.3
ESE	4	15	13	3						35	6.5	7.5
SE	1	13	4	2						20	6.3	7.2
SSE	2	6	20	11						39	8.3	9.6
S	3	11	21	10	1					46	8.2	9.4
SSW	3	9	9	9	4					34	9.3	10.6
SW	1	8	7							16	6.3	7.2
WSW		4	3	1						8	6.9	7.9
W	1	5	7							13	6.5	7.4
WNW	1	16	6	1						24	6.0	6.9
NW	2	3	6	1						12	7.2	8.2
NNW	1	11	29	26	6	1				74	10.6	12.2
CALM	33									33	0.0	0.0
TOTAL	85	234	264	126	30	5				744	7.7	8.9

Table 4.2-2

Sample Long-Term Wind Rose Data for

New Orleans, Louisiana

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED										M.P.H.
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47 OVER	TOTAL	
N	+	1	2	3	1	+	+	+		7	13.9
NNE	+	1	2	3	1	+				6	12.8
NE	+	2	3	3	+	+				8	11.0
ENE	+	2	4	2	+	+	+			8	9.9
E	+	2	3	1	+					6	9.1
ESE	+	1	1	1						3	8.4
SE	+	2	2	+	+					5	7.8
SSE	+	3	3	1	+	+		+		9	9.9
S	+	3	4	2	+	+				10	9.8
SSW	+	1	3	2	1	+				7	12.0
SW	+	1	1	+	+	+				3	8.6
WSW	+	1	1	+	+	+	+			2	10.7
W	+	1	1	1	+	+	+			2	11.8
WNW	+	1	1	1	+	+	+			3	12.5
NW	+	1	1	1	1	+	+			5	13.9
NNW	+	1	2	2	2	1	+	+		8	14.7
CALM	8									8	
TOTAL	11	22	34	23	7	2	+	+		100	10.3

Airport during January for the years 1951 through 1960, as published in the "Decennial Census of United States Climate." This 10-year summary of meteorological data is compiled for most U.S. Weather Bureau first order stations.

On January 1, 1964, the U.S. Weather Bureau changed the wind direction reporting procedure from 16 points to 36 - 10° intervals. Table 4.2-3 is the result; a 36-point wind rose. Since 36 cannot be divided by 16 there is no way of grouping 36 points into 16 points and there is no easy way of combining wind data if the wind rose summaries include both 16-point and 36-point wind direction observations. For this and other reasons, the 36-point wind rose was dropped after 1964. A few air quality models such as CRSTER require 36 point wind rose data, and for such an application, 1964 data must be used.

This report will present wind roses using a very simplistic format. The frequency of the wind direction for each of the 16 cardinal directions is plotted and lines are drawn connecting each directional frequency (See Section 4.4.1)

4.2.3 Atmospheric Stability

Whether the atmosphere has a tendency to enhance or to dampen out vertical motions is important to atmospheric processes which produce weather as well as to the effects upon air pollutant dispersion. The stability of the atmosphere is highly dependent upon the vertical distribution of temperature with height.

Adiabatic Lapse Rate

Due to the decrease of pressure with height, a parcel of air lifted to higher altitude will encounter decreased pressure and expand and, in undergoing this expansion, will cool. If this expansion takes place without loss or gain of heat to the parcel, the change is adiabatic. Similarly, a parcel of air forced downward in the atmosphere, will encounter higher pressures, contract, and become warmer. This rate of cooling with lifting, or heating with descent is the dry adiabatic lapse rate and equals 5.4°F per 1000 feet or approximately 1°C per 100 meters. This process lapse rate is the rate of heating or cooling of any descending or rising parcel of air in the atmosphere and should not be confused with the existing temperature variation with height at any one time, i.e., the environmental lapse rate.

Environmental or Prevailing Lapse Rate

The manner in which temperature changes with height at any one time is the environmental or prevailing lapse rate. This is principally a function of the temperature of the air and of the surface over which it is moving and the rate of exchange of heat between the two. For example, during clear days in midsummer the ground is rapidly heated by solar radiation. This in turn, provides for rapid heating of the layers of the atmoshpere

Table 4.2-3

A Typical Tabular 36 Point Wind Rose

DIRECTION	HOURLY OBSERVATIONS OF WIND SPEED										AVERAGE SPEED	
	0-3	4-6	7-10	11-16	KNOTS 17-22	22-27	28-33	34-40	41 OVER	TOTAL	KNOTS	M.P.H.
	0-3	4-7	8-12	13-18	M.P.H. 19-24	25-31	32-39	40-46	47 OVER			
01	3	5	2	3						13	6.9	8.0
02	7	9	8							24	5.3	6.0
03	3	9	7							19	5.4	6.2
04	7	22	2	1						32	5.3	6.1
05	9	15	7	4						35	5.9	6.8
06	11	27	17	6						61	6.2	7.1
07	4	27	16	3						50	6.2	7.1
08	3	7	13	3						26	7.2	8.3
09	1	9	6	5						21	7.7	8.8
10	5	9	4							18	5.1	5.8
11	5	11	5	1						22	5.8	5.5
12	5	5	4							14	5.9	5.7
13	2	4	3							9	6.0	6.9
14	5	7	6							18	5.2	6.0
15	1	7	5		1					14	7.1	8.1
16	1	8	4							13	5.9	6.8
17	1	6	4							11	6.2	7.1
18		6	9	6						21	8.8	10.1
19	2	2	3							7	5.7	6.6
20	3	5	7	5						15	7.1	5.1
21	2	2	3	1						8	6.6	7.6
22	2	2	5	6						15	8.6	9.9
23	4	2	7	3						16	7.3	8.3
24	5	2	2	1						10	5.3	6.1
25	3	1		1						5	5.0	5.8
26	2	3	4	4						13	7.6	8.8
27	2	6	1							9	5.0	5.8
28	3	5	4							12	5.5	6.3
29		2	9	7						18	9.7	11.2
30		3	4	7						14	10.1	11.7
31	2	2	2	12						18	10.3	11.9
32	2	3	12	10	1					28	9.9	11.4
33	1	7	9	13						30	9.4	10.8
34	1	2	11	11						25	9.6	11.0
35	3	1	1	2						7	6.7	7.7
36	4	6	8	2						20	7.0	8.1
00	53									53	0.0	0.0
TOTAL	167	249	209	117	2					744	6.4	7.4

nearest the surface. Further aloft, however, the atmospheric temperature will remain relatively unchanged. Conversely, at night, radiation from the earth's surface cools the ground and the air adjacent to it, resulting in only slight decrease of temperature with height, and in cases when the surface cooling is great enough, temperature may increase with height. This atmosphere is considered stable.

If the temperature decreases more rapidly with height than the dry adiabatic lapse rate, the air has a super-adiabatic or strong lapse rate and the air is unstable. If a parcel of air is forced upwards it will cool at the adiabatic lapse rate, but will still be warmer than the environmental air. Thus it will continue to rise. Similarly, a parcel which is forced downward will heat dry adiabatically but will remain cooler than the environment and will continue to sink.

For environmental lapse rates that decrease with height at a rate less than the dry adiabatic lapse (sub-adiabatic or weak lapse) a lifted parcel will be cooler than the environment and will sink; likewise, a descending parcel will be warmer than the environment and will rise. Figure 4.2-4 shows the relative relation between the environmental lapse rates of super-adiabatic (strong lapse), sub-adiabatic (weak lapse), isothermal, and inversion with the dry adiabatic process lapse rate presented as dashed lines.

Lifting motions which promote cooling at dry adiabatic lapse rates may be caused by upslope motion over mountains or warmer air rising over a colder air masses. Descending motion (subsidence) may occur to compensate for the lateral spreading of air in high pressure areas.

Classification Schemes

The dispersive power of the atmosphere can be categorized into seven classes, labeled stability categories, in accordance with a method proposed by Pasquill (1962) and modified by Gifford (1961) and Markee (1966). Pasquill's first three classes, A, B, and C, range from extreme to slight instability. Class D represents neutral or well-mixed conditions, while E and F represent slight and moderate stability, respectively. Dispersive power decreases with progression through these classes. Markee (1966) has further divided the original class F into classes F and G, with G representing extreme stability. For the purpose of simplifying the presentation, classes A, B, and C have been combined, in some instances, to form one category called unstable. Similarly, class D will be referred to as the neutral category, and classes E, F, and G together form the stable category.

The stability of the atmosphere is determined by various methods using numerous forms of meteorological data. A frequently used means of assessing ambient atmospheric stability is

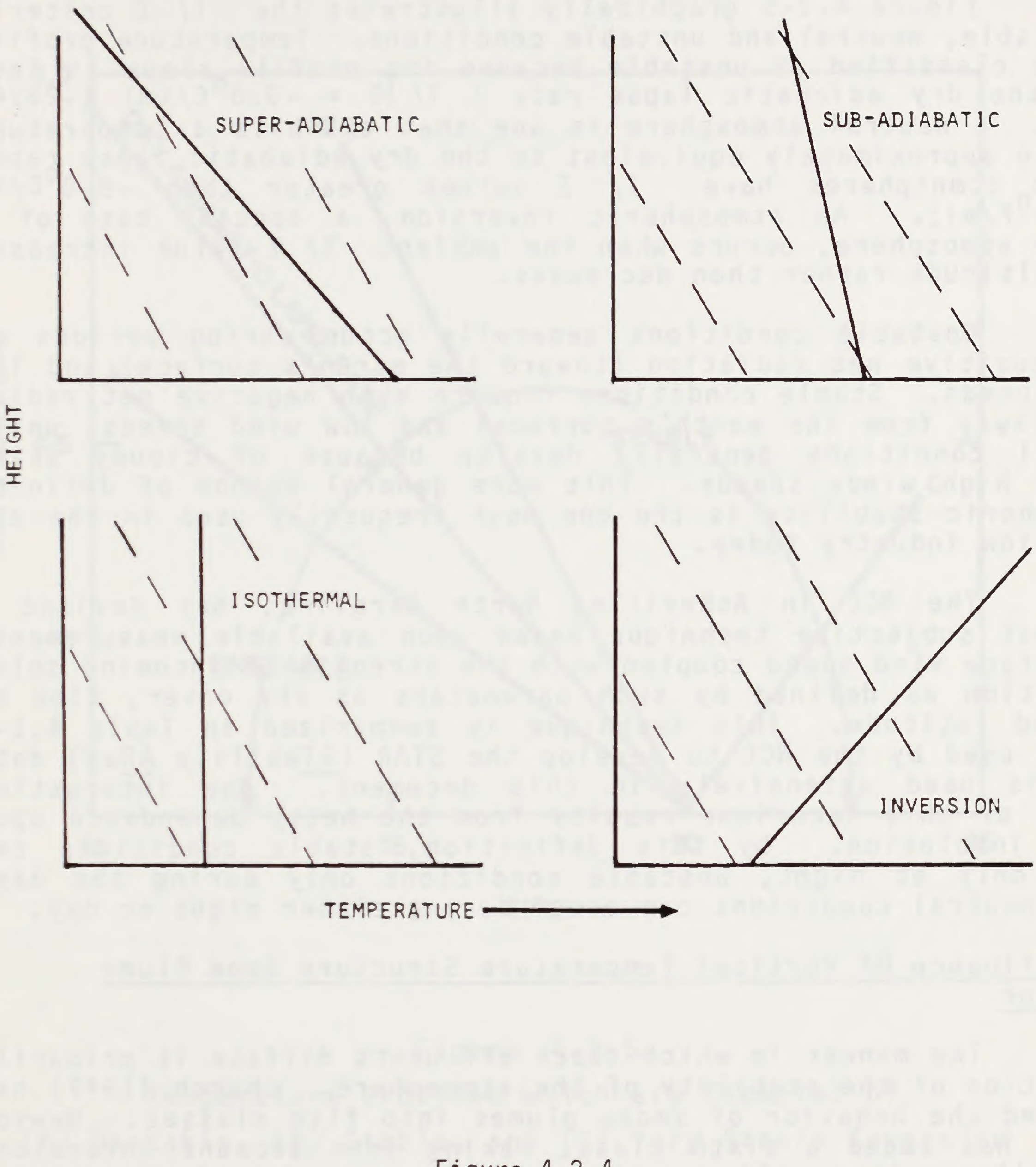

Figure 4.2-4

Types of Temperature Structure with Height Related to the Dry Adiabatic Process Lapse Rate through the measurement of changes in atmospheric temperature with altitude (T/ Z) above an area in question. This is accomplished by probing the atmosphere with specialized temperature sensors mounted on aircraft, balloons, or on tall meteorological towers.

Figure 4.2-5 graphically illustrates the T/ Z criteria for stable, neutral and unstable conditions. Temperature profile "A" is classified as unstable because its profile slope is less than the dry adiabatic lapse rate (T/ Z = -9.8°C/km) (-28.4° F/mi). A neutral atmosphere is one that exhibits a temperature profile approximately equivalent to the dry adiabatic lapse rate. Stable atmospheres have T/ Z values greater than -9.8°C/km (-28.4°F/mi). An atmospheric inversion, a special case of a stable atmosphere, occurs when the ambient T/ Z value increases with altitude rather than decreases.

Unstable conditions generally occur during periods of high positive net radiation (toward the earth's surface) and low wind speeds. Stable conditions require high negative net radiation (away from the earth's surface) and low wind speeds, while neutral conditions generally develop because of cloudy skies and/or high winds speeds. This more general method of defining atmospheric stability is the one most frequently used in the air pollution industry today.

The NCC in Asheville, North Carolina, has devised a somewhat subjective technique based upon available measurements of surface wind speed coupled with the strength of incoming solar insolation as defined by such parameters as sky cover, time of day and latitude. This technique is summarized in Table 4.2-4 and is used by the NCC to develop the STAR (STability ARay) data that is used extensively in this document. One interesting aspect of this technique results from the heavy dependance upon solar insolation. By this definition, stable conditions can occur only at night, unstable conditions only during the day, while neutral conditions can occur during either night or day.

The Influence Of Vertical Temperature Structure Upon Plume Behavior

The manner in which stack effluents diffuse is primarily a function of the stability of the atmosphere. Church (1949) has typified the behavior of smoke plumes into five classes. Hewson (1960) has added a sixth class, taking into account inversions aloft (Inversions will be discussed in more detail in section 4.2.4). Figure 4.2-6 depicts each class and the appropriate dispersion characteristics for an idealized chimney. The Pasquill stability classes are also noted.

Looping

Looping occurs with a super-adiabatic lapse rate. Large thermal eddies are developed in the unstable air and high concentrations may be brought to the ground for short time intervals.

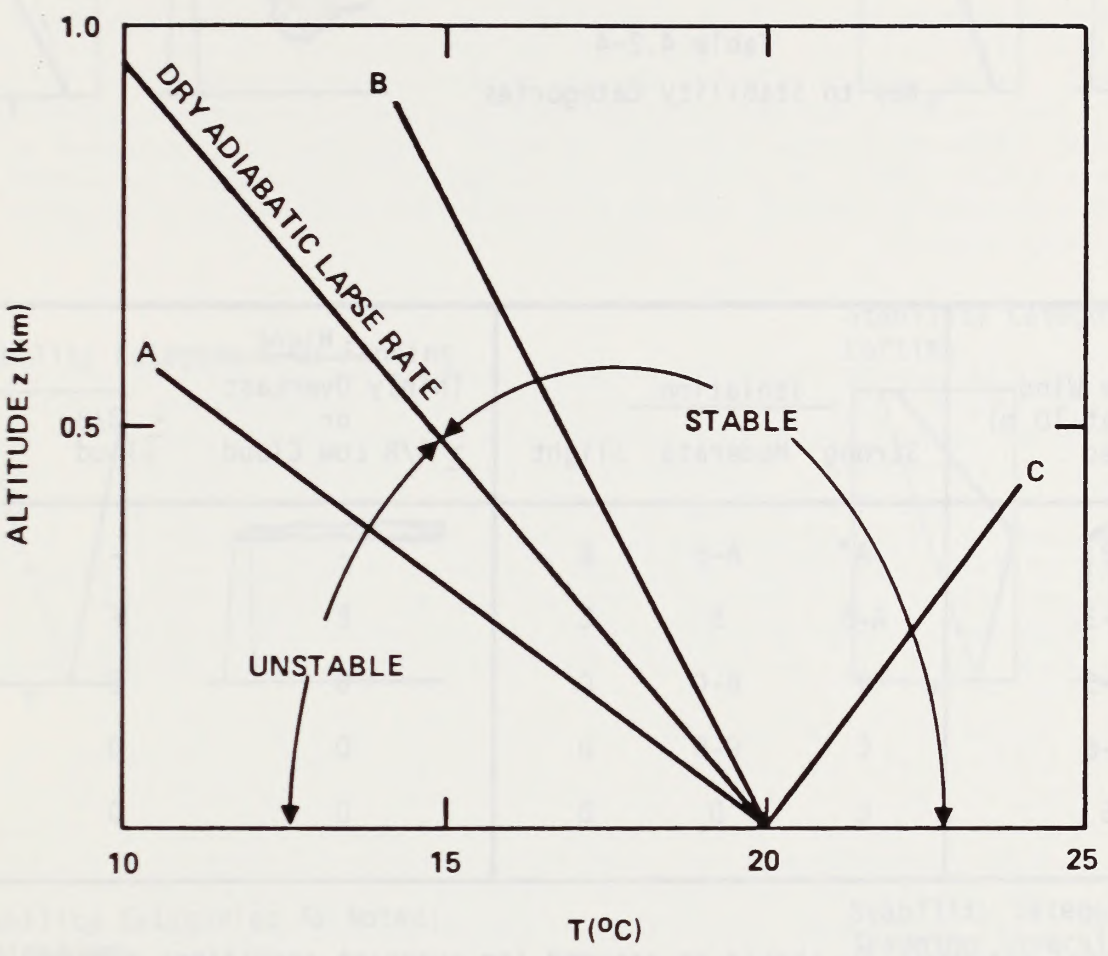

Figure 4.2-5
Temperature Profiles which are Examples of
(A) Unstable, (B) Stable, and (C) Very Stable Inversion
Lapse Rates in a Dry Atmosphere

Table 4.2-4

Key to Stability Categories

Surface Wind Speed (at 10 m) m/sec	Isolation			Night	
	Strong	Moderate	Slight	Thinly Overcast or ≥ 4/8 Low Cloud	≤ 3/8 Cloud
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

The neutral category, D, should be assumed for overcast conditions during day or night.

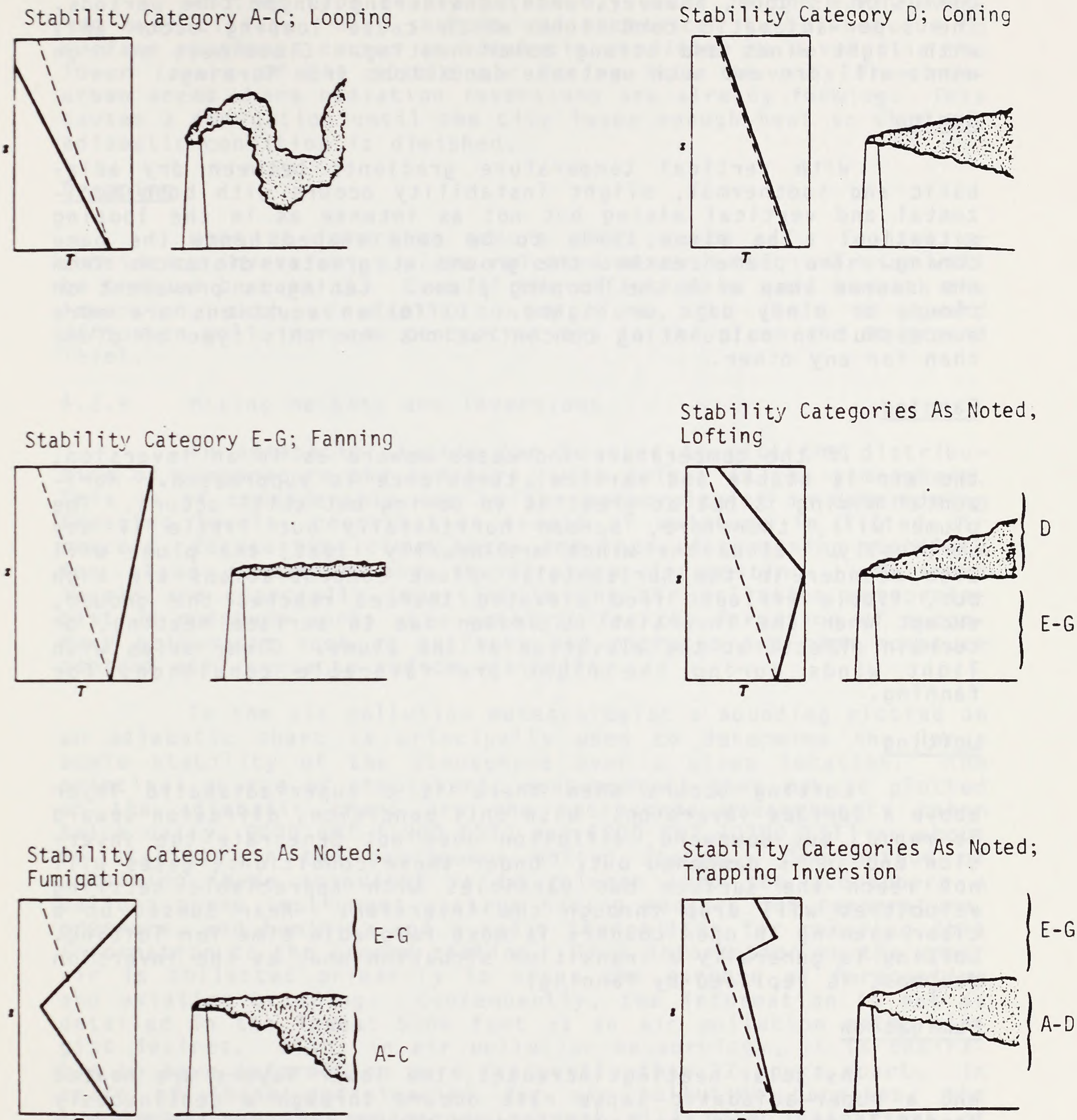

Figure 4.2-6

Typical Plume Behavior*

* Plume behavior influenced by the temperature lapse rate above and below the release height. The dashed lines in the profiles are the adiabatic lapse rates, included for reference, while the solid lines indicate the actual lapse rate. The Pasquill stability categories are also provided.

Diffusion is good, however, when considering longer time periods. The super-adiabatic conditions which cause looping occur only with light winds and strong solar heating. Cloudiness or high winds will prevent such unstable conditions from forming.

Coning

With vertical temperature gradients between dry adiabatic and isothermal, slight instability occurs with both horizontal and vertical mixing but not as intense as in the looping situation. The plume tends to be cone shaped hence the name coning. The plume reaches the ground at greater distances from the source than with the looping plume. Coning is prevalent on cloudy or windy days or nights. Diffusion equations are more successful in calculating concentrations for this type of plume than for any other.

Fanning

If the temperature increases upward as in an inversion, the air is stable and vertical turbulence is suppressed. Horizontal mixing is not as great as in coning but still occurs. The plume will, therefore, spread horizontally but little if any vertically. Since the winds are usually light, the plume will also meander in the horizontal. Plume concentrations are high but, little effluent from elevated sources reaches the ground, except when the inversion is broken due to surface heating, or terrain effects at the elevation of the plume. Clear skies with light winds during the night are favorable conditions for fanning.

Lofting

Lofting occurs when there is a super-adiabatic layer above a surface inversion. With this condition, diffusion upward is rapid, but downward, diffusion does not penetrate the inversion and so is dampened out. Under these conditions, gases will not reach the surface but particles with appreciable settling velocities will drop through the inversion. Near sunset on a clear evening in open country is most favorable time for lofting. Lofting is generally a transition situation and, as the inversion deepens, is replaced by fanning.

Fumigation

As solar heating increases, the lower layers are heated and a super-adiabatic lapse rate occurs through a continuously deeper layer. When the layer is deep enough to reach the fanning plume, thermal turbulence will bring high concentrations to the ground along the full length of the plume. This is favored by clear skies and light winds and is apt to occur more frequently in summer due to increased heating.

Another type of fumigation may occur in the early evening over cities. Heat sources and mechanical turbulence due to surface roughness causes an adiabatic condition to develop in the lower layers of the stable air moving into the city from non-urban areas where radiation inversions are already forming. This causes a fumigation until the city loses enough heat so that the adiabatic condition is dimished.

Trapping

When an inversion occurs aloft, such as a frontal or subsidence inversion, a plume released beneath the inversion will be trapped beneath it. Even if the diffusion is good beneath the inversion, such as with a coning plume, the limit to upward diffusion will increase concentrations in the plume and at ground level.

4.2.4 Mixing Heights and Inversions

An adiabatic diagram can be used to plot the distribution of temperature and moisture, with height in the atmosphere. This is of considerable use to the meteorologist in determining freezing levels, condensation levels of moisture in lifted air parcels, forecasting cloud bases and tops, determining stability for cloud formation and thunderstorm forecasting. Moisture levels are especially important to the air pollution meteorologist as moisture works as a catalyst for the formation of secondary pollutants such as sulfates and nitrates and high moisture content will serve to reduce visibility.

To the air pollution meteorologist a sounding plotted on an adiabatic chart is principally used to determine the large scale stability of the atmosphere over a given location. The principal source of atmospheric measurements that may be plotted on the adiabatic chart are the radiosonde measurements taken twice daily: 0000 GMT (1900 EST) and 1200 GMT (0700 EST) at about 66 stations in the contiguous United States. The method of obtaining these soundings is to release into the atmosphere a balloon borne instrument package having sensors for temperature, pressure, and humidity and a radio transmitter for relaying this information to the ground station. This information on the upper air is collected primarily to serve the purpose of forecasting and aviation briefing. Consequently, the information is not as detailed in the lowest 5000 feet as an air pollution meteorologist desires. Also, in air pollution meteorology, it is desirable to have information more frequently than 12 hours apart. In spite of these deficiencies for air pollution purposes, the soundings from the radiosonde network will give indications of the stability of the atmosphere. On an adiabatic chart, temperature is plotted on a linear scale against pressure on a logarithmic scale. A temperature sounding may be plotted by locating each significant level reported by the temperature and pressure given for that level. The plotted points may then be connected by straight lines to give the temperature sounding.

As indicated in Section 4.2.3, the stability of a portion of the sounding may be compared with the dry adiabatic lapse rate. If the temperature decreases more rapidly than the dry adiabats through a layer, this layer is super-adiabatic and quite unstable. If the temperature decreases, but at a rate less than the dry adiabatic lapse rate, the layer is sub-adiabatic and is more stable than super-adiabatic. If the temperature increases with height, it is an inversion.

Inversions with bases at ground level are generally radiation inversions caused by the cooling of the earth's surface and the adjacent air. However, there may also be advection inversions formed by the air's passage over a relatively cold surface. These two types of surface based inversions generally cannot be distinguished by inspection of the sounding plotted on an adiabatic diagram. A surface based inversion on an afternoon sounding is more apt to be an advection inversion.

There are two general classifications of inversions with bases above the ground: frontal inversions and subsidence inversions. Both of these, however, can also be ground based.

Frontal inversions are discontinuities in the temperature profile due to the transition between cold air below and warm air aloft. Frontal inversions usually are accompanied by increases in moisture through the inversion. Subsidence inversions are caused by the sinking motion above high pressure areas and generally have rapidly decreasing humidities above the base of the inversion.

Surveys of the meteorological aspects of air pollution are often concerned with the extent of horizontal and vertical mixing. A quantity referred to as the mixing depth is quite useful when considering dilution of pollutants in the vertical. The usual method of estimating mixing depths is to consider the stability as portrayed on a temperature sounding remembering that unstable lapse rates favor vertical mixing and stable lapse rates restrict vertical motion. The mixing depth is generally the height above the ground to which a super or dry-adiabatic lapse rate is maintained as depicted in Figure 4.2-7.

4.2.5 Influence of Topography on Transport and Diffusion

In many cases, the transport and diffusion of air pollutants is complicated by terrain features. Most large urban areas are located either in river valleys or on the shores of lakes or oceans. Both of these features alter meteorological conditions.

<u>Valley Effects</u>

- <u>Channeling</u>
  Although the more extreme effects of a valley location occur when the general flow is light, valleys tend to

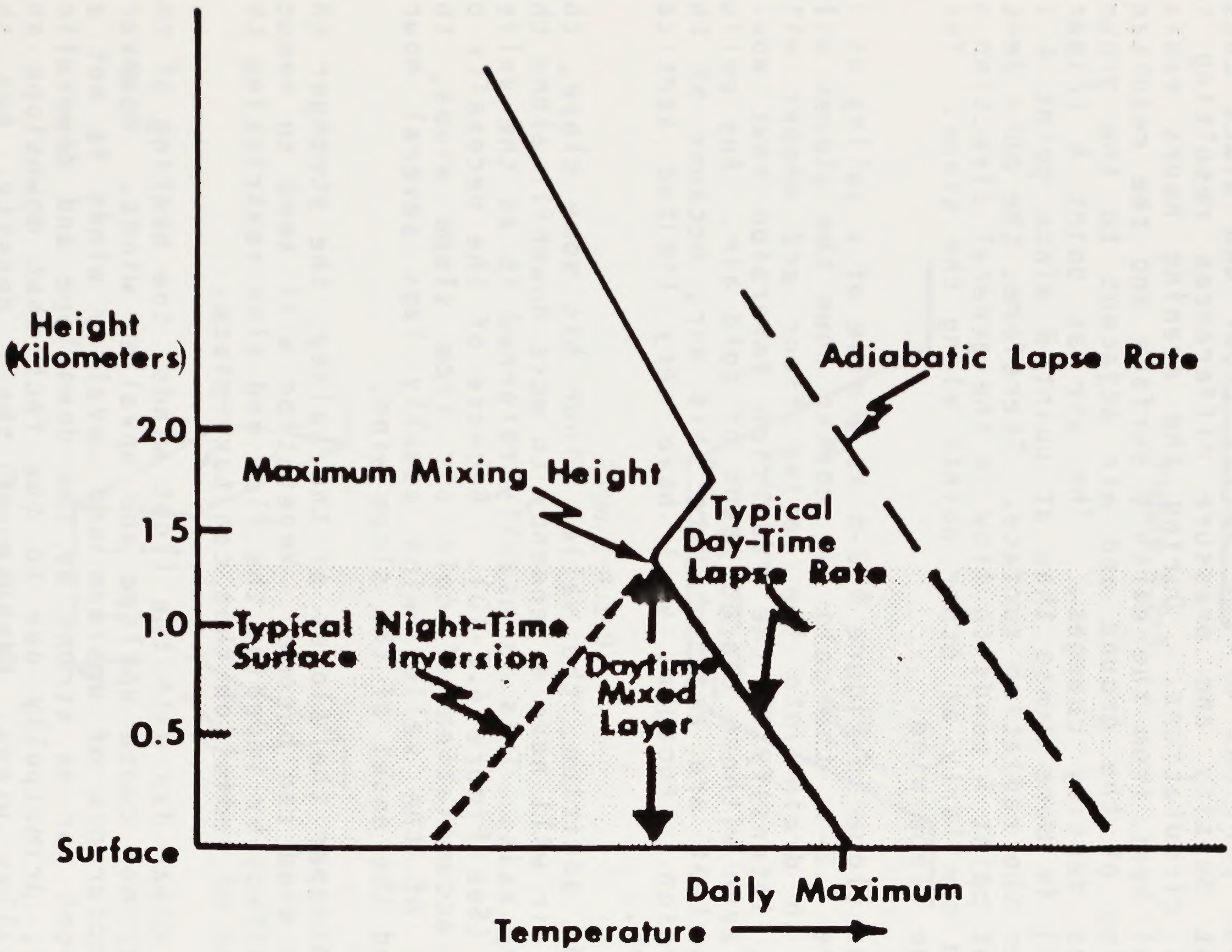

Figure 4.2-7
Calculation of Maximum Mixing Height

channel the general flow along the valley axis resulting in a bi-directional wind frequency distribution.

- Slope and Valley Winds
  When the general wind flow is light and skies are clear, the differences in rates of heating and cooling of various portions of the valley floor and sides cause slight density and pressure differences resulting in small circulations. During the evening hours radiational heat from the earth's surface and the resultant cooling of the ground and air adjacent to the ground causes density changes. The air at point A (Figure 4.2-8) is more dense than at point B since point A is nearer the radiating surface. Therefore, the more dense air at point A tends to flow in the general direction of B and similarly at other points along the slope. This is the slope wind.

  If the slope in Figure 4.2-8 is a side of a valley as in Figure 4.2-9, the cold air moving down the slopes will tend to drain into the valley floor and deepen with time, intensifying the radiation inversion that would form even without the addition of cold air. Any pollutants that are emitted into this air, because of the inversion structure, will have very limited vertical motion.

  If, in addition, the valley floor has some slope, the cold air will have a tendency to move downhill along the valley axis. This is usually referred to as the valley wind (See Figure 4.2-10). Because of the necessity of some accumulation of cold air from slope winds, the onset of the valley wind usually lags several hours behind the onset of the slope wind.

  The steeper the slopes of the valley, the stronger the slope wind can become. Vegetation will tend to reduce the effect by impeding the flow and also restricting the amount of radiation that can take place.

  On a clear day with the light winds, the heating of the valley may cause upslope and upvalley winds. However, the occurance of upslope and upvalley winds is not as frequent nor as strong as the downslope and downvalley winds, principally due to the fact that downslope and downvalley winds, because of their density, hug the surfaces over which they travel. Flow in complex valley systems where several valleys merge at angles or slopes varies, usually require special observations to determine flow under various meteorologic conditions.

- Inversions Aloft
  The trapping of air pollutants beneath inversions aloft is also a problem encountered in valleys. Two types of

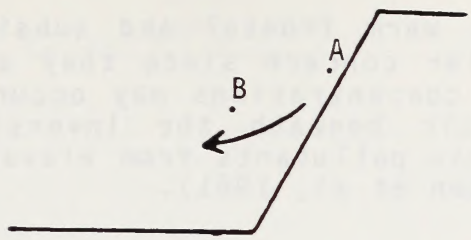

Figure 4.2-8

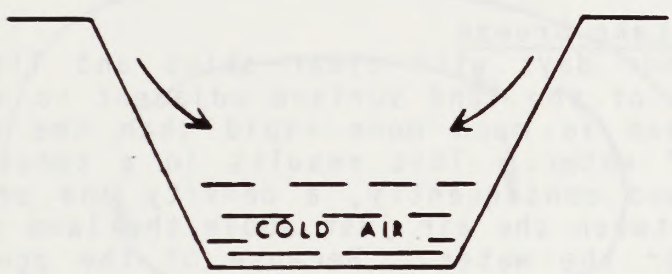

Figure 4.2-9

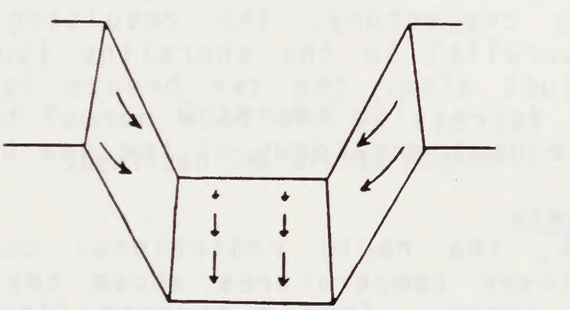

Figure 4.2-10

Valley Wind Circulations

inversions: warm frontal and subsidence inversions are of particular concern since they are usually slow moving. High concentrations may occur particularly if the layer of air beneath the inversion becomes unstable enough to mix pollutants from elevated sources to ground level (Hewson et al, 1961).

Shoreline Winds

The differences in heating and cooling of land and water surfaces and the air above them, result in the setting up of circulations if the general flow is light, and in the modification of thermal characteristics, and consequently, the diffusive abilities of the lower layers of the atmosphere when a general flow occurs.

- Sea or Lake Breeze
  On summer days with clear skies and light winds, the heating of the land surface adjacent to a large lake or the ocean is much more rapid than the heating of the body of water. This results in a temperature difference, and consequently, a density and pressure difference between the air just above the land surface and the air over the water. Because of the pressure gradient forces, a local circulation is set up with wind from the water toward the land, There is usually some upward motion over the land and subsidence over the water accompanying the sea breeze (Estoque, 1961). There may result a weak transport from land to water aloft completing a cellular structure (See Figure 4.2-11).

  In cases where a strong lake breeze occurs, air from quite some distance out over the water may be brought toward the land and, due to Coriolis forces acting over the long trajectory, the resulting flow will become nearly parallel to the shoreline (Sutton, 1953). This occurs just after the sea breeze is strongest and results in decreasing the flow normal to the coastline and the subsequent breakdown of the sea breeze.

- Land Breeze
  At night, the rapid radiational cooling of the land causes lower temperatures above the land surface than over the water. Thus a reverse flow, the land breeze, may result. The land breeze does not usually achieve as high a velocity as the lake breeze, and is usually shallower than the sea or lake breeze.

  Of course, any wind flow, because of the large scale pressure pattern, will alter the local circulation and the flow will be the resultant of the two effects. Usually, a light general flow is enough to overshadow the effects of land and sea breezes.

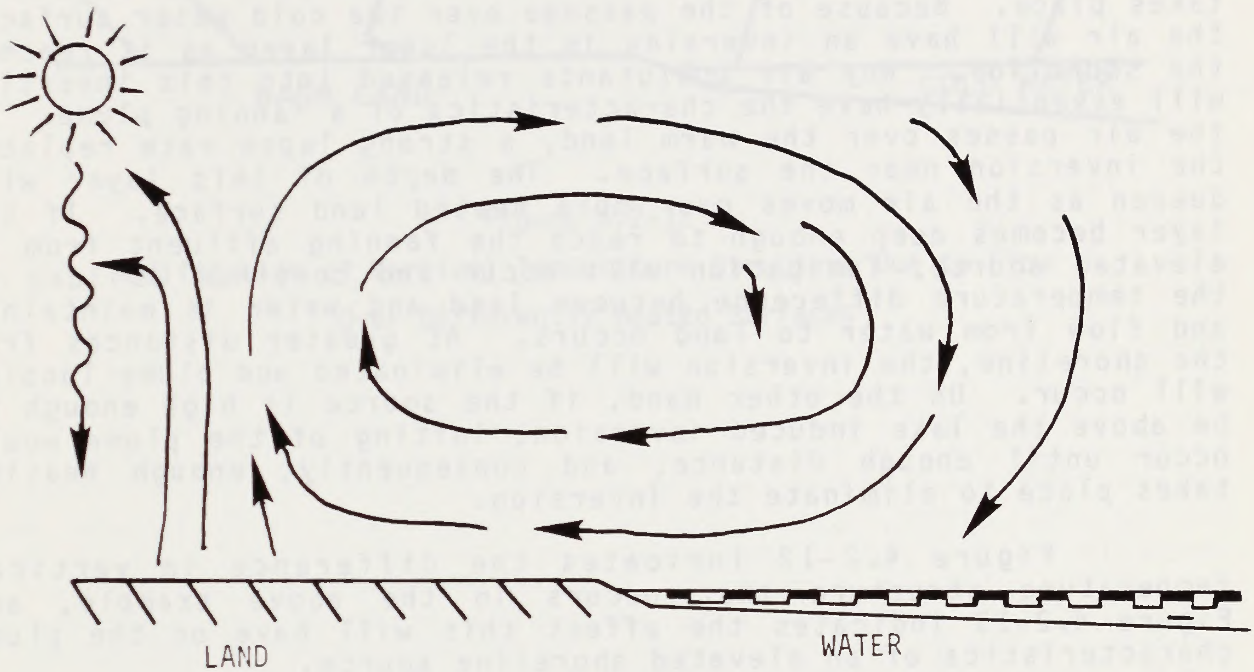

Figure 4.2-11

Idealized Sea Breeze Regime

Modification of Thermal Structure by Bodies of Water

At different seasons of the year and also different times of the day, the temperature of bodies of water and adjacent land surfaces may be quite different. For example, during the late spring, large bodies of water are still quite cold relative to adjacent land surfaces, and during mid-afternoon this difference is greatest due to the more rapid heating of the land surface. If the general flow in the area is such that the wind has a lengthly trajectory over the water and is blowing toward the shore, an interesting modification of the temperature structure takes place. Because of the passage over the cold water surface, the air will have an inversion in the lower layer as it reaches the shoreline. Any air pollutants released into this inversion will essentially have the characteristics of a fanning plume. As the air passes over the warm land, a strong lapse rate replaces the inversion near the surface. The depth of this layer will deepen as the air moves over more heated land surface. If the layer becomes deep enough to reach the fanning effluent from an elevated source, fumigation will occur and continue as long as the temperature difference between land and water is maintained and flow from water to land occurs. At greater distances from the shoreline, the inversion will be eliminated and plume looping will occur. On the other hand, if the source is high enough to be above the lake induced inversion, lofting of the plume would occur until enough distance, and consequently, enough heating takes place to eliminate the inversion.

Figure 4.2-12 indicates the difference in vertical temperature structure that occurs in the above example, and Figure 4.2-13 indicates the effect this will have on the plume characteristics of an elevated shoreline source.

At other times when the water is warmer than the land surface (late fall), offshore flow will result in fumigation over the water.

Influence of Hills

The influence of hills upon transport and diffusion depends upon a number of factors. Whether the source is on the windward or lee side of the hill or ridge is important. A smooth hill will only slightly alter the flow, while one with sharp ridges will cause turbulent eddies to form. The stability of the atmosphere will affect the overall influence of hills. During stable conditions, the air will tend to flow around obstructions. Under unstable conditions, the tendency is for air to move over obstructions.

When a source is located upwind of a hill or ridge, the pollutants may come in contact with the facing slope, particularly under stable conditions. If the ridge is quite rough, induced turbulence may cause mixing down to the slope even when the general flow is over the ridge. Wind tunnel studies or field

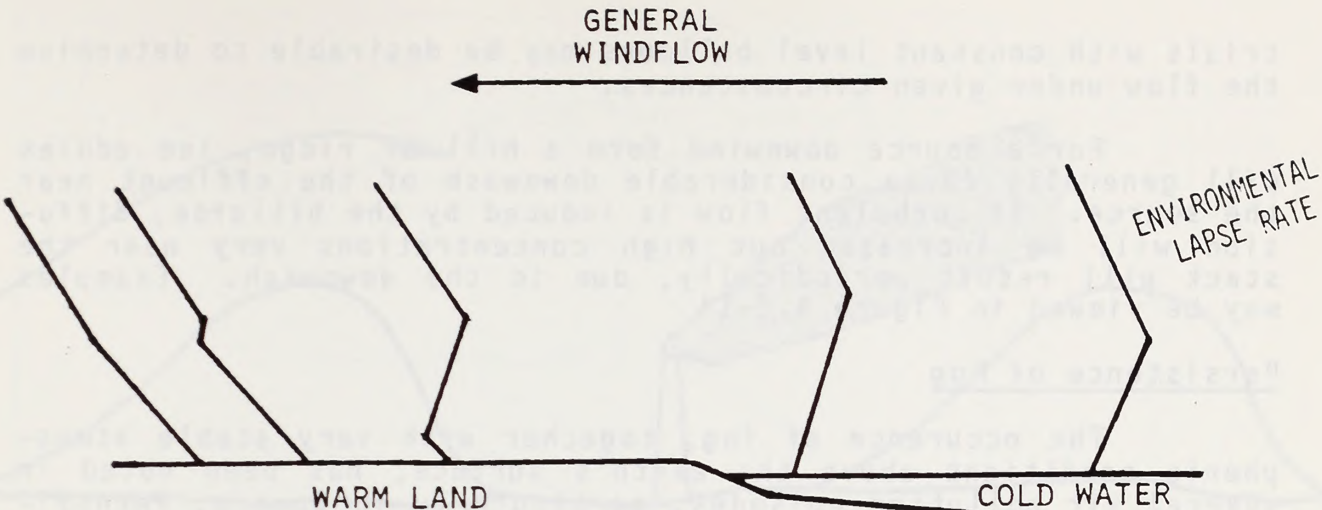

Figure 4.2-12

Modification of Vertical Temperature Structure Due to Flow Over Differently Heated Surfaces

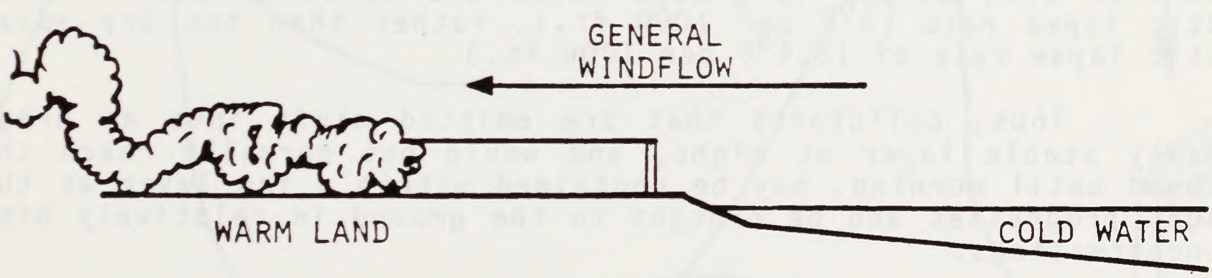

Figure 4.2-13

Effect Upon Plume Characteristics of Flow Over Differently Heated Surfaces trials with constant level balloons may be desirable to determine the flow under given circumstances.

For a source downwind form a hill or ridge, lee eddies will generally cause considerable downwash of the effleunt near the source. If turbulent flow is induced by the hillside, diffusion will be increased but high concentrations very near the stack will result periodically, due to the downwash. Examples may be viewed in Figure 4.2-14

Persistence of Fog

The occurence of fog, together with very stable atmospheric conditions above the earth's surface, has been noted in several air pollution episodes, particularly in Donora, Pennsylvania, in 1948. Under clear skies at night, the ground loses much heat because of outgoing radiation and the air in contact with the ground will cool. If, in such cases the air is sufficiently humid, cooling will bring the air to the saturation point and a fog will form. This is the mechanism which produces radiation fog and is quite common in valley locations. The top of a layer of fog will radiate essentially as a black body and cool further, thus forming an inversion layer directly above the fog. As the earth continues to radiate in the infrared, the fog droplets absorb nearly all this heat since the droplet size distribution is similar to the wavelengths of the radiation. Theory and observation have shown that when the top of a fog layer radiates during the night, the interior of the layer will become more unstable with time. Increased vertical mixing will occur from below but will be capped by the inversion. Since the air is saturated, an unstable lapse rate will exist if the temperature decrease with height is greater than the moist or pseudo-adiabatic lapse rate (3^oF per 1000 ft.), rather than the dry adiabatic lapse rate of (5.4^oF per 1000 ft.)

Thus, pollutants that are emitted aloft into an originally stable layer at night, and would not normally reach the ground until morning, may be contained within a fog layer as the night progresses and be brought to the ground in relatively high concentrations.

After daybreak, fog will often persist for several hours or even the entire day under full sunlight due to the high reflectivity of the top layer. The reflectivity or albedo of thick fogs averages 50% and can be as high as 85%. This delays and lessens the heating of the ground and subsequent evaporation of the fog droplets. An unstable lapse rate may occur above the fog layer, but due to a lack of surface heating, an inversion will often occur within the layer. If high concentrations of particulate pollutants are present, it may be difficult to determine just when the fog has dissipated since particulates scatter and absorb visible light very well and the visibility may remain quite restricted.

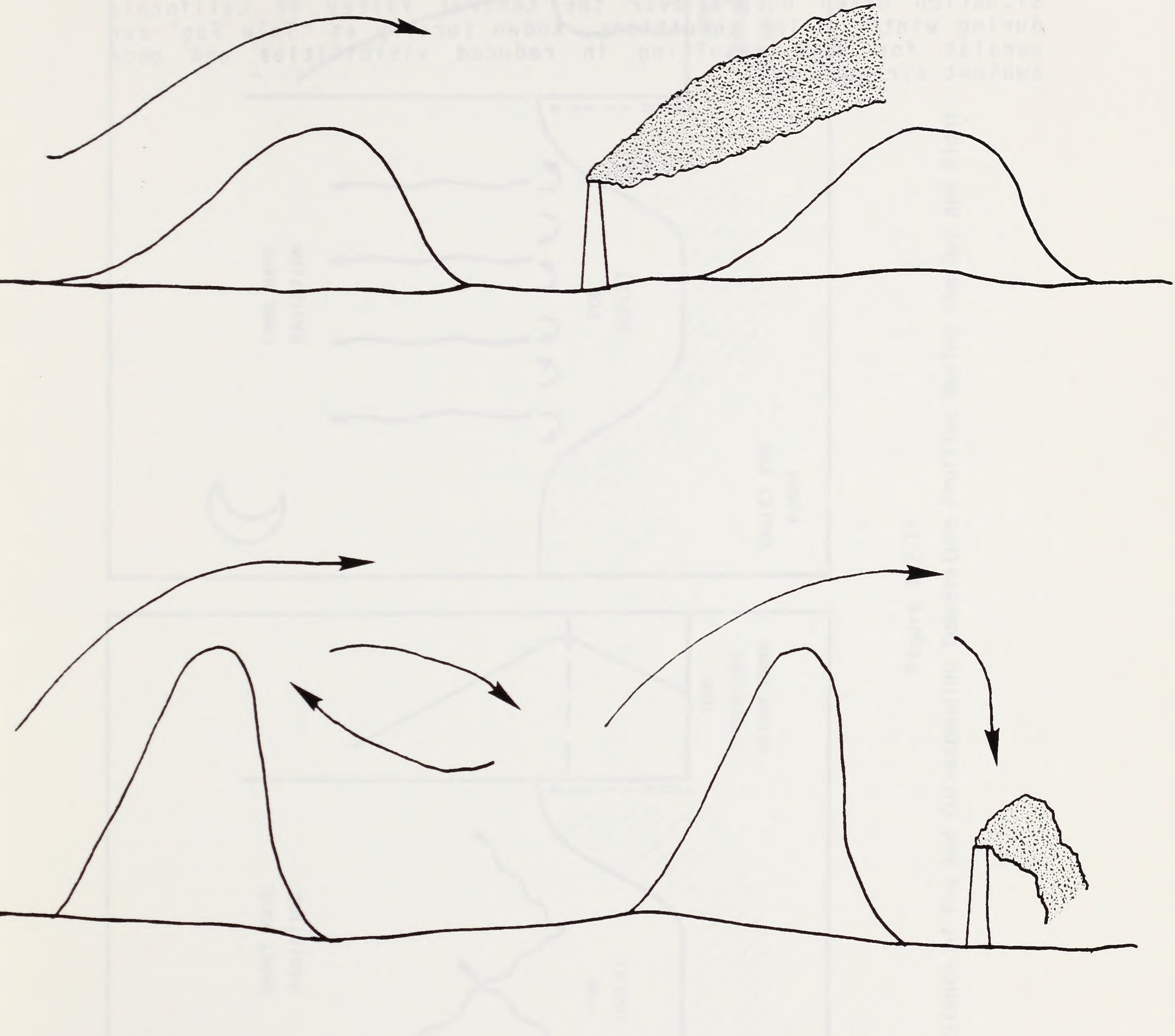

Figure 4.2-14
Influence of Hills Upon Transport and Diffusion

Figure 4.2-15 illustrates how fog can persist in valley situations and maintain a lid on vertical dispersion. This situation often occurs over the Central Valley of California during winter. The conditions, known locally as "Tule Fog" can persist for days resulting in reduced visibilities and poor ambient air quality.

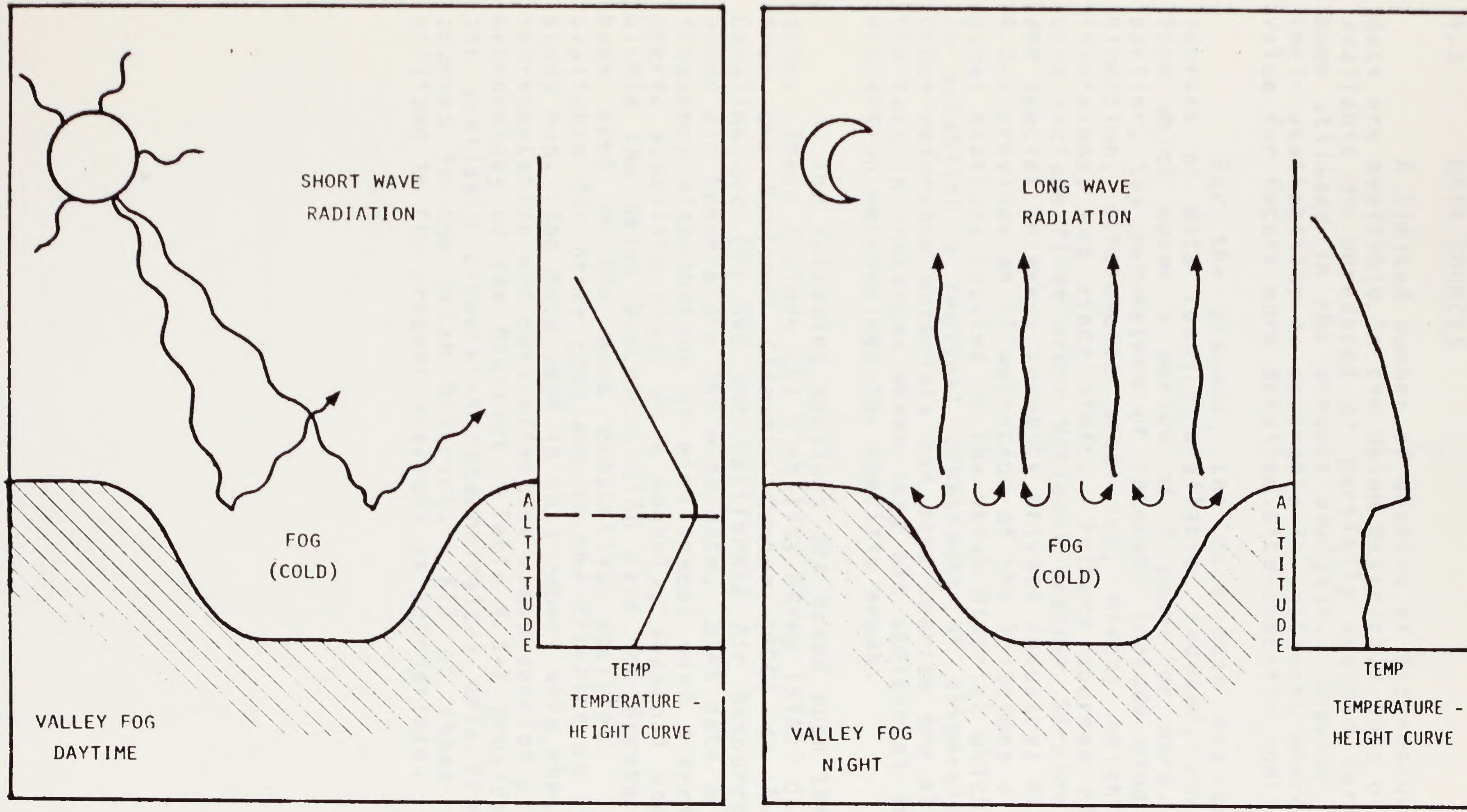

Figure 4.2-15

Persistence of Fog and Corresponding Temperature Profiles During the Day and Night

4.3 DATA SOURCES

A limited number of sources of dispersion meteorological data are available in the Ukiah District. Some of these data are available in unreduced or partially reduced form and have not been utilized in the present analysis. However, a knowledge of their availability is desirable in instances where they may be of value for future more detailed site-specific analyses.

For the present, the data base has been limited to sources of data readily available, reduced, and in summarized form which cover a period of 5 years or more. As discussed earlier, key parameters of interest include wind speed and wind direction, atmospheric stability, mixing heights, temperature inversions, and winds aloft. Primary sources of such complete data include first order National Weather Service (NWS) stations and special interest (usually private industry) stations. Figure 4.3-1 provides an illustration of the locations of key meteorological stations located in the Ukiah District which have been used to establish a regional assessment of dispersion meteorology. Other reference materials and data sources are also discussed in the text in instances where they add additional insight into the dispersion meteorology for specific areas.

The following sections are based upon three key sets of data. These include (1) STability ARray (STAR) data as available from the National Climatic Center (NCC) in Asheville, North Carolina and (2) NWS and California Air Resources Board (CARB) upper air temperature and wind data. STAR data provide the joint frequency distribution of wind speed, wind direction and atmospheric stability class on a monthly, seasonal and annual basis. Within the Ukiah District, STAR data for Arcata and Ukiah have been used in the more exhaustive analyses. STAR data are available for other stations in the district as indicated on the study map. The data used in this report were chosen to provide a representative and cost-effective cross-section of the dispersion meteorology of the District. Table 4.3-1 provides a summary of the available dispersion meteorological data from NWS and CARB sources in the Ukiah District. All of these data have been utilized in the present analysis as appropriate.

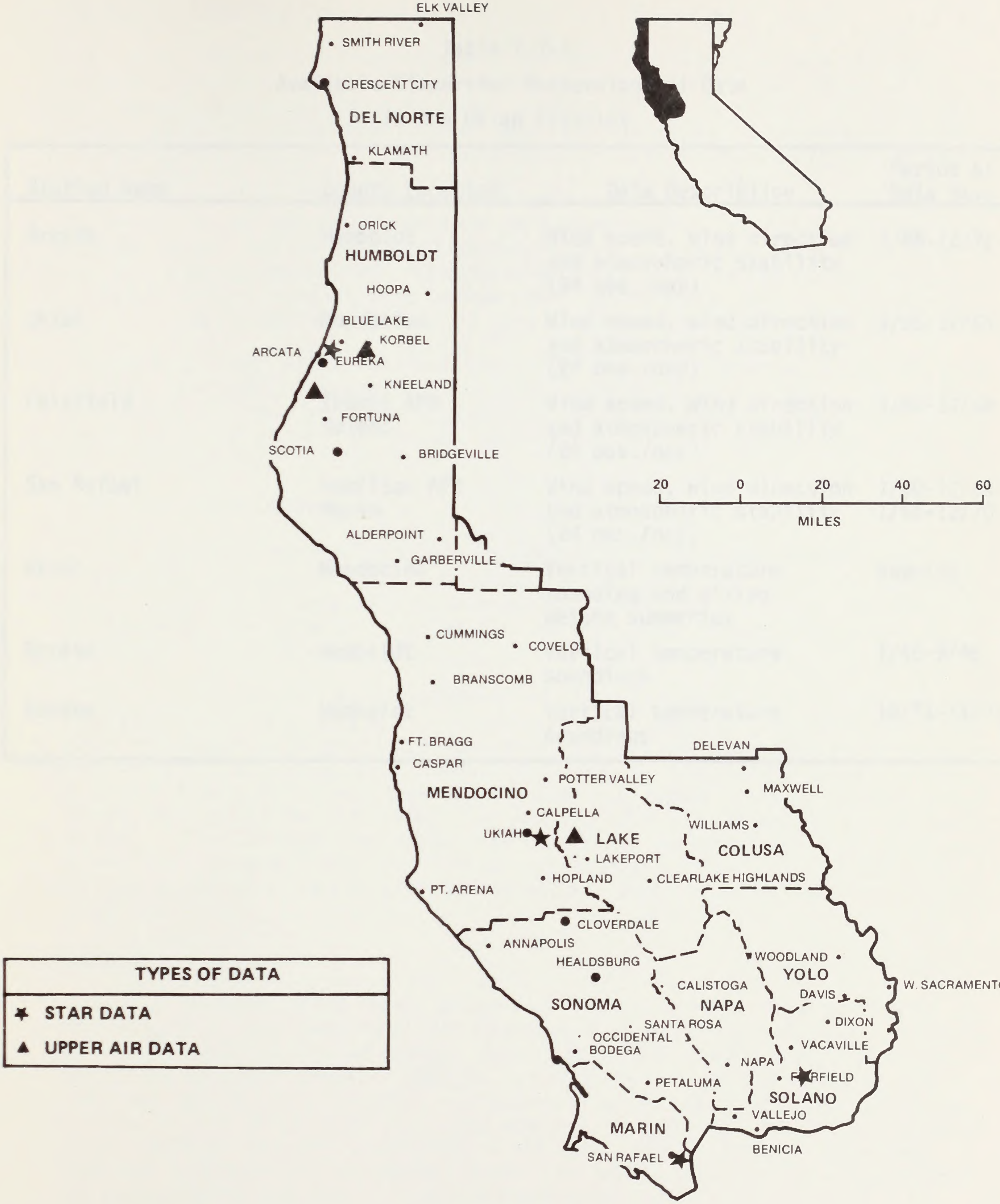

Figure 4.3-1
Sources of Dispersion Meteorological Data
Used in the Ukiah District Analysis

Table 4.3-1

Available Dispersion Meteorological Data

in the Ukiah District

Station Name	County Location	Data Description	Period of Data Base
Arcata	Humboldt	Wind speed, wind direction and atmospheric stability (24 obs./day)	1/68-12/72
Ukiah	Mendocino	Wind speed, wind direction and atmospheric stability (24 obs./day)	1/55-12/64
Fairfield	Travis AFB Solano	Wind speed, wind direction and atmospheric stability (24 obs./day)	1/60-12/64
San Rafael	Hamilton AFB Marin	Wind speed, wind direction and atmospheric stability (24 obs./day)	1/60-12/64 1/66-12/70
Ukiah	Mendocino	Vertical temperature sounding and mixing height summaries	ongoing
Arcata	Humboldt	Vertical temperature soundings	4/45-9/45
Eureka	Humboldt	Vertical temperature soundings	10/71-11/71

Upper air wind and temperature data are also available for certain portions of the Ukiah District. There are no first order stations routinely taking temperature and winds aloft data in the district. Nearby data from Oakland have been utilized by Holzworth (1972) to provide data on inversion types and frequencies, as well as mixing heights and mean wind speeds through the mixing layer. The CARB has also conducted various programs for the collection and summarization of temperature sounding and/or pilot balloon (winds aloft) release data at selected stations throughout the state. In the Ukiah District, this includes Ukiah. The availability of these data permits finer resolution of mixing heights and inversions in the district. The available NWS data would be insufficient to clearly describe these parameters in the Ukiah District.

4.4 PREVAILING WINDS

The characterization of prevailing surface winds and winds aloft is essential in the development of an understanding of the dispersion meteorology of the Ukiah District. This section provides analyses that are designed to identify specific characteristics of the prevailing winds. These analyses include:

- Wind Roses
- Diurnal Wind Distributions
- Wind Speed Distributions
- Wind Persistence Analyses
- Trajectory Analyses
- Winds Aloft

The prevailing winds define the net regional transport characteristics for pollutants in a given geographical area. An understanding of the physical behavior of air flow in and out of a particular area of interest provides insight as to the fate of air pollutants.

4.4.1 Wind Roses

Wind roses provide a graphical representation of the frequency of occurrence of winds from each of the 16 cardinal directions for specified averaging periods. This subsection discusses the prevailing winds using wind rose analyses on a seasonal and annual basis.

Regional wind characteristics throughout the Ukiah District are discussed in considerable detail in Section 3.4. This includes a summary of monthly and annual average wind speeds and prevailing wind directions throughout the study area. Also, a Ukiah District study map with numerous superimposed annual wind roses was provided in order to depict the air flow on a regional scale. The discussion provided in this section is designed to summarize prevailing air flow characteristics in terms of a dispersion analyses for subsequent use in pollutant impact studies.

Annual

Annual wind rose diagrams for selected key stations in the district are provided in Figures 4.4-1 through 4.4-4. Arcata and San Francisco wind roses describe wind conditions characteristic of coastal areas. Ukiah represents a typical inland valley station while Sacramento represents a Central Valley station. Figure 4.4-5 provides a study map of the district, superimposed with several annual wind rose diagrams. This figure appeared in Section 3.4 but is presented here, as well, due to its importance in describing regional flow characteristics.

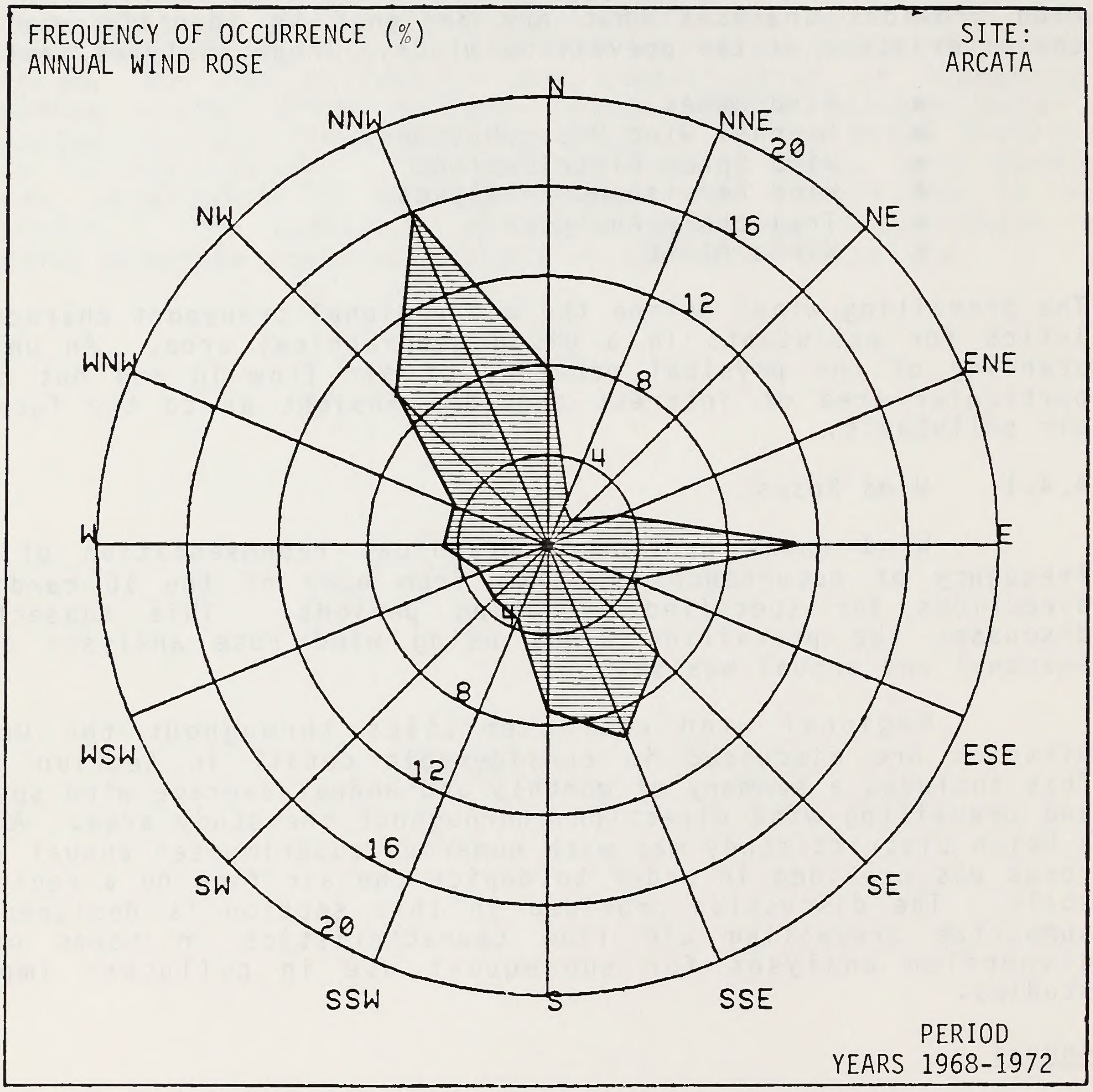

Figure 4.4-1
Annual Wind Rose for Arcata

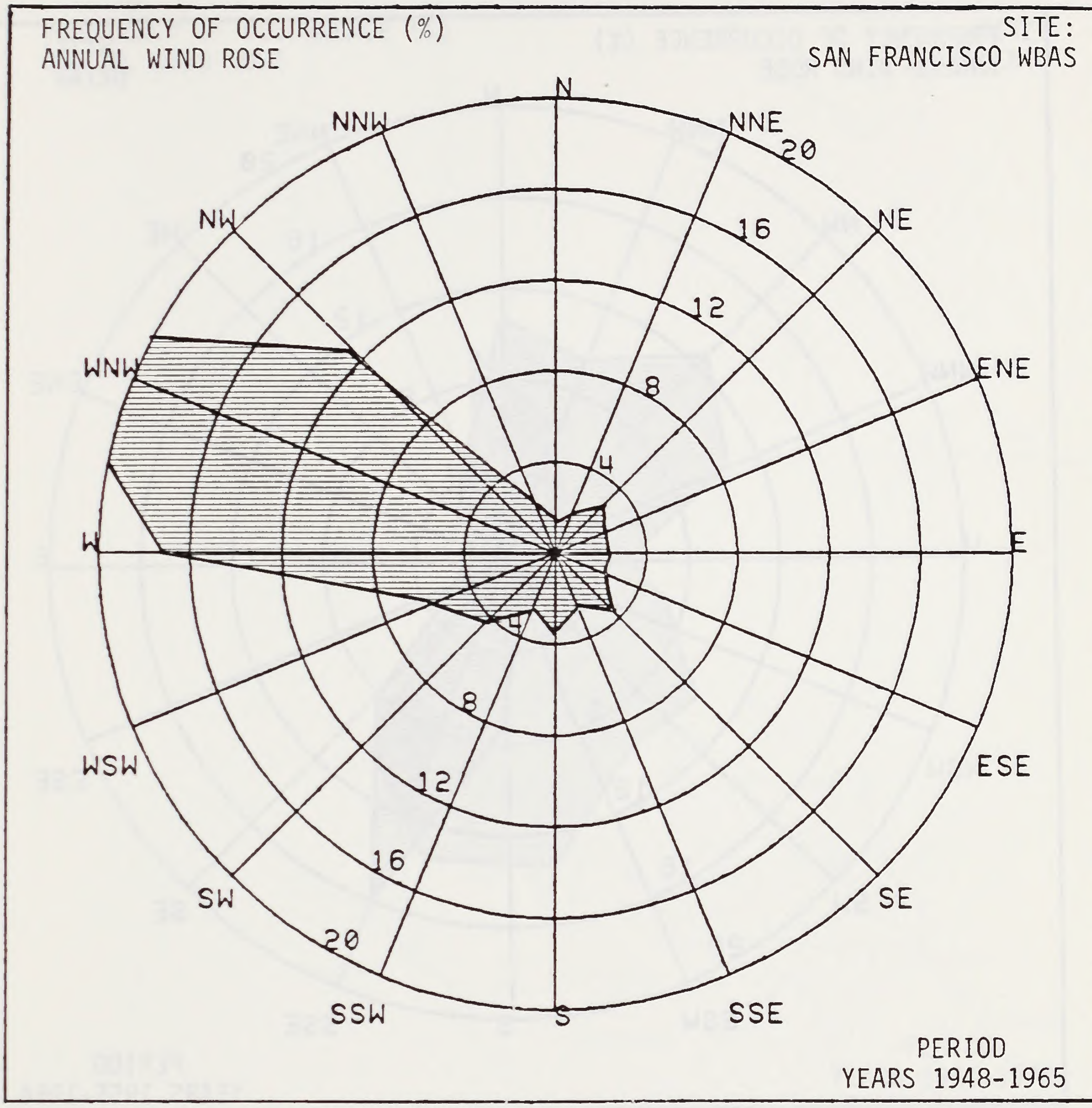

Figure 4.4-2
Annual Wind Rose for San Francisco

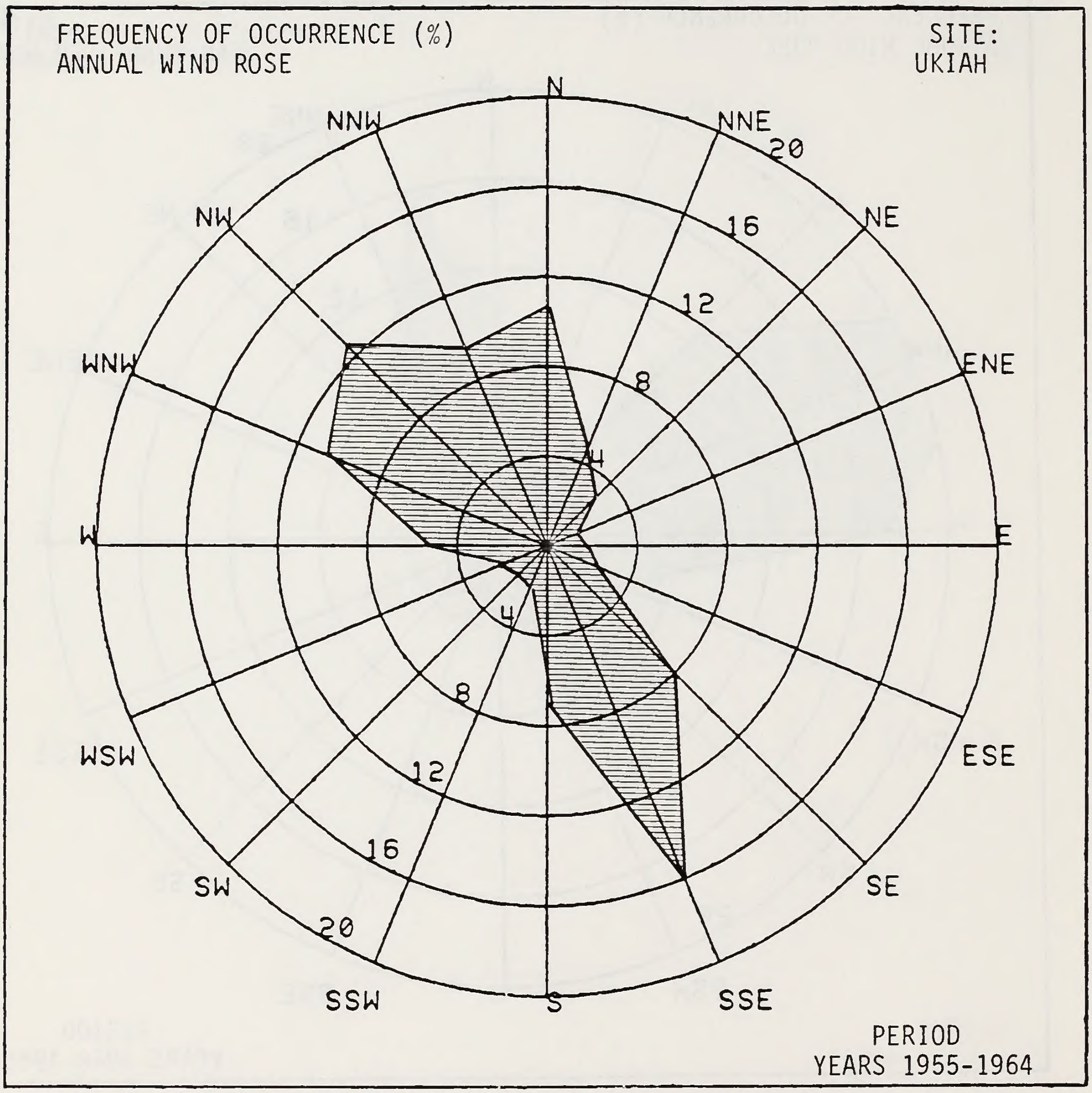

Figure 4.4-3
Annual Wind Rose for Ukiah

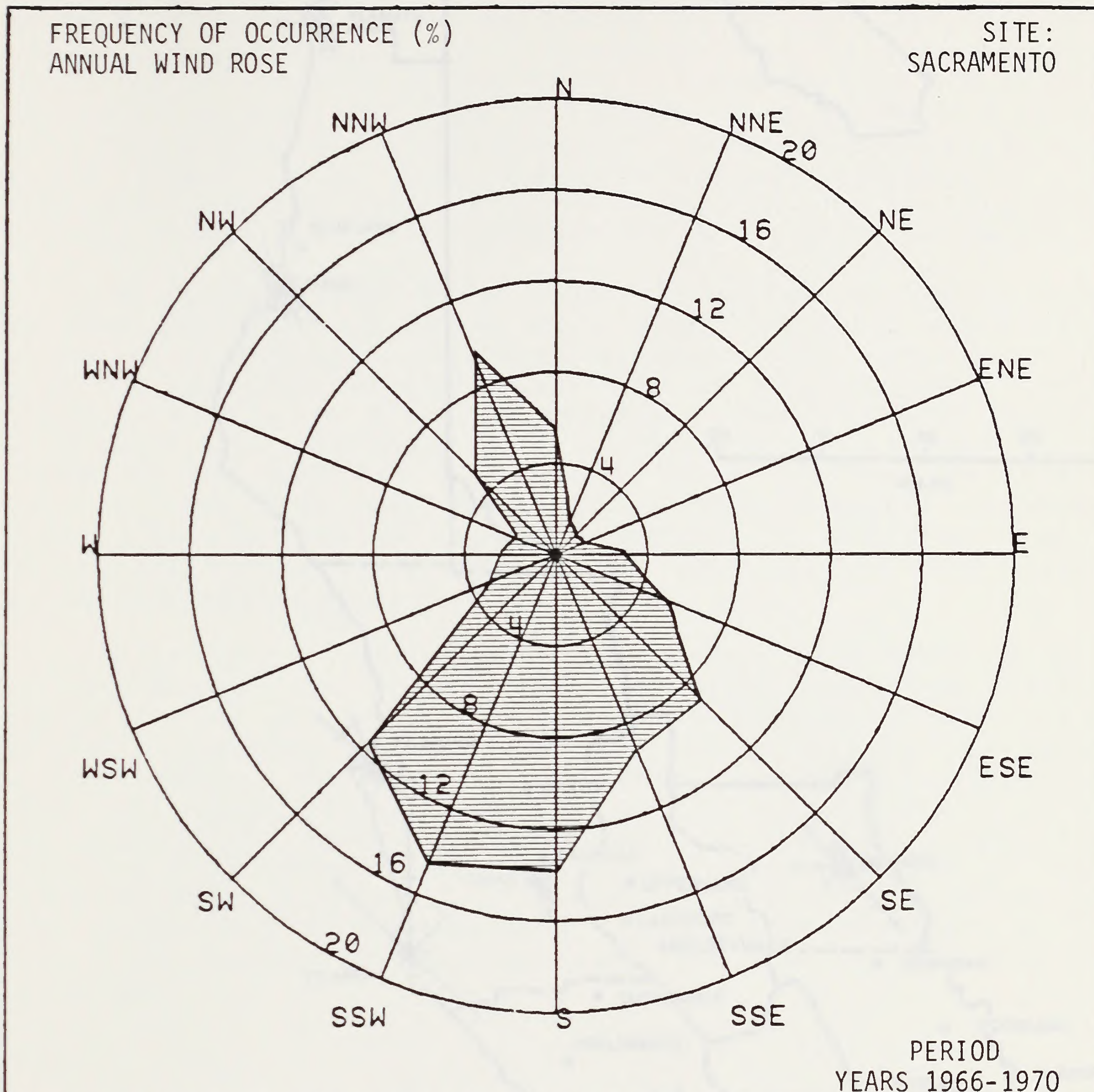

Figure 4.4-4
Annual Wind Rose for Sacramento

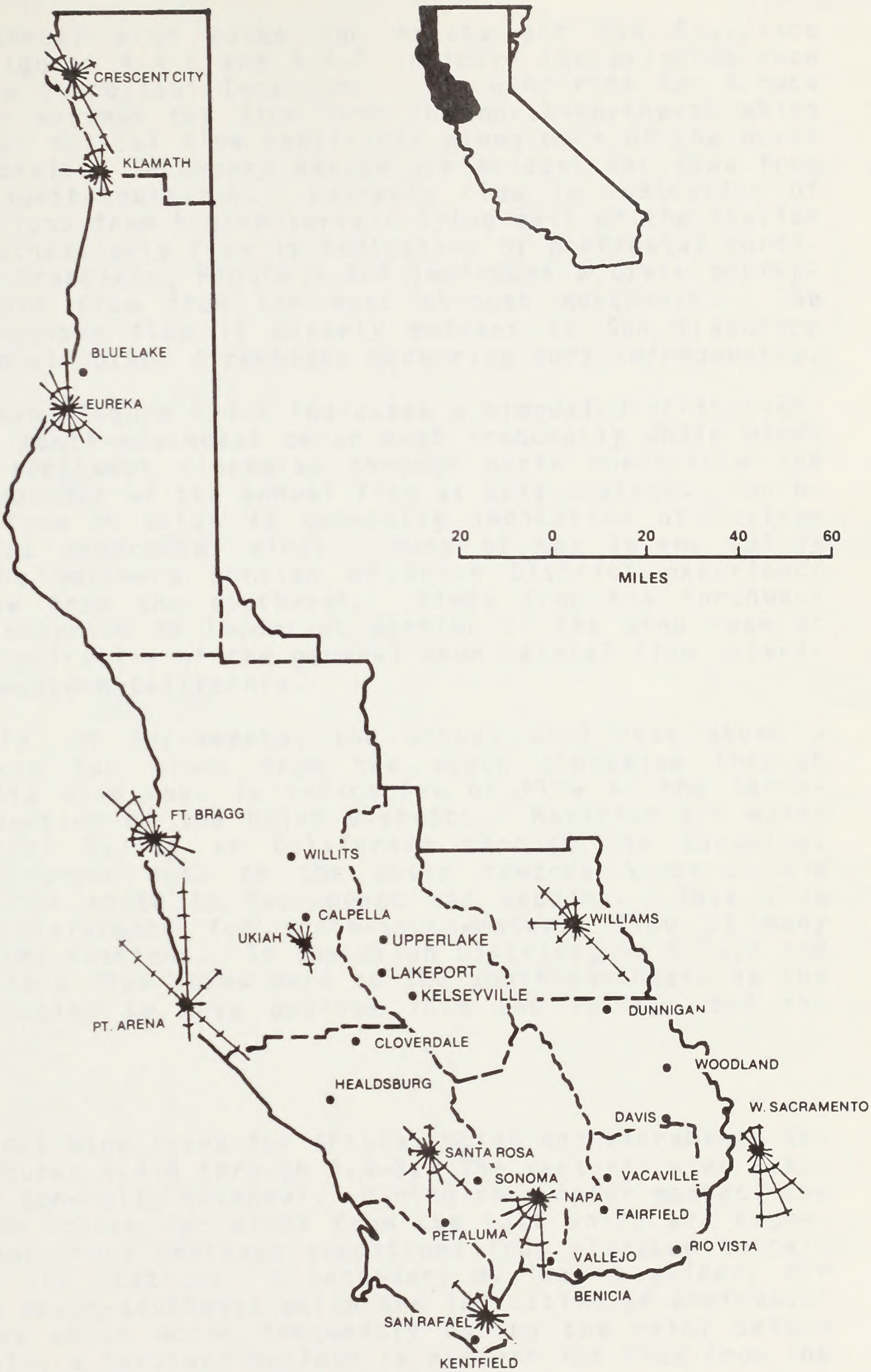

Figure 4.4-5
Annual Wind Roses at Selected Key Stations
in the Ukiah District

The annual wind roses for Arcata and San Francisco presented in Figures 4.4-1 and 4.4-2 indicate the preponderance of onshore flow at coastal locations. The wind rose for Arcata shows a primary maximum for flow from the north-northwest which is indicative of coastal flow conditions along much of the north coast of California. Secondary maxima are evident for flow from the east and south-southeast. Easterly flow is indicative of drainage conditions from higher terrain lying east of the station while south-southeasterly flow is indicative of prefrontal conditions. At San Francisco, Figure 4.4-2 indicates a clear preference for onshore flow from the west through northwest. The dominance of onshore flow is clearly evident in San Francisco with winds from all other directions occurring very infrequently.

At Ukiah, Figure 4.4-3 indicates a bimodal distribution. Winds from the south-southeast occur most frequently while winds from the west-northwest clockwise through north constitute the bulk of the remainder of the annual flow at this station. South-southeasterly flow at Ukiah is generally indicative of upslope flow as well as prefrontal winds. Many of the inland valley stations in the southern portion of Ukiah District experience prevailing flow from the southeast. Winds from the northwest quadrant also comprise an important portion of the wind rose at Ukiah and are indicative of the general down coastal flow experienced in northwestern California.

Finally, at Sacramento, the annual wind rose shows a clear preference for winds from the south clockwise through southwest. This wind rose is indicative of flow in the Sacramento Valley portion of the Ukiah District. Maritime air moves into the Central Valley of California through the Carquinez Straits and diverges both to the south towards Stockton and Fresno and to the north to Sacramento and Redding. This flow results in a preference for south-southwesterly flow at many Sacramento Valley stations. In the Ukiah District, in Colusa and Yolo Counties this flow turns more to the south-southeast as the maritime air begins to move upslope into the valleys and the Coast Ranges.

Seasonal

Seasonal wind roses for Arcata, Ukiah and Sacramento are provided in Figures 4.4-6 through 4.4-8. The seasonal wind roses for Arcata are generally trimodal. During the winter months, the primary maximum occurs for winds from the east which are representative of nocturnal drainage conditions from elevated terrain lying east of the station. A secondary maxima is evident for winds from the south-southeast which are indicative of prefrontal flow conditions which occur frequently during the rainy season months. Finally, a tertiary maximum is evident for flow from the north-northwest which is indicative of the more general down coastal wind flow conditions commonly observed throughout northwestern California. During spring and summer, the down coastal north-northwesterly flow represents the primary maximum at

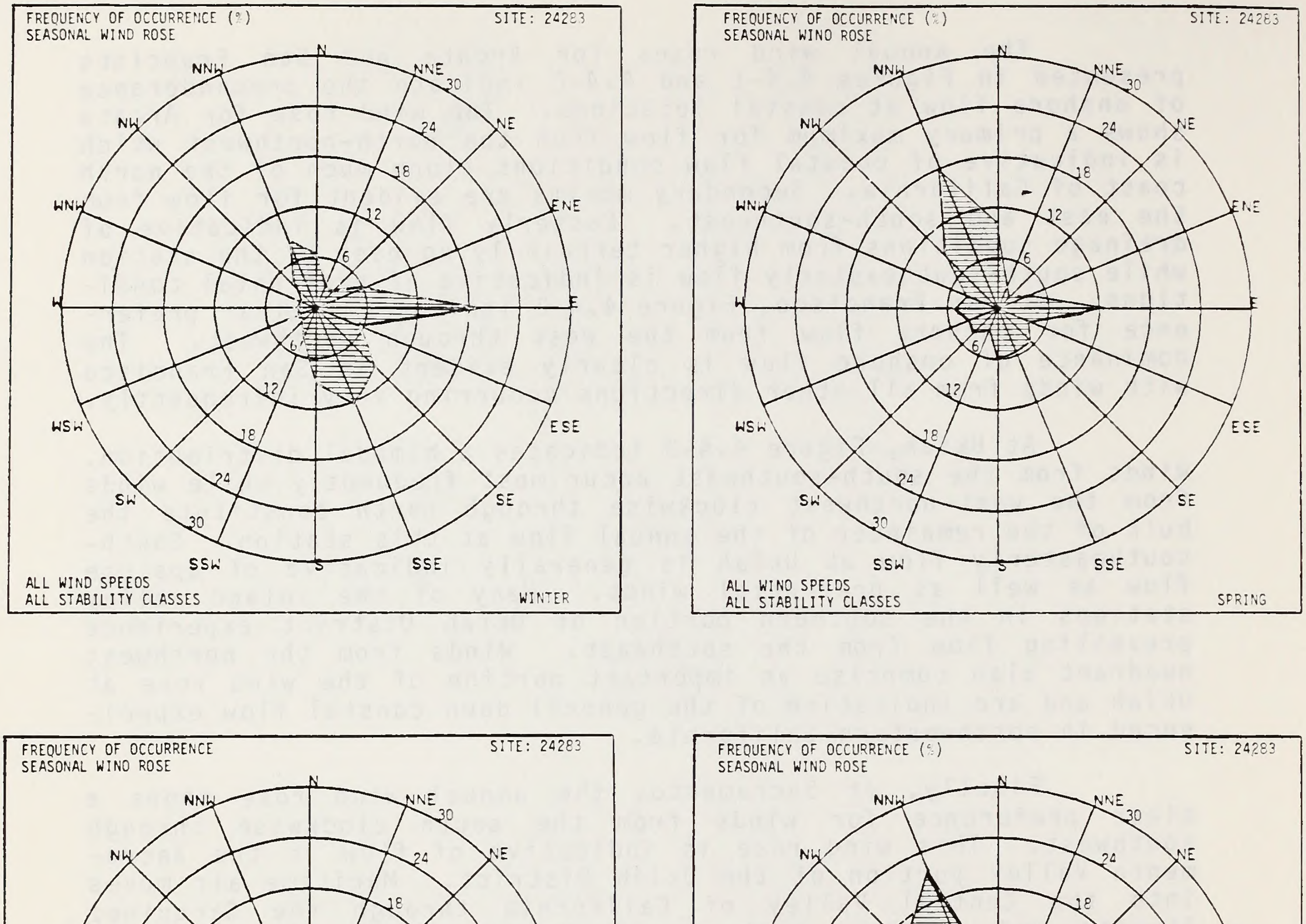

Figure 4.4-6

Seasonal Wind Roses for Arcata

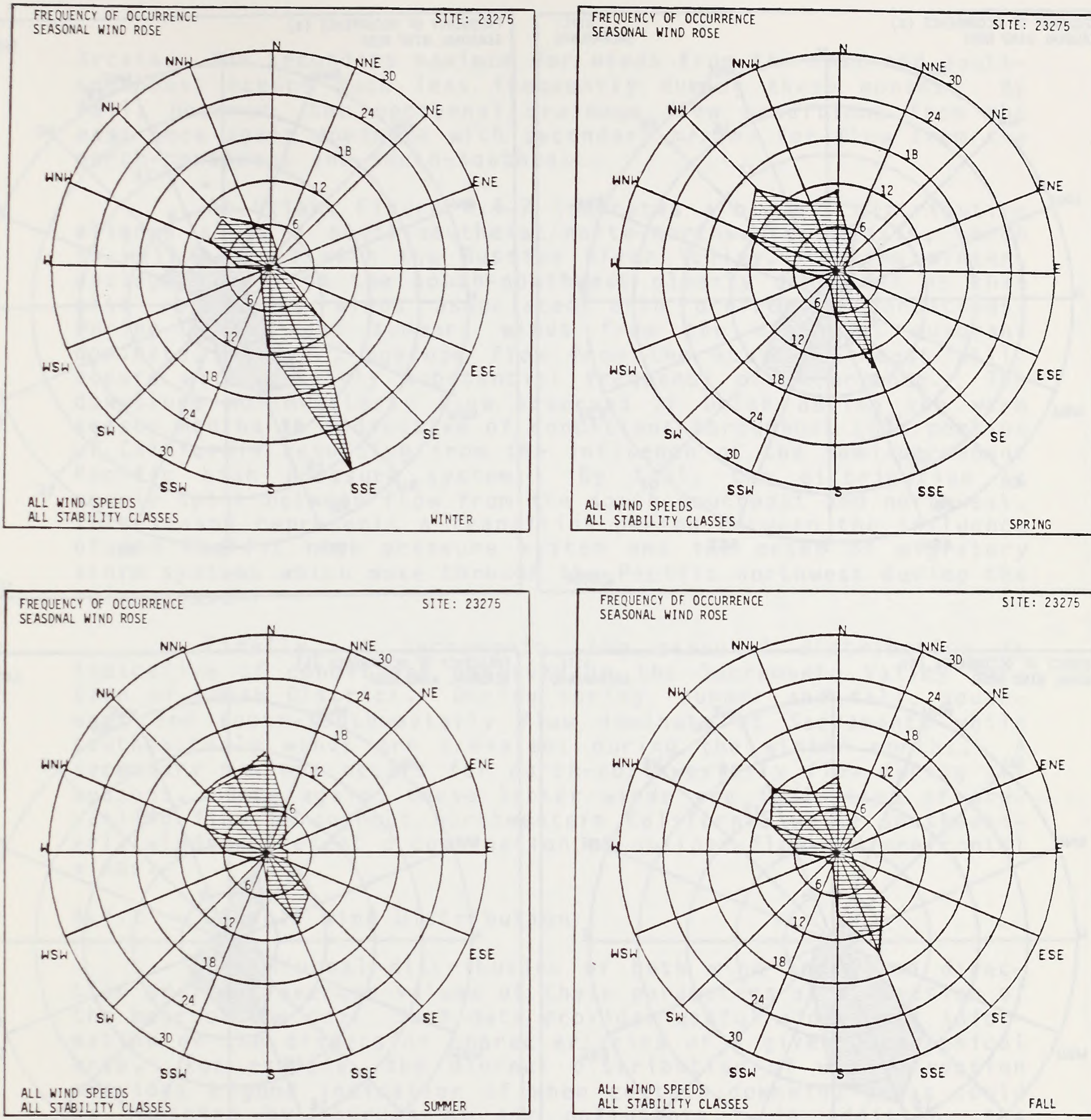

Figure 4.4-7

Seasonal Wind Roses for Ukiah

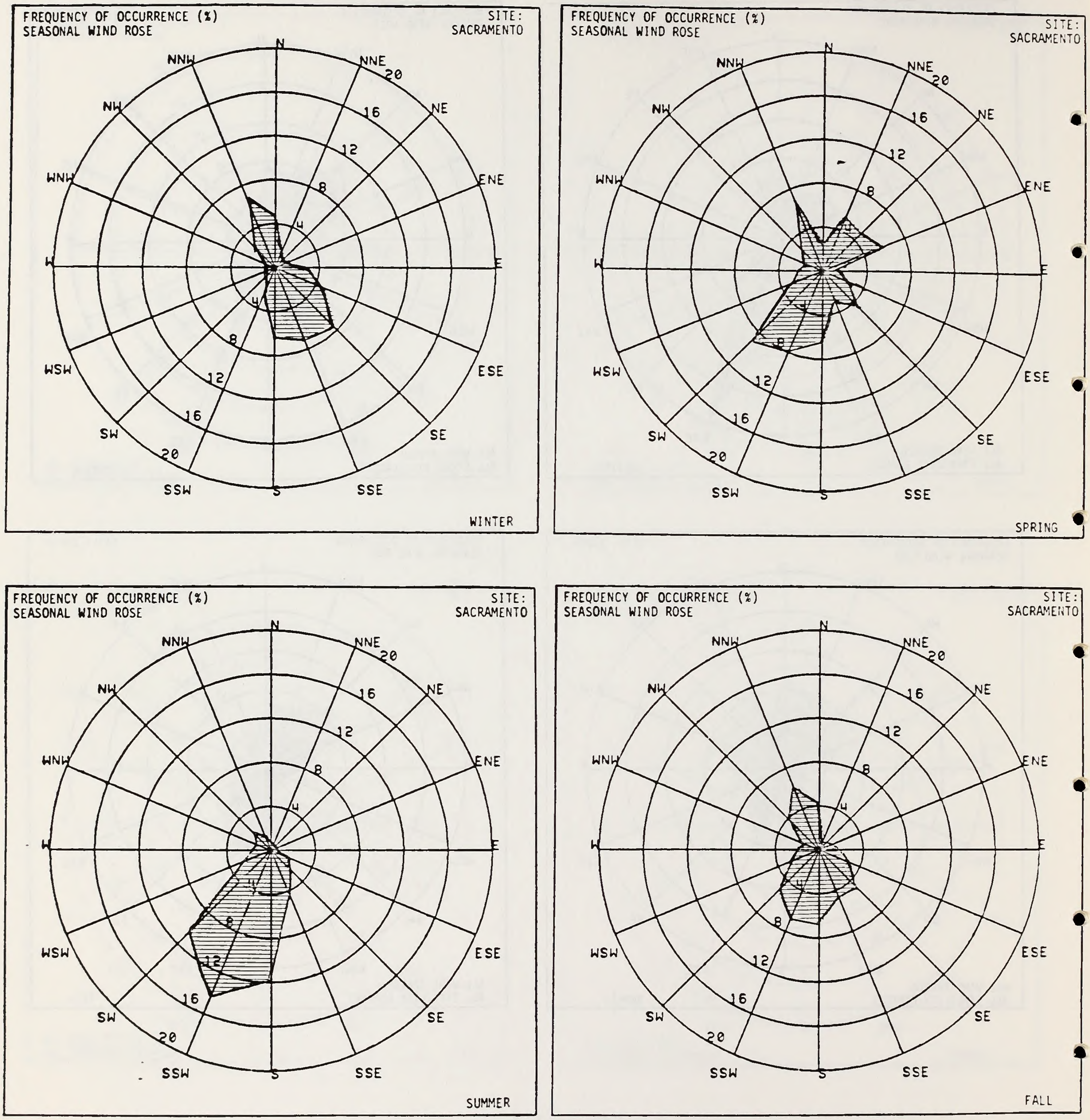

Figure 4.4-8
Seasonal Wind Roses for Sacramento

Arcata. The secondary maximum for winds from the east and south-southeast occurs much less frequently during these months. By fall, however, the nocturnal drainage flow conditions from the east once again dominate with secondary maxima for flow from the north-northwest and south-southeast.

At Ukiah, Figure 4.4-7 indicates a bimodal distribution aligned along a south-southeast/north-northwesterly axis, which is well aligned with the Russian River Valley. During winter, upslope flow from the south-southeast clearly dominates as this also represents winds associated with prefrontal conditions. During spring and summer, winds from the northwest quadrant dominate, however, upslope flow from the south-southeast still occurs with a fairly substantial frequency of occurrence. The downslope northwesterly flow observed at Ukiah during the warm season months is indicative of conditions throughout this portion of California resulting from the influence of the semi-permanent Pacific high pressure system. By fall, the distribution is nearly split between flow from the south-southeast and northwest. This season represents a transition period between the influence of the Pacific high pressure system and the onset of migratory storm systems which move through the Pacific northwest during the rainy season.

Finally, at Sacramento, the seasonal distribution is indicative of conditions observed in the Sacramento Valley portion of Ukiah District. During spring, summer and fall, southwest and south-southwesterly flow dominate at Sacramento while southeasterly winds are prevalent during the winter months. A secondary maximum occurs for north-northwesterly flow during all seasons. Once again, these latter winds are indicative of prevailing flow throughout northwestern California while southeasterly winds represent a combination of upslope flow and prefrontal winds.

4.4.2 Diurnal Wind Distribution

The diurnal distribution of both wind speed and direction provides average values of these parameters as a function of the hour of the day. Such data provides useful additional information on the dispersion characteristics of a given geographical area. For example, the diurnal distribution of wind direction provides a good indication of when certain downwind areas could be impacted by sources of air pollutants. In addition, the diurnal distribution of wind speed provides an indication of the time of day when best dispersion conditions can be expected based upon average wind speeds and the associated degree of pollutant transport. This is important to know in activities such as prescribed fires.

Wind Direction

Figures 4.4-9 and 4.4-10 present the diurnal wind direction distribution for Arcata and Ukiah. These data provide insight into the direction of the prevailing winds as a function

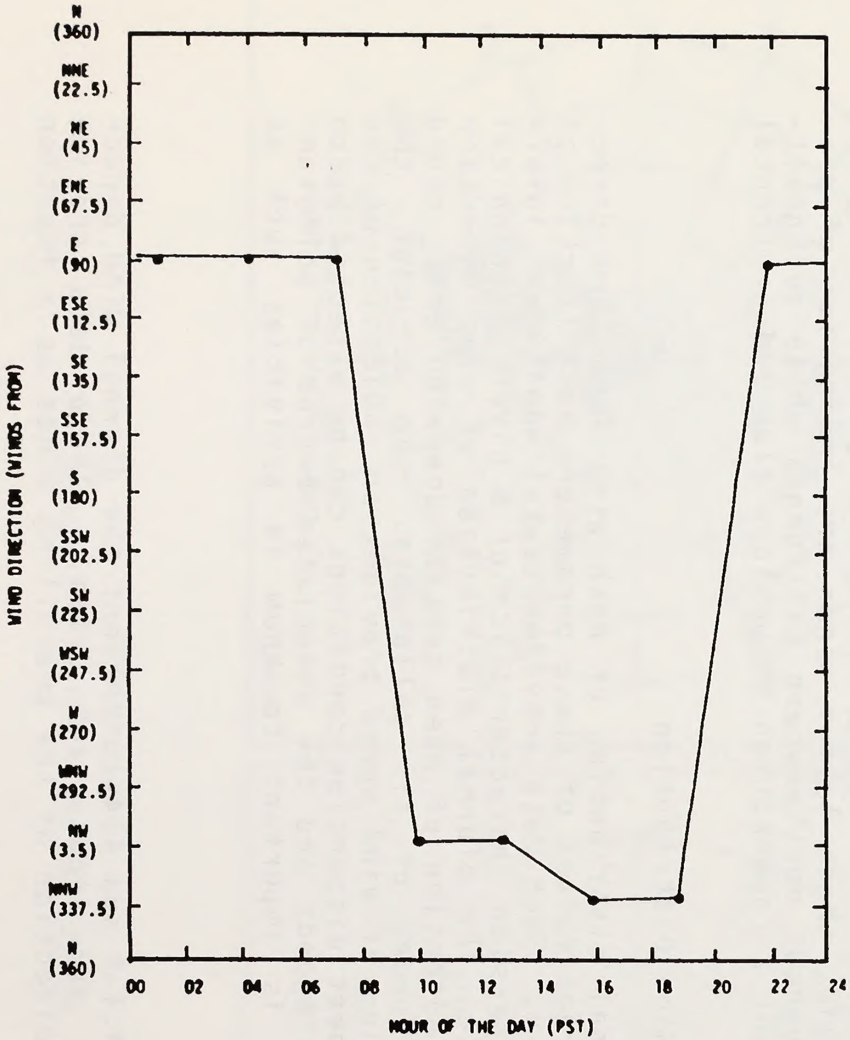

Figure 4.4-9
Diurnal Wind Direction Distribution
at Arcata, Ca (1968-1972)

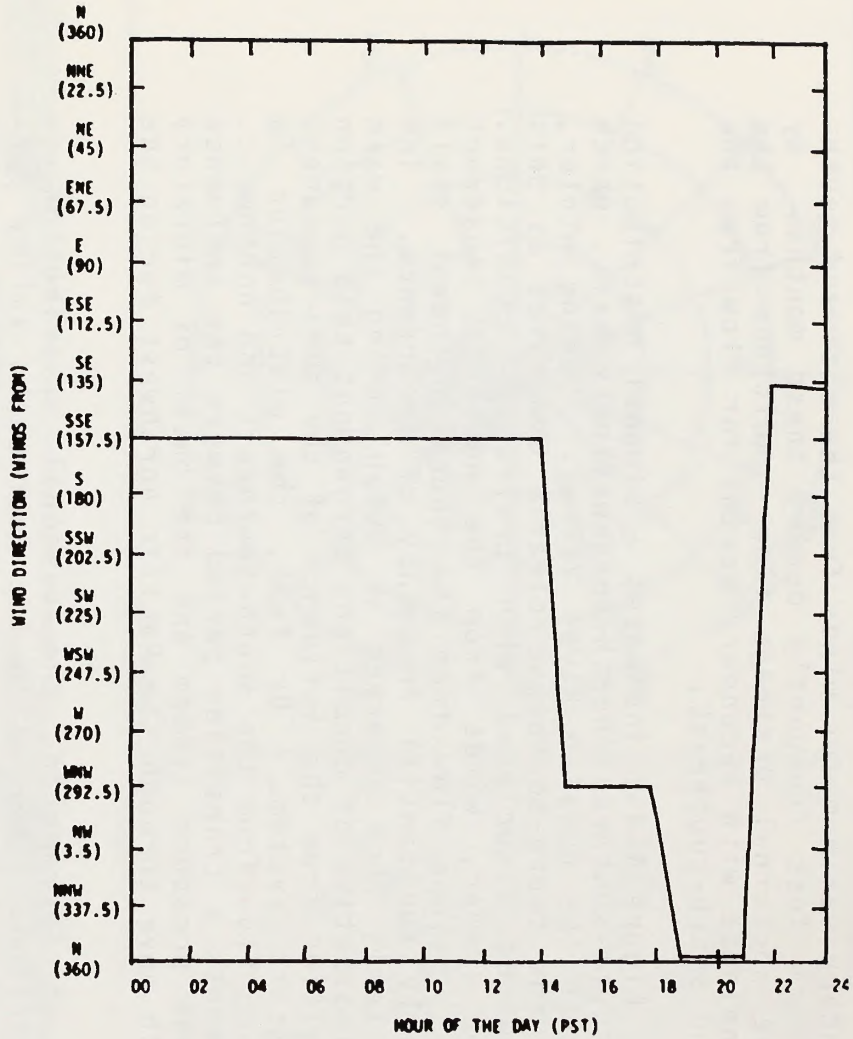

Figure 4.4-10
Diurnal Wind Direction Distribution
at Ukiah, Ca (1955-1964)*

*Analyses based on 8 obs/day

of time of day. This information can be valuable to community and industrial planners concerned with the control of existing emission sources and the placement of new sources since they can be used to determine which specific areas in a region are most likely to be adversely impacted by pollutants throughout the day.

The diurnal distribution of wind direction at Arcata as depicted in Figure 4.4-9 indicates the prevalence of easterly drainage flow from higher terrain lying east of the station during the evening and early morning hours. From mid-morning till sunset, the flow becomes generally northwesterly to west-northwesterly as the onshore flow of maritime air prevails. Further inland at Ukiah, flow from the south-southeast prevails during the nighttime and early morning hours. This is indicative of valley flow conditions. During the afternoon, flow from the northwest quadrant dominates as northwesterly flow indicative of conditions throughout this portion of the state begins to dominate.

Wind Speed

The wind speed distributions at Arcata and Ukiah are very similar as indicated in Figures 4.4-11 and 4.4-12. Wind speeds are generally lighter at Ukiah than at the more exposed coastal station of Arcata. At both stations, minimum wind speeds occurr during the early morning hours between midnight and approximately sunrise. Maximum wind speeds occur at Arcata between one and three in the afternoon and around four to five in the afternoon at Ukiah. Maximum wind speeds at Arcata average 4 meters per second (9 mph) with minimum wind speeds of roughly 1.7 meters per second (3.8 mph). At Ukiah, maximum wind speeds reach approximately 3 meters per second (6.6 mph) during the afternoon with overnight values reaching as low as 0.5 mps (1.1 mph).

In summary, available diurnal wind speed data for Arcata and Ukiah show similar distributions with wind speeds being lighter at the inland station, Ukiah. Wind speeds will tend to be higher along coastal regions of the Ukiah District and at exposed sites in rugged mountainous terrain. Wind speeds would be lowest in sheltered valley locations within the Coast Ranges.

4.4.3 Wind Speed Distribution

The distribution of wind speed as a function of the frequency of occurrence of designated wind speed categories is routinely available for first order stations within the Ukiah District. Figures 4.4-13 through 4.4-15 provide seasonal and annual distributions of wind speed as a function of six distinct categories including; (1) 0-3 knots (0-3.5 mph), (2) 4-6 knots (4.6-6.9 mph), (3) 7-10 knots (8.1-11.5 mph), (4) 11-16 knots (12.7-18.4 mph), (5) 17-21 knots (19.6-24.2 mph), and (6) greater than 21 knots (24.2 mph). The frequency of calms is also provided in each figure as well as conversion factors to facilitate the use of both English and metric units.

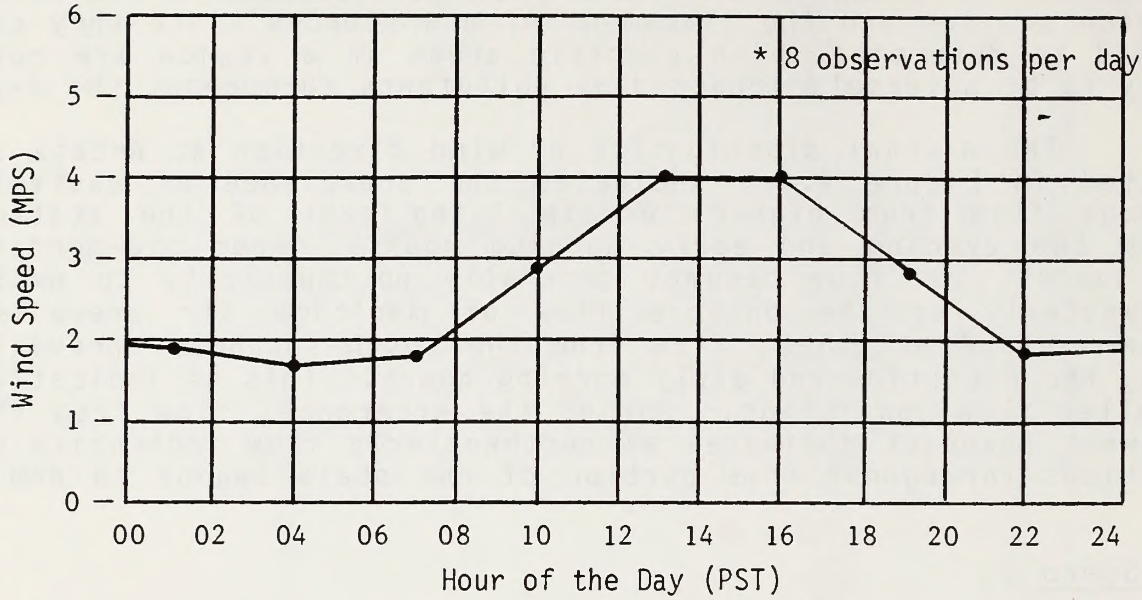

Figure 4.4-11

Diurnal Wind Speed Distribution at

Arcata, CA* (1968-1972)

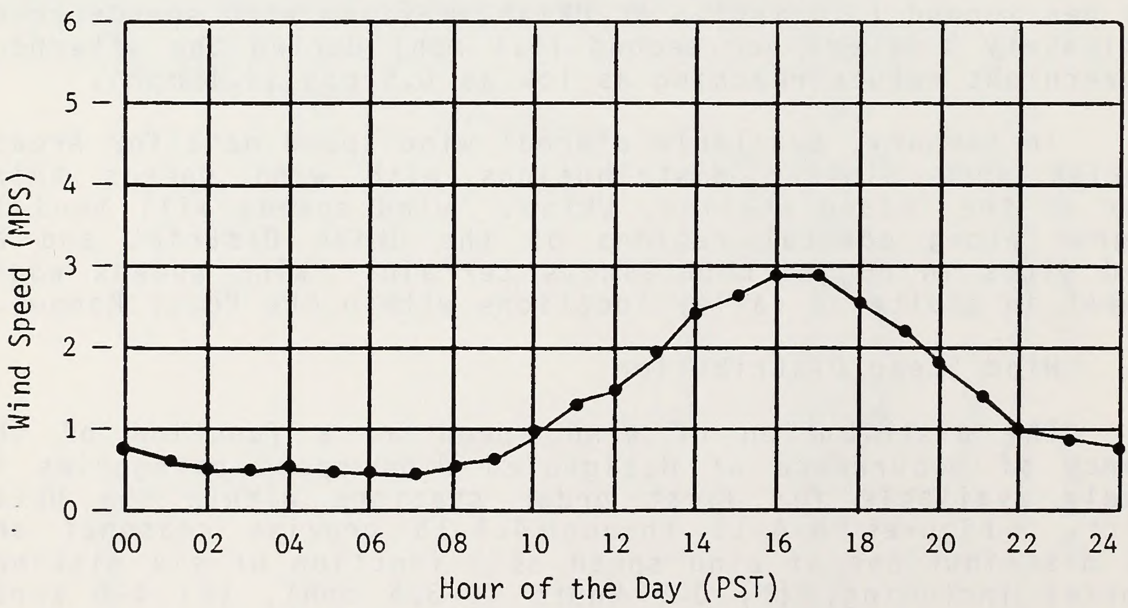

Figure 4.4-12

Diurnal Wind Speed Distribution at

Ukiah, CA (1955 - 1964)

Note: Diurnal Wind Speed as Defined by Magnitude Average Speed
1 MPS = 2.237 MPH = 1.944 Knots

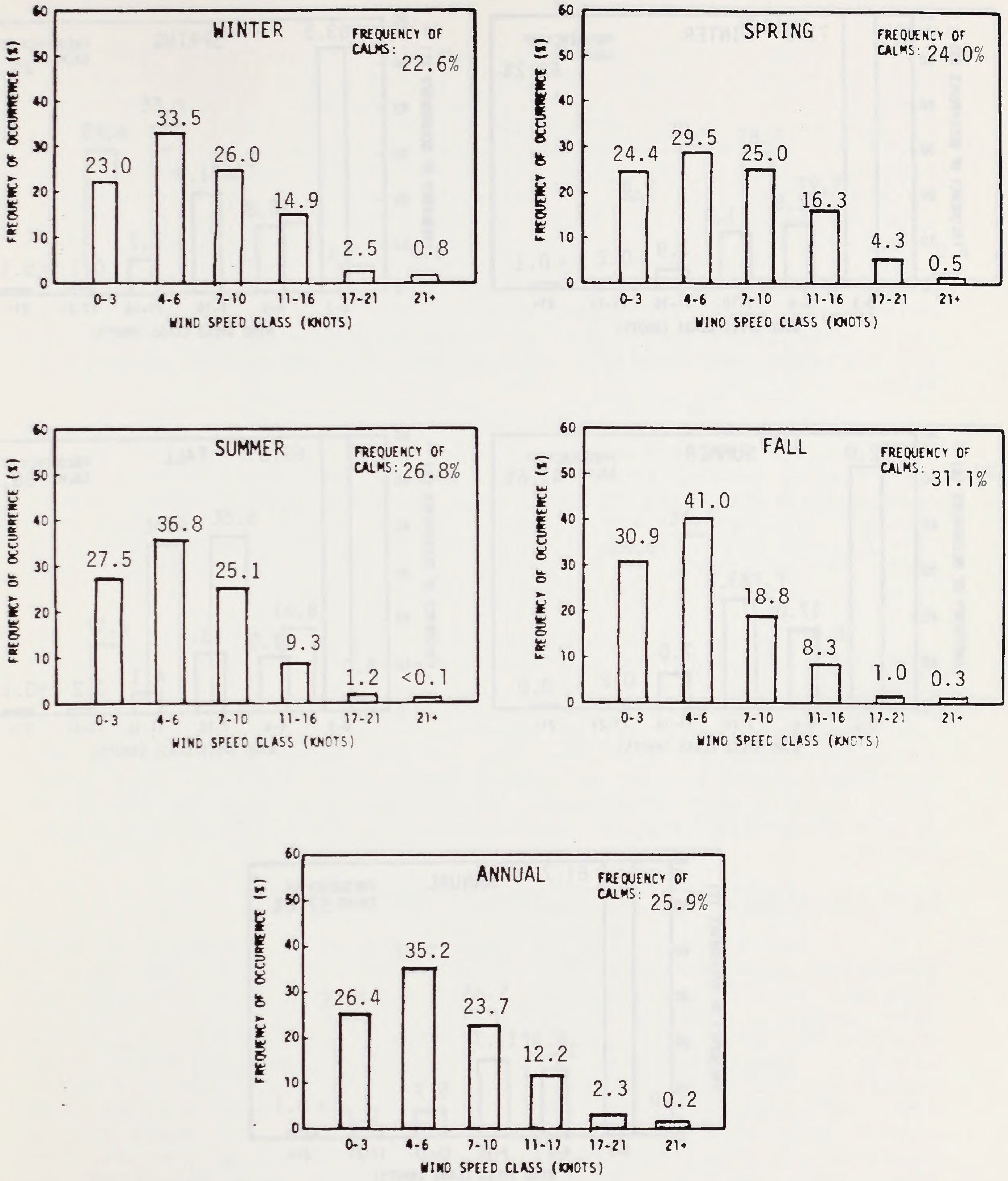

Figure 4.4-13
Annual-Seasonal Frequency of Occurrence of Key Wind Speed Classes
at Arcata, California (1968-1972)

Note: 1MPS = 2.237 MPH = 1.944 Knots

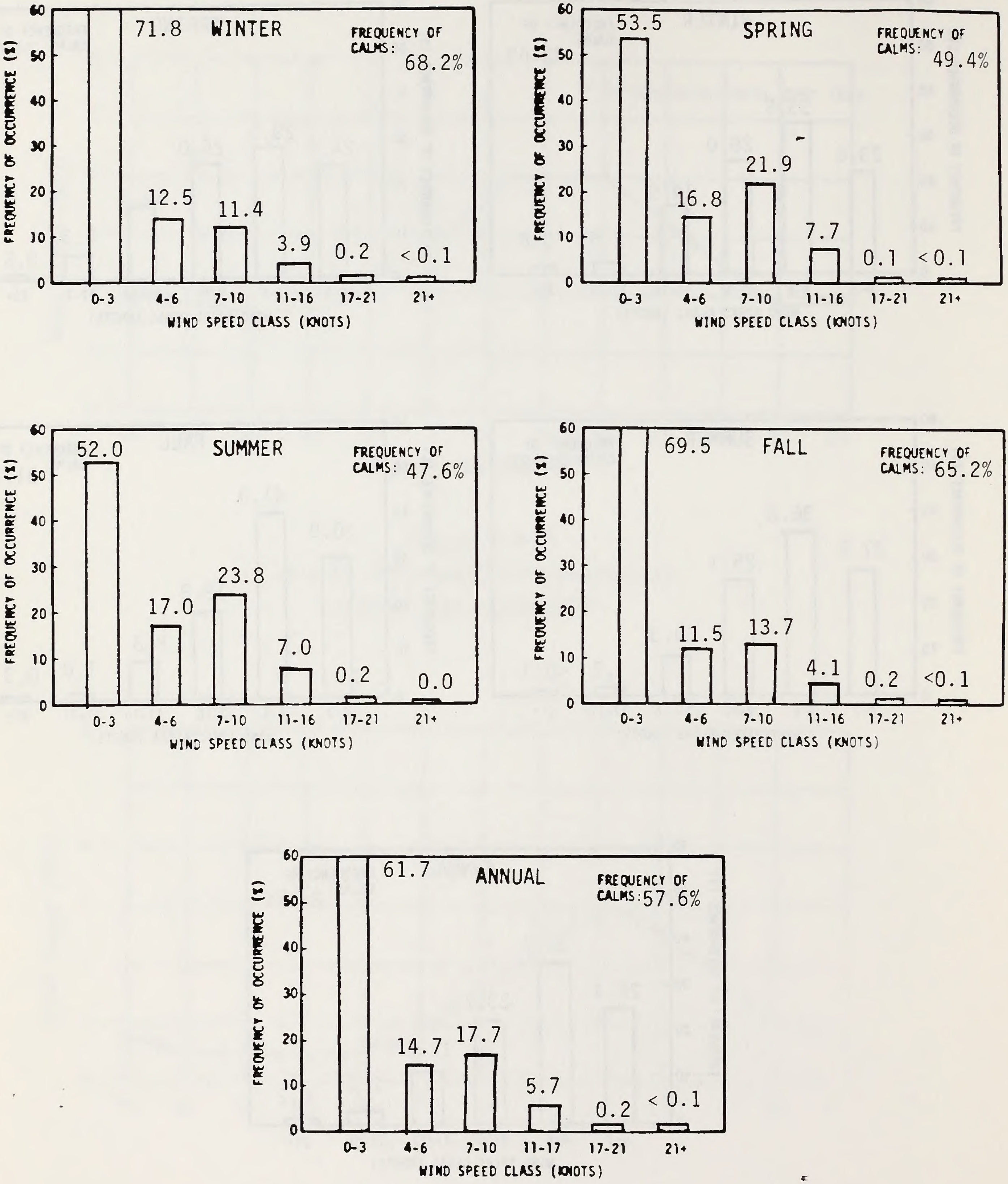

Figure 4.4-14
Annual-Seasonal Frequency of Occurrence of Key Wind Speed Classes
at Ukiah, California (1955-1964)

Note: 1MPS = 2.237 MPH = 1.944 Knots

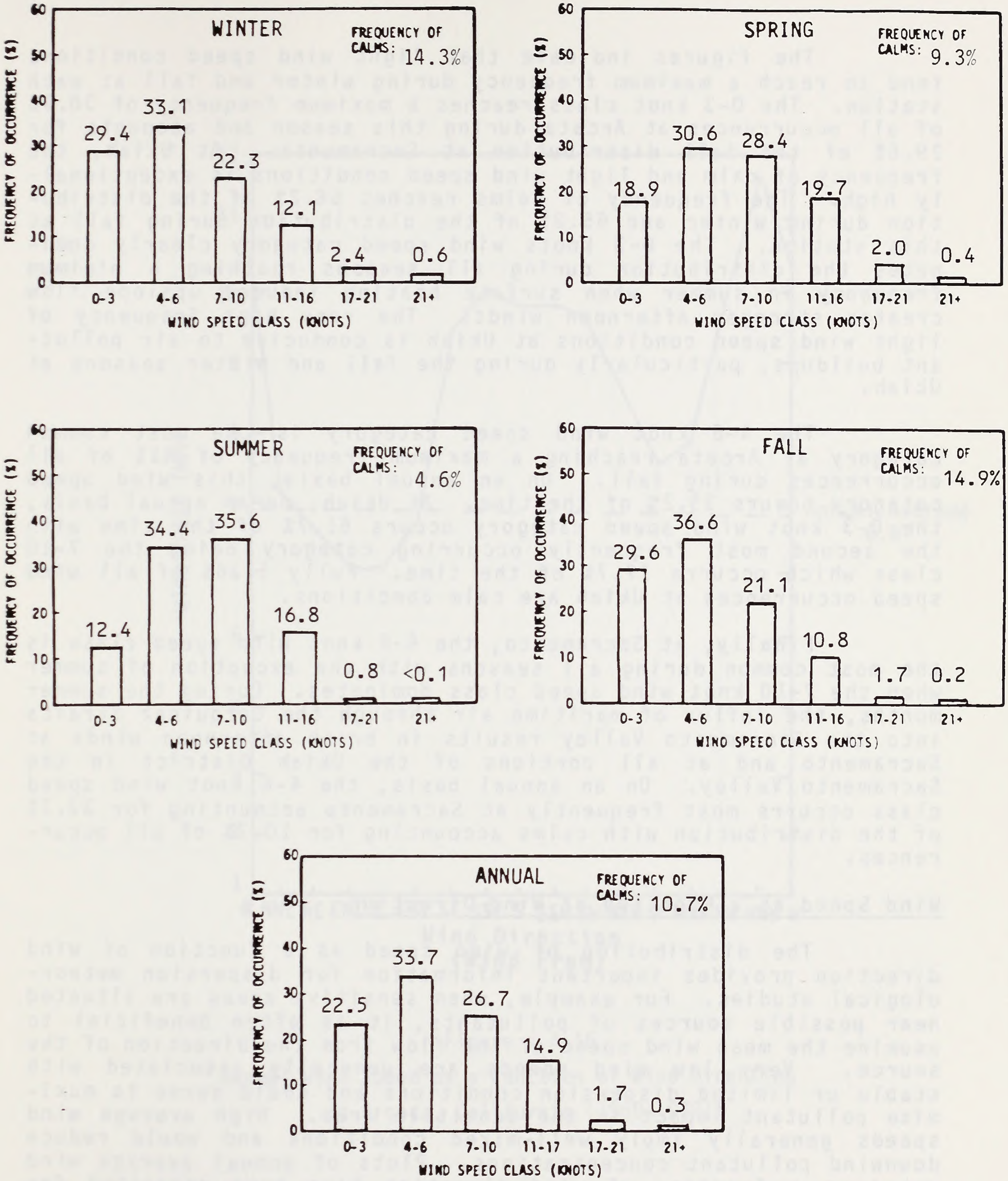

Figure 4.4-15

Annual-Seasonal Frequency of Occurrence of Key Wind Speed Classes at Sacramento, California (1966-1970)

Note: 1MPS = 2.237 MPH = 1.944 Knots

The figures indicate that light wind speed conditions tend to reach a maximum frequency during winter and fall at each station. The 0-3 knot class reaches a maximum frequency of 30.9% of all occurrences at Arcata during this season and accounts for 29.6% of the fall distribution at Sacramento. At Ukiah, the frequency of calm and light wind speed conditions is exceptionally high. The frequency of calms reaches 68.2% of the distribution during winter and 65.2% of the distribution during fall at this station. The 0-3 knots wind speed category clearly dominates the distribution during all seasons reaching a minimum frequency in summer when surface heating induced upslope flow creates stronger afternoon winds. The very high frequency of light wind speed conditions at Ukiah is conducive to air pollutant buildups, particularly during the fall and winter seasons at Ukiah.

The 4-6 knot wind speed category is the most common category at Arcata reaching a maximum frequency of 41% of all occurrences during fall. On an annual basis, this wind speed category occurs 35.2% of the time. At Ukiah, on an annual basis, the 0-3 knot wind speed category occurs 61.7% of the time with the second most frequently occurring category being the 7-10 class which occurrs 17.7% of the time. Fully 57.6% of all wind speed occurrences at Ukiah are calm conditions.

Finally, at Sacramento, the 4-6 knot wind speed class is the most common during all seasons with the exception of summer when the 7-10 knot wind speed class dominates. During the summer months, the influx of maritime air through the Carquinez Straits into the Sacramento Valley results in brisk afternoon winds at Sacramento and at all portions of the Ukiah District in the Sacramento Valley. On an annual basis, the 4-6 knot wind speed class occurrs most frequently at Sacramento accounting for 33.7% of the distribution with calms accounting for 10.7% of all occurrences.

Wind Speed as a Function of Wind Direction

The distribution of wind speed as a function of wind direction provides important information for dispersion meteorological studies. For example, when sensitive areas are situated near possible sources of pollutants, it is often beneficial to examine the mean wind speed of the flow from the direction of the source. Very low wind speeds are generally associated with stable or limited dispersion conditions and could serve to maximize pollutant impact in the sensitive area. High average wind speeds generally imply well-mixed conditions and would reduce downwind pollutant concentrations. Plots of annual average wind speed as a function of wind direction have been generated for Arcata, Ukiah and Sacramento and are presented in Figures 4.4-16 through 4.4-18. In addition, the average annual wind speed independent of wind direction for each station is presented with each plot.

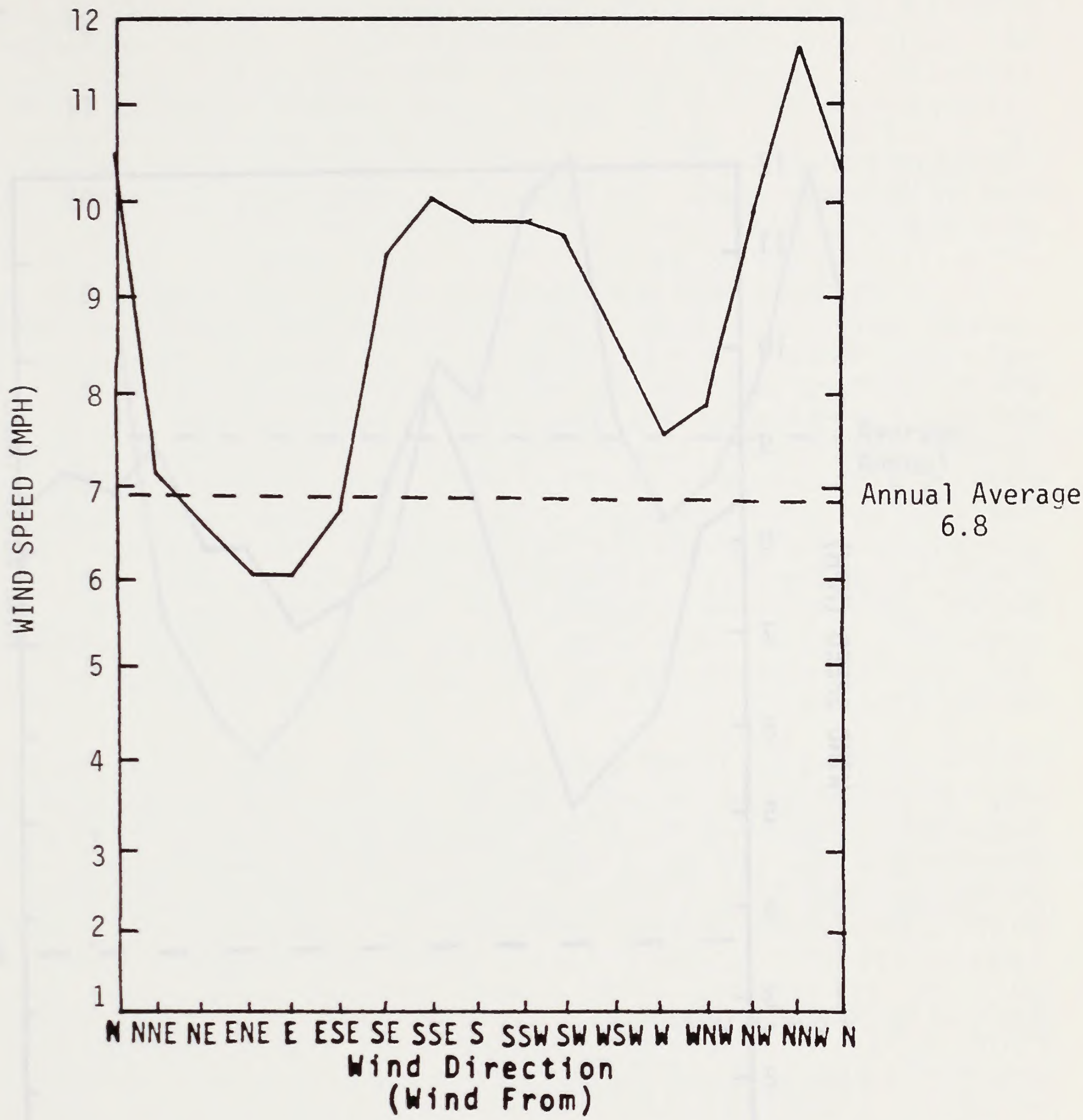

Figure 4.4-16

Annual Wind Speed as a Function of Wind Direction at Arcata, California (1968-1972)*

*8 Observations per day

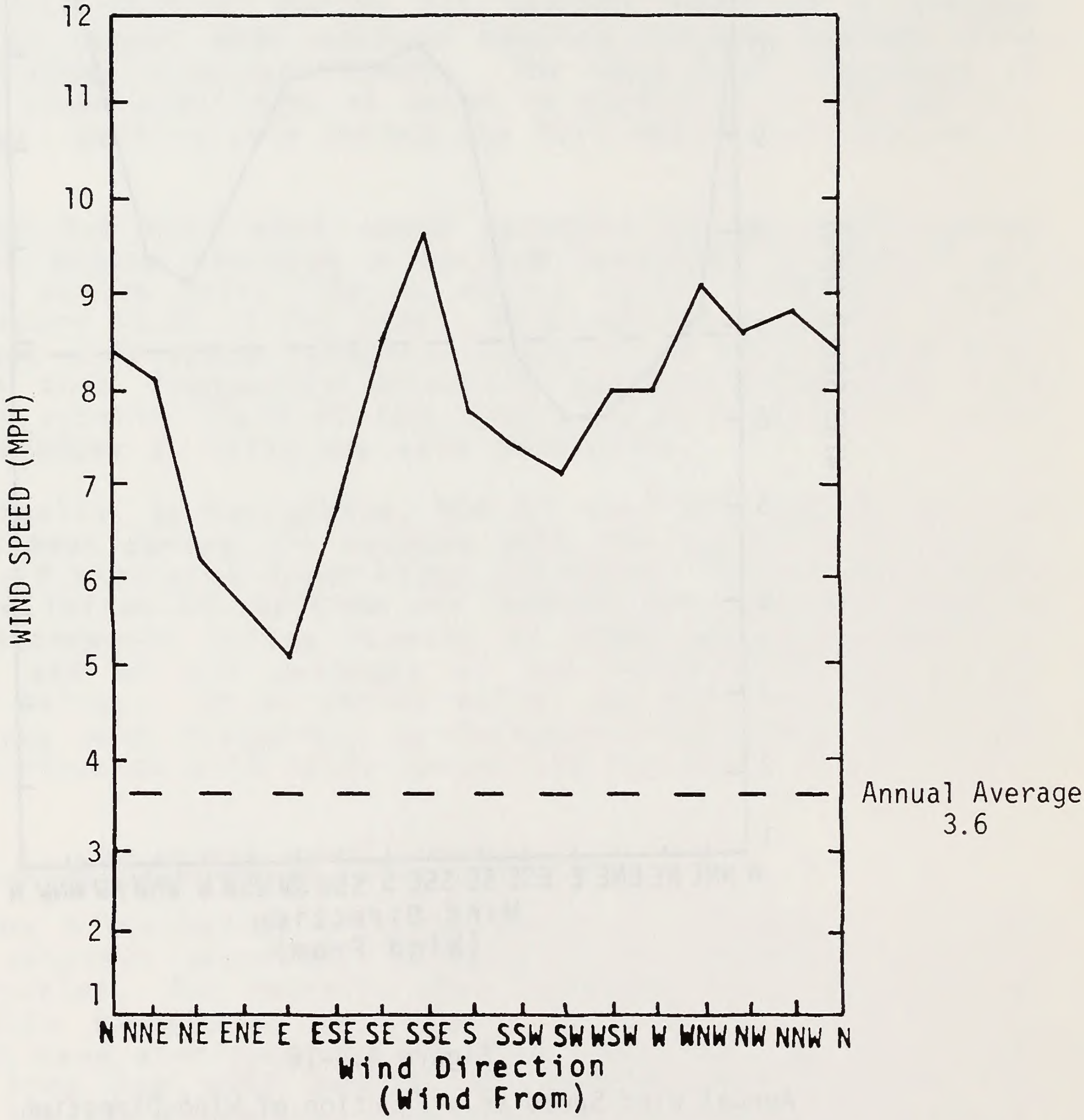

Figure 4.4-17

Annual Wind Speed as a Function of Wind Direction

at Ukiah, California (1955-1964)

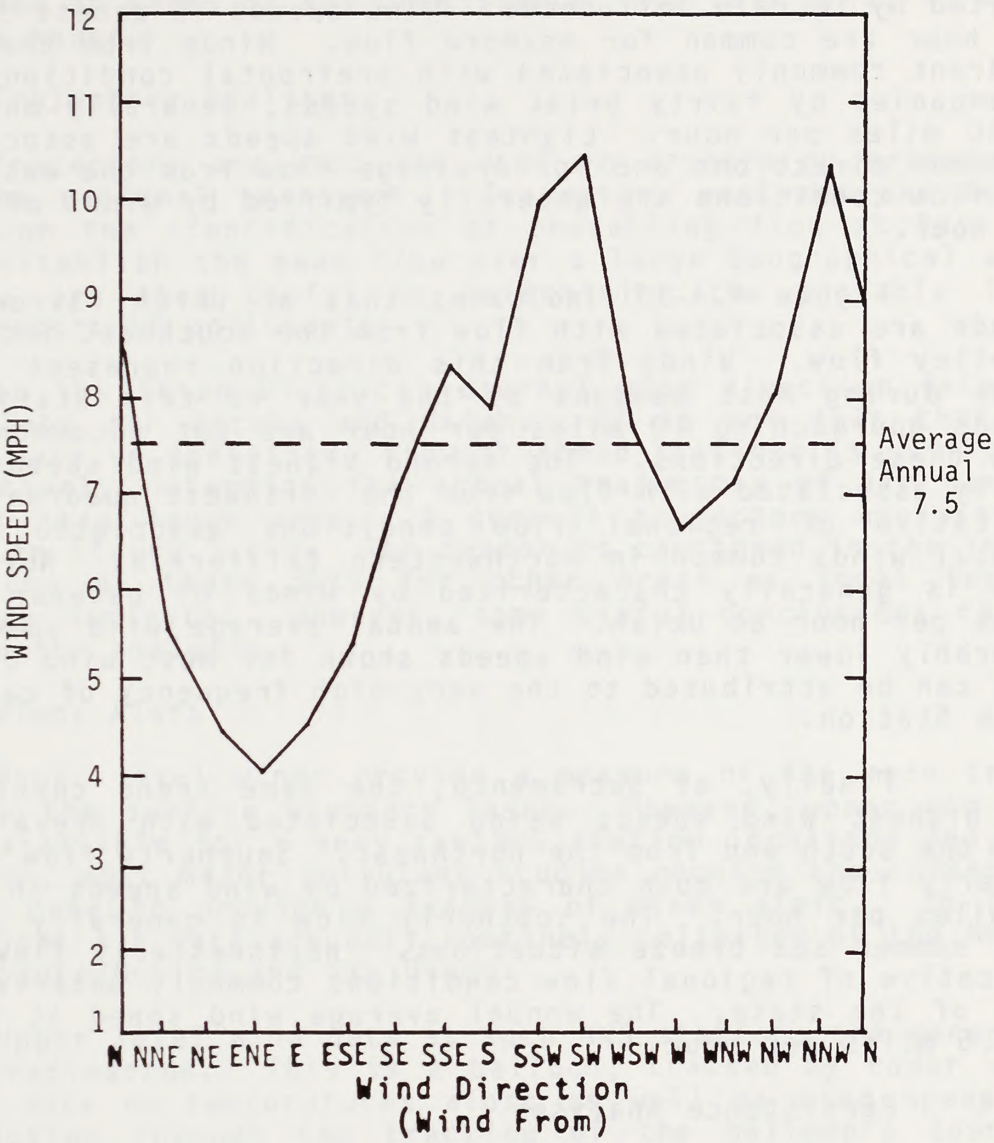

Figure 4.4-18

Annual Wind Speed as a Function of Wind Direction at Sacramento, California (1966-1970)*

*8 Observations per day

The data for Arcata indicate that the strongest wind speeds are associated with winds from the prevailing directions. Winds from the northwest quadrant account for the strongest wind speeds at this station as maritime air flows into the area uninhibited by terrain influences. Wind speeds in excess of 10 miles per hour are common for onshore flow. Winds from the southeast quadrant commonly associated with prefrontal conditions are also accompanied by fairly brisk wind speeds, generally on the order of 10 miles per hour. Lightest wind speeds are associated with uncommon directions and for drainage flow from the east. Drainage flow conditions are generally typified by winds of 6-7 miles per hour.

Figure 4.4-17 indicates that at Ukiah, strongest wind speeds are associated with flow from the southeast indicative of upvalley flow. Winds from this direction represent prevailing winds during most seasons of the year at this station. Wind speeds approaching 10 miles per hour are not uncommon for flow from these directions. The second highest wind speeds are generally associated with flow from the northwest quadrant which is indicative of regional flow conditions associated with down coastal winds common in northwestern California. Northwesterly flow is generally characterized by winds of between 8 and 10 miles per hour at Ukiah. The annual average wind speed is considerably lower than wind speeds shown for most wind directions. This can be attributed to the very high frequency of calms at the Ukiah Station.

Finally, at Sacramento, the same trend continues with the highest wind speeds being associated with prevailing flow from the south and from the northwest. Southerly flow and northwesterly flow are both characterized by wind speeds in excess of 10 miles per hour. The southerly flow is generally associated with summer sea breeze situations. Northwesterly flow is again indicative of regional flow conditions commonly observed in this part of the state. The annual average wind speed at Sacramento is 7.5 miles per hour.

4.4.4 Persistence Analyses

The persistence of both wind speed and wind direction also plays a very functional role in a complete analysis of dispersion meteorology. For example, the persistence of a particular wind direction provides information relative to the likelihood of continued impact at a given receptor location for either existing or proposed sources. In terms of wind speed, low wind speeds can often provide a maximum impact in a given region particularly if they persist for any length of time. Therefore, the persistence of calms or lower wind speed classes can also provide very useful information relative to the overall dispersion potential.

Tables 4.4-1 and 4.4-2 provide wind direction and wind speed persistence tables for Ukiah. Data are only available on a three hourly basis at Arcata eliminating its utility for persistence analyses. These data provide information on the persistence of these parameters in the primary BLM land area. The data are provided in terms of key persistence intervals of 2, 4, 10 or 24 or more hours.

4.4.5 Trajectory Analyses

Trajectory analyses are used in dispersion meteorology to describe regional transport. Trajectory analyses are developed through the identification of prevailing flow at key stations to establish the mean flow over a large geographical area. These data are then useful in determining the probable large scale transport of pollutants.

In the Ukiah District, diurnal wind direction data are only availabe for Arcata and Ukiah. It is not felt that the available data on prevailing flow at these stations is sufficient to definitively determine the actual trajectory of air parcels throughout this large area. A general trajectory analyses is presented in Figure 3.6-3. The reader is cautioned in the interpolative use of these data for other areas as local terrain effects may dominate. However, some useful conclusions can be drawn from the analysis.

4.4.6 Winds Aloft

Upper level winds provide a measure of the mean transport above the surface boundary layer. However, upper air data are only available for a very few NWS station locations and, for this reason, most major pollutant studies require the collection of onsite data to provide a measure of winds aloft. In California, upper air data are only routinely collected by the NWS at Oakland, Santa Monica and San Diego.

Upper level wind data at such NWS stations are generally taken by radiosonde. This is a balloon, tracked by radar which transmits data on temperatures aloft as well as wind speed and wind direction through the tracking of the balloon's downwind position. Upper level winds over most of California show a characteristic flow from the northwest quadrant at most levels. The impact of the dominating terrain characteristics of much of California and the Ukiah District is felt most critically in the first few thousand feet, the area of interest in pollution studies.

As stated previously, Oakland is the only regular upper air meteorological station operated by the NWS near the Ukiah District. Other winds aloft data have been collected by the (California Air Resources Board) CARB as part of its ongoing analysis of pollutant transport conditions as well as for use in the development of burn/no-burn forecasts. This data collection

Table 4.4-1

Wind Direction Persistence at Ukiah, Ca.

(1955-1964)

Persistence Interval	Frequency (%) for Winds From															
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
2 or More Hours	4.9	1.6	0.6	0.1	0.2	0.6	4.0	12.1	3.3	0.3	0.4	0.5	1.7	5.5	6.4	4.3
4 or More Hours	1.1	0.2	0.0	0.0	0.0	0.1	1.2	7.1	1.0	0.0	0.0	0.0	0.2	1.9	1.7	0.7
10 or More Hours	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
24 or More Hours	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 4.4-2

Wind Speed Persistence at Ukiah, Ca.

(1955-1964)

Persistence Interval	Frequency (%) of Wind Speeds for the Following Classes (Knots)						
	Calm	1-3	4-6	7-10	11-16	17-21	21+
2 or More Hours	52.7	4 2	15.0	9.1	1.3	0.0	0.0
4 or More Hours	49.1	0.9	7.2	4.1	0.6	0.0	0.0
10 or More Hours	39.7	0.0	0.8	0.4	0.0	0.0	0.0
24 or More Hours	5.7	0.0	0.0	0.0	0.0	0.0	0.0

program by the CARB is primarily geared to the identification of local inversion meteorology and the establishment of the mean height of the mixing layer. Data available from pilot balloon releases by the CARB as well as through programs operated by private industry indicate a continuation of the flow observed at the surface gradually turning towards the west through northwest as commonly observed over California at upper levels.

Holzworth (1972) has provided seasonal and annual values of the mean wind speed averaged through the mixing layer for both the morning and afternoon hours. These data are particularly useful in dispersion studies as they provide a realistic measure of mean transport in the layer of the atmosphere in which most pollutants are mixed.

Table 4.4-3 provides a summary of these data for the Ukiah District. The data provide a range of values across the district which indicate that lower wind speeds occur during the morning hours as opposed to the afternoon. In addition, winter and fall tend to be the most restrictive seasons in terms of lower wind speeds. A review of the geographical distribution of these data as provided by Holzworth (1972) indicates that the lower values occur in the interior with higher wind speeds generally along the Pacific Coast. It is pointed out, however, that the Holzworth (1972) data are based upon an analysis of data available from Oakland, Santa Monica and San Diego and as such are based upon very few data points. For this reason, the reader is cautioned in the utilization of these data, particularly in areas with important terrain effects.

The CARB data indicates that weak mixing layer winds are known to occur during summer at Ukiah. Mixing layer wind speeds are strong at Ukiah during winter. Other seasonal mixing layer wind speeds are not notable at Ukiah, the station that has been studied by the CARB (1974).

Table 4.4-3

Seasonal and Annual Average Wind Speeds (MPH) in the Mean Mixing Layer Over the Ukiah District

	Morning	Afternoon
Winter	4.5 - 8.9	8.9 - 11.2
Spring	6.7 - 8.9	13.4
Summer	4.5 - 6.7	11.2 - 13.4
Fall	4.5 - 6.7	8.9 - 11.2
Annual	6.7	11.2

4.5 ATMOSPHERIC STABILITY

The definition of atmospheric stability throughout the Ukiah District is a critical component of the dispersion meteorological analysis. Section 4.2.2 provides a detailed discussion of atmospheric stability and its role in defining the dispersion of airborne effluents. Figure 4.5-1, which also appears in Section 4.2.2, summarizes the dispersion characteristics associated with the various stability categories for the traditional dispersion scenarios. This section provides analyses that are designed to identify specific characteristics of atmospheric stability. These analyses include:

- Seasonal and Annual Distributions
- Diurnal Distributions
- Persistence Analyses
- Stability Wind Roses

These analyses describe a key component of the dispersion characteristics of the Ukiah District. Data are unfortunately available for only a few key stations in the region and the reader is cautioned in the use of these analyses, particularly in areas of rugged terrain or other locations not well represented by the available data.

4.5.1 Seasonal and Annual Stability Distributions

Annual stability distributions provide a means of quantifying the atmospheric dispersive power of an area in an easily comparative form. The seasonal variations in stability reflect the extent to which the dispersive power of the atmosphere changes with the seasons.

The ability of the local atmosphere to disperse airborne effluents from specific source types can be discussed in terms of atmospheric stability. When the atmosphere is stably stratified, the impact of ground level, non-buoyant emissions, will be greatest as both vertical and lateral diffusion are restricted. Examples of such emissions include automobile exhaust and fugitive dust. Typical similar sources which might impact BLM lands include range management activities and the use of unpaved surface roads. The lower atmosphere is most likely to be stable on calm clear nights when cold air tends to collect at lower elevations. Emissions from tall stacks under such conditions will have little or no impact at ground level as the plume remains relatively intact aloft. Fall and winter are the seasons when such conditions occur most frequently in California and in most areas of the United States. The impact of ground level sources is therefore at a maximum during these seasons.

Intense surface heating results in considerable convective activity and unstable conditions. Under such conditions, vertical diffusion is considerable and "fumigation" can occur as

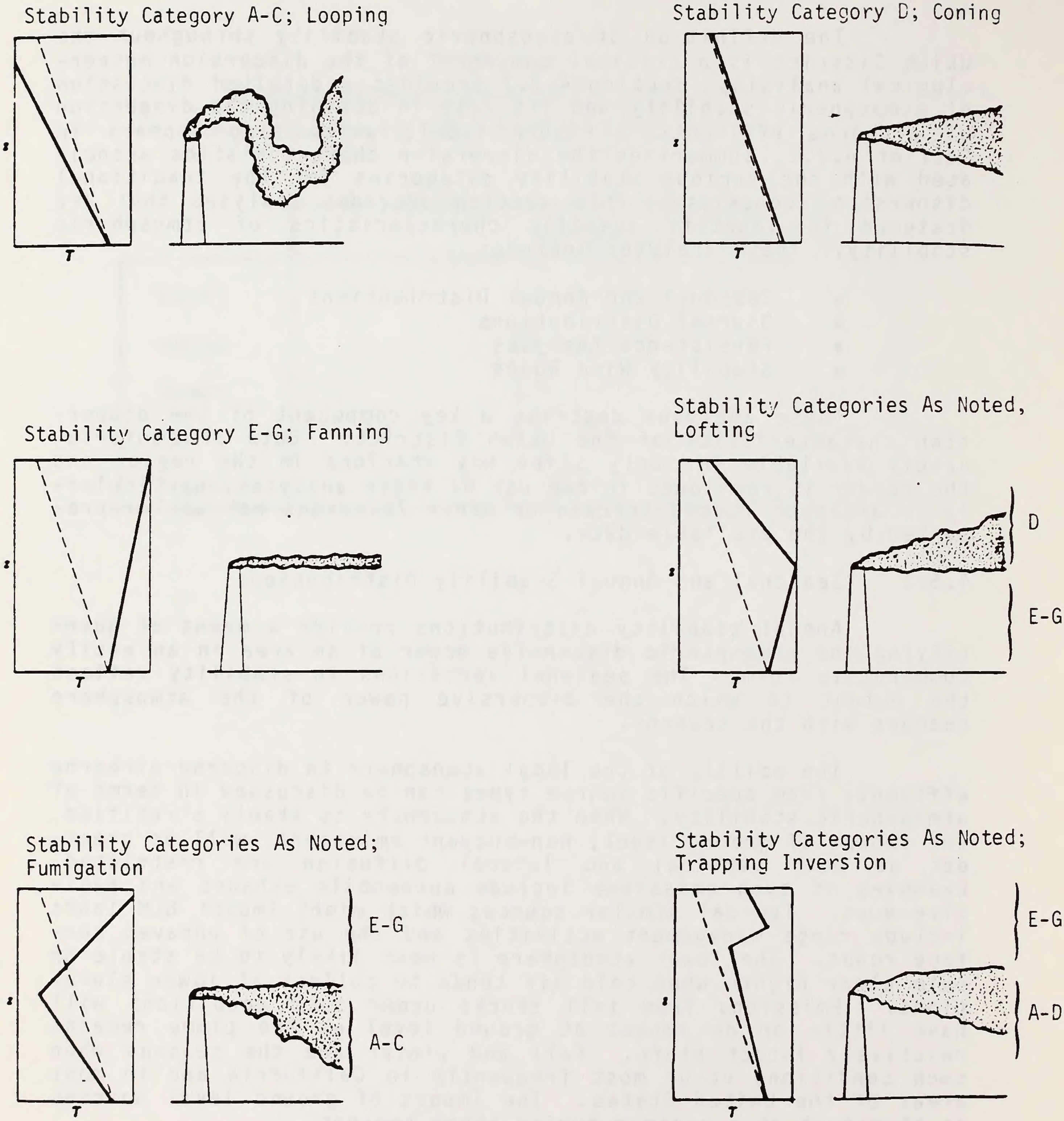

Figure 4.5-1

Typical Plume Behavior*

* Plume behavior influenced by the temperature lapse rate above and below the release height. The dashed lines in the profiles are the adiabatic lapse rates, included for reference, while the solid lines indicate the actual lapse rate. The Pasquill stability categories are also provided.

emissions from elevated sources are brought rapidly to the surface creating maximum ground-level concentrations. Examples of large elevated pollutant sources which could potentially impact BLM lands include power plants and other large industrial sources as well as large forest fires.

Finally, neutral atmospheric stability, characterized by a windy, well-mixed atmosphere, and generally indicative of good atmospheric dispersion, can result in locally high ground-level concentrations for stacks of intermediate height or stacks whose height is not substantially greater than the height of surrounding buildings. Most moderate sized industrial complexes are indicative of this source type; refineries and other processing industries serve as typical examples. In such cases, strong winds can bring the plume rapidly to the surface, resulting in high gound-level pollutant concentrations in a condition known as "downwash". Neutral conditions may also result in the re-entrainment of loose dust and soil particles associated with deserts and overgrazed arid lands. Reduced visibility and increased atmospheric particulate loading may occur in nearby populated areas as a result.

The following discussion provide seasonal and annual distributions of atmospheric stability which, combined with a knowledge of source types, can be used to identify probable periods of maximum impact. Seasonal and annual stability frequency distributions for various site locations throughout the Ukiah District are provided in Figures 4.5-2 through 4.5-4. At Arcata, neutral conditions dominate the stability distribution during all seasons of the year. On an annual basis, neutral conditions acccount for 60.9% of the distribution while stable conditions account for 25.9% of the distribution. Unstable conditions at Arcata are fairly infrequent. The frequency of neutral conditions in Arcata is highest in the summer months coinciding with the high frequency of occurrence of fog and stratus. Unstable conditions also reach the highest frequency of occurrence during this season when surface heating effects tend to become most intense. As a result, the frequency of stable conditions is at a low during the summer months. Fall tends to be the season with the lightest wind speeds and the highest frequency of clear skies in Arcata. Accordingly, the frequency of stable conditions reaches a seasonal maximum at 34.2% of the distribution.

At Ukiah, the frequency of neutral conditions is greatly diminished over that observed at Arcata. The inland more continental nature of this station results in a greatly enhanced frequency of stable conditions. On an annual basis, neutral conditions occur just 26.3% of the time while stable conditions account for 34% of the distribution. Seasonally, neutral conditions are highest in winter when the frequency of migratory low pressure systems reaches a peak. This is the rainy season in California and neutral conditions are generally associated with inclement weather. Stable conditions occur more frequently than

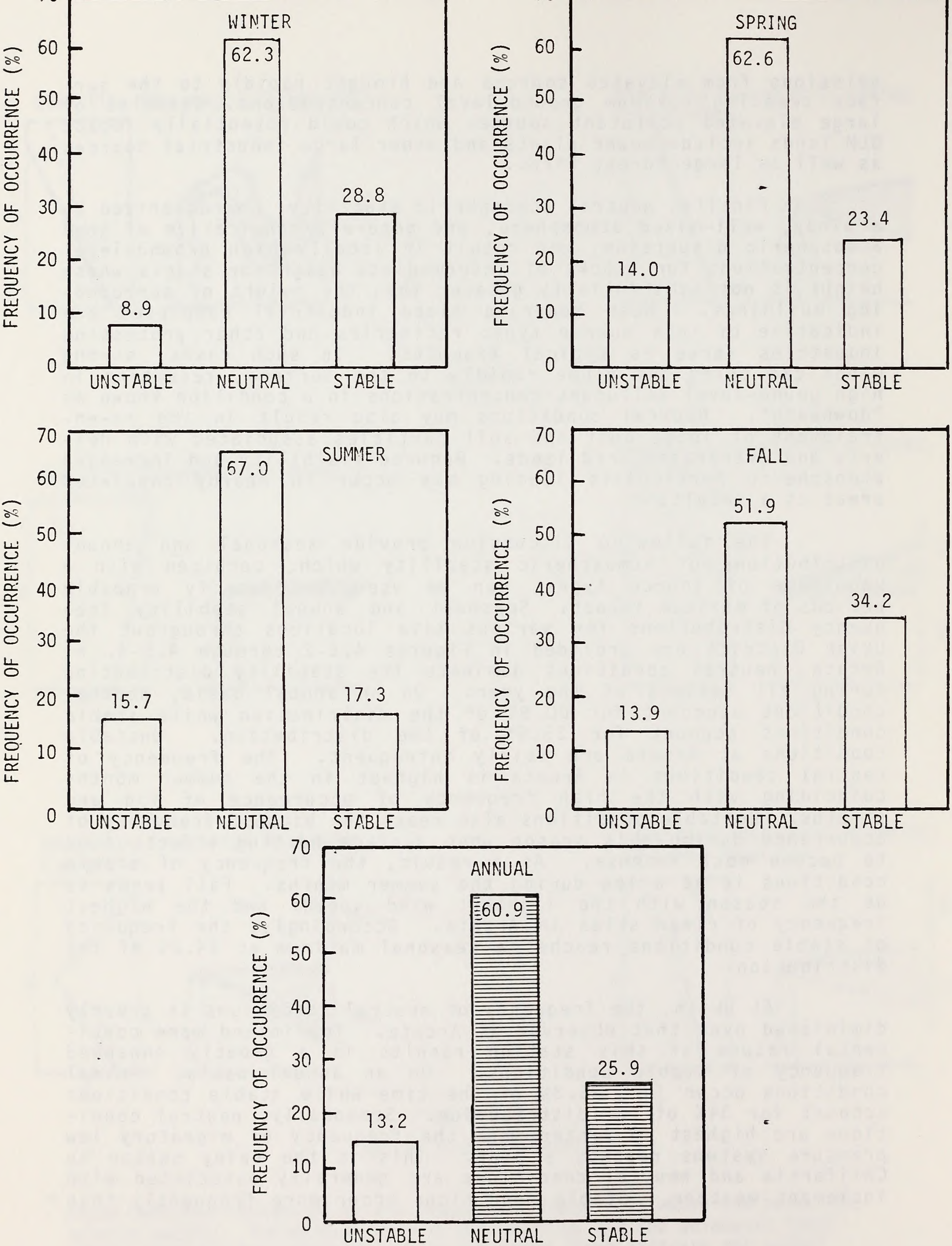

Figure 4.5-2

Seasonal/Annual Distribution of Atmospheric Stability at Arcata, Ca.

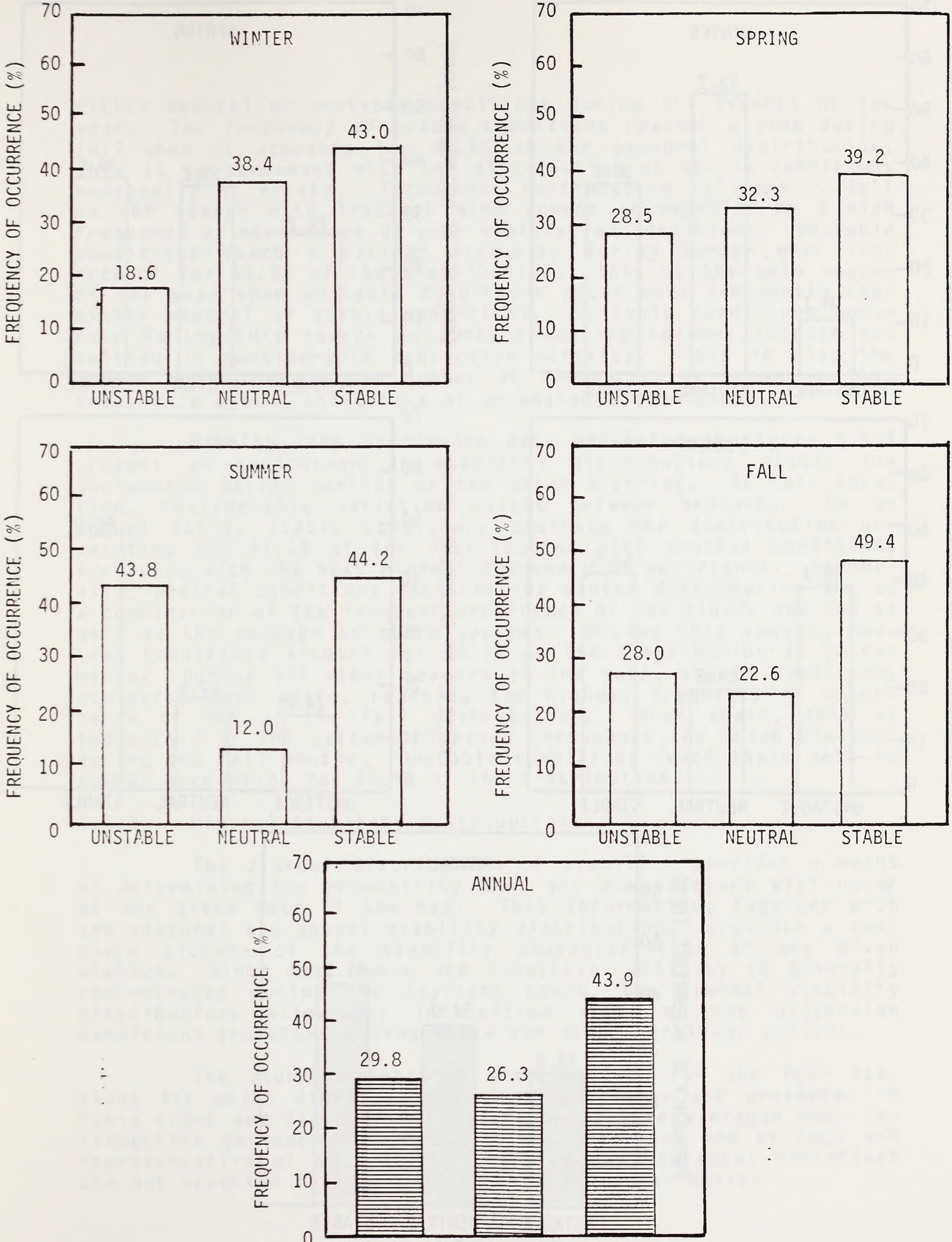

Figure 4.5-3
Seasonal/Annual Distribution of Atmospheric Stability at Ukiah, Ca.

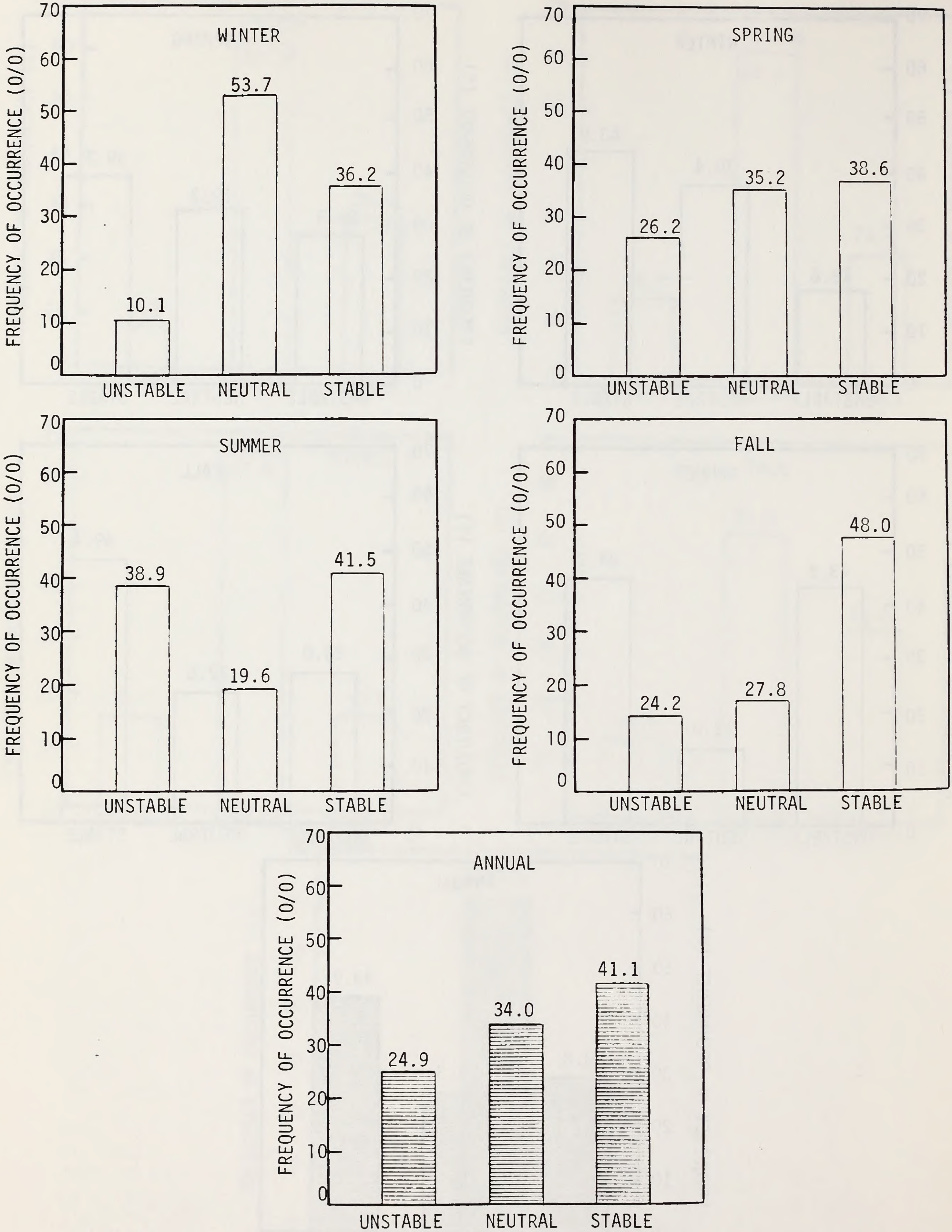

Figure 4.5-4

Seasonal/Annual Distribution of Atmospheric Stability
Sacramento, California

either neutral or unstable conditions during all seasons of the year. The frequency of stable conditions reaches a peak during fall when it accounts for 35.6% of the seasonal distribution. This is in agreement with the distribution of stable conditions seasonally at Arcata. Throughout northwestern California, fall is the season with lightest wind speeds accompanied by a high frequency of occurrence of poor ventilation conditions. Unstable conditions reach a maximum frequency during summer when they account for 43.8% of the distribution. This is the only season of the year when unstable conditions occur more frequently than either neutral or stable conditions. Unstable conditions dominate during this season as surface heating becomes intense resulting in considerable convective activity. This is also the season with the maximum number of thunderstorms occur in this area, once again, indicative of an unstable atmosphere.

Finally, the Sacramento data presented in Figure 4.5-4 present an indication of stability distributions within the Sacramento Valley portion of the Ukiah District. At this location, considerable variation exists between seasons. On an annual basis, stable conditions dominate the distribution accounting for 41.1% of the distribution with neutral conditions occurring with the next highest frequency of occurrence. Seasonally, neutral conditions dominate the winter distribution due to a combination of the frequent occurrence of low clouds and fog as well as the passage of storm systems. During this season, neutral conditions account for 53.7% of the distribution at Sacramento. During all other seasons of the year, stable conditions dominate, once again, reaching the highest frequency of occurrence of 48% of the fall distribution. Once again, this is indicative of the pattern observed throughout the Ukiah District during the fall months. Unstable conditions reach their peak in summer accounting for 38.9% of the distribution.

4.5.2 Diurnal Stability Distributions

The diurnal distribution of stability provides a means of determining the probability that any one category will occur at any given hour of the day. This information, together with the seasonal and annual stability distributions, provides a complete picture of the stability characteristics at any given station. Since most human and industrial activity is generally concentrated during the daylight hours, the diurnal stability distributions allow for intensified study of the dispersion conditions prevalent during those and other pertinent periods.

The diurnal stability distributions for the four stations for which digitized data were available are presented in Table 4.5-1 and Figure 4.5-5. These data were averaged over the respective periods of record for each station, and as such are representative of an annually averaged day; seasonal variations are not expected to be significant on a diurnal basis.

Table 4.5-1

Diurnal Frequency Distribution

of Stability in the Ukiah District

Hour	Arcata			Ukiah		
	U	N	S	U	N	S
1	0	56.2	43.8	0	19.1	80.9
2	*			0	20.6	79.4
3	*			0	21.5	78.6
4	0	59.1	40.9	0	22.3	77.7
5	*			0	24.3	75.8
6	*			0	25.6	74.3
7	11.6	63.2	25.3	12.4	28.6	59.0
8				38.7	28.8	32.6
9				56.5	29.4	14.0
10	35.2	64.8	0.0	72.8	27.3	0
11				75.5	25.5	0
12				77.2	22.8	0
13	40.4	59.6	0.0	77.5	22.5	0
14				76.0	24.0	0
15				70.9	29.1	0
16	18.1	76.8	5.1	64.6	35.5	0
17				50.6	40.3	9.1
18				29.2	42.7	28.2
19	0	56.4	43.6	13.6	38.1	48.3
20				0	24.2	75.8
21				0	21.3	78.7
22	0	51.4	48.6	0	20.1	79.9
23				0	18.4	81.6
24				0	19.0	81.0

U = Unstable
N = Neutral
S = Stable

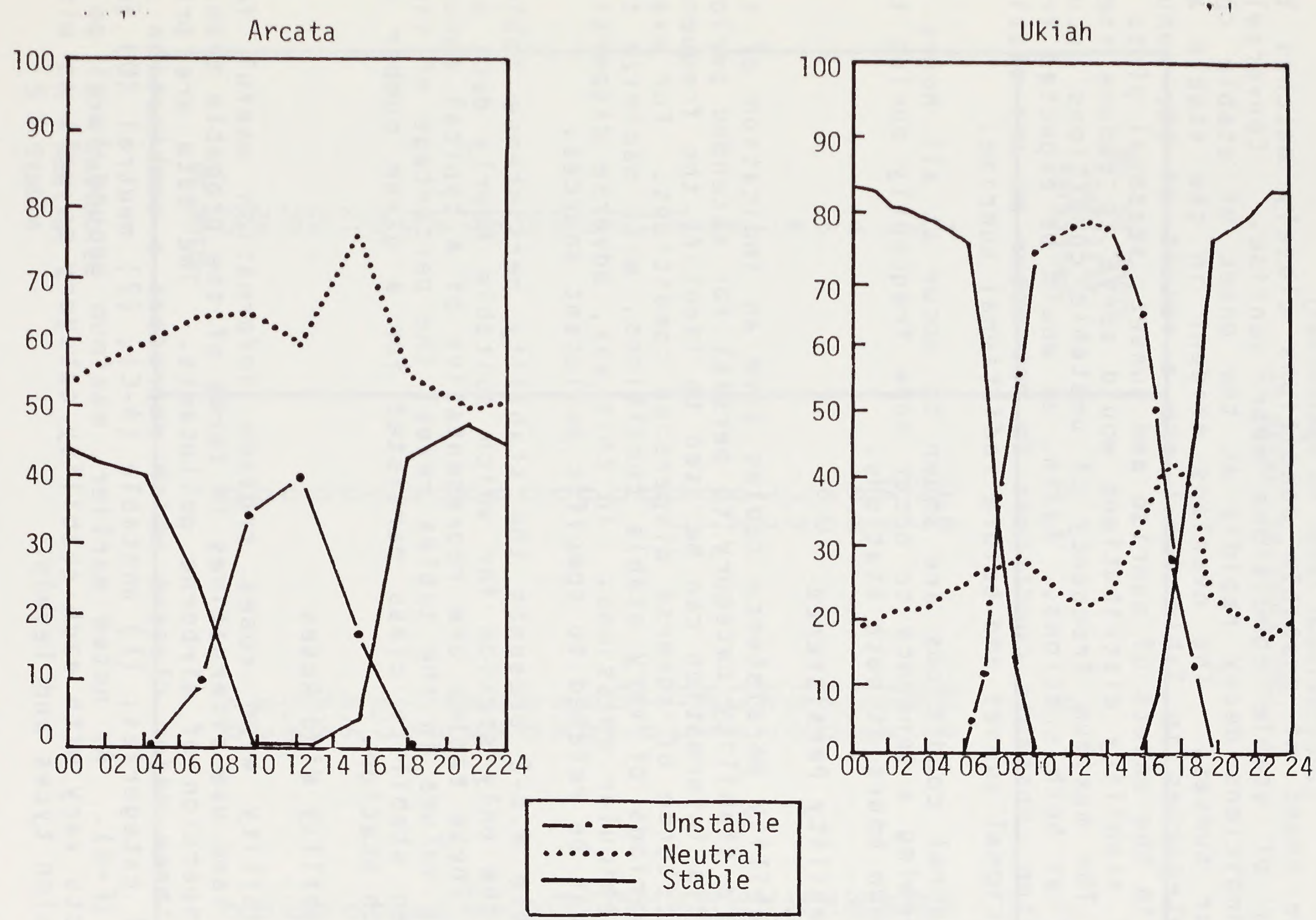

Figure 4.5-5

Diurnal Distribution of Atmospheric Stability

in the Ukiah District

As can be seen from the table, both stations exhibit very sharp increases in stable conditions after about 1600 PST and very sharp decreases at 0800 PST. These times correspond with the average limits of sunset and sunrise, respectively, on an annual basis. The maximum frequency of stable conditions occurs during the middle of the night at both stations.

The onset of unstable conditions closely matches the rapid decay of stable conditions near sunrise. Conversely, unstable conditions decay rapidly at the onset of stable conditions near sunset. The overlaps evident in the stable and unstable categories in Table 4.5-1 are a result of the annual variations in the onsets of sunrise and sunset; seasonal plots of the diurnal stability distributions would serve to reduce these overlaps. The maximum frequency of unstable conditions occurs at 1300 PST at both stations. Again, as would be expected from the definition, unstable conditions do not occur at any station after radiational sunset and before radiational sunrise.

Neutral conditions are shown to occur at all hours of the day, showing a tendency to occur more frequently during the late afternoon hours at both stations.

4.5.3 Stability Persistence

Stability persistence tables give an indication of the tendency of a stability category to persist for extended periods of time. This information can be used to identify the frequency of the persistence of adverse dispersion conditions. For example, long periods of very stable conditions, will maximize the impact of vehicular emissions. In this way, adverse dispersion conditions can be related to specific pollutant sources.

Table 4.5-2 presents the stability persistence tables for Ukiah, the only station for which suitable hourly data are available. These tables are representative of a typical annual period. The values in the tables reveal the percentage of time that a given stability class persisted for a given number of hours at each station.

4.5.4 Stability Wind Roses

Stability wind roses provide information useful for determining land use alternatives in terms of the probable transport and dispersion of airborne pollutants. The data are presented for three major classes which represent a combination of the Pasquill categories; (1) unstable (A-C), (2) neutral (D) and (3) stable (E-G). As noted earlier, maximum ground level pollution impacts vary with each stability category as well as with source emission types and levels.

Once again, stable conditions are generally characterized by light winds, hence, wind roses for this stability category are valuable in determining probable levels and areas of

Table 4.5-2
Persistence of Stability Class
(Percentage of Total Observations)
at Ukiah, CA (1955-1964)

No. of Hours Stability Persisted	U	N	S
1	31.0	23.2	45.8
2	22.7	20.7	42.7
3	14.9	18.8	40.5
4	9.8	17.3	38.9
5	6.0	16.0	37.8
6	3.7	15.0	36.6
7	1.7	14.1	35.5
8	0.4	13.2	34.4
9	0.1	12.5	32.9
10	0.1	11.7	30.4
11	0	11.0	27.4
12	0	10.3	22.1
13	0	9.9	17.1
14	0	9.5	13.0
15	0	9.0	9.5
16	0	8.6	5.5
17	0	8.3	2.8
18	0	7.8	0
19	0	7.4	0
20	0	6.7	0
21	0	6.4	0
22	0	5.9	0
23	0	5.6	0
24	0	5.3	0
25 or more	0	4.91	0

U = Unstable
N = Neutral
S = Stable

maximum impact from the low-level, non-buoyant emissions associated with many rural land uses, such as grazing and farming. Alternatively, neutral conditions with high wind speeds or unstable conditions can result in maximum impacts from elevated plume sources associated with heavier industrial activity.

Figures 4.5-6 and 4.5-7 provide stability wind roses as well as the annual wind rose for Arcata and Ukiah. As indicated earlier, stability class I refers to unstable conditions, stability class II refers to neutral conditions, and stable conditions are represented by stability class III. Each of the stability wind roses can be summed for comparison with the annual wind rose also depicted on each figure.

Figure 4.5-6 provides stability wind roses as well as the annual wind rose for Arcata, California. The figure shows that stable conditions are almost exclusively associated with nocturnal drainage flow from higher terrain lying east of the city. Neutral conditions, on the other hand, are well distributed and are represented by flow from each of the tertiary maxima that make up the annual wind rose. North-northwesterly flow is most frequently associated with neutral conditions and is indicative of general maritime flow of air down the northern Californian coast in this region. Unstable conditions occur very infrequently at Arcata and are almost exclusively associated with flow from the northwest quadrant. This primarily occurs during situations when sunny skies prevail associated with a light onshore flow.

The stability and annual wind roses for Ukiah, California are provided in Figure 4.5-7. The wind roses indicate that stable flow is once again associated with nocturnal drainage wind conditions associated with downvalley flow along the axis of the Russian River Valley. Accordingly, flow from the northwest quadrant dominates for stable flow conditions. Neutral conditions are generally associated with south-southeasterly flow which is indicative of conditions associated with migratory storm system passage. Finally, unstable conditions are well distributed between both the southeasterly and northwesterly maxima observed at this site. Unstable conditions occur with a fairly high frequency during the warmer months of the year when the wind directions are well distributed.

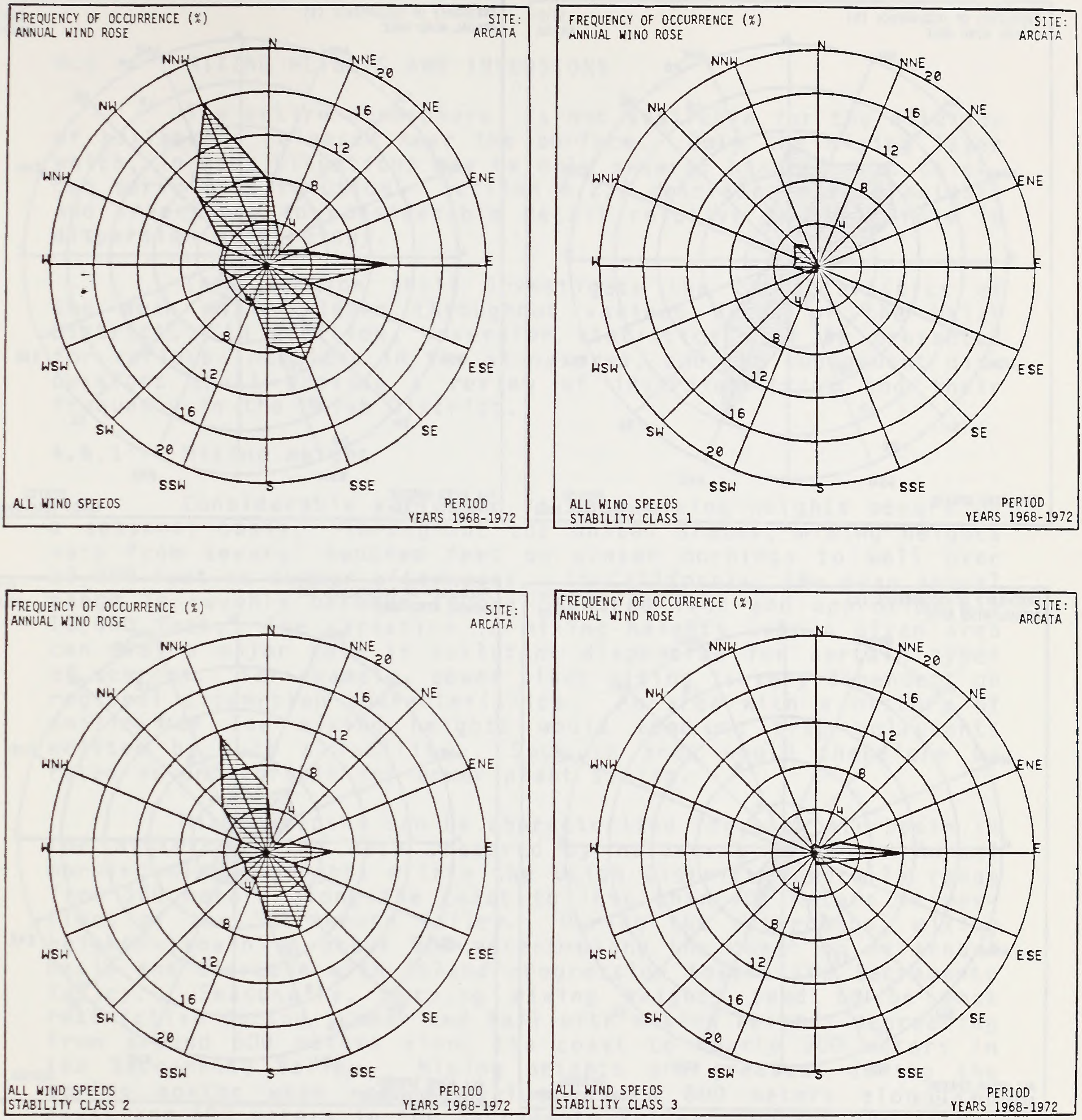

Figure 4.5-6

Stability Wind Roses for Arcata, California

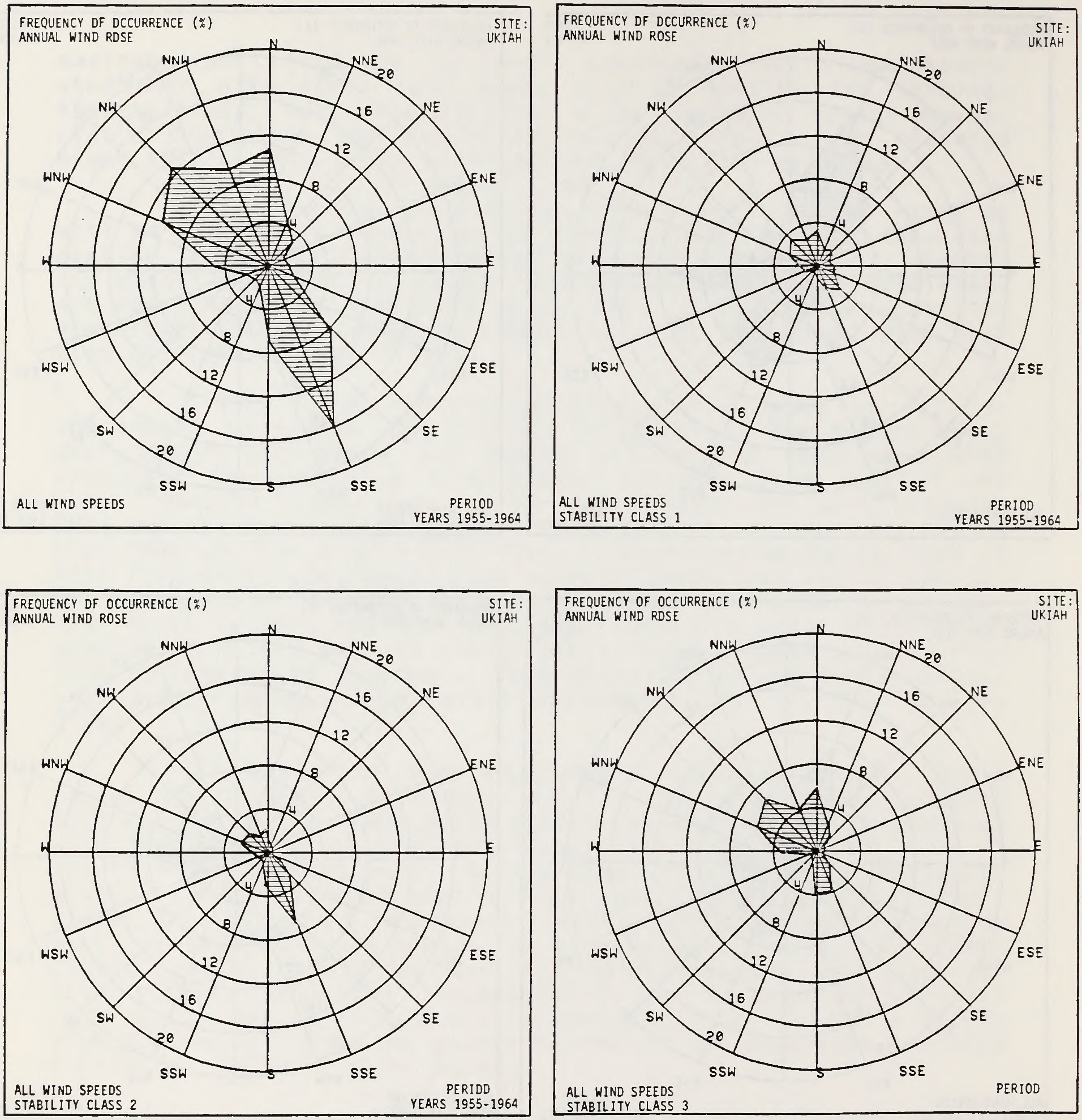

Figure 4.5-7
Stability Wind Roses for Ukiah, California

4.6 MIXING HEIGHTS AND INVERSIONS

The entire atmosphere, is not available for the dilution of pollutants released near the surface. Only the mixing layer which, in many situations may be only several hundred feet thick, can serve this function. Section 4.2.3 describes mixing heights and inversions in considerable detail relative to their role in dispersion meteorology.

This section shall investigate the characteristics of the mean mixing layer throughout various areas of the Ukiah District. In addition, inversion statistics will be presented for various locations in the study area, and the subsequent discussions shall provide a review of inversion types and their frequency in the Ukiah District.

4.6.1 Mixing Height

Considerable variation in mean mixing heights occurs on a seasonal basis. Throughout the United States, mixing heights vary from several hundred feet on winter mornings to well over 13,000 feet on summer afternoons. In California, the mean annual range is roughly between several hundred feet and approximately 10,000 feet. The variation in mixing heights over a given area can play a major role in pollutant dispersion for certain types of sources. For example, power plant siting is very dependent on regional dispersion characteristics. An area with a history of shallow or low mixing heights would tend to trap pollutants emitted by such a facility. Such an area would therefore be rated as unfavorable for power plant siting.

Mixing depths can be characterized for each air basin in the district using data prepared by Holzworth (1972). Annual morning mixing heights within the Ukiah District generally range from 500 meters along the coast to less than 400 meters in portions of the Sacramento Valley. During the afternoons, mixing heights remain at about 500 meters along the coast on an annual basis and decrease with inland progression toward the Sacramento Valley. Seasonally, morning mixing heights tend to be most restrictive during summer and fall with mixing heights decreasing from around 500 meters along the coast to nearly 300 meters in the Sacramento Valley. Mixing heights are greatest during the spring months when morning values reach 800 meters along the coast and 600 meters in the Sacramento Valley. During the afternoon hours, annual mixing heights increase with progression from the coastline ranging from around 800 meters to over 1200 meters in the Sacramento Valley. Seasonally, spring is again the best season with mixing heights ranging from 1200 meter along the coast to over 1600 meters in the Sacramento Valley. A very steep gradient in afternoon mixing heights exist during the summer and fall afternoons. In summer, mixing heights range from 600 meters near the coast to 1600 meters in the Sacramento Valley. This reflects a situation where a marine air at coastal stations results in a very shallow stable layer while inland surface heating effects tend to erode the stable layer near the surface and result in ample mixing heights.

The CARB (1974) has conducted upper air observations for winds and temperatures aloft at Sacramento, Red Bluff, Salinas, Fresno, Ukiah, Thermal and Riverside. The length of the data base presented in this report is less than three years in every case. The Ukiah data provide additional information relative to mixing height characteristics in the Ukiah District. Figures 4.6-1 and 4.6-2 provide a comparison of the mean spring morning mixing heights as defined using CARB and Holzworth data, respectively. Additional data from Sacramento, Red Bluff and Ukiah provide very useful additional information for the Ukiah District. The Holzworth data which, once again, was based on a very limited availability of upper air data indicates a linear decrease of mixing heights on spring mornings from 800 meters along the coast to around 600 meters at Sacramento and Red Bluff. The ARB data, however, indicates that this is not indicative of conditions in this area. The ARB data indicates that mixing heights are on the order of 400 meters along the coastline of Mendocino County decreasing to 300 meters in the Sacramento Valley portion of the Ukiah District. Higher mixing heights are observed in the San Francisco Bay region. The CARB data provide a better resolution in the Ukiah District as they are based upon the use of available data from Ukiah, Sacramento and Red Bluff. The data are only available for the morning hours and conclusions cannot readily be made relative to the utility of the Holzworth data for the afternoon. In addition, the additional resolution provided by the CARB data is only valid for the southern portion of the district and does not provide additional clarification relative to northern portions of the district. The CARB data provides the following highlights relative to morning mixing heights in appropriate portions of the district:

(1) The lowest average mixing heights occur during the summer at Red Bluff, Ukiah and Sacramento.

(2) During other seasons, mixing heights at these locations are unremarkable.

(3) Highest average mixing heights occur at Ukiah, Red Bluff and Sacramento during winter.

Table 4.6-1 provides seasonal and annual mean morning and afternoon mixing height values for selected stations throughout the Ukiah District. It is evident from these data that mixing heights tend to be higher along the coast during the morning hours and in the interior valleys during the afternoon.

Long-term mixing height and inversion data are not currently available for the mountain areas. As a result, interpolative estimates must be made from meteorological data from nearby locations in order to provide a reasonable evaluation of mixing height levels over mountainous terrain.

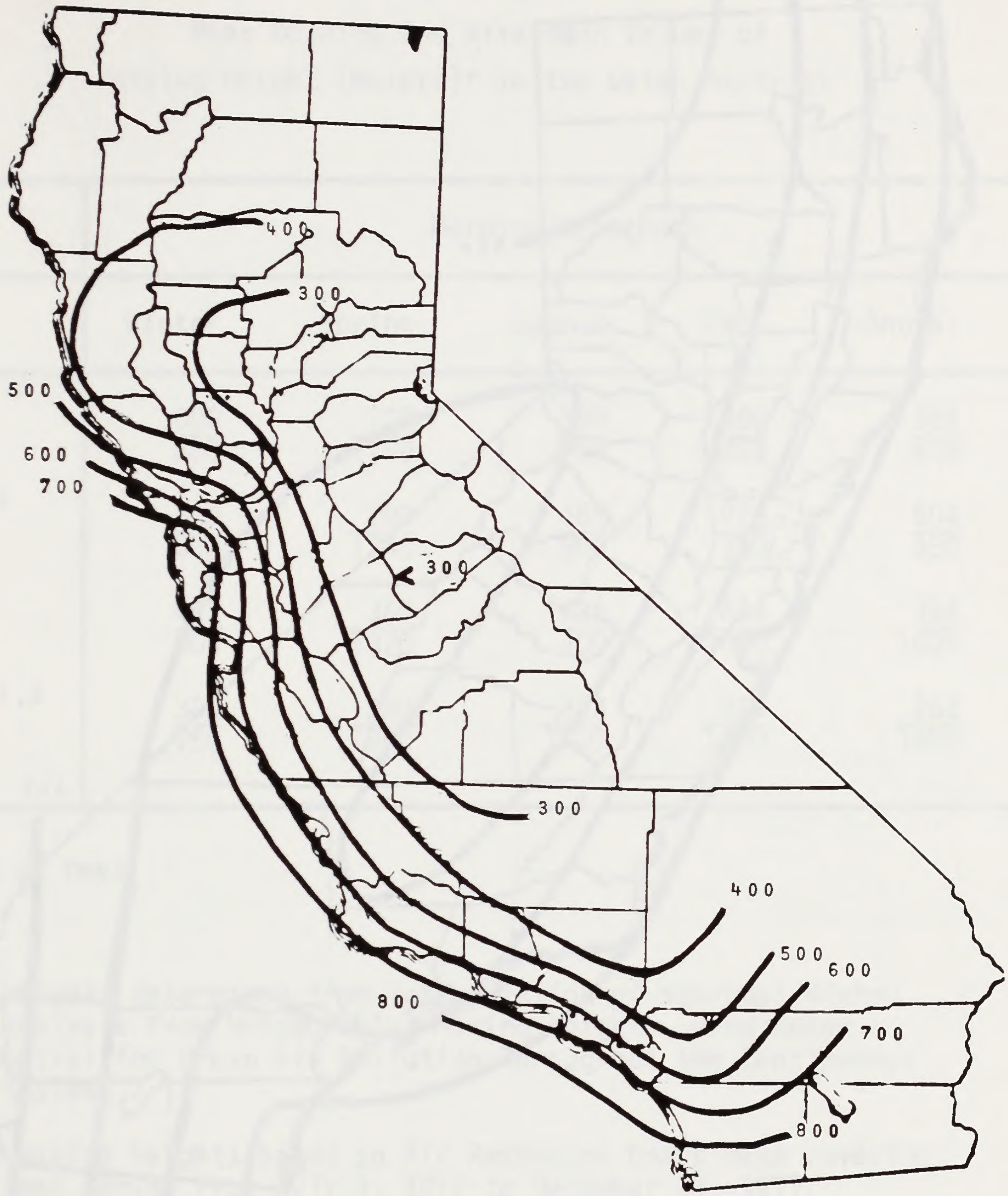

Figure 4.6-1
Isopleths of Mean Spring Morning
Mixing Heights (m) (with ARB Data)

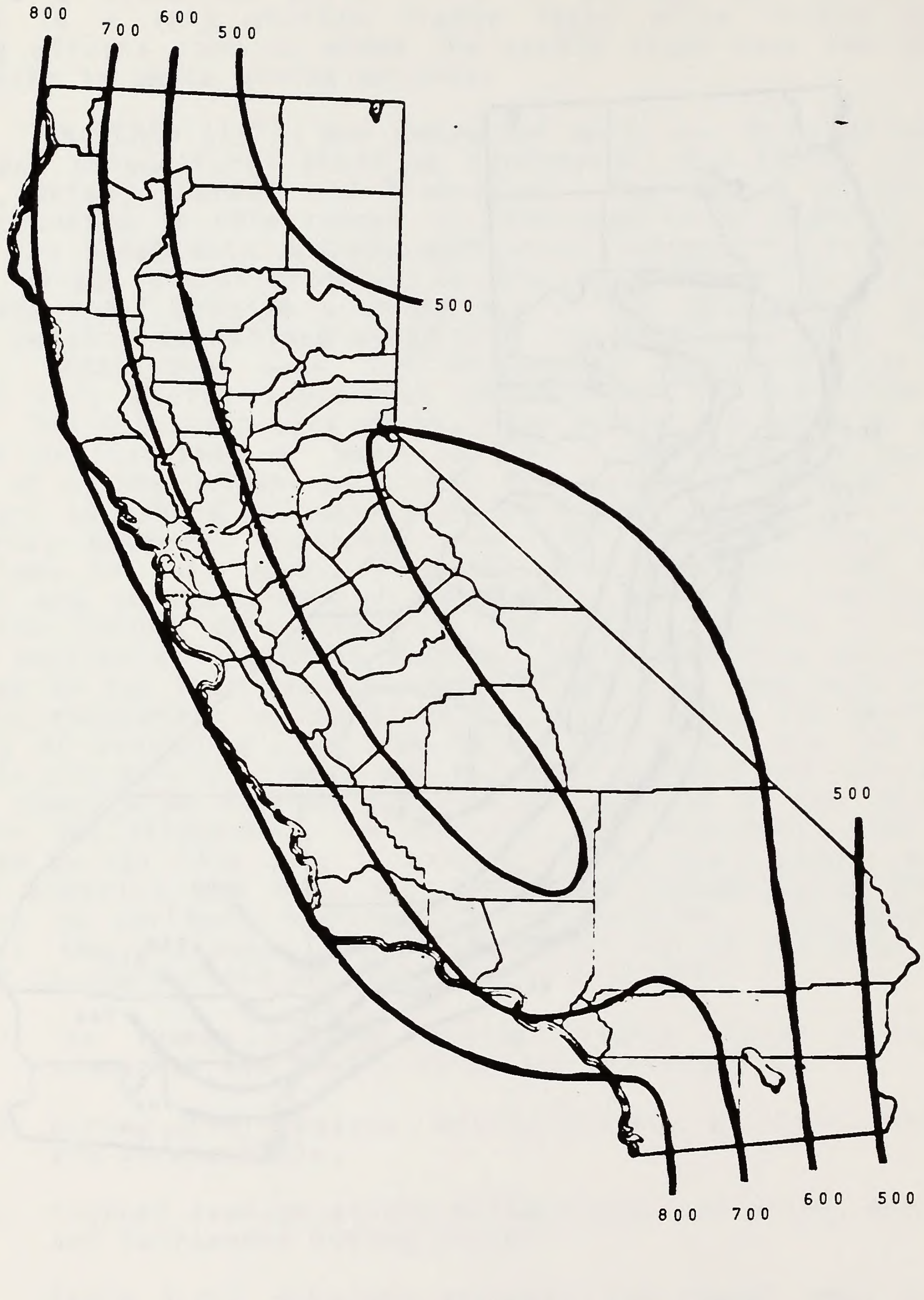

Figure 4.6-2
Isopleths of Mean Spring Morning
Mixing Heights (m) (from Holzworth)

Table 4.6-1

Mean Morning and Afternoon Values of

Mixing Height (Meters)* in the Ukiah District

	Morning/Afternoon				
	Winter	Spring	Summer	Fall	Annual
Eureka [1]	500/800	780/1150	500/700	480/850	565/875
Santa Rosa [1]	430/800	700/1240	465/800	425/960	504/950
Ukiah [1,2]	487/800	369/1320	286/900	434/1000	394/1005
Sacramento [1,2]	300/950	282/1900	223/1700	249/1400	263/1488

* meter = 3.28 feet

1. Mixing heights determined from interpolation of seasonal mixing height analysis from Holzworth's "Mixing Heights, Wind Speed, and Potential for Urban Air Pollution Throughout the Continguous United States".

2. Morning mixing heights based on Air Resources Board data covering a five year period from July 1, 1972 to December 31, 1977.

The steepness of windward mountain slopes and numerous meteorological parameters such as wind velocity, wind direction and atmospheric stability impact mixing height depths and their variability over rugged complex terrain. Figures 4.6-3 through 4.6-5 illustrate mixing layer alterations due to mountain flow for three hypothetical scenarios which vary atmospheric stability. As depicted in Figure 4.6-3, when the lower atmosphere is neutrally stratified, the inversion layer, which is the major determinant of the local mixing depth, tends to follow the contour of the local terrain. Hence, mixing height depths, as defined earlier, remain unchanged or tend to be slightly shallower over the mountainous area.

On the other hand, when a stable surface air mass is capped by an elevated inversion and is forced to rise over abrupt mountainous terrain, considerable variations in the characteristic mixing depth develop. The low lying, stable air is not easily displaced upward and over the mountain ridge; consequently, the surface air mass tends to pile up along the windward mountain slopes, thus forming a bulge in the atmospheric mixing layer just upwind of the mountain ridge. Under these conditions, as depicted in Figure 4.6-4, the mixing depth tends to be larger along the windward slope than along the valley floor or the leeward side of the mountain range.

Figure 4.6-5 presents the situation in which a surface unstable layer is isolated from the upper atmosphere by a lifted inversion. As flow moves over rugged terrain, dramatic changes in the mixing layer can occur. Basically, the low lying, unstable air is forced to ascend into and through the inhibiting inversion layer as surface air flow is swept up the steep western slopes of the Coast Ranges. This forced convective activity sometimes has the potential to completely wipe out the local inversion layer (or considerably weaken the stable layers) thus promoting considerable mixing of the lower lying air masses. Under such conditions, considerable cloudiness can develop and, at times, much precipitation. This is indicative of summer season conditions resulting in convective thundershower activity. As the flow passes over the mountain ridge and descends down the leeward slopes, the stable layer can once again develop.

The above discussion qualitatively depicts mean mixing height characteristics when flow is forced over mountainous terrain features such as the Coast Ranges. However, definitive analyses are needed to support the qualitative review presented for this area. Therefore, estimates and assessments of mixing layer depths over these areas are presently best determined by (1) the Holzworth document entitled: "Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States" and (2) the CARB data summarized in "Meteorological Parameters for Estimating the Potential for Air Pollution in California." Seasonal and annual mixing depth contour maps provided by the Holzworth publication are depicted

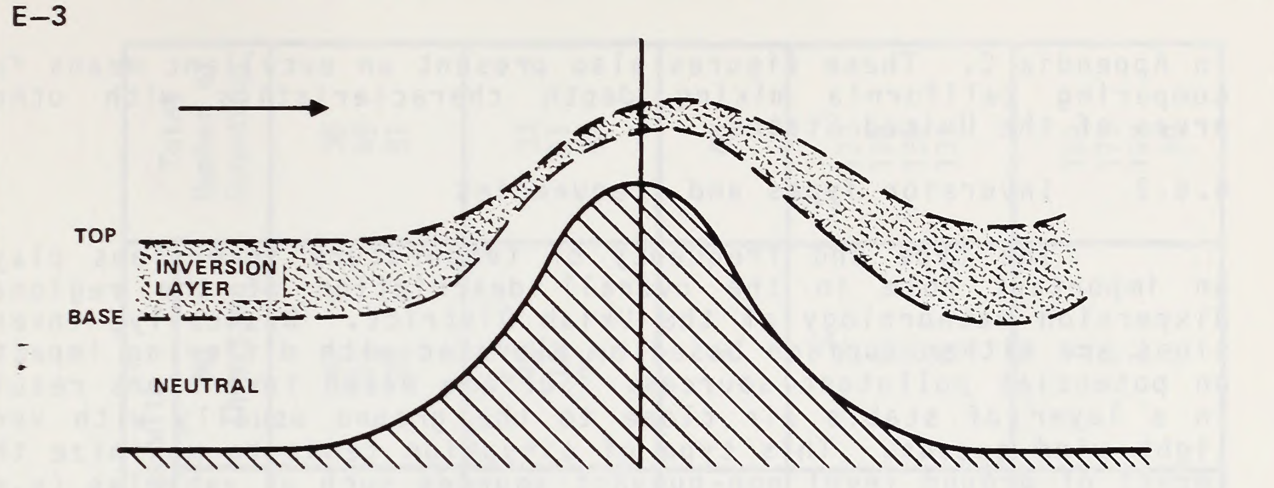

Figure 4.6-3
Depth of the Mixing Layer in Mountainous Terrain with Neutral Flow

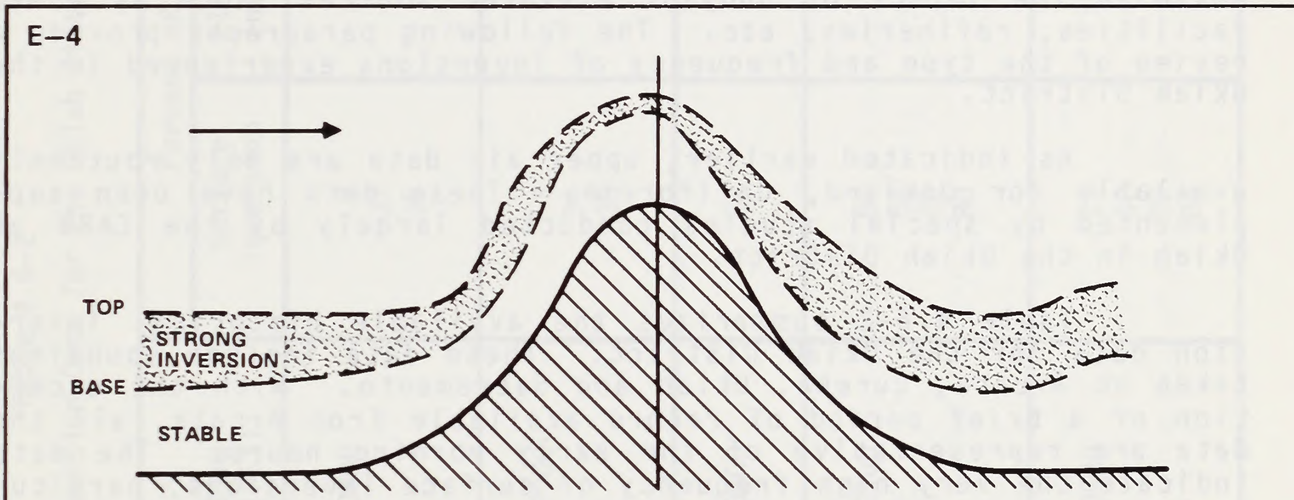

Figure 4.6-4
Depth of the Mixing Layer in Mountainous Terrain with Stable Flow

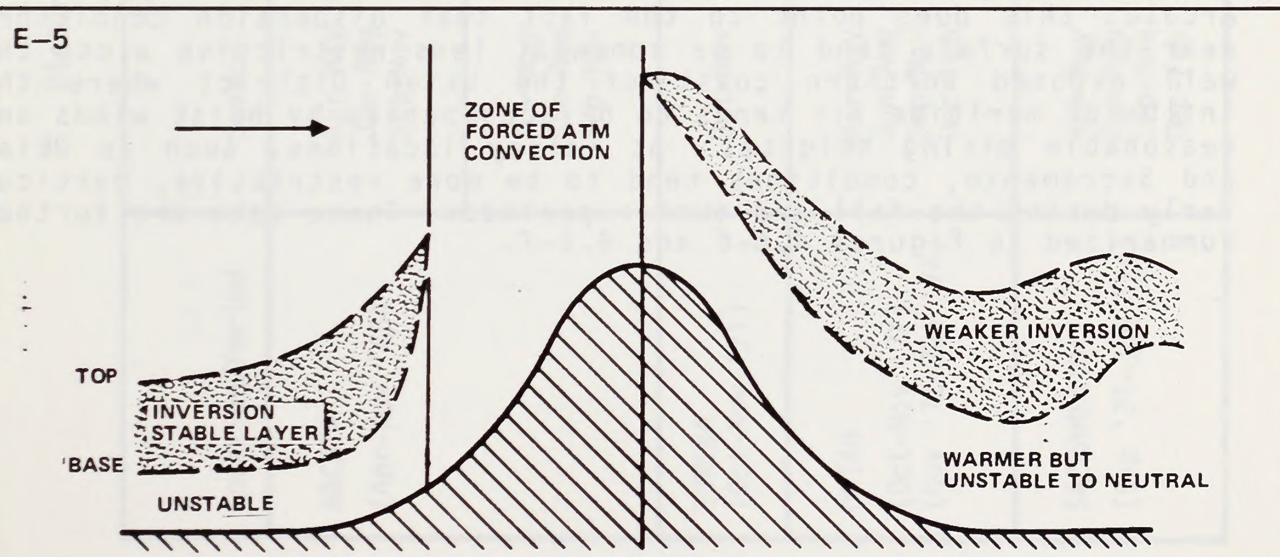

Figure 4.6-5
Depth of the Mixing Layer in Mountainous Terrain with Unstable Flow

in Appendix C. These figures also present an excellent means for comparing California mixing depth characteristics with other areas of the United States.

4.6.2 Inversion Types and Frequencies

The type and frequency of temperature inversions plays an important role in the overall description of the regional dispersion meteorology of the Ukiah District. Basically, inversions are either surface based or elevated with differing impacts on potential pollutant sources. Surface based inversions result in a layer of stable air close to the ground usually with very light wind speeds. This type of situation tends to maximize the impact of ground level non-buoyant sources such as vehicles (e.g. off road vehicles [ORV]) and fugitive sources (e.g. storage tanks, dirt roads, etc). Elevated inversions tend to limit the volume of air available for the mixing of pollutants and tend to maximize the impact of buoyant elevated sources, such as power facilities, refineries, etc. The following paragraphs provide a review of the type and frequency of inversions experienced in the Ukiah District.

As indicated earlier, upper air data are only routinely available for Oakland, California. These data have been supplemented by special studies conducted largely by the CARB at Ukiah in the Ukiah District.

Table 4.6-2 summarizes the available historical inversion data for the Ukiah District. These data include soundings taken at Arcata, Eureka, Ukiah and Sacramento. With the exception of a brief period of record available from Arcata, all the data are representative of the early morning hours. The data indicate the very high frequency of surface inversions, particularly at Ukiah and Sacramento. The frequency of times when there were no inversions present is quite rare with the exception of Arcata. At Arcata, no inversions existed during a substantial number of soundings. While the period of record is brief at Arcata, this does point to the fact that dispersion conditions near the surface tend to be somewhat less restrictive along the well exposed northern coast of the Ukiah District where the influx of maritime air tends to be accompanied by brisk winds and reasonable mixing heights. At valley locations, such as Ukiah and Sacramento, conditions tend to be more restrictive, particularly during the fall and summer periods. These data are further summarized in Figures 4.6-6 and 4.6-7.

Table 4.6-2
Historical Inversion Data for the Ukiah District

Location/Period	Season	Time (PST)	Percent of Soundings with: Surface Inversion	Elevated Inversion	No Inversion	Total Number of Soundings
ARCATA (Apr-Nov '45)	Apr-May	0800	3	50	47	38
	Jun-Aug		37	51	12	49
	Sep-Nov		35	37	28	51
	Apr-May	2000	3	52	45	33
	Jun-Aug		31	53	16	51
	Sep-Nov		36	39	25	44
EUREKA (Oct-Nov '71)	Oct-Nov	0600	82	15	3	40
UKIAH (Oct-Nov '71) (Nov '72-Jun '74)	Mar-May	0500	87	11	2	173
	Jun-Aug		84	16	0	119
	Sep-Nov		89	9	2	129
	Dec-Feb		80	20	0	131
SACRAMENTO (Sep '71-Jun '74)	Mar-May	0500	72	27	1	169
	Jun-Aug		52	48	0	175
	Sep-Nov		82	17	1	192
	Dec-Feb		84	16	0	89

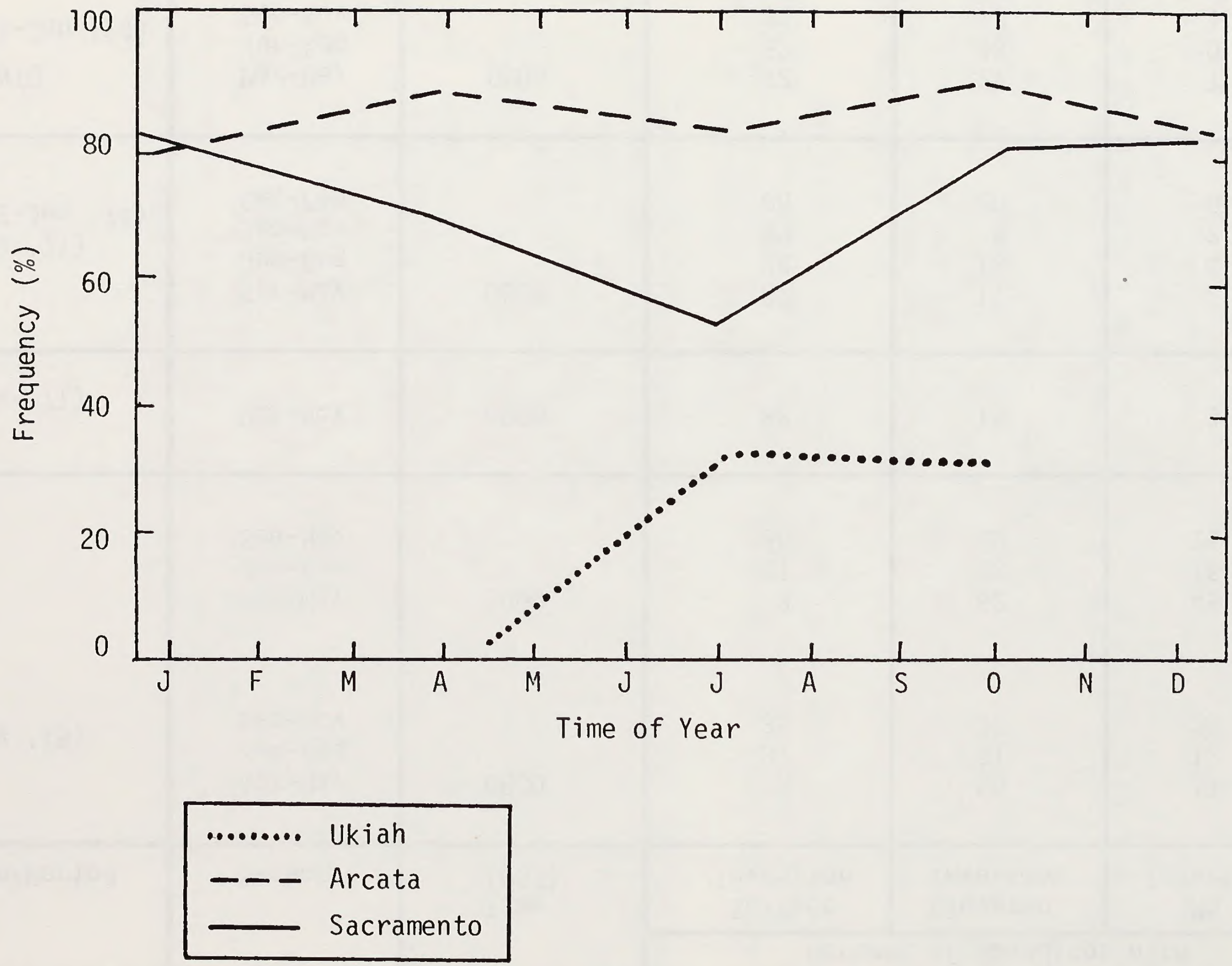

Figure 4.6-6
Seasonal Frequency of Surface Based Inversions in the
Ukiah District During the Morning Hours

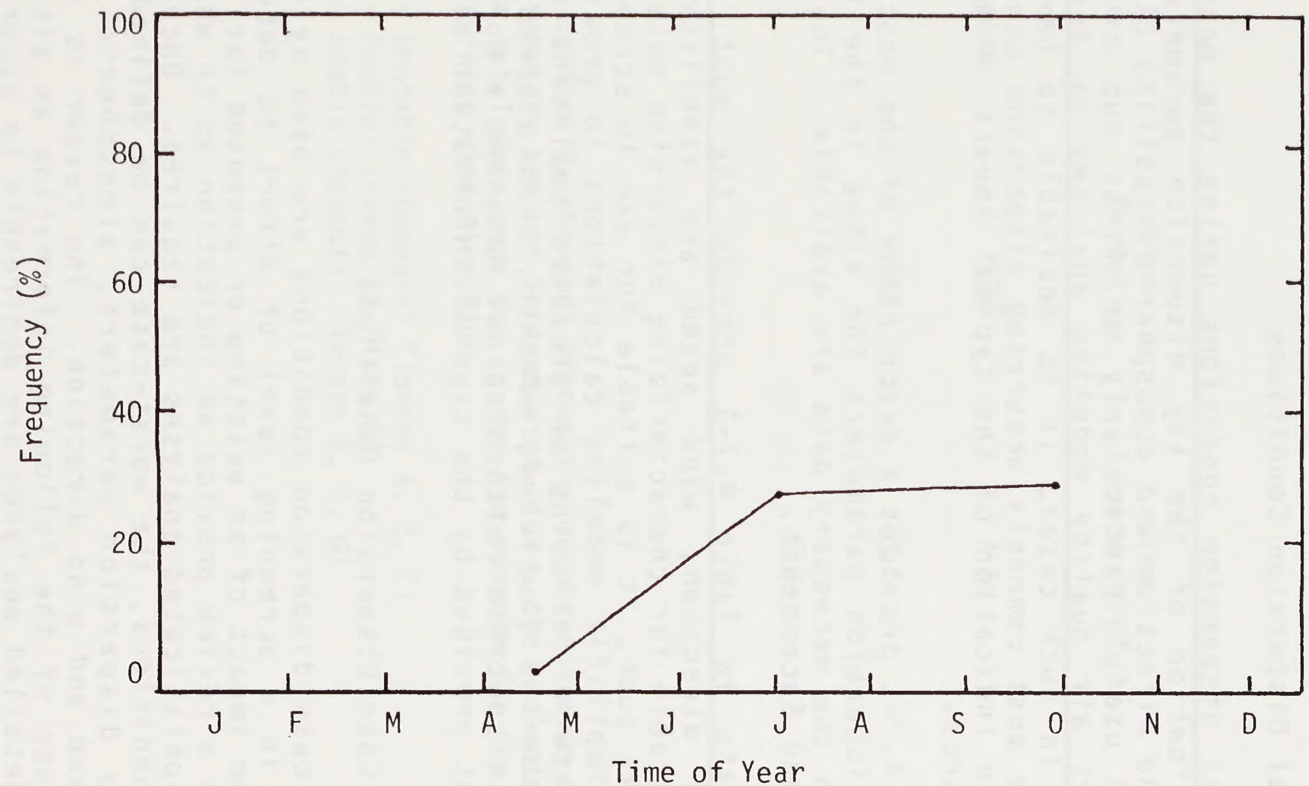

Figure 4.6-7
Seasonal Frequency of Elevated Inversions at Arcata
During the Afternoon Hours

4.7 TYPICAL AND WORST-CASE CONDITIONS

Previous sections have thoroughly examined and discussed the factors affecting the atmospheric dispersion characteristics of the Ukiah District. This permits the identification of typical and worst-case conditions for a variety of typical sources found in the Ukiah District. This analysis will provide a basis for determining an initial evaluation of the typical and worst-case impact of various land use alternatives using simplistic modeling techniques as described in Section 4.9.

4.7.1 Typical Dispersion Conditions

Typical dispersion conditions define the most commonly occurring combination of the key dispersion parameters, i.e., wind speed, wind direction and atmospheric stability class. This information is useful particularly in first cut or screening level of effort air quality modeling analyses as described in Section 4.9. In such cases, it is desirable to have a rough estimate of the most commonly occurring dispersion conditions in order to get an indication of the typical impact of an existing or proposed source.

Table 4.7-1 provides a description of the most frequently occurring dispersion parameters for sites in the Ukiah District for which the necessary data are available. These include Ukiah, Arcata and Sacramento.

The data in Table 4.7-1 provide the most frequently occurring wind direction, wind speed and stability category information suitable for characterizing dispersion meteorological conditions. As such, it is suitable for use in screening level of effort or simplistic modeling calculations to provide a preliminary estimate of existing or proposed pollutant source impacts. The reader is cautioned, however, that dispersion analyses require site specific meteorological data and a more thorough review than that provided by the type of information contained in the table.

4.7.2 Worst-Case Dispersion Conditions

Worst-case dispersion conditions are used by dispersion meteorologists in a screening level of effort to determine the probable maximum impact of an existing or proposed facility. The results of such a review provide an indication as to whether more detailed and sophisticated analyses are required. Once again, as with typical conditions, the worst-case can be defined in terms of the primary dispersion parameters, atmospheric stability class, wind speed and wind direction. The reader is again cautioned in the use of the following information as site-specific data and more detailed analyses are desireable to accurately gage pollutant impact.

Table 4.7-1

Description of Typical Meteorological Conditions [1]

Throughout the Ukiah District

Station	Wind Direction	Wind Speed (MPH)	Stability Category (2)
Sacramento	SSW	7.5	3
Ukiah	SSE	3.6	3
Arcata	E	6.8	2

1. As defined by the most frequently occurring value on an annual basis - parameters are not interrelated, i.e., the indicated wind speed is for the total data base and is not the average for the most frequently occurring wind direction.

2. 1 - Unstable (Pasquill Classes A, B, C)
   2 - Neutral (Pasquill Class D)
   3 - Stable (Pasquill Classes E, F, G)

In an effort to identify the historical worst-case conditions occurring in California, it was necessary to create a table of five pollutant sources with typical exit characteristics. Table 5.4-1 summarizes typical emission characteristics for fugitive dust, automobiles, oil recovery operations, oil refineries and large power plants. In addition, a traditional worst-case scenario often used by dispersion meteorologists is described. Although the primary pollutants generated from each of these sources may vary, the short-term characteristics of these gases and/or particulates in the atmosphere may be assumed to be highly similar. The five sources listed in Table 5.4-1 represent ground level, non-buoyant; ground level, slightly buoyant; low-level, buoyant; intermediate-level, buoyant; and elevated, buoyant emissions, respectively. Table 4.7-2 lists the worst-case dispersion conditions for each of these sources.

Table 4.7-3 provides the annual frequency of the selected worst-case scenarios for stations throughout the Ukiah District. The table indicates that the selected scenarios for the cross section of sources occur with considerable variability across the area. In addition, the frequency of the scenario selected for one type of source may occur with a substantially different frequency than that selected for another source. This highlights the importance of attaching the probability of occurrence to the selected worst-case meteorological condition for the source in question and the need to involve professional dispersion meteorologists in such programs.

Mixing height, an important parameter in the definition of both typical and worst-case conditions has not been included in the above analysis. This is often difficult to do as real time mixing height data are not generally available concurrently with surface wind speed, wind direction and atmospheric stability class data to provide for meaningful analysis. However, typical mixing heights can be obtained from the data presented in Section 4.6.1, while historical worst-case mixing heights are discussed by Holzworth in his publication "Meteorological Episodes of Slowest Dilution in Contiguous United States".

Table 4.7-2
Worst-Case Dispersion Conditions
For a Cross-Section of Typical Sources

Source[1]	Wind Speed (MPH)	Stability Class (Pasquill Class)[2]
Fugitive Dust	1.1	D
Automobiles	1.1	D
Oil Recovery Operations	26.8	C
Oil Refinery	6.7	A
Power Plant	6.7	A
Traditional[3] Worst-Case	2.3	F

1. Reference Table 5.4-1 for a description of the exit characteristics for the sources listed below.

2. Section 4.5 provides a complete discussion of atmospheric stability.

3. In theoretical or "back of the envelope" calculations, this case is often used by meteorologists to describe worst-case conditions.

Table 4.7-3

Annual Frequency (%) of Worst-Case Meteorological Conditions (1)

Throughout the Ukiah District

Worst-Cast Condition (St.Class/Wind Speed(MPH)	Arcata	Ukiah	Sacramento
F and 2.3	10.0	36.0	13.9
D and 1.1	13.0	9.4	2.9
C and 26.8	Neg.+	0.0	Neg.+
A and 6.7	0.2	0.8	0.6

1. As defined for the sources indicated in Table 4.7-2 and described in Table 5.4-1

\+ Neg. = Negligible but non-zero

4.8 AIR BASIN ANALYSIS

The State of California encompasses an extremely large land area which exhibits a wide variety of geographic and topographic features (see Section 2). As air masses migrate into California, the prevailing winds and dispersion characteristics are greatly influenced by terrain. The degree and nature of the influence can be characterized for geographically and/or meteorologically homogeneous areas. Such zones of similar atmospheric dispersion characteristics can be identified as air basins. Figure 4.8-1 provides the results of an air basin analysis for California while Figure 4.8-2 presents a summary map of the air basins located within the Ukiah District of California. The figures represent an original analysis independent of political boundaries and are, therefore, slightly different than the CARB air basin map for the State. The latter figure is also provided as Overlay F.

Air basins provide a means of isolating particular areas of the state that generally exhibit similar atmospheric flow, ventilation mechanisms and dispersion potential. As presented in the figure, these areas include:

- North Coastal Air Basin
- North Coastal Mountain Air Basin
- North East Hills Air Basin
- Mountain Area Air Basin
- Sacramento Valley Air Basin
- San Joaquin Valley Air Basin
- San Francisco Bay Area Air Basin
- Central Coast Air Basin
- Central Coastal Mountains Air Basin
- South Coastal Air Basin
- South Coastal Mountains Air Basin
- Great Basin Valley Air Basin
- South East Desert Air Basin

The development and use of an air basin classification scheme requires one to visualize the atmosphere as a moving fluid washing over mountain ridges and spilling into valleys and through canyon areas. As indicated above, physically and meteorologically homogeneous areas can be then identified and used in dispersion analyses. Regional terrain characteristics generally establish the boundaries of such areas. Terrain features are dominant in establishing air basins as mountain ranges and valleys obstruct or alter regional flow and, hence, dispersion conditions. Figure 4.8-1 illustrates the importance of terrain features in defining meaningful air basins.

While air basins are characteristically defined by major regional terrain features, the climatological and dispersion meteorological conditions existing in the area in question also provide considerable information relative to the identification of homogeneous air basins. An area can be homogeneous from a

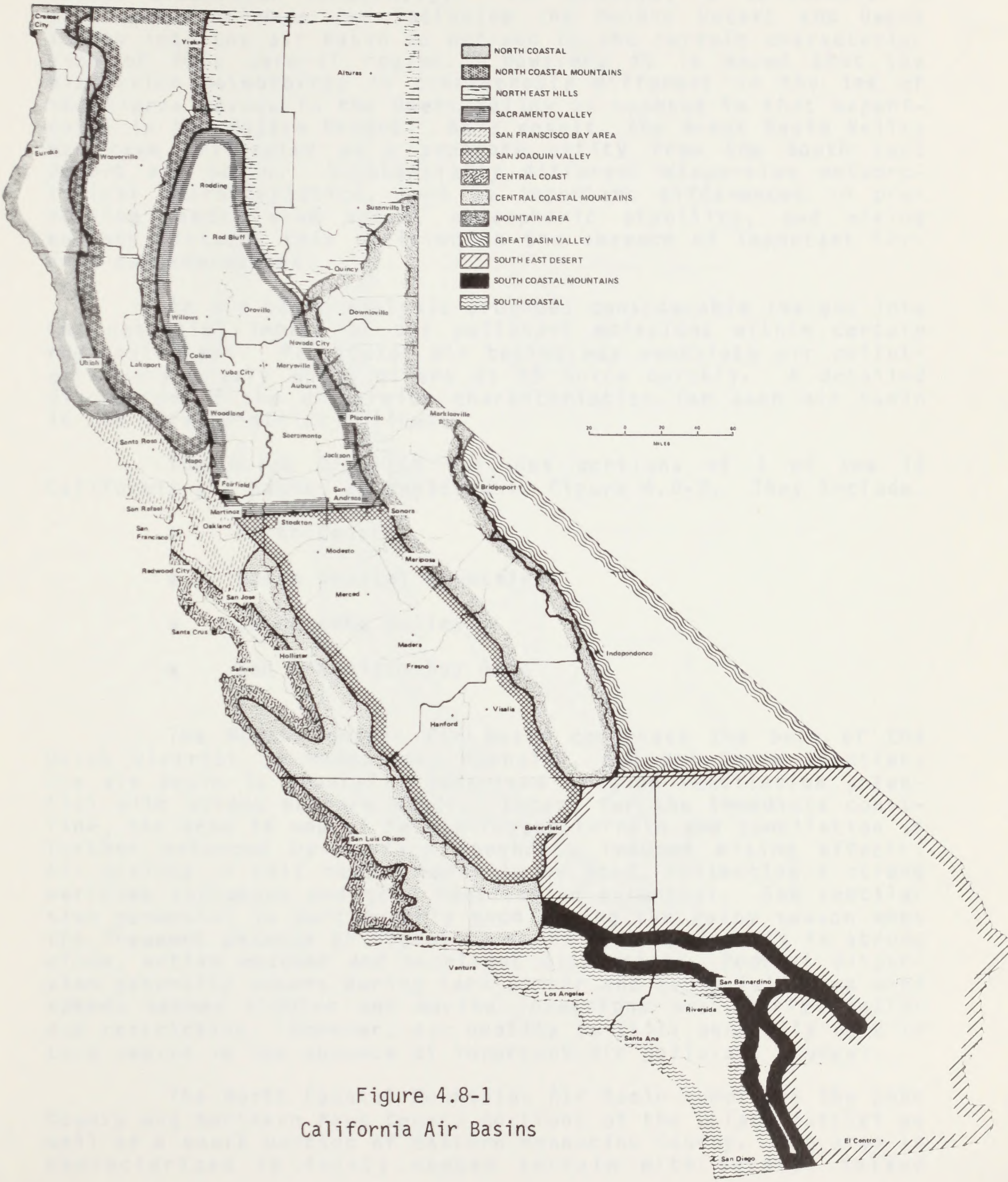

Figure 4.8-1

California Air Basins

terrain standpoint but may vary significantlly in terms of the actual dispersion meteorology. For example, in California, a case could be made for including the Mojave Desert and Owens Valley into one air basin as defined by the terrain characteristics of this general region. However, it is known that the dispersion meteorology is considerably different in the lee of the Sierra Nevada in the Owens Valley as opposed to that experienced in the Mojave Desert. As a result, the Great Basin Valley has been delineated as a separate entity from the South East Desert air basin. Substantially different dispersion meteorological characteristics, such as important differences in prevailing winds, wind speed, atmospheric stability, and mixing heights dictated this decision in the absence of important terrain considerations.

An air basin analysis provides considerable insight into the potential impact of air pollutant emissions within certain regional areas. Particular air basins may ventilate air pollutants very slowly while others do so quite quickly. A detailed discussion of the dispersion characteristics for each air basin in the Ukiah District follows.

The Ukiah District includes portions of 4 of the 13 California air basins as depicted in Figure 4.8-2. They include:

- North Coastal
- North Coastal Mountains
- Sacramento Valley
- San Francisco Bay Area

The North Coastal Air Basin comprises the bulk of the Ukiah District in Mendocino, Humboldt, and Del Norte Counties. The air basin is generally comprised by good ventilation potential with strong onshore winds. Except for the immediate coastline, the area is one of fairly rugged terrain and ventilation is further enhanced by surface roughness induced mixing effects. Air quality in this region tends to be good, reflecting a strong maritime influence and good ventilation potential. The ventilation potential is particularly good during the rainy season when the frequent passage of migratory storm systems results in strong winds, active weather and excellent dispersion. Poorest dispersion generally occurs during late summer and early fall when wind speeds become lighter and marine inversions are fairly shallow and restrictive. However, air quality is still generally good in this region in the absence of important air pollutant sources.

The North Coastal Mountains Air Basin comprises the Lake County and Northern Napa County portions of the Ukiah District as well as a small portion of eastern Mendocino County. The area is characterized by fairly rugged terrain with several inland terrain standpoint but may vary significantly in terms of the actual dispersion meteorology. For example, in California, a case could be made for including the Mojave Desert and Owens Valley into one air basin as defined by the terrain characteristics of this general region. However, it is known that the dispersion meteorology is considerably different in the lee of the Sierra Nevada in the Owens Valley as opposed to that experienced in the Mojave Desert. As a result, the Great Basin Valley has been delineated as a separate entity from the South East Desert Air Basin. Substantially different dispersion meteorological characteristics, such as important differences in prevailing winds, wind speed, atmospheric stability, and mixing heights dictated this decision in the absence of important terrain considerations.

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The North Coastal Mountains Air Basin comprises the Lake County and Northern Napa County portions of the Ukiah District as well as a small portion of eastern Mendocino County. This area is characterized by fairly rugged terrain with strongly defined

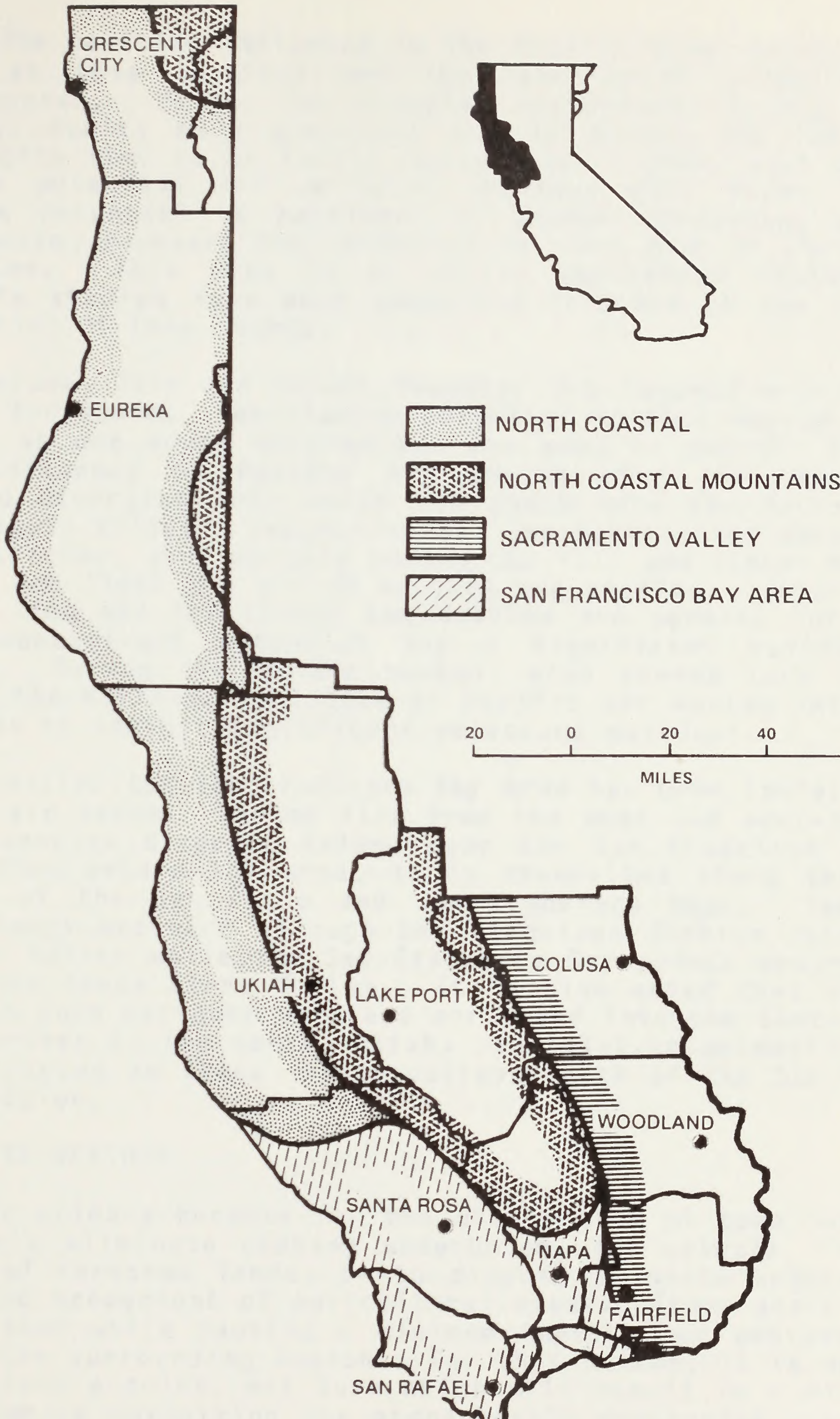

Figure 4.8-2
Air Basins in the Ukiah District

valleys. The maritime influence in the Pacific Ocean tends to be decreased at this location and the ventilation potential is slightly poorer. Ukiah, for example, experiences fairly light wind speeds during many occasions and in summer and fall the mixing heights tend to be fairly restrictive. Under such conditions, the potential for pollutant buildup does exist. The ventilation potential is excellent at higher elevations within this air basin, however, the potential is very poor at sheltered valley sites. This area is an active geothermal region and considerable studies have been conducted relative to the pollution potential of Lake County.

Colusa, Yolo and Solano Counties are located within the Sacramento Air Basin. Ventilation potential in this region tends to improve as one moves northward. The area is subject to the maritime influence of Pacific Air moving into the Carquinez Straits and diverging both north and south into the Sacramento and San Joaquin Valleys, respectively. The ventilation potential can be restricted, particularly during the fall and winter months when winds are light and mixing heights are shallow. Under such conditions, fog and low clouds can develop and persist for days with the concomitant potential for a significant buildup of pollutants. During the summer season, wind speeds tend to be strong and the maritime influence of Pacific air moving into the region tends to inhibit significant pollutant buildups.

Finally, the San Francisco Bay Area has been isolated as a separate air basin. Marine flow from the west and west-northwest is channeled directly inland over the San Francisco area. As marine flow enters the area, it is channelled along the two major axes of the San Paolo and San Francisco Bays. The San Paolo Bay loops eastward through the Carquinez Straits into the San Joaquin Valley while the San Francisco Bay points southeastward into the Santa Clara Valley. It is also noted that marine air tends to turn northwestward and northward into the Santa Rosa area and further to the north, Ukiah. Ventilation potential can become restricted in these inland valleys north of the San Francisco Bay region.

4.9 FIRE WEATHER

The primary purpose for the utilization of open burning is to quickly eliminate choking underbrush, for example, in the management of forested lands, or to dispose of waste vegetative growth in the management of agricultural areas. These goals must be accomplished while causing a minimum impact upon ambient air quality in the surrounding region. For this reason, it is desirable to achieve a quick, hot burn which will result in a minimum burn time, while maximizing the atmosphere's dispersive capabilities by getting the resulting smoke well above the surface layer.

Meteorology plays a very important role in the identification of proper periods during which to burn with a minimum impact on surrounding air quality. Burn versus no-burn days are forecasted daily by the CARB for each of the designated air basins in California. Forecasts for the following day are usually available by 1500 PST. If the issuance of a forecast is delayed, they are to be available by no later than 0745 PST on the day in question. The CARB uses some very basic criteria in making decisions relative to open burning in each of California's air basins. The forecasting criteria are designed to isolate those days on which the burning of large surface areas will have a minimum impact on local air quality, based upon the atmosphere's ability to disperse pollutants. Factors which impact this are the stability of the atmosphere, the presence of either surface or elevated inversions and the mean wind speed and wind direction. Previous sections have provided a review of the dispersion meteorology of the Ukiah District and reference is made to that discussion for more details relative to these parameters.

The dispersion of smoke generated from open burning is restricted by such features as stable atmospheric conditions, an elevated inversion which restricts the volume of air available for mixing, as well as low wind speeds which result in little movement of the pollutants once they are emitted. These meteorological considerations work hand in hand with the nature of the local terrain. Areas which are in a valley or a bowl and are surrounded by important terrain features tend to trap emitted pollutants near the source particularly when restrictive meteorological conditions combine with such terrain effects. Accordingly, the CARB forecasting criteria include a review of the anticipated strength of the morning surface inversion, the relative stability of the atmosphere from the surface to roughly 3,000 feet, the wind speed at the expected plume height, as well as the probable wind direction. Burning is not permitted on days when wind speeds are light, the atmosphere is stable, strong surface or elevated inversions exist, or if wind directions will tend to blow smoke toward populated areas.

Section 6.5.2 will provide a review of the regulatory constraints involved in open outdoor burning including the acquisition of permits. Once a permit is obtained, the basic decision whether or not to burn is based upon acquiring the burn/no-burn forecast from the CARB in Sacramento. In addition to this, local rules of thumb should be used to provide proper management of the burn in terms of meteorological conditions. The following provides an example of typical considerations:

- The wind direction at the probable plume height should be such that the plume will move away from Smoke Sensitive Areas (SSA). The California Division of Forestry (CDF) has designated SSA's in California which should not be impacted by any burn contemplated by BLM managers. Figure 4.9-1 provides a review of the location of such areas in the state. These regions include most of the populous areas of the state, as well as areas in rugged terrain subject to considerable recreational use.

- Low wind speeds should be avoided, particularly where SSA's may be impacted.

- Wind speeds should generally be greater than 15 miles per hour to maximize dispersion.

- Surface inversions should be avoided due to the potential for trapping the smoke near the surface. However, if the plume is carried above the inversion, the downward dispersion of contaminants will be inhibited by the surface based inversion.

- If the burn will be less than 12 hours, it is beneficial to start in the morning as this will tend to maximize the buoyant effects associated with the burn.

- If the burn is to last more than 12 hours, it may be beneficial to start at night as this may minimize adverse smouldering effects, experienced following the burn.

- Burning in precipitation is advantageous from an air quality viewpoint as much of the contaminants will tend to be washed out of the plume.

- Burning should not be conducted when visibility is less than 11 miles at the site or at a nearby SSA.

- Burning should never be conducted when fire danger exists and the manager should be cognizant of forest fire weather forecasts provided by the NWS.

- The manager should be able to respond to deteriorating conditions so that the burn can be downgraded should dispersion conditions become poor.

- Unlimited burning is never recommended unless the wind direction is away from a SSA, or a SSA is located more than 100 miles away, or if the burn is to be conducted during precipitation. Even in these instances, a quota should be established for the amount of dry fuel to be burned during the day.

- Burning should not be conducted when the wind direction will result in the movement toward a SSA if the area is within 30 miles.

[illegible] (Figure 4.1) [illegible] a review of the [illegible] areas [illegible] including [illegible] of the [illegible] scale, [illegible] as well as [illegible] to [illegible] local [illegible].

- [illegible] should be [illegible], particularly [illegible].

- Wind speeds should generally be greater than 10 miles per hour [illegible].

- Surface inversions [illegible] should be [illegible] the [illegible]. [illegible] of the [illegible] will [illegible] of the surface [illegible] inversion.

- If the burn will be less than 12 hours, it is [illegible] to start in the morning as this will [illegible] with the [illegible].

- If the burn [illegible] more than 12 hours, it may be beneficial to start at night so that [illegible] experienced [illegible].

- [illegible] from [illegible] of the [illegible] will [illegible] of the [illegible].

- Burning is not [illegible] when visibility [illegible] is less than [illegible].

- Burning should not be conducted when fire weather [illegible] and the [illegible]. Forest fire weather forecasts provided by the [illegible].

- The [illegible] should [illegible] to [illegible] conditions so that the burn can be done [illegible] should [illegible] conditions [illegible].

- [illegible] winds [illegible] from [illegible] or if the [illegible] during [illegible]. [illegible] these [illegible], a [illegible] should be established for the [illegible] of [illegible] during the day.

- Burning should not be conducted when the wind direction will result in [illegible] of the area [illegible] miles.

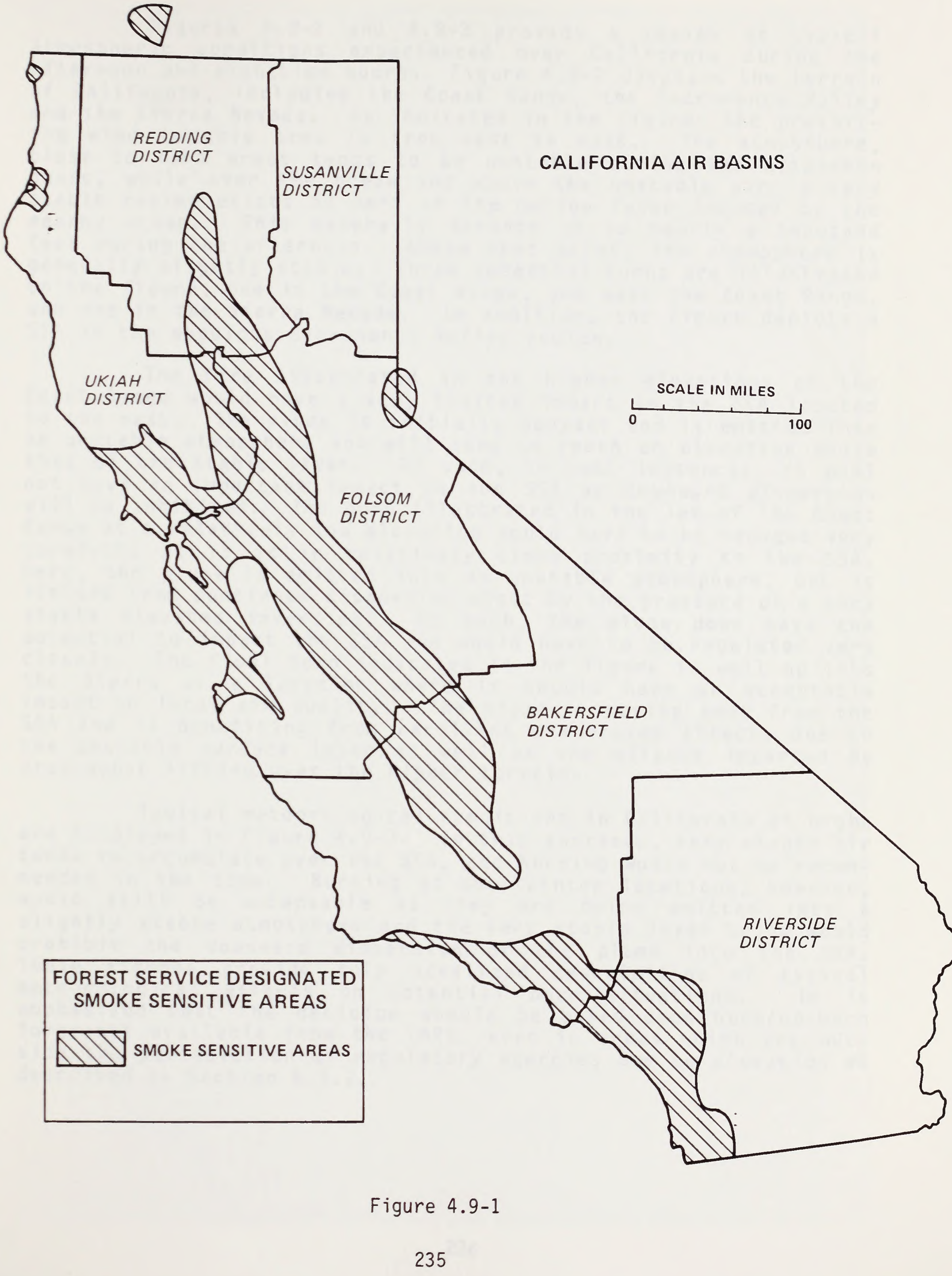
CALIFORNIA AIR BASINS
REDDING DISTRICT
SUSANVILLE DISTRICT
UKIAH DISTRICT
FOLSOM DISTRICT
BAKERSFIELD DISTRICT
RIVERSIDE DISTRICT
SCALE IN MILES
0
100
FOREST SERVICE DESIGNATED SMOKE SENSITIVE AREAS
SMOKE SENSITIVE AREAS

Figure 4.9-1

Figures 4.9-2 and 4.9-3 provide a review of typical atmospheric conditions experienced over California during the afternoon and nighttime hours. Figure 4.9-2 displays the terrain of California, including the Coast Range, the Sacramento Valley and the Sierra Nevada. As indicated in the figure, the prevailing wind in this area is from west to east. The atmosphere, close to land areas tends to be unstable during the afternoon hours, while over the ocean and above the unstable air, a very stable regime exists as part of the marine layer induced by the nearby ocean. This generally extends up to nearly a thousand feet during the afternoon. Above that point, the atmosphere is generally slightly stable. Three potential burns are illustrated on the figure; one in the Coast Range, one near the Coast Range, and one in the Sierra Nevada. In addition, the figure depicts a SSA in the populous Sacramento Valley region.

The fire illustrated in the higher elevations of the Coast Range would have a very limited impact in the SSA located to the east. The plume is initially buoyant and is emitted into an unstable atmosphere and will tend to reach an elevation above that of the stable layer. As such, in most instances, it will not have an important impact on the SSA as downward dispersion will be inhibited. The burn illustrated in the lee of the Coast Range at a relatively low elevation would have to be managed very carefully as it is in relatively close proximity to the SSA. Here, the plume is emitted into an unstable atmosphere, but is limited from continued dispersion aloft by the presence of a very stable elevated inversion. As such, the plume does have the potential to impact the SSA and would have to be regulated very closely. The final burn indicated in the figure is well up into the Sierra at a location where it should have an acceptable impact on local air quality. The plume is moving away from the SSA and is benefiting from excellent dispersion effects due to the unstable surface layer as well as the effects imparted by orographic lifting over the higher terrain.

Typical meteorological conditions in California at night are displayed in Figure 4.9-3. In this instance, very stable air tends to accumulate over the SSA, and burning would not be recommended in the zone. Burning at mountaintop locations, however, would still be acceptable as they are being emitted into a slightly stable atmosphere and the very stable layer below would prohibit the downward dispersion of the plume into the SSA. These figures provide only idealized descriptions of typical meteorological effects on potential burn situations. It is emphasized that the decision should be based upon burn/no-burn forecasts available from the CARB, even in areas which are outside the jurisdiction of regulatory agencies due to elevation as described in Section 6.5.2.

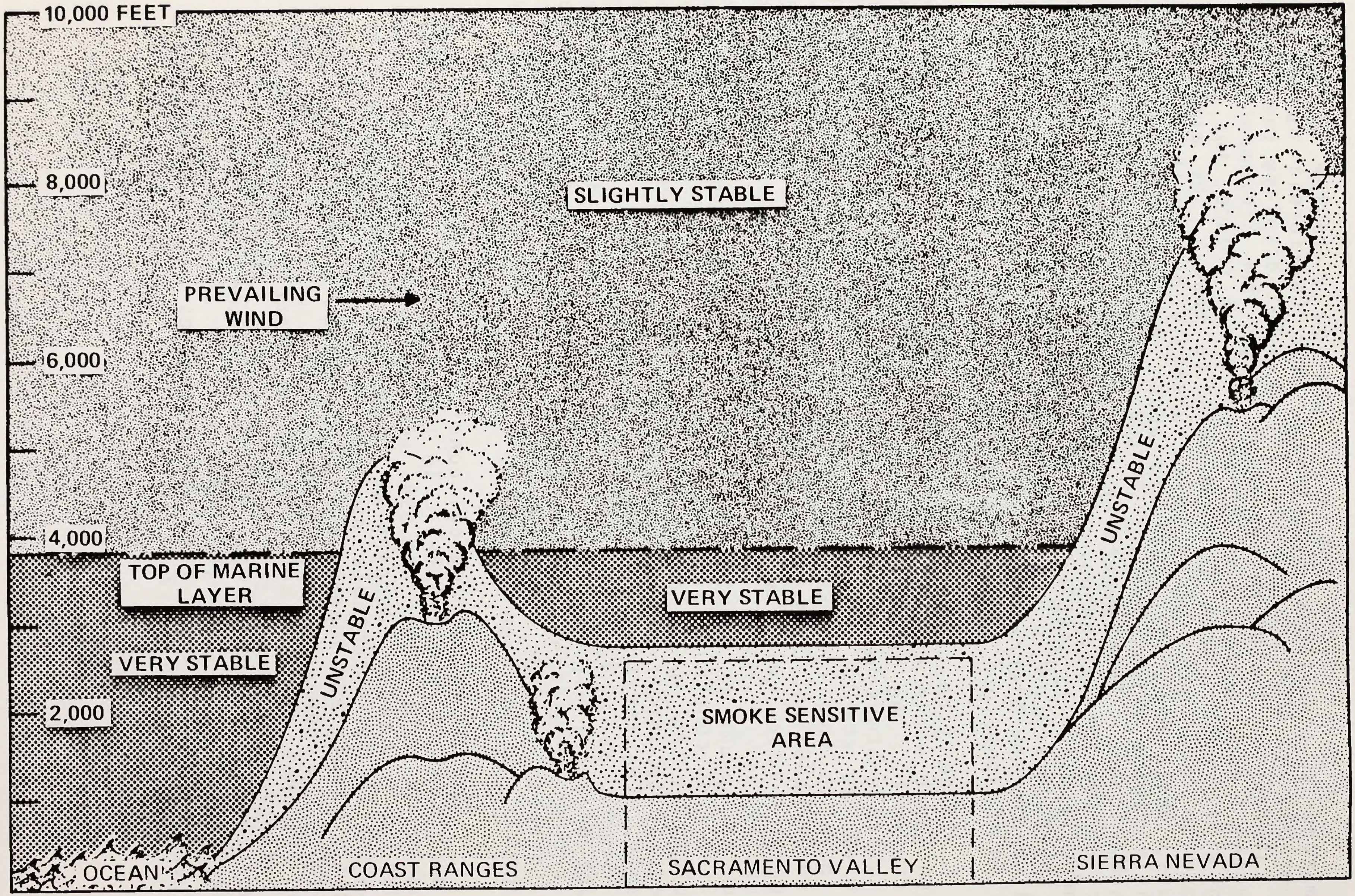

Figure 4.9-2

Typical Afternoon Dispersion Conditions and the Impact on Burning

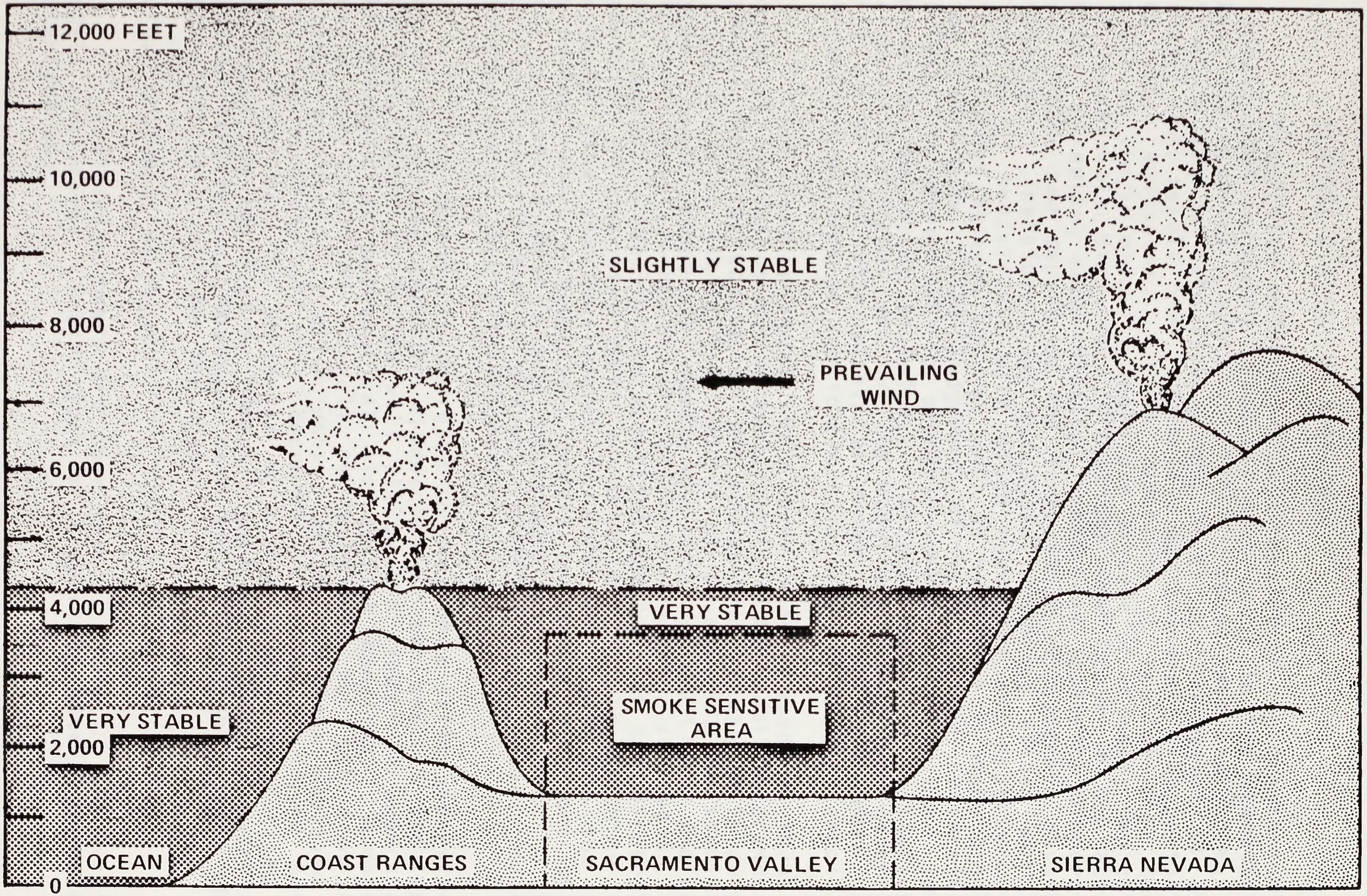

Figure 4.9-3

Typical Nighttime Dispersion Conditions and the Impact on Burning

4.10 GENERAL DISPERSION MODELING

Dispersion modeling is a mathematical representation or simulation of transport processes that occur in the atmosphere. There are numerous dispersion modeling techniques available, all of which aim to calculate ground level concentrations of pollutants that result from industrial, agricultural, transportation and urban emissions. It is important to realize that there exists no single modeling technique capable of properly depicting all conceivable dispersion situations that occur in the atmosphere. Likewise, meteorological conditions impacting dispersion are complex and depend on the interaction of numerous physical processes. Therefore, any successful modeling effort must be directed by individuals with broad knowledge and experience in air pollution meteorology, as well as expertise in data processing techniques. The judgement of well trained professional analysts is essential to properly evaluate the ground level impact of pollutant emissions. Without detailed validation/-calibration efforts, air quality modeling results are generally felt to be good only within an order of magnitude under many circumstances, such as applications in areas of rugged terrain.

Air quality models have been widely used to identify potential violations of National Ambient Air Quality Standards (NAAQS). Modeling studies of the atmosphere are useful in determining emission limits for industrial development in specified areas. Hence, dispersion models are vital to the timely and cost effective development of air pollution control strategies for most regions. Ideally, mathematical modeling of the dispersion potential of the atmosphere would allow optimum planning for proposed land use development in terms of minimizing the air pollution impact. Dispersion models provide a technique which can be used to help ensure attainment and maintenance of air quality standards and to prevent significant air quality deterioration due to future development.

This section is designed to present a basic understanding of dispersion modeling approaches to air qualtiy problems. The subsections to follow will allow the reader to understand the concepts of mathematical air quality modeling. Numerous models are described as well as techniques for selecting the optimum approach. English units, which have been employed in previous sections of this document, will not be used here. Calculations must be performed in metric units, as dictated by the equations and figures commonly used in dispersion modeling. English conversions, however, have been placed on figures as a convenient reference for the reader.

4.10.1 Classes of Models

Basically, there are four general types of air quality models available. These types of dispersion models are characterized as:

- Gaussian
- Numerical
- Statistical or Empirical
- Physical

Within each of these classes, there exists a large number of individual computational algorithms, each with its own specific application. For example, numerous air quality models have been developed based upon the Gaussian or log-normal solution to the fluid transport equation. Each particular model or algorithm is designed to handle a specific air quality and atmospheric scenario while computing pollution impacts through the use of the Gaussian diffussion equation. The models may, for example, consider different atmospheric parameters, terrain features, and various degrees of data resolution. The well-known EPA dispersion models such as the Climatological Dispersion Model (CDM), the Air Quality Display Model (AQDM), the Valley Model, and the Texas Climatological Model (TCM) are commonly referred to as individual models but in fact are all variations of the basic Gaussian model. In many cases, the only real difference between models is the degree of detail considered in the input and output of data.

Gaussian models are considered to be the state of the art technique for estimating the impact of non-reactive pollutants. These types of models assume instantaneous transport of effluents downwind of the emission source. However, numerical models are more appropriate than Gaussian models for source applications which involve reactive pollutants. Most numerical models employ numerous interactive steps allowing for downwind adjustments to time dependent chemical and thermal processes that take place in the plume. Statistical or empirical techniques are frequently employed in situations where an incomplete scientific understanding of the physical and chemical processes of the plume behavior makes the use of the Gaussian and numerical modeling approaches impractical. Physical modeling, the fourth generic type, involves the use of a wind tunnel or other fluid modeling facilities necessary to investigate dispersion in very confined, specialized environments isolated to only a few square kilometers. Physical modeling is a complex process which requires a high level of technical expertise.

4.10.2 Model Suitability and Application

The level of analysis for which a particular dispersion model is well suited depends on several factors. These include:

- The detail and accuracy of the data base (i.e., emission inventory, baseline air quality and meteorological data)
- The local topographic and meteorological complexities
- The technical competence of the individuals directing the modeling effort

- Available financial and computational resources

Air quality models require a data base which includes emission source characteristics, meteorological parameters and baseline air quality levels (and at times, local topographic data and temporal statistics). Models that require detailed and precise input data should not be applied when such data are unavailable.

Most dispersion models are intended for use only in areas of relatively simple topography. Specific modeling analyses for major topographic features and complex meteorological scenarios may start with a simplistic preliminary screening analyses using the Gaussian or other straightforward approach to define the level of impact. If these analyses point to a potentially important impact then more sophisticated modeling approaches must be implemented.

Applications of the various classes of air quality models previously mentioned require a two step approach with various levels of sophistication. The first level consists of general techniques that provide relatively simple and conservative estimates of air quality impact of a specific source or source category. This initial screening level, provides an understanding of air pollution impact due to a particular source(s) in the area in question. The major objective at this stage is to identify potential violations of air quality standards. This is done by using simple analytical techniques to isolate areas of projected maximum ground level concentrations for comparison with the most limiting standards, and is the level of effort the District Offices should strive to accomplish.

The second level of effort involves the use of analytical techniques which provide a more detailed treatment of physical and chemical processes once a potential problem has been identified. This step requires a more detailed and precise data base which will result in a more accurate estimate of source impact. At this point, an exhaustive data base specific to the study area is incorporated into the modeling analysis. For example, temporal variations in the baseline meteorology, air quality and emissions data can be input to the model. Emission inventory data can also be more accurately assessed in terms of such aspects as temporal variability.

The screening level approach to air quality modeling is highly recommended in all initial applications of dispersion models. If a problem is identified, then more sophisticated analyses are indicated. In any case, a multi-step approach to modeling is vital in accurately establishing regional air quality impact.

A specific plan of attack is required for each dispersion problem that is encountered. It is not the purpose of this section to recommend specific models for specific air quality impact situations, but rather to provide a foundation or framework in which to approach the basic air quality modeling problem, which may be used as a screening level to determine if further analysis is needed.

4.10.3 The Gaussian Model

Gaussian based models are considered to be the state of the art technique for estimating concentrations of non-reactive pollutants such as sulfur dioxide and particulate matter for most point source emissions. Numerous experiments have been conducted to study the shape of plumes. The publication "Meteorology and Atomic Energy" lists over twenty experiments, many of which have been conducted by the Atomic Energy Commission (now ERDA-Energy Research and Development Administration). In general, most investigators have been satisfied that a Gaussian distribution is a good mathematical approximation of plume behavior over time periods on the order of five minutes to one hour. Figure 4.10-1 illustrates the Gaussian plume distribution in the horizontal and the vertical.

The Gaussian model provides reasonable estimates in flat or gently rolling terrain. However, Gaussian based models are extremely inaccurate for air quality impact assessments in areas comprised of extremely rugged and varying terrain, such as hilly or mountainous regions. For such situations, statistical or physical modeling methods are best employed, since the dispersion potential of the atmosphere can then be characterized by empirical data obtained by local monitoring programs.

Properly used, a Gaussian model is unequalled as a practical diffusion modeling tool in terms of simplicity, flexibility and the successful correlation between predicted and measured values. For these reasons, the Gaussian model is used in this section to illustrate several simple modeling problems. All variables which will be used to solve the Gaussian equation will now be defined:

$C(x,y,z)$	is the concentration at a point (x,y,z).
$\bar{x}$	is the mean
σ_y, σ_z	are the standard deviations in the y and z directions
Q	is the emission rate
$\bar{u}$	is the mean wind speed and
H	is the height of the plume centerline when it becomes essentially level.

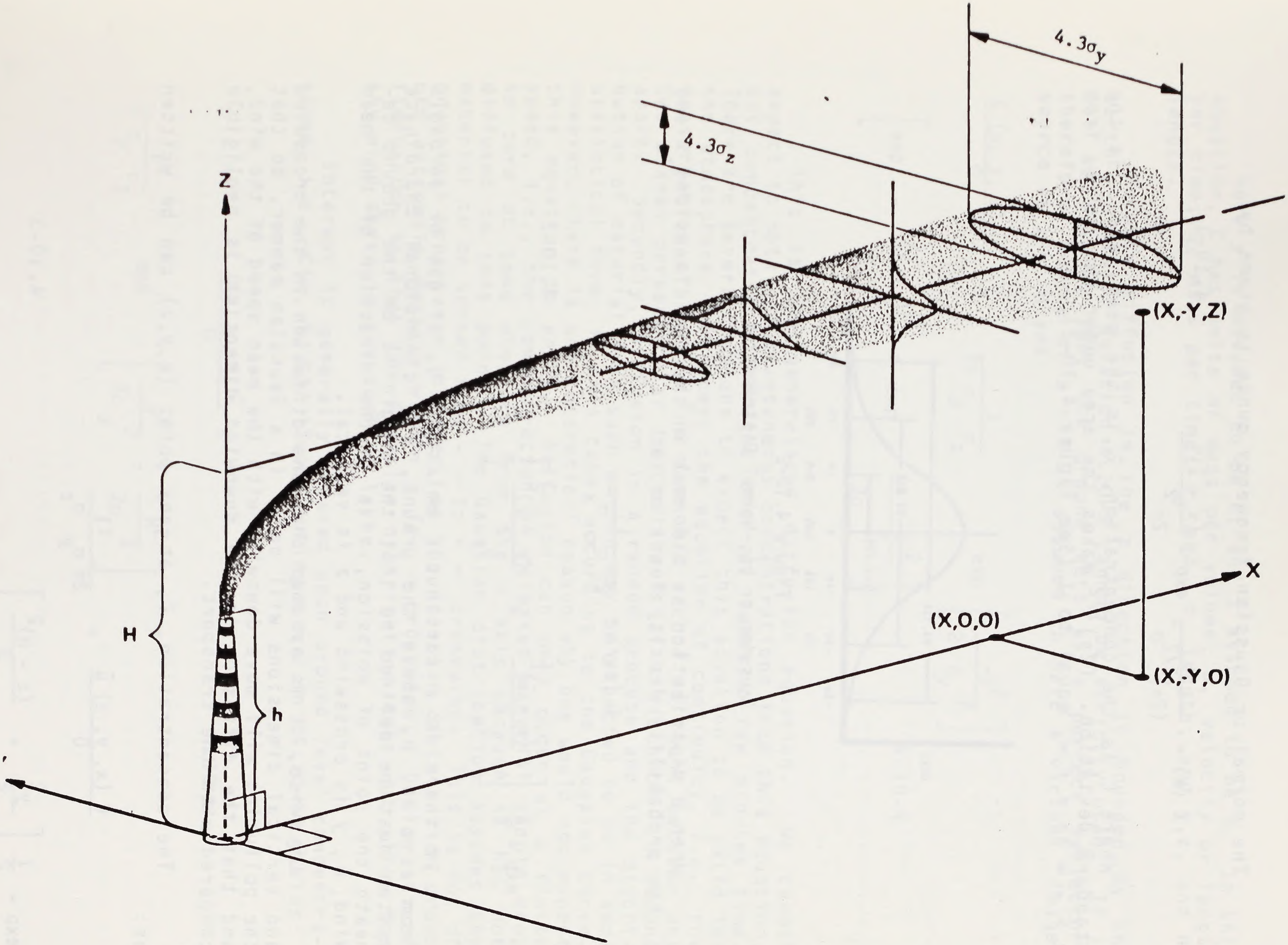

Figure 4.10-1

Coordinate System Showing

GAUSSIAN Distribution in the Horizontal and Vertical

The normal or Gaussian frequency curve is given by:

$$C(x) = \frac{1}{(2\pi)^{1/2}\sigma} \exp - \frac{(x - \bar{x})^2}{2\sigma^2} \qquad 4.10\text{-}1$$

Where C is the concentration, $\bar{x}$, is the mean, and σ is the standard deviation. $(2\pi)^{1/2}$ makes the area under the curve, from $x = -\infty$ to $= +\infty$, equal to 1 (See Figure 4.10-2).

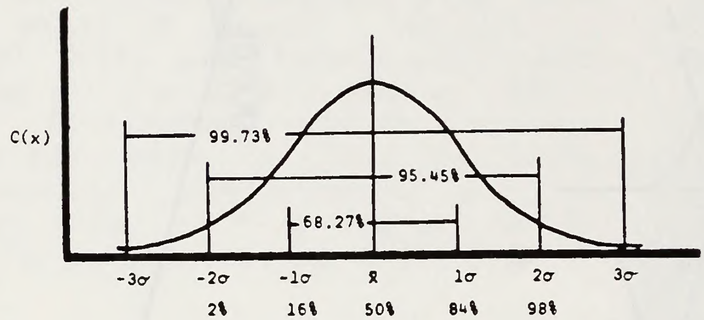

Figure 4.10-2

Gaussian or Log-Normal Distribution

When a distribution is binormal in the two dimensions x and y, the probability density function is:

$$C(x,y) = \frac{1}{2\pi\,\sigma_x\,\sigma_y}$$

$$\exp - \frac{1}{2}\left[\frac{(x - \bar{x})^2}{\sigma_x^2} + \frac{(y - \bar{y})^2}{\sigma_y^2}\right] \qquad 4.10\text{-}2$$

If there is a continuous emission, Q, of gas or aerosols from a point, H, above the ground, a 3 dimensional coordinate system must be defined so that the origin is on the ground beneath the point of emission, x is in the direction of the mean wind, $\bar{u}$, y is crosswind and z is vertical.

Likewise, it is assumed that the diffusion in the crosswind and vertical dimensions will occur in a Gaussian manner, so that the pollution will move downwind with the mean speed of the wind, and that the diffusion in the downwind direction is negligible compared with the transport.

The concentration, C, at any point (x,y,z) can be written as:

$$\frac{C(x, y, z)\,\bar{u}}{Q} = \frac{1}{2\pi\,\sigma_y\,\sigma_z}$$

$$\exp - \frac{1}{2}\left[\frac{y^2}{\sigma_y^2} + \frac{(z - H)^2}{\sigma_z^2}\right] \qquad 4.10\text{-}3$$

Here y is assumed to be 0, and $\bar{z}$ assumed to be H. In this equation, C has units of mass per volume; $\bar{u}$, velocity or length per time; Q, mass per time; σ_y and σ_z length; and y,z, and H, length.

Because diffusion in the z direction is bounded by the earth's surface, equation 4.10-3 cannot be strictly used. If it can be assumed that the ground acts as a perfect reflector, therefore, source at z = H is assumed to have a virtual "image" source at z = -H and

$$\frac{C(x, y, z)\,\bar{u}}{Q} = \frac{1}{2\pi\sigma_y\sigma_z} \exp\left[\frac{-y^2}{2\sigma_y^2}\right] \left[\exp - \frac{(z-H)^2}{2\sigma_z^2} + \exp - \frac{(z+H)^2}{2\sigma_z^2}\right] \qquad 4.10\text{-}4$$

This is the generalized diffusion equation. We cannot expect to obtain instantaneous concentrations from this equation, but concentrations averaged over at least a few minutes time. There are several reasons to expect this equation to be valid for the atmosphere. It obeys the equation of continuity, i.e., the conservation of mass. The mass Q/1 second is found between any two planes perpendicular to the x-axis at a distance $\bar{u}$ /1 second apart. Secondly, diffusion is a random process and the distribution of material from such motion may be expected to be in some statistical form; in this case, according to the Gaussian curve. However, there is one theoretical reason why one would not expect this equation to apply. Diffusion can only occur at a finite speed, i.e., the concentration of released material should drop to zero at some distance from the x axis because it has not diffused to this point. The Gaussian distribution assumes the material to be spread from - ∞ to + ∞ crosswind. This is not of practical importance, however, as the Gaussian distribution drops off extremely rapidly within a few σ crosswind. One practical limitation is that the Gaussian distribution does not allow for any wind shear in the surface layer.

Interest is generally focused upon ground level concentrations, i.e., C(x, Y, 0). Substituting z = 0 in (4.10-4) yields:

$$\frac{C(x, y, 0)\,\bar{u}}{Q} = \frac{1}{\pi\sigma_y\sigma_z} \exp - \left[\frac{y^2}{2\sigma_y^2} - \frac{H^2}{2\sigma_z^2}\right] \qquad 4.10\text{-}5$$

It will be noted that the 2 in the denominator in (4.10-4) is eliminated in (4.10-5) because of the 2

resulting from $2 \exp - \frac{H^2}{2\sigma_z^2}$ occurring in the numerator.

If the source is at ground level (H = 0), there is further simplification. Similarly, if one is interested only in centerline concentrations (directly downwind) then y = 0, and equation (4.10-5) may again be simplified.

This (4.10-5) is the basic equation for calculating the ground level concentration from a continuous point source. The usual units for the variables are:

C (x, y, 0)	gms/m^3
$\bar{u}$	m/sec
Q	gms/sec
σ_y, σ_z, y, H,	meters

As seen from Equation 4.10-5, the plume concentration (C) at various downwind distances (x) from the emission source is largely dependent upon horizontal and vertical dispersion coefficients (sigma y or sigma z). Figure 4.10-1 illustrates the coordinate system for a typical plume and visually describes the significance of the dispersion coefficients in the y and z directions.

Stability

The values of both σ_y and σ_z will depend upon the turbulent structure of the atmosphere. If measures of horizontal and vertical motions of the air are made as with a bivane, the resulting records may be used to estimate σ_y and σ_z (see Pasquill, 1961). If wind fluctuation measurements are not available, estimates of σ_y and σ_z may be made by first estimating the stability of the atmosphere from wind measurements at the standard height of 10 meters, and estimates of net radiation (Pasquill, 1961). Stability categories (in six classes) are given in Table 4.10-1 in terms of insolation during daytime (radiation received from the sun) and amount of cloud cover at night. Strong insolation corresponds to a solar altitude (above the horizon) greater than 60^o with clear skies, and slight insolation corresponds to a solar altitude from 15^o to 35^o with clear skies. Table 170, Solar Altitude, and Azimuth in the Smithsonian Meteorological Tables (List, 1951) is a considerable aid in determining insolation. Cloudiness will generally decrease insolation and should be considered along with a solar altitude in determining insolation. Insolation that would be strong with clear skies may be reduced to moderate with broken middle clouds and to slight with broken low clouds. Night refers to the period from one hour before sunset to one hour after sunrise. The neutral category, (D), should be assumed for overcast conditions during day or night.

Table 4.10-1

Key to Stability Categories

Surface Wind Speed (at 10 m) m/sec	Insolation			Night	
	Strong	Moderate	Slight	Thinly Overcast or $\geq$ 4/8 Low Cloud	$\leq$ 3/8 Cloud
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

The neutral category, D, should be assumed for overcast conditions during day or night.

Estimation of Vertical and Horizontal Dispersion

Having determined the stability class from Table 4.10-1, the measures of diffusion in the vertical, σ_z, and in the horizontal, σ_y, may be estimated as a function of downwind distance from the source, (x), using Figures 4.10-3 and 4.10-4. These values of σ_z and σ_y are valid for concentrations, (C), averaged over a few minutes time, and apply to open level country with no allowance made for turbulence due to buildings or topography. With very light winds on a clear night, the vertical spread may be less than the values for class F.

When conditions are such that the vertical structure of temperature indicates a definite limit to the vertical convection, particularly under unstable conditions, the σ_z should be allowed to increase only to $0.47h_1$ where h_1 is the limit of convection. At the distance x_1 where $\sigma_z = 0.47\ h_1$, the plume is still assumed to have a Gaussian vertical distribution. It can be assumed that by the time the plume travels twice this distance ($2x_1$), the plume has become uniformly distributed between the earth's surface and the limit of convection. A value of σ_z equal to $0.8h_1$ may be used and the exponential term dropped at distances equal to or greater than $2x_1$ and will make the concentration value computed by the equation, equal to that from a plume uniformly distributed in the vertical.

Estimation of Wind Speed

For mean wind speed, ($\bar{u}$), the value measured at 10 meters elevation (surface wind) should be used for x up to about 1 km for surface sources or short stacks. For greater distances or elevated sources, a mean speed through the vertical extent of the plume (about 2 σ_z) should be used. A speed midway between the surface and geostrophic speeds should be reasonable.

Calculation of Centerline Concentration From a Ground Level Source

For most practical purposes it will be sufficient to calculate the centerline concentration for the distances 100 m, 1 km, 10 km, and 100 km and plot these against downwind distance x, on log/log graph paper for interpolation of concentration for other distances. (For unstable or stable cases it is desirable to include several other distances.) This may be done using the equation:

$$C = \frac{Q}{\pi u \sigma_y \sigma_z} = \frac{3.18 \times 10^{-1} Q}{u \sigma_y \sigma_z} \qquad 4.10\text{-}6$$

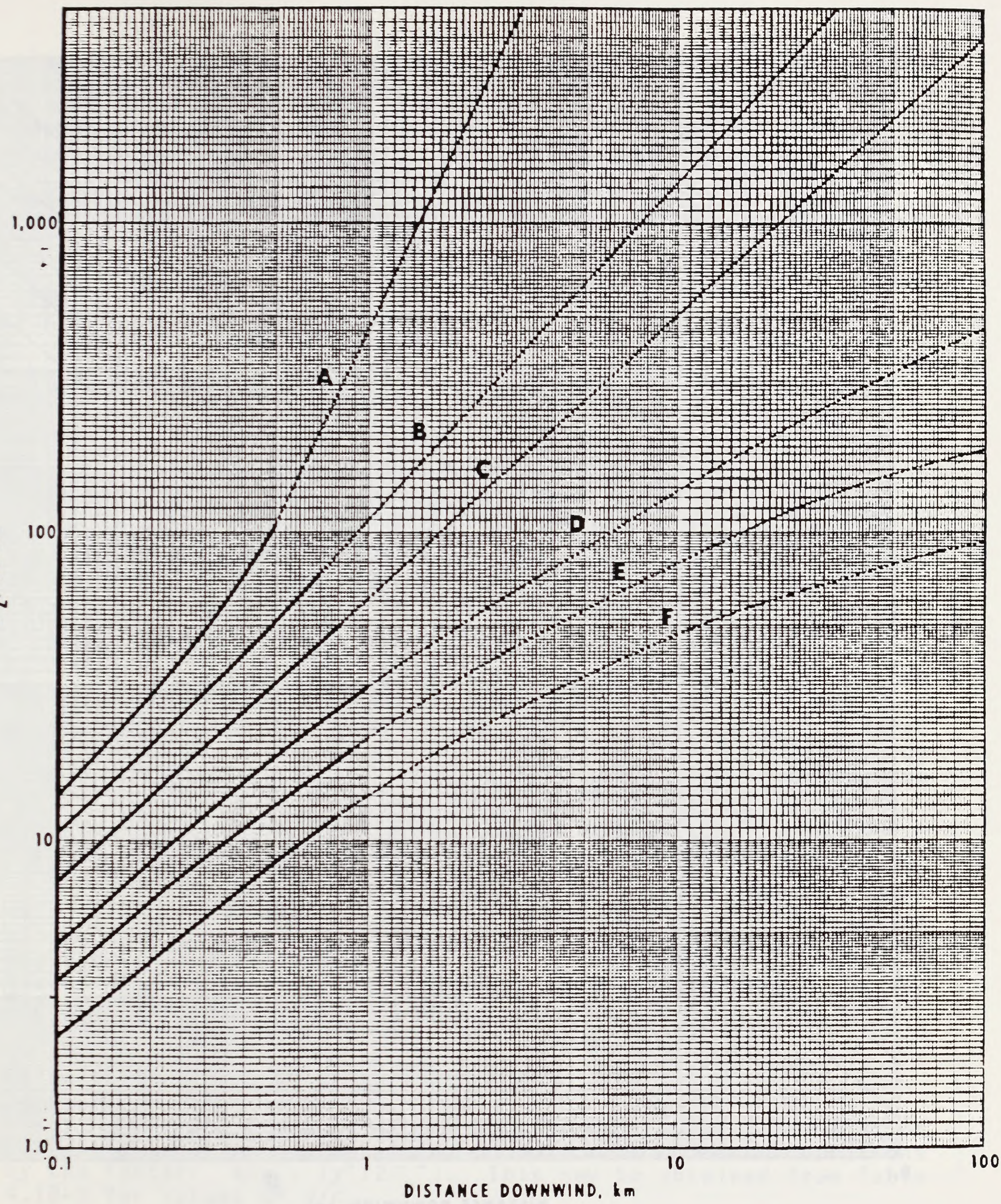

Figure 4.10-3

Vertical Dispersion Coefficient as a Function of Downwind Distance from the Source

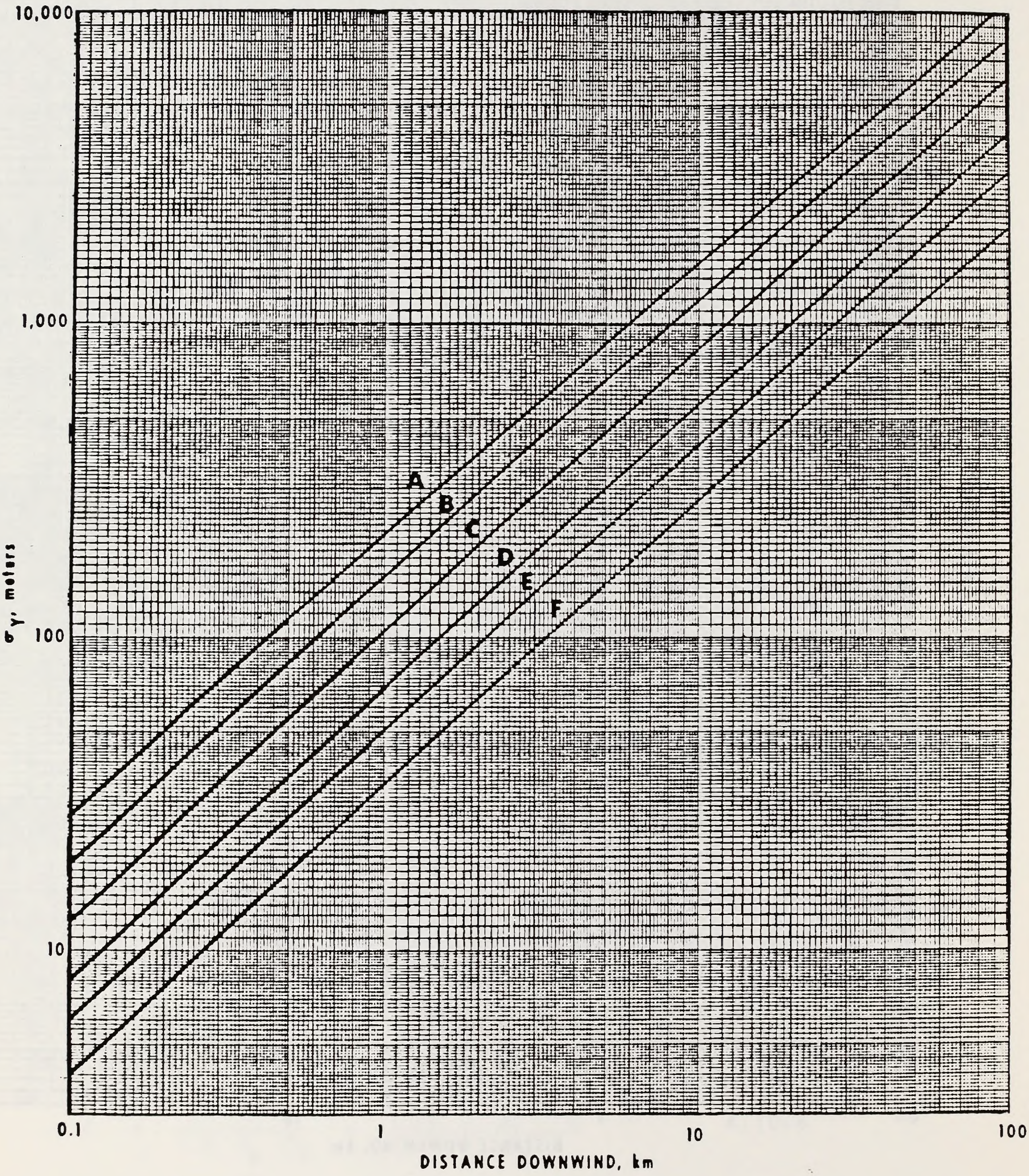

Figure 4.10-4

Horizontal Dispersion Coefficient as a Function of Downwind Distance from the Source

The zero subscript of C, concentration, indicates emission from a ground-level source. If there is a limit to convection (h), concentrations should also be calculated for distances x_1 and x_2 using $\sigma_z = 0.47h_1$ and $\sigma_z = 0.8\ h_1$ respectively. Line segments connecting the calculated concentrations for the various distances will give a plot of concentration with distance.

Calculation of Ground-Level Centerline Concentration From an Elevated Source

Concentrations from an elevated source may be calculated from:

$$C = \frac{Q}{\pi u \sigma_y \sigma_z} \exp - \frac{H^2}{2 \sigma_z{}^2} \qquad 4.10\text{-}7$$

where H is the effective height i.e., the physical stack height plus plume rise, of the elevated source.

Values of $\exp - H^2/2\sigma_z{}^2$ are found in Table 4.10-2. A is the ratio of H/σ_z and B, the expression in the body of the table, is the computed value of the exponential. The E represents x 10 to the power indicated by the following two digits. For example, if A = 3.55, the value of the exponential is 0.183×10^{-2}.

It is possible under light wind situations at nights that the plume from an elevated source will remain aloft with no significant vertical diffusion, in which case the ground-level concentrations would be zero. Vertical spread can then be started at a downwind position corresponding to the wind speed and the estimated time for breakdown of the stable situation.

Graphs for Estimation of Diffusion

Hilsmeier and Gifford (1962) have presented graphs of relative concentration times wind speed (Cu/Q) below the plume centerline, versus downwind distance for various stability classes. Figure 4.10-5 give Cu/Q as a function of x for a ground-level source whereas Figures 4.10-6 through 4.10-8 are for the indicated elevated sources.

Calculation of Off Axis Concentrations

Off-Axis concentrations may be calculated from equation 4.10-1, or by correcting ground-level centerline concentrations by the factor: $\exp - (y^2/2\sigma_y{}^2)$. This may be obtained from Table 4.10-3 for values of y/σ_y.

Plotting Ground-Level Concentration Isopleths

Table 4.10-2

$$\text{Values of Exp} - \frac{H^2}{2\sigma_z^2}$$

$$B = \exp - \tfrac{1}{2}(A)^2$$

A	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.00	0.100E 01	0.100E 01	0.100E 01	0.100E 01	0.999E 00	0.999E 00	0.998E 00	0.998E 00	0.997E 00	0.996E 00
0.10	0.995E 00	0.994E 00	0.993E 00	0.992E 00	0.990E 00	0.989E 00	0.987E 00	0.986E 00	0.984E 00	0.982E 00
0.20	0.980E 00	0.978E 00	0.976E 00	0.974E 00	0.972E 00	0.969E 00	0.967E 00	0.964E 00	0.962E 00	0.959E 00
0.30	0.956E 00	0.953E 00	0.950E 00	0.947E 00	0.944E 00	0.941E 00	0.937E 00	0.934E 00	0.930E 00	0.927E 00
0.40	0.923E 00	0.919E 00	0.916E 00	0.912E 00	0.908E 00	0.904E 00	0.900E 00	0.895E 00	0.891E 00	0.887E 00
0.50	0.882E 00	0.878E 00	0.874E 00	0.869E 00	0.864E 00	0.860E 00	0.855E 00	0.850E 00	0.845E 00	0.840E 00
0.60	0.835E 00	0.830E 00	0.825E 00	0.820E 00	0.815E 00	0.810E 00	0.804E 00	0.799E 00	0.794E 00	0.788E 00
0.70	0.783E 00	0.777E 00	0.772E 00	0.766E 00	0.760E 00	0.755E 00	0.749E 00	0.743E 00	0.738E 00	0.732E 00
0.80	0.726E 00	0.720E 00	0.714E 00	0.709E 00	0.703E 00	0.697E 00	0.691E 00	0.685E 00	0.679E 00	0.673E 00
0.90	0.667E 00	0.661E 00	0.655E 00	0.649E 00	0.643E 00	0.637E 00	0.631E 00	0.625E 00	0.619E 00	0.613E 00
1.00	0.607E 00	0.600E 00	0.594E 00	0.588E 00	0.582E 00	0.576E 00	0.570E 00	0.564E 00	0.558E 00	0.552E 00
1.10	0.546E 00	0.540E 00	0.534E 00	0.528E 00	0.522E 00	0.516E 00	0.510E 00	0.504E 00	0.498E 00	0.493E 00
1.20	0.487E 00	0.481E 00	0.475E 00	0.469E 00	0.464E 00	0.458E 00	0.452E 00	0.446E 00	0.441E 00	0.435E 00
1.30	0.430E 00	0.424E 00	0.418E 00	0.413E 00	0.407E 00	0.402E 00	0.397E 00	0.391E 00	0.386E 00	0.381E 00
1.40	0.375E 00	0.370E 00	0.365E 00	0.360E 00	0.355E 00	0.350E 00	0.344E 00	0.339E 00	0.334E 00	0.330E 00
1.50	0.325E 00	0.320E 00	0.315E 00	0.310E 00	0.306E 00	0.301E 00	0.296E 00	0.292E 00	0.287E 00	0.283E 00
1.60	0.278E 00	0.274E 00	0.269E 00	0.265E 00	0.261E 00	0.256E 00	0.252E 00	0.248E 00	0.244E 00	0.240E 00
1.70	0.236E 00	0.232E 00	0.228E 00	0.224E 00	0.220E 00	0.216E 00	0.213E 00	0.209E 00	0.205E 00	0.201E 00
1.80	0.198E 00	0.194E 00	0.191E 00	0.187E 00	0.184E 00	0.181E 00	0.177E 00	0.174E 00	0.171E 00	0.168E 00
1.90	0.164E 00	0.161E 00	0.158E 00	0.155E 00	0.152E 00	0.149E 00	0.146E 00	0.144E 00	0.141E 00	0.138E 00
2.00	0.135E 00	0.133E 00	0.130E 00	0.127E 00	0.125E 00	0.122E 00	0.120E 00	0.117E 00	0.115E 00	0.113E 00
2.10	0.110E 00	0.108E 00	0.106E 00	0.103E 00	0.101E 00	0.991E-01	0.970E-01	0.949E-01	0.929E-01	0.909E-01
2.20	0.889E-01	0.870E-01	0.851E-01	0.832E-01	0.814E-01	0.796E-01	0.778E-01	0.760E-01	0.743E-01	0.727E-01
2.30	0.710E-01	0.694E-01	0.678E-01	0.662E-01	0.647E-01	0.632E-01	0.617E-01	0.603E-01	0.589E-01	0.575E-01
2.40	0.561E-01	0.548E-01	0.535E-01	0.522E-01	0.510E-01	0.497E-01	0.485E-01	0.473E-01	0.462E-01	0.450E-01
2.50	0.439E-01	0.428E-01	0.418E-01	0.407E-01	0.397E-01	0.387E-01	0.377E-01	0.368E-01	0.359E-01	0.349E-01
2.60	0.340E-01	0.332E-01	0.323E-01	0.315E-01	0.307E-01	0.299E-01	0.291E-01	0.283E-01	0.276E-01	0.268E-01
2.70	0.261E-01	0.254E-01	0.247E-01	0.241E-01	0.234E-01	0.228E-01	0.222E-01	0.216E-01	0.210E-01	0.204E-01
2.80	0.198E-01	0.193E-01	0.188E-01	0.182E-01	0.177E-01	0.172E-01	0.167E-01	0.163E-01	0.158E-01	0.154E-01
2.90	0.149E-01	0.145E-01	0.141E-01	0.137E-01	0.133E-01	0.129E-01	0.125E-01	0.121E-01	0.118E-01	0.114E-01
3.00	0.111E-01	0.108E-01	0.105E-01	0.101E-01	0.984E-02	0.955E-02	0.926E-02	0.898E-02	0.871E-02	0.845E-02
3.10	0.819E-02	0.794E-02	0.769E-02	0.746E-02	0.723E-02	0.700E-02	0.679E-02	0.658E-02	0.637E-02	0.617E-02
3.20	0.598E-02	0.579E-02	0.560E-02	0.543E-02	0.525E-02	0.509E-02	0.492E-02	0.477E-02	0.461E-02	0.446E-02
3.30	0.432E-02	0.418E-02	0.404E-02	0.391E-02	0.378E-02	0.366E-02	0.354E-02	0.342E-02	0.331E-02	0.320E-02
3.40	0.309E-02	0.299E-02	0.289E-02	0.279E-02	0.269E-02	0.260E-02	0.251E-02	0.243E-02	0.235E-02	0.227E-02
3.50	0.219E-02	0.211E-02	0.204E-02	0.197E-02	0.190E-02	0.183E-02	0.177E-02	0.171E-02	0.165E-02	0.159E-02
3.60	0.153E-02	0.148E-02	0.143E-02	0.138E-02	0.133E-02	0.128E-02	0.123E-02	0.119E-02	0.115E-02	0.110E-02
3.70	0.106E-02	0.103E-02	0.989E-03	0.952E-03	0.918E-03	0.884E-03	0.851E-03	0.820E-03	0.789E-03	0.760E-03
3.80	0.732E-03	0.704E-03	0.678E-03	0.653E-03	0.628E-03	0.604E-03	0.582E-03	0.560E-03	0.538E-03	0.518E-03
3.90	0.498E-03	0.479E-03	0.460E-03	0.443E-03	0.426E-03	0.409E-03	0.393E-03	0.378E-03	0.363E-03	0.349E-03
4.00	0.335E-03	0.322E-03	0.310E-03	0.297E-03	0.286E-03	0.274E-03	0.263E-03	0.253E-03	0.243E-03	0.233E-03
4.10	0.224E-03	0.215E-03	0.206E-03	0.198E-03	0.190E-03	0.182E-03	0.175E-03	0.168E-03	0.161E-03	0.154E-03
4.20	0.148E-03	0.142E-03	0.136E-03	0.130E-03	0.125E-03	0.120E-03	0.115E-03	0.110E-03	0.105E-03	0.101E-03
4.30	0.966E-04	0.925E-04	0.886E-04	0.849E-04	0.813E-04	0.778E-04	0.745E-04	0.713E-04	0.683E-04	0.653E-04
4.40	0.625E-04	0.598E-04	0.572E-04	0.548E-04	0.524E-04	0.501E-04	0.479E-04	0.458E-04	0.438E-04	0.419E-04
4.50	0.401E-04	0.383E-04	0.366E-04	0.350E-04	0.334E-04	0.320E-04	0.305E-04	0.292E-04	0.279E-04	0.266E-04
4.60	0.254E-04	0.243E-04	0.232E-04	0.221E-04	0.211E-04	0.202E-04	0.193E-04	0.184E-04	0.175E-04	0.167E-04
4.70	0.160E-04	0.152E-04	0.145E-04	0.139E-04	0.132E-04	0.126E-04	0.120E-04	0.115E-04	0.109E-04	0.104E-04
4.80	0.993E-05	0.946E-05	0.902E-05	0.859E-05	0.819E-05	0.780E-05	0.743E-05	0.708E-05	0.674E-05	0.642E-05
4.90	0.611E-05	0.582E-05	0.554E-05	0.528E-05	0.502E-05	0.478E-05	0.455E-05	0.433E-05	0.412E-05	0.392E-05

Table 4.10-2 (Continued)

$$B = \exp - \tfrac{1}{2}(A)^2$$

A	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
5.00	0.373E-05	0.354E-05	0.337E-05	0.321E-05	0.305E-05	0.290E-05	0.276E-05	0.262E-05	0.249E-05	0.237E-05
5.10	0.225E-05	0.214E-05	0.203E-05	0.193E-05	0.183E-05	0.174E-05	0.165E-05	0.157E-05	0.149E-05	0.142E-05
5.20	0.134E-05	0.128E-05	0.121E-05	0.115E-05	0.109E-05	0.103E-05	0.982E-06	0.932E-06	0.884E-06	0.838E-06
5.30	0.795E-06	0.754E-06	0.715E-06	0.678E-06	0.643E-06	0.609E-06	0.577E-06	0.547E-06	0.519E-06	0.491E-06
5.40	0.466E-06	0.441E-06	0.418E-06	0.396E-06	0.375E-06	0.355E-06	0.336E-06	0.318E-06	0.301E-06	0.285E-06
5.50	0.270E-06	0.255E-06	0.242E-06	0.229E-06	0.216E-06	0.205E-06	0.194E-06	0.183E-06	0.173E-06	0.164E-06
5.60	0.155E-06	0.147E-06	0.139E-06	0.131E-06	0.124E-06	0.117E-06	0.111E-06	0.104E-06	0.987E-07	0.932E-07
5.70	0.881E-07	0.832E-07	0.786E-07	0.742E-07	0.701E-07	0.662E-07	0.625E-07	0.590E-07	0.556E-07	0.525E-07
5.80	0.496E-07	0.468E-07	0.441E-07	0.416E-07	0.393E-07	0.370E-07	0.349E-07	0.329E-07	0.311E-07	0.293E-07
5.90	0.276E-07	0.260E-07	0.245E-07	0.231E-07	0.218E-07	0.205E-07	0.193E-07	0.182E-07	0.172E-07	0.162E-07
6.00	0.152E-07	0.143E-07	0.135E-07	0.127E-07	0.120E-07	0.113E-07	0.106E-07	0.998E-08	0.939E-08	0.884E-08
6.10	0.832E-08	0.782E-08	0.736E-08	0.692E-08	0.651E-08	0.612E-08	0.576E-08	0.541E-08	0.509E-08	0.478E-08
6.20	0.450E-08	0.423E-08	0.397E-08	0.373E-08	0.351E-08	0.329E-08	0.309E-08	0.291E-08	0.273E-08	0.256E-08
6.30	0.241E-08	0.226E-08	0.212E-08	0.199E-08	0.187E-08	0.175E-08	0.165E-08	0.154E-08	0.145E-08	0.136E-08
6.40	0.128E-08	0.120E-08	0.112E-08	0.105E-08	0.987E-09	0.925E-09	0.867E-09	0.813E-09	0.762E-09	0.714E-09
6.50	0.669E-09	0.627E-09	0.587E-09	0.550E-09	0.516E-09	0.483E-09	0.452E-09	0.424E-09	0.397E-09	0.371E-09
6.60	0.348E-09	0.325E-09	0.305E-09	0.285E-09	0.267E-09	0.250E-09	0.234E-09	0.218E-09	0.204E-09	0.191E-09
6.70	0.179E-09	0.167E-09	0.156E-09	0.146E-09	0.137E-09	0.128E-09	0.119E-09	0.112E-09	0.104E-09	0.974E-10
6.80	0.910E-10	0.850E-10	0.794E-10	0.742E-10	0.693E-10	0.647E-10	0.604E-10	0.564E-10	0.527E-10	0.492E-10
6.90	0.459E-10	0.428E-10	0.400E-10	0.373E-10	0.348E-10	0.325E-10	0.303E-10	0.282E-10	0.263E-10	0.246E-10
7.00	0.229E-10	0.213E-10	0.199E-10	0.186E-10	0.173E-10	0.161E-10	0.150E-10	0.140E-10	0.130E-10	0.121E-10
7.10	0.113E-10	0.105E-10	0.981E-11	0.914E-11	0.851E-11	0.792E-11	0.738E-11	0.687E-11	0.639E-11	0.595E-11
7.20	0.553E-11	0.515E-11	0.479E-11	0.446E-11	0.415E-11	0.386E-11	0.359E-11	0.334E-11	0.310E-11	0.288E-11
7.30	0.268E-11	0.249E-11	0.232E-11	0.215E-11	0.200E-11	0.186E-11	0.173E-11	0.160E-11	0.149E-11	0.138E-11
7.40	0.129E-11	0.119E-11	0.111E-11	0.103E-11	0.955E-12	0.887E-12	0.823E-12	0.764E-12	0.709E-12	0.658E-12
7.50	0.610E-12	0.566E-12	0.525E-12	0.487E-12	0.452E-12	0.419E-12	0.388E-12	0.360E-12	0.334E-12	0.309E-12
7.60	0.287E-12	0.266E-12	0.246E-12	0.228E-12	0.211E-12	0.196E-12	0.181E-12	0.168E-12	0.156E-12	0.144E-12
7.70	0.133E-12	0.124E-12	0.114E-12	0.106E-12	0.980E-13	0.907E-13	0.839E-13	0.777E-13	0.718E-13	0.665E-13
7.80	0.615E-13	0.569E-13	0.526E-13	0.486E-13	0.450E-13	0.416E-13	0.384E-13	0.355E-13	0.328E-13	0.303E-13
7.90	0.280E-13	0.259E-13	0.239E-13	0.221E-13	0.204E-13	0.189E-13	0.174E-13	0.161E-13	0.149E-13	0.137E-13
8.00	0.127E-13	0.117E-13	0.108E-13	0.996E-14	0.919E-14	0.848E-14	0.782E-14	0.722E-14	0.666E-14	0.614E-14
8.10	0.566E-14	0.522E-14	0.481E-14	0.444E-14	0.409E-14	0.377E-14	0.348E-14	0.320E-14	0.295E-14	0.272E-14
8.20	0.251E-14	0.231E-14	0.213E-14	0.196E-14	0.180E-14	0.166E-14	0.153E-14	0.141E-14	0.130E-14	0.119E-14
8.30	0.110E-14	0.101E-14	0.930E-15	0.856E-15	0.787E-15	0.724E-15	0.666E-15	0.613E-15	0.564E-15	0.518E-15
8.40	0.477E-15	0.438E-15	0.403E-15	0.370E-15	0.340E-15	0.313E-15	0.287E-15	0.264E-15	0.243E-15	0.223E-15
8.50	0.205E-15	0.188E-15	0.173E-15	0.159E-15	0.146E-15	0.134E-15	0.123E-15	0.113E-15	0.103E-15	0.949E-16
8.60	0.871E-16	0.799E-16	0.733E-16	0.672E-16	0.617E-16	0.566E-16	0.519E-16	0.476E-16	0.436E-16	0.400E-16
8.70	0.367E-16	0.336E-16	0.308E-16	0.282E-16	0.259E-16	0.237E-16	0.217E-16	0.199E-16	0.182E-16	0.167E-16
8.80	0.153E-16	0.140E-16	0.128E-16	0.117E-16	0.107E-16	0.983E-17	0.900E-17	0.823E-17	0.753E-17	0.689E-17
8.90	0.631E-17	0.577E-17	0.528E-17	0.483E-17	0.441E-17	0.404E-17	0.369E-17	0.337E-17	0.308E-17	0.282E-17
9.00	0.258E-17	0.235E-17	0.215E-17	0.197E-17	0.180E-17	0.164E-17	0.150E-17	0.137E-17	0.125E-17	0.114E-17
9.10	0.104E-17	0.952E-18	0.869E-18	0.793E-18	0.724E-18	0.661E-18	0.603E-18	0.550E-18	0.502E-18	0.458E-18
9.20	0.418E-18	0.381E-18	0.347E-18	0.317E-18	0.289E-18	0.263E-18	0.240E-18	0.219E-18	0.199E-18	0.182E-18
9.30	0.166E-18	0.151E-18	0.137E-18	0.125E-1	0.114E-18	0.104E-18	0.946E-19	0.861E-19	0.784E-19	0.714E-19
9.40	0.650E-19	0.592E-19	0.538E-19	0.490E-1	0.446E-19	0.406E-19	0.369E-19	0.336E-19	0.305E-19	0.278E-19
9.50	0.253E-19	0.230E-19	0.209E-19	0.190E-19	0.173E-19	0.157E-19	0.143E-19	0.130E-19	0.118E-19	0.107E-19
9.60	0.972E-20	0.883E-20	0.802E-20	0.729E-20	0.662E-20	0.601E-20	0.545E-20	0.495E-20	0.450E-20	0.408E-20
9.70	0.370E-20	0.336E-20	0.305E-20	0.277E-20	0.251E-20	0.228E-20	0.207E-20	0.187E-20	0.170E-20	0.154E-20
9.80	0.140E-20	0.127E-20	0.115E-20	0.104E-20	0.943E-21	0.855E-21	0.775E-21	0.702E-21	0.636E-21	0.576E-21
9.90	0.522E-21	0.472E-21	0.428E-21	0.387E-21	0.351E-21	0.318E-21	0.288E-21	0.260E-21	0.236E-21	0.213E-21

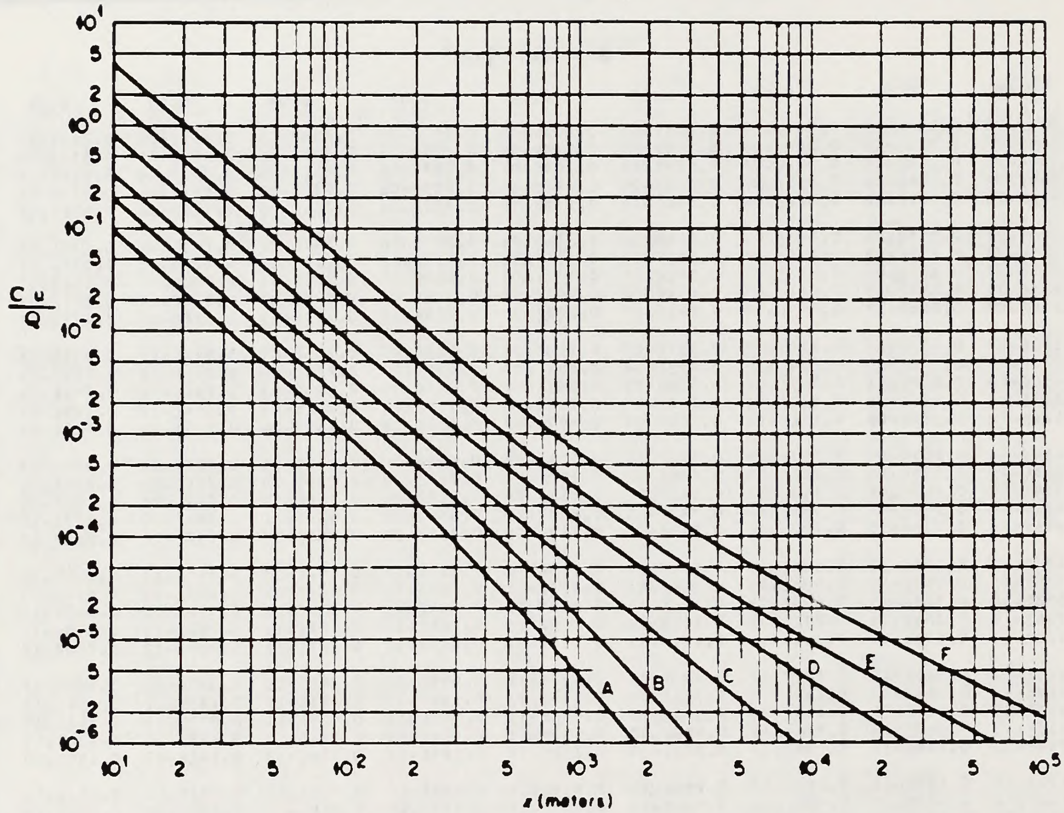

Figure 4.10-5

Values of $\frac{Cu}{Q}$ for a Ground Level Source

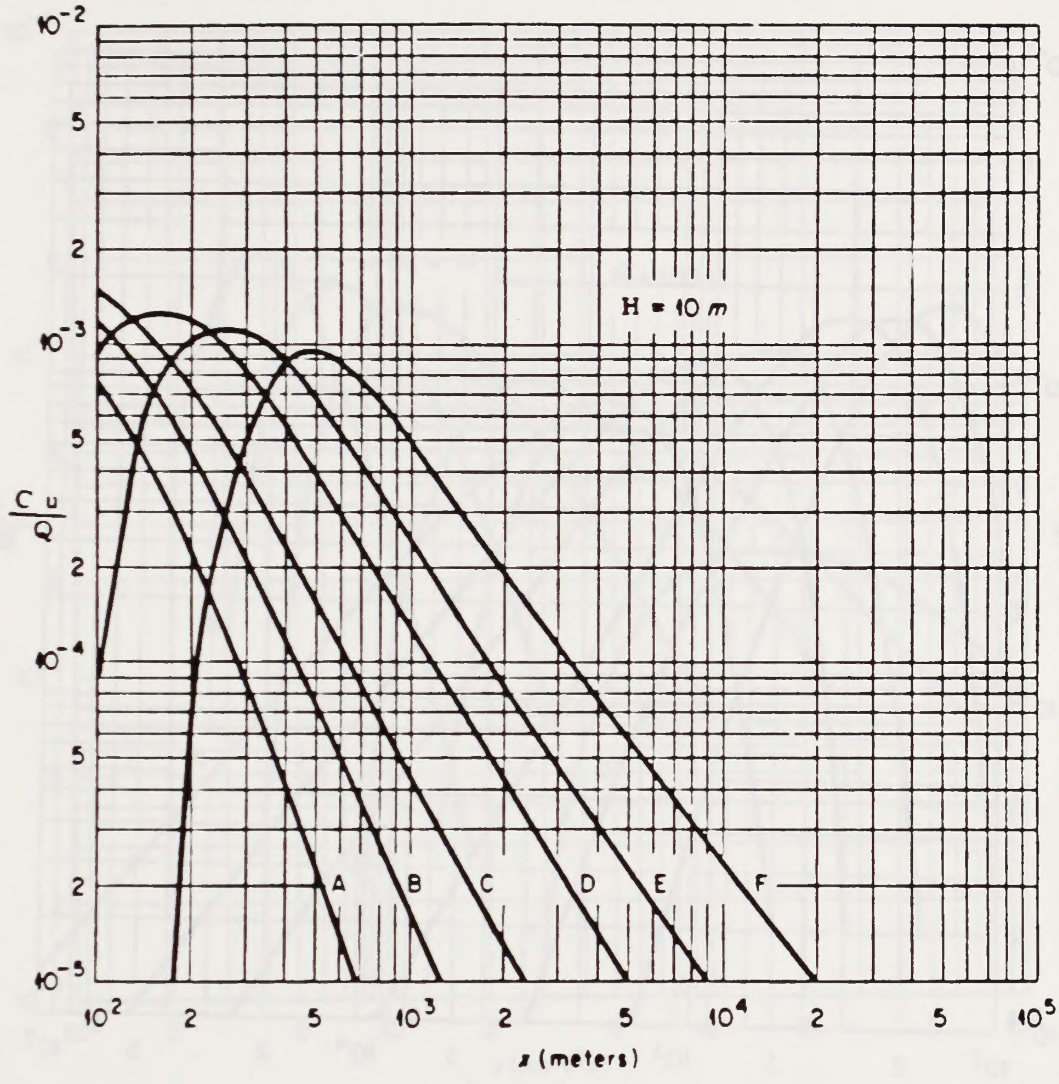

Figure 4.10-6

Values of $\frac{Cu}{Q}$ for H = 10 meters

1 meter = 39.37 inches

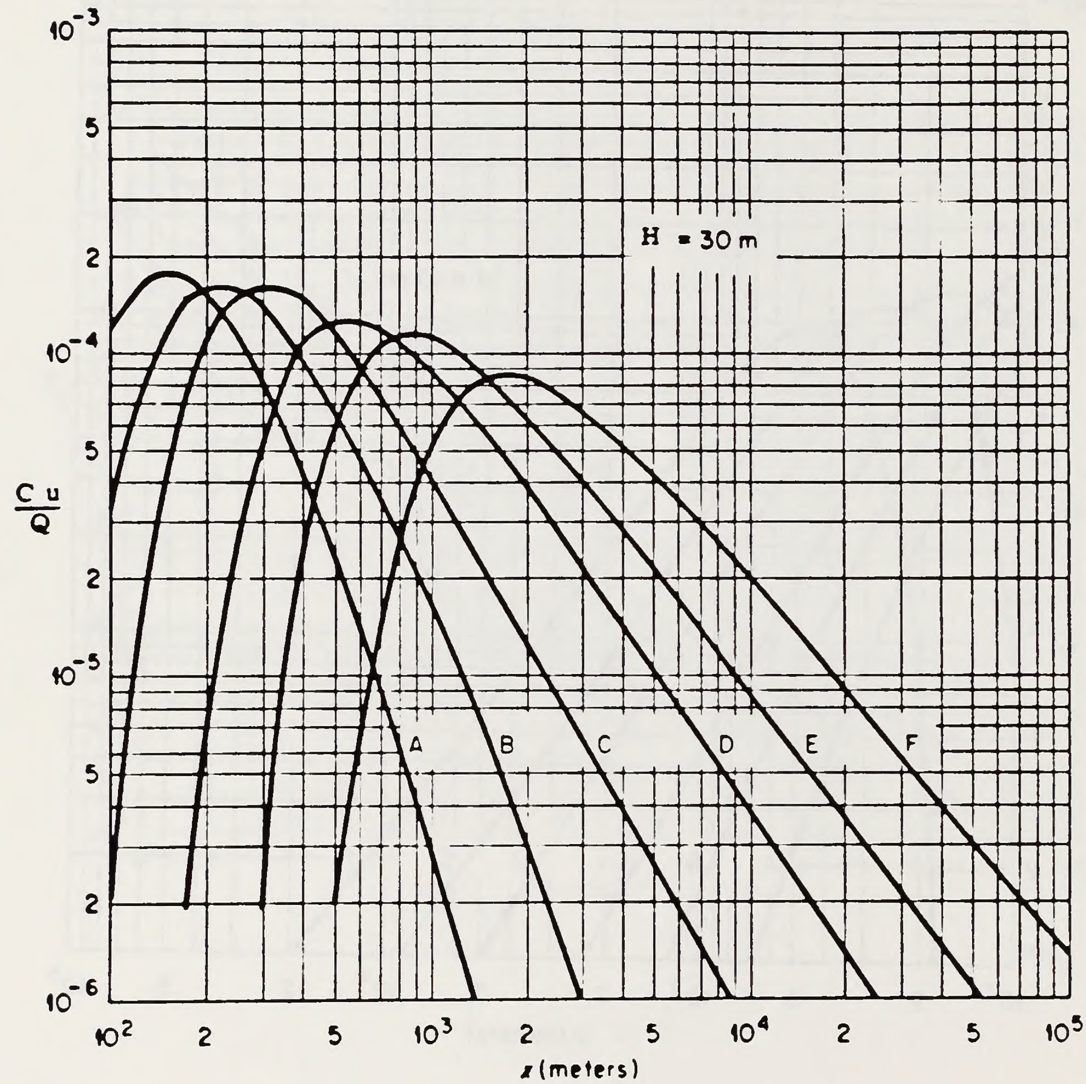

Figure 4.10-7

Values of $\frac{Cu}{Q}$ for H = 30 meters

1 meter = 39.37 inches

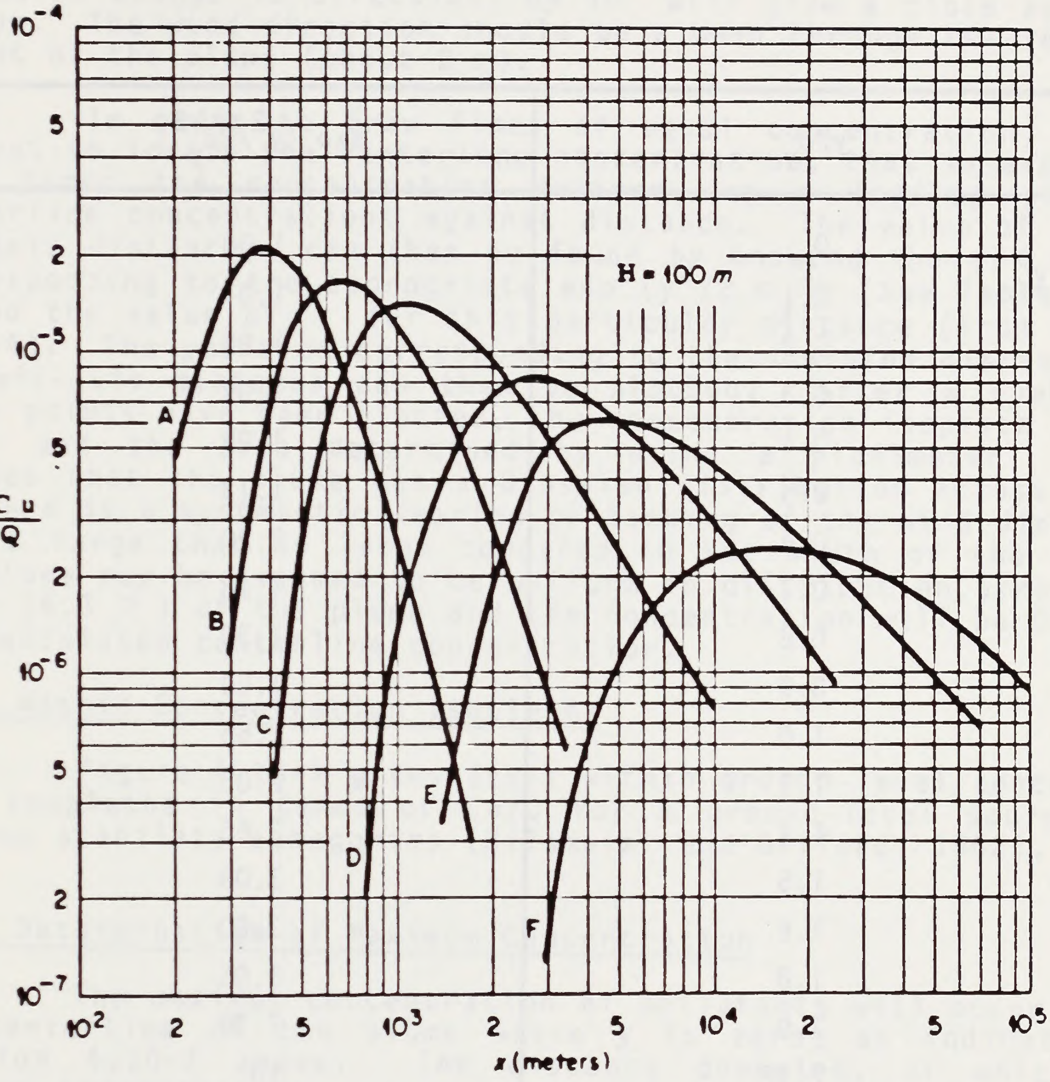

Figure 4.10-8

Values of $\frac{Cu}{Q}$ for H = 100 meters

1 meter = 39.37 inches

Table 4.10-3

Values of Exp $(y^2/2\sigma_y^2)$ for y/σ_y

y/σ_y	$\exp(y^2/2\sigma_y^2)$
0	1.00
0.1	1.01
0.2	1.02
0.3	1.05
0.4	1.08
0.5	1.13
0.6	1.20
0.7	1.28
0.8	1.38
0.9	1.50
1.0	1.65
1.2	2.05
1.4	2.66
1.5	3.08
1.6	3.60
1.8	5.05
2.0	7.39
2.15	10
3.04	10^2
3.72	10^3
4.29	10^4
4.80	10^5

It may be of interest in a given application to plot the position of the centerline of the plume and to determine areas covered by concentrations greater than a given magnitude. First the axial position of the plume must be known. The mean wind direction will determine the position. The surface wind may be used up to 1 km. Between 1 km and 100 km, the average of the surface direction and the geostrophic direction backed (counter-clockwise change in direction) by 10^0 will give a close approximation. The wind direction should be a mean through the vertical extent of the plume (about 2 σ_z).

In order to draw lines of equal concentration, it is easiest to locate the centerline concentration, that is exp $(y^2/2 \sigma_y^2)$ times the concentration desired, on a log/log plot of centerline concentrations against distance. The value of y (the off-axis distance), can then be found by knowing the y/σ_y value corresponding to the appropriate exp $(y^2/2 \sigma_y^2)$ (See Table 4.10-3) and the value of for this particular distance (from Figure 4.10-4). The position corresponding to the downwind distance and the off-axis distance can then be plotted. After a number of these points have been plotted, the concentration isopleth may be drawn and the area determined by using a planimeter. This assumes that the plume has a Gaussian distribution across wind. If there is a systematic veering or backing of the wind direction over a range that is large compared to the width of the trace, the plume may be assumed to be uniform in distribution across the width (4.3 σ) of the plume and the concentration will be 0.58 of the calculated centerline concentration.

Areas Within Concentration Isopleths

Figure 4.10-9 gives areas within ground-level concentration isopleths in terms of Cu/Q for a ground-level source for various stability categories (Hilsmeier and Gifford, 1962).

Rapid Determination of Maximum Concentration

The maximum concentration of pollutants will occur along the centerline of the plume where y is zero, as indicated in equation 4.10-7 above. The distance downwind, at which the maximum concentration occurs at ground level, is a function of effective source height and stability. Figure 4.10-10 is a nomogram from which the relative value of the maximum concentration can be determined given the stability and effective source height. If the relative value of that concentration is multiplied by $Q/\bar{u}$, the maximum concentration for a specific set of conditions is obtained. The nomogram is designed for source strength expressed in grams/sec and wind speed in meters/sec.

Accuracy of Computations

The method will, in general, give only approximate estimates of concentrations, especially if wind fluctuation measurements are not available and estimates of dispersion are

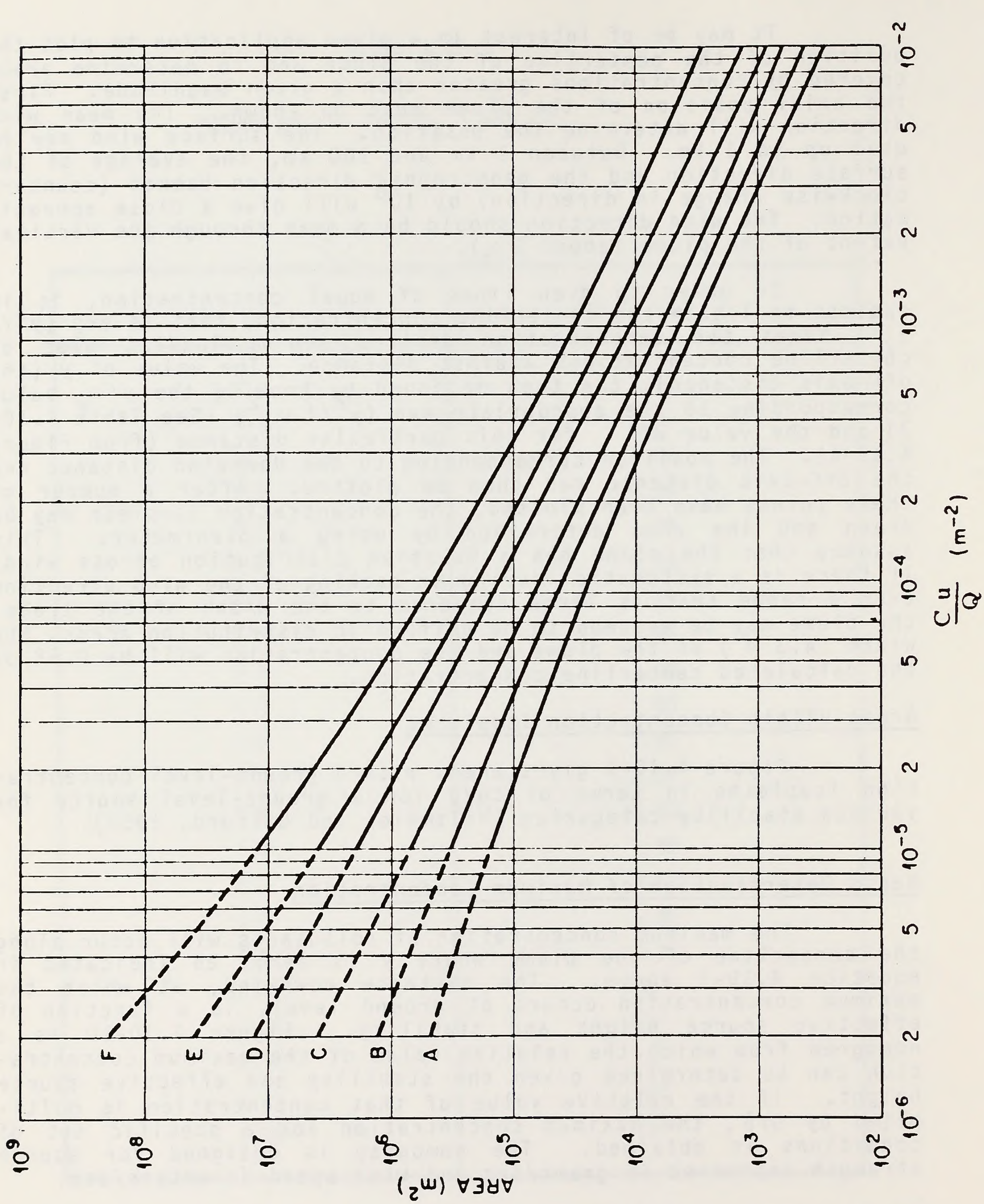

Figure 4.10-9

Area Within Ground Level Concentration Isopleths for Values of Cu/Q and Atmospheric Stability

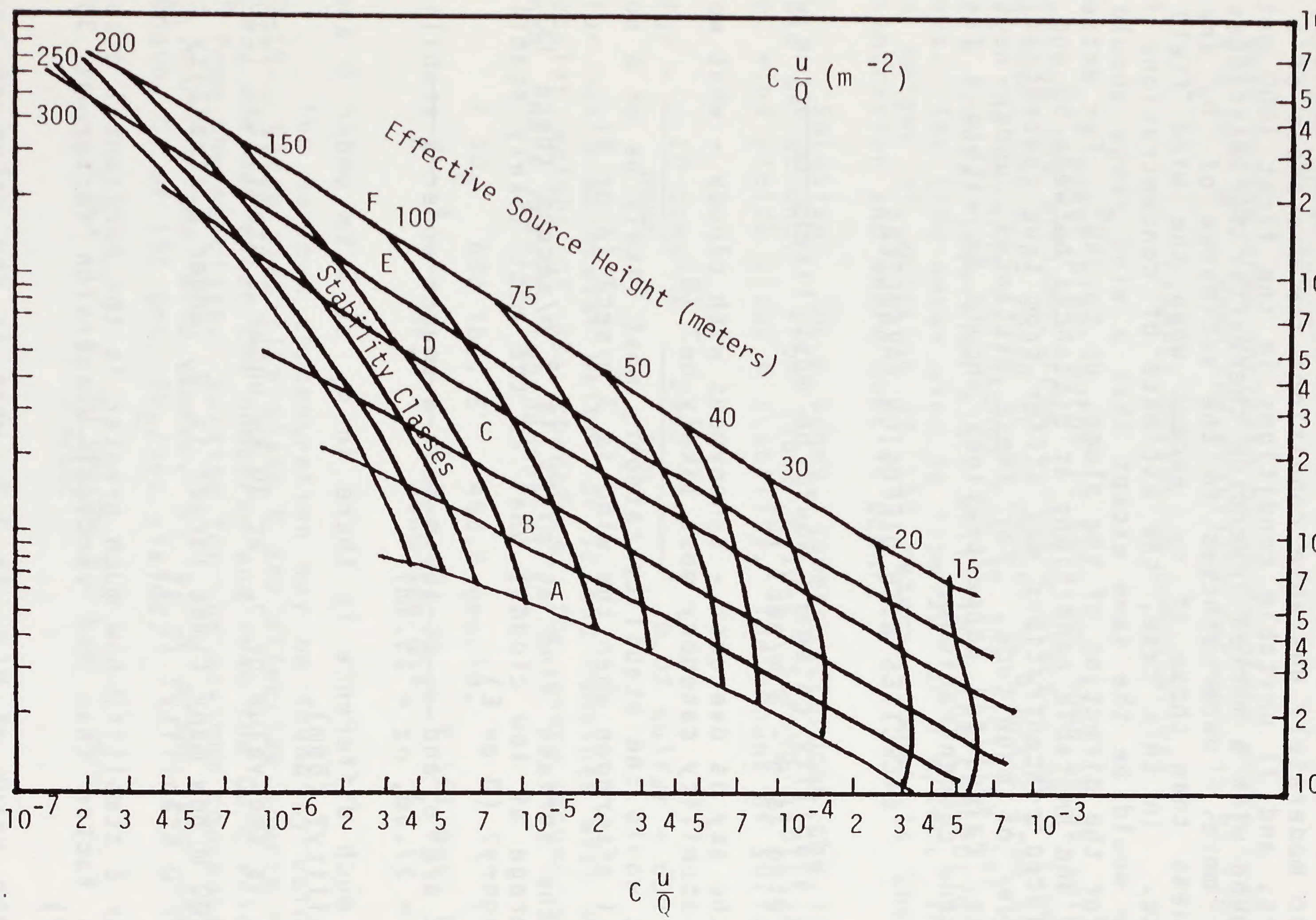

Figure 4.10-10

Distance from Source and Relative Value of Maximum Concentations for Various Source Heights and Stability Classes

1 meter = 39.37 inches

obtained from Figures 4.10-3 and 4.10-4. In the unstable and stable cases, errors of σ_z of several fold may occur for longer travel distances. There are cases where σ_z may be expected to be within a factor of 2. These are: 1) all stabilities for distances of travel of a few hundred meters in open country; 2) neutral to moderately unstable conditions for distances of a few kilometers; and 3) unstable conditions in the first 1000 meters above ground with a marked inversion thereafter for distances of 10 km or more. Uncertainties in the estimates of σ_y are in general less than those of σ_z except when the wind field is indefinite. In this case, the estimate of concentrations from the plume would be the same except that a wind range should be allowed for the direction of the plume, up to 360^o. For extremes of stable and unstable conditions at distances between 50 and 100 km calculated concentrations may differ from true concentrations by an order of magnitude. For these distances, under neutral conditions, calculated concentrations should be within a factor of 5 of true concentrations.

EXERCISES WITH DIFFUSION PARAMETERS

1. What stability category would be most likely to occur when the wind is 6 - 8 m/sec? (D)

2. If the sky is overcast - synonymous with cloudy - what would the stability category most likely be? (D)

3. What would the stability category most likely be on a sunny April afternoon when the wind is 3 m/sec? (A or B)

4. If the surface wind at night is 3 m/second there is 5/8 coverage of low clouds, what is the most likely stability category? (D or E)

5. What are σ_y and σ_z at 150 m from a source under B stability? (σy = 27.5m, σz = 15.5m)

6. How much difference is there in σ_z at 5 km under D and F stability? (55m)

7. What is the value of σ_y at 30 km under C stability? (2200m)

8. At 300 m how many times larger is σ_y under B stability than under D stability? (2.4)

9. Under E stability how much greater is the horizontal dispersion factor than the vertical dispersion factor at 300m? (7.7)

10. If the value of H/σ_z is 1.8, what is the value of exp - - 1/2 $(H/\sigma_z)^2$? (1.6)

11. The value of exp - $1/2(H/\sigma_z)^2$ is 2.2×10^{-3}. What is H/σ_z? (3.49)

12. Under D stability and a wind speed of 5 m/sec, a plume is emitted at 100 m above the ground. What is the value of C/Q at 4 km?
(1.4×10^{-6} sec/m^3)

13. What is the area enclosed by an isopleth whose Cu/Q value is 4×10^{-4} m^{-2}, when the stability category is B? ($10^4 m^2$)

EXAMPLE DIFFUSION COMPUTATIONS

#1 A power plant burns 10 tons per hour of 3% sulfur coal, releasing the effluent from a single stack. On a sunny summer afternoon, the wind speed at 10 meters is 4 m/sec from the north-east. The morning radiosonde run in the vicinity has indicated that a frontal inversion aloft will limit the convection to 1500 meters. The 1200 meter wind is from 30^o at 5 m/sec. The effective height of emission is 150 meters. What is the maximum concentration and where does it occur?

Solution: On a sunny, summer afternoon the insolation should be strong. From Table 4.10-1, strong isolation and 4 m/sec wind yields class B stability. The amount of sulfur burned is:

$$\text{Sulfur} = \frac{10 \text{ tons}}{\text{hour}} \text{ X } \frac{2000 \text{ lbs}}{\text{ton}} \text{ X } 0.03 \text{ sulfur} = 600 \text{ lbs/hr.}$$

Sulfur has a molecular weight of 32 and combines with O_2 with a molecular weight of 32; therefore, for every pound of sulfur burned, there results two pounds of SO_2.

$$Q = \frac{2 \ SO_2}{S} \text{ X } \frac{600 \text{ lbs. S}}{\text{hr.}} \text{ X } \frac{453.6 \text{ gms/lb.}}{3600 \text{ sec/hr}} = 151 \text{ gms. } SO^2\text{/sec.}$$

The maximum concentration may be found by using Figure 4.10-10. Given stability class B and effective source height of 150 m., one may enter the nomogram and read the Cu/Q value of 8×10^{-6} from the abscissa. Solving for the maximum concentration, $C_{(max)}$, using the wind speed, u, of 4 m/sec and the source strength, Q, of 151 gms. SO_2/sec yields.

$$C_{(max)} = 8 \times 10^{-6} \times \frac{151 \text{ gms/sec}}{4 \text{ m/sec}} = 3 \times 10^{-4} \text{ gm/m}^3$$

The distance from the power plant at which the maximum concentration occurs under these meteorological conditions can be read from the ordinate in Figure 4.10-10. This distance is 1000m.

#2 Using the conditions in the above problem, draw a graph of centerline sulfur dioxide concentrations beneath the plume with distance from 100 meters to 100 km.

Solution: Since the frontal inversion limits the convection to h_1 = 1500 meters, the distance where σ_z = 0.47 h_1 = 700 meters is x_1 = 5.5 km. At distances equal to or greater than 2 x_1 = 11.0 km, σ_z= 0.8 h_1 = 1200 meters. Equation 4.10-7 is used to find concentration as a function of distance.

$$C = \frac{151}{\pi u \sigma_y \sigma_z} \exp - \frac{1}{2} \left(\frac{H}{\sigma_z} \right)^2$$

In this case H = 150 meters. Solutions for this equation are given in Table 4.10-4. The values of concentrations in Table 4.10-4 are plotted against distance in Figure 4.10-11.

#3 Draw a graph of concentration versus cross-wind distance at a downwind distance of 800 meters for the conditions of problems 1 and 2.

Solution: From problem 2, the centerline concentration at 800 meters is 2.9×10^{-4} gms/m^3. To determine the concentrations at distances y from the x axis, the centerline concentration must be multiplied by the factor $\exp -1/2(y/\sigma_y)^2$. σ_y= 120 meters at x = 800 meters. Values for this computation are given in Table 4.10-5.

The preceeding exercises illustrate one of the simplest approaches to air quality modeling. Numerous levels of sophistication can be incorporated into the basic Gaussian modeling approach to determine pollution concentrations at downwind receptor locations. As mentioned before, the next level incorporates mathematical simulations of plume rise. Plume rise is mainly a function of momentum and thermal buoyancy. Terms related to one or both of these factors are included in nearly all plume rise formulas. For cold stacks (JETS), those with emissions of less than 10 to 20°F above ambient, momentum is probably the most important factor. On the other hand, for hot stacks, when gases are warmer than 200°F, buoyancy is the most important aspect of the plume rise formula. Numerous plume rise formulas have been proposed by a multitude of qualified investigators. No one formula provides the best estimate for all types of stacks and atmospheric conditions. The most widely accepted plume rise formulas were derived by Holland (1953) and Briggs (1969). The basics of their plume rise simulation formulae are applied by most Environmental Protection Agency (EPA) accepted air quality models.

Table 4.10-4
Solutions for Problem #2

Col. a	Col. b	Col. c	Col. d	Col. e	Col. f	Col. g
x (km)	u (m/sec)	σ_y m	σ_z m	H/σ_z	$\exp - \frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2$	C gms/m^3
0.3	4	52	30	5.0	3×10^{-6}	2.3×10^{-8}
0.5	4	77	53	2.83	1.7×10^{-2}	5.0×10^{-5}
0.8	4	120	93	1.61	0.27	2.9×10^{-4}
1	4	150	125	1.20	0.48	3.1×10^{-4}
2.8	4.5	375	700	0.21	0.98	4.0×10^{-5}
5.6	4.5	700	1200	0.125	0.98	1.25×10^{-5}
10	4.5	1200	1200	0.125	0.98	7.3×10^{-6}
100	4.5	8400	1200	0.125	0.98	1.04×10^{-6}

Col. c from Figure 4.10-4
Col. d from Figure 4.10-3
Col. e 150 m over value in Col. d
Col. f Value in Table 4.10-2 corresponding to H/σ_z in Col. e
Col. g Solution to equation 4.10-7

Table 4.10-5

y (m)	y/σ_y	$\exp - \frac{1}{2}(y/\sigma_y)^2$	C(y) gms/m^3
± 100	0.834	0.7	2.03×10^{-4}
± 200	1.67	0.25	7.25×10^{-5}
± 300	2.5	4.2×10^{-2}	1.22×10^{-5}
± 400	3.33	3.7×10^{-3}	1.07×10^{-6}

This is graphed in Figure 4.10-12

1 m = 3.281 feet
1 km = 0.6214 miles
1 m/s = 3.281 feet/second
1 gm/m^3 = 6.243×10^{-7} lbs/feet^3

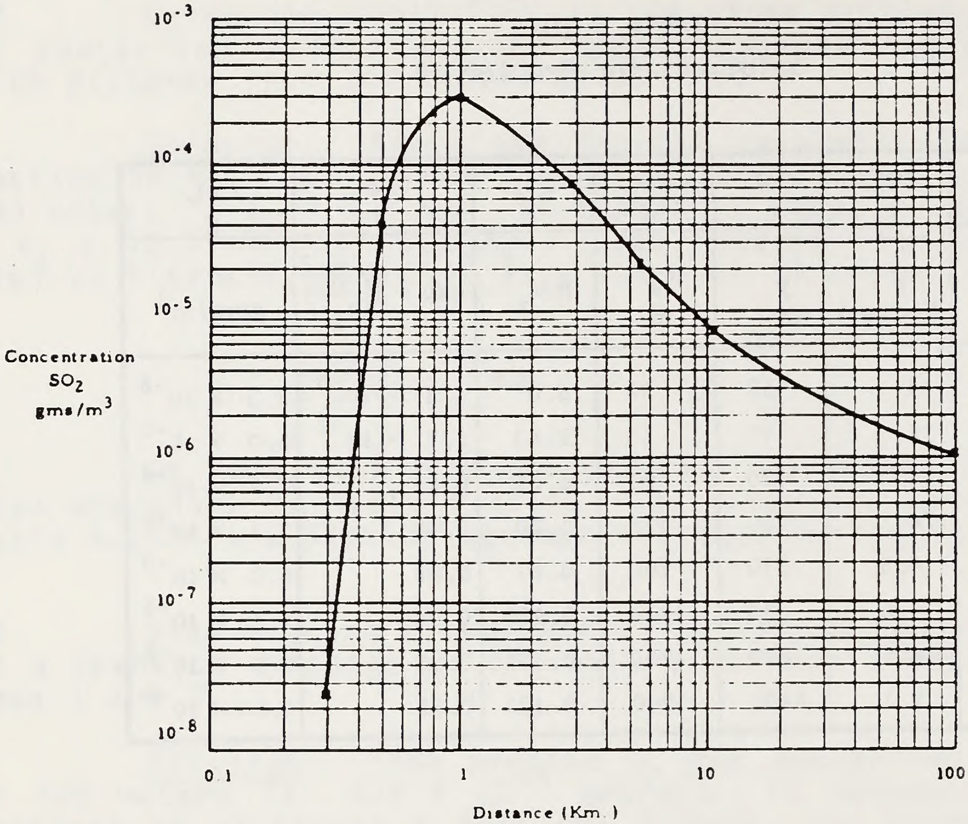

Figure 4.10-11

Concentration of SO_2 (gms/m^3) as a Function of Distance (km). (Problem 2)

1 gm/$_m$3 = 6.243 x 10^{-7} lbs/ft^3

1 km = 0.6214 mi

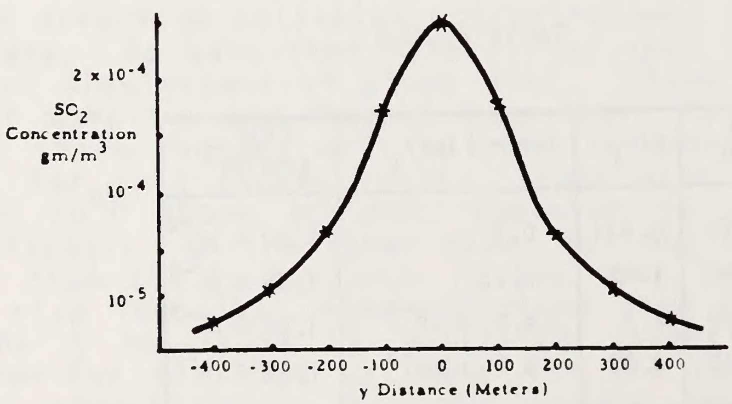

Figure 4.9-12

Concentration of SO_2 (gms/m^3) Across Wind at a Distance of 800 Meters (Problem 3)

1 gm/$_m$3 = 6.243 x 10^{-7} lbs/ft^3

1 m = 1.094 yds

Briggs in his recent publication, Plume Rise (1969), has presented both a critical review of the subject and a series of equations applicable to a wide range of atmospheric and emission conditions. These equations are being employed by an increasing number of meteorologists and are used almost exclusively within EPA. An important result of this study is that the rise of buoyant plumes from fossil-fuel plants with a heat emission of 20 megawatts (MW) - 4.7 x 10^6 cal/sec - or more can be calculated from the following equations under neutral and unstable conditions.

$$\Delta H = 1.6 F^{1/3} u^{-1} x^{2/3} \qquad 4.10\text{-}8$$

$$\Delta H = 1.6 F^{1/3} u^{-1} (10 h_s)^{2/3} \qquad 4.10\text{-}9$$

where:

ΔH = plume rise
F = buoyancy flux
u = average wind at stack level
x = horizontal distance downwind of the stack
h_s = physical stack height

Equation 4.10-8 should be applied out to a distance of 10 h_s from the stack and equation 4.10-9 can be used for greater distances.

The buoyancy flux term, F, may be calculated from:

$$F = \frac{g\,Q_H}{\pi\, c_p\, \rho T} \simeq 3.7 \times 10^{-5}\ \frac{m^4/sec^3}{cal/sec}\ Q_H \qquad 4.10\text{-}10$$

where:

g = gravitational acceleration
Q_H = heat emission from the stack, cal/sec
c_p = specific heat of air at constant pressure
ρ = average density of ambient air
T = average temperature of ambient air

Alternatively, if the stack gases have nearly the same specific heat and molecular weight as air, the buoyancy flux may be determined from:

$$F = \frac{\Delta T}{T_s}\, g\, v_s\, r^2 \qquad 4.10\text{-}11$$

Notation has been previously defined.

In stable stratification, equation 4.10-8 holds approximately to a distance $x = 2.4\ us^{-1/2}$. S may be defined as a stability parameter:

$$s = \frac{g}{T} \quad \frac{\partial \theta}{\partial z} \qquad 4.10\text{-}12$$

where:

$\frac{\partial \theta}{\partial z}$ = lapse rate of potential temperature

Beyond this point the plume levels off at about

$$\Delta H = 2.4 \left(\frac{F}{u\ s} \right)^{1/3} \qquad 4.10\text{-}13$$

However, if the wind is so light that the plume rises vertically, the final rise can be calculated from:

$$\Delta H = 5.0\ F^{1/4}\ s^{-3/8} \qquad 4.10\text{-}14$$

For other buoyant sources, emitting less than 20 MW of heat, a conservative estimate will be given by equation 4.10-8 up to a distance of:

$$x = 3x^* \qquad 4.10\text{-}15$$

where:

$$x^* = 0.52 \quad \left[\frac{sec^{6/5}}{ft.^{6/5}} \right] \quad F^{2/5}\ h_s^{3/5=} \qquad 4.10\text{-}16$$

which is the distance at which atmospheric turbulence begins to dominate entrainment.

Sophisticated modeling more complex than the simple Gaussian are often required. These sophisticated algorithms applied to the basic Gaussian approach include the computation of downwind ground level concentrations as a function of stability class and wind speed. Such an approach would incorporate wind speeds as a function of stability class. Further sophistication in the Gaussian modeling approach would incorporate relative frequency distributions of wind speeds, wind direction and stability class. This type of model would be useful in isolating long-term air pollution concentrations in the study area.

There is a limitless number of levels of sophistication with regard to the Gaussian model. The accuracy and refinement of each generation of the model depends upon the quality and resolution of the data base used. As the problem becomes more complex, more sophisticated numerical models must be employed particularly in instances where terrain or conversion effects become important. Such modeling is beyond the scope of this document, however the EPA may be contacted for more information on dispersion models such as the Climatological Dispersion Model (CDM), the Air Quality Display Model (AQDM), the Valley Model, and the Texas Climatological Model (TCM).

4.11 ASSISTANCE IN DISPERSION METEOROLOGICAL PROBLEMS

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- Abstracts

  Meteorological and Geoastrophysical Abstracts
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  45 Beacon Street
  Boston 8, Mass.

- Periodicals

  Bulletin of the American Meteorological Society
  American Meteorological Society (See above)

  Journal of Applied Meteorology
  American Meteorological Society

  Journal of the Atmospheric Sciences (formerly Journal of Meteorology)
  American Meteorological Society

  Monthly Weather Review
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  49 Cromwell Road
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- Books

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  Geiger, R. (Transplanted by Scripta Technica Inc.) The Climate Near the Ground.
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Professional Meteorological Consultants

Professional meteorologists advertise their services in the Professional Directory section of the Bulletin of the American Meteorological Society. In the May 1979 Bulletin, 83 such firms and individuals were listed. The American Meteorological Society has in the last several years instituted a program of certifying consulting meteorologists. Of the 83 professional services listings in the Bulletin, 40 list Certified Consulting Meteorologists.

Local U.S. National Weather Service Office

A wealth of meteorological information and experience is available at the local city or airport Weather Service Office pertaining to local climatology, pecularities in local micro-meteorological conditions including topographic effects, and exposure and operating characteristics of meteorological instruments. The Air Stagnation Advisories are received here by teletype from the National Meteorological Center. Often the public telephones the Weather Service with air pollution complaints which the meteorologists may have traced back to a specific source by examining local wind circulations. Through personal contact with the meteorologist-in-charge (MIC), specific, localized forecasts may be arranged to support a short-term air pollution investigation or sampling program.

Contract Work

Many universities do contract work for private organizations and for government agencies on meteorological problems.

4.12 GLOSSARY OF TERMS

Adiabatic	A thermodynamic change of state of a system in which there is no transfer of heat or mass across the boundaries of the system. In an adiabatic process, compression always results in warming, expansion in cooling.
Adiabatic Diagram	A thermodynamic diagram with temperature as abscissa and pressure to the power 0.286 as ordinate, increasing downward.
Advection Inversion	A type of inversion which occurs over an area due to the horizontal transport of a stable layer (e.g., marine inversion noted along coastal California are the result of the advection of cool, stable air from the nearby Pacific.
Aerodynamic	Pertaining to forces acting upon any moving solid or liquid body other than a stationary object relative to a gas (especially air).
Air Basin	An area created by topographic boundaries which serves to contain air pollutants emitted into the area by pollution sources and to restrict air exchange with other air basins.
Air Flow Pattern	The typical movement of air currents as graphed on wind roses.
Air Parcel	An imaginary body of air to which may be assigned any or all of the basic dynamic and thermodynamic properties of atmospheric air.
Algorithm	A procedure for solving a problem (as in mathematics) that frequently involves repetition of an operation.
Backing	According to general internationally accepted usage, a change in wind direction in a counterclockwise sense.
Bimodal	A distribution having two maxima.
Black Body	A body which absorbs all incident electromagnetic radiation; i.e., one which neither reflects nor transmits any incident radiation.
Buoyancy Flux	An empirical term used in plume rise calculations to define the heat content of an industrial source.

Burn/No-Burn	Used to determine when weather conditions Forecasts favor the rapid dispersion of pollutants created by the burning of agricultural wastes and other industrial operations.
Calm	A period when the air is motionless. In the United States, the wind is reported as calm if it has a speed of less than one mile per hour (or one knot).
Centerline Concentration	The concentration of gaseous pollutants or aerosols at the center of the plume.
Channeling	The effect of terrain, particularly valleys, in modifying the prevailing winds along the path of lowest terrain heights.
Cold Stacks (Jets)	Cold, non-buoyant sources with emission temperatures less than 10 to 20°F above ambient temperatures.
Condensation Levels	The level at which a parcel of moist air lifted dry adiabatically would become saturated.
Coning	When the vertical temperature gradient is between dry adiabatic and isothermal, slight instability occurs with both horizontal and vertical mixing. An industrial plume tends to become cone shaped, hence the name.
Constant Level Balloons	A balloon designed to float at a constant pressure level.
Convective Thundershowers	Showers caused when layers of air are forced to rise rapidly.
Diffusion	In meteorology, the exchange of fluid parcels between regions in space, in the apparently random motions of a scale too small to be treated by the equations of motion.
Digitized Data	Data which is recorded in a computer acceptable format (as opposed to analog or strip chart data).
Dispersion Modeling	The mathematical representation or simulation of transport precesses that occur in the atmosphere.
Dispersion Potential	The ability of a system such as the atmosphere, to dilute the concentration of a sub stance or pollutant by molecular and turbulent motion; e.g., smoke in the air.

Diurnal	Daily, especially pertaining to actions which are completed within twenty-four hours and which recur every twenty-four hours.
Downwash	The condition resulting when strong winds push a plume rapidly to the surface, resulting in high ground-level pollution concentrations. The phenomenon is usually observed in the lee of buildings.
Drainage Flow	The movement of cold air off high ground, caused by gravity and typical of mountainous regions.
Dry Adiabatic Rate	The rate of decrease of temperature with Lapse height when dry air is lifted adiabatically (due to expansion as it is lifted to lower pressure).
Effective Stack	The physical stack height plus plume rise, i.e., the point above ground at which the gaseous effluent becomes esentially level.
Elevated Inversion	An inversion layer above the immediate surface. Such an inversion inhibits dispersion of bouyant pollutants, such as those given off by power facilities and refineries.
Empirical	An approach based upon observation and experimentation.
Environmental Lapse Rate	The actual rate of decrease of temperature with elevation at at given time and place.
Exit Characteristics	Parameters pertaining to a gas exiting from a stack including gas temperature, exit velocity, emission rate, stack height, and stack diameter.
Fanning	When the atmosphere is stabily stratified, an industrial plume will spread horizontally but little if any vertically.
Fire Management	The practice of controlling range undergrowth, such as chapparal, through controlled burning.
Fire Weather	The state of the weather with respect to its effect upon the kindling and spreading of forest fires.
Fluid Dynamics	The level of physics that treats the action of force on fluids and gases in motion or at rest.

Freezing Level	The lowest altitude in the atmosphere over a given location at which the air temperature is 32°F.
Front	The transition zone between two air masses of different densities.
Frontal Inversion	A temperature inversion encountered in the atmosphere, upon vertical ascent through a sloping front.
Fugitive Dust	Solid air borne particles emitted from any source other than a stack.
Fugitive Source	A source emitting pollutants other than from a stack.
Fumigation	The rapid mixing of a fanning plume down to the ground, such as during inversion breakup.
Gaussian Diffusion Equation	An equation used to evaluate the concentration of gases or aerosols assuming a Gaussian or normal distribution.
Horizontal Dispersion Coefficient	The horizontal standard deviation of plume pollutant concentration. The parameter varies as a function of downwind distance and atmospheric stability.
Induced Flow	A flow of air caused by uneven heating of terrain and its associated air parcels.
Insolation	Solar radiation received at the earth's surface.
Inversion	A departure from the usual decrease or increase with altitude of the value of an atmospheric property (almost always of temperature). In a temperature inversion, temperature increases with altitude. A temperature inversion is stable, allowing little turbulent exchange to occur.
Inversion Layer	That layer of air which departs from the usual decrease in temperature with increasing altitude.
Isopleth	A line of equal or constant value of a given quantity, with respect to either space or time.
Isothermal	Of equal or constant temperature, with respect to either space or time.

Jet (Low-Level)	A high-speed wind that attains its velocity through channeling due to terrain configuration such as a narrow mountain pass or canyon.
K-Theory	K-theory or gradient transport theory assumes that turbulent diffusion is proportional to the local mean concentration gradient.
Land Breeze	A coastal breeze blowing from land to sea, caused by the temperature difference when the sea surface is warmer than the adjacent land.
Lapse Rate	The decrease of an atmospheric variable (almost always temperature) with height.
Line Source	A source of pollutants occurring at a reasonably continuous rate along a fixed line (e.g., highway).
Lofting	Lofting of an industrial plume occurs when there is a superadiabatice layer above a surface inversion. It is a condition which encourages diffusion upward but not downward because of the presence of a stable layer below.
Looping	The looping of an industrial plume occurs with a superadiabatic lapse rate.
Mixing Height/ Depth	Height (Depth) of the layer of air where well-mixed conditions exist, usually the height of the first significant inversion above the surface.
Mixing Layer	That thin layer of the troposphere available for the dispersion of pollutants released near the surface.
Momentum Exchange	The turbulent transfer of momentum; the product of mass and velocity.
Mountain Flow	The regular flow of air around portions of raised terrain. Air will stream toward and up mountain slopes during the day and downward and away during the night.
Neutral Atmospheric Stability	Neutral stratification of the atmosphere, i.e., the lapse rate is equal to the dry-adiabatic lapse rate, therefore, a parcel of air displaced vertically will experience no buoyant acceleration.
Nocturnal Air Flow	A flow pattern characteristic of clear nights and rapid radiational cooling, which tends to stabilize the atmosphere promoting air flow from higher terrain towards low lying areas.

Nucleation	The condensation out of molecules on airborne particles.
Numerical Modeling	The development of a means of computing the future state of the atmosphere from the basic theoretical equations which govern that state.
Orographic	Of, pertaining to, or caused by mountains.
Pasquill's Stability Categories	Stability classes as defined by Dr. F. Pasquill of the British Meteorological Service, including extremely unstable, unstable, slightly unstable, neutral, slightly stable, and stable.
Persistence	Time period over which a certain parameter is maintained.
Physical Modeling	Physical modeling is based uopon the actual simulation of events in the real atmosphere or in a scale model.
Physical Stack Height	Actual height of a stack, i.e., a pollutant source.
Plume	A large, conspicuous cloud of smoke, dust, or water vapor arising from a stack.
Plume Rise	The velocity and heat of an industrial source will cause it to rise to a certain height. The difference between this height and the physical stack height is called plume rise.
Positive Net Radiation	Amount of incoming solar radiation in excess of outgoing terrestrial radiation.
Prevailing Wind(s)	The wind direction(s) most frequently observed during a given period.
Profile	A graph of the value of a scalar quantity (such as temperature) versus a horizontal, vertical, or time scale.
Pseudo-Adiabatic Lapse Rate	The rate of decrease of temperature with height of an air parcel lifted at saturation through the atmosphere. Less than the dry adiabatic lapse rate.
Radiational Cooling	Cooling of the earth's surface and surrounding air accomplished (mainly at night) whenever the earth's surface experiences a net loss of heat.
Radiational Inversion	An inversion at the surface due to radiation cooling.

Radiosonde	A balloon-borne instrument used for measuring and transmitting weather data, such as pressure, temperature and humidity.
Re-entrainment	The mxing of environmental air into an organized air current of which it formally was a member.
Regime	The character of the seasonal distribution of a weather phenomenon at any place; e.g., the summer sea breeze regime.
Screening Level	A simplistic approach designed to determine the need for additional, more detailed analyses.
Sky Cover	The amount of sky covered or concealed by clouds or other obscuring phenomena.
Slope Winds	Winds caused by uneven surface heating and cooling in areas of rugged terrain.
Smoke Sensitive Area	An area which, due to high population density, recreational value or scenic beauty, is con sidered particularly sensitive to smoke plumes from forest management burning.
Solar Altitude	The elevation angle of the sun above the horizon.
Solar Insolation	Solar radiation received at the earth's surface.
Sorption	The deposition of molecules due to collision with an object.
Sounding	Any penetration of the natural environment for scientific observation. In meteorology, commonly refers to the environmental lapse rate.
Stability	A measure of the extent to which vertical and horizontal mixing will take place. Commonly measured as unstable, neutral or stable.
Stable	The lapse rate is less than the dry adiabatic lapse rate and vertical motion is suppressed.
STAR (STability ARray)	A description of a type of meteorlogical program developed by the National Climatic Center in Asheville, North Carolina. The program provides joint frequency distributions of wind speed, wind direction, and atmospheric stability class.

Stability Wind Roses	Diagrams designed to show the distribution of wind direction experienced at a given location over a desired time period for a given atmospheric stability class.
Stack	Any chimney, flue, conduit, or duct arranged to conduct emissions to the outside air.
Statistical Modeling	Statistical modeling is based upon the stochastic nature of turbulence and describes diffusion as an ensemble average of many particles emitted from a source.
Sub-Adiabatic	A lapse rate which is less than the dry adiabatic lapse rate (5.5°F per 1,000 feet).
Subsidence Inversion	A temperature inversion produced by the warming of a layer of descending air. The effect is the creation of a limited mixing volume below the stable layer.
Super-Adiabatic	A lapse rate which is greater than the dry adiabatic lapse rate.
Surface Based Inversion	An inversion layer of stable air close to the ground. Such an inversion inhibits dispersion of fugitive dust and other non-buoyant sources of pollutants.
Surface Boundary Layer	The thin layer of air immediately adjacent to the earth's surface.
Surface Data	Observations of the weather from a point at the surface of the earth, as opposed to upper-air or winds-aloft observations.
Surface Roughness	Irregulatities of the earth's surface (provided by trees, buildings, etc.) which increases air turbidity, and consequently, pollutant dispersion.
Synoptic Scale Winds	Strong winds created by weather patterns of high and low pressure systems in the lower troposphere.
Temperature Profile	A graph of temperature versus a horizontal, vertical, or time scale.
Temperature Sounding	Upper-air observations of temperature as taken by a radiosonde.
Thermal Buoyancy	The impetus provided by heat for an emission to rise or remain suspended in the atmosphere.

Thermal Low	An area of low atmospheric pressure due to high temperatures caused by intensive heating at the earth's surface.
Transport	The rate by which a substance or quantity, such as heat, suspended particles, etc., is carried past a fixed point.
Trapping	When an inversion occurs aloft such as a frontal or subsidence inversion, a plume released beneath the inversion will be trapped beneath it.
Trajectory Analyses	The depiction of regional wind direction patterns at the surface of the earth, as generated from the most frequent wind direction occurring at each of several stations in an area for selected averaging periods.
Tropopause	The boundary between the troposphere and the stratosphere.
Troposphere	The lowest 10 to 20 km (6-12 miles) of the atmosphere. It is characterized by decreasing temperature with height, appreciable vertical wind motion, appreciable water vapor content, and weather.
Typical Conditions	The most commonly occurring combination of the key dispersion factors - wind speed, wind direction, and atmospheric stability class. Knowledge of the most commonly occurring dispersion condidtions provides some indication of the effect of an existing or proposed pollution source.
Unstable	The environmental lapse rate is greater than the dry adiabatic lapse rate and vertical turbulence is enhanced.
Valley Winds	A wind which ascends a mountain valley during the day.
Veering	According to general international usage, a change in wind direction in a clockwise sense.
Ventilate	To cause to circulate as in the dispersion of air pollutants.
Vertical Circulation	The movement or mixing of air along a vertical axis.

Vertical Dispersion Coefficient	The vertical standard deviation of plume pollutant concentration. The parameter varies as a function of downwind distance and atmospheric stability.
Vertical Temperature Profile	A graph of temperature versus altitude.
Vertical Wind Profile	A graph of the variation of mean wind speed with height in the surface boundary layer.
Virtual Source	The theoretical location of a point source with respect to an actual area source which would result in plume dispersion at the actual point of emission indicative of the area source.
Wind Tunnel	A small scale model of the atmosphere which permits experimentation in the laboratory.
Winds Aloft	Wind speeds and directions at various levels in the atmosphere above the surface.
Worst-case Conditions	That combination of wind speed, wind direction, and atmospheric stability class that would result in the greatest possible pollutant impact of an existing or proposed source.

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5.0 BASELINE AIR QUALITY EMISSION LEVELS

5.1 FORMATION OF AIR POLLUTANTS

5.1.1 Introduction

Polluted atmospheres generally are associated with man's industrial and domestic activities. However, many of the major gaseous pollutants are also emitted by nature. Taken on a worldwide basis, the total mass of trace gases emitted by nature exceeds those emitted by man by several orders of magnitude. Nonetheless, man's activities do adversely affect the quality of the atmosphere, particularly in dense urban areas and near large emission sources. For many of the pollutants, serious long-term worldwide effects are feared. The effects may be immediate and obvious, such as poor visibility, eye irritation, and objectionable odors; or the effects may be noticeable only through longer periods of observation, such as in corrosion. More subtle effects require sophisticated statistical studies to determine such things as human health effects and changes in the earth's energy balance.

Table 5.1-1 compares typical concentrations of pollutants (Cadle, 1970) with those found in uncontaminated areas. It can be seen that the ratio of concentration of polluted air to clean air ranges from fractional to 1000-fold. Table 5.1-2 by Robinson and Robbins (1972) summarizes the worldwide sources, atmospheric concentrations, residence times, and removal reactions for eight principal gaseous air pollutants. Except for sulfur dioxide, emissions from natural sources exceed those from pollution sources. Figure 5.1-1 and 5.1-2 show the relationship between outdoor and indoor pollution levels for sulfur dioxide and carbon monoxide. Measurements such as these indicate serious penetration into homes near strong pollution sources (Benson, et. al., 1972).

5.1.2 The Gaseous Compounds of Carbon

The gaseous compounds of carbon found in natural and polluted atmospheres comprise a broad spectrum of the compounds of organic chemistry. Because carbon can form bonds with elements such as hydrogen, oxygen, nitrogen, and sulfur and at the same time combine with itself to form a series of straight and branched chain, cyclic, and combined cyclic-chain systems, an almost infinite number of compounds are possible. Many gaseous carbon compounds such as methane (marsh gas), carbon dioxide, carbon monoxide, the terpenes (Table 5.1-3 [Rasmussen, 1972]), and other volatile plant materials are emitted in nature through biological processes, volcanic action, forest fires, natural gas seepage, etc. In areas inhabited by man, the emissions of commerce, industry and transportation are largely concentrated in urban areas and generate high local concentrations of volatile solvents and fossil fuel combustion products.

Table 5.1-1

Comparison of Trace Gas Concentrations (ppm)

	Clean air	*Polluted air*	*Ratio polluted-to-clean*
CO_2	320	400	1.3
CO	0.1	40-70	400-700
CH_4	1.5	2.5	1.3
N_2O	0.25	(?)	—
$NO_2(NO_x)$	0.001	0.2	200
O_3	0.02	0.5	25
SO_2	0.0002	0.2	1000
NH_3	0.01	0.02	2

Table 5.1-2

Summary of Sources, Concentrations, and Major Reactions of Atmospheric Trace Gases

Contaminant	Major pollution sources	Natural sources	Estimated emissions (tons)		Atmospheric background concentrations	Calculated atmospheric residence time	Remoral reactions and sinks	Remarks
			Pollution	Natural				
O_2	Combustion of coal and oil	Volcanoes	146×10^6	No estimate	0.2 ppb	4 days	Oxidation to sulfate by ozone or, after absorption, by solid and liquid aerosols	Photochemical oxidation with NO_2 and HC may be the process needed to give rapid transformation of $SO_2 \rightarrow SO_4$
H_2S	Chemical processes, sewage treatment	Volcanoes, biological action in swamp areas	3×10^6	100×10^6	0.2 ppb	2 days	Oxidation to SO_2	Only one set of background concentrations available
CO	Auto exhaust and other combustion	Forest fires, oceans, terpene reactions	304×10^6	33×10^6	0.1 ppm	<3 years	Probably soil organisms	Ocean contributions to natural source probably low
NO/NO_2	Combustion	Bacterial action in soil (?)	53×10^6	NO: 430×10^6 NO_2: 658×10^6	NO: 0.2–2 ppb NO_2: 0.5–4 ppb	5 days	Oxidation to nitrate after sorption by solid and liquid aerosols, hydrocarbon photochemical reactions	Very little work done on natural processes
NH_3	Waste treatment	Biological decay	4×10^6	1160×10^6	6 ppb to 20 ppb	7 days	Reaction with SO_2 to form $(NH_4)_2SO_4$ oxidation to nitrate	Formation of ammonium salts is major NH_3 sink
N_2O	None	Biological action in soil	None	590×10^6	0.25 ppm	4 years	Photodissociation in stratosphere, biological action in soil	No information on proposed absorption of N_2O by vegetation
Hydrocarbons	Combustion exhaust, chemical processes	Biological processes	88×10^6	CH_4: 1.6×10^9 Terpenes: 200×10^6	CH_4: 1.5 ppm non CH_4: <1 ppb	4 years (CH_4)	Photochemical reaction with NO/NO_2, O_3; large sink necessary for CH_4	"Reactive" hydrocarbon emissions from pollution = 27×10^6 tons
CO_2	Combustion	Biological decay, release from oceans	1.4×10^{10}	10^{12}	320 ppm	2–4 years	Biological adsorption and photosynthesis, absorption in oceans	Atmospheric concentrations increasing by 0.7 ppm/year

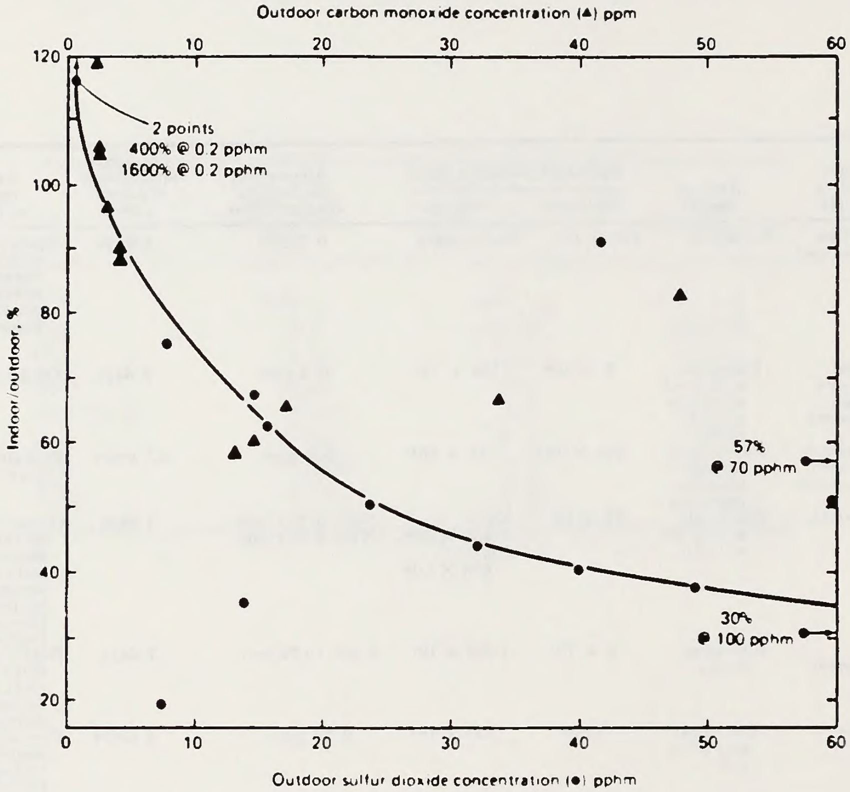


Figure 5.1-1

Indoor concentrations of sulfur dioxide and carbon monoxide as a function of outdoor concentrations.

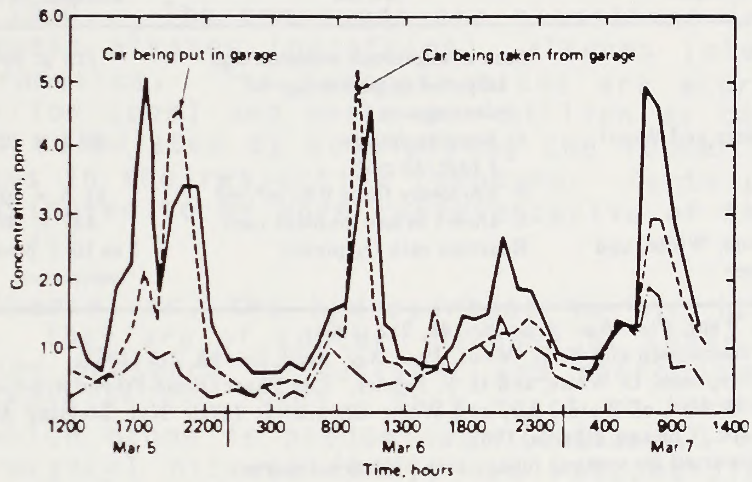


Figure 5.1-2

Carbon monoxide concentrations in house with gas range and furnace and with attached garage. Solid line, kitchen; dashed line, family room; dotdashed line, outside.

Table 5.1-3

Worldwide Terpene Emission Estimates

Investigator	*Method*	*Estimate in tons*
Went[a]	Sum of sagebrush emission and terpenes as percentage of plant tissues	175×10^6
Rasmussen and Went[b]	1. Bagging foliage 1 liter/10 cm^2	23.4×10^{6d}
	2. Enclosure forbs 0.65 m^2/m^2	13.5×10^{6d}
	3. Direct *in situ* ambient conc.	432×10^6
Ripperton, White, and Jeffries[c]	Reaction rate O_3/pinene	2 to 10 × previous estimates

[a] F. W. Went, *Proc. Nat. Acad. Sci.* **46**, 212 (1960).
[b] R. A. Rasmussen and F. W. Went, *Proc. Nat. Acad. Sci.* **53**, 215 (1965).
[c] L. A. Ripperton, O. White, and H. E. Jeffries, "Gas Phase Ozone–Pinene Reactions," pp. 54–56. Div. of Water, Air, and Waste Chemistry, 147th Nat. Meeting Amer. Chem. Soc., Chicago, Illinois, 1967.
[d] Not corrected for vertical foliage area over ground area.

Table 5.1-4

Estimates of Hydrocarbon Emissions, 1940-1970 (10^6 tons/year)

(United States)

Source category	*1940*	*1950*	*1960*	*1968*	*1969*	*1970*
Fuel combustion in stationary sources	1.4	1.3	1.0	1.0	0.9	0.6
Transportation	7.5	11.8	18.0	20.2	19.8	19.5
Solid waste disposal	0.7	0.9	1.3	2.0	2.0	2.0
Industrial process losses	3.3	5.2	4.3	4.4	4.7	5.5
Agricultural burning	1.9	2.1	2.5	2.8	2.8	2.8
Miscellaneous	4.5	4.2	4.4	4.9	5.0	4.4
Total	19.1	25.6	31.6	35.2	35.2	34.7
Total controllable[a]	14.7	21.4	27.2	30.3	30.2	30.3

[a] Miscellaneous sources not included.

5.1.2.1 The Hydrocarbons

Table 5.1-4 shows the emissions of hydrocarbons in the United States since 1940 (Cavender et al, 1973). Transportation is by far the principal emitting source, and these data indicate that its emissions seem to have peaked starting in 1968. Table 5.1-5 gives the average concentration for about 30 hydrocarbon compounds identified and measured in Los Angeles, California air (LAAPCD, 1970-72). More than 60 hydrocarbons have been identified, but the total number possible is very large and is limited only by the sensitivity and selectivity of the analytical method used (USEPA, 1970). The compounds are classified into four major functional types: alkanes (paraffins), alkenes (olefins), acetylenes, and aromatics. The concentrations are expressed in both parts per million (ppm) and parts per million as carbon (ppm C). The latter is calculated by multiplying the former by the number of carbon atoms in the respective compound. Parts per million as carbon is considered to be more representative of the hydrocarbon burden of the air.

In themselves, the hydrocarbons in air have relatively low toxicity. They are of concern because of their photochemical activity in the presence of sunlight and nitrogen oxides (Tuesday, 1971; Gordon et al, 1968). They react to form photochemical oxidants of which ozone is predominant (Table 5.1-6). Oxidants, including peroxyacyl nitrate (PAN), are responsible for much of the plant damage and eye irritation associated with smog. Methane has very low photochemical activity. As a consequence, hydrocarbon concentrations are often measured separately as methane on the one hand and non-methane hydrocarbons on the other (Figure 5.1-3). Methane will vary from 40% to 80% of the total hydrocarbons in an urban atmosphere (Figure 5.1-4 (Altshuller et al, 1973).

Strictly speaking, hydrocarbons are the compounds of hydrogen and carbon. At least two of the techniques used for measuring "total" hydrocarbons in air include many other classes of organic compounds. The nondispersive infrared method (NDIR), for example, measures compounds containing carbon-hydrogen bonds. This includes most organic compounds. The flame ionization method measures anything that reacts to form ions in a hydrogen flame. Pure hydrocarbons give higher specific responses, but without prior separation; the longer chain alcohols, aldehydes, esters, acids, etc., also give responses.

5.1.2.2 The Oxygenated Hydrocarbons

The oxygenated hydrocarbons, like the hydrocarbons, include an almost infinite number of compounds. They are classified as alcohols, phenols, ethers, aldehydes, ketones, esters, peroxides, and organic acids (Roberts and Caserio, 1967).

Some minor amounts of oxygenated hydrocarbons are emitted as solvent vapors from the chemical, paint and plastics

Table 5.1-5
Average Hydrocarbon Composition from 218 Ambient Air Samples Taken in Los Angeles, California

Compound	Concentration	
	ppm	*ppm (as carbon)*
Methane	3.22	3.22
Ethane	0.098	0.20
Propane	0.049	0.15
Isobutane	0.013	0.05
n-Butane	0.064	0.26
Isopentane	0.043	0.21
n-Pentane	0.035	0.18
2,2-Dimethylbutane	0.0012	0.01
2,3-Dimethylbutane	0.014	0.08
Cyclopentane	0.004	0.02
3-Methylpentane	0.008	0.05
n-Hexane	0.012	0.07
Total alkanes (excluding methane)	0.3412	1.28
Ethylene	0.060	0.12
Propene	0.018	0.05
1-Butane + isobutylene	0.007	0.03
trans-2-Butene	0.0014	0.01
cis-2-Butene	0.0012	Negligible
1-Pentene	0.002	0.01
2-Methyl-1-butene	0.002	0.01
trans-2-Pentene	0.003	0.02
cis-2-Pentene	0.0013	0.01
2-Methyl-2-butene	0.004	0.02
Propadiene	0.0001	Negligible
1,3-Butadiene	0.002	0.01
Total alkenes	0.1020	0.29
Acetylene	0.039	0.08
Methylacetylene	0.0014	Negligible
Total acetylenes	0.0404	0.08
Benzene	0.032	0.19
Toluene	0.053	0.37
Total aromatics	0.085	0.56
Total	3.7886	5.43

Table 5.1-6

Ozone Levels Generated in Photooxidation of Various Hydrocarbons with Oxides of Nitrogen

Hydrocarbon	*Ozone level, ppm*	*Time, min*
Isobutene	1.00	28
2-Methyl-1,3-butadiene	0.80	45
trans-2-Butene	0.73	35
3-Heptene	0.72	60
2-Ethyl-1-butene	0.72	80
1,3-Pentadiene	0.70	45
Propylene	0.68	75
1,3-Butadiene	0.65	45
2,3-Dimethyl-1,3-butadiene	0.65	45
2,3-Dimethyl-2-butene	0.64	70
1-Pentene	0.62	45
1-Butene	0.58	45
cis-2-Butene	0.55	35
2,4,4-Trimethyl-2-pentene	0.55	50
1,5-Hexadiene	0.52	85
2-Methylpentane	0.50	170
1,5-Cyclooctadiene	0.48	65
Cyclohexene	0.45	35
2-Methylheptane	0.45	180
2-Methyl-2-butene	0.45	38
2,2,4-Trimethylpentane	0.26	80
3-Methylpentane	0.22	100
1,2-Butadiene	0.20	60
Cyclohexane	0.20	80
Pentane	0.18	100
Methane	0.0	—

• Hydrocarbon concentration (initial) 3 ppm; oxide of nitrogen (NO or NO_2, initial) 1 ppm.

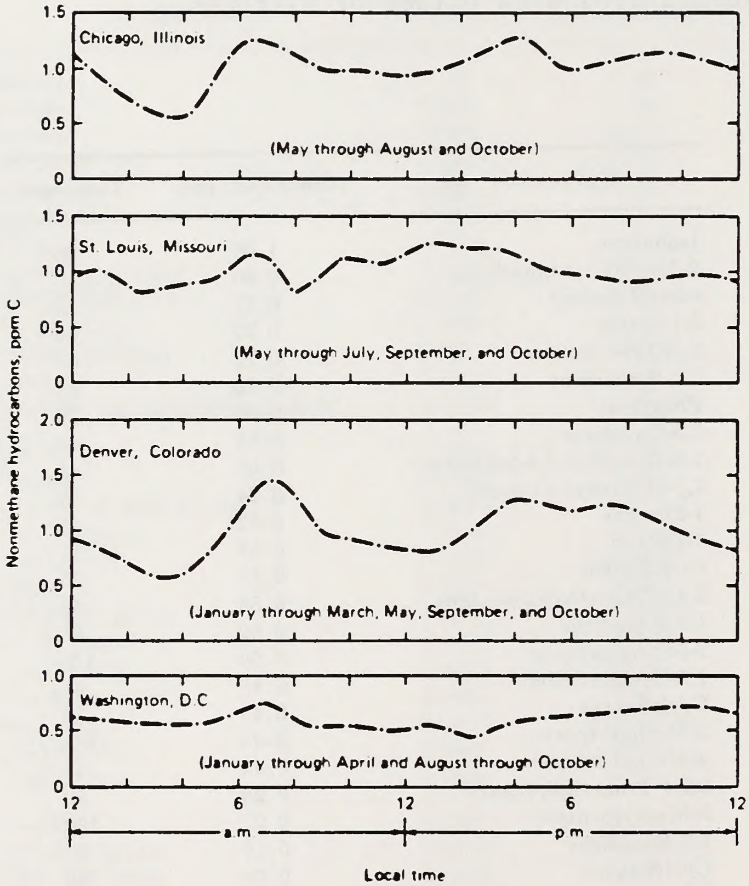


Figure 5.1-3

Nonmethane hydrocarbons as measured by a flame ionization analyzer, averaged by hour of day over several months for various cities.

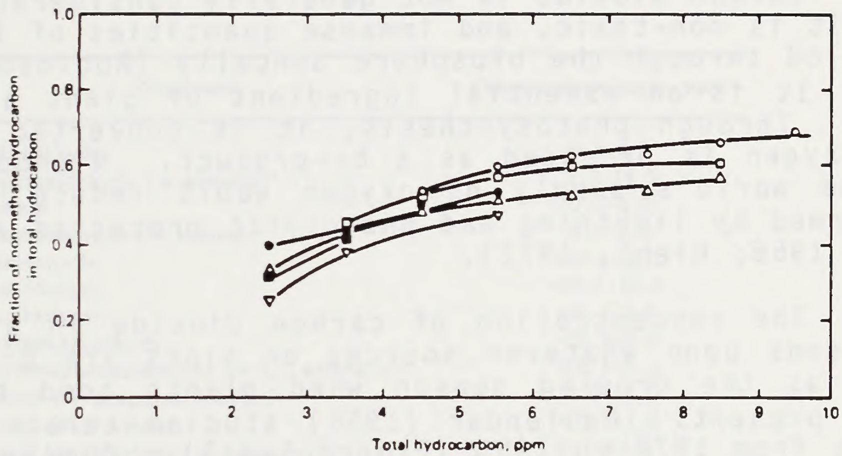


Figure 5.1-4

Nonmethane hydrocarbon fraction to total hydrocarbon for selected locations. ○: Los Angeles, California, 1967; □: Azusa, California, 1967; △: Los Angeles, California, 1968; ▽: Los Angeles, California, 1968---Sundays; ◆: Brooklyn, New York, 1069; ■: Bayonne, New Jersey, 1968 industries. The greater quantities of primary emissions are more usually associated with the automobile. Table 5.1-7 (Seizinger and Dimitriades, 1972) lists some typical oxygenates found in automobile exhaust. The aldehydes are the preponderant oxygenates in emissions but are emitted in minor amounts when compared to hydrocarbon, carbon dioxide, carbon monoxide and nitrogen oxide emissions. Many oxygenated compounds are formed as secondary products from photochemical reactions (Tuesday, 1971).

5.1.2.3 The Oxides of Carbon

Carbon Dioxide

Carbon dioxide is not generally considered an air pollutant. It is non-toxic, and immense quantities of it (10^{12} tons) are cycled through the biosphere annually (Robinson and Robbins, 1972). It is an essential ingredient of plant and animal life cycles. Through photosynthesis, it is converted to plant tissues; oxygen is produced as a by-product. Without photosynthesis, the world's supply of oxygen would reduce drastically to that formed by lightning and photolytic processes acting on water (Mason, 1966; Riehl, 1972).

The concentration of carbon dioxide in air is variable and depends upon whatever sources or sinks are present and such factors as the growing season when plants tend to deplete the amounts present. Callendar (1958) studied carbon dioxide measurements from 1870 to 1955 (Figure 5.1-5). A nineteenth century base value of 290 ppm was established and is generally accepted. Present day values have been set at 320 ppm with an annual growth rate of about 0.7 ppm (Robinson and Robbins, 1972).

Worldwide combustion of fossil fuel is a primary cause of the relatively rapid increase in carbon dioxide in the atmosphere. Robinson and Robbins (1972) have reviewed the sources, sinks and effects of carbon dioxide. Table 5.1-8 shows carbon dioxide emissions projected to the year 2000. A relative increase of nearly 300% in emissions over those of 1965 is predicted. Robinson and Robbins (1972) assume that half the carbon dioxide emitted remains in the atmosphere. This would result in an increase to about 370 ppm.

Carbon dioxide contributes to what is called a "greenhouse" effect in the atmosphere. As in a greenhouse, radiation penetrates the atmosphere and is absorbed by the earth. The earth also radiates energy into space at a reduced level and at longer wavelengths; otherwise, the earths temperature would continue to increase in temperature indefinitely. A balance is maintained between the incoming and outgoing energy. Figure 5.1-6 (Sellers, 1965) shows two radiation envelopes: one at $6000^{o}K$ to indicate the radiation coming in from the sun; the other at $300^{o}K$ to indicate the energy radiating from the earth at longer wavelengths. Carbon dioxide absorbs radiation strongly from this envelope and consequently contributes to a warming, or

Table 5.1-7

Oxygenates in Exhaust from Simple Hydrocarbon Fuels

Oxygenate	*Concentration range, ppm*[a]
Acetaldehyde	0.8–4.9
Propionaldehyde (+ acetone)[b]	2.3–14.0
Acrolein	0.2–5.3
Crotonaldehyde (+ toluene)[c]	0.1–7.0
Tiglaldehyde	<0.1–0.7
Benzaldehyde	<0.1–13.5
Tolualdehyde	<0.1–2.6
Ethylbenzaldehyde	<0.1–0.2
o-Hydroxybenzaldehyde (+ C_{10} aromatic)[d]	<0.1–3.5
Acetone (+ propionaldehyde)[b]	2.3–14.0
Methyl ethyl ketone	<0.1–1.0
Methyl vinyl ketone (+ benzene)[e]	0.1–42.6
Methyl propyl (or isopropyl) ketone	<0.1–0.8
3-Methyl-3-buten-2-one	<0.1–0.8
4-Methyl-3-penten-2-one	<0.1–1.5
Acetophenone	<0.1–0.4
Methanol	0.1–0.6
Ethanol	<0.1–0.6
C_4 alcohol (+ C_8 aromatic)[f]	<0.1–1.1
2-Buten-1-ol (+ C_4H_8O)	<0.1–3.6
Benzyl alcohol	<0.1–0.6
Phenol + cresol(s)	<0.1–6.7
2,2,4,4-Tetramethyltetrahydrofuran	<0.1–6.4
Benzofuran	<0.1–2.8
Methyl phenyl ether	<0.1
Methyl formate	<0.1–0.7
Nitromethane	<0.8–5.0
C_4H_6O	<0.1
C_4H_8O	<0.1–0.2
$C_4H_{10}O$	<0.1–0.3

[a] Values represent concentration levels in exhaust from all test fuels.
[b] Data represent unresolved mixture of propionaldehyde + acetone. Chromatographic peak shape suggests acetone to be the predominant component.
[c] Toluene is the predominant component.
[d] The C_{10} aromatic hydrocarbon is the predominant component.
[e] Benzene is the predominant component.
[f] The aromatic hydrocarbon is the predominant component.

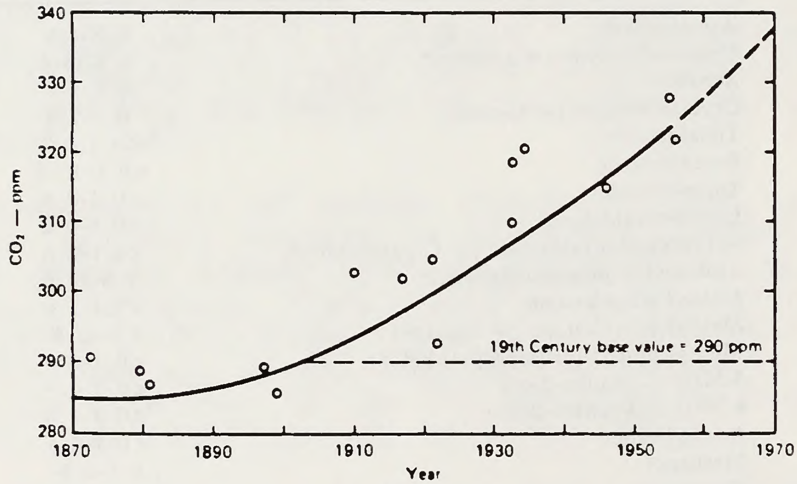


Figure 5.1-5

Average CO_2 concentration in North Atlantic region 1870-1956.

Table 5.1-8

Projected CO_2 Emissions: 1965-2000

	Emissions, 10^9 tons/year				
	1965	*1970*	*1980*	*1990*	*2000*
Coal	7.33	7.40	7.55	7.70	7.85
Petroleum	4.03	5.28	8.57	13.90	22.50
Natural gas	1.19	1.62	2.79	4.80	8.27
Incineration	0.46	0.51	0.61	0.73	0.88
Wood fuel	0.68	0.68	0.68	0.68	0.68
Forest fires	0.39	0.39	0.39	0.39	0.39
Total	14.08	15.88	20.59	28.20	40.57
Relative change	100%	113%	146%	200%	288%

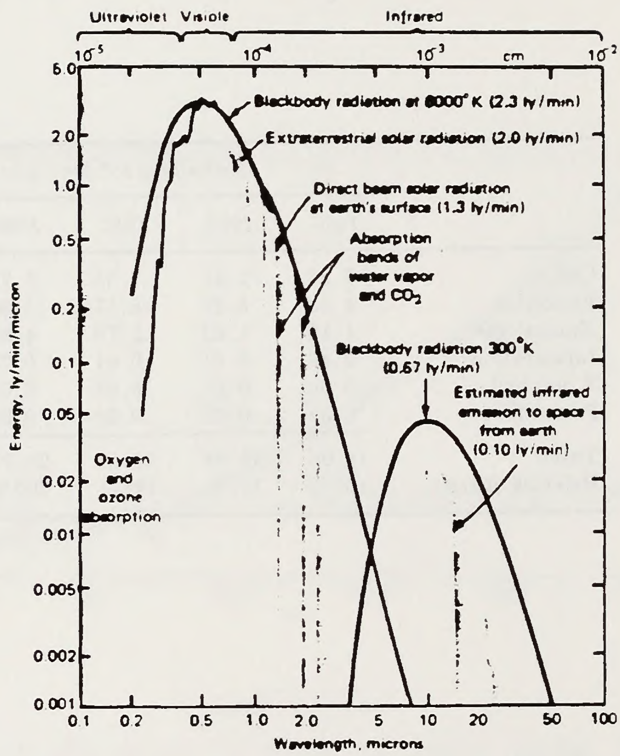


Figure 5.1-6

Spectra of Solar and Earth Radiation

greenhouse, effect. The temperature increase theoretically resulting from an increase of concentration to 370 ppm would be 0.5^{o}C (Manabe and Wetherald, 1967). In reality the earth's energy balance is much more complicated. Water vapor, which absorbs strongly in the infrared, the amount of clouds which reflect sunlight, and global atmospheric circulation patterns all play important roles (Robinson and Robbins, 1972; Sellers, 1965). An increase in the reflectivity of the earth's atmosphere caused by an increase in suspended particulate matter (McCormick and Ludwig, 1967) or an increase in cloud cover could offset the warming tendency of carbon dioxide.

Carbon Monoxide

Carbon monoxide is a colorless, odorless, and tasteless gas which is slightly lighter than air. It is considered a dangerous asphyxiant because it combines strongly with the hemoglobin of the blood and reduces the blood's ability to carry oxygen to cell tissues. Untold numbers of deaths have been caused by carbon monoxide in coal mines, fires and non-ventilated places. A healthy working person can work eight hours a day, 40 hours a week, without noticeable adverse effects at carbon monoxide concentrations of 25 ppm (the threshold limit value).

Carbon monoxide is a product of incomplete combustion of carbon and its compounds. It is emitted by fossil fuel combustion sources in greater quantities than all other pollutant sources combined. Table 5.1-9 summarizes the estimates of emissions in the United States (Cavender et al, 1973). The automobile is by far the largest single pollution emission source. Figure 5.1-7 shows that maximum carbon monoxide concentrations found at eight Continuous Air Monitoring Program (CAMP) stations in the United States (Chang and Weinstock, 1973).

Recent carbon isotope studies conducted at the Argonne National Laboratory (Stevens et al, 1972) showed that nature produces huge quantities of carbon monoxide: from 3 to 640 X 10^9 tons/year as compared to 0.275 x 10^9 tons/year from worldwide pollution sources (Table 5.1-2). The principal natural source is believed to be the result of the photochemical oxidation of methane through an OH radical mechanism (Stevens et al, 1972; Weinstock, 1972). Other natural sources include the decomposition of chlorophyll to give relatively high concentrations of carbon monoxide particularly in the fall (0.2 to 0.5 X 10^9 tons/-year). Volcanoes, natural gas, forest fires, bacterial action in the oceans (0.15 X 10^9 tons/year) are other sources. The estimated total amount of carbon monoxide emissions from natural sources, given in Table 5.1-2, are, consequently, low by 30- to 50-fold, and the residence time of carbon monoxide in air needs to be reduced by a factor of 0.1 to 0.3 per year (Weinstock, 1972; Maugh, 1972).

The background concentration of carbon monoxide is estimated from data gathered in the Pacific (Robinson and Robbins, 1972; 1970) to be approximately 0.1 ppm. Table 5.1-10

Table 5.1-9

Estimates of Carbon Monoxide Emissions (United States) 1940-1970 (10^6 tons/year)

Source category	*1940*	*1950*	*1960*	*1968*	*1969*	*1970*
Fuel combustion in stationary sources	6.2	5.6	2.6	2.0	1.8	0.8
Transportation	34.9	55.4	83.5	113.0	112.0	111.0
Solid waste disposal	1.8	2.6	5.1	8.0	7.9	7.2
Industrial process losses	14.4	18.9	17.7	8.5	12.0	11.4
Agricultural burning	9.1	10.4	12.4	13.9	13.8	13.8
Miscellaneous	19.0	10.0	6.4	5.0	6.3	3.0
Total	85.4	103.0	128.0	150.0	154.0	147.0
Total controllable[a]	66.4	92.9	121.0	145.0	148.0	144.0

[a] Miscellaneous sources not included.

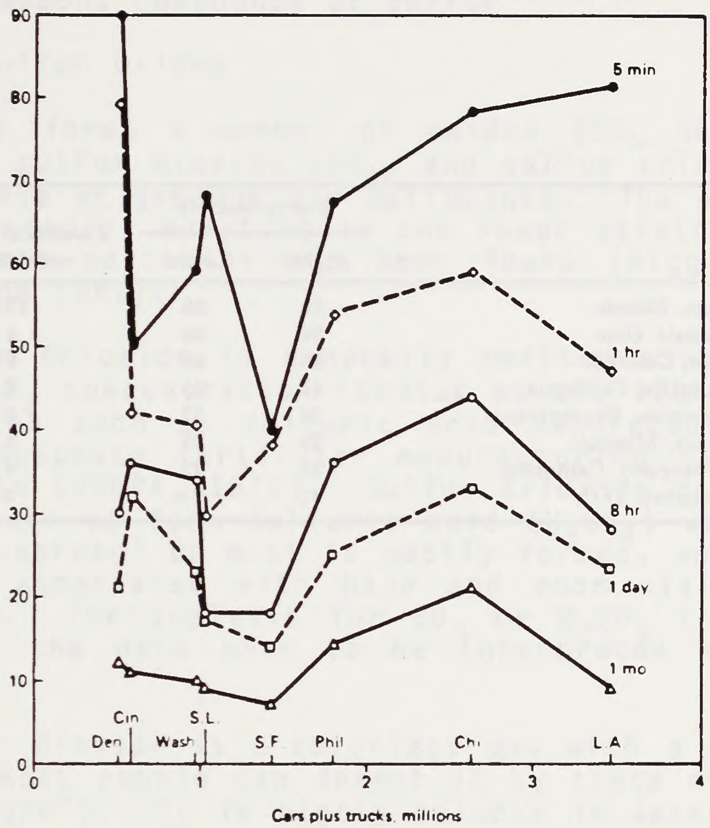


Figure 5.1-7

Maximum CO concentrations at Continuous Air Monitoring Program (CAMP) stations. 1962-1968 maxima vs cars plus trucks. Denver (Den.), Colorado; Cincinnati (Cin.), Ohio; Washington (Wash.), D.C.; St. Louis (S.L.), Missouri; San Francisco (S.F.), California; Philadelphia (Phil.), Pennsylvania; Chicago (Chi.), Illinois; Los Angeles (L.A.), California.

Table 5.1-10

Carbon Monoxide Concentrations in Representative United States Cities. Hourly Maxima in ppm. 1962-1967

	Yearly maxima		*Theoretical geometric mean (17, 51)*
	Highest	*Lowest*	
Chicago, Illinois	59	28	13.2
Cincinnati, Ohio	34	20	4.8
Denver, Colorado	55	40	6.7
Los Angeles, California	47	35	9.7
Philadelphia, Pennsylvania	54	37	6.9
St. Louis, Missouri	29	25	5.5
San Francisco, California	38	22	4.8
Washington, D.C.	41	25	3.5

shows the range of maximum hourly average values for the years of 1962-1967 for eight major United States cities (USEPA, 1970; Faith and Atkisson, 1972). The theoretical geometric mean hourly concentrations for the entire period are also shown. CO concentrations are more than ten times the level of concentrations of other major pollutants.

5.1.3 The Gaseous Compounds of Sulfur

5.1.3.1 The Sulfur Oxides

Sulfur forms a number of oxides (SO, SO_2, S_2O_3, SO_3, S_2O_7) but only sulfur dioxide (SO_2) and sulfur trioxide (SO_3) are of any importance as gaseous air pollutants. The peroxide, S_2O_7, has been suggested as existing in the lower stratosphere where a layer of sulfate particles has been found (Bigg et al, 1970; Junge and Manson 1961).

Sulfur trioxide is generally emitted with SO_2 at about 1%-5% of the SO_2 concentration (Cholak et al, 1958; Tice, 1962). A few industries such as sulfuric acid manufacturing, electroplating and phosphate fertilizer manufacturing may emit higher relative amounts (USEPA, 1972). Sulfur trioxide rapidly combines with water in air to form sulfuric acid (H_2SO_4) which has a low dew point. An aerosol or mist is easily formed, and SO_3 or H_2SO_4 is frequently associated with haze and poor visibility in air (Figure 5.1-8). The analysis for SO_3 or H_2SO_4 in air is quite difficult, and the data have to be interpreted with some care (USEPA, 1972).

Sulfur dioxide is a colorless gas with a pungent, irritating odor. Most people can detect it by taste at 0.3 to 1 ppm (780 to 2620 $\mu g/m^3$). It is highly soluble in water: 11.3 gm/100 ml as compared to 0.169 gm/100 ml for carbon dioxide, forming weakly acidic sulfurous acid (H_2SO_3). In clean air, it oxidizes slowly to sulfur trioxide. It is oxidized more readily by atmospheric oxygen in aqueous aerosols. Heavy metal ions in solution catalyze the reaction which stops when aerosols become acidic. Atmospheric ammonia neutralizes the acid to form ammonium sulfate, which is commonly found in atmospheric particles (Johnstone and Coughanowr, 1958, 1960). In moist air and in the presence of nitrogen oxides, hydrocarbons, and particulates, sulfur dioxide reacts much more rapidly (Urone, 1972; Urone and Schroeder, 1969).

Today, sulfur dioxide remains one of the major atmospheric pollutants. Its worldwide emissions have been estimated at 146 megatons/year by Robinson and Robbins (Table 5.1-2) and more recently as 100 (150 as sulfate) megatons per year by Kellogg et al. (1972) who predict emissions of about 275 megatons per year for the year of 2000. Estimated United States sulfur dioxide emissions for 1970 were 33.9 megatons (Table 5.1-11). Fuel combustion and stationary sources and industrial emissions accounted for 70% and 18% of this figure, respectively (Cavender,

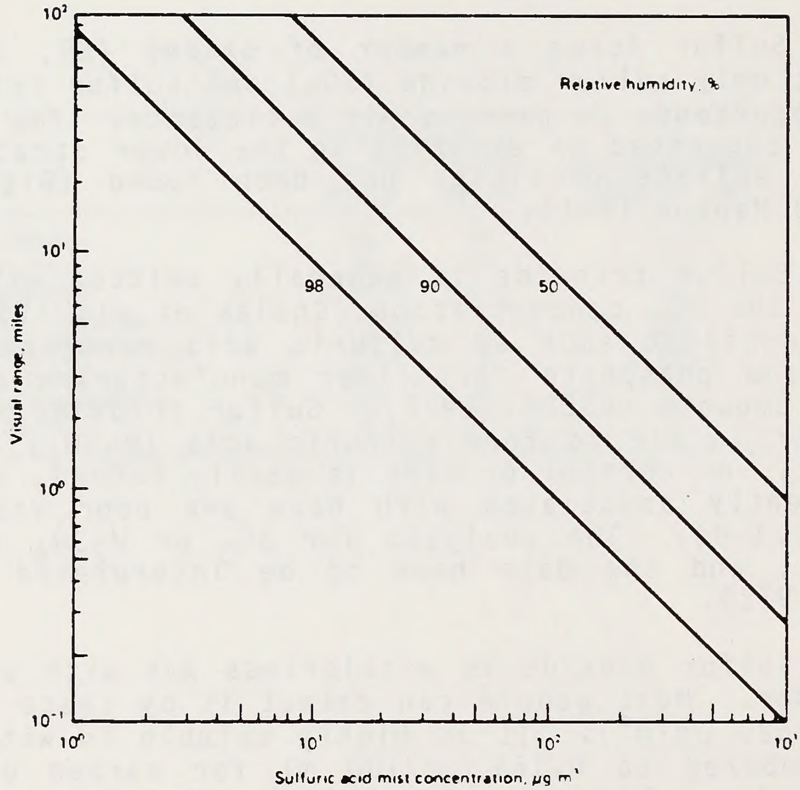


Figure 5.1-8
Calculated visibility (visual range) in miles at various sulfuric acid mist concentrations and different relative humidities.

Table 5.1-11

Estimates of Sulfur Oxide Emissions (United States) 1940-1970 (10^6 tons/year)

Source category	*1940*	*1950*	*1960*	*1968*	*1969*	*1970*
Fuel combustion in stationary sources	16.8	18.3	17.5	24.7	25.0	26.5
Transportation	0.7	1.0	0.7	1.1	1.1	1.0
Solid waste disposal	Neg[a]	0.1	0.1	0.1	0.2	0.1
Industrial process losses	3.8	4.2	4.7	5.1	5.9	6.0
Agricultural burning	Neg	Neg	Neg	Neg	Neg	Neg
Miscellaneous	0.2	0.2	0.3	0.3	0.2	0.3
Total	21.5	23.8	23.3	31.3	32.4	33.9
Total controllable[b]	21.3	23.6	23.0	31.0	32.2	33.6

[a] Negligible (less than 0.05 × 10^6 tons/year).
[b] Miscellaneous sources not included.

Table 5.1-12

Sulfur Dioxide Concentrations in Representative United States Cities Hourly Maxima, ppm, 1962-1967

	Yearly maxima		
	Highest	*Lowest*	*Theoretical geometric mean (17, 51)*
Chicago, Illinois	1.69	0.86	0.111
Cincinnati, Ohio	0.57	0.41	0.018
Denver, Colorado	0.36	0.17	0.014
Los Angeles, California	0.29	0.13	0.014
Philadelphia, Pennsylvania	1.03	0.66	0.060
St. Louis, Missouri	0.96	0.55	0.031
San Francisco, California	0.26	0.11	0.006
Washington, D.C.	0.62	0.35	0.042

et al, 1973). Intensive efforts are being made to control sulfur dioxide emissions by either removing sulfur from coal and oil or removing sulfur dioxide at the combustion source (USEPA, 1969).

Ambient air concentrations of sulfur dioxide are routinely measured in many cities and have been the subject of a large number of studies. Table 5.1-12 give typical data obtained from the United States Continuous Air Monitoring Program (CAMP). Figure 5.1-9 shows the frequency distribution of sulfur dioxide measurements made in selected United States cities. An approximate log-normal distribution is shown by the straight portions of the lines. This confirms to some extent the model developed by Larsen and others (Larsen, 1969; USEPA, 1969; Larsen, 1971).

5.1.3.2 Reduced Sulfur Compounds

Hydrogen Sulfide

Hydrogen sulfide (H_2S) is a toxic, foul smelling gas well known for its rotten egglike odor. It can be detected at concentrations as low as 0.5 ppb (7 $\mu g/m^3$) (A.D. Little, Inc., 1968). Its natural emission sources include anaerobic biological decay processes on land, in marshes and in the oceans. Volcanoes and natural hot water springs also emit hydrogen sulfide. A total of approximately 100 megatons (268 when expressed as sulfate) is estimated to be emitted in nature (Table 5.1-2) (Kellogg et al, 1972). However this estimate has been made with strong reservations. The analysis of very low concentrations in air is subject to error because some of the hydrogen sulfide is oxidized to sulfur dioxide during the sampling process (Kellogg et al, 1972).

Approximately three megatons of H_2S are estimated to be emitted each year by pollution sources (Robinson and Robbins, 1972) (Table 5.1-2). One of the larger single sources is the kraft pulp industry which uses a sulfide process to extract cellulose from wood (Blosser, 1972). Because of the strong odor of sulfides, such facilities can be detected by their odor 40 miles or more downwind, unless emissions are carefully controlled. Other hydrogen sulfide pollution sources include the rayon industry, coke ovens and the oil refining industry. The processing of "sour" crude oil results in the emission of hydrogen sulfide and other volatile organic sulfides. Hydrogen sulfide emissions from industrial processes are sometimes used as fuel for boilers or are released in burning flares. In either case, they are burned to sulfur dioxide and emitted to the air. Today, many modern refineries recover their sour gasses and process them to form sulfuric acid or elemental sulfur (Faith et al, 1965).

Hydrogen sulfide concentrations in urban air are rarely higher than 0.1 ppm (140 $\mu g/m^3$). Cholak (1952) analyzed Cincinnati air over a period of five years and rarely found hydrogen sulfide to exceed 0.01 ppm (14 $\mu g/m^3$). A survey in Houston,

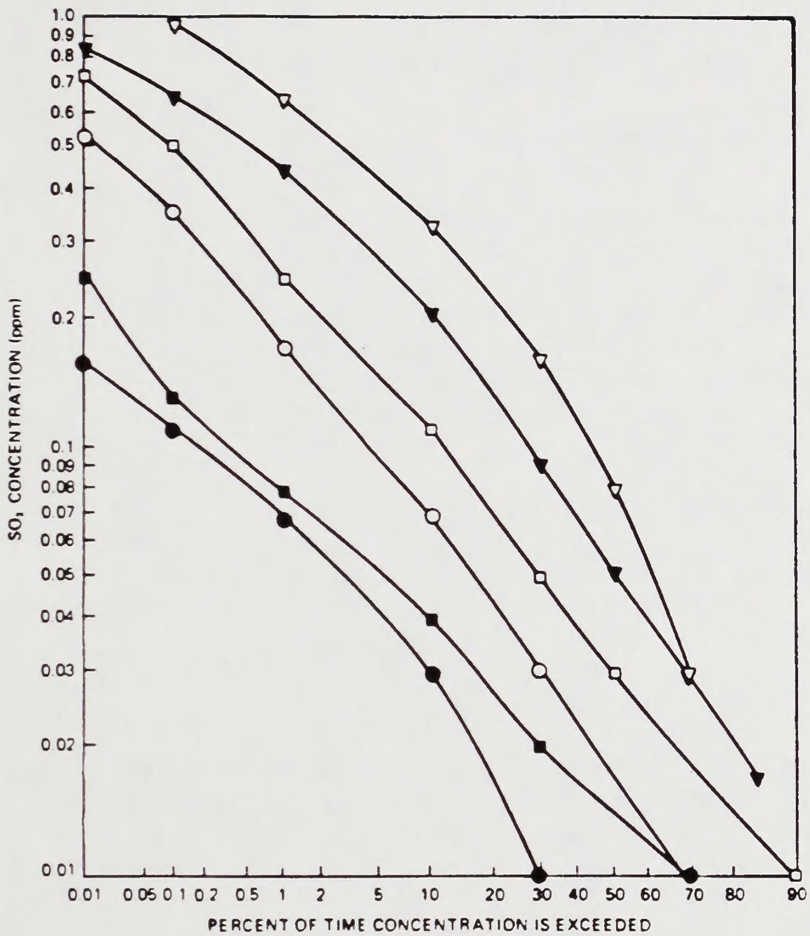


Figure 5.1-9

Frequency distribution of sulfur dioxide levels in selected United States cities, 1962-1967. ▽, Chicago, Illinois; ▼, Philadelphia, Pennsylvania; □, St. Louis, Missouri; ■, Cincinnati, Ohio; ○, Los Angeles, California; ●, San Francisco, California.

Texas showed average values of 0.02 ppm in the most highly polluted section of the city. The highest level measured was 0.28 ppm (390 μg/m^3) (Faith and Atkisson, 1972; SRI, 1957). Katz (1955) found relatively high levels in Windsor, Ontario with a mean concentration of approximately 0.1 ppm and a maximum of 0.6 ppm (835 μg/m^3).

Hydrogen sulfide blackens lead-based paints. A level of 0.1 ppm is said to produce blackening of such paints within 1 hour (Faith and Atkisson, 1972). In air, hydrogen sulfide is oxidized to sulfur dioxide within hours, adding to the ambient sulfur dioxide level (Kellog et al, 1972).

Mercaptans and Sulfides

Other sulfur compounds that are of interest in air pollution, principally because of their strong odors, are methyl mercaptan (CH_3SH), dimethyl sulfide (CH_3SCH_3), dimethyl disulfide (CH_3SSCH_3), and their higher molecular homologs (Blosser, 1972). They have odors similar to those emitted by skunks and rotting cabbage. Total emissions of these compounds are unknown. A number of studies have been concerned with their evaluation (Schmall, 1972) and their measurement in air (Figure 5.1-10 (Rasmussen, 1972).

5.1.4 The Gaseous Compounds of Nitrogen

Nitrogen forms the very stable diatomic gas, N_2, which makes up over 78% of the atmosphere and, fortunately, helps temper the oxidative power of atmospheric oxygen. It also forms a large number of gaseous and nongaseous compounds, many of which are essential to living matter.

They are produced by such natural processes as bacterial fixation, biological growth and decay, lightning, and forest and grassland fires. To a lesser extent, but in higher local urban concentrations, nitrogen compounds are produced by man through a wide number of agricultural, domestic, and industrial activities. In the reduced state, nitrogen forms such compounds as ammonia, amides, amines, amino acids and nitriles. In the oxidized state, it forms seven oxides and a large number of nitro, nitroso, nitrite and nitrate derivatives (Cotton and Wilkinson, 1966).

5.1.4.1 The Oxides of Nitrogen

The oxides of nitrogen include nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2), nitrogen trioxide (NO_3), nitrogen sesquioxide (N_2O_3), nitrogen tetroxide (N_2O_4), and nitrogen pentoxide (N_2O_5). They and two of their hydrates, nitrous acid (HNO_2) and nitric oxide (NO), and nitrogen dioxide (NO_2) are found in appreciable quantities. The latter two, NO and NO_2, are often analyzed together in air and are referred to as "nitrogen oxides" and given the symbol "NO_x". Nitrous oxide

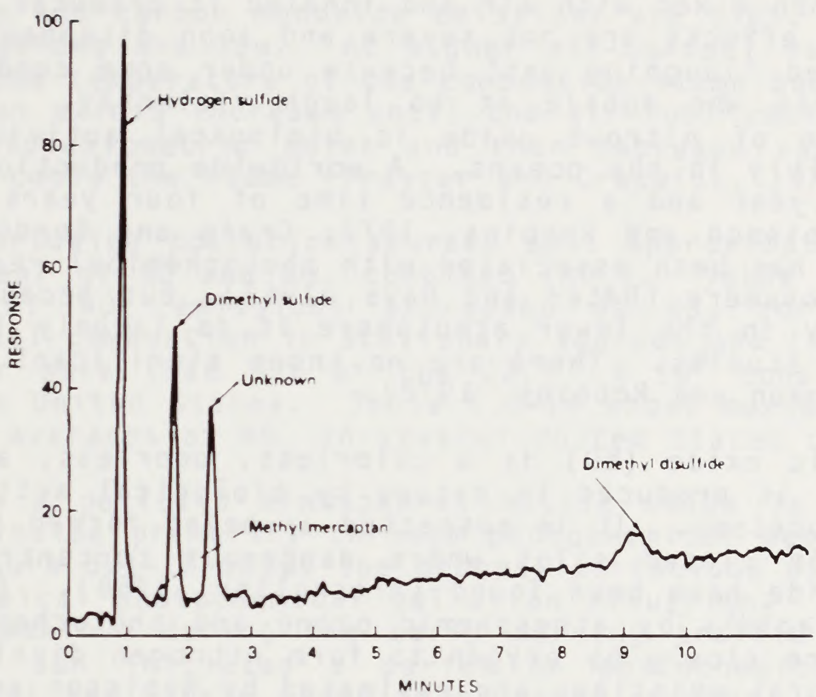


Figure 5.1-10
Sulfur Gases in Ambient Air, In-Situ Analysis

(N_2O) is not included in the "NO_x" measurement, but it is possible for the higher oxides to be included if they happen to be present (APHA, 1972).

Nitrous oxide (N_2O) is a colorless, slightly sweet, nontoxic gas present in the natural environment in relatively large amounts (0.25 ppm) when compared to the concentrations of the other trace gases except carbon dioxide, methane, and the noble gases. It is used as an anesthetic in minor surgery and dentistry. When mixed with air and inhaled it produces a loss of feeling. Its effects are not severe and soon disappear. It is commonly called "laughing gas" because under some conditions it can cause those who inhale it to laugh violently. The major natural source of nitrous oxide is biological activity in the soil and possibly in the oceans. A worldwide production rate of 10^9 tons per year and a residence time of four years has been estimated (Robinson and Robbins, 1972; Craig and Gordon, 1963). Nitrous oxide has been associated with photochemical reactions in the upper atmosphere (Bates and Hays, 1967), but because of its low reactivity in the lower atmosphere it is largely ignored in air pollution studies. There are no known significant pollution sources (Robinson and Robbins, 1972).

Nitric oxide (NO) is a colorless, odorless, and tasteless gas. It is produced in nature by biological action and by combustion processes. It is suspected as being formed and rapidly oxidized in closed silos where dangerous concentrations of nitrogen dioxide have been found (Altshuller, 1958). In air, it is oxidized rapidly by atmospheric ozone and photochemical processes and more slowly by oxygen to form nitrogen dioxide (NO_2). Worldwide natural emissions are estimated by Robinson and Robbins (1972) to be 430 X 10^6 tons per year. Background concentrations are variable and difficult to measure. They are estimated to range from 0.25 to 6 ppb. The residence time in air is about five days (Robinson and Robbins, 1972).

As a pollutant, nitric oxide is produced largely by fuel combustion in both stationary and mobile sources such as the automobile. In the high temperatures of the combustion zone, nitrogen reacts with oxygen to form nitric oxide:

$$N_2 + O_2 \rightleftharpoons 2\ NO \qquad (5.1\text{-}1)$$

The reaction is endothermic and proceeds to the right at high temperatures. At low temperatures, the equilibrium lies almost completely to the left, but the rate of recombination is extremely slow. Consequently, the amount of NO emitted is a function of the flame structure and temperature as well as the rate at which the combustion mixture cools. If the cooling rate is rapid, equilibrium is not maintained and the NO concentration, although thermodynamically unstable, remains high (Trayser and Creswick, 1970; Hall and Blacet, 1952). The proper catalyst can, of course, expedite its decomposition to nitrogen and oxygen. In exhaust gases, where higher concentrations and temperatures prevail, some of the nitric oxide is oxidized to nitrogen dioxide. This generally varies from 0.5% to 10% of the nitric oxide present (USEPA, 1971).

Figure 5.1-11 shows the relative amounts of nitrogen oxides, hydrocarbons, and carbon monoxide in the exhaust of an automobile as a function of the ratio of the air-to-fuel mixture used for the engine. At low air-to-fuel ratios ("rich" mixtures), flame temperatures are low, combustion is incomplete, hydrocarbon and carbon monoxide emissions are high, and nitrogen oxides emissions are low. At higher air-to-fuel ratios ("lean" mixtures) the temperature of the combustion flame becomes hotter, the nitrogen oxides increase until the air-fuel ratio is greater than the stoichiometric point and then decrease rapidly as the excess air cools the flame (Trayser and Creswick, 1970).

Worldwide pollution sources emit approximately 53 X 10^6 tons per year of NO and NO_2 combined (NO_x). Table 5.1-13 gives estimates of NO_x emissions expressed as NO_2 for the United States. Fuel combustion in stationary sources and transportation account for more than 95% of the 22.7 X 10^6 tons emitted per year in the United States. Table 5.1-14 shows maximum and minimum hourly averages of NO_x in several United States cities.

In a polluted atmosphere, nitric oxide is oxidized to nitrogen dioxide primarily through photochemical secondary reactions. Figure 5.1-12 shows the diurnal variations of NO, NO_2 and O_3 in a typical photochemical pollution situation. Nitric oxide reaches a maximum during the early morning traffic rush hours. The rising sun initiates a series of photochemical reactions which convert the nitric oxide to nitrogen dioxide. Within a few hours the nitrogen dioxide reaches a maximum during which it photochemically reacts to form ozone and other oxidants. Both the nitrogen dioxide and the ozone eventually disappear through the formation of nitrated organic compounds, peroxides, aerosols, and other terminal products. The cycle is repeated the following day. If the air mass is not swept away or is brought back by a reversing wind, the residual gases add to the new day's pollutants (Tuesday, 1971).

Nitrogen dioxide is a reddish-brown gas with a pungent, irritating odor. At concentrations higher than those found in the atmosphere, it forms a colorless dimer, nitrogen tetroxide (N_2O_4). Natural emissions are due primarily to biological decay involving nitrates being reduced to nitrites, followed by conversion to nitrous acid (HNO_2), decomposition to nitric oxide and oxidation to nitrogen dioxide. Natural emissions are estimated to be 658 X 10^6 tons per year.

Nitrogen dioxide is one of the more invidious pollutants. It is irritating and corrosive in itself, but more importantly, it serves as an energy trap by absorbing sunlight to form nitric oxide and atomic oxygen:

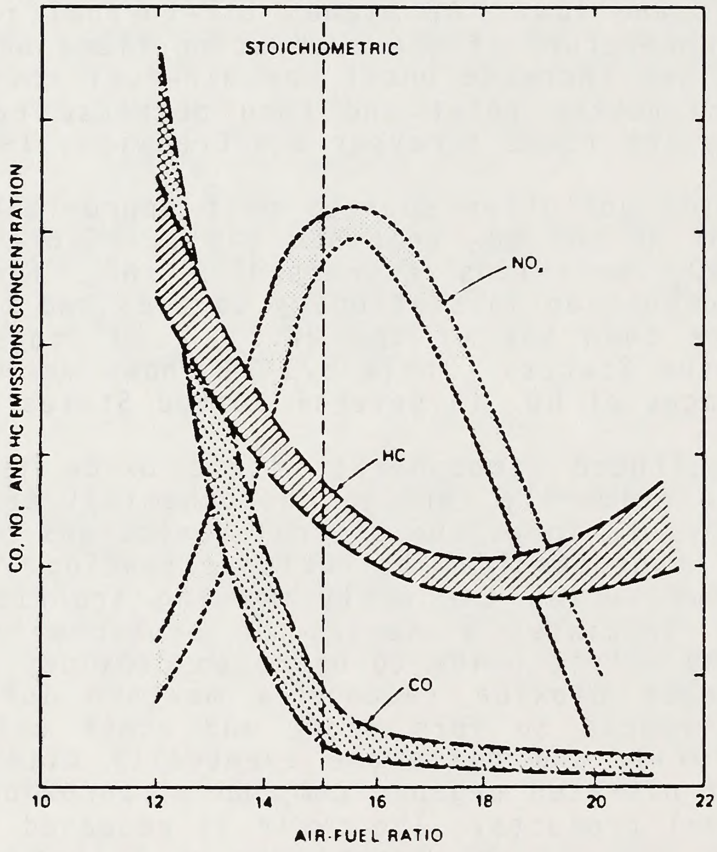


Figure 5.1-11

Effects of air-fuel ratio on exhaust composition (approximate ranges, not to scale).

Table 5.1-13

Estimates of Nitrogen Oxide (NO_x) Emissions (United States), 1940-1970 (10^6 tons/year)

Source category	*1940*	*1950*	*1960*	*1968*	*1969*	*1970*
Fuel combustion in stationary sources	3.5	4.3	5.2	9.7	10.2	10.0
Transportation	3.2	5.2	8.0	10.6	11.2	11.7
Solid waste disposal	0.1	0.2	0.2	0.4	0.4	0.4
Industrial process losses	Neg[a]	0.1	0.1	0.2	0.2	0.2
Agricultural burning	0.2	0.2	0.3	0.3	0.3	0.3
Miscellaneous	0.8	0.4	0.2	0.2	0.2	0.1
Total	7.9	10.4	14.0	21.3	22.5	22.7
Total controllable[b]	7.1	10.0	13.8	21.1	22.3	22.6

[a] Negligible (less than 0.05 × 10^6 tons/year).
[b] Miscellaneous sources not included.

Table 5.1-14

Nitrogen Oxide (NO_x) Concentrations in Representative United States Cities Hourly Maxima, ppm, 1962-1968

	Yearly maxima		*Geometric*
	Highest	*Lowest*	*mean*
Chicago, Illinois	1.06	0.69	0.75
Cincinnati, Ohio	1.42	0.45	0.83
Denver, Colorado[a]	0.72	0.56	0.62
Los Angeles, California	1.35	0.98	1.24
Philadelphia, Pennsylvania	1.79	0.97	1.53
St. Louis, Missouri[b]	0.92	0.44	0.57
Washington, D.C.	1.30	0.68	0.83

[a] 1965–1968
[b] 1964–1968

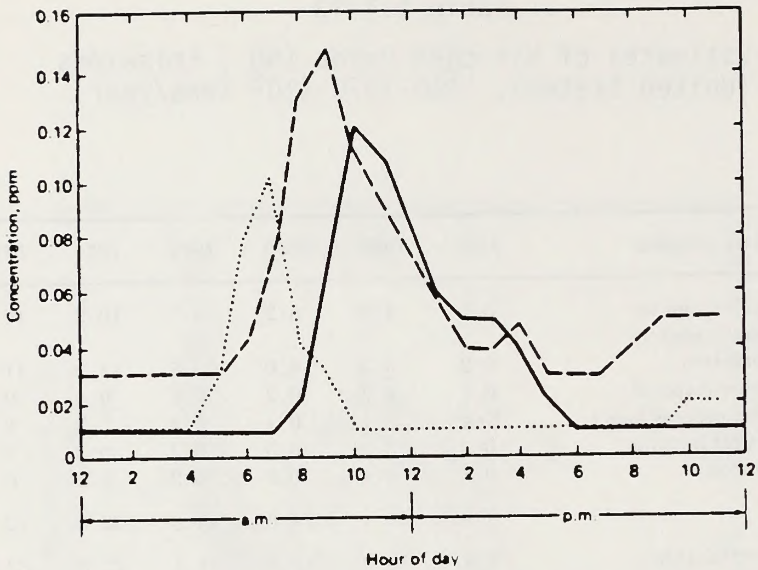


Figure 5.1-12

Typical diurnal variation of NO, NO_2, and O_3 concentrations in Los Angeles, California. Solid line, ozone; long dashed line, nitrogen dioxide; dotted line, nitric oxide.

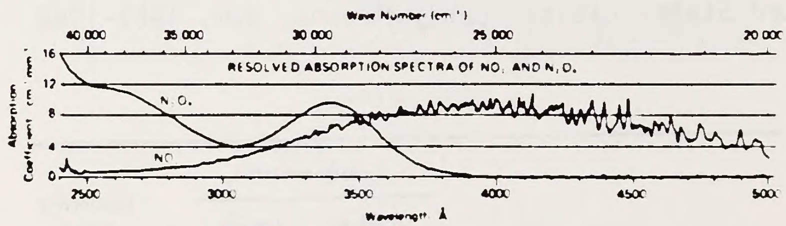


Figure 5.1-13

Absorption coefficients (1/pl $\log_{10} I_0/I$) of NO_2 and N_2O_4 vs wavelength and wave number, measured at 25°C.

$$NO_2 + h\nu \longrightarrow NO + O \qquad (5.1\text{-}2)$$

The atomic oxygen is very reactive, forming ozone with oxygen, and initiating a number of secondary photochemical chain reactions. Nitrogen dioxide absorbs light strongly in the yellow to blue end of the visible spectrum and the near ultraviolet. Figure 5.1-13 (Hall and Blacet, 1952) shows the absorption spectrum of nitrogen dioxide, and Figure 5.1-14 (USEPA, 1971) indicates the amount of light absorbed in terms of parts per million - mile concentrations. A mile thick layer of air containing 0.1 ppm of NO_2 reduces the ultraviolet light reaching the ground by more than 25%. Viewed through a horizontal layer of 10 miles, the same concentration reduces the blue and ultraviolet light more than 90% (Figure 5.1-14). The yellow-brown haze often seen hovering over a city is in a large part due to nitrogen dioxide and the aerosols it helps generate (Carlson and Ahlquist, 1969).

Nitrogen trioxide (NO_3) and nitrogen pentoxide (N_2O_5) have been postulated as intermediates in the photochemical oxidation of hydrocarbons and sulfur dioxide (Urone, 1972; Louw, 1973; Gay and Bufalini, 1971; Schuck et al, 1966). They are not commonly observed; their concentrations are expected to be small and difficult to measure in air in the presence of NO, NO_2 and their various photochemical reaction products. The pentoxide hydrolyzes readily with water vapor in the air to form nitric acid vapor (HNO_3) which has been detected in the stratosphere by spectroscopic means (Cadle and Allen, 1970). Peroxyacetyl nitrate (PAN), an eye-irritating photochemical reaction product from hydrocarbons and nitrogen oxides, has been identified and measured in air (Hall and Blacet, 1952; Hanst, 1971). Atmospheric concentrations as high as 0.1 ppm (500 $\mu g/m^3$) have been reported (USEPA, 1971).

5.1.5 Ozone and Oxidants

Ozone, O_3, is a bluish gas about 1.6 times as heavy as air and highly reactive. It is formed at high altitudes by photochemical reactions involving molecular and atomic oxygen (Cotton and Wilkinson, 1966). Its concentration in the atmosphere depends upon the altitude; being greatest in the stratosphere. At 20 km, its concentration is 0.20 ppm. Its concentration in rural areas, away from pollution sources, is approximately 0.02 ppm (USEPA, 1970). Very minor amounts of ozone are formed during lightning and thunderstorms. Ozone strongly absorbs ultraviolet light in the wavelength region of 2000-3500 A and very weakly at about 6000 A. Its absorption of the energetic portion of the ultraviolet light prevents serious damage to living tissues (USEPA, 1970).

Ozone and other oxidants such as PAN (Stephens, 1961) and hydrogen peroxide (Bufalini et al, 1972) are formed in polluted atmospheres as a result of a rather wide variety of photochemical reactions (Tuesday, 1971; Leighton, 1961). High ozone levels have been found not only in urban areas, where it follows

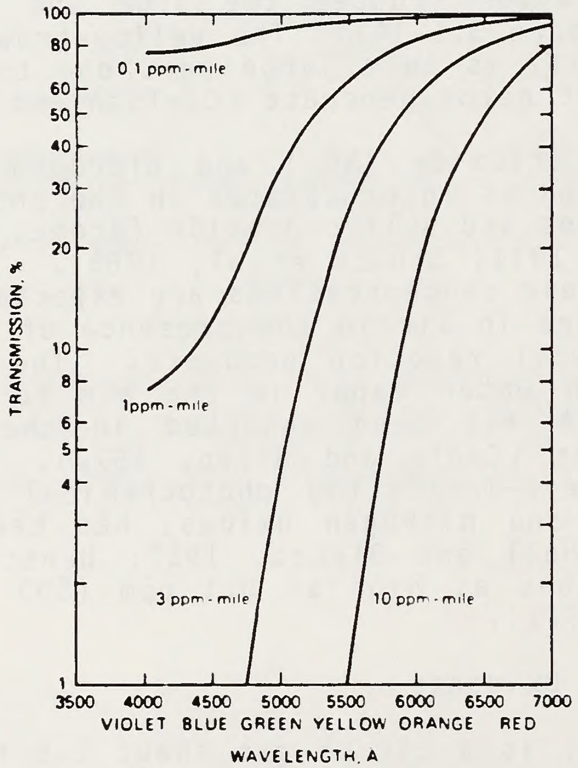


Figure 5.1-14
Transmittance of Visible Light at Different NO_2
Concentrations and Viewing Distances

a trend of build-up during the day and break-down during the night, but also in rural areas. It is believed that ozone or its precursors are being transported long distances or there may may be a nautral source within rural areas.

The overall effect of ozone is a stinging of the eyes and mucous membranes. This reaction was first noticed in Pasadena, California, a suburb of Los Angeles. Shortly thereafter, polluted atmospheres were labeled as "Los Angeles" type because of their general oxidative character. "London"(England) type smogs (i.e., smoke plus fog) were reductive in nature because of their higher concentrations of sulfur dioxide and soot from the burning of coal. Figure 5.1-12 shows the diurnal variation of nitrogen oxides and ozone in a typical Los Angeles type of photochemical pollution. However, since London has cleared its air with a vigorous smoke abatement program, it is experiencing Los Angeles type of pollution as shown by Figure 5.1-15 (Derwent and Stewart, 1973).

To prevent possible serious health effects, an ambient air quality standard maximum 1-hour concentration of 240 g/m^3 (0.12 ppm) has been adopted. Alert levels were set at 200 g/m^3 (0.1 ppm). Figure 5.1-16 shows the number of times that the alert level was exceeded in Los Angeles, California for 1967 thru 1971 (Sagersky, 1973). A study of oxidant levels in the San Francisco, California Bay Area show a trend to smaller annual oxidant levels (Cramer, 1973). However greater efforts are needed to reduce these values. Two studies have shown that indoor air follows outdoor air concentrations rather closely (Mueller, et al, 1973; Thompson et al, 1973).

A number of areas have been measuring total oxidant and ozone concentrations above the alert levels (USEPA). There is reason to believe that the "oxidative" conditions in these instances are not the same as those found in larger cities. Ripperton, et al. (1971), for example, have found evidence for tropospheric photochemical production of ozone.

Chesick (1972) and others (IDA, 1973) have been concerned over the effect that high-flying jet planes would have on the upper atmosphere. Water vapor and nitrogen oxides emitted from the jet exhausts conceivably could react with ozone and reduce its insulating quality for strong ultra-violet rays.

5.1.6 Particulate Matter

The particulate matter commonly found dispersed in the atmosphere is composed of many substances: flourides, beryllium, lead, and asbestos (all toxic), aerosols, dust and other matter such as wood waste generated by forest fires. Combustion also produces particles. Particles larger than 10 m result from many mechanical processes such as wind erosion, grinding and spraying. Trees produce terpenes which can result in organic particles and oceans produce salt particles as well. Only three general classes of physical properties can reasonably be said to apply to all particulate matter. These properties all involve the interface

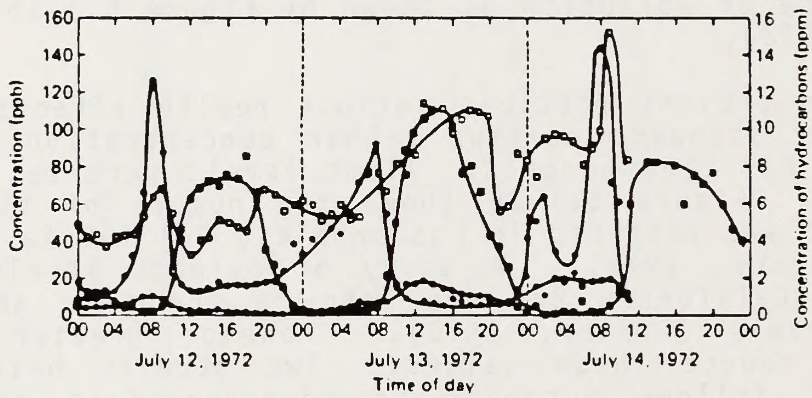


Figure 5.1-15

Diurnal variations of air pollutants measured in London, England from July 12 to July 14, 1972. ■, Ozone, ppb; ●, nitric oxide, ppb; □, nitrogen dioxide, ppb; ○, hydrocarbons, ppm.

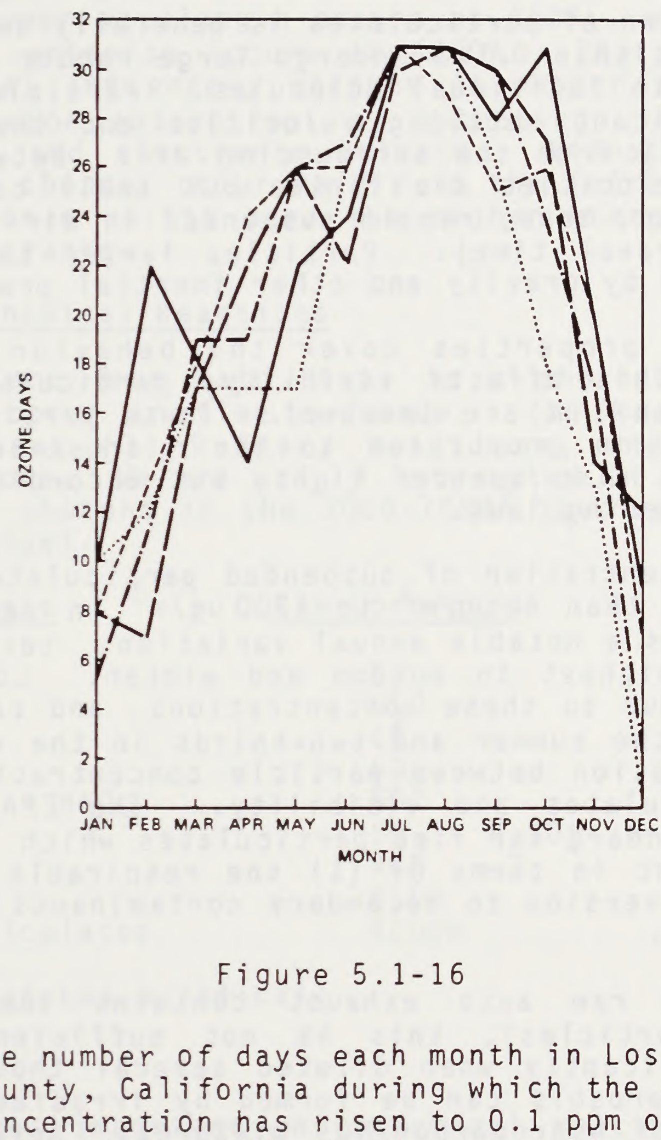


Figure 5.1-16

The number of days each month in Los Angeles County, California during which the ozone concentration has risen to 0.1 ppm or above. Solid line: 1967; short dashed line: 1968; long dashed line: 1969, dashed-dotted line: 1970; dotted line: 1971.

between particles and their surroundings, and include (1) surface properties, (2) motion, and (3) optical properties.

Surface properties include sorption, nucleation and adhesion, among others. Sorption is the deposition of molecules due to collision with an object. If the molecules are in a supersaturated atmosphere, the deposited molecules can attract other molecules causing them to condense out around the original deposit. This is nucleation.

The motion of particulates is generally defined by size. Particles of less than 0.1μm undergo large random motions caused by collisions with individual molecules. Particles larger than 1 μm have significant settling velocities and their motion can vary significantly from the surrounding air. Between 0.1 μm and 1 μm, settling velocities are finite but small compared to air motion. These can, thus, remain suspended in air for long periods (and long travel time). Particles larger than 5-10 μm are generally removed by gravity and other inertial processes.

Optical properties cover the behavior of particles toward light. This affects visiblity, particularly when particles larger than 1 μm are involved. These particles intercept or scatter light in proportion to their cross-sectional area. Smaller particles also scatter light, but according to far more complicated scattering laws.

The concentration of suspended particulate matter which ranges from less than 60 $\mu g/m^3$ to 1700 $\mu g/m^3$ in various American cities often shows a notable annual variation. Levels are lowest in summer and highest in autumn and winter. Losses of solar radiation occur due to these concentrations, and can run as high as one-third in the summer and two-thirds in the winter. There is also a correlation between particle concentrations and rainfall, and particulates and visibility. The EPA is presently considering a standard for fine particulates which are felt to be the most important in terms of (1) the respirable fraction, (2) the catalytic conversion to secondary contaminants and (3) visibility impairment.

Although raw auto exhaust contains some particulate matter (smoke particles), this is not sufficient to degrade visibility significantly when diluted several thousandfold with air. However, aerosols can be formed by irradiation of dilute auto exhaust or of hydrocarbon/NO_x mixtures. Aerosol formation is much enhanced by the addition of sulfur dioxide to the mixture. This suggests that sulfuric acid plays a role since H_2SO_4 is not only very nonvolatile but it also will absorb water.

5.1.7 Atmospheric Chemistry of Air Pollution

The solution of many air pollution problems involves knowledge of the chemistry of the atmosphere, when it may be termed "clean" and when it is "dirty." Also, the nature of air pollutants as they react as a whole must be determined. In general, the two classes of polluted smogs are called either the London type - a reducing smog where contaminants form nuclei for condensation of water vapor into fogs--or the Los Angeles type - an oxidizing smog where contaminants are photolysed to irritants.

- Solar Radiation

  The sun approaches a perfect black body radiator most closely in the region of 6000°K (12,300°F). Its maximum energy per wavelength occurs at 4500Å, while its maximum photon emission occurs at 6000Å. Photons produce many chemical and energy changes in matter at the molecular level upon absorption, by upsetting vibrational, rotational and electronic balance. Vibrational and rotational changes occur mainly in the infrared region while electronic shifts need the higher energy of the ultraviolet range.

- Photochemical Reactions

  There are four main steps in a photochemical reaction which occur in time sequence: (1) Radiation, (2) Absorption, (3) Primary Reactions, and (4) Secondary reactions. We are mainly interested in substances which absorb photons in the 3000-7000Å spectral region (visible range).

Absorbers	Non-absorbers
O_2	N_2
O_3	H_2O
NO_2	CO
SO_2	CO_2
HNO_2 - HNO_3	NO
RCHO	SO_3 - H_2SO_4
RCO	RCH
RCOO	RCOH
Particulates	RCOOH

(R denotes a radical)

- Oxygen

  The most important photochemical reactions involve the very reactive single oxygen atom.

$$O + O_2 \longrightarrow O_3$$

$$O + \text{OLEFINS} \longrightarrow \text{Several Fragments}$$

$$O + NO_2 \longrightarrow NO + O_2$$

$$O + SO_2 \longrightarrow SO_3$$

These atoms are produced by two main reactions:

$NO_2 + hv \rightarrow NO + O$ $O_3 + hv \rightarrow O_2 + O$	Major fragments of photochemical reaction in the atmosphere where h = Plank's constant and v = the frequency of the radiation.

Oxygen atoms are produced at the rate of 150 pphm hr^{-1}, but because of their reactivity, their stationary concentration in air is usually only 1-2 ppht (parts per hundred thousand).

- Ozone

Ozone is very important as a reactant in photochemical type smog. It is produced through the photolysis of nitrogen dioxide and the reactive oxygen atom.

$$NO_2 + hv \rightarrow NO + O$$

$$O + O_2 \rightarrow O_3$$

Ozone is a strong oxidizer and its main atmospheric reactions are:

90% $O_3 + NO \rightarrow NO_2 + O_2$

Equal Rate:

$O_3 + NO_2 \rightarrow NO_3 + O_2$

O_3 + Olefins → Free radicals, other organic fragments

Sulfur Dioxide

Sulfur dioxide is the major sulfur containing compound formed during fuel combustion. Hydrogen sulfide is easily oxidized to sulfur dioxide in air, especially in the presence of sunlight. In sunlight, sulfur dioxide reacts with either atomic or molecular oxygen to form an aerosol, particularly if water vapor is present. This aerosol is dilute sulfuric acid when uncontaminated with particulates, which are found in reducing type smogs. Sulfur dioxide also reacts with organics to form various sulfonic acids which are also irritants. Relative humidity plays a very important role in the photochemical reactions of sulfur dioxide by determining particulate-aerosol formations.

Organic Compound Reactions

The range of classes of organic compounds emitted from various processes and industries is very wide. Most of the higher molecular weight products settle rapidly, but short carbon chain molecules tend to be more reactive as ionic character outweighs the usual covalent nature of organic materials and they are very important as irritant precursors. Absorption of photons often leads to dissociation into free radicals - short fragments with extra electrons which are extremely reactive. Olefins, aldehydes, ketones, peroxides, are classes which easily absorb photons and form free radicals, and are among the usual products of combustion, especially from oil base fuels.

Nitrogen Oxide Reactions

Oxides of nitrogen are formed in practically all combustion processes in air, but the diurnal peaks and valleys of concentration are a matter of concern in air pollution studies due to the high buildup in the morning hours within urban areas as vehicular traffic reaches a peak. The sequence of reactions

$$NO_2 + h\nu \rightarrow NO + O$$

$$O + O_2 \rightarrow O_3$$

$$NO + O_3 \rightarrow NO_2 + O_2$$

is the fastest, most important, and results in the highest concentrations of actual and potential irritant concentrations in air pollution - atmospheric chemistry. Second in importance, photochemically, is olefin photolysis and ozone - organic molecule interaction. Other nitrogen oxide reactions of less importance are:

$$NO_2 + O_3 \rightarrow NO_3 + O_2$$

$$NO + NO_2 + H_2O \rightarrow 2\ HNO_2$$

$$N_2O_5 + H_2O \rightarrow 2HNO_3$$

Non-photochemical Reactions

A secondary reaction following photochemical reaction which is very important is :

$$O_3 + \text{Olefins} \rightarrow \text{free radical fragments}$$

Olefins are the most important beginning class of organic compounds for production of irritants and phytotoxicants.

Reaction with water vapor:

$$NO_x + H_2O \rightarrow HNO_2 - HNO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Other inorganic and organic classes of compounds are also emitted to the atmosphere such as flourides which quickly react with various surfaces, ammonia which forms acids, hydrogen sulfide which reacts with organics and forms sulfates, carbon monoxide which slowly oxidizes to carbon dioxide and organic amines which oxidize to acids. The above reactions are generally not of importance except in small localized areas.

Particulate Material Reactions

Particulate matter consists of an entirely different size category than we have examined thus far. As such, it provides reactive surfaces and can act as a third body and catalyst. Interaction with a particulate surface can cause either an energy level change or complete chemical change.

Examples of the former are:

$O\lambda_1 2 + M \rightarrow O\lambda_2 2 + M$ Change in absorption

$CH_3 + M \rightarrow CH_3 + M$ Termination of free radical

Examples of the latter are:

$Zn\ O(M) + H_2O\ \text{vapor} \xrightarrow{h\nu} H_2O_2 + M$

where:

λ = is the wavelength and
M = represents an energy-accepting third body

Catalyzed by photons:

$SO_2 + H_2O\ \text{drop} \rightarrow H_2SO_3\ \text{drop}$

$H_2SO_4 \bullet H_2O\ \text{drop} + Ca\ CO_3 \rightarrow CaSO_4 + CO_2 + H_2O$ Change in particulate

Kinetics in Atmospheric Chemistry

Without becoming involved in the rigors of kinetic theory, a few elementary definitions should be stated. The basis for determining the importance of any photochemical reaction, stationary concentration, rate of reaction, etc., is the Stark-Einstein Law which states that one photon must be absorbed to initiate photolysis. From this theory is derived the important equation:

$$K_a = \frac{I_a}{jc}$$

Where k_a is the specific absorption rate, I_a is the rate of absorption, j is a conversion factor, and c is the concentration of the absorbing substance. k_a represents the average fraction of absorbing molecules which receive photons per unit time. Primary quantum yield is very important as it tells us what percent of molecules that absorb photons will acutally react to the absorbed energy via a specific process. Absorption of a photon may result either in energy level change, shown by florescence, or chemical change, shown by dissociation or direct reaction. The rate of formation of excited molecules A' is given by:

$$+ \frac{d(A')}{dt} = I_a = k_a (A) = k_a c \quad \text{where}$$

$(A) = c$, the concentration of the absorber.

For secondary photochemical reactions rate constant is important. For a bimolecular reaction $A + B \rightarrow C + D$, the decrease in concentration of A will be:

$$- \frac{d(A)}{dt} = k_1 (A)(B)$$

where K, is the rate constant of the reaction. In general, the larger the rate constant, the more probable and more important part the reaction plays in the atmosphere.

Thus, a knowledge of what general reactions take place in the atmosphere under different meterological conditions, can help answer questions concerning the relative importance of contaminating substances. From a meteorological point of view, relative humidity and percent possible sunshine are the most important parameters to consider. This is because nitrogen dioxide-olefin photolysis and the reactions which follow are sunshine dependent and the sulfur dioxide-particulate reactions are largely humidity dependent. Further consideration involves precipitation which functions as a removal method, and low wind speed which causes the atmosphere to function as a stable reaction vessel. Extremes of temperature either help catalyze photochemical reactions, as in los Angeles, or enhance fog formation of particulate - SO_2 reactions, as in London.

The state of knowledge of atmospheric chemical reactions and interactions leaves a good bit to be desired as the subject is very complex. Experiments in all the areas discussed are increasing our knowledge and the total picture is slowly emerging.

[illegible] ultraviolet [illegible] molecules [illegible] [illegible] the concentration of the absorber.

For [illegible] photochemical reactions, rate constant is important. [illegible]

$$[illegible]$$

where k is the rate constant of the reaction. In general, the larger the rate constant, the more probable the more important part the reaction plays in the atmosphere.

Since a thousand or more general reactions take place in the atmosphere under different meteorological conditions, [illegible] questions concerning the relative importance of [illegible]. From a meteorological point of view, [illegible] and [illegible] possible [illegible] are the most important [illegible] to consider. This is because nitrogen [illegible] and the [illegible] reactions which follow are [illegible] dependent and the [illegible] particularly reactions are [illegible]. [illegible] consideration involves [illegible] which functions as a removal method, and the wind speed which causes the atmosphere to [illegible] is a [illegible] reaction [illegible] of temperature [illegible] photochemical [illegible], as in the [illegible] for formation of [illegible] - SO_2 reactions, as in London.

The state of knowledge of atmospheric chemical reactions and interactions leaves a good bit to be desired as the subject is very complex. Experiments [illegible] increasing our knowledge and the total picture is slowly emerging.

5.2 AIR POLLUTION EFFECTS ON AIR QUALITY RELATED VALUES

A pollutant can be roughly defined as a harmful chemical or waste material which is discharged into the atmosphere or water. Pollutants add stress to the biosphere, thereby affecting the quantity, quality or diversification of populations. State and local governments have regulated air pollutants for many years, but the first federal legislation was not seen until 1955, with the establishment of an air pollution research program. Public awareness of air pollutant hazards has increased tremendously since that time, and culminated in the enactment of the 1977 Clean Air Act Amendments. As stated in the Act, the purpose of this legislation is "to protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare" (CAAA, 1977). Falling under the umbrella of public health and welfare is not only man, but all air quality related values, including soils, vegetation, wildlife, watersheds, archaeology, and visibility. In general, all aquatic and terrestrial flora and fauna and their habitats must be evaluated to determine threshhold levels, or the point at which a pollutant can no longer be tolerated by a population. Section 5.1 detailed the formation of air pollutants. This section will describe the effect of these pollutants on the environment.

As depicted in Section 2, the majority of BLM lands are situated within the 500-3000 foot elevation range; however, areas as low as sea level and as high as 6000 feet are also found within the Ukiah District. The major vegetation types concentrated in these areas include redwood, Douglas fir, fir, pine, woodland, plains grass, chaparral, saltbush and marsh. While pollutant effects have been felt severely by California's agricultural crops, these will not be discussed to the extent of the aforementioned vegetation types, as they are not of primary importance to the BLM. Effects on fisheries and native animals will also be discussed to the extent that they have been researched. It is also valuable to note that effects of air pollutants have been seen in archeological sites, such as ancient Grecian ruins, and in geology throughout Europe and the Eastern United States. Although these later effects have not been seen or researched in California, they may become a serious future concern.

Particulates

Within the BLM lands in the Ukiah district, man-made emission densities for particulates range from 0-12,000 tons per year, with the highest emissions density being found in Humboldt County. Particulates may be defined as dispersed matter in the liquid or solid phase. A few of the wide variety of chemical constituents of particulate matter are listed in Table 5.2-1. Individual particles range from 0.005 to 500 μm in diameter. While emission control devices can remove up to 99% of stack particulate emissions, their efficiency becomes considerably lower for particles in the size range of 0-5 μm. These particles, therefore, are more readily emitted and can be transported over great distances. Also, this size range is easily passed into the lungs of man and animals, making these smaller particles the most deleterious.

The effect that particulate matter will evoke depends largely on its chemical composition. In general, most trace elements deposited on soil will remain in the surface layers, except in very acidic or sandy soils. While this accumulation serves to protect groundwaters from contamination in the short term, in time, natural processes such as surface runoff, erosion, and windblown dust may serve to contaminate aquatic biota. One of the most important factors in determining potential soil effects is the concentration of naturally occurring endogenous trace elements. Impacts of added particulates will be more severe in areas where endogenous concentrations are currently close to the tolerance limit for any population member. On the other hand, benefit in a deficient area may be gained by the addition of essential trace elements, such as copper, boron, molybdenum, zinc and manganese, (Dvorak, 1978).

Effects on vegetation will vary considerably. Visible effects range from chlorosis, necrosis and discoloration to stunting and deformation. These may be linked to changes in enzymatic reactions or metabolic processes, such as photosynthesis and respiration and will depend not only on the chemical composition of the particulate matter, but also on the exposure concentration, and plant species. In a natural vegetation area, such as the forests of the Ukiah District, where the majority of the vegetation is recycled rather than consumed, concentration build-up will exceed that found in agricultural areas.

As trace elements collect in the edible plants the entire food chain will be impacted. Herbivorous wildlife are affected through ingestion and also by the loss of sensitive plant species within their habitat. These factors may contribute to reduced numbers of wildlife species or possibly the elimination of certain species from the affected environment. Ingestion, along with inhalation, are the two modes of entry of trace elements into animals. Several effects of these elements are detailed in Table 5.2-1.

Sulfur Dioxide

All areas monitoring SO_2 levels within the Ukiah District have SO_2 concentrations below one-tenth pphm as shown in Figure 5.3-7 and are classified either as better than national standards or unclassified. However, this classificaiton does not preclude effects from being seen within this area. Sources of SO_2 and sulfur compounds include high sulfur fuel combustion (SO_2), anaerobic decompostion of plants material (H_2S), and the industrial production of sulfuric acid. Coal-fired power plants alone account for 40% of total U.S. sulfur-compound emissions.

Table 5.2-1

General Manifestations of Trace Elements in Animals

Element	Target organs or characteristics of toxicity	Comments
Arsenic	Has been associated with increased incidence of lung cancer.	Non-accumulative in animals but has affinity for hair, nails, and skin.
Barium	Has strong stimulating effect on all muscles in acute poisoning.	Poorly absorbed with generally little retention in tissue.
Beryllium	Characteristic granulomatous changes of lung tissue is brought about by long-term exposure.	Via inhalation, beryllium is correlated with an interference in the passage of oxygen.
Cadmium	Is linked with the incidence of hypertension in experimental animals.	Accumulative in all animals and toxic to all systems and functions in humans and animals.
Cobalt	Causes changes in lungs typical of pneumoconiosis. Also causes induction of polycythemia in many species.	With increasing age, the body burden of cobalt diminishes.
Copper	Associated with induction of haemolytic disease, especially in certain species.	In excess, results in some accumulation in the tissue, especially in the liver.
Chromium	Hexavalent compounds extremely toxic to body tissue. Insoluble forms retained in lung tissue.	In particular, the respiratory tract and fat tissue accumulate this metal.
Fluoride	Contributes to dental fluorosis in animals.	Deposits in bone tissue.
Lead	Newly absorbed lead is mostly retained in the body as lead triphosphate, especially in liver, kidneys, pancreas, and aorta.	Has strong affinity to accumulate in bone tissue.
Manganese	Acute intoxication involves changes in the respiratory system, whereas chronic poisoning affects the central nervous system.	Most amounts taken into the body are retained, especially in liver and lymph nodes.
Mercury	Organic forms have effects on brain tissue. The inorganic form is more linked to damage to liver and kidneys.	Can bioaccumulate in tissues of animals.
Molybdenum	Associated with degenerative changes in liver cells.	Can accumulate in tissues.
Nickel	Associated with cancer of lungs.	Very poorly absorbed from gut.
Selenium	Associated with alkali disease in cattle.	Is converted in the body into a volatile compound which is eliminated through breath and sweat.
Vanadium	Is found to inhibit the synthesis of cholesterol and other lipids. Other complications leading to cardiovascular diseases are also prevalent.	Vanadium salts are poorly absorbed from the gastrointestinal tract.
Zinc	Intoxication produces either lung or intestinal tract manifestations.	Absorbed or injected zinc is incorporated at varying rates into different tissue, indicating varying rates of zinc turnover.

Source: Dvorak, 1978

Highest levels of exposure from such plants may be expected in the Western U.S., where scrubbers are not used (Dvorak, 1977). Since many BLM land areas contain major coal reserves, this may be an area of great concern in the future.

The effects of gaseous air pollutants such as SO_2 on plants and animals are typically classified according to the exposure. Acute effects are those related to exposures of short duration (up to one month) and comparatively high concentrations. Chronic effects are evoked when organisms are exposed to low-level concentrations for periods of one month to several years. Long-term effects are the result of exposures lasting for decades or longer. These are characterized by abnormal changes in the ecosystem or subtle physiological changes in the organism. Acute injury to vegetation from SO_2 exposured is characterized by collapsed marginal or intercostal leaf areas, which later become dried and bleached to an ivory color in many species, or brownish red or brown in other species. Chronic injury is seen as leaf yellowing from the margins to intercostal areas. Both acute and chronic injuries can result in death of the plant. Long-term injury may also occur without visible symptoms, but may be implied by subtle changes in the ecosystem (Dvorak, 1976).

Sensitivity to SO_2 will vary according to the plant species and microclimate in which it exists. Several vegetation types native to BLM lands in the Ukiah District have been listed in Table 5.2-2, according to the sensitivity level as determined by the reference. Plants may also be affected in the following ways: increased respiration, decreased protein content and metabolism, decreased sugar, vitamin and starch content, decreased glucosidase activity and altered terpene activity.

Studies concerning SO_2 and SO_2 with NO_2 effects on desert-type vegetation of the Southwestern U.S. have been conducted by Hill, et.al. (1974). The area studied included Utah and New Mexico at elevations of 4500 to 6500 feet. Using concentrations of 0.5 to 11 ppm SO_2 + 0.1 to 5 ppm NO_2 for 2-hour fumigation periods, the study ranked sensitivity according to Table 5.2-3. Studies have been ranked together as no synergistic effects were found. Common injuries appeared as leaf necrosis and interveinal patches of necrotic tissue on broad leaves. Color of injured tissue varied from tan, gray brown and yellow to rusty brown depending on the species. With desert plants, often the entire leaf was injured. Results of the study suggested that middle-aged and older leaves were more sensitive than younger, expanding leaves and years with unusually high rainfall could cause more severe injury to desert type vegetation (Hill, 1974).

Caldwell, et al (1976) also studied SO_2 effects on southwestern U.S. desert vegetation. Fumigation studies were conducted in the Catalina Mountains near Tucson at 7700 ft. Results were similar to those by Hill, et. al. (1974); however, Caldwell noted that SO_2 will injure vegetation to a maximum distance of 30 to 40 miles. Past that point, the plume will be

Table 5.2-2

SO_2 Injury to California Native Vegetation

Common Name	Sensitivity	Reference
Pine, Jack & Red	Sensitive	Davis & Wilhour (1976)
Douglas Fir	Intermediate	Davis & Wilhour (1976)
Fir, Basalm & Grand	Intermediate	Davis & Wilhour (1976)
Pine, Lodgepole	Intermediate	Davis & Wilhour (1976)
Pine, Ponderosa	Intermediate	Davis & Wilhour (1976)
Pine, Western White	Intermediate	Davis & Wilhour (1976)
Fir, Silver	Resistant	Davis & Wilhour (1976)
Fir, White	Resistant	Davis & Wilhour (1976)
Pine, Limber	Resistant	USDA (1973)
Pine, Mugs	Resistant	Davis & Wilhour (1976)
Pine, Pinton	Resistant	Davis & Wilhour (1976)
Fir, Subalpine	Sensitive	Davis & Wilhour (1976)
Pine, Short Leaf	Intermediate	Treshow (1970)
Sagebrush, Big	Intermediate	Davis & Wilhour (1976)

Source: Dvorak, 1978

Table 5.2-3
Percent of the Total Leaf Area Injured by Different Concentrations of SO_2 in Two-Hour Field Fumigation Studies

	Average percent injury						Number of replications					
	SO_2											
Species	.5 ppm	1 ppm	2 ppm	4 ppm	6 ppm	10 ppm	.5 ppm	1 ppm	2 ppm	4 ppm	6 ppm	10 ppm
Abies concolor (White fir)		0		0	0			1		1	3	
Abies lasiocarpa (Alpine fir)					0	22					5	2
Acer glabrum (Rocky Mountain maple)		0		10	60			1		1	1	
Achillea millefolium (Yarrow)		0	0	0	16	38		1	1	2	5	2
Agoseris glauca (Mountain dandelion)		0	0	10	15			3	2	7	6	
Agropyron caninum (Wheatgrass)			0	0	0	78			1	1	5	2
Agropyron desertorum (Crested wheatgrass)					20						1	
Ambrosia sp. (Ragweed)		0	0	0	1	1		1	3	4	2	1
Amelanchier utahensis (Utah serviceberry)	0	0.2	3	22	33	80	1	3	3	1	3	1
Antennaria sp. (Pussytoes)			0	0					1	1		
Arabis pulchra (Rockcress)				0						1		
Artemisia ludoviciana (Louisiana sage)		0		0	21			2		1	4	
Artemisia tridentata (Big sagebrush)			0	4	9	2			2	5	7	3
Aster chilensis (aster)		0	0	1	5			3	1	6	4	
Astragalus utahensis (Locoweed)		2	0	30	50			1	1	2	2	
Atriplex canescens (Fourwing saltbush)				0	0					1	1	
Atriplex confertifolia (Shadscale)				0	0					1	1	
Betula occidentalis (River birch)				50						1		
Bouteloua barbata (Six-weeks grama grass)		0	0	0	0			3	2	7	9	
Bouteloua gracilis (Blue grama grass)					0						1	
Bromus ciliatus (Fringed brome)		0	0	0	13	96		2	3	5	2	1
Bromus inermis (Smooth brome)						0.6						1
Bromus tectorum (Cheatgrass)			0	0	0	10			1	3	3	1
Cercocarpus ledifolius (Curl-leaf mountain mahogany)					0.4	25					5	1
Cercocarpus montanus (Mountain mahogany)				5						2		
Chenopodium fremontii (Goosefoot)		0	2	5	7			5	3	5	6	
Chrysothamnus nauseosus (Big rubber rabbitbrush)				0	1	40				3	3	1
Chrysothamnus stenophyllus (Little-leaf rabbitbrush)				0						1		
Chrysothamnus viscidiflorus (Sticky-flower rabbitbrush)		0		0	5			2		1	2	
Cirsium undulatum (Thistle)		0		6	14			2		4	4	
Clematis ligusticifolia (Western virgin's bower)				0	0.2					1	1	
Cleome sp. (Beeplant)				0						1		
Cowania mexicana (Cliffrose)					0	3					1	1
Cryptantha humilis (Catseye)				0	15	80				1	1	2
Cynoglossum officinalis (Houndstongue)		0	0.4	8	16			5	4	15	7	
Descurainia californica (Tansy mustard)				0		40				1		1
Ephedra viridis (Mormon tea)		0		0	2	95		2		2	4	1
Equisetum sp. (Horsetail)		0	0	0	0			1	1	2	1	
Eriogonum racemosum (Buckwheat)		0		43	19			1		2	3	
Euphorbia serpyllifolia (Spurge)		0	0	12	15			5	2	9	10	
Eurotia lanata (Winterfat)				6	0					1	2	
Geranium richardsonii (White geranium)			3	7	86				2	2	2	
Gilia aggregata (Scarlet gilia)			0.8	3	14				1	2	2	

Table 5.2-3 (cont.)

Species	Average percent injury SO$_2$ .5 ppm	1 ppm	2 ppm	4 ppm	6 ppm	10 ppm	Number of replications .5 ppm	1 ppm	2 ppm	4 ppm	6 ppm	10 ppm
Gutierrezia sarothrae (Snakeweed)			0	0	21	78			4	2	13	3
Hackelia floribunda (Stickseed)		0		0				1		1		
Haplopappus nuttallii (Goldenweed)					0	100					1	1
Hedysarum boreale (Sweet vetch)			0	0	40	75			2	1	1	1
Hilaria jamesii (Galleta)		0	0	0	0	0		3	2	5	9	1
Hymenoxys richardsonii (Hymenoxys)				0						1		
Juniperus osteosperma (Utah juniper)					0	28					1	2
Juniperus scopulorum (Rocky Mountain juniper)		0		0	0	25		1		1	4	1
Lepidium sp. (Peppergrass)		0						1				
Machaeranthera canescens (Spiny-leafed aster)				25						1		
Mahonia repens (Oregon grape)		0		0	0			1		1	2	
Malacothrix sonchoides (Desert dandelion)				0						2		
Munroa squarrosa (False buffalograss)		0	0	0	0			3	2	7	9	
Oenothera sp. (Evening primrose)		6	12	5	3			3	1	3	1	
Opuntia sp. (Prickly pear cactus)					0						1	
Oryzopsis hymenoides (Indian ricegrass)	0.2	2	2	17	29	90	4	9	8	14	17	1
Oryzopsis micrantha (Ricegrass)				4						1		
Pachystima myrsinites (Mountain lover)					0						1	
Penstemon sp. (Penstemon)				15		70				1		1
Phacelia corrugata (Scorpion weed)				0						2		
Picea pungens (Blue spruce)			0	0	0				1	2	3	
Pinus edulis (Pinyon pine)				0	0.06	2				4	9	4
Pinus ponderosa (Ponderosa pine)				0	0	1				2	3	1
Poa pratensis (Kentucky blue grass)			0	0	7				1	5	3	
Populus angustifolia (Narrowleaf cottonwood)	0	0	2	11	20		3	6	2	5	2	
Populus tremuloides (Quaking aspen)	0	0	0	12	7	0	1	2	3	11	8	1
Pseudotsuga taxifolia (Douglas fir)				0	0.8					5	4	
Quercus gambelii (Gambel oak)					0	8					1	1
Rhus trilobata (Squawbush)					0.3	0					1	1
Rosa woodsii (Wild rose)		0	1	15	90	60		6	3	5	2	1
Salsola kali (Russian thistle)				7	3					3	2	
Senecio streptanthifolius (Groundsel)				0	8					3	1	
Silene menziesii (Catchfly)				0						1		
Sitanion hystrix (Squirreltail)			0						1			
Sphaeralcea sp. (Cutleaf globe mallow)			0	0.03	17	40			2	4	3	1
Sphaeralcea parvifolia (Globe mallow)	20	22	43	38	30		2	7	3	7	2	
Sporobolus cryptandrus (Sand dropseed)		0	0	0	0	0		3	2	8	7	1
Stipa occidentalis (Needlegrass)					0	73					4	2
Symphoricarpos oreophilus (Snowberry)		0.3	6	18	32			4	4	6	3	
Tragopogon dubius (Goatsbeard)			0	4	8				2	2	3	
Trisetum spicatum (Trisetum)						90						1
Viola sp. (Viola)					25						2	
Yucca sp. (Yucca)						0						1
Zygadenus paniculatus (Death camas)			0	0	13				1	1	2	

too dilute to cause any effects. The most resistant species (Douglas Fir, Pinon Pine, and Arizona Ponderosa) all grow in higher elevations and the three most sensitive species, (Gooding's Willow, Cocklebury, and Sunflower), all grow in low, wet areas. Humidity plays a role in determining the threshhold value for SO_2 injury. Higher humidities tend to lower the SO_2 levels needed to create a response. Generally, injury was proportional to new growth and smaller, less developed individuals were more sensitive. Symptoms were visible within one and one-half days after fumigation. High temperature and wind increased symptom maturation (Caldwell, 1976).

Plants, in general, are more sensitive than animals to SO_2 injury; however, animals are impacted indirectly by changes in habitat or food species. Direct effects in animals also occur. Sulfur is known to inactivate enzymes, thus altering protein synthesis. Enzymes such as diastase, peroxidase and catalase are particularly sensitive. In man, the effects may be increased airway resistance, decreased mucus flow rate, increased susceptibility to respiratory infection and chronic respiratory disease. Six to ten exposures of 0.2 ppm for 10 seconds each has produced altered electro-encephalograms. Recent population studies indicate that, at lower concentrations, inhaled sulfuric acid and specific sulfates produce even greater irritability than from SO_2 (Coffin and Knelson 1976).

Studies by Colucci (1976) show deleterious effects to pulmonary function in laboratory animals with acute exposures of 6.75 ppm for two to three hours. Pulmonary dysfunction occurred with chronic concentrations of 4.86 ppm for several months. Epidemiological studies indicate that chronic exposures of 0.04 ppm can adversely affect human populations. It follows that animals with higher ventilation rates or more exposed mucosal tissue per body size would be more sensitive (Dvorak, 1976). Results of Colucci's studies may be reviewed in Table 5.2-4.

Another integral part of SO_2 emissions concerns the combination of SO_2 and nitric oxide as acid precipitation. The acidification of many freshwater lakes and streams has become an area of extreme concern in Northern Europe and Northeastern North America. The acidity of precipitation has been on the rise in this area since the early 1900's because of increased emissions of acid-forming sulfur and nitrogen compounds. This acidic precipitation can lower the pH of soils and natural waters causing mineral leaching and damage to many aspects of the biosphere.

Studies by Hendrey, et. al. (1976) show that the acidification of freshwaters produces many changes in the aquatic environment. In six Swedish lakes, where pH had decreased by 1.4 to 1.7 units during a forty-year period, bacterial activity had apparently decreased, leaving dense amounts of fungal hyphai on sediment surfaces. Decreased pH was believed to be the cause for the shift in dominance of organisms from bacteria to fungi, with the consequent decrease in oxygen consumption and interference with nutrient recycling by microdecomposers (Hendry, 1976).

Table 5.2-4

Summary of Toxicological Experiments with Sulfur Dioxide (SO_2)[a]

Species	Concentration (10^5 µg/m³)	Duration	Effects
Monkey	<0.034	78 weeks	None
Donkey	<0.078		None
	<0.78		Impaired bronchial clearance
Dog	0.13	21 hours/day for 620 days	None
Monkey	0.13	78 weeks	None
Guinea pig	<0.13	22 hours/day for 365 days	None
Dog	0.13	21 hours/day for 225 days	Increased pulmonary resistance
Rat	0.026-0.079	12 hours/day for 4 months	None
Mouse	0.18 -0.26	7 days	Increased sensitivity to pneumonia infection
Rabbit	0.26	3-10 days	Increased S-sulfonate clearance
Mouse	0.26	Up to 72 hours	Lesions in respiratory tract
Rat	0.26	6 hours/day, 5 days/week for 113 days	None
	2.6	6 hours/day, 5 days/week, for 22 days	40% mortality
	~15	6 hours/day, 5 days/week, for 12 days	~90% mortality
Guinea pig	0.26	6 hours/day for 20 days	None
Cat	0.52		Increase in pulmonary flow resistance
Rabbit	~0.52	14 and 62 hours	Formation of S-sulfonate
Mouse	13	5 min/day, 5 days/week for 300 days	Accelerated onset of neoplasia
Hamster	14	3 hours/day for 75 days	Increased pulmonary infection
Dog	13-14	2 hours/2 times/week for 4 to 5 months	Change in goblet cells of bronchi and bronchioles
Rat	13-78		Change in goblet cell release
Rat	26	Up to 6 weeks	None
	52	Up to 6 weeks	Bronchial damage
	104	Up to 6 weeks	Death within 22 days
Rat	78	6 hours/day for 10 days	Increased acid phosphatase activity
Rat	78	2 hours	Gastric inhibition
Mouse	≤78	10 exposures of 10 minutes, with 3 or 7 minutes recovery between exposures	Initial decrease in respiratory rate, then progressive return to preexposure rate; desensitization to successive exposures.
Mouse	Various		Sensitized mice to pneumonia infection

[a]Data extracted from summary of Colluci (1976) and presented in order of increasing concentration, except where there is more than one entry for a single experiment.

Source: Dvorak, 1978

The interference with microdecomposer activities impacts on invertabrates, as food availability and variety is decreased (Hendrey, 1976). Devastating effects have been seen in fish species. In Norway, huge amounts of adult salmon and trout have been killed in connection with spring snow melt or heavy autumn rains. Sweden has reported the extinction of the salmonid population, and severe effects in the roach, perch, and pike communities. Metal smelters in Sudbury, Canada, which emit 2.64 million tons of SO_2 annually, have been thought to be the cause of the rapid disappearance of lake trout, lake herring, white suckers, and other species in the La Coche mountain region during the 1960's. PH values as low as 4.5 were not uncommon in this region. In the Adirondack Mountains of New York State, intensive studies revealed pH levels less than five to be present in 51% of the higher elevation lakes, and 90% of these lakes were devoid of fish life. Species such as brook trout, lake trout, white sucker, brown bullhead and several cyprinid species were completely eliminated over a period of forty years. Cause of death at pH levels less than three may be the result of a coagulation of mucous on gill surfaces and subsequent anoxia. At pH levels of four to five, the cause may be a disturbance of the normal ion and acid-base balance. It appears that small fish are more sensitive than larger members of the same species. Smaller fish have a larger gill surface area per unit weight, which hastens ion fluxes. Age-specific mortality has not been clearly defined although there are indications that age may play a role in some species (Schofield, 1976).

The effect of acid precipitation on soils may be beneficial as well as harmful. Because it increases the amounts of sulfur and nitrogen, the added nutrient benefit may outweigh any deleterious effects. However, leaching of valuable soil minerals, such as Calcium and Manganese, and other cations, has been linked to acid precipitation. Inasmuch as soil structure, texture, and cation exchange capacity vary so widely, it is difficult to determine completely the effect that increased acid will create without first classifying the soil type. Susceptibility, as discussed by Malmer (1976), varies as follows. Natural soils with high pH and base saturation are usually highly resistant, along with soils rich in clay and organic colloids. On the other hand, acid and sandy soils and soil types that are transitional between brown earths and podsals will be more seriously affected by increased acidity. It is relevant also to bear in mind that acid precipitation may carry many other pollutants to the soil, which may increase or counteract expected effects (Malmer, 1976).

As soils are affected, biological effects will be seen on forest vegetation. Some species of lichens, which have the capacity to fix molecular nitrogen from the air, are quite sensitive to SO_2 and lose their nitrogen-fixing ability when subjected to acid precipitation. However, this may not be harmful to forest trees as they are not obligate nitrate plants. The addition of acid rain is also expected to cause the release of aluminum and heavy metal ions from the soil, which are toxic to many plants. It is also felt that nitrogen is accumulating in forest soil, and this accumulated nitrogen is expected to be transformed to nitrate and leached after clearfelling or forest fires. The results of this net acidification during a short period of time is not clearly known. However, it is expected that this condition will contribute to a decreased growth rate of trees (Tamm, 1976). Although effects of acid precipitation have not been established in California, it is being monitored presently in the Ukiah District in order to evaluate trends for future consideration.

Nitrogen Oxides

Like SO_2, coal-fired power plants are a major source of nitrogen oxides. These plants are responsible for 11% of the total nitrogen oxide emissions in the U.S. Other sources of atmospheric nitrogen include ammonia (NH_4) from biodecay and fertilizers, nitrogen oxides (chiefly NO and NO_2) from biochemical reactions within the soil, and also high-temperature combustion processes. Taken on a global scale, most NO_x is produced by bacteria, about 50 x 10^7 tons per year as compared to man-made sources which account for 5 x 10^7 tons per year. In the Ukiah District, typical emissions densities for oxides of nitrogen are within the range of 5,000 to 12,000 tons per year (TPY). Sonoma and Solano Counties exhibits the highest level of NO_x emissions (12,000-18,000 TPY).

Soils and plant life have not shown any detrimental effects of increased atmospheric nitrates at their present level (Noggle, et. al., 1978). In fact, atmospheric nitrate is beneficial because it restores the small quantities of nitrates lost in a mature ecosystem.

Animals and man, however, can be adversely affected by nitrous oxides as they are quite destructive to lung tissue. NO_2 is relatively insoluble in water and therefore is not scrubbed by tracheal and bronchial linings. This results in greater penetration into the lungs, interference with bacterial activity of macrophages, increased susceptibility to infection, bronchial inflammation, and loss of cilia. Long-term, low-level doses may result in an emphysema-type injury, decreased pulmonary compliance, and increased lung weight (Kavet and Brown).

Predicted worst-case NO_x emissions from a 2100 MWe generating station within about a one-half mile radius exceed 5.3 ppm for a short time period. Table 5.2-5 gives an indication of the adverse effects possible even at this level. Epidemiological studies indicate that humans may be adversely affected by chronic exposures to 0.53 of NO_2. The effectiveness of extrapolating these data to wildlife in the region is uncertain (Dvorak, 1978).

It is known that NO_2 in combination with SO_2 can produce severe effects at levels where SO_2 or NO_2 alone would not produce a visible response. Since coal combustion in power plants accounts for approximately 40% of total sulfur compound emissions

Table 5.2-5

Summary of Toxicological Experiments with Nitrogen Oxides (NO_x)[a]

Species	Concentration (10^5 µg/m³)	Duration	Effects
		Acute exposures	
Guinea pig	0.01-0.20	4 to 24 hours/day for up to 14 days	Elevated protein in urine
Guinea pig	0.04	Up to 21 days	Increased average area per alveolar wall cell
Mouse	0.02-0.30	Up to 17 hours	Impaired bacterial defense
Monkey	0.2 -1.0	2 hours	Decreased tidal volume, progressive histopathological damage
Rat	0.30-0.34	48 hours	Increase in Type II pneumocytes
Rabbit	0.16-1.2	3 hours	Impaired bacterial defense at all levels of exposure
Hamster	0.60-0.70	7 to 10 days	Bronchiolitic lesions
		Chronic exposures	
Mouse	0.01	Up to 12 months	Reduction of functional lung tissue
Monkey	0.02	493 days	Slight to moderate emphysema
Monkey	0.04	14 months	Hypertrophy of bronchiolar epithelium in bronchiole
Rat	0.02	14 months	Marginal changes in epithelium
Guinea pig	0.02	6 months	Higher mortality
Rat	~0.06	9 months	Decrease in lung compliance
Rat	0.04	Lifetime	"Emphysema-like" injury suggested
Rat	0.04 0.34	Up to 360 days Up to 7 days	Increase in number of cells preparing to divide
Rat	0.12	6 weeks	Interstitial edema, vascular congestion
Rat	0.20	90 days	Decreased body size
Rat	0.30	90 days	Decreased body size
Mouse	~0.80	Up to 8 weeks	Epithelial damage near terminal bronchioles
Hamster	0.9-1.1	10 weeks	Respiratory rate increased, hyperplasia and hypertrophy in terminal and respiratory bronchioles

[a]Data extracted from summary of Ziskind and Hausknecht (1976) and presented in order of increasing concentration, except where there is more than one entry for a single experiment.

Source: Dvorak, 1978

and about 11% of total nitrogen oxide emissions in the continental U.S., it is important to look to these immediate areas for pollutant responses.

Carbon Monoxide

Within the Ukiah District, BLM lands in Yola, Napa, Marin and southern parts Solano and Sonoma Counties are in non-attainment areas. Other BLM lands are situated in areas that are unclassified or better than national standards as shown in Figure 5.3-4.

The toxic properties of carbon monoxide have been known to man for quite some time. Unfortunately, studies involving environmental aspects such as soils, wildlife, vegetation and archaelogy have not been published to the same extent as many other air pollutants. For this reason, carbon monoxide effects on man and mammals alone will be discussed.

Ninety-five percent of carbon monoxide emissions may be attributed to automobile exhaust and, because they are released near the ground, these emissions do not undergo substantial diffusion. This fact coupled with CO's lack of involvment in further atmospheric reactions to form secondary pollutants, accounts for the very high levels in urban areas. The situation is complicated further in that CO measurements in urban areas may be critically underestimated. Studies were conducted by Cortese and Spengler (1976) in the Boston area to determine the ability to represent carbon monoxide exposure by fixed monitoring stations. In this experiment, 66 non-smoking individuals carried portable CO samplers at breathing levels for the period October 1974 through February 1975. Results showed that four of the 66 volunteers, who commuted to work daily, were exposed to 37 ppm CO because of faulty automobile exhaust systems. This level is in excess of the National Ambient Air Quality Standard for one-hour 35 ppm. Considering the other volunteers, concentration of 5 to 20 ppm occurred 85% of the time, 5% were greater than 23 ppm and 1% were over 31 ppm. Comparison of these levels to fixed location monitors in the area, show that the mean one-hour personal exposure concentration (25.3 ppm) was 1.6 times greater than the fixed monitoring concentration (15.6 ppm) for all area stations. This difference may be due to the fact that CO concentrations at breathing level may diminish by 5 to 15% by the time they reach the usual monitoring height of 15 feet (Cortese, et al, 1976). This study would indicate that CO concentrations, as monitored, may actually be significantly higher in urban areas or on heavily traveled roadways.

Effects on small mammals may be derived through studies by Mordelet-Dambrine (1978) and Finelli, et. al. (1976). Mordelet-Dambrini ventilated guinea pigs and rats with 2.84% CO. After two minutes, tracheal pressure variations were seen and blood pressure and heart rate decreased within one to two minutes, respectively. Rats appeared to be more sensitive than guinea pigs to CO inhalation. It was postulated that their higher heart rate could trigger the higher sensitivity level (Mordelet-Dambrini, 1978).

Finelli, et. al. (1976) studied the effects of clean air, exhaust emissions with a catalytic converter, and carbon monoxide emissions on 20 male rats for a period of four weeks. CO levels of 57.5, 172.5 and 517.7 mg/m^3 were used. During the exposure period, 18 animals were killed, and there was a dramatic loss in heart, spleen and body weight. A trend of lower serum cholesterol levels was significant in the rats exposed to the highest CO levels. These effects were not seen in the group exposed to the exhaust equipped with the catalytic converter as CO amounts had been greatly reduced (Finelli, 1976).

Parallel studies have shown that adult rats exposed to automobile exhaust without catalytic converters may also exhibit elevated hematocrit and hemoglobin, cardiac hypertrophy, loss in body weight and increased levels of serum lactate dehydrogenase. Low levels have also caused increased serum and aortic cholesterol in rabbits. This may be a factor in the development of arteriosclerosis in humans (Finelli, 1976). Also in humans, it is known to affect the heart, brain and muscle tissue most seriously because CO has a high affinity for hemoglobin and thus limits the amount of oxygen available to all body tissues, these three being extremely sensitive to oxygen deficiencies. CO has also been associated with reduced ability to perform vigilance tasks and reduced exercise tolerance (Cortese, 1976).

Any of these symptoms may also be seen in species native to the Ukiah District. Possibly, symptoms may be more severe in animals with higher heart rates and more lung tissue relative to body weight. However, care should be taken in extrapolation of data.

Hydrocarbons

Hydrocarbon emissions are below 25,000 tons per year in all areas of the Ukiah District with the exception of Sonoma County where emissions reach 26,000 tons per year. As in the case for carbon monoxide, studies involving hydrocarbons as an air pollutant are not as numerous as those concerning many other air pollutants.

There are three basic sources of hydrocarbons: animal, mineral and vegetable, such as municipally operated sewage treatment systems, industrial discharges from oil-dependent industries and decaying vegetation. Over 90% of major discharges of petroleum hydrocarbons escape from pipelines, tank ships, tank barges, marine facilities and onshore production storage facilities (Boyd, 1976).

At the 1977 American Petroleum Oil Spill Conference, it was reported that in California, concentrations of petroleum hydrocarbons were found in almost all benthic and sandy intertidal sediment samples collected in the Southern California borderland (Reed, 1977). As hydrocarbons collect in soils and water, an effect will be seen on algae and photoplankton. Retardation of algae growth and inhibition of photosynthesis has been linked to the presence of petroleum hydrocarbons. A reported growth stimulation in photoplankton may be due to the slight carcinogenic stimulatory activity of low HC levels (Vandermuelen, 1976).

Effects of hydrocarbons on fish have been well documented by Adams (1975). Studies indicate that recreational vehicles, such as snowmobiles and motor boats, add dangerously high amounts of hydrocarbons to lakes. Death of fish may occur at levels of a few ppm and feeding, homing and reproduction are disrupted at levels of 10 to 100 ppb. These exhaust hydrocarbons concentrate in fatty tissue such as lateral line muscle and visceral fat. These compounds remain in the tissues and are passed to higher animals through the food chain (Adams, 1975). Further discussion of hydrocarbon effects on fish will be included in a subsequent section, as this experiment also involved lead values.

Ozone

Hydrocarbons and nitric oxides in the presence of sunlight are known to produce ozone. Automobile exhaust, therefore, may be considered as a primary source of the precursors which give rise to oxidant. High ozone levels have been found not only in the urban environment but also in rural areas, on mountain tops, and at night. The reason for this ozone build-up is not fully known; however, it is believed that ozone or its precursors are being transported long distances or there may be a natural source of hydrocarbons and nitric oxides within forests and swamps, such as terpenes and methane. Within the Ukiah District, areas in the southeastern section of the District have been in violation of the federal one-hour standard for oxidant levels as seen in Figure 5.3-11; however, these violations are on the order of less than one percent of all observations per year.

Ozone is known to reduce photosynthesis in plants, thereby reducing the nutrient value of the plant. Studies of air pollution damage to the forests of the Sierra Nevada Mountains by Williams et al (1974), indicated widespread oxidant-caused injury to conifers. Especially susceptible were the ponderosa and Jeffery pine as measured by the extent and intensity of chloratic mottle on current year needles. Since ozone is dose-accumulative for a variety of sensitive plants, a concentration of 0.06 ppm over a five-month growing season would produce chlorotic mottle on current year needles of the ponderosa pine. It should be noted that this quoted level is within the federal standard of 0.12 ppm (Williams, 1977).

Results of the 1974 Sierra Nevada field survey showed ozone injury to be most abundant in the mixed conifer forest types located from 6000-8000 ft. in elevation. However, injuries at mid-elevation, (4000-6000 feet), where many BLM lands are located, tended to be more severe. These studies indicate that ozone injury is dependent on elevation. At mid elevations, where inversion levels are often found, injuries will be most severe. At higher levels, where ozone is quite abundant, injuries are more prevalent (Williams, 1977). Injuries to other species are detailed in Table 5.2-6.

The California Department of Agriculture yearly assesses damage to vegetation as caused by air pollution. In their 1970 summary, Millecan (1971) details the history of ozone damage to California forests. In the early 1950's in the San Bernardino National Forest, several pines began to turn chloratic and drop needles. Ponderosa and Jeffery pine were particularly involved. In 1963, it was first suggested that ozone might be the cause. Later, in 1969, aerial surveys by the Forest Service and University of California at Riverside revealed the extent of ozone damage. More than 161,000 acres of the ponderosa and Jeffery pines in the San Bernardino National Forest, an estimated two-thirds of the trees, were damaged by ozone. Of these, 3% were dead, another 15% were severely affected, and 82% were moderately or lightly affected (Millecan, 1971). Damage estimates have also been assessed by the Statewide Air Pollution Research Center of the University of California. Figure 5.2-1 reveals the extent of oxidant injury as seen in 1974. Elevations over 8000 feet were not considered in this study.

The Forest Service has been assessing ozone injury since 1974. A recent survey by Pronos et al (1978) revealed the extent of ozone injury in the Sierra and Sequoia National Forests as depicted in Figure 5.2-2. The worst injuries found were considered to be moderate and these were generally found at elevations of 4000 to 7000 feet on the Front Range mountains west of the San Joaquin Valley and along major river drainages. However, a quick comparison of this data to photochemical levels found in the San Bernardino National Forest show that the ozone levels of the southern Sierra do not even approach the levels found in Southern California forests as shown in Table 5.2-7 (Pronos, 1978). Presently, no evidence of ozone injury has been seen or documented in the forests of the Ukiah District, but it is valuable for the BLM Manager to be aware of the potential.

Impacts of ozone on man, animals and other air quality related values have not been studied to the same extent as with vegetation. However, ozone has been found to attack the cell membrane, breaking double bonds and removing hydrogen atoms. In humans, this process acts as a bronchoconstrictor, whereby less air reaches the lungs. There is increased coughing and breathlessness, and lung elasticity is decreased. Also, there is damage to alveolar macrophages in the presence of high concentrations of ozone, increasing the susceptibility to infection and

Table 5.2-6

Site Characteristics and Extent of Ozone Injury

Location	Elevation (meters)	Topography	Site	Species with symptoms	Land use
Delilah LO	1564	Ridge	Flat, Dry	Ponderosa (PP)	National Forest (NF)
Mt. Sampson	1623	Ridge	Steep Dry	PP Black Oak (BO)	NF, Private
McKensie Ridge	1600	Ridge	Flat, Dry	PP, BO	NF
Converse Basin	1577	Basin	Mesic	PP, Sugar Pine (SP) Giant Sequoia (GS)	NF
Hume Lake	1577	Basin	Mesic	PP, SP, Jeffery Pine (JP)	NF
Boyden Cave	970	Canyon Bottom	Dry, Steep	PP	NF, National Park (NP)
Park Ridge	2199	Ridge	Steep, Rocky, Moist	PP, JP, SP White Fir (WF)	NP
Buck Rock	2578	Ridge	Steep, Rocky	JP Lodgepole Pine?	NF
Weaver Lake	2669	Flat	Dry	JP, Lodgepole Pine?	NF
Whitaker Expt. Forest	1638	West Slope	Moist	PP, BO, WF, SP, GS	Univ. of Calif.
Pinehurst	1095	West Slope	Dry	PP, BO, WF	NF, Private
Badger F.S.	1000	Flat	Dry	PP, BO	NF, County, Private
Sierra Glenn	970	Flat	Dry	PP	Private, County, State
Eshom Creek	1517	Variable	Moist	PP, BO	NF
Eshom Point	1517	Ridge	Dry	PP, BO	NF
Skagway Grove, Muir Grove	1517	Flat	Moist, Rocky	JP	NP
Lodgepole RS	2038	Flat	Moist, Rocky	JP, LP	NP
Crystal Cave	1456	Flat	Mesic	PP, BO, WF	NP
Giant Forest	1911	Flat	Mesic	JP, BO	NP
Colony Mill RS	1638	Ridge	Dry	PP, WF, BO	NP
Moro Rock	1880	South Slope	Mesic	PP	NP
Crescent Meadow	1914	Meadow	Mesic	JP	NP
Milk Ranch Peak	1897	South Slope	Dry	PP, WF, SP, BO	NP
Mineral King	2254	Canyon Bottom	Mesic	JP	NF

Source: Williams, 1977

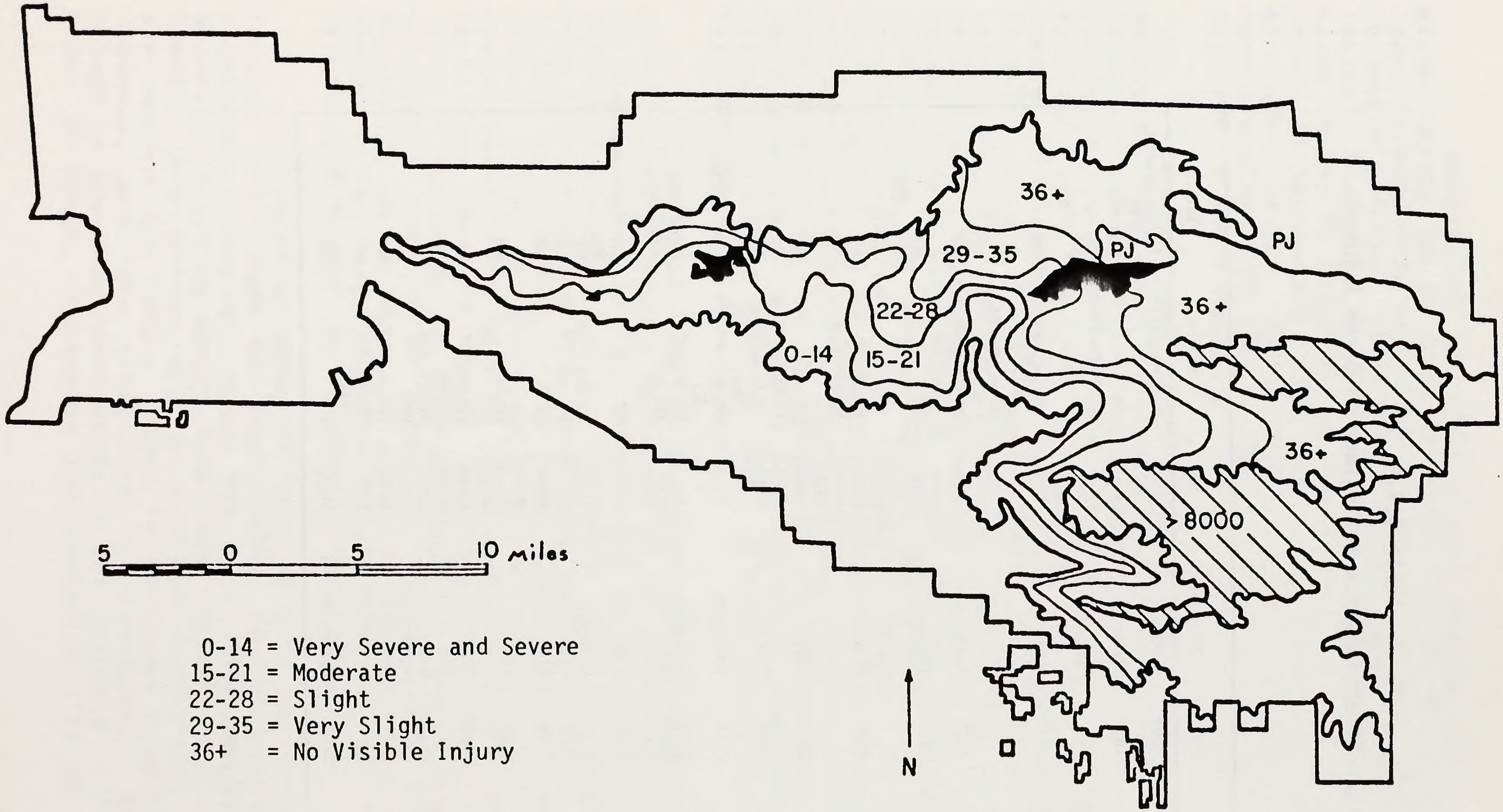


Figure 5.2-1

Preliminary Map of the Extent and Severity of Oxidant Injury to Ponderosa and Jeffrey Pines in the San Bernardino National Forest (1974)

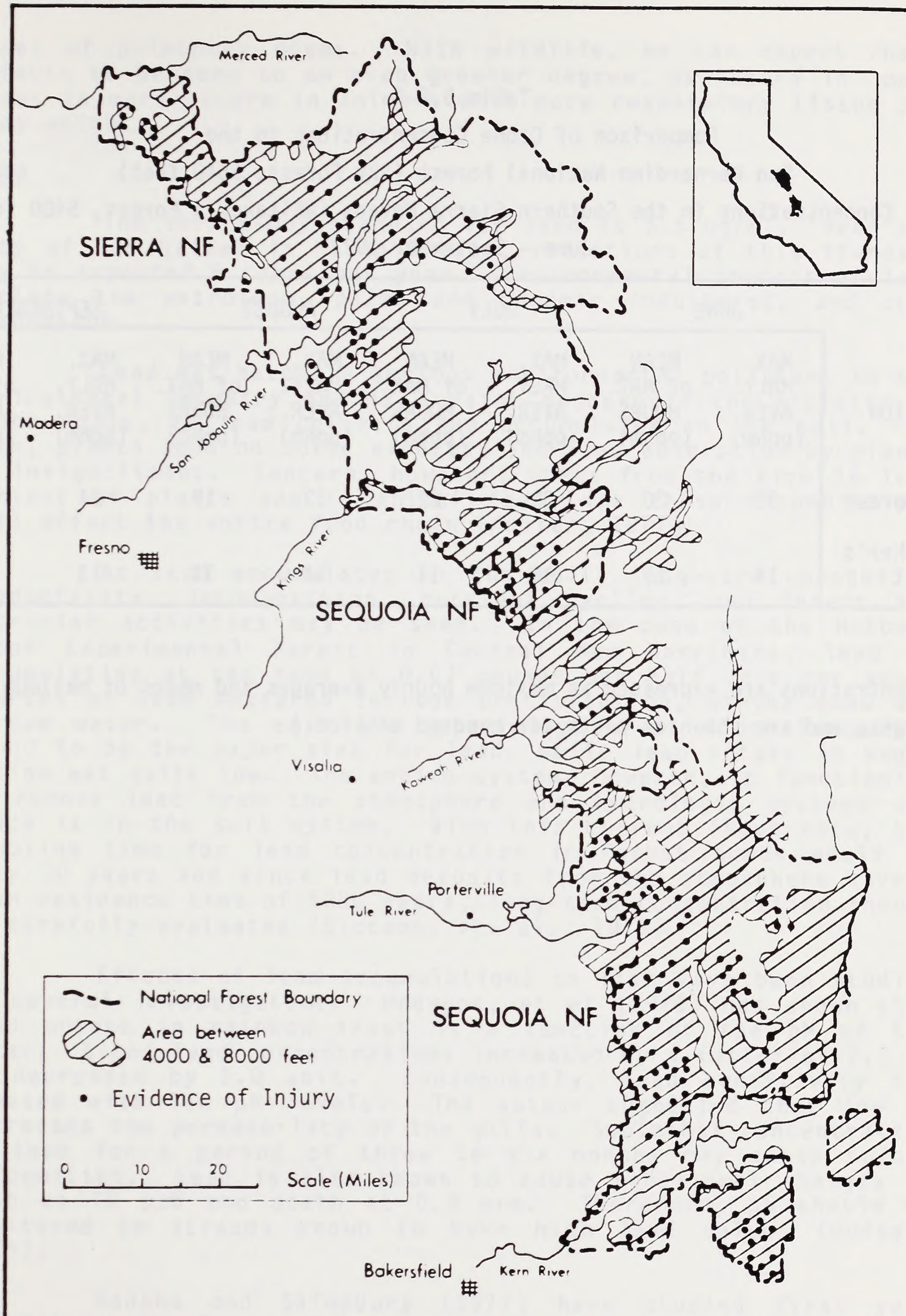


Figure 5.2-2

Location of Ozone Injury in the Sierra and Sequoia National Forests, 1977

Source: Pronos, 1978

Table 5.2-7

Comparison of Ozone Concentrations in the San Bernardino National Forest (Sky Forest, 5640 feet) With Concentrations in the Southern Sierra Nevada (Whitaker's Forest, 5400 feet) June - September 1977

LOCATION	JUNE		JULY		AUGUST		SEPTMEBER	
	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)
Sky Forest	32	20	30	22	33	19	24	14
Whitaker's Forest	14	10	15	11	14	11	13	9

(Concentrations are expressed as maximum hourly averages and means of maximum hourly averages, and are shown as parts per hundred million.)

cases of pulmonary edema. With wildlife, we can expect these effects to be seen to an even greater degree, as injury in most cases is more severe in animals with more respiratory tissue per body weight.

Lead

The thirty-day standard for lead is 1.5 $\mu g/m^3$. Near the city of San Rafael in Marin County, violations of this standard may be expected 6 times per year. Environmental sources of lead include the petroleum, paint and ceramic industries, and coal combustion.

Lead has become a serious environmental pollutant to the agricultural industry and is a major concern in the vicinity of major roads, as lead collects and accumulates in the soil. To date, plants show no toxic effects, and lead absorbtion by plants is insignificant. Concern, however, stems from the rise in lead content of plants and in animal feed, for these accumulations will affect the entire food chain (Keller, 1977)

As lead accumulates in the soil, long-term changes in productivity, decomposition, nutrient cycling, and insect and mycrobial activities may be seen. In the case of the Hubbard Brook Experimental Forest in Central New Hampshire, lead is accumulating at the rate of 0.67 pounds per half acre per year. Sources of lead measured include precipitation, winter snow and stream water. The soil and especially forest floor humus was found to be the major sink for lead, while lead uptake in vegetation was quite low. The entire system, however, is functioning to remove lead from the atmosphere and hydrologic systems and place it in the soil system. With this current input rate, the doubling time for lead concentration in forest humus would be only 50 years and since lead deposits from the atmosphere have a mean residence time of 5000 years, long-term concentration should be carefully evaluated (Siccama, et. al., 1978).

Effects of lead accumulations on fish have been studied by several investigators. Hodsons, et al (1978) has shown that lead uptake in rainbow trout is a function of the pH of the water. Blood lead concentrations increased by a factor of 2.1 as pH decreased by 1.0 unit. Consequently, lead sensitivity increased with low pH levels. The author suggested that low pH increases the permeability of the gills. Sublethal concentration of lead for a period of three to six months may cause spinal deformities. Lead is also known to cause behavioral changes in fish at 70 ppb and death at 0.3 ppm. Therefore, pH should be monitored in streams known to have high lead values (Hodson, 1978).

Badsha and Sainsbury (1977) have studied first year whitings in the Severn Estuary and feel that bioaccumulations are functions of the food chain rather than respiration and gills. Therefore, bottom feeders would be expected to accumulate relatively higher lead amounts than other types of predators. Once ingested, lead is not rejected and slowly increases (Badsha, et. al., 1977). Effects on fresh water fish may be quite similar according to experiments by Rehwoldt, et. al. (1978) in the fresh water stretch of the Hudson River system. In this study several species of fish were caught and lead levels were compared to those of preserved samples. Results are given in Table 5.2-8 and indicate that lead levels are time independent in a relatively clean system such as the Mid-Hudson (Rehwoldt, 1978).

Studies by Adams (1975) involve the effects of lead and hydrocarbons on brook trout. Increasing amounts of these two pollutants are released to the aquatic environment by snowmobiles and outboard motors each year and are attracting much attention. Towle's Pond in Freeport, Maine, served as the site for several experiments. Water samples in November 1971 showed 4.1 ppb lead and no detectable hydrocarbons as a baseline concentration. Through the winter seasons of 1971 and 1972, 56.8 liters of gasoline were burned in snowmobiles operating on the pond. During ice-out, lead levels increased to 88 ppb in 1972 and 135 ppb in 1973. These lead levels decreased rapidly within 72 hours of ice-out and returned to near normal within six days. Lead levels in exposed fish were 15.7 and 8.8 times those of control fish in 1972 and 1973, respectively. Four fish died during the first six hours of the 1973 experiment. Cause of death has been attributed to low oxygen levels in the pond during that period. Hydrocarbon levels ranged from 1 to 10 ppm and an oil slick was visible on the pond for one week after ice-out each year. Levels in exposed fish ranged from 0.1 to 1 ppm. Laboratory study revealed highest lead levels occur in the digestive tract (3.3 times that in control groups) and lowest in the gills, which may further indicate that bottom predators may be seriously affected by increasing lead levels. Elevated lead levels were also found in muscle skin and gills (Adams, 1975).

The pathological effects of lead in small mammals are detailed in reports by Roberts, et. al. (1978). Two abandoned metaliferous mines in Wales were chosen as the sites for soil, vegetation and mammal tissue measurements to determine lead accumulations. The area was typified by sparse natural vegetation, with a limited range of species, as few populations could survive the heavy metal concentrations in the soil. Table 5.2-9 indicates the lead amounts found in the soil, vegetation and invertebrate populations. Small mammals were caught in the area and examined for lead content. Vegetarian feeders were found to have the highest level concentrations and insectivorous mammals the least. In these mammals, bone and kidney tissues had the highest lead concentration, and the liver, brain, and muscle tissues had the least. This supports the generally accepted idea that the skeleton is the main long-term storage site for lead (Roberts, 1978).

Mice were fed lead acetate at levels of 0.1% and 4.0% in experiments by Eyden, et. al. (1978), to determine toxicity. The animals suffered weight reductions, increased sperm abnormalties,

Table 5.2-8

Average Values (m/g) for Lead in Dry Weight

Common Name	Source*	Pb
Alewife	MC 10 (1976)	0.30
	VC 2 (1953)	0.61
Atlantic Sturgeon	MC (1976)	0.82
	NYS 5 (1924)	0.71
Fundulus	MC 21 (1976)	0.51
	VC 4 (1953)	0.62
	NYS 3 (1936)	0.41
	AMNH (2) (1973)	1.10
Small Mouth Bass	MC 11 (1976)	1.06
	NYS 3 (1936)	0.99
Spottail Shiner	MC 17 (1936)	0.59
	VC 5 (1953)	0.69
	AMNH 2 (1973	0.77
Striped Bass	MC 14 (1976)	0.92
	NYS 2 (1936)	0.40
	AMNH 5 (1973)	0.21
Sunfish	MC 23 (1976)	0.25
White Perch	MC 26 (1976)	1.06
	VC 2 (1953)	1.02
	NYS 1 (1936)	0.80

* MC Marist College
VC Vassar College
NYS New York State Museum and Science Service
AMNH American Museum of Natural History

Number after source is sample size
Number in paranthesis is year caught

Source: Rehwoldt, et.al., (1978)

Table 5.2-9

LEAD CONCENTRATIONS (μg/g dry weight) IN SOIL, VEGETATION AND INVERTEBRATES (mean ± standard error, number of samples in brackets)

	Vegetation Lead	Invertebrates Lead	Surface Soil Lead
Mine A	120 ± 5.40(8)	61.9 ± 14.5(6)	8430 ± 2050(9)
Control	20.8 ± 3.89(8)†	18.4 ± 1.87(6)†	96.3 ± 24.4(10)†
Mine B	249 ± 33.7(9)	81.7 ± 18.6(5)	14010 ± 6160(7)
Control	28.9 ± 2.73(9)†	22.3 ± 4.79(6)†	78.0 ± 10.1(8)†

† Denotes statistical significance at $p < 0.001$ (NS = $p > 0.05$).

Source: Roberts, 1978

early hair loss, lethargy and reductions in mean survival time. Symptoms were dose-dependent and the authors suggested that death may be attributed to internal organ malfunction resulting from enzyme interference, lack of nervous or hormonal infection from depressed immunological competence (Eyden, 1978).

Lead is also known to accumulate in humans within the blood, bones, urine, aorta, teeth, kidneys and liver. It has been associated with anemia, arterioclerosis, diseases of the central nervous system, bone deterioration, kidney failure, chromosome abberations, and brain damage. It is also known that lead will pass through the placenta in pregnant women. Most serious effects may be seen in young children, ages one to four, as this is the time for normal development of the central nervous system and bone tissue. Yankel et. al. (1977) observed blood lead levels in young children living near a lead smelter in northern Idaho and found amounts as high as 70 mg Pb/100ml. Ambient air, soil and dust lead levels were attributed to be the major cause for the elevated lead levels. Air exposure alone explained 55% of the variance (Yankel, 1977).

This section has detailed the effects of various pollutants on air quality related values. Whenever possible, environmental concerns typical of the Ukiah District were stressed. Where data was lacking, similar species or areas were described. Relating these data to the Ukiah District may help to point out critical areas for immediate study or future areas of concern.

Hydrogen Sulfide

The southern portions of the Ukiah District are located within a natural geothermal area. Therefore, hydrogen sulfide (H_2S) is emitted to the atmosphere and most likely, these natural emissions have caused violations of the California standard (0.03 ppm) for the past 50,000 years. Development of the geothermal potential of this area, while decreasing natural emissions, has at the same time increased man-made emissions.

1979 data from geothermal sources, as reported by the State Energy Commission, show H_2S controlled emissions to be 1600 tons per year and unabated emissions of 3100 tons per year. Geothermal processes also release very low concentrations of radon-222, mercury, arsenic, SO_2, ammonia and boron. Presently, all fifteen operating geothermal power units are located in Northern Sonoma County; however, the potential for development also exists in Lake, Mendocino, and Napa Counties. Violations of the standard may be expected on the order of a few hours per year. Studies in the Geysers-Calistoga Geothermal Area have noted unabated H_2S maximum concentrations of 1.0 ppm and average levels of 0.2 ppm during an 8-hour period. The worst known H_2S accumulation occurred at the Big Sulphur Creek watershed during a nocturnal inversion and averaged 0.1-0.2 ppm. Fumigation studies by Coyne and Bingham (1978) using H_2S concentrations of 0.74 ppm showed a ten percent increase in photosynthetic rates for field snap bean. Further studies by Shinn, et. al. (1976) also found a significant increase in photosynthetic rates for lettuce. Therefore, it is assumed that H_2S levels found in the geysers area are not harmful to vegetation types. According to Malloch (1979), there is no evidence of H_2S effects on water quality or on animals, and ambient H_2S levels are beneficial to vegetation (Malloch, 1979).

However, vegetation stress and damage has been noted near the Geysers-Calistoga Known Geothermal Resource Area (KGRA) since 1973. Symptoms such as needle tip burn, leaf bronzing, glazing, chlorosis, necrosis, reduced vigor and decreased lichen abundance and diversity have been observed. Malloch, et. al. (1979) have studied the vegetation injury in this area. High concentrations of boron have been found in circulating water, surface soils and leaf tissues and it is believed these harmful effects may be attributed to boron toxicity rather than H_2S (Malloch, 1979).

5.3 BASELINE AMBIENT AIR QUALITY

The Ukiah District encompasses portions of four air basins as described in Section 4.8 - North Coastal, North Coastal Mountains, San Francisco Bay Area and Sacramento Valley. Air quality monitoring in the district is concentrated in major cities for most of the pollutants, with an expanded network for the monitoring of total suspended particulates (TSP). The existing monitoring network is shown in subsequent figures in conjunction with the pollutant-specific attainment status for each county.

The California Air Resources Board (CARB), in accordance with the requirements of the Clean Air Act Amendments of 1977, has classified each county in terms of attainment of the National Ambient Air Quality Standards (NAAQS). Air quality regulations are discussed in considerable detail in Section 6; however, a review of the attainment status of counties within the Ukiah District provides an excellent means for defining baseline ambient air quality. Figures 5.3-1 through 5.3-4 show the current status for each pollutant as designated for counties in the Ukiah District. The figures illustrate which areas have been designated as non-attainment, cannot be classified, or better than national standards for total suspended particulates and sulfur dioxide. For oxidant, carbon monoxide, and nitrogen dioxide, areas with sufficient data and poor air quality have been designated as non-attainment. Those areas with good air quality or insufficient data have been categorized as "cannot be classified or better than national standards." Since the unclassified areas denote the lack of sufficient baseline air quality data, these maps also indicate which counties require additional monitoring stations to determine their status and thus their problem areas.

Baseline Levels

Ambient air quality values for 1977 for selected stations can be found in Appendix D while long-term baseline data are presented in Appendix E. The values cover all of the major pollutants, although every station does not measure all pollutants of interest. The listings include the number of observations, the yearly high, the arithmetic and geometric means with their standard deviations and the seasonal means and highs. The frequency with which standards are equalled or exceeded is also provided for each station.

Baseline ambient air quality data from Appendix D have been summarized in Figures 5.3-5 and 5.3-6 for total suspended particulates and sulfur dioxide, respectively. These parameters have been selected for graphical presentation and detailed analysis as they comprise the most readily available air quality data. They also provide a good representation of the effects of both industrial and agricultural (or outdoor) sources.

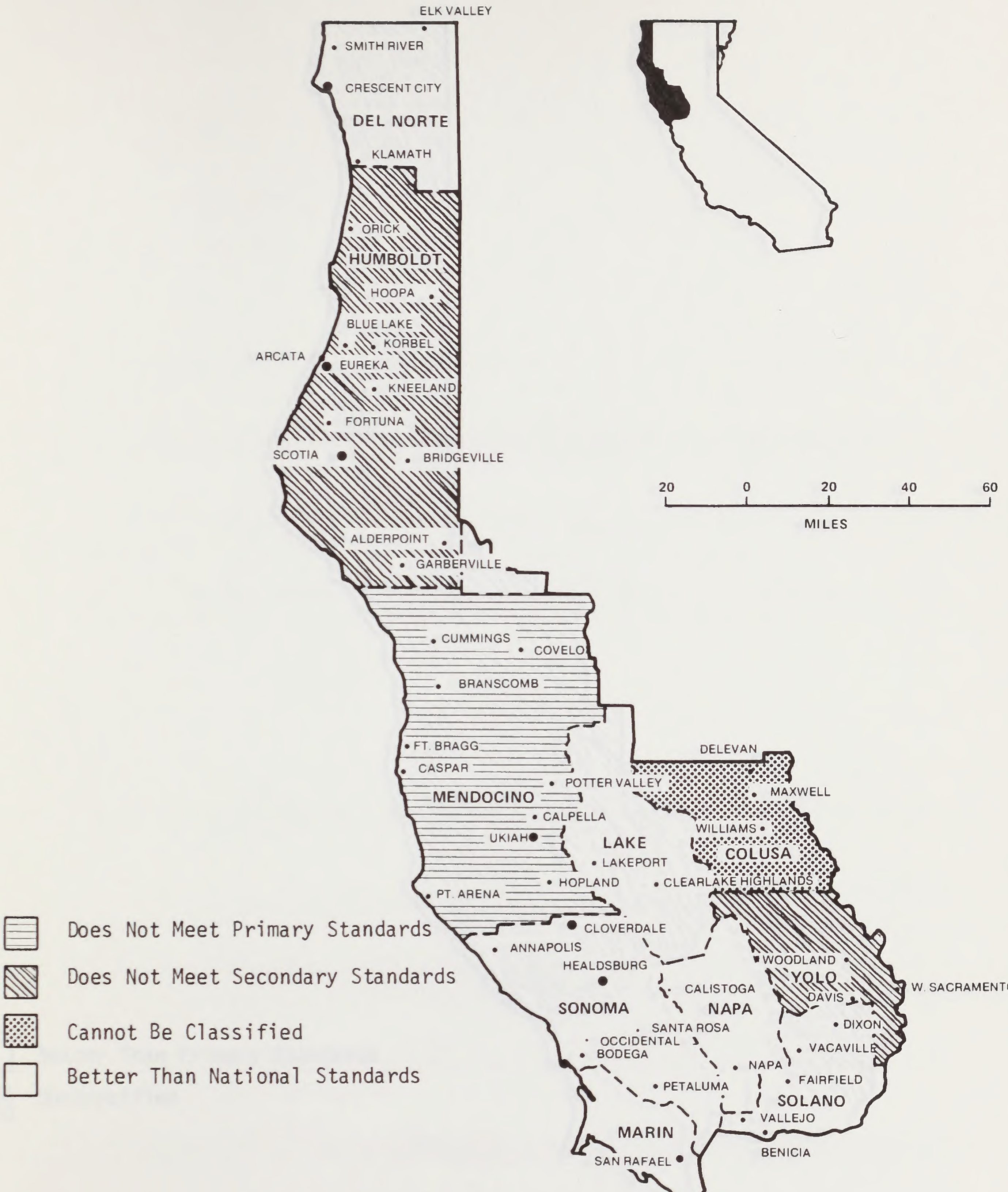
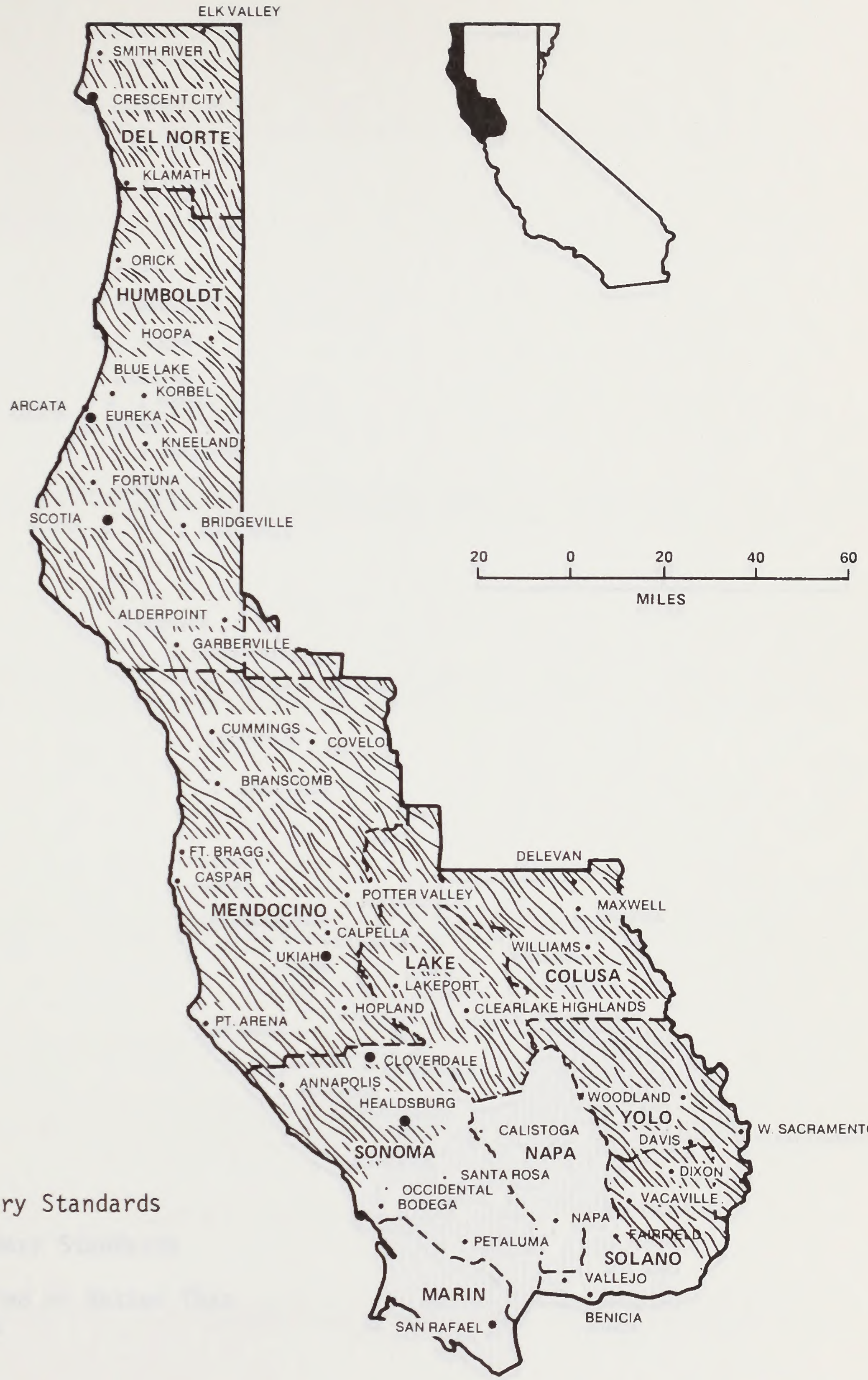


Figure 5.3-1
Ukiah District TSP Classifications



Better Than Primary Standards

Unclassified

Figure 5.3-2
Ukiah District SO_2 and NO_2 Classifications

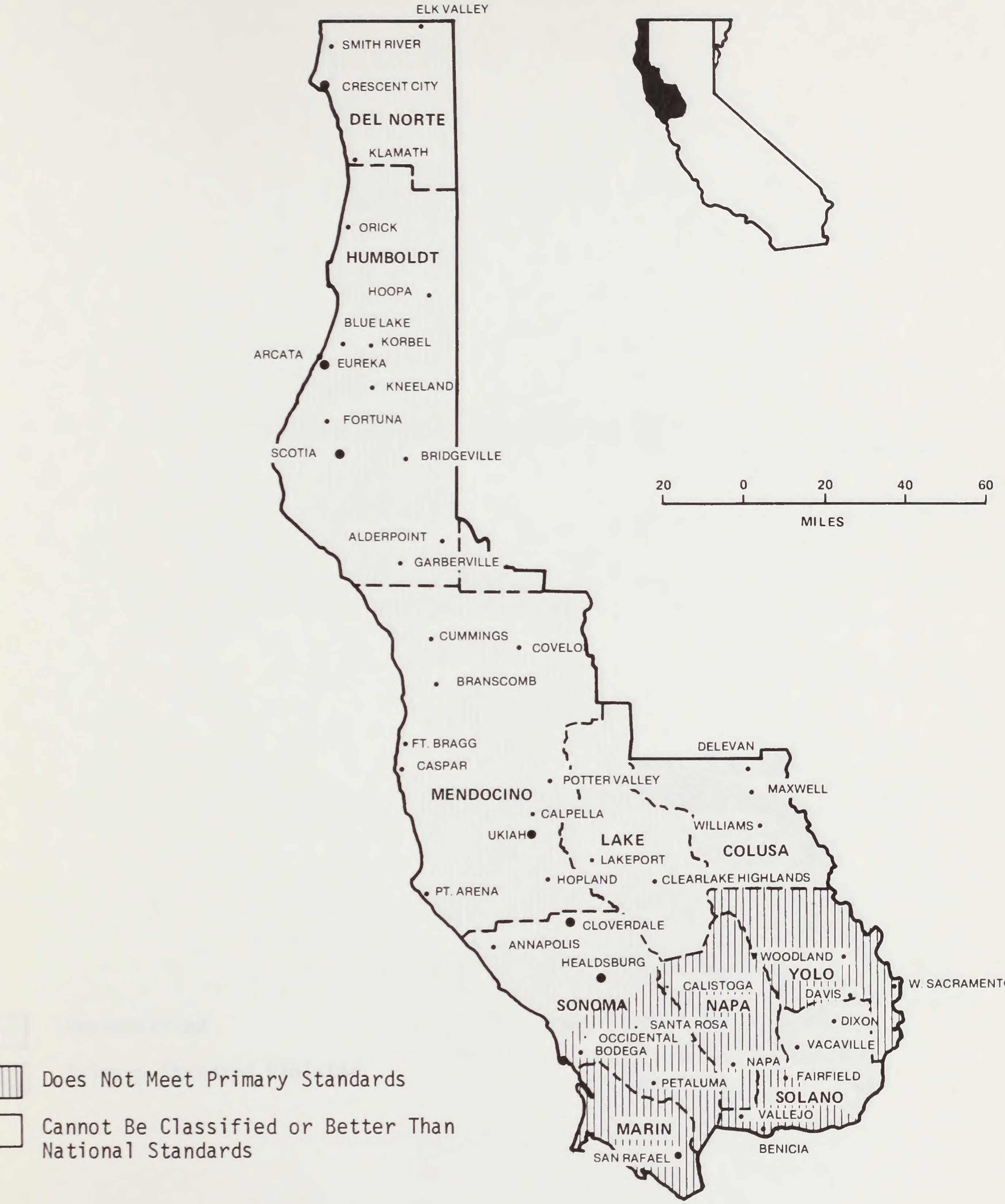


Figure 5.3-3
Ukiah District CO Classifications

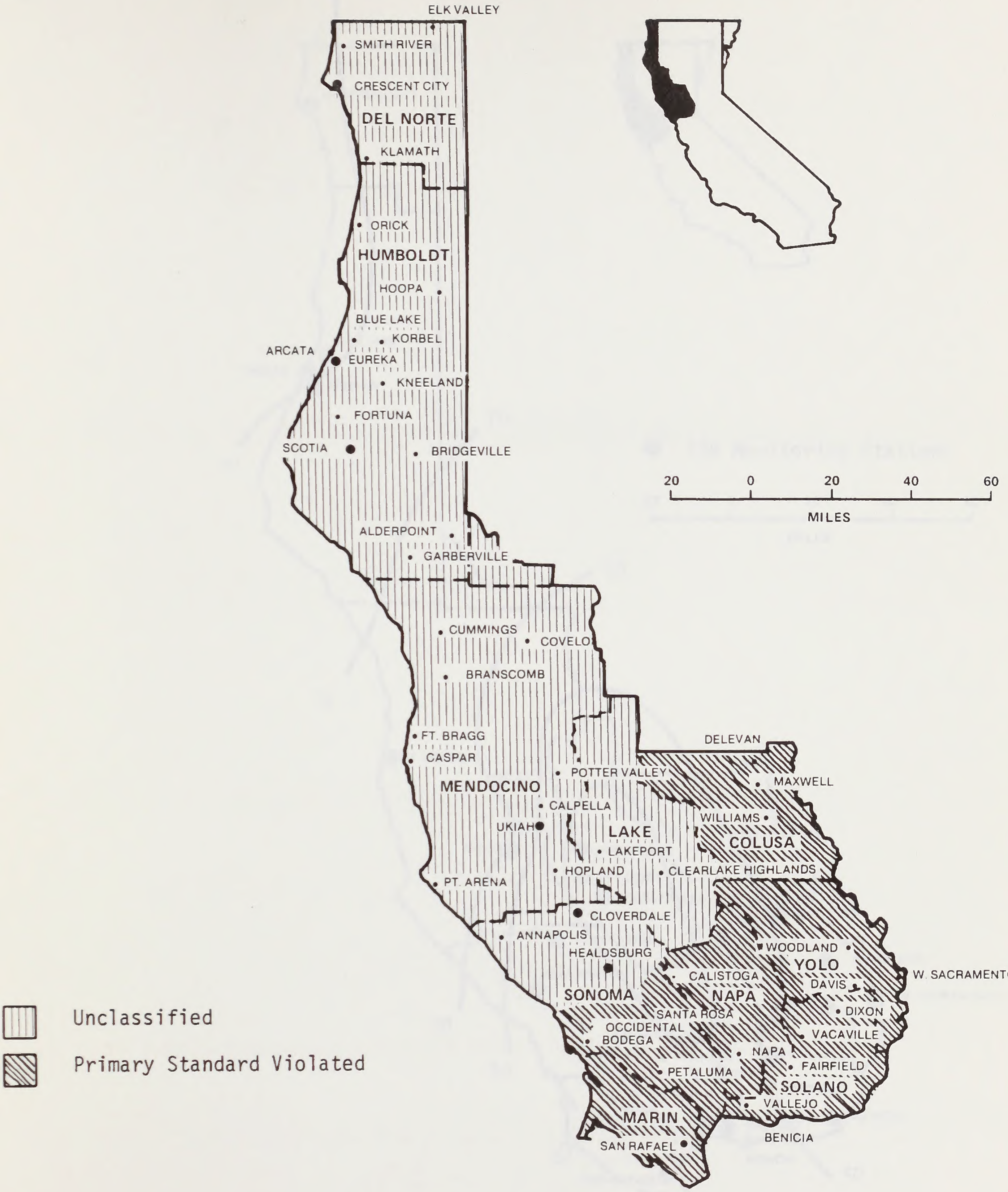


Figure 5.3-4
Ukiah District Ozone Classifications

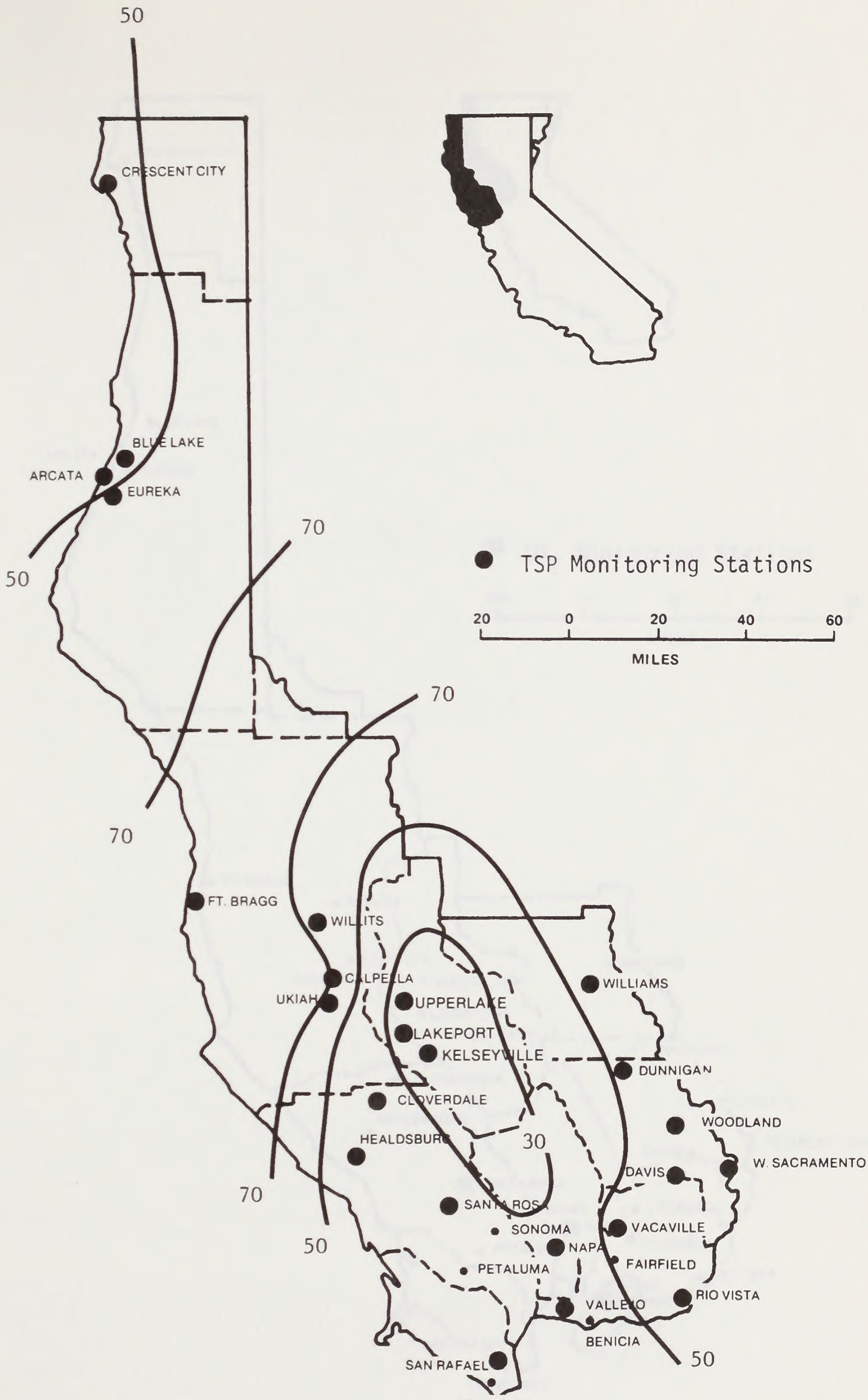


Figure 5.3-5

Annual Geometric Means ($\mu g/m^3$)

For Total Suspended Particulates in the Ukiah District

NATIONAL AMBIENT AIR QUALITY STANDARD FOR TSP = 75 $\mu G/M^3$ ANNUAL GEOMETRIC MEAN
CALIFORNIA TSP STANDARD = 60 $\mu G/M^3$ ANNUAL GEOMETRIC MEAN

Figure 4.5-2

Annual Geometric Means (ug/m³)

For Total Suspended Particulates in the Ukiah District

NATIONAL AMBIENT AIR QUALITY STANDARD FOR TSP = 75 ug/m³ ANNUAL GEOMETRIC MEAN
CALIFORNIA TSP STANDARD = 60 ug/m³ ANNUAL GEOMETRIC MEAN

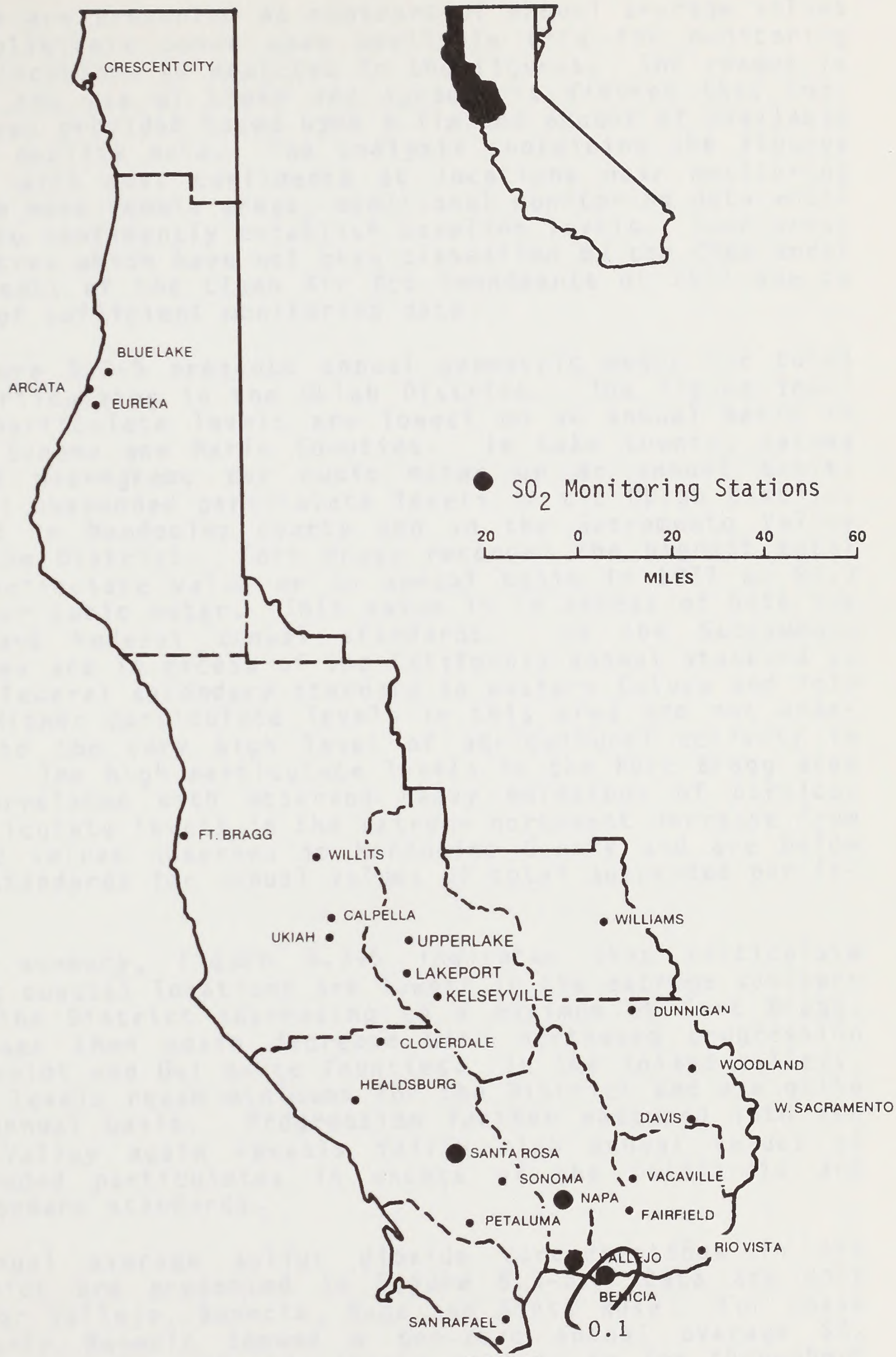


Figure 5.3-6

Annual Average SO_2 Concentrations (pphm)

in the Ukiah District

NATIONAL AMBIENT AIR QUALITY STANDARD FOR SO_2 = 0.03 ppm

Source: CARB, 1977

Figure 5.1-6

Annual Average SO_2 Concentrations (ppm) in the Great Basin District

NATIONAL AMBIENT AIR QUALITY STANDARD FOR SO_2 = 0.03 ppm
Source: CARB, 1977

Data are presented as contours of annual average values for these pollutants based upon available data for monitoring stations at locations as depicted in the figures. The reader is cautioned in the use of these and subsequent figures that contours have been provided based upon a limited amount of available baseline air quality data. The analysis containing the figures can be used with most confidence at locations near monitoring stations. In more remote areas, additional monitoring data would be required to confidently establish baseline levels. Such areas include counties which have not been classified by the CARB under the requirements of the Clean Air Act Amendments of 1977 due to the absence of sufficient monitoring data.

Figure 5.3-5 presents annual geometric means for total suspended particulates in the Ukiah District. The figure indicates that particulate levels are lowest on an annual basis in Lake, Napa, Sonoma and Marin Counties. In Lake County, values are less 30 micrograms per cubic meter on an annual basis. Highest total suspended particulate levels in the Ukiah District are observed in Mendocino County and in the Sacramento Valley portion of the District. Fort Bragg recorded the highest total suspended particulate value on an annual basis in 1977 at 86.3 micrograms per cubic meter. This value is in excess of both the California and Federal annual standards. In the Sacramento Valley, values are in excess of the California annual standard as well as the Federal secondary standard in eastern Colusa and Yolo Counties. Higher particulate levels in this area are not unexpected due to the very high level of agricultural activity in this region. The high particulate levels in the Fort Bragg area are well correlated with observed heavy emissions of particulates. Particulate levels in the extreme northwest decrease from the elevated values observed in Mendocino County and are below applicable standards for annual values of total suspended particulates.

In summary, Figure 5.3-5 indicates that particulate levels along coastal locations are lowest in the extreme southern portion of the District increasing to a maximum at Fort Bragg. Coastal values then again decrease with northward progression through Humboldt and Del Norte Counties. In the inland valleys, particulate levels reach minimums for the District and are quite low on an annual basis. Progression further eastward into the Sacramento Valley again reveals fairly high annual values of total suspended particulates in excess of the California and Federal secondary standards.

Annual average sulfur dioxide concentrations in the Ukiah District are presented in Figure 5.3-6. Data are only available for Vallejo, Benecia, Napa and Santa Rosa. For these stations, only Benecia showed a non-zero annual average SO_2 concentration. Sulfur dioxide levels tend to be low throughout California and particularly in fairly rural areas such as the bulk of the Ukiah District. No values in excess of the Federal annual standard have been noted within the District.

The 1977 (CARB, 1977) data indicate that pollutant levels in the Ukiah District are subject to fairly strong seasonal variations. Oxidant readings are highest between April and October while carbon monoxide reaches peak levels from October to January. It should be noted that ozone formation is primarily due to mobile source emissions (autos, trucks, etc.). The formation of ozone has a delay time from initial emissions of NO_2 and HC during which time these pollutants react with the sun and O_2 in the atmosphere to form ozone. Sulfur dioxide, unlike ozone, remains at fairly steady levels throughout the year. This indicates that most SO_2 is attributable to stationary sources while other pollutant levels are affected by seasonal changes in transportation patterns as they are related to the combustion of transportation fuels.

Frequency of Violations

Figures 5.3-7 through 5.3-10 provide the frequency of violations of key standards for total suspended particulates, carbon monoxide, oxidant and lead. A specific figure for sulfur dioxide, nitrogen dioxide and sulfates has not been provided as violations of these short-term standards were not were not recorded.

Figure 5.3-7 provides the frequency of violations of the California twenty-four hour standard for total suspended particulates (100 $\mu g/m^3$). The figure indicates that the short-term standard is violated in all areas with the exception of the extreme southeast which includes most of Sonoma, Napa and Marin Counties. The highest frequency of violations occurred at Fort Bragg where the short-term was violated nearly 40 percent of the time. Along the coastal portions of the Ukiah District, the frequency of violations ranges from zero in the extreme southeast gradually increasing to nearly 40 percent at Fort Bragg, decreasing again with northward progression into Humboldt and Del Norte Counties where the frequency of violations drops off to 5 to 10 percent. The frequency of violations is also quite low in Napa and Lake Counties which is in good agreement with the trend noted on Figure 5.3-5 which presented the annual total suspended particulate levels throughout the region. The frequency of violations of the short-term standards increases with progression into the Sacramento Valley portion of the Ukiah District. Eastern Colusa, Yolo and Solona Counties show violations of the short-term standard for total suspended particulates 10 to 20 percent of the time. Violations in this area are largely due to agricultural activity while the violations noted along the north coast are due largely to natural sources and local fugitive dust emissions. The high values observed in Mendocino County correlate well with the high emission densities as described in Section 5.4.

The frequency of violations of the Federal eight-hour standard for carbon monoxide is depicted in Figure 5.3-8 for the Ukiah District. The figure shows a violation only at Vallejo, a

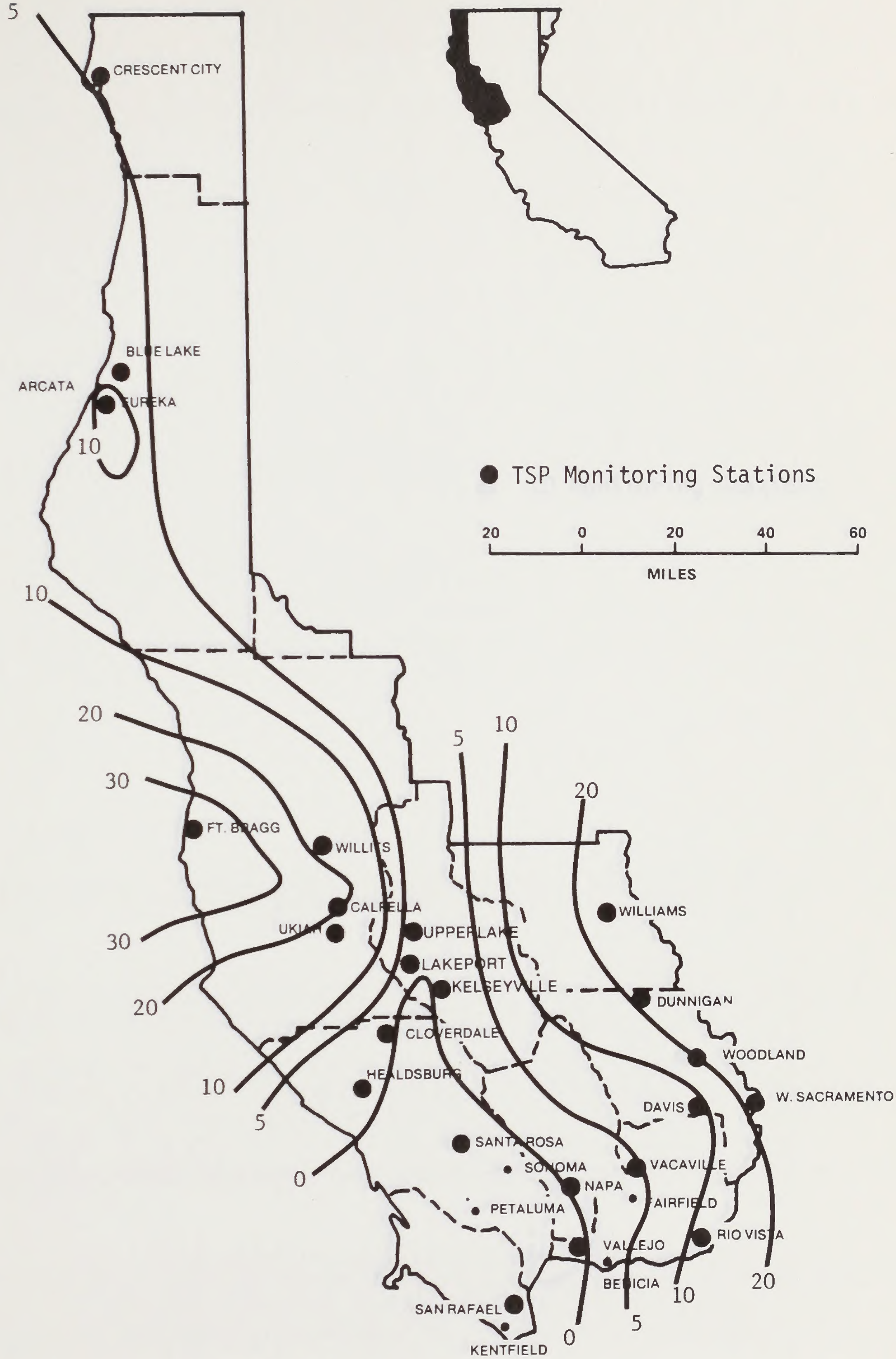


Figure 5.3-7

Frequency (%) of Violations of the California 24-Hour Standard (1) for Total Suspended Particulates

(1) CALIFORNIA 24-HOUR STANDARD FOR TOTAL SUSPENDED PARTICULATES = 100 $\mu G/M^3$

Source: CARB, 1977

Figure 5.3-8
Frequency (%) of Violations of the Federal 8-Hour
Standard (1) for Carbon Monoxide

(1) FEDERAL 8-HOUR STANDARD FOR CARBON MONOXIDE = 9 ppm

Source: CARB, 1977

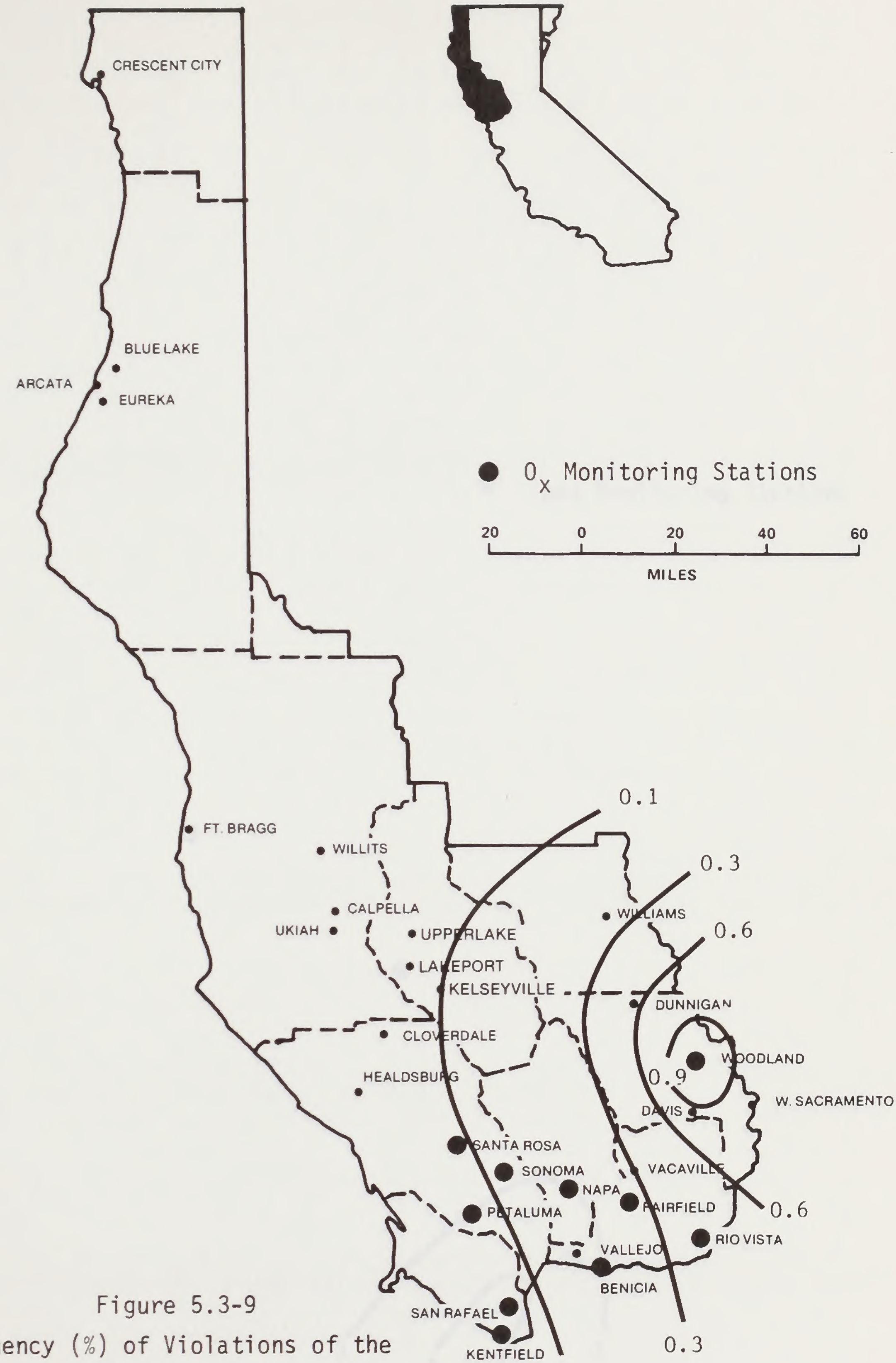


Figure 5.3-9

Frequency (%) of Violations of the

Federal 1-Hour Standard (1) for Oxidant

(1) FEDERAL 1-HOUR STANDARD FOR OZONE = 0.12 ppm*

* THE FREQUENCY OF VIOLATIONS WAS DETERMINED WITH RESPECT TO THE 0.08 ppm STANDARD WHICH WAS IN EFFECT IN 1977. THE CARB DATA SHOWS FREQUENCIES WITH RESPECT TO THE OLD STANDARD AND FREQUENCY OF VIOLATIONS WITH RESPECT TO THE 0.12 STANDARD CAN NOT BE DETERMINED FROM THESE DATA

Source: CARB, 1977

Figure 6.2-2

Frequency (%) of Violations of the

Federal 1-Hour Standard (1) for Oxidant

(1) FEDERAL 1-HOUR STANDARD FOR OZONE = 0.12 PPM

* THE FREQUENCY OF VIOLATIONS WAS DETERMINED WITH RESPECT TO THE 0.08 PPM STANDARD WHICH WAS IN EFFECT IN 1977. THE 1979 DATA SHOWS FREQUENCY WITH RESPECT TO THE OLD STANDARD AND FREQUENCY OF VIOLATIONS WITH RESPECT TO THE 0.12 STANDARD CAN NOT BE DETERMINED FROM THESE DATA.

Source: CARB, 1977

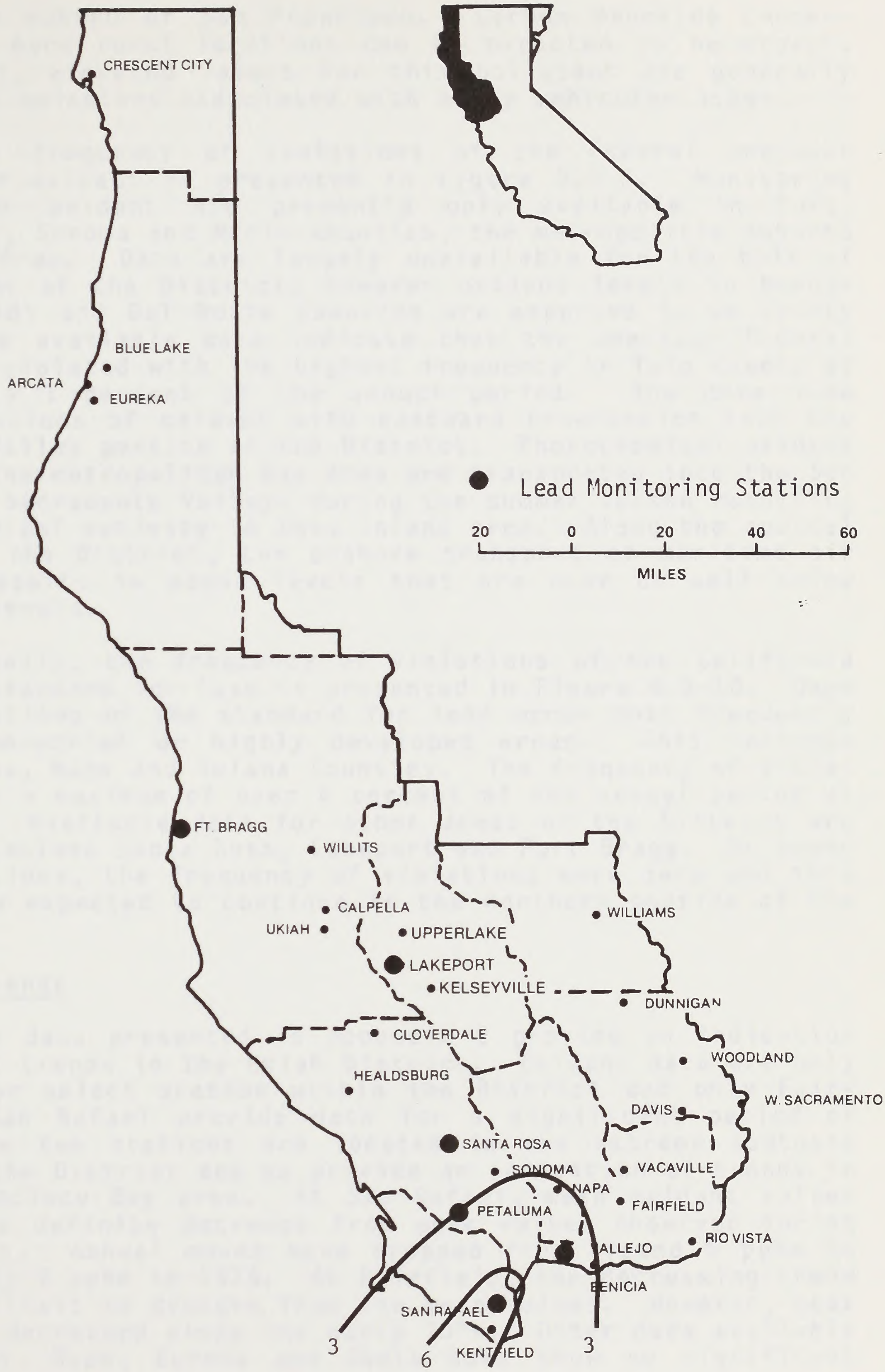


Figure 5.3-10

Frequency of Violations of the
California 30-Day Standard (1) for Particulate Lead

(1) NUMBER OF MONTHLY AVERAGES $\geq$ 1.5 μG/M^3
Source: CARB, 1977

metropolitan suburb of San Francisco. Carbon monoxide concentrations in more rural locations can be expected to be modest. As indicated, elevated values for this pollutant are generally due to large emissions associated with heavy vehicular usage.

The frequency of violations of the Federal one-hour standard for oxidant is presented in Figure 5.3-9. Monitoring stations for oxidant are presently only available in Yolo, Solono, Napa, Sonoma and Marin Counties, the metropolitan suburbs of the Bay Area. Data are largely unavailable for the bulk of the remainder of the District; however oxidant levels in Mendocino, Humboldt and Del Norte Counties are expected to be fairly modest. The available data indicate that the one-hour Federal standard is violated with the highest frequency in Yolo County at approximately 1 percent of the annual period. The data show increasing values of oxidant with eastward progression into the Sacramento Valley portion of the District. Photochemical oxidant emitted in the metropolitan Bay Area are transported into the San Joaquin and Sacramento Valleys during the summer season resulting in photochemical activity in this inland area. Along the coastal portions of the District, the onshore transport of maritime air generally results in ozone levels that are near or well below background levels.

Finally, the frequency of violations of the California thirty-day standard for lead is presented in Figure 5.3-10. Once again, violations of the standard for lead occur most frequently in heavy industrial or highly developed areas. This includes Marin, Sonoma, Napa and Solana Counties. The frequency of violation reaches a maximum of over 6 percent of the annual period at San Rafael. Available data for other areas of the District are sparse and include Santa Rosa, Lakeport and Fort Bragg. At these latter locations, the frequency of violations were zero and this trend can be expected to continue in the northern portion of the District.

Long-Term Trends

The data presented in Appendix E provide an indication of pollutant trends in the Ukiah District. Oxidant data are only available for select station within the District and only Fairfield and San Rafael provide data for a significant period of time. These two stations are located in the extreme southern portion of the District and do provide an indication of trends in the San Francisco Bay area. At San Rafael, mean oxidant values have shown a definite decrease from peak values observed during the mid 60's. Annual means have dropped from around 5 pphm to approximately 2 pphm in 1975. At Fairfield, the decreasing trend is more difficult to discern from the mean values. However, peak values have decreased since the early 70's. Other data available for Petaluma, Napa, Eureka and Santa Rosa show no significant trends.

Carbon monoxide data are only available for Eureka, Napa, San Rafael and Santa Rosa. Nine years of data are presented in the appendix for San Rafael. At this station carbon monoxide levels have been fairly constant for at least six years. Peak values have shown a modest decline, from roughly 20 ppm to 16 ppm in 1975. Data at Santa Rosa for the period 1972 to 1975 have also shown a slight decline for the period. Data for Eureka and Napa are not available for a significant period of record from which to deduce more current trends.

Sufficient data for sulfur dioxide are not available in the Ukiah District to permit a long-term trend analysis. A significant period of nitrogen dioxide data are available from San Rafael. These data show little difference in mean NO_2 values for the period 1969 through 1975, although values during this period are lower than peak values observed in 1967 and 1968. Nitric oxide values at San Rafael have shown a definite increase from the low values observed during 1969 and 1970. Hydrocarbons at San Rafael have shown a definite decrease in mean values since the late 60's with very low values being observed in 1979 when the peak value was 6 ppm.

Hi-volume data comprise the most readily available source of pollutant data in the Ukiah District. Discernible long-term trends are generally not evident the fairly constant levels observed in the northern part of the District. At Napa, values have decreased during the four year period 1972 through 1975, and a decrease has also been noted at San Rafael.

5.4 POINT AND AREA SOURCES OF THE UKIAH DISTRICT

The Ukiah District encompasses counties in four air basins - the North Coastal, the North Coastal Mountain, the Sacramento Valley and the San Francisco Bay Area. This geographical distribution allows a diverse range of agricultural and industrial activities and settlement patterns. Industrial activities include rock aggregates, oil and shipyards. Timber and the associated milling, veneer, plywood, redwood, pulp and paper industries include grain warehouses and driers, sugar and rice. These industries also comprise the bulk of major emitters (100 tons/yr or more) for the district. Other sizable emitters include West Sacramento and open burning dumps.

With many possible types of emitters, a wide range of stack, flow and emission characteristics occur. Many of the lumber and timber related industries do not have stacks. Equipment includes bark boilers, crushers and kilns (with vents) which emit pollutants. The temperature range for emissions from such equipment is wide - from ambient (77^oF) to 600^oF. Other lumber products are made more generally at $300-400^oF$. Typical emissions from the lumber companies are particulates and carbon monoxide. Particulate emissions fall in the 150-250 tons/yr range, with carbon monoxide output reaching as high as 1500 tons/yr. Typical carbon monoxide emission levels are 250-350 tons/yr. Table 5.4-1 provides a summary of typical source exit characteristics for a variety of source types. These data can be used for simplistic or screening level modeling as discussed in more detail in Section 4.9.

There are a few large lumber industry facilities which do not have stack data. Typically, however, there are 6 stacks, 80 feet tall (some range to 300 ft.) with diameters from 5 to 12 ft. and flow rates reaching 210,000 ACFM. Typical flow rates, however, are 30,000 to 65,000 ACFM. Stack temperatures range from 77^oF to 465^oF usually falling around 400^oF. These plants also typically emit carbon monoxide and particulates as principal pollutants; however, emissions of hydrocarbons can reach 150 tons/yr.

There are few power plants in the district which are major emitters. In the district, power facilities generally have only one to two stacks with heights at about 120 feet and exit diameters of around 10 feet. Typical exit temperatures are 320^oF with flow rates around 200,000 ACFM. Other industrial plants (sugar, ports, warehouses and so on) and open burning dumps do not have (or do not list) stack exit characteristics. Pollutants commonly are TSP and NOx with some hydrocarbons and carbon monoxide. Most TSP emissions are in the 100-250 tons/yr range. Figures 5.4-1 through 5.4-5 indicate the emission densities of the criteria pollutants by county in the district.

The emission densities presented in Figures 5.4-1 through 5.4-5 are comprised of area and point sources. Area sources comprise three principal types: solid waste disposal,

Table 5.4-1

Exit Characteristics For

A Cross-Section of Typical Sources

Source	Primary Pollutant(s)	Emission Type	Typical Upward Exit Velocity	Typical Exit Temp.	Typical Exit Height	Typical Exit Diameter
Fugitive Dust	TSP	Ground-level, non-buoyant	Zero	Ambient	4 to 10m (mechanical lift)	N/A
Automobiles	NO_x, CO, HC	Ground-level, slightly buoyant	Zero	150^oC to 200^oC	0.5m	0.6 to 1.5m
Oil Recovery Operations (Steam Generators)	SO_2, NO_x	Low-level, buoyant	2 to 6 m/s	200^oC to 300^oC	3 to 7m	1 to 1.5m
Oil Refinery	SO_2, NO_x, CO	Intermediate Level buoyant	6 to 8 m/s	200^oC to 400^oC	20 to 30m	1 to 2m
Power Plant	SO_2, NO_x, TSP	Elevated, buoyant	8 to 15 m/s	200^oC to 500^oC	120 to 180m	4 to 10m

N/A = Not Applicable

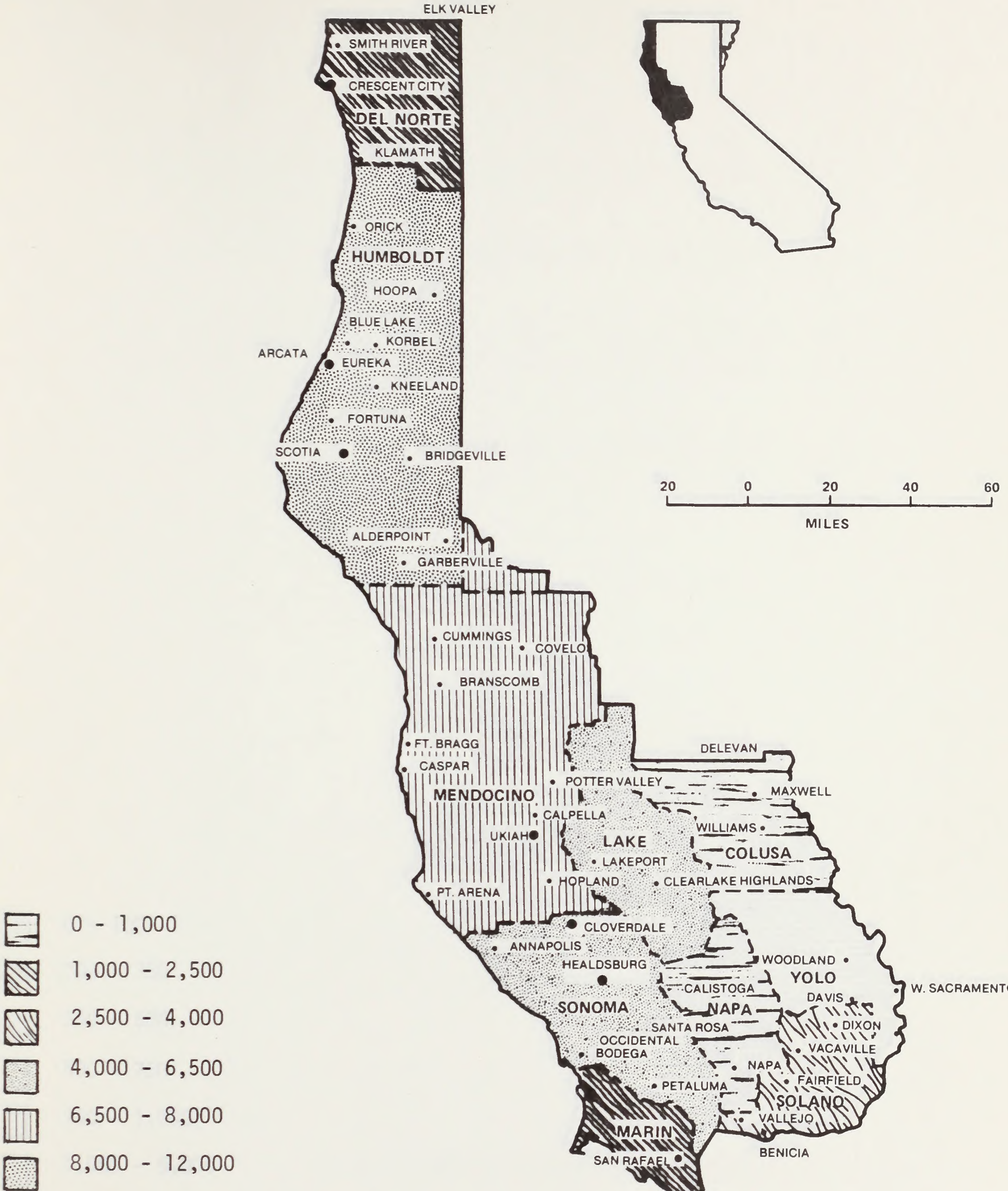


Figure 5.4-1
Total Emissions of TSP (Tons/Year)
in the Ukiah District

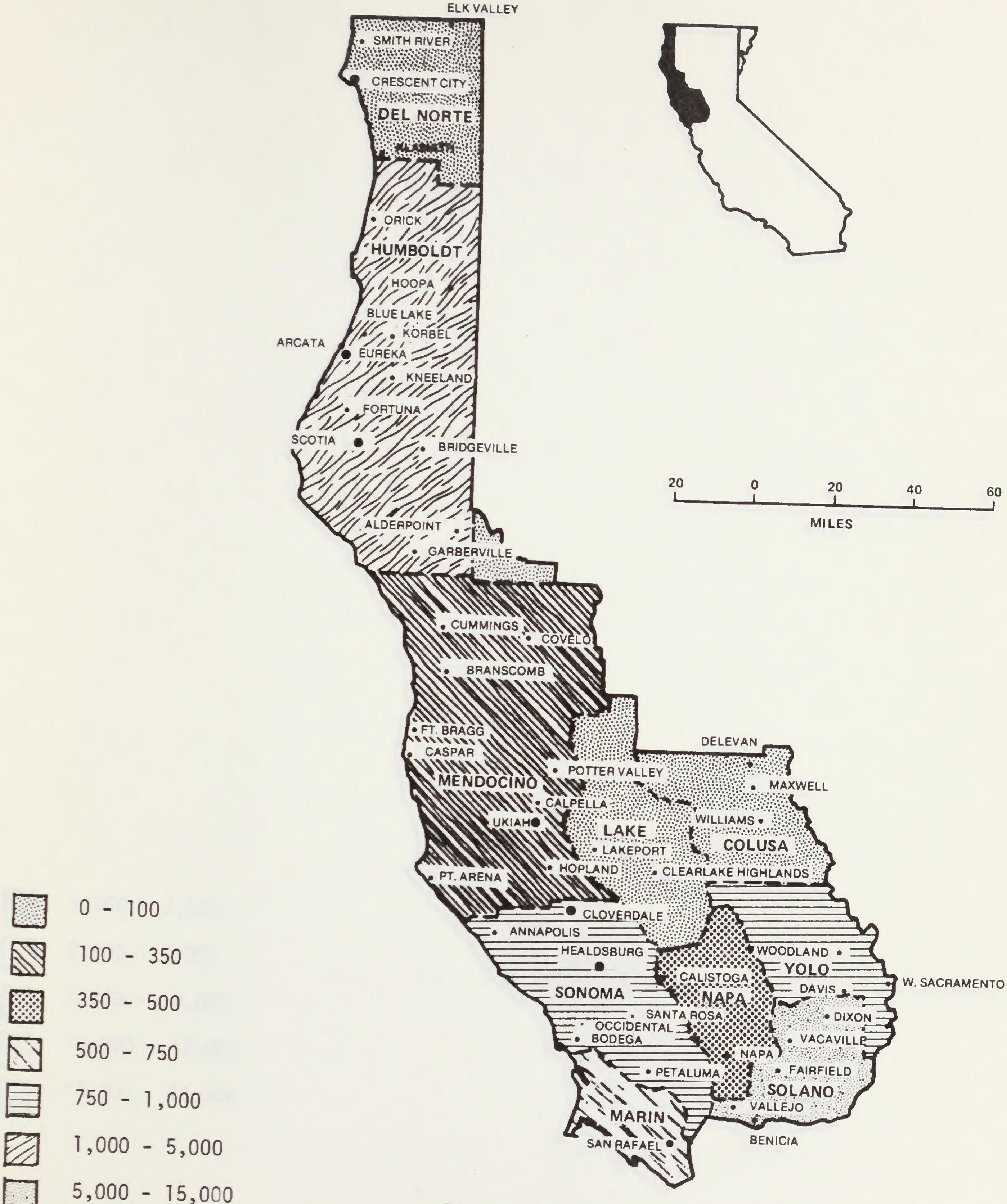


Figure 5.4-2
Total Emissions of Sulfur Dioxide (Tons/Year)
in the Ukiah District

0 - 100
750 - 1,000
5,000 - 15,000

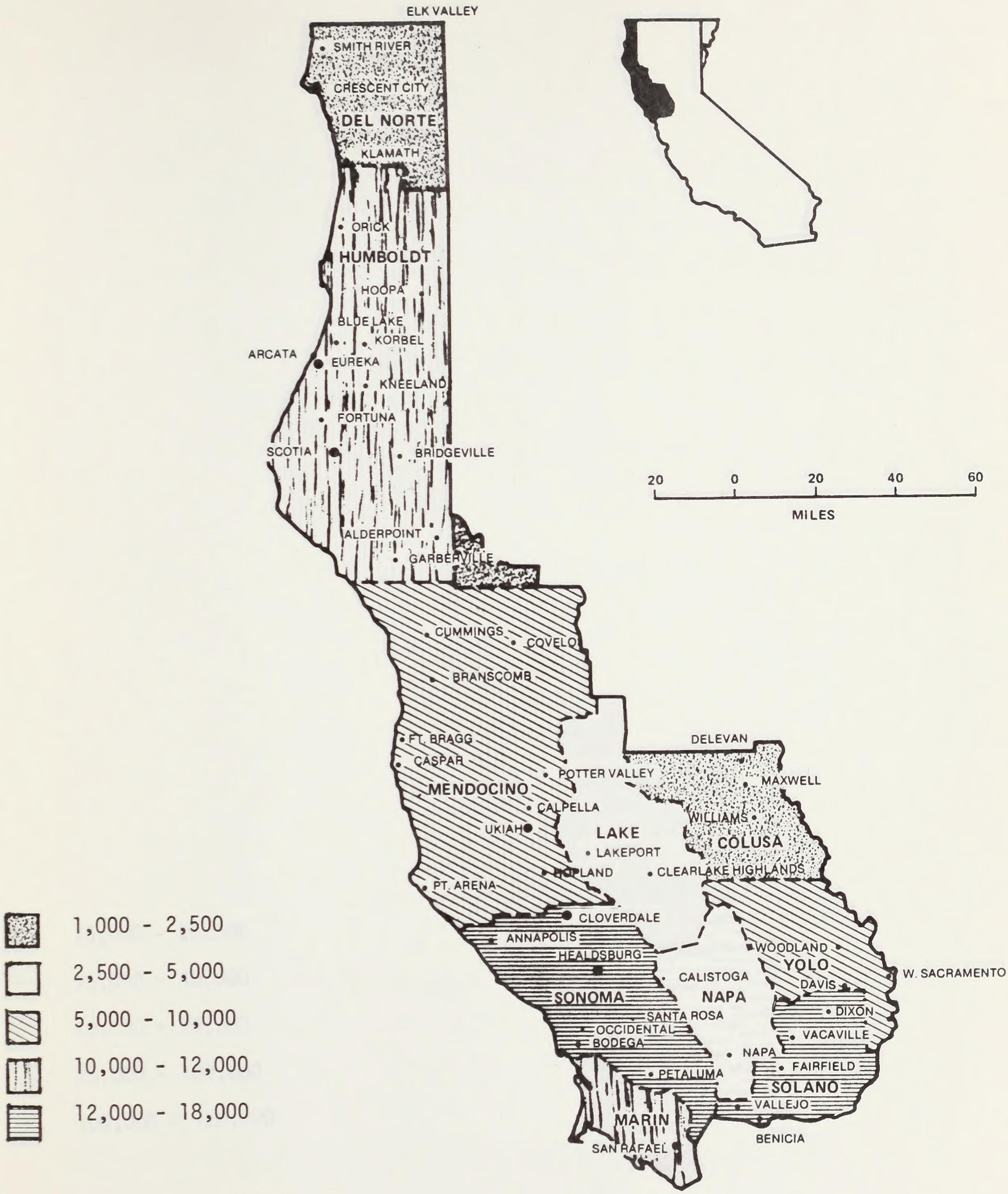


Figure 5.4-3
Total Emissions of Oxides of Nitrogen (Tons/Year)
in the Ukiah District

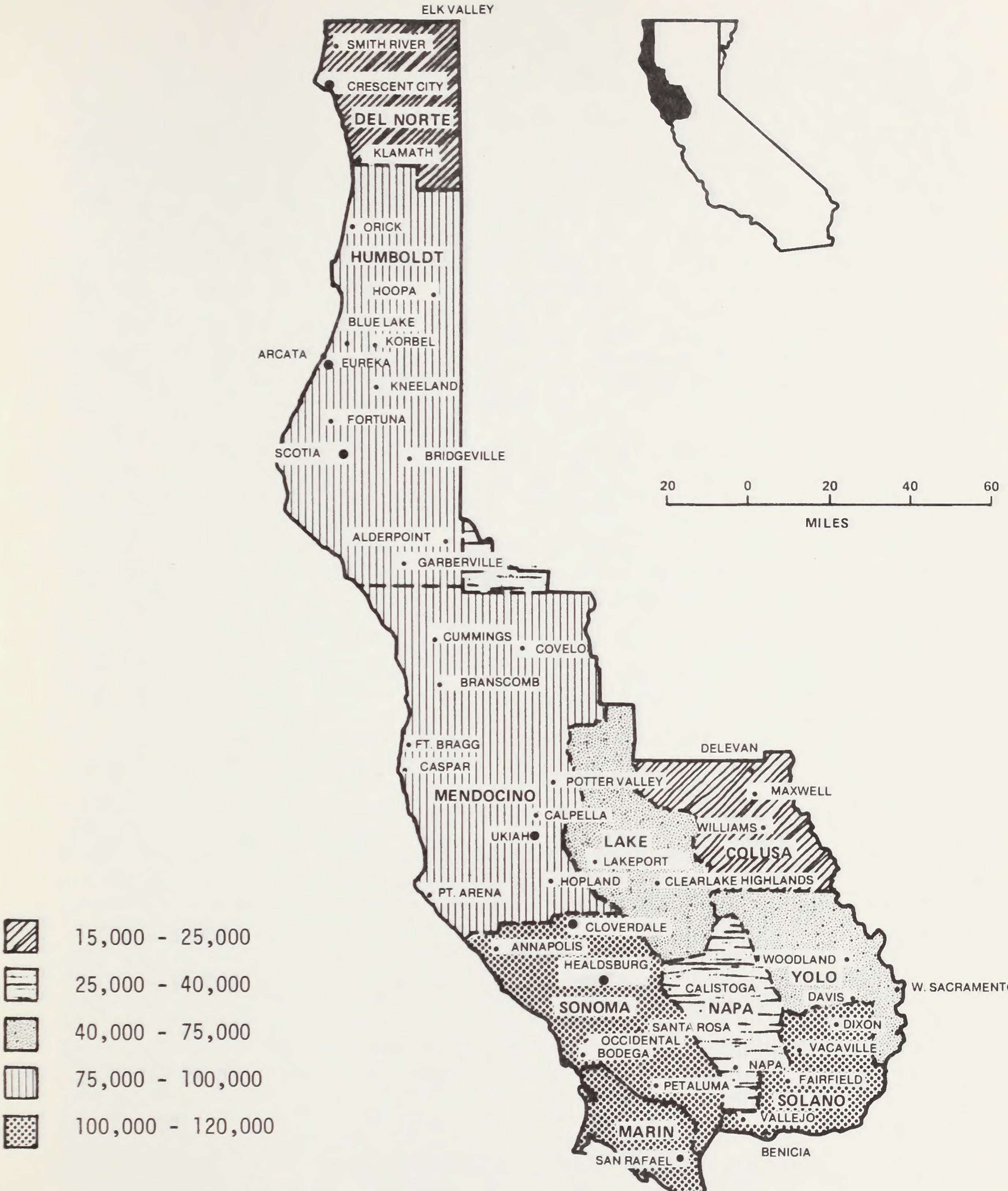


Figure 5.4-4
Total Emissions of Carbon Monoxide (Tons/Year)
in the Ukiah District

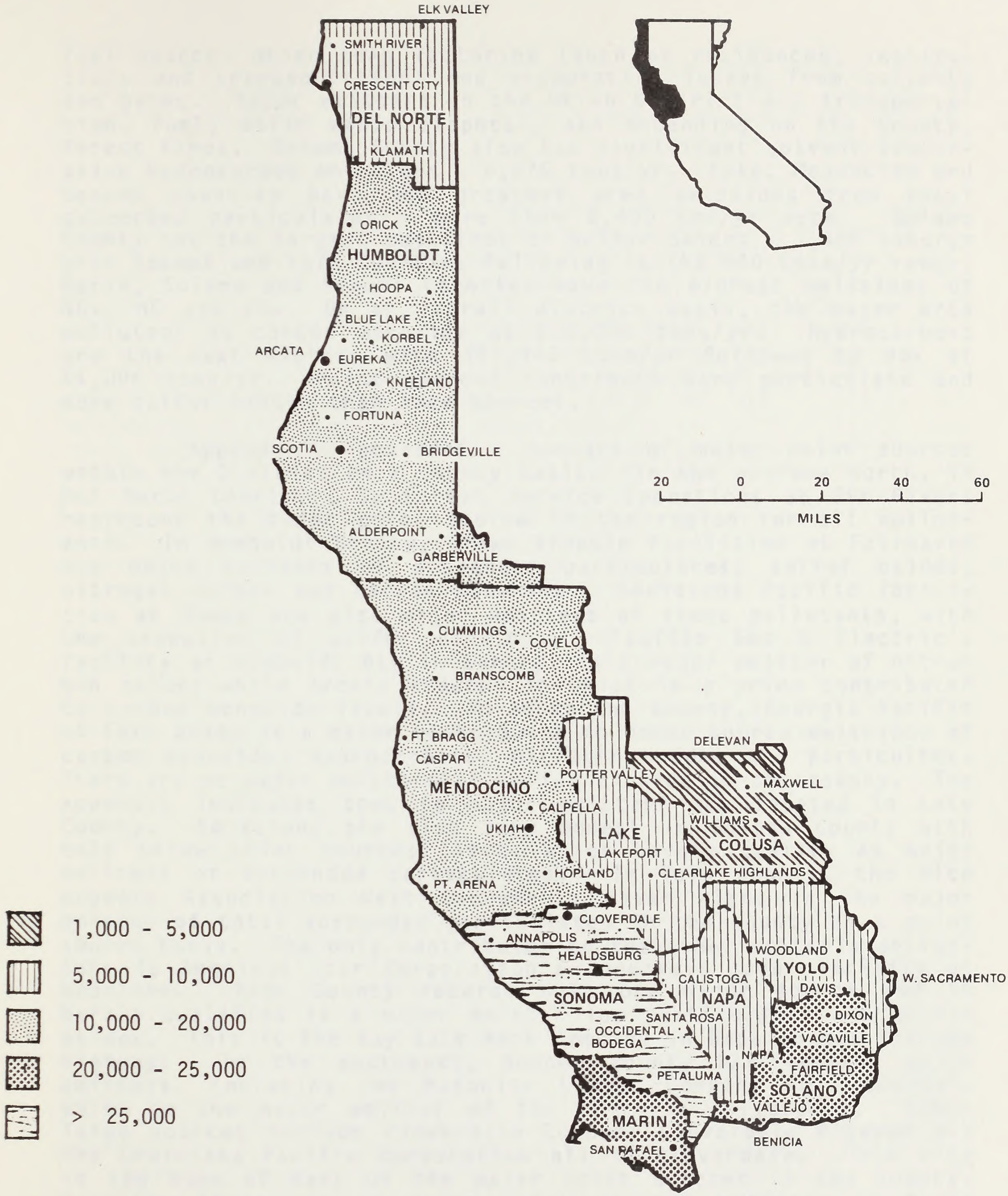


Figure 5.4-5

Total Emissions of Hydrocarbons (Tons/Year)

in the Ukiah District

fuel sources other than factories (such as residences, institutions and transportation) and evaporative losses from solvents and gases. Major emitters in the Ukiah District are transportation, fuel, solid waste disposal, and depending on the county, forest fires. Sonoma County also has significant solvent evaporative hydrocarbon emissions - 6,476 tons/yr. Lake, Mendocino and Sonoma counties have the greatest area emissions from total suspended particulates - more than 2,400 ton/yr each. Solano County has the largest emissions of sulfur oxides - 1,426 tons/yr with Sonoma and Yolo Counties following in the 800 tons/yr range. Marin, Solano and Sonoma Counties have the highest emissions of NOx, HC and CO. On an overall district basis, the major area pollutant is carbon monoxide at 613,226 tons/yr. Hydrocarbons are the next highest with 127,945 tons/yr followed by NOx at 64,006 tons/yr. Point sources contribute more particulate and more sulfur oxides than area sources.

Appendix F provides a summary of major point sources within the District on a county basis. In the extreme north, in Del Norte County, U.S. Forest Service operations at Six Rivers represent the major point source in the region for all pollutants. In Humboldt County, Crown Simpson Facilities at Fairhaven are major emitters of suspended particulates, sulfur oxides, nitrogen oxides and carbon monoxide. Louisiana Pacific facilities at Somoa are also major emitters of these pollutants, with the exception of sulfur dioxides. Pacific Gas & Electric's facility at Humboldt Bay in Eureka, is a major emitter of nitrogen oxides while Arcata Redwook in Orick is a prime contributor to carbon monoxide levels. In Mendocino County, Georgia Pacific at Fort Bragg is a major contributor to point source emissions of carbon monoxide, hydrocarbons, nitrogen oxide, and particultes. There are no major emitters of sulfur dioxide in the county. The appendix indicates that no major emitters are located in Lake County. Emissions are also very modest in Colusa County with only three point sources listed which barely qualify as major emitters of suspended particulates. In Yolo County, the Rice Growers Association West Sacramento River Plant is the major emitter of total suspended particulates in the county on a point source basis. The only contributor to the other criteria pollutants is American Star Corporation's Spreckels Sugar facility at Woodland. Napa County records only one major source and it barely qualifies as a major emitter for particulates and sulfur oxides. This is the Bay Salt Rock Company in Napa on the Vallejo Highway. In the southeast, Sonoma County has several major emitters, including the Masonite Lumber Company in Cloverdale which is the major emitter of the criteria pollutants. Other large sources include Cloverdale Lumber, Cloverdale Plywood and the Louisiana Pacific Corporation all in Cloverdale. This city is the home of many of the major point sources in the county. Finally, there are no major point sources recorded in Marin County.

As Figures 5.4-1 through 5.4-5 indicate, the counties of Marin, Solano and Sonoma have the largest emissions of CO, NO_2, HC and SO_2. However, the counties with the highest TSP emissions are the northern counties, due to the lumber industry which is concentrated there.

The Ukiah District is also the site of a special type of natural and manmade air pollutants. The Geyser's Known Geothermal Resource Area (KGRA) is a major geothermal development area. This area, depicted in Figure 5.4-6, is a source of emissions associated with geothermal development, including well drilling, testing, well bleeds, uncontrolled wells, stacking, pipeline vents, and natural fumaroles. The plant emissions are the largest source of hydrogen sulfide in the KGRA with natural fumaroles accounting for only 0.3 percent of the total emissions (Weres, et al, 1976). Plant emissions at Geysers Units 1 through 10 during the fall of 1976 with a rated power of 396 megawatts. Geothermal developments are also sources of carbon dioxide and sulfur dioxide. Other pollutants emitted in quantity include carbon monoxide, ammonia, boron, hydrogen, nitrogen, arsenic, radon and mercury. The impact of some of the latter heavy metals is of critical concern to biological species surrounding the large cooling towers which must be used to dissipate heat at most geothermal developments (Pacific Gas & Electric, 1979).

Figures 5.3-1 through 5.3-4 indicate the attainment status of the various counties in the district. It is evident that most of the district is subject to PSD for SO_2 and NO_2. PSD would also apply to ozone in all counties except for the Bay Area counties, for CO for all counties except Marin, Napa, the Bay Area portions of Sonoma and Solano, and Yolo, and for TSP for all counties except Humboldt, Mendocino and Yolo.

The Bay Area counties will be subject to non-attainment rules for oxidant and CO. Humboldt, Mendocino and Yolo will be subject to non-attainment rules for particulates.

Since BLM lands are concentrated in Lake, Napa and Mendocino counties, their classifications are of particular interest to the district. Lake's attainment status for TSP has already been mentioned. It is unclassified for SO_2, CO and NO_2 and ozone as is Mendocino. Mendocino is non-attainment for TSP. Depending upon BLM projected usages of these lands, the PSD increments (see Section 6.4) will limit the amount of new construction possible in the area, the type and size of proposed facilities and control equipment to be used for projected emissions. New Source Performance Standards will have to be considered in conjunction with PSD and NESHAPS to provide a balance between developmental requests to utilize BLM lands and the recreational functions now substantially governing land use.

5.5 ASSISTANCE IN AIR POLLUTION PROBLEMS

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Professional Meteorological Consultants

Professional meteorologists advertise their services in the Professional Directory section of the Bulletin of the American Meteorological Society. In the May 1979 Bulletin, 83 such firms and individuals were listed. The American Meteorological Society has in the last several years instituted a program of certifying consulting meteorologists. Of the 83 professional services listings in the Bulletin, 40 list Certified Consulting Meteorologists.

Local U.S. National Weather Service Office

The Air Stagnation Advisories are received here by teletype from the National Meteorological Center. Often the public telephones the Weather Service with air pollution complaints which the meteorologists may have traced back to a specific source by examining local wind circulations. Through personal contact with the meteorologist-in-charge (MIC) specific, localized forecasts may be arranged to support a short-term air pollution investigation or sampling program.

USEPA

The USEPA provides a complete information service to all individuals, groups, companies, etc. This includes information on regulations, publications as well as expert advice.

Contract Work

Many universities do contract work for private organizations and for government agencies on meteorlogical problems and also on air pollution surveys.

5.6 GLOSSARY OF TERMS

Acetylenes — A group of unsaturated hydrocarbons whose carbon atoms possess a triple bond.

Acid — A compound that turns blue litmus paper red, generally tastes sour and most often is corrosive; in solution it produces hydrogen ions or protons which can be replaced by metal to form a salt. Acids usually contain hydrogen, neutralized alkalis and form well defined salts.

Adhesion — The force of attraction between unlike molecules, causing adjoining or attachment.

Aerosol — A system of collodial particles dispersed in a gas.

Affinity — A natural liking or reaction; the phylogenetic relationship between two organisms or groups of organisms resulting in a resemblence in general plan or structure; the force by which atoms are held together in chemical compounds.

Alcohol — C_2H_6O or C_2H_5OH, a volatile, colorless pungent liquid; often used as a generic term which includes ethyl alcohol, methol alcohol, amyl alcohol and glycerin.

Aldehyde — Dehydrogenated alcohol.

Alert Levels — A concentration of pollution which dictates the issuance or notification by State Regulatory Agencies to the general public that a threat to human health may occur due to elevated pollution levels.

Algae — Simple aquatic plants without leaves, stems or roots sometimes having brown or reddish pigments.

Alkanes — The group of hydrocarbons in the methane series, also called saturated hydrocarbons or parafins (C-H).

Alkenes — A group of hydrocarbons with one double bond; also called olefins or unsaturated hydrocarbons (C=C).

Amides — Organic compounds that contain the CO NH_2 radical or an acid radical in replacement for one hydrogen atom of an ammonia molecule.

Amines	Ammonia bases, that is, chemical substances resulting from replacing ammonia hydrogen atoms with alkyl groups $[(CH_3)_x\text{-N-}H_y]$; amines are products of animal or vegetable decomposition.
Amino Acids	Fundamental structural units of proteins; they are fatty acids in which one hydrogen atom has been replaced by an amino group.
Amphibole	Any of the complex group of the hydrous silicate materials containing chiefly calcium, magnesium, sodium, iron and aluminum, and including hornblend, asbestos, etc.
Anaerobic	Living in the absence of air or free oxygen.
Anoxia	Without oxygen, lack of oxygen for body use.
Aortic	The conveyance of blood from the left ventrical of the heart to all of the body except the lungs.
Aqueous	Water acting as a solvent in a solution; a fluid resembling water.
Aromatics	Any unsaturated hydrocarbon with cyclic molecules resembling benzene, C_6H_6, in chemical behavior, so named because of the fragrant odor of many in the class.
Arteriosclerosis	An arterial disease characterized by an inelasticity and thickening of the vessel walls, with lessened blood flow.
Asbestos	A fibrous amphibole used for making fire-proof articles.
Asphyxiant	An agent or substance which causes death or loss of consciousness by the impairment of normal breathing.
Biosphere	That portion of the world and its atmosphere in which humans, animals and plants can survive.
Broncho-constrictor	An agent that causes the contraction of the muscles which control the pharynx.
Carcinogenic	Refers to a substance that is known to induce cancer.

Catalase	The enzyme responsible for the decomposition and oxidation of hydrogen peroxide into water and oxygen.
Catalyst	A substance which accelerates or promotes a chemical action by a reagent which itself remains unchanged.
Catalytic Convertor	A device attached to an automobiles internal combustion engine which chemically alters emissions from the engine prior to release through the exhaust system. The catalytic convertor was introduced on modern-day automobiles in the mid-1970's in an effort to reduce harmful automobile exhaust emissions and promote a cleaner environment.
Cation	Ions of positive charge deposited on the cathode.
Cellulose	The complex carbohydrate substance that forms the material of cell walls of plants.
Chloratic Mottle	Brown or red spots on the surface of a leaf caused by chemical pollution.
Chlorosis	A diseased condition in green plants marked by yellowing or blanching.
Cholestrol	A sterol, $C_{17}H_{45}OH$, occurring in all animal fat and oils, bile, gall stones, nerve tissue, blood, etc.
Chrysotile	A fibrous variety of serpentine; asbestos.
Colloid	A substnace in a state of matter characterized by having small power of diffusion.
Cyprinid	Any fish belonging to the minnow family; carplike in form or structure.
Diastase	The enzyme responsible for starch utilization.
Deformation	The act of marring the natural form or shape of an object; distortion.
Discoloration	The act or fact of changing or spoiling the color of an object; a fade or a stain.
Dissociation	The breaking up of a compound into its simpler constituents by means of heat or electricity.

Ecosystem	A habitable environment existing naturally or created artificially.
Edema	Effusion of serous fluid into the interstices of cells, in tissue spaces or into body cavities.
Emission Density	Emissions per unit area.
Endogenous	Originating or developing internally or within.
Endothermic	Noting or pertaining to a chemical change that is accompanied by an absorption of heat.
Enzyme	A protein substance secreted in animals or by plants whose function is catalytic, promoting chemical reactions for metabolic or physiological processes.
Ester	A compound produced by the reaction between an acid and an alcohol with the elimination of a molecule of water.
Ether	A series of compounds formed by dehydration of alcohols.
Fauna	Collective animal life of any prticular geographical area or time.
Fixation	The act of making stable in consistence or condition; reduction from fluidity or volatility to a more permanent state.
Flora	Collected plant life of any particular area or time.
Flourescence	Emitting radiation (such as light) as a result of, and only during the time of, exposure to radiation from another source.
Glucosidase	The enzyme that catalyzes glucose.
Greenhouse Effect	Most of the infrared radiation emitted by the earth is absorbed by carbon dioxide and water in the atmosphere. Part of the infrared radiaiton absorbed is re-radiated back to earth. This trapping and recycling of terrestrial radiation, which makes the earth warmer than it would be otherwise, is known as Greenhouse Effect, because it was once thought that greenhouses remain warm by the same process.

Heavy Metal	A metal which is made up of elements having large atomic weights.
Hematocrit	A centrifuge for separating the cells of the blood from the plasma.
Hemoglobin	The protein coloring matter of the red blood corpuscles, serving to convey oxygen to the tissues and occurring in reduced form in venous blood and in conbination with oxygen in arterial blood.
Herbivorous	Feeding on plants.
Homolog	An object corredsponding in structure and in origin, but not necessarily in function, to another object; chemicals of the same type, but which differ by a fixed increment in certain constituents.
Humus	The dark organic material in soil produced by the decomposition of vegetable or animal matter.
Hydrate	Compounds with large amounts of water as part of their molecular structure and without re-arrangement of the atoms of the H_2O group; hydration is the chemical union of water and any substance.
Hydrolyze	To subject or be subjected to decomposition in which a compound is split into other compounds by taking up the elements of water.
Hypertrophy	An abnormal enlargement of a part or organ.
Hyphai	One of the thread-like elements of the vegetative part of fungi.
Inertial	Matter having the property by which it retains its state of rest or its velocity along a straight line so long as it is not acted upon by an external force.
Insectivorous	Adapted to feeding on insects.
Intercostal Leaf Area	Leaf area between the ribs.
Irradiation	The act of having been heated with radiant energy; the act of having been exposed to radiation.

Irritant	A biological, chemical or physical agent that stimulates a characteristic function or elicits a response, especially an inflammatory response.
Ketones	A group of organic compounds characterized by a carbonyl radical (C=O) united wih two hydrocarbon radicals; usually colorless, pungent substances.
Leach	A process by which a liquid filters through another substance.
Lichen	A plant composed of an algae and fungi growing together.
Macrophage	A large cell that characteristically engulfs a foreign material and consumes debris and foreign bodies.
Marginal Leaf Area	Leaf edges.
Mercaptan	Compound analogous to alcohol containing sulfur in place of oxygen (R-S-H).
Metabolism	The chemical activity that takes place in the cells of living organisms involving two fundamental procedures, catabolism and anabolism, simultaneously at work; the former refers to the breaking up of substances into constituent parts, the latter, building up of the substances from simpler ones.
Microdecomposer	Bacteria which breakdown waste material in soil and in water as a prelude to the initiation of a nutrient recycling process.
Necrosis	Death or decay of tissue.
Nitriles	Any of a class of organic compounds with the general formula RC = N.
Nucleation	Any process by which a phase change (condensation, sublimation, freezing) is initiated at certain loci (points).
Olefins	Members of a hydrocarbon group characterized by the formula C_nH_{2n} and including ethylene, propoylene and butylene; they are highly reactive and can be formed by destructive distillation of coal petroleum.

Organic Acids	Acids which are usually derived from natural or living sources.
Oxidizer	A substance which causes the conversion of an element into its oxide (which is accompanied by an increase in oxidation number as opposed to a reducing agent which promotes a decrease in oxidation number); a substance which promotes the covering of an element with a coating of oxide or rust.
Pathological	Caused by or involving disease.
Peroxidase	A type or class of oxidoreductase enzymes that causes the oxidation of a compound by the decomposition of hydrogen peroxide or an organic peroxide.
Peroxides	A class of compounds containing oxygen and other elements, with the O_2 group having a valence of two (-) and acting like a radical.
Phenol	A white crystalline solid obtained from the distillation of tar; it is poisonous and corrosive with a characteristically pungent odor.
Photochemical	Refers to the effects of radiation, visible or ultraviolet, upon chemical reactions.
Photon	A quantum of energy; a fundamental bundle of radiation whose energy is directly proportional to the frequency of the radiation.
Photoplankton	The aggregate of passively floating or drifting organisms in a body of water which derive most of their energy from light.
Photosynthesis	The process by which green plants, containing chlorophyll, with the aid of energy from the sun, manufacture carbohydrates from water and carbon dioxide.
Phototoxicant	A substance that is poisonous to plants.
Podsal	An infertile, acidic forest soil having an ash-colored upper layer depleted of colloids and of iron and aluminum compounds, and a brownish lower layer in which these colloids and compounds have accumulated.
Precursor	A person or object that goes before and indicates the approach or something else.

Primary Pollutant	A pollutant in the form that it is released from its source is considered a primary pollutant as opposed to a secondary pollutant which has undergone chemical change after being emitted to the atmosphere.
Progenitor	An original or model for later developments; predecessor; precursor.
Pulmonary	Of or pertaining to the lungs.
Pulmonary Fibrosis	A condition marked by an increase of interstitial fibrous tissue in the lungs.
Radical	A combination of atoms that stay together and take part in the chemical reaction as a unit or a group as if it were a single element.
Reactant	Any substance that undergoes a chemical change in a given reaction.
Reactivity	Pertaining to or characterized by reaction.
Secondary Pollutant	A pollutant is considered a secondary pollutant if a chemical change has occurred subsequent to its release from its source.
Serpentine	A common mineral, hydrous magnesium silicate, usually oily green and sometimes spotted, occurring in many varieties, used for architectural and decorative purposes.
Serum Lactate Dehydrogenase	A class of oxide reductase enzymes that catalyze the removal of hydrogen from the esters or salts of lactic acid.
Sink	A lower state or condition.
Sorption	The binding of one substance by another by any mechanism, such as absorption, adsorption or persorption.
Source	A place from which something comes, arises or is obtained.
Spectroscopy	A procedure for observing the spectrum of light or radiation from any source. Spectroscopy permits the examination and measurement of the spectrum of radiant energy.

Stark-Einstein Law — A law of chemistry which states that one proton must be absorbed by a substance to initiate chemical decomposition.

Stoichiometry — Branch of chemistry dealing with weights and proportions of elements in chemical combination and the methods of determining them.

Stunting — Stopping or slowing down of the growth or development of an object.

Sulfate — Chemical compounds (such as SO_3) created by the photochemical reaction of sulfur dioxide. Sulfates are secondary pollutants with important health and visibility effects.

Sulfide — A binary compound of sulfur with the valence of two (-); also a salt of hydrosulfuric acid.

Synergism — The principal that a cooperative action between two agents - chemical and mechanical for instance - results in an effect greater than the sum of the two effects taken independently.

Terpene — A series of hydrocarbons of the general formula $C_{10}H_{16}$ found in resins.

Thermodynamics — Deals with the principals of conversion of heat into other forms of energy and vice versa.

Toxicity — The quality, relative degree or specific degree of being toxic or poisonous.

Unclassifiable — With respect to air quality, unclassifiable refers to those areas of the country which cannot be a designated attainment or non-attainment area due to insufficient baseline air quality information.

Volatile — Easily vaporized; tending to evaporate at ordinary temperatures and pressure conditions.

Stark-Einstein Law — A law of photochemistry which states that each quantum which was absorbed by a substance is [illegible] chemical transformation.

Stoichiometry — Branch of chemistry dealing with weights and proportions of elements in chemical combinations and methods of determining them.

Stunting — Stopping or slowing down of the growth or development of an organism.

Sulfate — Chemical compound (such as SO_4) formed in the atmosphere [illegible] and associated with [illegible] health and visibility effects.

Synergism — [illegible] of two or more substances [illegible] an effect greater than [illegible] effects (see antagonism).

Synoptic — A general and simultaneous view of the general [illegible] in weather.

Thermodynamics — Deals with the principles of conversion of [illegible] forms of energy and action.

Toxicity — The quality, relative degree or specific degree of being toxic or poisonous.

Trade Limitations — [illegible] the country which [illegible] nonattainment area [illegible] insignificant [illegible]

[illegible] — [illegible] vertical displacement [illegible] conditions

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6. AIR QUALITY REGULATIONS

6.1 EXECUTIVE SUMMARY

6.1.1 Background

The Clean Air Act, as amended in 1977, is the primary legislative tool for improving and monitoring air quality in the United States. Many requirements of the Act apply to BLM activities, as well as to those of the Fish and Wildlife Service, the National Park Service and the National Forest Service.

The Clean Air Act was originally passed in 1955 and numerous Amendments have been initiated over the past 25 years. Under the 1970 Amendments, for example, specific limits for pollutant levels were established including dates for compliance. These pollutant levels, called the National Ambient Air Quality Standards (NAAQS) were based upon air "quality" effects on health. The 1970 Act mandated the States to formulate plans to achieve compliance with the ambient standards. These plans, known as State Implementation Plans (SIPs), required State transportation control plans, emissions limits for specific categories of sources, and permit rules for new or modified sources of air pollution.

Once these plans were adopted by the State, and approved by the EPA, they were binding as law. The State then had the jurisdictional authority to enforce the regulations under the plan. If a State was found by the EPA to be deficient in its administration of the plan, the EPA was able to intervene and administer the plan until it felt that the State could once again resume adequate control of the program(s). It should be noted that this concept has remained in the latest amendments to the Act.

On August 7, 1977, Congress again passed amendments to the Clean Air Act (CAAA). These Amendments significantly altered approaches to maintaining and achieving the adopted Air Quality Standards. The three most substantial alterations to the Act are considered to be (1) New Source Review Requirement (NSR) (2) Prevention of Significant Deterioration (PSD), and (3) the requirement that States, by July 1979, again design programs (SIP) for achieving the NAAQS. Note that items (1) and (2) are an integral part of the State plan (3).

The CAAA also extended the original deadlines for achieving the NAAQS to December 1982, with provisions for extending compliance to 1987 for areas with severe oxidant and/or carbon monoxide problems. Furthermore Congress empowered EPA to implement sanctions if a State did not have an acceptable SIP by July 1979. The major sanctions that the EPA is able to impose are to ban construction of major sources in non-attainment areas, and to withold Federal funding for projects such as highway and sewage facilities. As part of an acceptable SIP, a State which requests an extension of the ozone and/or carbon monoxide compliance date, must implement a statewide motor vehicle inspection and maintenance (I/M) program.

A number of areas in California have requested an extension of the oxidant and CO NAAQS to 1987 (e.g., Los Angeles, San Diego, etc.). However, due to the reluctance of the California Legislature to adopt a statewise I/M program, the California SIP is in jeopardy of being rejected. As of July 1, 1979, new major sources (and certain modifications to existing major sources) are prohibited from locating in non-attainment areas of the state. Additionally, if the Legislature does not adopt an I/M program prior to the time(s) EPA's conditional approval(s) expire, then Federal Highway & Sewage funding will also be withheld.

6.1.2 Permit Rules for New or Modified Sources

Since 1970, the Clean Air Act has required that any new, or modified source(s) of air pollution undergo a preconstruction review. The purpose of this review is to ensure that such sources would not violate any ambient standard or contribute to any existing violations of these standards. This review is known as New Source Review, and has been expanded by the Amendments of 1977.

6.1.2.1 Nonattainment Areas

In nonattainment areas (areas that do not meet the NAAQS), States are required to develop permit rules which meet the requirements of the CAAA. Specifically, these permit rules must require the following: (1) new or modified source locating in a non-attainment area must obtain a high degree of emission control (called Lowest Achievable Emission Rate or LAER) for the problem pollutant(s), and (2) obtain emission reductions of that pollutant, commonly called emission offsets or tradeoffs. Tradeoffs are generally obtained by retrofitting existing sources with air pollution control equipment, or by "retiring" older units. Because of the permit moratorium for nonattainment areas, sources wishing to locate in such areas may not receive permits until the nonattainment portion of the SIP has been approved by the EPA.

The State of California has numerous non-attainment areas and as such, a majority of the State Implementation Plan consists of "plans" or "tactics" to bring the affected regions (air basins) into compliance with the NAAQS.

6.1.2.2 Attainment Areas and Prevention of Significant Deterioration Review

In attainment areas (areas in which the air quality is better than the NAAQS), the Clean Air Act amendments require SIPs to contain a special permit program for new or modified sources. This permit program is called Prevention of Significant Deterioration of air quality. As a result of this requirement, the

EPA, on June 19, 1978, promulgated the Prevention of Significant Deterioration (PSD) regulations. The basic intent of these regulations is to keep "clean air clean." This is accomplished by placing ambient air quality limitations for SO_2 and particulate matter in addition to the NAAQS which have been established for these pollutants. The increase in ambient concentration of these two pollutants from a given baseline concentration is limited by what are called "increments." These increments differ depending on the class designation of the area in which the new or modified source is attempting to locate (see Figure 6.1-1).

The Clean Air Act and the PSD regulations established three "classes" of clean air areas. Each class has been assigned numerical increments for particulate matter and sulfur dioxide concentrations; increments will be set in the near future for all other criteria pollutants. These increments indicate the limit to the ambient concentration increase above baseline concentration which will be allowed in each particular "class" area.

Class I increments allow only minor air quality increases; Class II increments allow a moderate amount of deterioration; Class III increments allow the most air quality deterioration, although violations of the NAAQS are never permitted. Class I areas include national memorials and national wilderness areas exceeding 6,000 acres in size.

Sources subject to PSD must use Best Available Control Technology (BACT) on the proposed new sources or modified sources, and furthermore, must demonstrate that the emissions will not result in concentrations in excess of the PSD increments for SO_2 and particulate matter. The most important aspect of these regulations is that increment consumption is viewed from a cumulative viewpoint. That is, if a source consumes part of the increment, then the next source to apply for a permit(s) must work within the remaining portion of the increment. Thus, it is possible for the increment to be "used up" in a particular area. Increment consumption is granted on a first-come, first-serve basis.

6.1.2.3 Role of the Federal Land Manager in the Permit Review Process

Federal Land Managers (FLM) have input to the PSD permitting process if a project will have an impact on a Class I area. Once a source makes an application to the EPA, the EPA must make a determination as to the probable impacts the project will have. As early as possible, the EPA must contact the appropriate FLM if it is thought that the project will have an impact on a Class I area. The FLM may then review all air quality studies performed in conjunction with the EPA permit application within the 60 day review period. If the FLM finds that the facility would have an adverse impact on the "air quality related values" of the land area, a permit cannot be issued. The source must then demonstrate that no adverse impact would occur. Denial

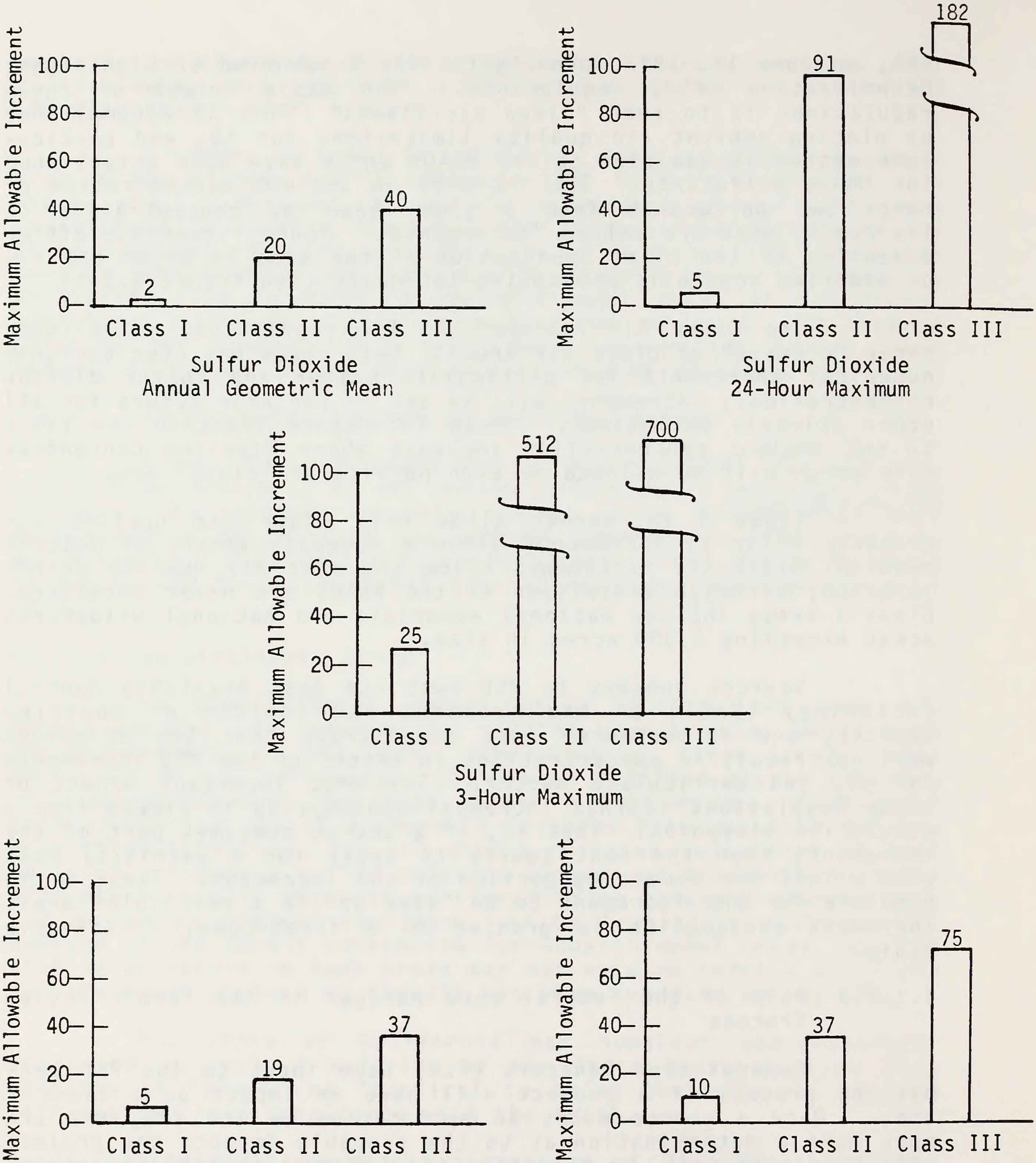


Figure 6.1-1
Prevention of Significant Deterioration
Maximum Allowable Increments as a Function of Class Designation
($\mu g/m^3$)

by the FLM may be made even if it has been demonstrated that the Class I increments will not to be exceeded by the project.

It is also important to note that if the FLM proposes activities on land within his jurisdiction, the available increment must not be exceeded. This may inhibit future land management decisions, and should be considered in the early part of the decision process.

6.1.2.4 Role of the Federal Land Manager in Class Redesignation Procedures

The FLM also has a minor role in the process of redesignating a particular class area (for example, a Class II area to be redesignated to a Class I area). Redesignations may only be proposed by the state or by an Indian Governing Body. If the area to be redesignated contains Federal lands, the FLM is to be notified of the proposal. The FLM will be allowed to comment on the proposal, and if he is opposed to it but the State wishes to continue to pursue it, he must be provided with an explanation of the reasons why the State feels it should be redesignated. The FLM may also provide input at the public hearing which is required for all redesignations; however, the State has the ultimate authority.

6.1.3 Visibility Protection

The 1977 Amendments added to the Clean Air Act a section entitled "Visibility Protection for Federal Class I Areas". This section declares as a national goal "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas" where impairment results from man-made air pollution. Such a list of Mandatory Class I federal areas was first published in the November 3, 1977 Federal Register and was revised on Nov. 30,1979. Those areas so designated are presented in Table 6.4-2 and Figure 6.4-1, respectively. The Amendments also required that by February 1978, the Secretary of Interior, in consultation with the States and the FLM's, identify any mandatory Class I areas where visibility contributes significant value to that particular area. These areas were published in the February 24, 1978 Federal Register. As such, all Class I areas are areas in which visibility is an important value. The EPA, by February 1979, was to have completed a study and report to Congress on available methods for implementing this national goal. This document was not available in time to be addressed in this report. Additionally, the EPA was authorized to promulgate regulations requiring retrofits on specified pieces of equipment so that visibility would be maintained, or enhanced. The FLM must be consulted with regard to these regulations.

6.1.4 Emission Standards

The Clean Air Act gave the EPA the authority to promulgate emission standards for specific categories of equipment. It also gave EPA the authority to designate certain pollutants as "hazardous", and to set emission standards for such hazardous pollutants for specific categories of equipment.

The EPA has promulgated New Source Performance Standards (NSPS) and National Emission Standards for Hazardous Air Pollutants (NESHAPS). The NSPS standards presently consist of emission limits of pollutants for 28 sources categories. The NESHAPS have been established for mercury, beryllium, asbestos, vinyl and chloride (a NESHAPS for benzene has been proposed).

6.1.5 State Regulations

6.1.5.1 Permit Rules

As previously discussed, a major intent of the Clean Air Act was to establish procedures for permit rules, and require States to adopt such rules as part of their SIP. Until such time as these rules are approved by the EPA, and incorporated in the SIP, the EPA still retains permitting authority over affected sources.

The lead State agency in California is the Air Resources Board (ARB). ARB is responsible for coordinating the SIP and has exclusive authority over mobil sources. Additionally, it monitors local agencies (County Air Pollution Control Districts) activities over stationary sources, and also conducts compliance tests.

ARB also adopts modal rules governing all sources, and encourages the local districts to adopt similar rules, so that there is a degree of uniformity throughout the State. Note, however, as discussed in Section 6.5, local districts tend to adopt rules which reflect the nature of the area (i.e., industrial vs. rural).

6.2 THE ROLE OF THE FEDERAL LAND MANAGER

As defined in the Clean Air Act Amendments of 1977, the Federal Land Manager (FLM) for the BLM has the responsibility to protect the air quality related values of lands within his jurisdiction. This responsibility must be addressed in a number of programs including protection of visibility, fire management, oil and gas leasing, land use planning of Federal lands, issuance of right-of-way permits, and the preparation of Environmental Impact Statements (EIS's) attendant to such permits. Land management by the BLM is primarily concerned with recreational areas (e.g., wilderness areas) but the concerns of the Land Manager are certainly not limited to these aspects. For example, oil wells, or gas pipelines which are on Federal lands, come under the jurisdiction of the FLM. In order for the Manager to issue a BLM permit for such activities, he must ascertain that the owner or operator of the project has obtained all necessary State, local and Federal permits. These include environmental permits in many cases. Thus, it is imperative for the FLM to be familiar with the legislative and regulatory aspects of air quality in addition to the baseline meteorology and air quality with which the permit is concerned. An understanding of the rudiments of the air quality review processes in California can be helpful in the preparation of future EIS's, since many applicants are required by law to prepare air quality assessments to obtain project approval. Such assessments could be used by the FLM in preparation of an EIS and in making a final decision.

In recent years, the role of the FLM in the protection of air quality has increased. Recent federal legislation has provided increasingly stringent restrictions to protect the clean air resource from further deterioration by new or modified sources. The 1977 Amendments require the FLM to take an active role in the EPA's PSD permit process. Specifically, the Clean Air Act has given the FLM the authority to comment on projects which impact the air quality in areas designated as Class I (i.e., national parks, monuments or wilderness areas in excess of 6,000 acres, or any other area designated by the State as a Class I Area). In the words of the Act, the FLM must actively protect the "air quality related values, including visibility" of such lands and may oppose programs felt to be deleterious to Class I areas. The Act also authorizes the FLM to take an affirmative role in visibility protection in these areas, as well as taking part in altering the Class designation of any area incorporating federal lands.

Because "air quality related values" are one of the concerns of the FLM, it is necessary that the Managers be familiar with the implications of clean air legislation as it affects Federal lands. Section 6.3 discusses the Federal legislative history concerning air pollution provisions of the 1977 Amendments pertinent to Federal land areas and visibility protection, and also indicates where the FLM may participate in the implementation of such provisions.

6.3 HISTORY OF AIR QUALITY LEGISLATION

Public concern for the nations air quality and for the effect that polluted air has on human health and welfare led to the passage of National Air Pollution Legislation in 1955. Amendments to this legislation were passed in 1963, 1965, 1967, 1970 and 1977 (Table 6.3-1 is a list of clean air legislation enacted by the Federal Government). Prior to the 1970 amendments, the responsibility for air quality was held by the States with the Federal Government providing little more than financial and technical assistance. Some progress toward cleaner air was achieved; however, in the opinion of a significant portion of the population, it was insufficient. As a result, the 1970 Amendments introduced the Federal Government as a regulatory force. The States remained responsible for developing air quality Implementation Plans but, under the 1970 Amendments, specific limits were set and certain pollutant concentration levels had to be achieved by stipulated dates. The specific concentration levels are called the National Ambient Air Quality Standards (NAAQS).

Two types of NAAQS were mandated by the Amendments of 1970. Primary standards set levels which allow an adequate margin of safety for public health while Secondary standards specify levels which protect the public welfare from any known or anticipated adverse effects associated with a pollutant's presence in the ambient air. Secondary effects on public welfare refer to impacts on soils, water, crops, visibility, as well as effects on economic values and on personal comfort and well being. Table 6.3-2 shows the standards at current levels. As can be seen, the secondary standards are, in most cases, more stringent, due primarily to the wide range of items included under 'public welfare' which the secondary standards must protect.

The 1977 Amendments attempted to deal with controversies that had developed concerning achievement of the regulations and the overall achievement of the goals of the Clear Air Act. The energy shortage and the cost and development of air quality control equipment on both stationary and mobile sources caused industry to seek delays in achieving mandatory standards. Environmental organizations, through the use of the judicial system, had forced the EPA to promulgate legislation to prevent the significant deterioration of air quality in regions of the country where the air was cleaner than the established standards. Promulgation of the original PSD regulations brought opposition from persons concerned about such issues as industrial growth, employment, the economy and EPA authority. These and other concerns influenced the Congress to consider amending the Clean Air Act to establish new deadlines for achieving certain standards and to resolve the PSD issue.

Table 6.3-1

Clean Air Legislation Enacted by the Federal Government

Date	Public Law	Purpose of Law
6/55	84-159	Provide research and technical assistance relating to air pollution control.
9/59	86-365	Extend the Federal Air Pollution Control Law PL 84-159.
6/60	86-493	Direct the Surgeon General to study and report on health effects of automobile emissions.
12/63	88-206	Improve, strengthen and accelerate programs for the prevention and abatement of air pollution.
10/65	89-272	(Title: Motor Vehicle Air Pollution Control Act). Require standards for automobile emissions and authorize research in solid waste disposal programs.
10/66	89-675	(Title: Clean Air Act Amendments of 1966). Authorize grants to air pollution control agencies for maintenance of control programs.
11/67	90-148	(Title: Air Quality Act of 1967). Authorize planning grants, expand research relating to fuels, and authorize air quality standards.
12/69	91-190	(Title: National Environmental Policy Act). Establish the Council on Environmental Quality, direct Federal agencies to consider environmental quality regulations.
12/70	91-604	(Title: Clean Air Act Amendments of 1970). Provide a more effective program to improve the quality of air.
6/74	93-319	(Title: Energy Supply and Environmental Coordination Act). Provide means of dealing with the energy shortage.
8/77	95-95	(Title: Clean Air Act Amendments of 1977). Requires BACT review on a much expanded basis. Established PSD requirements. Required visibility be considered.

Table 6.3-2

National Primary and Secondary Ambient Air Quality Standards

Air Contaminant	Averaging Time	Federal Primary Standard	Federal Secondary Standard
Nitrogen Dioxide1/	Annual Average	100 $\mu g/m^3$ (0.05 ppm)	100 $\mu g/m^3$ (0.05 ppm)
Sulfur Dioxide	Annual Average	80 $\mu g/m^3$ (0.03 ppm)	- - -
	24-Hour	365 $\mu g/m^3$ (0.14 ppm)	- - -
	3-Hour	- - -	1300 $\mu g/m^3$ (0.5 ppm)
Suspended Particulate	Annual Geometric Mean	75 $\mu g/m^3$	60 $\mu g/m^3$
	24-Hour	260 $\mu g/m^3$	150 $\mu g/m^3$
Hydrocarbons (corrected for Methane)	3-Hour 6-9 a.m.	160 $\mu g/m^3$ (0.24 ppm)2/	160 $\mu g/m^3$ (0.24 ppm)
Photochemical Ozone (oxidant)	1-Hour	240 $\mu g/m^3$ (0.12 ppm)	240 $\mu g/m^3$ (0.12 ppm)
Carbon Monoxide	8-Hour	10 mg/m^3 (9 ppm)	10 mg/m^3 (9 ppm)
	1-Hour	40 mg/m^3 (35 ppm)	40 mg/m^3 (35 ppm)
Lead	30-Day	1.5 $\mu g/m^3$	- - -

Source: 38 Code of Federal Regulations 25678, September 14, 1973

NOTE: ppm = parts per million
ug/m^3 = micrograms per cubic meter
mg/m^3 = milligrams per cubic meter

1/ Nitrogen dioxide is the only one of the nitrogen oxides considered in the ambient standards.

2/ Maximum 3-hour concentration between 6-9 a.m.

6.4 SUMMARY OF THE CLEAN AIR ACT AMENDMENTS OF 1977, AND RELATED REGULATIONS

President Carter signed the Clean Air Act Amendments of 1977 (PL 95-95) into law on August 7, 1977. The Amendments add to the Clean Air Act Part C, concerning the Prevention of Significant Deterioration (PSD) of air quality and visibility enhancement. Part B adds a section on ozone protection. Part D adds provisions for State Implementation Plan requirements for non-attainment areas. In general, the PSD section establishes a scheme for protecting areas with air quality cleaner than minimum national standards and requires the EPA to promulgate a permit regulation for new or modified sources in such areas. Such regulations were promulgated on June 19, 1978 and will be discussed more fully below. These regulations are generally more comprehensive than those originally promulgated by the EPA in 1974.

The amendments continue the use of two major control schemes designed by the 1970 amendments: National Ambient Air Quality Standards (NAAQS) and New Source Performance Standards (NSPS). In the five year period from January 1971 through January 1976, the EPA promulgated emission limits, or NSPS, for 19 source categories. The Amendments of 1977 increased the 19 source categories to 28. Additionally, the 1977 Amendments require EPA to update NSPS every four years.

6.4.1 National Ambient Air Quality Standards (NAAQS)

As mentioned above, the Clean Air Act amendments of 1970 mandated the EPA to promulgate primary and secondary NAAQS. The 1977 Amendments require that the EPA complete, by December 31, 1980, and at five-year intervals thereafter, a thorough review of air quality criteria, and that, if appropriate, the National Ambient Air Quality Standards be revised. The EPA is also mandated to promulgate a NAAQS for NO_2 concentrations over a measurement period of not more than three hours. This was originally due by August, 1978, but the EPA has not as yet issued such a regulation. If the EPA finds that there is no significant evidence that such a standard is needed to protect public health, such a standard will not be required to be promulgated (the Nov. 30, 1979 Federal Register indicated this decision would be made by May 1, 1980).

6.4.2 Designation of Attainment Status

The Clean Air Act Amendments of 1977 required that by December 6, 1977, every State submit to the EPA a listing of the attainment status of its Air Quality Control Regions (AQCR's) for each of the six pollutants for which a NAAQS has been established. In the March 19, 1979 and Sept 11th and 12th, 1979 issues of the Federal Register, a re-listing of all nonattainment areas, by state, were published. If an area has air quality better than the NAAQS for SO_2 and TSP, it will be designated as an attainment area; if air quality is worse than the NAAQS, it will be designated as a nonattainment area. AQCR's may be subdivided with areas designated as "attainment", as well as areas being designated as "nonattainment". Areas for which there is insufficient information to determine whether the standards have been met will be designated as "unable to classify." Attainment/nonattainment designations will be made on a pollutant-specific basis. Thus, an area may be an attainment area for one pollutant, and a nonattainment area for another pollutant.

6.4.3 State Implementation Plans

The 1977 Amendments retained the use of the State Implementation Plan (SIP) which was originally introduced in the 1970 Amendments. All SIPs will have to be revised to implement the standards and regulations mandated by the Amendments. The SIPs as originally devised in the 1970 Amendments required transportation control plans, emission limits for specific categories of sources, and permit rules for new or modified sources of pollution. The goal of these plans, as stated above, was to ensure that the NAAQS would be met in all areas of the country.

As stated previously, the 1977 Amendments expand upon the SIP requirements, and differentiate between two different plan types:

- Areas in which the NAAQS are being met (attainment areas)
- Areas in which one or more of the NAAQS are being violated (nonattainment areas)

Thus, a State may have to address both concepts in developing its State Implementation Plan.

6.4.3.1 Nonattainment Areas

Under the new Amendments, States containing nonattainment areas must have submitted to the EPA by July 1, 1979, an approvable implementation plan which provides for attainment of primary standards by December 31, 1979. The plan must provide for the implementation of "reasonably available control measures" on existing stationary sources to be determined by the State. If, despite these "reasonable available control measures", a State cannot attain primary standards for carbon monoxide or photochemical oxidant before the 1982 deadline, it may request an extension to 1987. To be eligible for an extension, a vehicle inspection and maintenance program must be adopted by that State.

The Amendments also made specific requirements regarding permit rules. Since 1970, the Clean Air Act has required that any new or modified source of air pollution must undergo a <u>preconstruction review</u>. The purpose of this review is to ensure that such sources would not violate any ambient standard or contribute to any existing violations of these standards. This review is known as New Source Review.

The Amendments require that in nonattainment areas, the SIP must also contain permit requirements for the review of new or modified sources which would include the requirement for such sources to achieve a "Lowest Achievable Emission Rate" (LAER) for that particular source and pollutant, and to secure emission offsets for that particular pollutant in the locality of the project.

Most importantly, the Amendments impose a permit moratorium. No permits may be issued in a nonattainment area (neither by the State nor the EPA) after July 1, 1979 unless a SIP for that area has been approved by the EPA. Thus, sources wishing to locate in such areas may not receive permits until the nonattainment portion of the SIP for that area has been approved by the EPA. Numerous States did not comply with the SIP time frames established by the Clean Air Act Amendments and on November 23, 1979, EPA announced that conditional approvals for SIP's would not be extended past the time the States were originally given to correct any SIP deficiencies. No second conditional approvals would be given, and in those cases where a State has failed to meet a scheduled commitment date - the SIP would be rejected, and the sanctions authorized under the Act would be imposed.

The lead state agency in California is the Air Resources Board (ARB). ARB is responsible for coordinating the SIP and has exclusive authority over mobile sources. Additionally, it monitors local agencies (County Air Pollution Control Districts) activities over stationary sources, and also conducts compliance tests.

ARB also adopts modal rules governing all sources, and encourages the local districts to adopt similar rules, so that there is a degree of uniformity throughout the State. Note, however, as discussed in Section 6.5, local districts tend to adopt rules which reflect the nature of the area (i.e., industrial vs. rural).

6.4.3.2 Attainment Areas

- Prevention of Significant Deterioration (PSD)

  The 1977 Amendments kept active the concept of PSD. This is a permit rule which must be incorporated into SIPs for attainment areas. It applies to specific sources which are named in the Clean Air Act and the EPA's subsequent regulation. It is essentially a New Source Review rule for those sources in attainment areas, or in those areas which have been designated as "unable to be classified", according to Section 107 of the Clean Air Act as amended.

Unlike the nonattainment areas, there is no permit moratorium imposed. The failure of a State to adopt into their SIP a permit rule incorporating the PSD requirements of the Clean Air Act, does not impose a moratorium on permits. Thus, if a SIP is not approved by the EPA in an attainment area, sources will be required to obtain such permits from the EPA, as well as obtaining any permits required by the State. When the State adopts a PSD-type rule which is approved by the EPA, then the State has the jurisdictional authority to administer it, and a source need only obtain the State permit.

The basic intent of the PSD regulations is to keep "clean air clean". This is accomplished by placing limitations on the amount that pollutant concentrations can be increased above what is termed "baseline concentration". This will be discussed in further detail below.

- Classification of Attainment Areas under PSD

The Clean Air Act, and subsequent PSD regulations designate all attainment areas as either Class I, II or III, depending on the degree of deterioration that is to be allowed. Limits are assigned to increases in pollution concentrations for SO_2 and particulate matter for each classification (See Table 6.4-1). Class I increments allow only minor pollutant concentration increases while Class III increments allow the most concentration increases. However, in no instance may the NAAQS be exceeded.

Congress specified that certain areas were to be automatically designated Class I. These areas include national memorials, parks and wilderness areas exceeding 6,000 acres in size, already in existence by the date of enactment. A list of the Class I areas for California are presented in Table 6.4-2 and illustrated in Figure 6.4-1 (this may be viewed in conjunction with overlay G). These areas may not be redesignated.

Under PSD regulations, the remaining areas are all presently Class II. These areas may be redesignated by the states to either Class I or Class III, following the procedures outlined in the regulations, and which will be discussed in the FLM's role in the Redesignation of Area Classifications. All new Wilderness Areas must be designated as either Class I or II.

- Applicability and Review Requirements

On June 19, 1978, the EPA promulgated the requirements for PSD as required in the Clean Air Act Amendments of

Table 6.4-1

Prevention of Significant Deterioration
Maximum Allowable Increments
(In Micrograms Per Cubic Meter)

Pollutant	Class I	Class II	Class III
Particulate Matter			
Annual Geometric Mean	5	19	37
24-Hour Maximum*	10	37	75
Sulfur Dioxide			
Annual Arithmetic Mean	2	20	40
24-Hour Maximum*	5	91	182
3-Hour Maximum*	25	512	700

*May be exceeded once per year

Table 6.4-2

Mandatory Class I Areas Under 1977

Clean Air Act Amendments for California

National Parks

- Kings Canyon
- Lassen Volcanic
- Redwood
- Sequoia
- Yosemite

National Wilderness Areas Over 6,000 Acres

- Agua Tibia
- Caribou
- Cucamonga
- Death Valley
- Desolation
- Dome Land
- Emigrant
- Hoover
- Joshua Tree
- John Muir
- Kaiser
- Lava Beds
- Marble Mountain
- Minarets
- Mokelumne
- Pinnacles
- Point Reyes
- Salmon Trinity Alps
- San Gabriel
- San Jacinto
- San Rafael
- South Warmer
- Thousand Lakes
- Ventana
- Yolla-Bolly Middle Eel

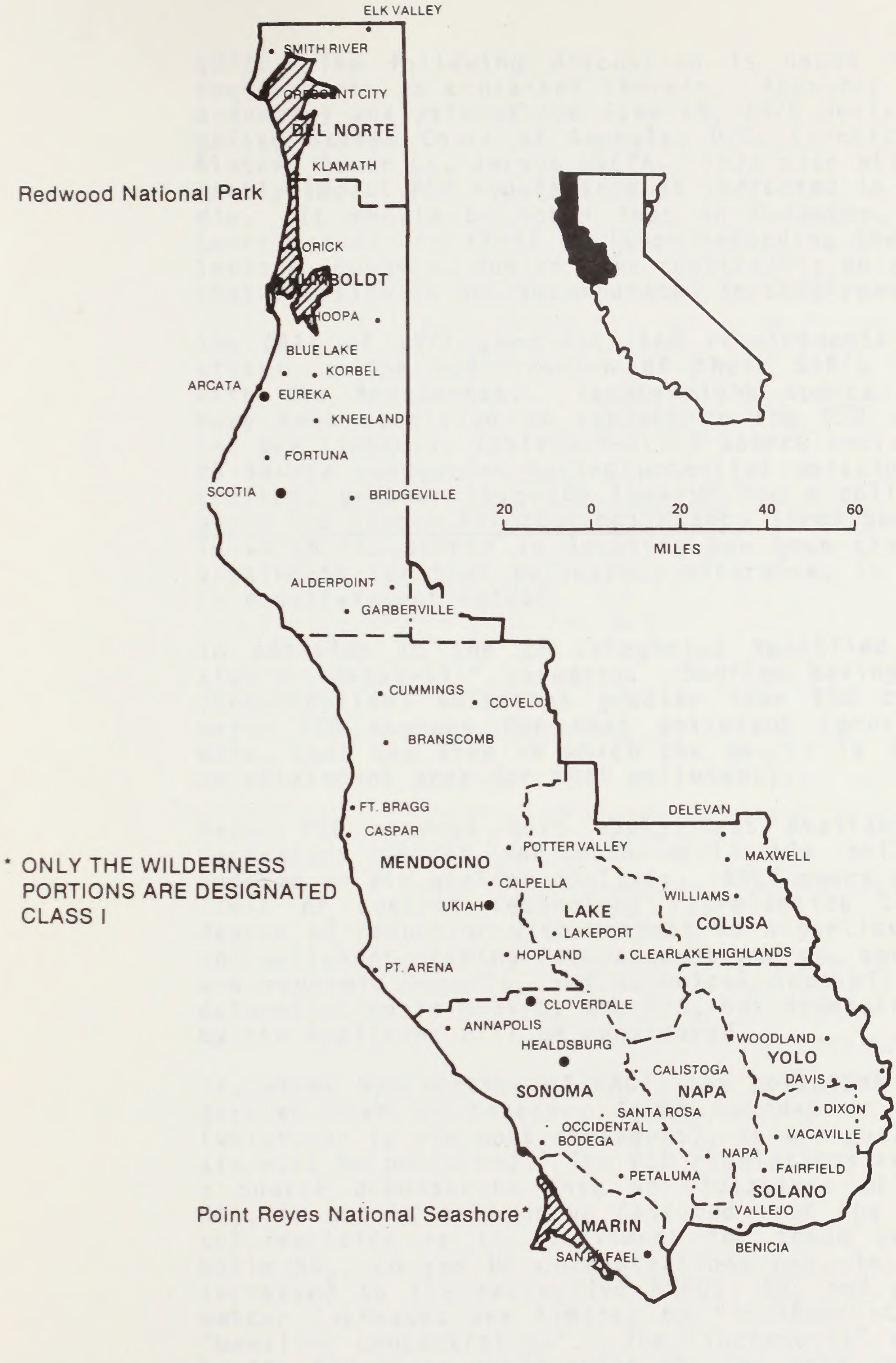


Figure 6.4-1
Mandatory Class I Areas Under 1977 Clean Air Act Amendments

1977. The following discussion is based on the PSD requirements as contained therein. Appendix H contains a summary analysis of the June 18, 1979 decision by the United States Court of Appeals, D.C. Circuit regarding Alabama Power Co. versus USEPA. This case will significantly impact PSD regulations as indicated in the Appendix. It should be noted that in December, 1979, the Court issued its final decision regarding the PSD regulations; however, due to time constraints an analysis of that decision is not incorporated in this report.

The CAAA of 1977 gave detailed requirements to assist states in the modification of their SIP's to conform with the Amendments. Twenty-eight source categories have been specified as subject to the PSD regulations and are listed in Table 6.4-3. A source included in the 28 source categories having potential emissions (uncontrolled) greater than 100 tons/yr for a pollutant is a major PSD source for that pollutant, (provided the area in which the source is locating has been classified as attainment for that pollutant; otherwise, it is subject to nonattainment rules).

In addition to the 28 categories specified, there is also a "catch-all" category. Sources having potential (uncontrolled) emissions greater than 250 tons/yr are major PSD sources for that pollutant (provided, once more, that the area in which the source is locating is an attainment area for that pollutant).

Major PSD sources must apply Best Available Control Technology (BACT) for each applicable pollutant and undergo an air quality analysis. BACT means an emission limit or control technology representing the maximum degree of reduction with respect to a particular source and pollutant, taking into account energy, environmental and economic impacts, and technical feasibility. This determination is made by the EPA, but demonstration made by the Applicant will be considered.

If, after application of BACT, the pollutant levels are greater than 50 tons/yr, 1,000 lbs/day or 100 lbs/hr (whichever is the most stringent), an air quality analysis must be performed. The PSD regulations require that a source demonstrate that no violations of NAAQS for NO_2, CO and HC will occur (assumed that the area under consideration is in attainment for these pollutants). While NO_2, CO and HC concentrations can, in effect, be increased to the respective NAAQS, SO_2 and particulate matter increases are limited by "increments" above the "baseline concentration". The "increments" are defined by the PSD Class designation for the area in which the source is located.

Table 6.4-3

PSD Major Stationary Sources

Potential Emission of Any Pollutant Greater than 100 tons/yr

- Fossil-Fuel Fired Steam Electric Plants (More than 250 MMBTU/Hr Input)
- Coal Cleaning Plants (with Thermal Dryers)
- Kraft Pulp Mills
- Portland Cement Plants
- Primary Zinc Smelters
- Iron and Steel Mill Plants
- Primary Aluminum Ore Reduction Plants
- Primary Copper Smelters
- Municipal Incinerators (Capable of Charging More than 250 Tons Refuse/Day)
- Hydrofluoric, Sulfur and Nitric Acid Plants
- Petroleum Refineries
- Lime Plants
- Phosphate Rock Processing Plants
- Coke Oven Batteries
- Sulfur Recovery Plants
- Carbon Black Plants (Furnace Process)
- Primary Lead Smelters
- Fuel Conversion Plants
- Sintering Plants
- Secondary Metal Production Plants
- Chemical Process Plants
- Fossil Fuel Boilers (or Combinations Thereof) (With Total Storage Capacity Exceeding 300 Thousand BBLS)
- Taconite Ore Processing Plants
- Glass Fiber Processing Plants
- Charcoal Products Plants

and

Notwithstanding the sources above, any source which emits or has potential to emit 250 tons/yr or more of any pollutant regulated under the act.

Baseline concentration is essentially the air quality, or concentration level of SO_2 and particulate matter that "existed" on August 7, 1977. Thus, the emissions from a proposed source are "modeled" via computer simulation, and a concentration prediction is obtained. The SO_2 and/or particulate matter concentration obtained must not exceed the incremental PSD limit for the area in which the source is locating; furthermore the concentration obtained (or "used") is applied against the increment. This means increment consumption is cumulative. That is, if emissions from the source result in SO_2 and particulate concentrations which consume part of the increment allowed from the "baseline concentration", then the next source(s) to apply for PSD permits must work within the remaining increment (See Figure 6.4-2).

It should be noted that SO_2 and particulate concentrations are prohibited from exceeding the NAAQS. Thus, if a "baseline concentration" is close to the NAAQS, and the additional "increment" defined by the values in Table 6.4-1 would exceed the NAAQS, then NAAQS becomes the upper limit, and the increment is "reduced" accordingly.

Federal Land Manager's Role in Class I Area Reviews

- Denial; impact on air quality related values

FLM's have input to the PSD permitting process if a project is believed to have an impact on a Class I area. Once a PSD application is submitted, the EPA must contact the appropriate FLM if it is believed that the project will have any air quality impact on a Class I area.

If the FLM finds that emissions from a proposed facility would have an adverse impact on "air quality related values" (which include visibility) of the land area (even though allowable Class I increments would not be exceeded), he can recommend to the EPA that the permit be denied. If the EPA concurs with the FLM's demonstration, a permit will not be issued.

- Class I variances

Conversely, in a situation where Class I increments are predicted to be exceeded, the applicant may appeal to the FLM. The applicant must demonstrate to the FLM that the emissions from the facility will not adversely impact air quality related values. If the FLM concurs with this demonstration, he must certify this concurrence, and the state may then authorize the EPA to issue a permit which would allow the facility to comply with less stringent air quality increments. In such cases,

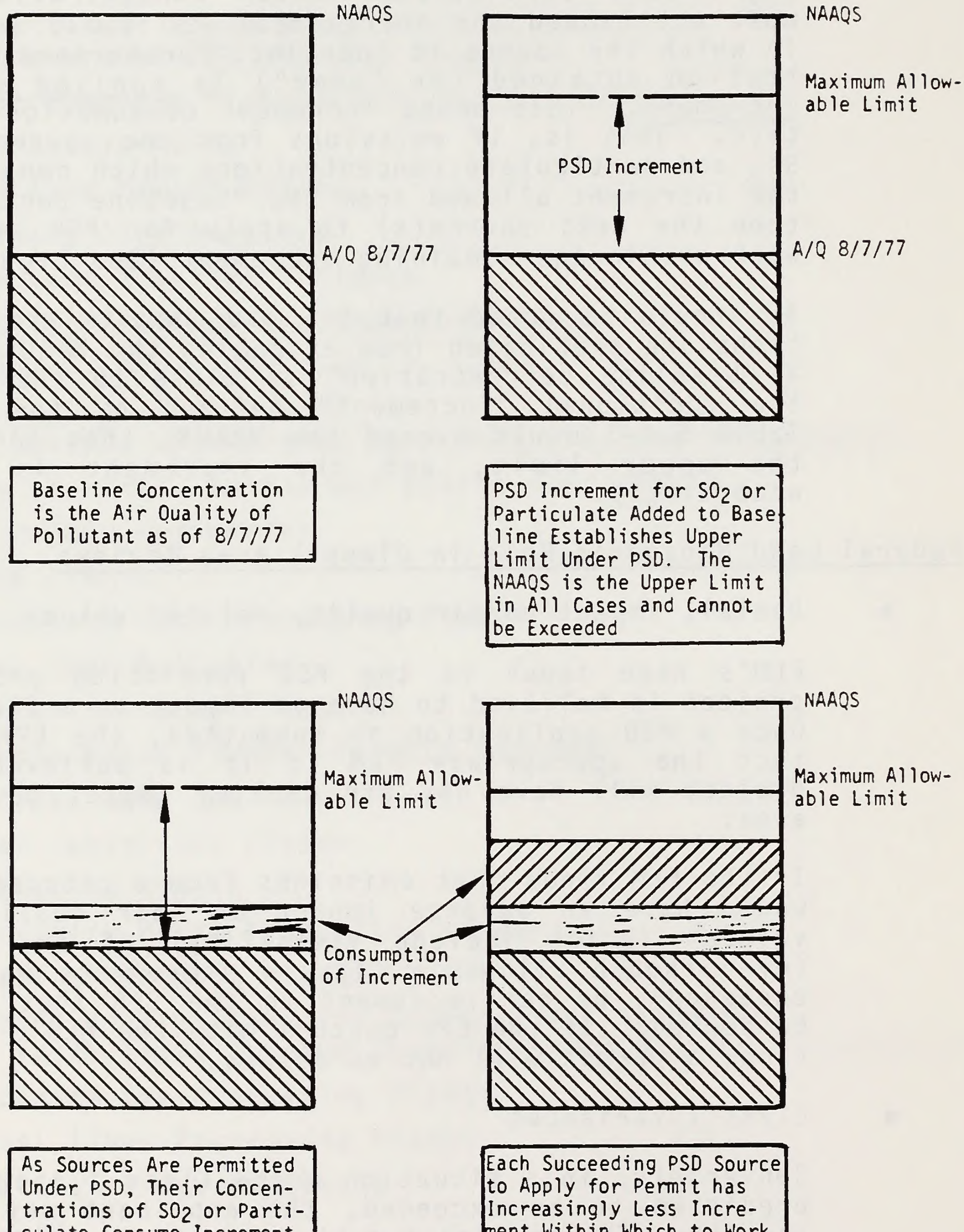


Figure 6.4-2

Determination of Maximum Allowable Ambient Limit Under PSD Increment the maximum increments imposed are the same as the Class II values, except for the three-hour SO_2 increment limit which is not to exceed 325 g/m^3 (The Class II three-hour SO_2 increment is 512 g/m^3.)

- SO_2 variance by Governor with FLM's concurrence.

  In situations where the Class I increments are predicted to be exceeded, and the source would exceed the relaxed SO_2 increments as described above, the applicant may appeal to the Governor to receive a variance for <u>sulfur dioxide only.</u> Particulate matter variances cannot be obtained. In making this appeal, the applicant must demonstrate that neither the 24-hour nor the 3-hour SO_2 increment limits can be achieved. The annual SO_2 increment of 20 g/m^3 must be met, however. Additionally the applicant must also demonstrate that the project will not adversely affect the air quality related values of the area. The FLM, again, has input in this process and is required to make a recommendation to the Governor who can agree or disagree with the FLM recommendation. In addition, a public hearing must be held. After considering the public input, the Governor, may grant a variance. The EPA can then issue a permit, and the source would then be permitted to exceed the SO_2 increments presented in Table 6.4-4 for no more than 18 days per year.

- Variance by the Governor with the President's concurrence

  If, in the above process, the FLM does not concur, the permit can not be approved, unless the Governor overrides the FLM's veto. The Governor has the authorization to override this veto and recommend a variance. In such a situation, the recommendations of both the FLM and the Governor are sent to the President. The President may approve the Governor's recommendation if he finds the variance to be in the national interest. If the variance is approved, the EPA may issue a permit, and the source would then be permitted to exceed the SO_2 increments presented in Table 6.4-4 for no more than 18 days per year.

  The procedure discussed above is outlined in Figure 6.4-3.

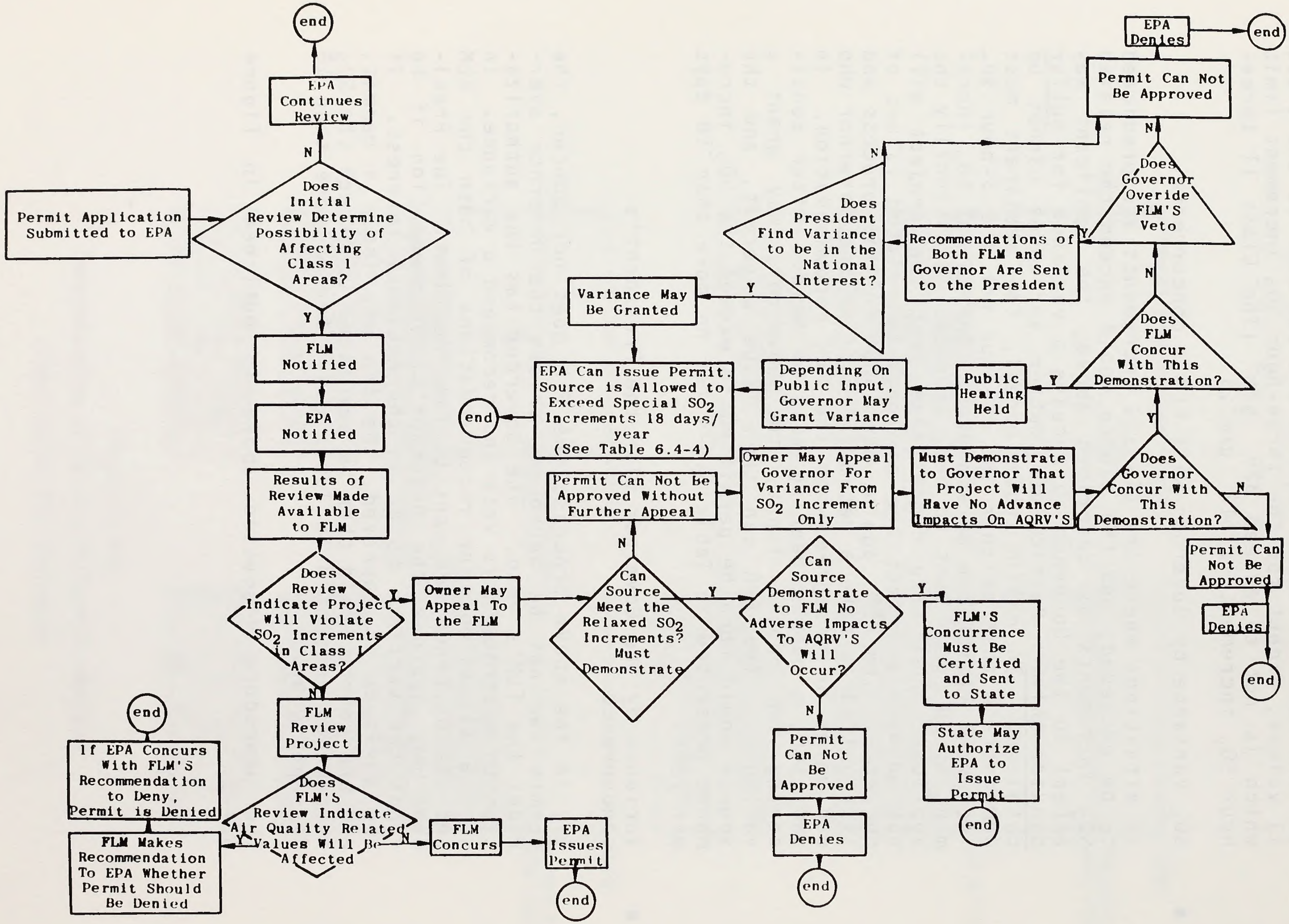


Figure 6.4-3

The PSD Permit Application Process

Table 6.4-4

Maximum Allowable Increase (gm/^{3})

Under Class I SO_2 Variances

Period of Exposure	Terrain Areas	
	Low	High
24-hour maximum	36	62
3-hour maximum	130	221

- Air Quality Related Values

  The only "air quality related value" specifically cited in the 1977 Amendments is visibility. Other values may include fish and wildlife resources, vegetation, archaelogic sites and soil impacts. The EPA has yet to provide general guidelines regarding the evaluation of impacts of proposed emitting sources on "air quality related values" and until such guidance is available, determinations are to be made on a case-by-case basis. The FLM reviewing the permit can recommend conditions which would ensure protection of air quality related values. For example, a condition that the facility monitor the impacts of its emissions, and reduce their level if adverse effects begin to occur may be recommended.

FLM role in Redesignation of Area Classifications

A state may redesignate any area to Class I. States are also permitted to redesignate certain areas to Class III except the following areas greater than 10,000 acres in size: present national monuments, primitive areas, recreation areas, wild and scenic rivers, wildlife refuges, lakeshores, seashores, and future national parks and wilderness areas. Redesignation of an area to Class III is a complicated process requiring approval by the governor, public notices and hearings, consultation with the state legislature, and approval by a majority of potentially affected local residents.

Detailed analyses are required prior to public hearing including health, environmental, economic, social and energy impacts of the proposal. Redesignation of areas within Indian reservations may only be done by the applicable Indian governing body.

The EPA Administrator may disapprove a proposed redesignation only if the redesignation does not meet the procedural requirements of Part C of the Act. If federal lands are included in the proposed redesignation area, the FLM is to submit recommendations on the proposal, but the state's decision, if it differs, is binding. The EPA may be requested to resolve disputes between states and Indian tribes on proposed redesignations. The redesignation process is summarized in Figure 6.4-4.

6.4.4 Visibility Protection

The 1977 Amendments added to the Clean Air Act a section entitled "Visibility Protection for Federal Class I Areas". This section declares as a National goal "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas" where impairment results from man-made air pollution. The Amendments also required that by February 1978, the Secretary of Interior, in consultation with the states and the FLM's, are to identify any mandatory Class I areas where visibility contributes significant values to the area. These areas were published in the February 24, 1978 Federal Register. As such, all Class I areas in California are areas in which visibility is considered to be an "important" value. As stated previously, the EPA was to have conducted a study on visibilty (by Feb 1979), and promulgate regulations on visibility by August, 1979.

These regulations, in essence, are to provide guidelines to the states on the various techniques and methods to be used to achieve the National goal for visibility. Such a goal would be stated, in all probability, as a "visibility standard".

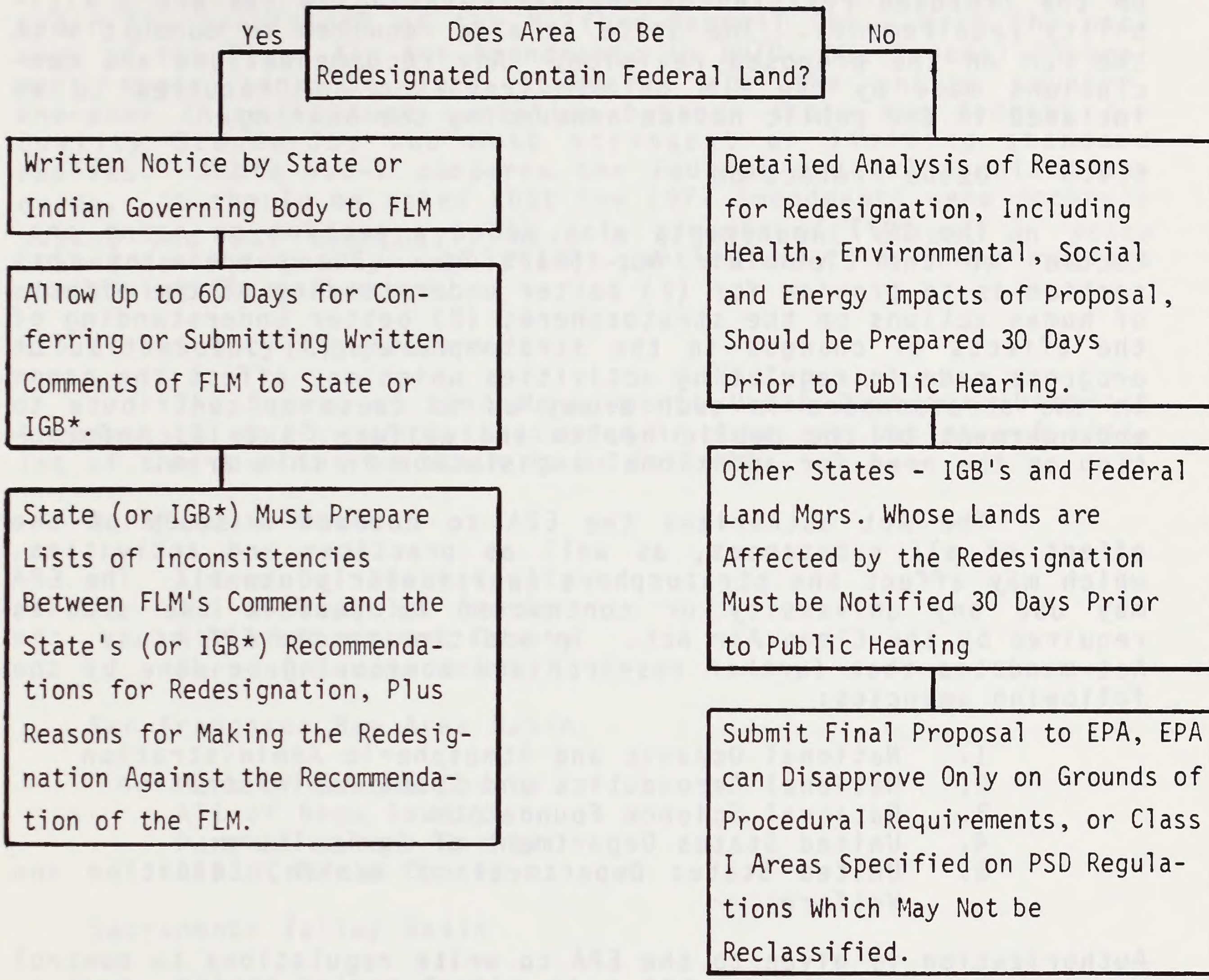
The regulations would identify "impaired visibility areas" and would require each SIP in such areas to adopt emission limits on sources of pollution, compliance schedules and other measures necessary to achieve the visibility standard. These measures will include what the Clean Air Act terms "Best Available Retrofit Technology" (BART). Thus, SIPs must impose BART on specific sources named in the Clean Air Act. These sources consist of the sources in the 28 PSD categories, which have potential (uncontrolled) emissions greater than 250 tons/yr of any pollutant. In addition to these measures, the SIPs must develop long-term strategies for achieving the visibility standard.

The EPA is allowed to exempt sources from BART; such exemptions can be made if the EPA feels that such sources will not contribute to visibility impairment. The EPA may not however, give this source-wide exemption to fossil-fuel fired power plants greater than 750 MW. These units would be included in the states' regulations and BART must apply. Exemptions for these units may only be made on a case-by-case basis, where the owner of such units demonstrates to the EPA that the unit of concern would not contribute to impairment of visibility.

Any exemption that the EPA makes regarding these sources and their inclusion in the SIP, must go through the FLM. The Clean Air Act mandates that the FLM's concurrence must be ob-

Figure 6.4-4

Redesignation Procedure



* Indian Governing Body

tained in order for any exemption of this type to be effective. (Section 169A(c)(3) of the Clean Air Act).

The Clean Air Act requires that a public hearing be held on the proposed revision of any SIP relating to the EPA's visibility requirements. The State is also required to consult with the FLM on the proposed revision. Any recommendations and conclusions made by the FLM on this revision are required to be included in the public notice announcing the hearing.

6.4.5 Ozone Protection

The 1977 Amendments also added a section on ozone protection to the Clean Air Act (Part B). The purpose of this section is to provide for (1) better understanding of the effects of human actions on the stratosphere; (2) better understanding of the effects of changes in the stratosphere; (3) information on progress made in regulating activities which may affect the ozone in the stratosphere in such a way as to cause or contribute to endangerment of the public health and welfare; and (4) information on the need for additional legislation in this area.

The Act authorizes the EPA to conduct a study of the effect of all substances, as well as practices and activities, which may affect the stratosphere (particularly ozone). The EPA may use any university or contractor to perform the studies required by the Clean Air Act. In addition to the EPA study, the Act mandates that further research and monitoring be done by the following agencies:

1. National Oceanic and Atmospheric Administration
2. National Aeronautics and Space Administration
3. National Science Foundation
4. United States Department of Agriculture
5. United States Department of Health, Education and Welfare

Authorization is given to the EPA to write regulations to control any substance which the EPA believes, based on their studies, would affect the stratosphere, particularly in the formation of ozone. This would include chlorofluorocarbon emissions from aerosol cans and emissions from airplanes, cars, etc. These regulations must take into account the feasibility and the costs of achieving these controls. However, such regulations may exempt medical use products for which the EPA determines there is no suitable substitute.

6.5 STATE AND COUNTY REGULATIONS

6.5.1 State Ambient Air Quality Standards

California began setting Air Quality Standards in 1969 under the provisions of the Mulford-Carrell Act. With the passage of the Clean Air Act Amendments in 1970, the Federal Government began adopting such standards for the entire country. Wherever there is some variation between state and federal Air Quality Standards, the most stringent or limiting standard applies. Table 6.5-1 compares the Federal and California standards. It should be noted that the 1977 Amendments were recently passed and may eventually have a significant effect on state standards and county regulations-particularly in those regions containing Class I areas.

6.5.2 County Regulations

The Bureau of Land Managements Ukiah District (District 4) consists of 10 counties situated in four air basins. A listing of the counties by basin is as follows:

North Coast Basin

- All of Del Norte County
- All of Humboldt County
- All of Mendocino County
- Part of Sonoma County

San Francisco Bay Area Basin

- Part of Sonoma County
- All of Napa County
- Part of Solano County
- All of Marin County

Sacramento Valley Basin

- All of Colusa County
- All of Yolo County
- Part of Solano County

Lake County Air Basin

- All of Lake County

The counties of the San Francisco Bay Area Basin also comprise the Bay Area Air Quality Management District (AQMD). The individual county Air Pollution Control Districts in the North Coast Air Basin have adopted common rules and regulations. The counties of Yolo and Solano have formed the Yolo-Solano APCD. The counties of Lake and Colusa are individual APCD's.

Table 6.5-1

Ambient Air Quality Standards

Pollutant	Averaging Time	California Standards[1]		National Standards[2]		
		Concentration[3]	Method[4]	Primary[3, 5]	Secondary[3, 6]	Method[7]
Oxidant (Ozone)	1 hour	0.10 ppm (200 ug/m^3)	Ultraviolet Photometry	240 µg/m^3 (0.12 ppm)	Same as Primary Std.	Chemiluminescent Method
Carbon Monoxide	12 hour	10 ppm (11 mg/m^3)	Non-Dispersive Infrared Spectroscopy	—	Same as Primary Standards	Non-Dispersive Infrared Spectroscopy
	8 hour	—		10 mg/m^3 (9 ppm)		
	1 hour	40 ppm (46 mg/m^3)		40 mg/m^3 (35 ppm)		
Nitrogen Dioxide	Annual Average	—	Saltzman Method	100 ug/m^3 (0.05 ppm)	Same as Primary Standards	Proposed: Modified J-H Saltzman (O_3 corr.) Chemiluminescent
	1 hour	0.25 ppm (470 ug/m^3)		—		
Sulfur Dioxide	Annual Average	—	Conductimetric Method	80 ug/m^3 (0.03 ppm)	—	Pararosaniline Method
	24 hour	0.05 ppm (131 ug/m^3)[9]		365 ug/m^3 (0.14 ppm)	—	
	3 hour	—		—	1300 ug/m^3 (0.5 ppm)	
	1 hour	0.5 ppm (1310 ug/m^3)		—	—	
Suspended Particulate Matter	Annual Geometric Mean	60 ug/m^3	High Volume Sampling	75 ug/m^3	60 ug/m^3	High Volume Sampling
	24 hour	100 ug/m^3		260 ug/m^3	150 ug/m^3	
Sulfates	24 hour	25 ug/m^3	AIHL Method No. 61	—	—	—
Lead	30 Day Average	1.5 ug/m^3	AIHL Method No. 54	1.5 µg/m^3	—	High Volume Sampling
Hydrogen Sulfide	1 hour	0.03 ppm (42 ug/m^3)	Cadmium Hydroxide Stractan Method	—	—	—
Hydrocarbons (Corrected for Methane)	3 hour (6-9 a.m.)	—	—	160 ug/m^3 (0.24 ppm)	Same as Primary Standards	Flame Ionization Detection Using Gas Chromatography
Ethylene	8 hour	0.1 ppm	—	—	—	—
	1 hour	0.5 ppm				
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility to less than 10 miles when the relative humidity is less than 70% (8)		—	—	—
APPLICABLE ONLY IN THE LAKE TAHOE AIR BASIN:						
Carbon Monoxide	8 hour	6 ppm (7 mg/m^3)	NDIR	—	—	—
Visibility Reducing Particles	1 observation	In sufficient amount to reduce the prevailing visibility to less than 30 miles when the relative humidity is less than 70% (8)		—	—	—

NOTES:

1. California standards are values that are not to be equaled or exceeded.

2. National standards, other than those based on annual averages or annual geometric means, are not to be exceeded more than once per year.

3. Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25°C and a reference pressure of 760 mm of mercury. All measurements of air quality are to be corrected to a reference temperature of 25°C and a reference pressure of 760 mm of Hg (1,013.2 millibar); ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.

4. Any equivalent procedure which can be shown to the satisfaction of the Air Resources Board to give equivalent results at or near the level of the air quality standard may be used.

5. National Primary Standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. Each state must attain the primary standards no later than three years after that state's implementation plan is approved by the Environmental Protection Agency (EPA).

6. National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state must attain the secondary standards within a "reasonable time" after implementation plan is approved by the EPA.

7. Reference method as described by the EPA. An "equivalent method" of measurement may be used but must have a "consistent relationship to the reference method" and must be approved by the EPA.

8. Prevailing visibility is defined as the greatest visibility which is attained or surpassed around at least half of the horizon circle, but not necessarily in continuous sectors.

9. At locations where the state standards for oxidant and/or suspended particulate matter are violated. Federal standards apply elsewhere.

6.5.3 Permit Rules

As mentioned previously, the intent of the Clean Air Act in establishing procedures for permit rules is to require the states to write and adopt such permit rules into their individual SIPs. Until such time as these rules are approved by the EPA and incorporated in the SIP, the EPA still remains the permitting authority. Thus, in California, many Applicants who are required to obtain a PSD permit from the EPA, are also required to obtain a New Source Review permit from the County.

In nonattainment areas, however, no permits may be issued until the SIP for these areas is approved by the EPA. Thus, in California, no permits can be issued in these areas. At the present time, many counties have rewritten their permit rules to conform with a model or guideline rule which was drafted by the CARB.

The permit rules have in the last year been rewritten by the local districts to conform to the CARB Model Rule. Although there are individual differences between the various districts' rules regarding cut-off limits for review, control technology, etc., the basic content of the rules follows the CARB Model Rule. Thus a description of the provisions of the Model Rule will suffice to describe the general district requirements.

At the present time, these rewritten rules have been submitted to the CARB by the local districts. CARB is in the process of reviewing these rules to see if they conform with the Model Rule. After CARB reviews the local rule, and concurs with it, it then submits it to the EPA for review and inclusion in the SIP. A local District may not submit directly to the EPA; only the State may submit individual rules to the EPA for inclusion in the SIP. At this point, no rules have been submitted to the EPA; they are presently either being adopted by the local District for submission to the CARB, or have already been submitted to CARB and are waiting for their review.

6.5.3.1 Description of Model Rule/Districts' Rules

The CARB Model Rule was written to ensure compliance with the requirements of the Clean Air Act, and to provide the individual APCD's with guidance in writing their rules. By and large, most of the Districts in California have adopted the rule, with some minor changes between Districts. Thus, a description of CARB's Model Rule will suffice to describe the indivudual Districts' rules in California.

The Model Rule/District Rules currently apply in both attainment and nonattainment areas (A state PSD rule will eventually control sources in attainment areas). All sources, regardless of emission levels, must first demonstrate compliance with all District rules and regulations (emission limits, etc.). It must also demonstrate that all company-owned sources in the State are in compliance with all emission limitations and standards which are part of the SIP approved by the EPA.

If the emissions from the source are greater than 250 lbs/day (per the Model Rule; this may differ from District to District), for any pollutant, BACT is required for all pollutants.

If, after application of BACT, emissions of any pollutant are greater than 250 lbs/day, the source must meet specific requirements which differ according to two different scenarios as illustrated below:

- Sources Locating in Nonattainment Areas
  Offsets must be obtained for pollutants, in ratios greater than 1.2:1.

- Sources Locating in Areas which are Attainment or Show Infrequent Violations
  Offsets are required only as much as is needed to prevent a new violation or to prevent the worsening of an existing one.

6.5.3.2 California's Air Conservation Program (ACP)

In 1976, the CARB began writing a proposed guideline permit rule affecting new or modified sources locating in attainment areas of the State. It was the state's version of the EPA's PSD program, and was called the California Air Conservation Program (ACP). The CARB had drafted a rule incorporating a four-level classification system of lands, as opposed to the EPA's three-class increment system.

However, since the Clean Air Act Amendments of 1977 drastically changed the PSD requirements for states, and with the rush of activity associated with nonattainment planning, the ACP for the State was temporarily dropped.

Activity resumed recently on drafting the California version of PSD. However, at this time, the rule is being written to be equivalent to the EPA's present PSD regulations, and will not contain extensive additions, or differences, as in the original version. The CARB's purpose in their actions is to draft a rule that the local Districts can easily adopt and which would be easily approvable by the EPA. The rule would then be part of the SIP, and could be enforced by the local Districts.

Subsequent to inclusion in the SIP, the CARB will then commence work on a new version of the ACP which would eventually replace their PSD regulation. Thus, their PSD regulation serves only as an interim measure in order to obtain full State jurisdictional authority to administer permit programs in attainment areas. The ACP will, in essence, be a more detailed PSD regulation which is tailored to the air quality concerns and needs of California. It is not known at this time whether the ACP will include the utilization of the national Class I, II, and III increment or another suitable increment standard.

The CARB wishes to have their interim PSD regulation (Model Rule) drafted by October. They wish to have the Districts adopt this regulation by the end of 1979.

6.5.3.3 Emission Regulations

The remainder of this section is categorized by the pollutant causing event or by the pollutant. Each category is followed by a discussion that describes either the typical regulation as adopted by all or a vast majority of the APCD's, or the regulations as adopted by an individual or group of APCD's. The discussions are not intended to be all-inclusive; for more detailed information and for special incidences, refer to the county rules and regulations directly.

Visible Emissions

This regulation prohibits the discharge of air pollutants for more than three minutes in any hour which is as dark or darker than No. 1 or No. 2 on the Ringelmann Chart (as published by the U.S. Bureau of Mines) depending on the APCD. Some APCDs allow exceptions.

The Bay Area APCD and Mendocino County APCD use Ringelmann No. 1. The Lake County APCD, Yolo-Solano APCD, and all of the APCDs in the North Coast Air Basin with the exception of Mendocino County use Ringelmann No. 2. The following exceptions generally apply:

1. Smoke from fires for prevention of a fire or health hazard which cannot be abated by any other means.
2. Smoke from fires for instruction of public and industrial employees in methods of fighting fire.
3. Agricultural operations used in the growing of crops or raising of fowl, animals, or bees.
4. The use of an orchard or citrus grove heater which does not produce unconsumed solid carbonaceous matter at a rate in excess of one (1) gram per minute.
5. Emissions which fail to meet the requirement solely because of the presence of uncombined water.

The Ringelmann Chart is actually a series of charts, numbered from 0 to 5, that simulate various smoke densities by presenting different percentages of black. The charts are commonly referred to by number, thus a Ringelmann No. 1 is equivalent to 20 percent black; a Ringelmann No. 5 is equivalent to 100 percent black. They are used for measuring the opacity of smoke generated from stacks and other sources by matching with the actual effluent the various numbers, or densities, indicated by the charts. Persons can be trained and certified to use the Ringelmann method using visual judgment without the use of the charts.

Incinerator Burning

The burning of combustible refuse in any incinerator is prohibited except in multiple-chamber incinerators or other equipment found in advance by the Air Pollution Control Officer to be equally effective for controlling air pollution. This rule generally does not apply to incinerators used to burn only household rubbish and yard trimmings from single or two-family dwelling on its premises. However, in some counties, burning in non-approved equipment may be done only on "burn-days".

A multiple chamber incinerator is any article, machine, equipment, contrivance, structure or part of a structure used to dispose of combustible refused by burning, consisting of three or more refactory lined combustion furnaces in series, physically separated by refractory walls, interconnected by gas passage ports or ducts and employing adequate design parameters necessary for maximum combustion of the material to be burned.

Particulate Matter

These regulations limit the amount of particulate matter that can be discharged from a source. A limit is also established on the allowable rate of particulate emission based on process weight. The rate varies for the APCDs.

Yolo and Solano County APCDs prohibit the discharge of particulate matter in excess of 0.3 gr/SCF of exhaust volume as calculated for standard conditions.

The Bay Area AQMD limits the weight of particulates in an exhaust gas stream to 0.15 gr/SCF. For any incineration operation or salvage operation capable of burning 100 tons of waste per day, the limit is 0.05 gr/SCF. In addition, an allowable rate of emission is established based on a process weight table contained in the regulations. Maximum emissions allowed under this table are 40 lbs/hr.

Lake County limits combustion contaminants from sources other than combustion sources to 0.2 gr/SCF or the emission limit as established by the process weight table contained in the regulations. Maximum emissions allowed under this table are 40 lbs/hr.

Combustion sources must meet the following particulate matter limitations in Lake County:

1. 0.2 gr/SCF calculated at 12% CO_2 for equipment in use prior to December 20, 1971;

2. 0.1 gr/SCF of gas calculated at 12% CO_2 for equipment beginning operation after December 20, 1971.

The above particulate emission limits also apply to geothermal operations although an exemption can be made during the air drilling phase of the operation, during which time the particulate emission rate may reach a level of 100 lbs/hr for a time period not to exceed 16 days.

The North Coast Air Basin has the following particulate matter rules:

1. The discharge from any combustion source in excess of 0.2 gr/SCF (0.46 grams per standard cubic meter (g/SCM) of exhaust gas), calculated at 12% of CO_2 is prohibited.

2. Steam generating units, installed or modified after July 1, 1976 may not discharge in excess of 0.1 gr/SCF (0.23 g/SCM) of exhaust gas calculated at 12% CO_2.

3. Kraft recovery furnaces may not discharge in excess of 0.1 gr/SCF of exhaust gas.

4. Non-combustion sources may not discharge in excess of 0.2 gr/SCF of exhaust gas.

The above emission limits are summarized in the table below:

Table 6.5-2
Limits for Particulate Matter

County/District	Stack Gas Concentration Limit	Emission Limit
Yolo/Solano APCD	0.3 gr/SCF	--
Bay Area AQMD		
(1) Incinerator operation or Salvage operation	0.5 gr/SCF	Process weight table used to determine allowable emission rate. Maximum limit allowed is 40 lbs/hr.
(2) All other sources	0.15 gr/SCF	
Lake County		
(1) All sources other than combustion sources	0.2 gr/SCF	Process weight table used to determine allowable emission rate. Maximum limit allowed is 40 lbs/hr.

(2) Combustion sources in use prior to December 20, 1971	0.2 gr/SCF	Process weight table used to determine allowable emission rate. Maximum limit allowed is 40 lbs/hr.
(3) Combustion sources in use after December 20, 1971	0.1 gr/SCF	Process weight table used to determine allowable emission rate. Maximum limit allowed is 40 lbs/hr.

<u>North Coast Air Basin</u>

(1) Combustion sources	0.2 gr/SCF	Process weight table used to determine allowable emission rate. Maximum limit allowed is 40 lbs/hr.
(2) Steam generating units installed or modified after July 1, 1976	0.1 gr/SCF	Process weight table used to determine allowable emission rate. Maximum limit allowed is 40 lbs/hr.
(3) Kraft recovery furnaces	0.1 gr/SCF	Process weight table used to determine allowable emission rate. Maximum limit allowed is 40 lbs/hr.
(4) Non-combustion sources	0.2 gr/SCF	Process weight table used to determine allowable emission rate. Maximum limit allowed is 40 lbs/hr.

<u>Sulfur Compounds</u>

These regulations limit either the emission of sulfur compounds at the point of discharge or the atmospheric concentration of sulfur compounds.

In the Bay Area AQMD, sources of sulfur dioxide must either meet a 300 ppm limit at the emission point or a much more restrictive limit at ground level - 0.5 ppm for three consecutive minutes or 0.5 ppm averaged over 60 minutes or 0.04 averaged over 24 hours. Further, the limits specified below are also not to be exceeded:

Table 6.5-3

Bay Area AQMD
Maximum Allowable SO_2 Ground Level Limits

SO_2 Concentration ppm (vol)	Averaging Time (hrs)
1.5	0.05
0.5	1.0
0.3	3.2
0.1	9.6
0.04	24.0

The Bay Area AQMD has established the following limitations for sulfur recovery plants, sulfuric acid plants and refinery equipment in refineries:

Table 6.5-4

Bay Area AQMD
Emission Limitations for Sulfur Recovery Plants and Refinery Equipment

Source	SO_2 Limitation
• Existing Controlled Plants	The more restrictive of 1500 ppm (vol) or 120 lbs per short ton of sulfur products By 1984, such plants must meet the more restrictive of: 250 ppm (vol) or 4 lb per short ton of sulfur produced.
• Existing Uncontrolled Plants	3000 ppm (vol) By 1981 the limit shall be: The more restrictive of 250 ppm (vol) or 4 lbs per short ton of sulfur produced.
• New Sulfur Recovery Plants	The more restrictive of: 250 ppm (vol) or 4 lbs SO_2/ton sulfur produced.

- Existing Sulfuric Acid Plants
  - Acid plants constructed prior to 1955 — 6000 ppm through 1981
  - Acid plants constructed after 1955 — 3000 ppm through 1981

    By 1981 the limit shall be: More restrictive of 300 ppm (vol) or 7 lbs SO_2/ton H_2SO_4 produced

- New Sulfuric Acid Plants — More restrictive of 30 ppm (vol) or 4 lbs SO_2/ton $H_2 SO_4$ product
- Fluid Catalytic Cracking Units, Fluid Cokers — 1000 ppm (vol)
- Coke Calcining Kilns — More restrictive of 400 ppm (vol) or 250 lbs/hr.

Lake County prohibits the discharge from any sulfur recovery unit producing elemental sulfur of effluent process gas containing more than: (1) 300 ppm by volume of sulfur compound calculated as SO_2, (2) 10 ppm by volume of hydrogen sulfide, and (3) 100 pounds per hour of sulfur compounds calculated as sulfur dioxide.

For geothermal wells and power plants, Lake County has recently adopted rules for the control of H_2S emissions. H_2S is limited to 150 ppm from geothermal wells, unless there is an H_2S control system capable of achieving a 75% or greater reduction in emissions. In all cases, the H_2S emissions must be demonstrated not to exceed the 1-hour ambient state standard for H_2S.

Exemptions to the 150 ppm limit and the H_2S control system may be made if the developer installs an ambient monitoring system in the downwind direction of the geothermal well, and the ambient air standard for H_2S is not exceeded. However, an upper limit of 1000 ppm is imposed.

Geothermal power plans must meet the following time schedule of H_2S emissions:

Table 6.5-5

Emission Limits of H_2S from Geothermal Power Plants in Lake County

Source	Emission Limit
Plants which have received Authority to Construct (A/C) prior to January 1, 1979	175 g/MW-hr until 1990
Plants receiving A/C on or after January 1, 1979	100 g/MW-hr until 1990
Plants receiving A/C on or after January 1, 1983	50 g/MW-hr until 1990
All plants by 1990	50 g/MW-hr

In Northern Sonoma County, the emission limitations for H_2S from geothermal power plants are the same as those listed above for Lake County. However, geothermal wells are limited to 2.5 kg H_2S/hr.

The North Coast Air Basin has the following regulations for emissions of total reduced sulfur (TRS):

1. Kraft recovery furnaces: (a) 10 ppm or 0.30 pounds of TRS per ton of kraft pulp mill production as a monthly arithmetic average, whichever is more restrictive; (b) 15 ppm of TRS as a daily arithmetic average; (c) 40 ppm of TRS for more than 60 cumulative minutes in any one day.

2. Lime kilns: shall not exceed 40 ppm of TRS or 0.20 pounds of TRS per ton of kraft pulp mill production as a daily arithmetic average, whichever is more restrictive.

3. Other kraft mill sources: shall not exceed 20 ppm of TRS or a cumulative value of 0.20 pounds of TRS per ton of kraft pulp mill production as a daily arithmetic average, whichever is more restrictive.

Nitrogen Oxides

The Bay Area APCD limits nitrogen oxide emissions from stationary sources. The limits are as follows:

1. Sources with heat input equal to or greater than 250 million Btu/hr. - 125 ppm when burning natural gas and 225 ppm when burning oil.

2. Sources with heat input equal to or greater than 1,750 million Btu/hr. - 175 ppm when burning natural gas and 300 ppm when burning oil.

Lead Emissions

The Bay Area AQMD prohibits any source from emitting more than 13 lbs. of lead per day resulting in a ground level concentration of 1.0 micrograms per cubic meter in excess of the background level.

Odors

Two methods have been used by counties to regulate odors in the atmosphere. In most counties, odors are covered under regulations for nuisances (see separate section). The Bay Area APCD Regulations call for district personnel to take a sample of a suspected odor if ten citizen complaints are received within 90 days. The sample is then diluted with four parts of odor free air. If it remains odorous after dilution, the source is in violation of the regulation.

Nuisances

This regulation generally prohibits any source from emitting air contaminants or other material which cause injury, detriment, nuisance or annoyance to any considerable number of persons or to the public or which endanger the comfort, repose, health or safety of any persons or the public or which cause or have a tendency to cause injury or damage to business or property. The working of this regulation varies with the overall detail of the county or district regulations. In some cases, nuisances such as odors are separated out and dealt with directly.

Sulfur Content of Fuels

The Bay Area AQMD limits the sulfur in fuels to 0.5 percent or the emissions from fuel burning to 300 ppm (as SO_2).

Reduction of Animal Matter

This prohibits the reduction of animal matter in a source unless all generated emissions are incinerated at temperatures of not less than 1200 degrees Fahrenheit for a period of not less than 0.3 seconds or processed in a manner determined by the Air Pollution Control Officer to be equally or more effective for the purpose of air pollution control.

Miscellaneous Regulations

Other common regulations usually, but not always included by counties and districts, include prohibitions on emissions from organic solvents, new source performance standards, emission standards for hazardous air pollutants, regulations on organic liquid loading, regulations on loading gasoline into stationary tanks.

6.5.3.4 Burning Regulations

The CARB has promulgated regulations governing the use of open outdoor fires for agricultural operations and forest management. Agricultural burning guidelines and meteorological criteria for the regulation of agricultural burning were promulgated for each air basin on March 17, 1971. The purpose of the regulation was to permit burning on days with good meteorology based upon established meteorologiccal criteria. Regulations were adopted on March 17, 1971 and revised on June 21, 1972, February 20, 1975, with a proposed revision April 27, 1978.

The regulations require that burning permits be obtained prior to the use of open outdoor fires. These permits are to be prepared by the designated agency and/or the appropriate APCD. In most instances, the California Department of Forestry (CDF) serves as the designated agency for burning in forested areas throughout the state and, therefore, is responsible for the issuance of permits.

While the CDF serves as the designated agency for the issuance of burning permits in California, this responsibility can be further delegated to other agencies. In some instances, the BLM has been given authority by the CDF to issue permits for land areas managed by the Department of Interior. These include the Susanville and Bodie Planning Units. In these instances, BLM area managers are directly responsible for the issuance of permits and for coordination with other agencies. However, unless this authority has been properly delegated, BLM area managers are not responsible for permitting for open outdoor burning.

BLM area managers responsible for the administration of Department of Interior lands in California must be cognizant of the procedures necessary prior to any burning activities in these areas. The principal points of contact for the BLM area managers include the local APCD, the CARB, the National Weather Service (NWS) and the CDF. The latter agency should serve as an initial point of contact for area managers faced with the problem of burning on federal lands for the first time. CDF personnel can explain permit issuance procedures to BLM personnel and it is good practice for BLM land managers to become very familiar with this process. Table 6.5-6 provides a list of all CDF contacts within California suitable for use by BLM land managers.

The requirements for a burning permit apply to all land areas in the state with a few exceptions. Open burning for agricultural operations in the growing of crops or the raising of fowl or animals, as well as disease or pest prevention are exempt from permitting requirements above an elevation of 3,000 feet MSL. This exception does not apply in the Tahoe Air Basin. Land

Table 6.5-6

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF FORESTRY

DIRECTORY

Administrative Unit	Administrative Officer	Title	Street Address	Post Office	Telephone No.	P.O. Box
State Headquarters	Lewis A. Moran	Director	1416 Ninth Street	Sacramento 95814	916-445-3976	
	Larry E. Richey	Deputy Director	1416 Ninth Street	Sacramento 95814	916-445-2921	
	Frank Torkelson	Deputy Director	1416 Ninth Street	Sacramento 95814	916-445-6650	
I. North Coast Headquarters	George Grogan	Chief	135 Ridgeway Avenue	Santa Rosa 95401	707-542-1331	Box 670
	Richard Day	Assistant Chief	135 Ridgeway Avenue	Santa Rosa 95401	707-542-1331	Box 670
Humboldt-Del Norte	Wm Harrington	State Forest Ranger	118 Fortuna Blvd.	Fortuna 95540	707-725-4413	Box 516
Lake-Napa	Byron Carniglia	State Forest Ranger	1572 Railroad Avenue	St. Helena 94574	707-963-3601	Box 73
Mendocino	Thomas Neil	State Forest Ranger	17501 N. Highway 101	Willits 95490	707-459-5561	
Sonoma	Frank Crossfield	State Forest Ranger	2560 W. College Ave.	Santa Rosa 95401	707-546-1544	
II. Sierra Cascade Headquarters	Gary Todd	Chief	1000 Cypress Street	Redding 96001	916-246-6311	Box 2238
	Ross Dunwoody	Assistant Chief	1000 Cypress Street	Redding 96001	916-246-6311	Box 2238
Butte	Robert Paulus	State Forest Ranger	176 Nelson Avenue	Oroville 95965	916-533-6365	
Lassen-Modoc	Jack Burke	State Forest Ranger	Highway 36	Susanville 96130	916-257-4171	
Nevada-Yuba-Placer	John Odgers	State Forest Ranger	13760 Lincoln Way	Auburn 95603	916-885-3722	
Shasta-Trinity	Howard Bromwell	State Forest Ranger	1050 Parkview Avenue	Redding 96001	916-243-1436	
Siskiyou	Richard Miralles	State Forest Ranger	Fair Lane Road	Yreka 96097	916-842-3516	Box 128
Tehama-Glenn	Robert Kersteins	State Forest Ranger	604 Antelope Blvd.	Red Bluff 96080	916-527-2213	Box 1210
IV. South Sierra Headquarters	Gervice Nash	Chief	1234 East Shaw Avenue	Fresno 93710	209-222-3714	
	Don Petersen	Assistant Chief	1234 East Shaw Avenue	Fresno 93710	209-222-3714	
Amador-El Dorado	Ralph Smith	State Forest Ranger	2840 Mt. Danaher Road	Camino 95709	916-644-2345	
Fresno-Kings	Carl Armstrong	State Forest Ranger	210 So. Academy Ave.	Sanger 93657	209-485-7500	
Madera-Mariposa	John Morrow	State Forest Ranger	5366 N. Highway 49	Mariposa 95338	209-966-3622	
Tulare	Raymond H. Banks	State Forest Ranger	1968 S. Lovers Lane	Visalia 93277	209-732-5954	
Tuolumne-Calaveras	James Taylor	State Forest Ranger	785 El Dorado St.	San Andreas 95249	209-754-3831	Star Rt. 1
V. Central Coast Headquarters	John Hastings	Chief	2221 Garden Road	Monterey 93940	408-372-4536	
	Richard Bawcom	Assistant Chief	2221 Garden Road	Monterey 93940	408-372-4536	
San Benito-Monterey	Thomas Perkins	State Forest Ranger	401 Canal Street	King City 93930	408-385-5412	
San Luis Obispos	Theodore Waddell	State Forest Ranger	Morro Road	San Luis Obispo 93401	805-543-4244	Box 151
San Mateo-Santa Cruz	Robert Voss	State Forest Ranger	6059 Highway 9	Felton 95018	408-335-5355	Drawer F-2
Santa Clara	Leroy Taylor	State Forest Ranger	15670 Monterey St.	Morgan Hill 95037	408-779-2121	
VI. Southern California Headquarters	Joseph C. Springer	Chief	2524 Mulberry Street	Riverside 92501	714-781-4140	Box 1067
	James Chambers	Assistant Chief	2524 Mulberry Street	Riverside 92501	714-781-4140	Box 1067
Orange	Carl Downs	State Forest Ranger	180 S. Water Street	Orange 92666	714-538-3551	Box 86
Owens Valley	Ivan Phillips	State Forest Ranger		Bishop 93514	714-387-2401	Rt. 2, Box 22L
Riverside	David Flake	State Forest Ranger	210 W. San Jacinto	Perris 92370	714-657-3183	Box 248
San Bernardino	Rex Griggs	State Forest Ranger	3800 Sierra Way	San Bernardino 92405	714-882-1227	
San Diego	James Dykes	State Forest Ranger	2249 Jamacha Road	El Cajon 92020	714-442-0874	
California Department of Forestry Fire Academy	James Simmons	State Forest Ranger		Ione 95640	209-274-2426	Rt. 1, Box 69

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areas located at an elevation above 6,000 feet MSL, except in the Tahoe Air Basin, are exempt from permitting requirements for all agricultural burning which includes outdoor fires for agriculture, pest control, forest management, range improvement, improvement of land for wildlife and game habitat, as well as in the raising of fowl or animals. Most burning on BLM lands will be for forest management or range improvement activity and therefore would be exempt to permitting requirements above 6,000 feet MSL. Below this level, a permit will probably be required for burning on BLM lands. Other special aspects of permitting requirements include the permission to burn between the period of January through May for range management, even on no-burn days if 50% of the land area has been chemically treated. In addition, BLM land planners can notify the CARB seven days in advance for a major burn at an altitude below 6,000 feet MSL. The agency will then provide a special forecast 48-hours prior to the burn and daily thereafter as a special service.

Once again, the CDF will serve as the designated agency for permitting for most BLM lands in California. Other points of contact for BLM land managers include the CARB for burn/no-burn decisions for land areas at altitudes below 6,000 feet MSL. In addition, close contact must also be maintainted with the NWS relative to fire weather forecasts such that all burning can be strictly controlled during dangerously dry periods. These are the key contacts. It is important to proceed with an attitude of cooperation with all agencies to insure safe outdoor burning as well as to limit the possible impacts on ambient air quality by the resultant smoke. BLM land managers will be required to keep a record of the amount of acreage and the tonnage of material burned daily as the APCD's will request this information in preparing their required quarterly reports to the CARB regarding burning permits.

Individual counties will prohibit such burning unless the appropriate permit from CDF or other designated agency has been obtained. In addition, the individual APCD's or county air pollution control officer may designate a particular day as a "burn day" or "no-burn day" dependent upon the meteorological conditions within his jurisdiction and time of year. Persons with the appropriate permits may commence their outdoor burning subject to the conditions of their permits on days designated "burn days". Individual county burning requirements are discussed below.

Open Burning*

Prohibits the maintenance of an open fire (i.e., outdoor burning unless specifically allowed by regulation. The language of the regulation and the exceptions which apply vary by APCD.

* Including provisions for agricultural, forest management and range improvement burning.

On permissive burn days, the Yolo-Solano APCD exempt the following fires:

1. A fire set or permitted by any public officer for the purpose of preventing a health hazard which cannot be abated by any other means, or for the instruction of industrial employees in the method of fighting fires.

2. For right of way clearing by a public entity or utility, or for levee, reservoir, and ditch maintenance when the material has been prepared by stacking, drying, or other methods to promote combustion as specified by the Air Pollution Control Officer (APCO).

3. Agricultural burning permitted by law.

On all days this rule does not apply to the following fires in the Yolo-Solano APCD:

1. A fire set or permitted by any public officer for the instruction of a public or industrial employees in the methods of fighting fire where a permit has been issued by the APCO, or backfires necessary to save life or valuable property.

2. Fires for recreational use and cooking of foods.

3. To abate fires pursuant to Chapter 2 of Part 1 of Division 12 of the California Health and Safety Code.

4. Fires not used for disposal of materials and which the APCO determines necessary and not to have significant air pollution effects.

5. Fires to burn empty sacks or containers which contain pesticides or other toxic substances.

The Yolo-Solano APCD further prohibit the use of open outdoor fires for the disposal of petroleum waste, demolition debris, construction debris, tires or other rubber materials, materials containing tar, or for metal salvage or burning of vehicle bodies.

The Bay Area APCD allows the following exceptions to the general prohibition of open fires.

1. Cooking and recreational fires.

2. Fires burning as safety flares or for the combustion of waste gases.

3. The use of flame cultivation which uses LPG or natural gas-fired burners designed and used to kill seedling grass and weeds in orchards, vineyards and field crops and the growth is such that the combustion will not continue without the burner.

4. Any fire demonstrated to emit under all operating conditions nothing but carbon dioxide, nitrogen oxides, or water vapor.

5. Agricultural fires allowed by the County Agricultural Commissioner for disease and pest prevention.

6. Fires allowed by public officials for prevention of fire hazards including the disposal of dangerous materials.

7. Fires for the instruction of public and industrial employees in fire fighting methods. (Each fire fighting agency may set one fire for the purpose of training volunteer fire fighters per quarter year on other than a permissive burn-day if the APCO is notified at least two weeks in advance.)

8. Agricultural fires permitted by the proper officer necessary to establish an agricultural crop in a location which formerly contained another type of agricultural crop or natural growth, during a period between October 1 and April 30.

9. Agricultural fires permitted by the proper officer necessary to maintain and continue the growing fruit and nut trees, vineyards and cane fruits, as a gainful occupation; and for the purpose of disposal of periodic prunings and attrition losses from fruit and nut trees, vineyards and cane fruits, during a period beginning December 1 and ending April 30.

10. Agricultural fires permitted by the proper officer for disposal of grain stubble from agricultural operations on which both grain and vegetable crops are harvested during the same calendar year and on which it is necessary to remove the grain stubble and straw before planting a field vegetable crop, during a period beginning June 1 and ending August 31.

11. Agricultural fires permitted by the proper officer necessary to maintain and continue growing of field crops as a gainful occupation and for the purpose of disposal of stubble and straw, during a period beginning September 1 and ending December 31.

12. Fires necessary to control the growth of vegetation in irrigation ditches and canals.

13. Fires for preventing or eliminating a flood.

14. Fires certified by the Department of Fish and Game and necessary for the improvement of lowland and marsh for wildlife and game habitat, during a period beginning February 1 and ending March 31, and a period beginning October 1 and ending October 31.

15. Fires necessary to remove wood and vegetation debris deposited by flood waters, for continuing or maintaining agriculture as a gainful occupation during a period between October 1 and May 31.

16. Range management fires permitted by the State Forester necessary to maintain and continue the grazing of animals as a gainful occupation and for range improvement and grazing, during a period between July 1 and April 30. Brush to be burned shall be treated at least six months prior to burn if determined to be technically feasible. Unwanted trees over six inches in diameter are to be felled and dried for a minimum of six months.

17. Forest management fires to remove debris and for forest management purposes during a period between November 1 and April 30.

All burning in the Bay Area APCD must be conducted only on permissive burn-days or with the permission of the APCO. Other conditions are: (1) no material or fuel is to be ignited nor any material or fuel added to any fire when the wind velocity is less than 5 miles per hour, or when the wind direction at the site causes the smoke to drift toward populated areas; (2) all piled material is to be dried a minimum of 60 days prior to ignition or demonstrated to contain less than 23 percent moisture on a dry basis; (3) material to be burned is not to contain more than 5 percent native soil on a weight basis; and (4) piled material in most cases is limited to a base area not to exceed 25 square yards and the height is to be at least 2/3 of the average width of the pile.

The North Coast Air Basin prohibits open fires for the disposal of rubber petroleum or plastic wastes, demolition debris, tires, tarpaper, wood waste, asphalt shingles, linoleum, cloth, household garbage or burning of automobile bodies, except for the following:

1. Cooking and recreational fires.

2. Fires for: (a) the prevention of a fire, health or safety hazard which cannot be abated by any other means; (b) training personnel in the methods of fire fighting; (c) backfires necessary to save life or valuable property.

3. Fires used in the operation of a solid waste dump for which a limited time extension has been granted by the California Air Resources Board.

The following open outdoor fires are permitted in the basin on permissive burn-days:

1. Agricultural operations for the growing of crops or raising of fowl or animals.

2. Range improvement to remove unwanted vegetation or establish an agricultural practice.

3. Forest management to remove forest debris.

4. Wildlife improvement to enhance wildlife or game habitat.

5. Disposal of approved combustibles from single or two-family dwellings on their premises. (Such burning is exempt from permissive burn-day notification except in the Humboldt Bay Air Basin and the Ukiah-Little Lake Air Basin.)

6. Right-of-way clearing by a public entity or utility.

7. Ditch, levee and reservoir maintenance.

Lake County prohibits outdoor fires for the purpose of disposal of burning of petroleum wastes, demolition debris, fires, trees, wood waste, or other combustible or flammable solid or liquid waste; or for metal salvage or burning of motor vehicle bodies. Open fires may be conducted for the following purposes:

1. Prevention of a fire hazard which cannot be abated by any other means on permissive burn-days.

2. The instruction of public and industrial employees in methods of fighting fire.

3. Backfires necessary to save life or valuable property.

4. Disposal of solid waste from single or two-family dwellings on its premises on burn-days.

5. Cooking and recreational fires.

6. Right-of-way clearing by a public entity or utility or for levee, reservoir, and ditch maintenance on burn-days.

7. For disposal of Russian thistle.

Agricultural burning, range improvement burning, and forest management burning require a permit from the U.S. Forest Service, the California Division of Forestry, or a County Fire Protection District. Range improvement and forest management burning may be conducted on no-burn days between January 1 to May 31.

The APCO in Lake County and the North Coast Air Basin may authorize by permit open fires for the purpose of disposing of agricultural wastes, or wood waste from trees, vines, bushes, or other wood debris free of non-wood materials in a mechanized burner such that no air contaminant is discharged into the atmosphere for a period of more than 30 minutes in any 8 hour period which is as dark or darker than No. 1 on the Ringelmann Chart, as published by the U.S. Bureau of Mines.

A permissive burn-day is any day on which a designated person or agency (i.e., California Air Resources Board, APCD) determines that certain specified burning is permitted. The primary criteria for determining a burn-day are meteorological conditions.

6.6 GLOSSARY OF TERMS

Air Pollution Control District	In California, the county regulatory body responsible for the administration of air pollution regulations.
Air Quality Related Values	Under the Prevention of Significant Deterioration Regulations for Class I areas, the effect of potential pollutant emissions on such variables of soils, vegetation and, most importantly, visibility must be reviewed.
Attainment Areas	The term attainment area means for any air pollutant an area which is shown by monitored data or which is calculated by air quality modeling to comply with any National Ambient Air Quality Standard for such a pollutant.
Baseline Concentration	The ambient concentration level reflecting actual air quality as of August 7, 1977 minus any contribution from major stationary sources and major modifications on which construction commenced on or after January 6, 1975.
Best Available Control Technology (BACT)	An emission limitation (including a visible emissions standard) based on the maximum degree of reduction for each pollutant subject to regulation under the Act which would be emitted from any proposed major stationary source or major modification which the Administrator, on a case by case basis, taking into account energy, environmental and economic impacts and other costs determined to be achievable for such source or modification through application of production processes or available methods, systems and techniques including fuel cleaning or treatment or innovative fuel combustion techniques for control of such pollutant. BACT must always be at least as stringent as the Applicable New Source Performance Standard.
Best Available Retrofit Technology (BART)	Same as Best Available Control Technology with specific application to existing sources.
Burn Day	A burn day is any day on which a designated person or agency determines that certain specified burning is allowed.
Class Designation	The designation of the country as either Class I, II or III under the rules for the Prevention of Significant Deterioration. Class I areas reflect the most stringent requirements while Class III areas are the most lenient.

Clean Air Act (CAA)	The body of air quality legislation promulgated 1955 in with Amendments in 1963, 1965, 1967, 1970, and 1977, and codified in 42USC740/et seq., which are designed to regulate the nations air quality for the purpose of protecting human health and welfare.
Clean Air Act Amendments of 1977	They represent the latest in a series of expanding regulatory requirements designed to protect the air quality resource in the United States. The Amendments of 1977 (PL95-190) introduced key concepts including the Prevention of Significant Deterioration, the use of Best Available Control Technology and the protection of ambient visibility levels.
Criteria Pollutants	That group of pollutants for which National Ambient Air Quality Standards have been promulgated based upon an analysis of the effects of such pollutants upon human health and welfare. Currently, SO_2, NO_x, CO, HC, TSP, lead and photochemical oxidants are criteria pollutants.
Designated Agency	The governmental agency with final authority relative to air quality regulations.
Federal Land Manager	Federal Land Manager means with respect to any lands in the United States, the Secretary of the Department with authority over such lands.
Increments	The maximum allowable increase in a specific pollutant concentration over and above existing "baseline concentrations" as specified in Section 163 of the CAA or as limited by the difference between Air Quality Standards and baseline concentrations for that pollutant.
Indian Governing Body	The term means the governing body of any tribe, band or group of Indians subject to the jurisdiction of the United States and recognized by the United States as possessing power of self government.
Lowest Achievable Emission Rate (LAER)	The emission control technology applicable to source located in a nonattainment area is established based upon the term Lowest Achievable Emission Rate. This term means that level of emissions which reflects the most stringent emission limitation that is contained in the Implementation Plan of any state or the most stringent emission limitation which is achieved in practice on such class or category of source which ever is more stringent.

Mandatory Class I Area	The term means Federal areas which may not be designated as other than Class I areas under the Clean Air Act Amendments of 1977. These areas are specified in Section 162(a) of the Act.
Modification	Any physical change in the method of operation or an addition to a stationary source, which increases the potential emission rate of any pollutant regulated under the Act by either 100 tons/year or more for any source category identified by the New Source Performance Standards or by 250 tons/year or more for any stationary source.
National Ambient Air Quality Standards (NAAQS)	The Clean Air Act Amendments of 1970 required that specific pollutant concentration levels be identified for the protection of human health (i.e., Primary Standard) and welfare (i.e., Secondary Standards) for each of the criteria pollutants. These specific pollutant levels comprise the National Ambient Air Quality Standards.
National Emissions Standards for Hazardous Air Pollutants (NESHAPS)	Standards promulgated for air pollutants for which no ambient air quality standard is applicable and which in the judgement of the Administrator cause or contribute to air pollution which may reasonably be anticipated to result in an increase in mortality or an increase in serious irreversible or incapacitating reversible illness.
New Source	Any new structure, building, facility, equipment, installation or operaiton which is located on one or more continuous or adjacent properties and which is owned or operated by the same person.
New Source Performance Standards (NSPS)	National Standards promulgated by the USEPA which set emissions limitations for standards of performance for each of 28 separate categories of stationary sources.
New Source Review	No major emitting facility on which construction is commenced after the date of the enactment of the Clean Air Act Amendments of 1977 may be constructed in any area unless the formal permit application process has been completed in accordance with regulations required by Section 165 of the Clean Air Act Amendments of 1977.

No Burn Day	A no burn day is any day on which a designated person or agency determines that certain specified burning is not permitted.
Nonattainment Areas	The term nonattainment area means, for any air pollutant, an area which is showed by monitored data or, which is calculated by air quality modeling, to exceed any National Ambient Air Quality Standard for such pollutant.
Offsets	Soruces locating in nonattainment areas, must obtain emission reductions form other existing sources in the region that more than offset the increase in emissions from the new source. Such offsets must produce a positive net air quality benefit resulting in reasonable further progress toward attainment of the applicable standard.
Permit Moratorium	The cessation of the air quality permitting process pending the resolultion of mandatory regulatory activity.
Potential Emissions	Potential Emissions refer to the maximum emission of pollutants in the absence of air pollutant control equipment.
Pre-Construction Review	No major emitting facility on which construction is commenced after the date of the enactment of the Clean Air Act Amendments of 1977 may be constructed in any area unless the formal permit application process has been completed in accordance with regulations required by Section 165 of the Clean Air Act Amendments of 1977.
Prevention of Significant Deterioration	Specific requirements contained in the Clean Air Act Amendments of 1977 (i.e. Part C, Sections 160 through 169) designed to protect the air quality resource in regions of the country where present baseline pollutant levels are below the National Ambient Air Quality Standards.
Primary Standards	Standards promulgated as part of the National Ambient Air Quality Standards which set pollutant levels which provide an adequate margin of safety for public health.
Reasonably Available Control Technology (RACT)	The least stringent in the control technology heirarchy applicable to existing sources which require a level of control necessary to insure compliance with existing emissions regulations.

Retrofitting	The installation of additional control technology on existing sources of air pollutants.
Secondary Standards	Standards promulgated as part of the National Ambient Air Quality Standards which specify levels which protect the human welfare from known or anticipated adverse effects associated with a pollutants presence in the ambient air.
State Implementation Plan (SIP)	The concept of State Implementation Plans was introduced in the 1970 Clean Air Act Amendments. There purpose is to insure that the NAAQS are met in all areas of the country and require a transportation control plan, emissions limits for specific categories for sources and permit rules for new or modified sources of pollutants.

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7. MONITORING RECOMMENDATIONS

7.1 GENERAL REQUIREMENTS

Possible alternatives for future land development of BLM lands within the Ukiah District may require the preparation of extensive environmental research reports and impact analyses. In light of this fact, it is important to isolate areas currently under BLM administration that lack substantial onsite data necessary for the preparation of air quality and meteorological analyses. Additionally, areas within the Ukiah District that require enhancement of the current existing data base must be identified so that transport and diffusion analyses can be accurately performed.

The ultimate objective is to be able to define air transport and dispersion characteristics and associated baseline ambient air quality levels within the Ukiah District. An accurate and current data base provides the means to achieve this objective and enhances credibility of regional environmental impact statements. It is of vital importance to all organizations concerned with future land development within the Ukiah District, that the most accurate and complete environmental impact statements be developed.

A review of the previous sections describing regional air quality, dispersion meteorology and baseline climatology for the Ukiah District indicates that certain areas lack the satisfactory historical data base necessary to provide a definitive characterization of these topical items which are essential in environmental analyses. Climatological data are generally adequate for all portions of the Ukiah District. Ambient air quality data are readily available for most areas of the district where there exist substantial population centers. These cities and communities are well distributed along the Pacific Coast. Detailed dispersion meteorological data are available at a few select locations throughout the district and represent the least resolved data base of all the major air quality components. Data are available to provide an assessment of regional dispersion for most of the Ukiah District; however, the extent of the current data base available for site-specific dispersion analyses on lands under BLM administration is generally not satisfactory.

Lands within the Ukiah District currently under BLM jurisdiction entail three basic geographical areas. As depicted in Figure 7.1-1, a majority of the BLM lands in the Ukiah District are located in the mountainous areas. A small portion of the BLM lands are located along the coast.

Alternative future land uses for these areas may include construction or expansion of energy related facilities, other commerical industrialization, recreation, agriculture, forestry and many others. The development of BLM administered lands for

7 MONITORING RECOMMENDATIONS

7.1 GENERAL REQUIREMENTS

The site circumstances and future land use alternatives at BLM lands within the Ukiah District may require the preparation of extensive environmental reports and impact analyses. In light of this fact, it is important to indicate areas currently under BLM jurisdiction that lack adequate baseline data necessary for the preparation of air quality and meteorological analyses. Additionally, areas within the Ukiah District that exhibit exceedances of the current existing (AQ) also need to be identified so that strategies and diffusion analyses can be given early definition.

The ultimate objective is to be able to define air resource and quality baselines and associated siting concerns in environmentally sensitive areas within the Ukiah District. In creating such current data inventories the needs to address data operations and enhanced credibility of regional environmental impact statements. It is of vital importance to all organizations concerned with future land development within the Ukiah District that the BLM generate the baseline environmental impact statements in this area.

A review of the previous sections describing regional air quality and baseline meteorology, the data on instrumentation for the Ukiah District, indicates that certain areas lack representative historical data sets. Such data are necessary to provide a definitive characterization of those physical items which are essential to environmental analyses. Climatological data are generally available for all portions of the Ukiah District. Ambient air quality data are readily available for most areas of the county where there exist large population centers. These cities are generally well distributed along the Pacific Coast. Meteorological dispersion/diffusion data are available at a few select locations throughout the district and represent the least reliable data base of all the major air quality components. These data are adequate to provide an assessment of regional dispersion for most of the Ukiah District. However, the extent of the current data base precludes the use of specific dispersion analyses on lands under BLM jurisdiction is generally not satisfactory.

Lands within the Ukiah District currently under BLM jurisdiction extend throughout several geographical areas. As depicted in Figure 1.1-1, a majority of the BLM lands in the Ukiah District are located in the mountainous areas. A small portion of the BLM lands are located along the coast.

Alternative future land uses for these areas may include construction or expansion of energy related facilities, other commercial industrialization, recreation, agriculture, forestry and many others. The development of BLM administered lands for

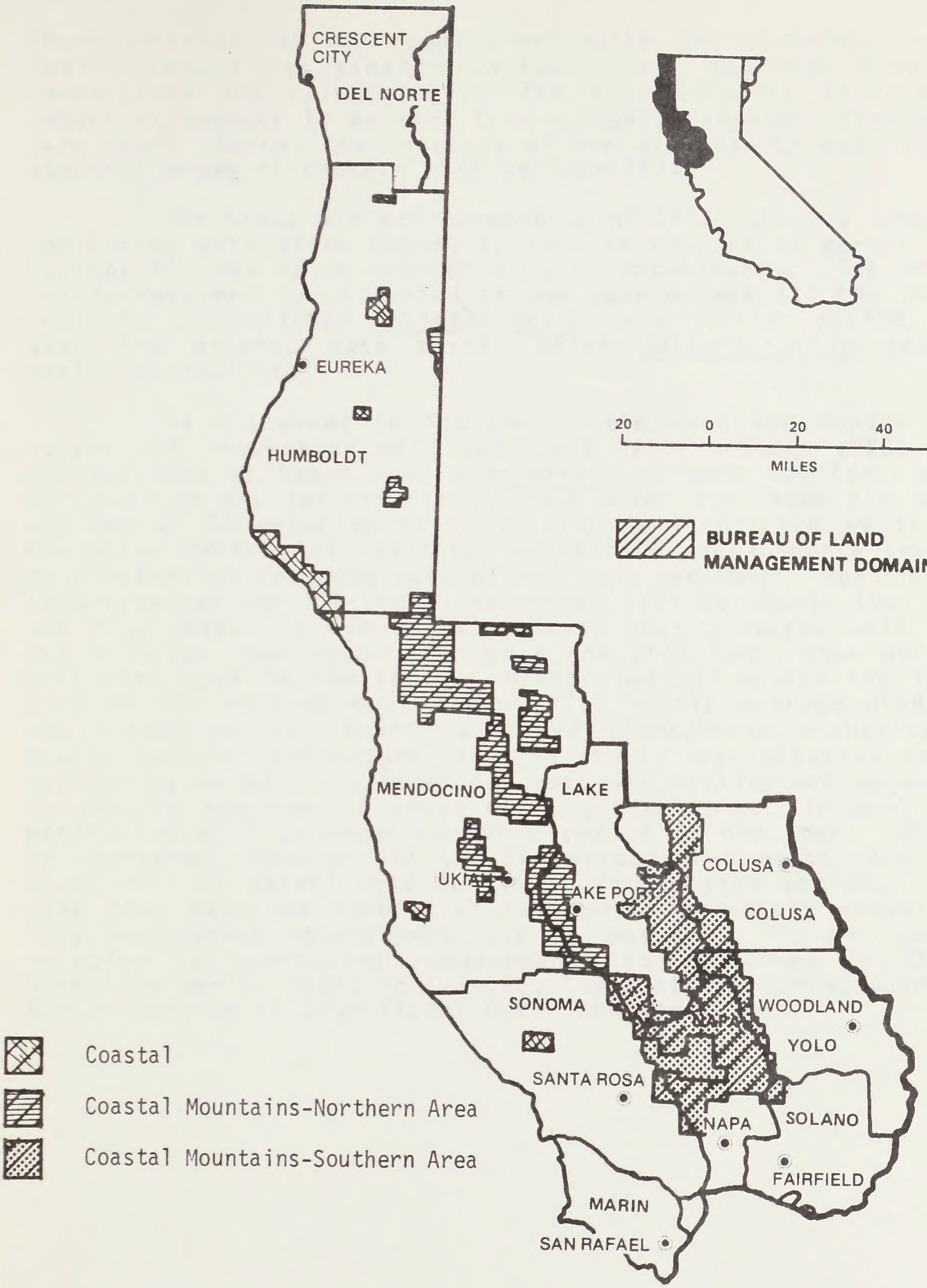


Figure 7.1-1
Categories of BLM Lands in the Ukiah District

these alternatives may require extensive and elaborate environmental impact assessments including air quality, dispersion meteorology and climatology. The most accurate environmental impact assessment is derived from a highly detailed site-specific data base. Hence, the adequacy of the air quality data base for specific areas of concern must be identified.

The Clean Air Act Amendments of 1977 required continuous monitoring data after August 7, 1978 in support of permit applications for new major sources of air contaminants. The monitoring is required for a period of one year unless (1) the analysis could be accomplished satisfactorily in a shorter period or (2) available offsite data exists which satisfactorily describes onsite conditions.

As discussed in Section 6, the need for monitoring in support of Prevention of Significant Deterioration (PSD) permit applications is based upon a potential to emit 100 tons or more per year of any pollutant regulated under the Clean Air Act for any one of 28 major emitting facilities identified by the Act. For other classes of industry, monitoring requirements are based on a potential emission rate of 250 tons per year. Monitoring is then required for TSP (total suspended particulates), SO_2, CO, O_3 and NO_2, unless it can be established that a source will exceed the emission requirement for only one pollutant, then only that pollutant need be monitored. Meteorological monitoring in support of the program must include (1) hourly average wind speed and direction, (2) hourly averaged atmospheric stability, (3) hourly surface temperature, and (4) hourly precipitation amounts. Monitoring at multiple sites for both air quality and meteorology is usually required in areas of rugged terrain. In most cases, monitoring will be required for a period of one year. This may be shortened, however, if the EPA agrees that worst case conditions will be established during a reduced time period. In the case that baseline conditions have been adequately established, this monitoring requirement may be waived. Further guidance relative to monitoring requirements is contained in the EPA Guideline Series OAQPS No 1.2-096, "Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD)."

7.2 INSTRUMENTATION

This section provides a brief review of instrumentation that is commonly used to monitor the various air quality and meteorological parameters. A summary of costs associated with the management and operation of monitoring programs is also provided.

7.2.1 General Requirements

The purchase of an instrument requires the consideration of two classes of requirements:

1. General Instrumentation
2. Specific Objectives

There are many instrumentation requirements that will obviously depend on the specific objectives of the study for which the instrument is needed. There are, however, a number of instrument requirements that should be considered before the purchase of any instrument. The purpose of this section is to describe these general requirements so that a buyer will be able to distinguish between the instrumentation attributes that are important, and those that are only "window dressing". The EPA may be contacted for futher guidance on instrumentation and methods of procedure.

<u>Reliability</u>

Reliability is possibly the most important criterion for an instrument in continous use. Regardless of how accurately an instrument is calibrated and read, it must be reliable to give reproducible results.

<u>Quality Control</u>

Quality control are those activities performed to insure that equipment is maintained and calibrated within specifications.

<u>Quality Assurance</u>

Quality assurance is the method which verifies that quality control activities are performed, e.g., adherence to schedule, documentation, double checks, etc.

<u>Accuracy</u>

Accuracy is defined as the closeness of the instrument output reading to the true value of the parameter. The qualifications of an accurate instrument are as follows:

1. It is properly calibrated under known conditions

2. It has characteristics that are unchanging with time

3. The reactions of the instrument (dynamic response) to changes in the measured parameter are known to within the limits of error requirements.

Precision

Precision is generally defined as the degree of closeness of a series of readings of an unchanging parameter. There often is confusion between the terms accuracy and precision. One way of clarifying their meanings is through the use of the "bulls eye" analogy. Figure 7.2-1 depicts this analogy.

Sensitivity

Sensitivity is defined as the smallest change in the measured variable that causes a detectable change in the output of the instrument.

Simplicity

The lack of instrumentation experience among most observers makes this attribute a must for most meteorological and air quality instrumentation. The qualifications of a simple instrument are as follows:

1. Operational adjustments of the instrument should be simple

2. A simply written Standard Operating Procedures (SOP) manual should accompany the instrument

3. Adjustments that are not intended to be made by the purchaser should require a special tool.

Durability

Obviously, an instrument should be durable enough to survive vibrations and shock encountered in transportation, rough handling, etc. A meteorological or air quality instrument, in addition, should be able to perform reliably in all seasons of the year, and in a smoggy and corrosive atmosphere.

Convenience

Convenience of operation is definitely a must for an operational instrument. As a general rule, an instrument that is simple to operate is also convenient to operate.

Other requirements such as time constants, damping ratio, etc. are objective oriented, and will be covered in a later section.

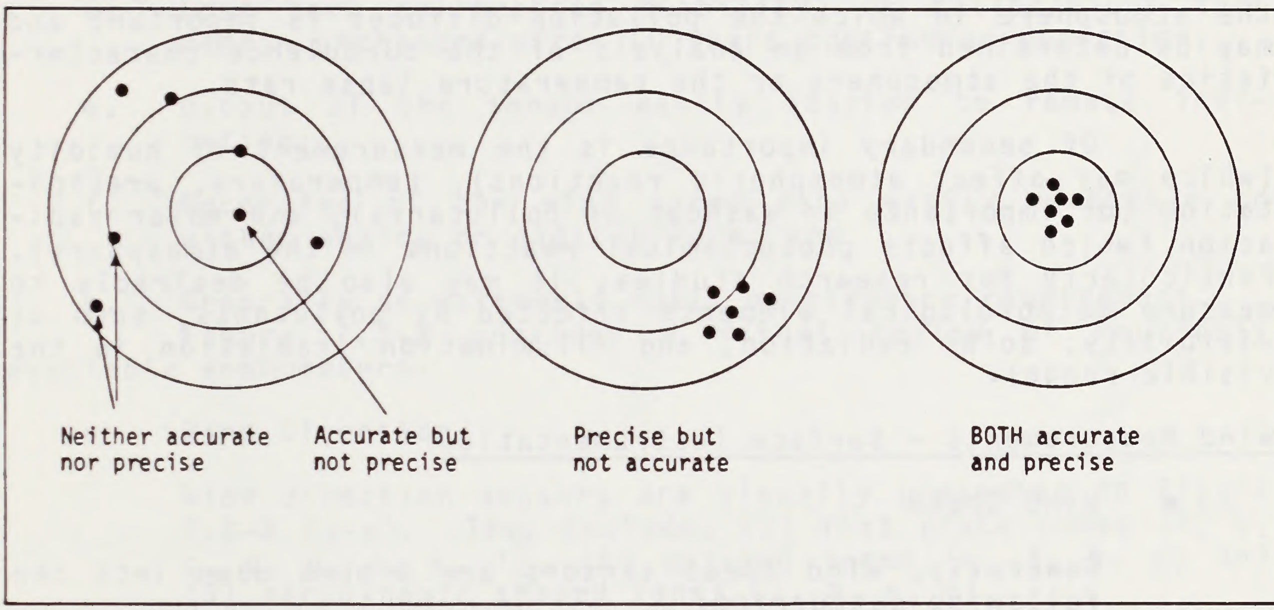


Figure 7.2-1
The Relationship Between
Instrument Accuracy and Precision

7.2.2 Meteorological Instruments

Measurement of atmospheric variables that affect the diffusion and transport of air pollutants is a necessity in nearly every air pollution investigation. Suitable measurements may be available from existing instrumentation at Weather Service city offices, airport stations, or from universities or industries with meteorological installations. Frequently, however, existing instrumentation does not give detailed enough measurements, is not representative of the area in question, or does not measure the variables desired (such as turbulence) and additional instruments must be operated.

Of primary importance in air pollution meteorology is the measurement of wind, including both velocity (direction and speed) and the turbulence. The stability of the lower layers of the atmosphere in which the pollution diffuses is important and may be determined from an analysis of the turbulence characteristics of the atmosphere or the temperature lapse rate.

Of secondary importance is the measurement of humidity (which may affect atmospheric reactions), temperature, precipitation (of importance in washout of pollutants), and solar radiation (which affects photochemical reactions in the atmosphere). Particularly for research studies, it may also be desirable to measure meteorological elements affected by pollutants, such as visibility, solar radiation, and illumination (radiation in the visible range).

<u>Wind Measurements - Surface Instrumentation</u>

- Wind Speed

  Generally, wind speed sensors are broken down into the following categories:

a. Rotational Anemometers
   1) Vertical Shaft
   2) Horizontal Shaft

b. Pressure Anemometers
   1) Flat Plate Type Anemometer
   2) Tube Type Anemometer

c. Bridled Cup Anemometer

d. Special Types
   1) Hot Wire Anemometer
   2) Sonic Anemometer
   3) Bivane
   4) Vertical/Horizontal (UVW) Anemometer

Pressure anemometers, hot wire and sonic anemometers have enjoyed extensive use in research type operations, but they all have disadvantages which have prohibited their use in operational type situations, such as air pollution surveys. The rotational type anemometers are the most common type of wind speed sensor in use today mainly because they are the only types that satisfy all of the following desirable operational features:

a. Essentially linear relationship between the sensor output and the wind speed;

b. Calibration unaffected by changes in atmospheric temperature, pressure or humidity;

c. Able to measure a wide range of wind speeds (<2 to 200 mph [.9 to 90 m/s]).

d. Long term calibration stability, or calibrations that remain unchanged after 10 years continuous operation;

e. Output of the sensor easily adapted to remote indication;

f. Recording of the wind speed data easily adaptable to either analog or digital form; and

g. Generally an extremely small maintenance requirement.

Figure 7.2-2 provides a visual review of routinely available anemometers.

- Wind Direction

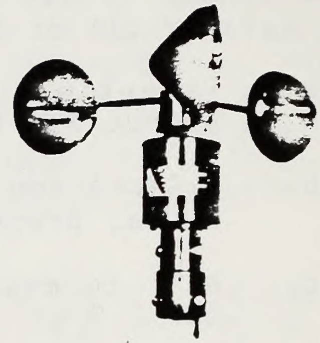
Wind direction sensors are visually presented in Figure 7.2-3 (a-p). They include; (1) flat plate vanes (a, b, c, d, g, i, k, l), (2) splayed vanes (e, f, h, p) and (3) aerodynamic shaped vanes (j, m, n, o).

The splayed vane of Figure 7.2-3 has, mainly because of its durability and reliability, found widespread use in its role as the main wind direction sensor for the National Weather Service. It should be noted that wind direction data obtained from the National Weather Service should be used only as an indication of average wind direction.

A bi-directional vane is designed to rotate around a vertical axis to measure the azimuth angle of the wind, as does a conventional wind vane. It also can move in the vertical to measure the elevation angle of the wind. Because the vertical motions of the atmosphere are frequently of a different character than the horizontal motions (anisotropic turbulence), measurement of both the horizontal and vertical motions are desirable. This is particularly true under stable conditions when the

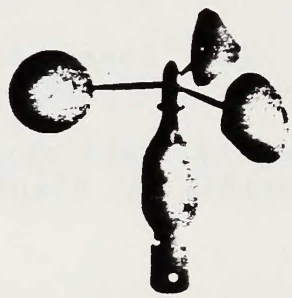
Climet Inst. Co. (a)

R.M. Young Co. (b)

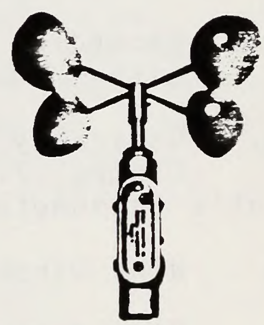


Belfort Inst. Co. (c)

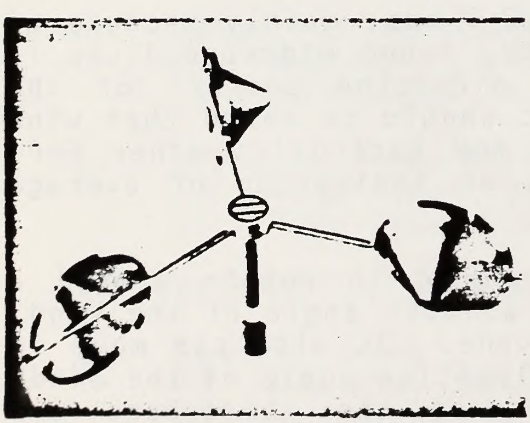
Henry J. Green Co. (d)



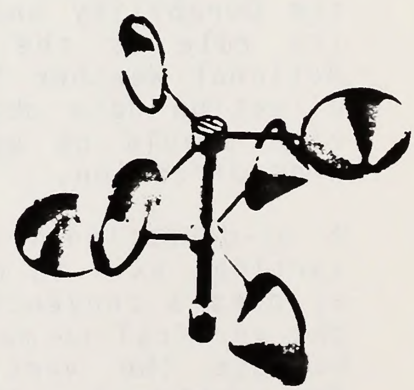
Electric Speed Indicator Co. (e)



Science Associates Inc. (f)



Teledyne-Geotech (Bkmn & Whtly) (g)



Teledyne-Geotech (Bkmn & Whtly) (h)

Figure 7.2-2
Cup Anemometers

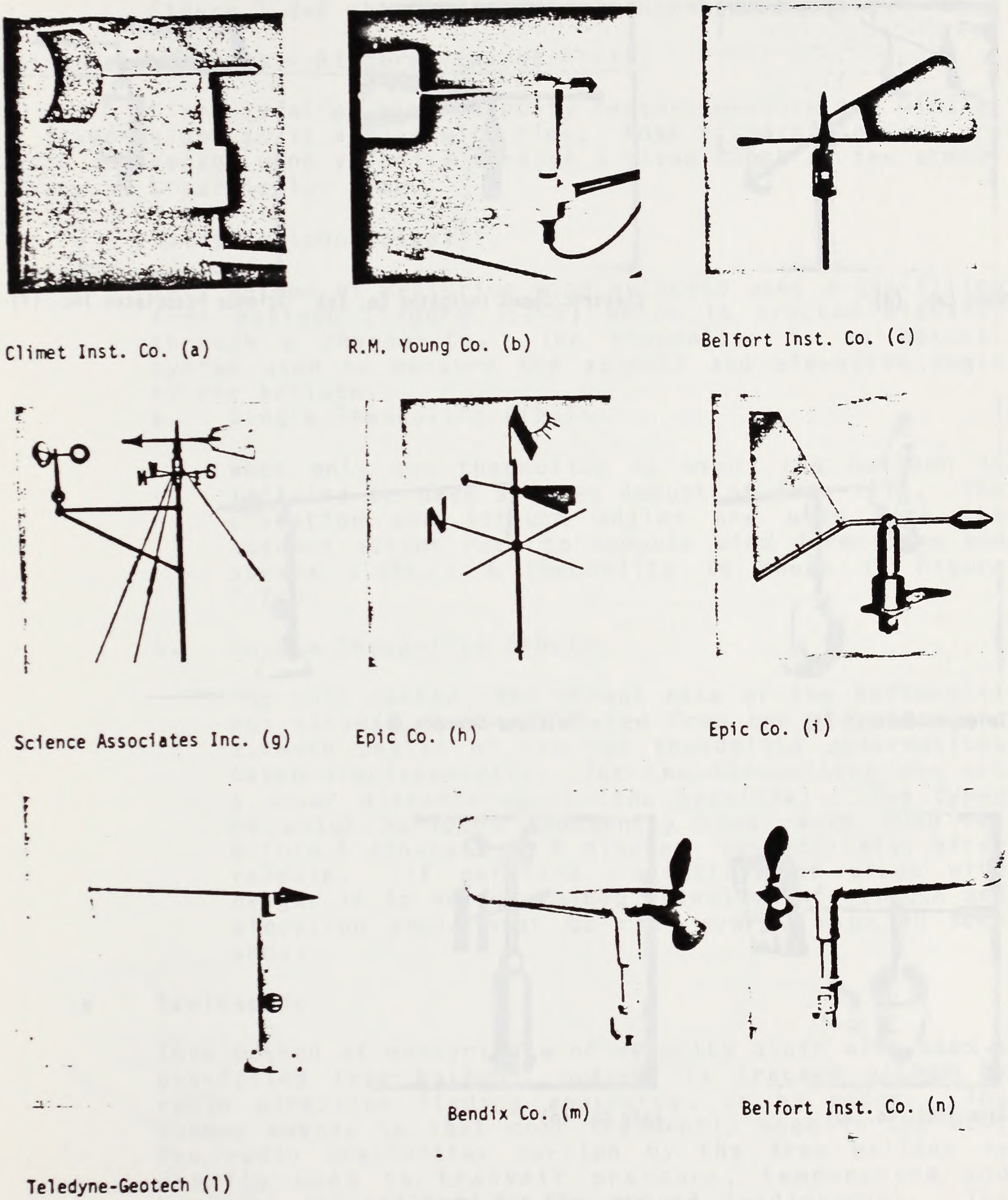
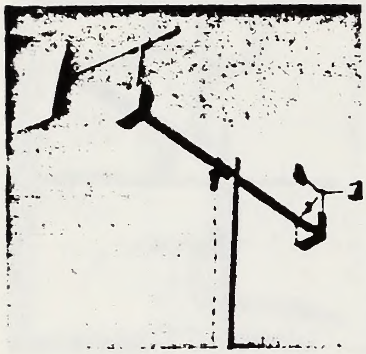
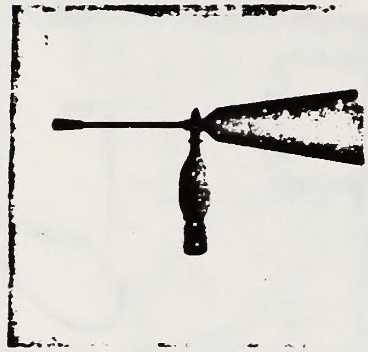


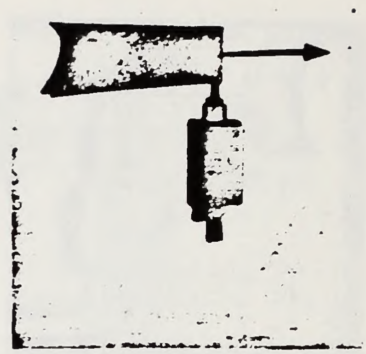
Figure 7.2-3
Wind Vanes



Wong Lab. (d)

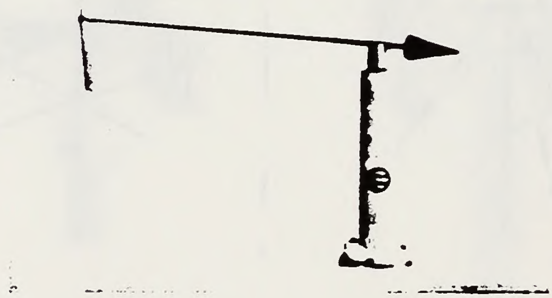


Electric Speed Indicator Co. (e)

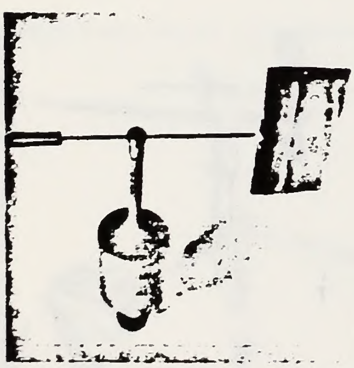


Science Associates Inc. (f)

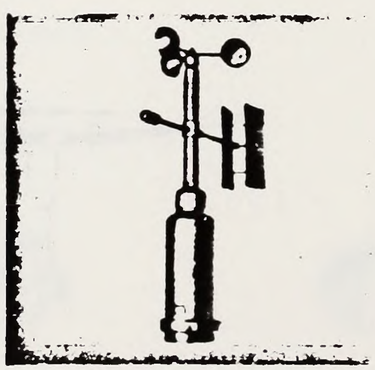
Teledyne-Geotech (j)



Teledyne-Geotech (k)



Raim Inst. Co. (o)



Epic Co. (p)

Figure 7.2-3 (Cont.)
Wind Vanes

vertical motion is almost absent, but horizontal changes in wind direction may be appreciable. Micro-potentiometers are usually used to produce an analog record of both angles. The total wind speed can be measured by replacing the counterweight with a propeller anemometer. Figure 7.2-4 shows two typical anemometer bivanes.

Wind Measurements - Airborne (Winds Aloft)

Fixed location wind velocity sensors measure the wind at a fixed height as it varies with time. Most airborne sensors are used to average wind velocity through a given depth of the atmosphere at a particular time.

- Pilot Balloon (pibal)

  This method of measuring wind velocity uses a gas-filled free balloon (Figure 7.2-5) which is tracked visually through a theodolite. The theodolite is an optical system used to measure the azimuth and elevation angle of the balloon.

  a. Single Theodolite Pibals

     When only one theodolite is used, the balloon is inflated to have a given amount of free lift. The elevation and azimuth angles are used with the assumed ascent rate to compute wind directions and speeds aloft. A theodolite is shown in Figure 7.2-6.

  b. Double Theodolite Pibals

     By this method, the ascent rate of the balloon is not assumed, but calculated from the elevation and azimuth angles of the two theodolite observations taken simultaneously. The two theodolites are set a known distance apart (the baseline). Two types of pilot balloons frequently used reach 3000 ft. within 5 minutes and 8 minutes, respectively, after release. If detailed structure of winds with height is to be determined, readings of azimuth and elevation angle must be read every 15 or 30 seconds.

- Rawinsonde

  This method of measuring wind velocity aloft also uses a gas-filled free balloon, but it is tracked either by radio direction finding apparatus, or by radar. The former method is that most frequently used in the U.S. The radio transmitter carried by the free balloon is usually used to transmit pressure, temperature and humidity information to the ground (radiosonde). The

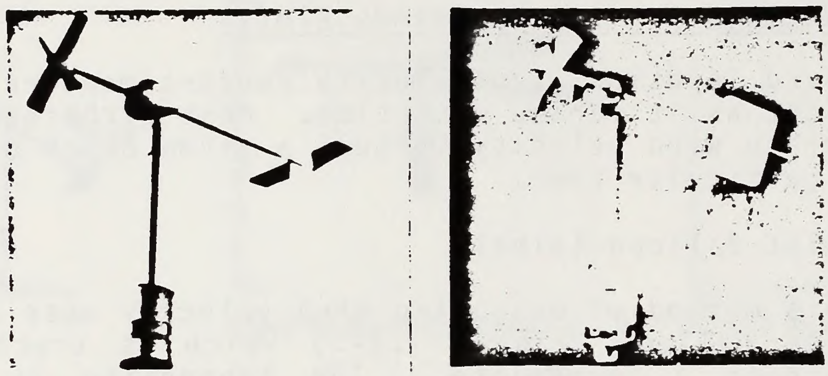


Figure 7.2-4 Anemometer Bivanes

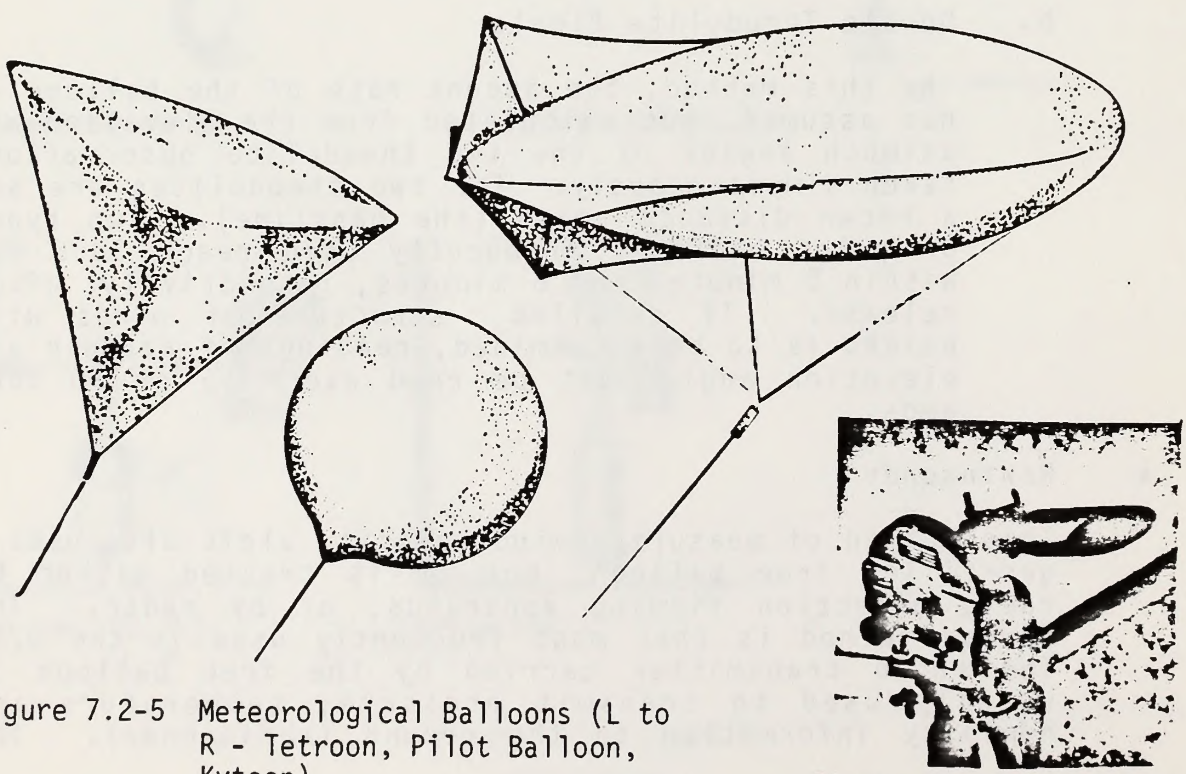


Figure 7.2-5 Meteorological Balloons (L to R - Tetroon, Pilot Balloon, Kytoon)

Figure 7.2-6 Theodolite

radio direction finding equipment determines the elevation angles and azimuth angles of the transmitter. The height is determined by evaluation of the temperature pressure sounding. Using radar, the slant range is available for determining height. Soundings taken with this type of equipment are made on a routine basis for supporting forecasting and aviation activities. The ascent rate of these balloons is on the order of 1000 feet/minute, so they do not yield as much detailed information on winds in the lowest part of the atmosphere as is desired for many air pollution meteorological purposes.

- Rocket Smoke Plumes

  A system using a cold propellant, recoverable rocket to emit a vertical smoke trail to an altitude of 1200 feet has been developed. This smoke trail is photographed simultaneously at short time intervals by two cameras 2000 feet from the launch site, at right angles to each other. The difference in position of the smoke trail from two successive photographs is a measure of one component (north-south for example) of the wind and can be determined at any number of heights from ground level to 1200 feet. Another similar system has been reported by Cooke (1962).

- Constant Level Balloons

  Unlike the previous airborne sensors for wind velocity which obtain average measurements through a vertical layer, constant level balloons are used to determine the trajectory or path of an air parcel during a given time interval. In order to maintain a constant altitude (more accurately to fly along a constant air density surface) the balloon must maintain a constant volume. A tetrahedron shaped balloon (tetroon) of mylar has been used for this purpose (Figure 7.2-5). These have been tracked visually and by radar (Angell and Pack, 1960).

Temperature Lapse Rate

The vertical structure of temperature gives an indication of the stability and turbulence of the atmosphere.

- Temperature Difference Measurements

  One method of estimating the vertical structure of temperature is by measuring the difference in temperature between sensors mounted at different heights. This, of course, gives an average condition between any two particular sensors.

• Balloon-borne Sensors

Temperature sensors may be lifted by either free or captive balloons. By these methods, temperature, not temperature difference, is measured.

1. Radiosonde

The method of radiosonde (radio-soundings) observations is used routinely for temperature, pressure and humidity soundings of the upper air. A free balloon carries the sensors and a radio transmitter aloft. Cycling from sensor to sensor is accomplished by means of an aneroid barometer, and consequently, is a function of pressure. Observations are normally made twice daily at 0000 GMT and 1200 GMT at approximately 70 stations in the contiguous U.S. The ascent rate of the balloon is about 1000 ft/minute. Generally only 4 to 6 temperature readings are recorded within the lower 3000 feet, so the vertical temperature information is not too detailed, but it is still of considerable use when more detailed information is not available.

2. T-Sonde

This system consists of a temperature sensor and radio transmitter which is carried aloft by a free rising balloon. The main difference between this system and the radiosonde system is that only temperature is measured. Ten to twelve measurements are taken within the lower 3000 feet of the atmosphere, thus giving a more detailed structure of temperature with height.

3. Tethered Kite Balloon

Using a captive balloon system to make vertical temperature measurements has the advantages of both a complete recovery of all components of the system, and as detailed a temperature sounding as is desired may be made by controlling the level of the sensor. A balloon having fins is much easier to control and gives greater lift in slight winds than a spherical balloon (see Figure 7.2-5). Most kite balloons can be used in winds less than 15 knots and for air pollution meteorology purposes, these light wind periods are of greatest interest. Because of hazards to aircraft, prior permission from the FAA is required for flights exceeding 500 feet above ground and several methods of relaying the observation to the ground have been used.

- Aircraft Borne Sensors

  In some cases, light aircraft or helicopters have been used for obtaining temperature lapse rate measurements. Although there are complete systems commercially available for this metod of temperature lapse rate measurement, one can use standard temperature sensors (thermisters, resistence thermometers, etc.) and recorders, as long as exposure guidelines are followed.

Precipitation

Because large particles and water soluble gases may be removed from the atmosphere by falling precipitation, measurements of this element may be needed. Chemical or radioactive analysis of rainwater may also be desired.

- Standard Rain Gauge

  The standard rain gauge consists of a metal funnel 8 inches in diameter, a measuring tube having 1/10 the cross-sectional area of the funnel, and a large container 8 inches in diameter (Figure 7.2-7). Normally, precipitation is funneled into the measuring tube and the depth of water in the tube is measured using a dip stick having a special scale (because of the reduction in area). Measurements with this instrument, because they are made manually, yield only accumulated amount since the last measurement.

Humidity

Because of its influence upon certain chemical reactions in the atmosphere and its influence upon visibility, it may be desirable to measure humidity in connection with an air pollution investigation. Also, some air pollutants affect receptors differently with different humidities, so measurement may be important in this respect.

- Hygrothermograph

  This instrument measures both temperature and humidity by activating pen arms to give a continuous record of each element on a strip chart. The chart generally can be used for 7 days. The humidity sensor generally uses human hairs which lengthen as relative humidity increases and shorten with humidity decreases. Temperature measurements are usually made with a bourdon tube which is a curved metal tube containing an organic liquid. The system changes curvature with changes in temperature, activating the pen arm. A hygrothermograph is shown in Figure 7.2-8.

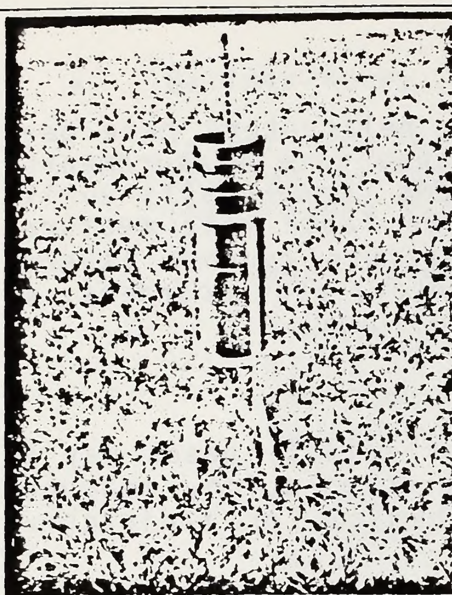


Figure 7.2-7 - Standard Rain Guage

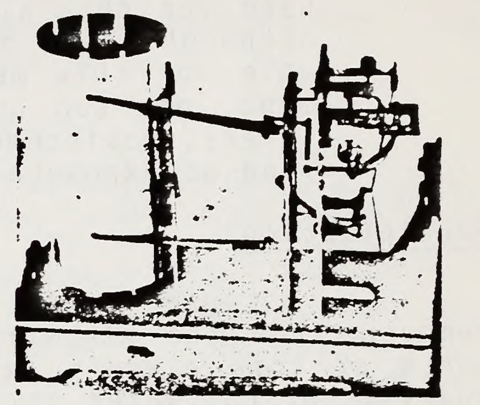


Figure 7.2-8 - Hygrothermograph

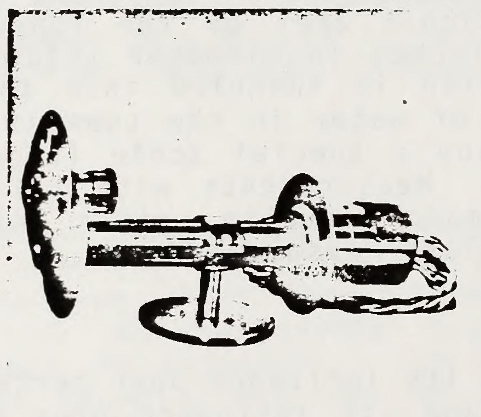


Figure 7.2-10 - Pyrheliometer

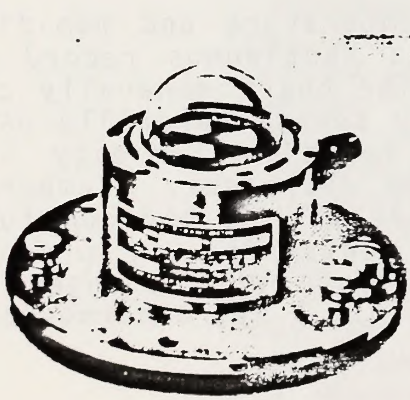


Figure 7.2-9

"Black and White" Pyranometer

Figure 7.2-11 - Equatorial Mount

• Psychrometers

Humidity measurement by a psychrometer involves obtaining a dry bulb temperature and a wet bulb temperature from a matched set of thermometers. One thermometer bulb (wet bulb) is covered with a muslin wick moistened with distilled water. There must be enough air motion to cause cooling of the wet bulb due to evaporation of the water on the wick. To obtain this a motor driven fan may be used to draw air at a steady rate past the moistened wick while a reading is taken. A sling psychrometer has both thermometers mounted on a frame which is whirled through the air to cause cooling by evaporation. Relative humidity is then determined from the dry and wet bulb readings through the use of tables. Continuous measurements of humidity, however, can not be obtained using psychrometers.

Radiation

The influence of the sun's radiation upon the turbulence of the atmosphere and upon certain photochemical reactions is sufficient to make measurements of radiation quite important. In addition, radiation may be reduced due to particulate pollution in the atmosphere. Particularly for research purposes, it may be desirable to measure this effect by comparisons between urban and non-urban stations with similar instruments.

• Total Radiation

The direct radiation from the sun plus the diffuse radiation from the sky may be measured by pyranometers. These instruments are mounted so that the sensor is horizontal and can receive the radiation throughout the hemisphere defined by the horizon. The instrument illustrated in Figure 7.2-9 is of this type.

• Direct Solar Radiation

The direct solar radiation may be measured continuously by using the pyrheliometer shown in Figure 7.2-10 mounted upon an equatorial mount (Figure 7.2-11) to keep it pointed toward the sun. By using filters, different spectral regions of radiation may be determined.

• Net Radiation

The difference between the total incoming (solar plus sky) radiation and the outgoing terrestial radiation may be useful in determining the stability, and hence, the turbulent character of the lowest portion of the atmosphere. A net radiometer serves this purpose and is shown in Figure 7.2-12.

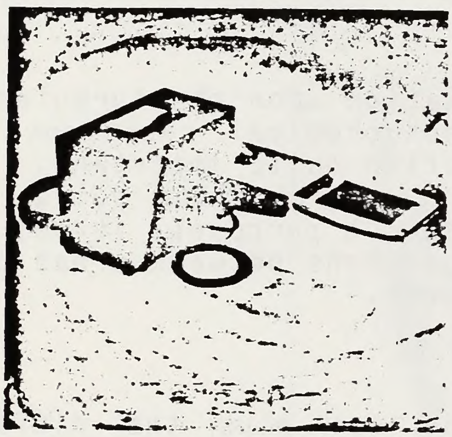


Figure 7.2-12
Net Radiometer

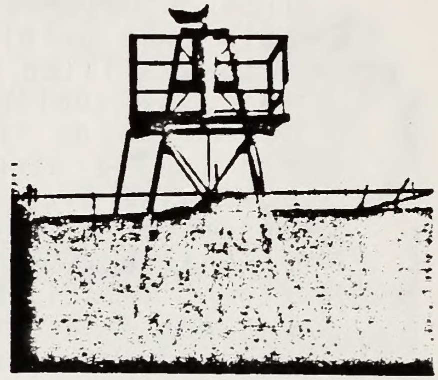


Figure 7.2-13
Transmissometer Detector

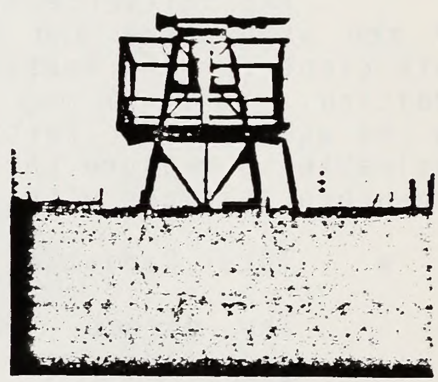


Figure 7.2-14
Transmissometer Receiver

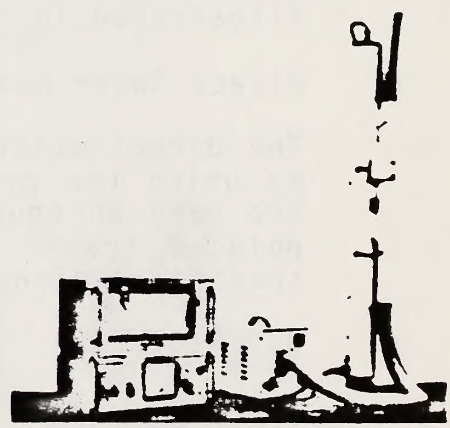


Figure 7.2-15
Integrating Nephelometer

Visibility

Visibility, in addition to being affected by precipitation, is affected by humidity and air pollution. Frequently, visibility is estimated by a human observer. An instrument to measure visibility, called a transmissometer, measures the transmission of light over a fixed baseline, usually on the order of 500 to 700 feet. An intense light source from the projector is focused on a photocell in the detector. The amount of light reaching the photocell over the constant baseline distance is assumed to be proportional to visibility. The transmissometer is restricted to estimating visibility in one direction only.

A transmissometer is also limited in that the light transmission it detects is affected mainly by liquid droplets in the air. It does not detect, to any great efficiency, the particulate matter in the atmosphere. The projector is shown in Figure 7.2-13 and the detector in Figure 7.2-14. A relatively new instrument, called a nephelometer, has been developed which measures the amount of light scattered by impurities, (mainly dust) and thus indicates visibility as it is affected by particulate matter in the atmosphere. It provides for continuous output, operating day or night, rain or shine and is relatively easy to calibrate. It is limited, however, in that measurements may be taken only at the instrument location. An integrating nephelometer is shown in Figure 7.2-15.

Another instrument used to determine visibility is the Vista Ranger (telephotometer), which provides radiance values of a target and the sky, contrast transmittance and data regarding target chromaticity. In other words, it is a telescope type instrument which looks at the sky and a target (such as a mountain peak) and measures the brightness contrast between the two and transmits information on the true color of what is seen. Measurements can be made over long path lengths (tens of Km) and provide quantitative and continuous output. The Vista Ranger, however, can be used only during daytime and readings are more accurate during times of higher sun angle and relatively clear skies.

7.2.3 Air Quality Instruments

The following paragraphs discuss sampling techniques for the measurement of the criteria pollutants TSP, SO_2, NO_2, CO, O_3 and non-methane (unreactive) hydrocarbons (NMHC). Sampling for more sophisticated pollutant species (e.g., sulfates, organic compounds, etc.) is beyond the realm of the discussion and reference is made to the bibliography for a more detailed discussion.

7.2.3.1 Particulates

Particulate pollutants are divided generally into dust that settles in air and dust that remains suspended as an aerosol. The physical consideration determining the class into which a particle falls is the particle diameter.

As a matter of working definition, particles larger than 10 inch diameter are usually thought of as "settleable" while those of a smaller diameter are referred to as "suspended".

Instruments designed to collect either class of particulates are ordinarily chemically passive physical collectors whose function is merely to permit measurement of the collected material without regard to the composition. Generally, the particulates encountered include various mineral dusts (i.e. metallic oxides, sand, carbon particles, flyash fibers and pollen). These particulates can be collected using equipment based on one or more of the following principles.

Dust Sampling by Gravity Settling (Dustfall)

Particles generally larger than 10 in diameter, which are known to settle from air and collect on horizontal surfaces, can be sampled merely by placing an open container in an outdoor area that is free from overhead obstructions. These collectors are ordinarily constructed of polyethylene, glass, or stainless steel, since the inside walls must be inert to atmospheric oxidative flaking, which would contribute to sample weight. In addition, identical dustfall containers should be employed in the same sampling network or where a comparison of results will be made. Figure 7.2-16 presents a simple dustfall collector.

In sampling rather large areas, such as entire communities, it is common to employ at least one dustfall container for every 10 square miles. On the other hand, when dustfall sampling is intended to measure the effect of a given industry or industrial complex, containers may be placed as close as a few hundred feet apart.

This basic working principal is the foundation for the atmospheric deposition station located in the Ukiah District. There are 40 to 60 similar stations nationwide measuring the following elements: SO_4^{-2}, NO_3^{-}, PO_4^{-3}, CO, NH_4, K^{+}, Na^{+}, Ca^{++}, Mg^{++}, and pH including total and free acidity and alkalinity and electrical conductivity. The objectives of this program are to measure atmospheric deposition, through precipitation and particulate settling, identifying spatial and temporal trends, to evaluate the importance of natural phenomena (volcanos, soil erosion, etc.) and human activities (power plants, industrial emissions, etc.) as they contribute to the total atmospheric deposition and finally, to research the effect these elements will have on activities such as agricultural, forest, range, fisheries and wildlife management.

Dust Sampling by High-Volume Filtration (The High Volume Sampler)

The high-volume (hi-vol) sampler (see Figure 7.2-17) employs the sloping roof of the shelter as a means for causing air entering the sampler under the eaves of the roof to change

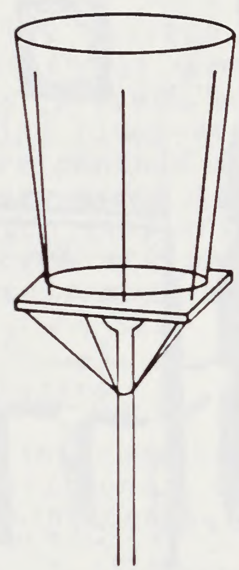


Figure 7.2-16

Simple Dustfall Collector

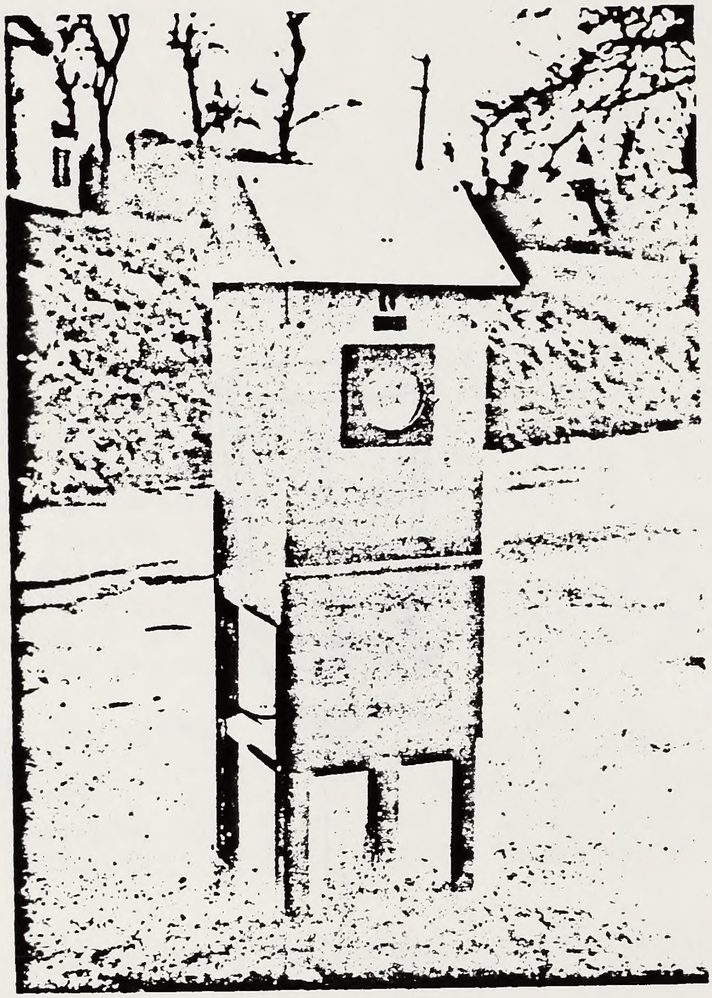


Figure 7.2-17
High Volume (hi-vol) Air Sampler

direction at least 90^0 before entering the horizontal filter. Particles that remain entrained in the air sample prior to horizontal filtration have, in so doing, satisfied the definition of truly suspended dust or dust that is not subject to settling under the influence of gravitational force.

The hi-vol is a vacuum cleaner-type motor that is used to draw sample air through a filter area. The filter most frequently employed is the 8 X 10 inch mat, which allows collection of an air sample at a rate from 40 to 60 cubic feet per minute (cfm) over a normal sampling period of 24 hours. These conditions permit the sampling of from 58,000 to 86,000 ft^3 of ambient air, with consequent extraction of about 1/2 gram of suspended particulate (aerosol). This provides quite a substantial weight of sample, which greatly simplifies subsequent chemical or physical analysis.

The motor is usually started and stopped by a simple clock timer, and the duration of sampling is measured by an elapsed time meter that is placed in series with the Hi-Vol motor. Starting and finishing times are at the discretion of the operator, although the EPA recommends starting and finishing from midnight to midnight--24 hours every sixth day. The National Air Sampling Network operates such samplers over the entire country. On the other hand, short-term studies to determine day-to-day variation in particulate levels may require continuous daily 24-hour sampling.

7.2.3.2 Continuous Gas Analyzers

In general, these instruments are based on one of the following principles of operation: colorimetry, atomic or molecular absorption, chemiluminescence, conductivity, coulometry, or combustion.

In the past, colorimetric instructions have been used with varying degrees of success to monitor air by adapting classical color-forming reactions to such plumbing and electronics as were required to produce continuous recorded data. More recently, however, the realm of solid-state physics has produced gas-sensing equipment that respond to physical rather than chemical properties at even the lowest levels of gaseous air contaminants.

Therefore, emphasis is placed on the more recent physical instrumentation for the individual air contaminants. Future development in continuous air monitoring systems will probably be along the lines of physics rather than solution or chemical measurement.

<u>Carbon Monoxide</u>

Automated continuous methods for CO include applications of gas chromatography, nondispersive infrared absorption, catalytic oxidation, and displacement of Hg from HgO to produce mercury vapor.

The most commonly used instruments for CO measurement are those which use the principle of nondispersive infrared, employing either a long path (40 in) or, more recently, a 10 cm (0.39 in) path of infrared radiation.

These analyzers depend on the characteristic energy of absorption of the CO molecule at not only its absorption wavelength maximum of 4.6 but also at a number of equally specific lines ranging from 2 to 15 , which together differentiate CO from such interferences as CO_2, H_2O, SO_2 and NO_2.

As shown in Figure 7.2-18, these instruments employ a heated filament as the source of radiation, a chopper to alternate radiation between the sample and reference cells, a sample cell (usually copper or brass), a reference cell of the same material, and a detector.

Sulfur Dioxide (SO_2)

Among the earliest applications of continuous analyzers to ambient air monitoring were those involving measurement of SO_2. Both continuous and intermittent (sequential) sampling methods have been employed. These often made use of the colorimetric method of West and Gaeke. The West-Gaeke method was first adopted as the approved reference method by the National Air Pollution Control Association (NAPCA, 1969), before being replaced by the EPA colorimetric method.

For the past several years, the monitoring of sources such as kraft paper mills and oil refineries, whose emissions require a continuous total sulfur analyzer, has been accomplished by means of a total combined-sulfur flame photometer.

In this analyzer, sample air is admitted into a hydrogen-rich air flame. Specificity to sulfur arises from the use of a narrowband interference filter that shields the photomultiplier tube detector from all but the 394 m emission energy of flame-excited sulfur atoms.

Nitrogen Dioxide (NO_2)

Traditionally, continuous analyzers for NO_2 have employed the Griess-Saltzman modified colorimetric method. Recently, several continuous NO_2-measuring instruments operating on the principle of chemiluminescence have been marketed. Here, a photomultiplier detector is used to measure the luminescence produced in the gas phase reaction between ozone and NO.

This method directly measures NO rather than NO_2. It is mentioned here because it forms the basis for a reliable differential measurement of NO_2 through the use of a reducing medium such as stainless steel at 230^{o}C, to convert NO_2 to NO. Subsequent reaction of NO, thus formed, with ozone produces chemiluminescence equivalent to NO_x, where NO_2 = NO - NO. The sensitivity of this method is reported as 0.01 ppm. To date, sufficient

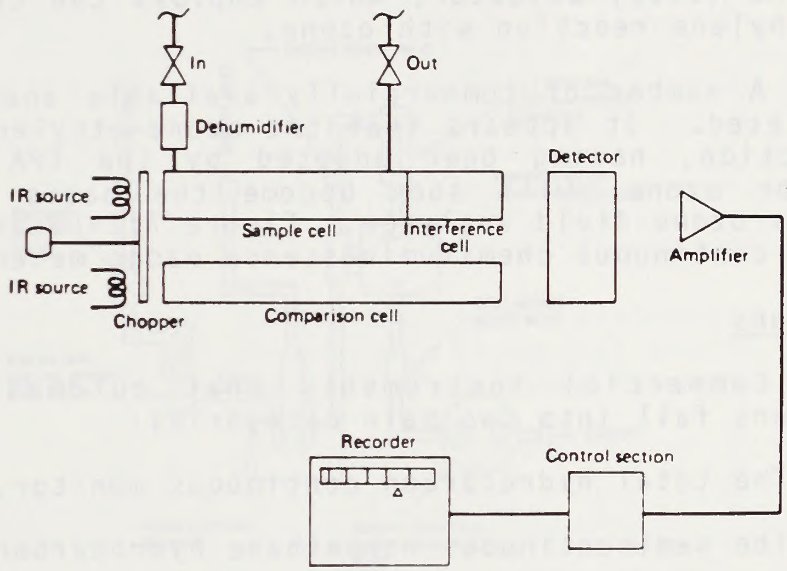


Figure 7.2-18
Diagram of Nondispersive Infrared Analyzer

field experience has been obtained to indicate the overall reliability of the instrument over long periods of operation.

Ozone

The first chemiluminescence approach to a specific ozone determination probably was developed by Regener (1960) Regener found that, when air containing ozone contacts the surface of a plate prepared by absorbing rhodamine B on silica gel, a luminescence is produced from the chemical reaction. The intensity of the luminescence is proporational to the concentration of ozone present to concentrations as low as 0.001 ppm.

Regener's detector was found to be subject to a number of interferences, such as NO_2. It was soon followed by the Nederbracht (1965) detector, which employs the chemiluminescence of the ethylene reaction with ozone.

A number of commercially available analyzers have now been marketed. It appears that the ozone-ethylene chemiluminescent reaction, having been adopted by the EPA as a standard method for ozone, will soon become the basis for the common continuous ozone field analyzer. Figure 7.2-19 presents a schematic of a continuous chemiluminescence ozone meter.

Hydrocarbons

Commercial instruments that automatically measure hydrocarbons fall into two main categories:

1. The total hydrocarbon continuous monitor, and

2. The semicontinuous nonmethane hydrocarbon monitor.

Briefly, automatic monitoring of hydrocarbon levels depends on the fact that most organic compounds easily pyrolyze when introduced into an air-hydrogen flame. This pyrolysis produces ions that are collected either by the metal of the flame jet itself (charged negative) or by a cylindrical collecting grid (positively charged) that surrounds the flame. The sensitivity to organic materials varies slightly depending on the number and kind of ions. As a general rule, however, detector response is in proportion to the number of carbon atoms in the chain of the organic molecule. Thus, propane (three carbon atoms) gives roughly three times the intensity of response as does methane, and so on.

This "nonselectivity" is both an advantage and a disadvantage, depending on the information expected from the air analysis. Nonselectivity toward hydrocarbons, but selectiviity in the sense that other compounds do not cause response, provides this continuous instrument with the capability of measuring the whole general class of organic compounds without concern for interference. When the instrument response is calibrated using

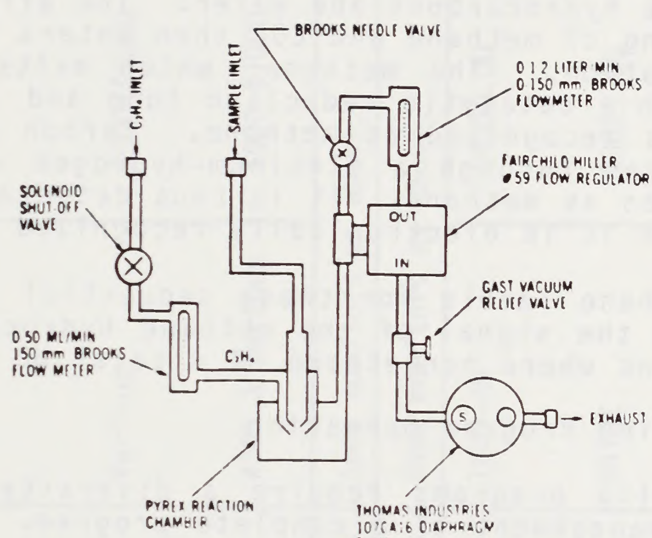


Figure 7.2-19

Diagram of Air-Ethylene System for

Continuous Chemiluminescent Ozone Meter

methane, the continuous strip chart readout is then a record of the real-time variation in ambient hydrocarbons as though they were 100% methane.

The Federal ambient air quality standard of 0.24 ppm (6:00 to 9:00 a.m.) average for nonmethane hydrocarbons necessitates the selective measurement of this class of compounds in preference to total hydrocarbons, especially when elevated levels of ozone are either known or suspected.

This analysis is accomplished by a differential measurement using the following procedure. First, small measured volumes of air are delivered intermittently (4 to 12 times/hr) to a flame ionization detector to measure total hydrocarbons. Following this measurement, another similar sample volume is admitted into a stripper column, which removes the relatively heavy non-methane hydrocarbons and water. The effluent from this column, consisting of methane and CO, then enters a gas chromatograph for separation. The methane, which exits first, passes unchanged through a catalytic reduction tube and into the detector, where it is recognized as methane. Carbon monoxide, which exits next, passes through a platinum-hydrogen reducing atmosphere, and emerges as methane. It is thus detectable by the ionizing flame where it is electronically recognized as CO.

Nonmethane levels for these sequential samples results from subtracting the signal of the methane hydrocarbons from the total hydrocarbons where nonmethane HC = total HC - methane HC.

7.2.4 Monitoring Program Operation

Monitoring programs require a diversity of skills for the successful management of a complete program. Key components of a monitoring program include:

- Site Selection
- System Design
- Equipment Selection and Purchase
- Initial Calibration and Installation
- Onsite Surveillance, Maintenance and Repair
- Quarterly Calibration
- Data Handling, Reduction, Summarization and Analysis
- Quality Assurance
- Report Preparation

The costs associated with air quality and meteorological monitoring programs can be enormous. Therefore, it is important to isolate the specific data requirements necessary for a particular study area.

Tables 7.2-1 and 7.2-2 recommend various types of air monitoring and meteorological instrumentation that can provide reliable data necessary for air quality/meteorological analyses.

Table 7.2-1

Summary of Air Quality Monitoring Equipment

Parameter	Manufacturer or Source	Model	Cost	Instrument Type and Comments
Total Suspended Particulates	General Metal Works, Inc. 8368 Bridgetown Rd. Cleves, Ohio 45002	Various	\$500→\$1000	High-Volume Sampler. Options include flow control, timer/programmer, particle sizing, calibration kit.
TSP	Misco Scientific	Various	\$500→\$1000	High-Volume Sampler. Similar options. Special designs available.
TSP	Sierra Instruments	#305 & various	\$500→\$1000	High-Volume Sampler. Similar options.
Lead	Chemical analysis of TSP filters.	Same monitors as above.		
Sulfates	Chemical analysis of TSP filters.	Same monitors as above.		
Ozone	Dasibi Environmental Corp. 616 E. Colorado St. Glendale, CA. 91205	1003-AH	\$4000.00	Chemiluminescent Analyzer. Probably the best, UV absorption priniciple.
Ozone	Monitor Labs, Inc. 4202 Sorrento Valley Blvd. San Diego, CA. 92121	8410E	\$3025.00	Chemiluminescent Analyzer.
Ozone	Meloy Labs, Inc. 6715 Electronic Dr. Springfield, VA. 22151	OA 325-2R	\$3130.00	Chemiluminescent Analyzer.
Ozone	Bendix P. O. Drawer 831 Lewisburg, W. Va. 24901	8002	\$3950.00	Chemiluminescent Analyzer.
Ozone	Beckman Instruments, Inc. 2500 Harbor Blvd. Fullerton, CA. 92634	950 A	\$3645.00	Chemiluminescent Analyzer.

Table 7.2-1

Summary of Air Quality Monitoring Equipment

(Continued)

Parameter	Manufacturer or Source	Model	Cost	Instrument Type and Comments
SO_2	TECO (Thermo Electron Corp.) 108 South Street Hopkinton, MA. 01748	43	$6850.00	Pulsed Fluorescent Analyzer
SO_2	Monitor Labs	8450E	$4900.00	Flame Photometric Detection (FPD) Analyzer
SO_2	Meloy Labs	SA 285-E	$4950.00	FPD Analyzer (4 linear ranges)
SO_2	Bendix	8300	$5885.00	FPD Analyzer
SO_2	Beckman	953	$6750.00	Chopped Fluorescence Analyzer
SO_2	Philips	PW 9755/02	$6800.00	Coulometric Titration Analyzer
$NO/NO_2/NO_x$	Monitor Labs	8440 E	$5375.00	Chemiluminescent Analyzer
$NO/NO_2/NO_x$	Bendix	8101 C	$5870.00	Chemiluminescent Analyzer
$NO/NO_2/NO_x$	TECO	14 B/E	$5775.00	Chemiluminescent Analyzer
$NO/NO_2/NO_x$	Meloy Labs	NA 530-R	$7500.00	Chemiluminescent Analyzer
$NO/NO_2/NO_x$	Beckman	952 A	$5890.00	Chemiluminescent Analyzer
Methane (CH_4) & total HC (THC)	Bendix	8201, 8202	$5490.00	Flame Ionization Detection (FID) Analyzer
Methane (CH_4) & total HC (THC)	Meloy Labs	HC 500-2C	$3780.00	FID Analyzer

Table 7.2-1

Summary of Air Quality Monitoring Equipment

(Continued)

Parameter	Manufacturer or Source	Model	Cost	Instrument Type and Comments
Methane(CH_4) & total HC (THC)	Mine Safety Appliances (MSA) Co. 400 Penn Center Blvd. Pittsburgh, PA 15235	11-2	$7200.00	Dual FID Analyzer
CO	Bendix	8501-5CA	$6295.00	NDIR Analyzer
CO	MSA	Lira M202S	$4270.00	NDIR Analyzer
CO, CH_y, HC, Ethylene	Beckman	6800 with options	$10→$15K	Out of production. Gas Chromatograph
CO, CH_y, HC Ethylene	Byron	Cannot locate any information.		
CO, CH_y, HC Ethylene	Bendix	Special Order	$9K→$12K	Any combinations available.
H_2S	(1) SO_x scrubber, then convert H_2S to SO_2 for SO_2 specific monitors.			
	(2) Direct measurement using total sulphur analyzers with SO_x scrubbers.			
H_2S	Meloy Labs	SA 285-E	$5100.00	FPD (2) Analyzer
H_2S	TECO	45	$8550.00	FPD (1) Analyzer
H_2S	Philips	PW 9780/00	$7000.00	FPD (2) Analyzer

Table 7.2-2

Summary of Meteorological Monitoring Equipment

Parameter	Manufacturer or Source	Model	Cost	Instrument Type and Comments
Wind Speed/ Wind Direction	Meteorology Research, Inc. (MRI) 464 West Woodbury Rd. Altadena, CA. 91001	1071	$2500.00	Anemometer. Mechanical Station; includes temperature, built-in recorder. Options.
WS/WD	MRI	1074-2	$3000.00	Anemometer. WS/WD sensors in one housing. Options. With signal processors.
WS/WD	MRI	1022	$2800.00	Anemometer. Individual sensors. Options. With signal processors.
WS/WD	MRI	1053	$4800.00	Anemometer. Measures azimuth, elevation, sigmas and WS. With signal processors.
WS/WD	Climatronics Corp. 1324 Motor Parkway Hauppauge, N.Y. 11787	EWS	$2300.00	Anemometer. AC/DC powered. Includes temperature, recorder. Options.
WS/WD	Bendix Corp. Dept. 81 1400 Taylor Ave. Baltimore, MD. 21204	120	$850.00	Anemometer. Aerovane. Translator Model 135 is $900.00.
WS/WD	Met-One, Inc. 154 San Lazaro Sunnyvale, CA. 94086	WS→#010 WD→#020	$1500.00	Anemometer. Micromet quality. With signal processors.
WS/WD	Met-One	WS→#014 WD→#024	$1100.00	Anemometer. AC/DC portable system. With signal processors.
WS/WD	Texas Electronics, Inc. P. O. Box 7225 Dallas, TX. 75209	446A	$1800.00	Anemometer. AC/DC with recorders and signal translator.

Table 7.2-2

Summary of Meteorological Monitoring Equipment

(Continued)

Parameter	Manufacturer or Source	Model	~ Cost	Instrument Type and Comments
WS/WD	Texas Electronics, Inc.	450LC-5	$2500.00	Anemometer. Includes signal translators and recorders.
WS/WD	R. M. Young Company 2801 Aero-Park Drive Traverse City, MI. 49684	12002	$1200.00	Anemometer. Gill microvane/ anemometer.* Includes signal translator.
WS/WD	R. M. Young Company	21003	$1800.00	Anemometer. Gill anemometer bivane.* Includes signal translator.
WS/WD	R. M. Young Company	35003	$1500.00	Anemometer. Gill propeller vane.* Includes signal translator.
Temperature	MRI**	840-1	$900.00	Thermometer. Power aspirated. Includes signal translator.
T	MRI	815-1	$650.00	Thermometer. Naturally aspirated. Includes signal translator.
T	Met-One**	Shield→#076 Sensor→#060A	$650.00	Thermometer. Power aspirated. Includes signal translator.
T	Met-One	Shield→#071 Sensor→#063	$550.00	Thermometer. Vane aspirated. Includes signal translator.
T	Texas Electronics	R2-1015	$500.00	Thermometer. Naturally aspirated. Includes signal translator and recorder.

* Fragile - not for rugged environments.
** Also can supply ΔT systems.

Table 7.2-2

Summary of Meteorological Monitoring Equipment

(Continued)

Parameters	Manufacturer or Source	Model	Cost	Instrument Type and Comments
T	R. M. Young Company**	Shield #43103A Sensor #78-0039-0007	$550.00	Thermometer. Naturally aspirated. Includes signal conditioner.
T	R. M. Young Company	Shield #4304A Sensor #78-0039-0007	$750.00	Thermometer. Power aspirated. Includes signal conditioner.
Precipitation	MRI	304	$900.00	Rain gauge. Built-in recorder, battery operated.
Precipitation	MRI	302	$600.00	Rain gauge. Includes signal conditioner. (No recorder.)
Precipitation	Climatronics	100097	$650.00	Rain gauge. Includes signal translator.
Precipitation	Texas Electronics	R2-1014P	$700.00	Rain gauge. Includes signal translator and recorder.
Visibility	MRI	1590	$4000.00 to $4500.00	Integrating nephalometer. Dependent on visual range requirements.
Visibility	MRI	3030	$4300.00	Vista Ranger. Measurer over large path (tens of km). Quantitative & continuous output.

The cost associated with these particular types of instrumentation as presented in the tables include the purchase price only. Table 7.2-3 provides a review of total program costs as a function of the various components as detailed above. The range of cost varies from a simplistic approach (e.g., particulate sampling) to the sophisticated (e.g., full PSD permit support monitoring of gaseous, particulate and meteorological parameters). The prices vary from approximately $10,000 to $200,000 for a year of monitoring. A sophisticated, multiple site program can easily cost over one million dollars.

Figure 7.2-20 presents a schedule for the completion of a one-year monitoring program which indicates a 16 month period from project inception to completion. This schedule assumes that no problems arise. Realistically, it often takes two years to obtain one year of data.

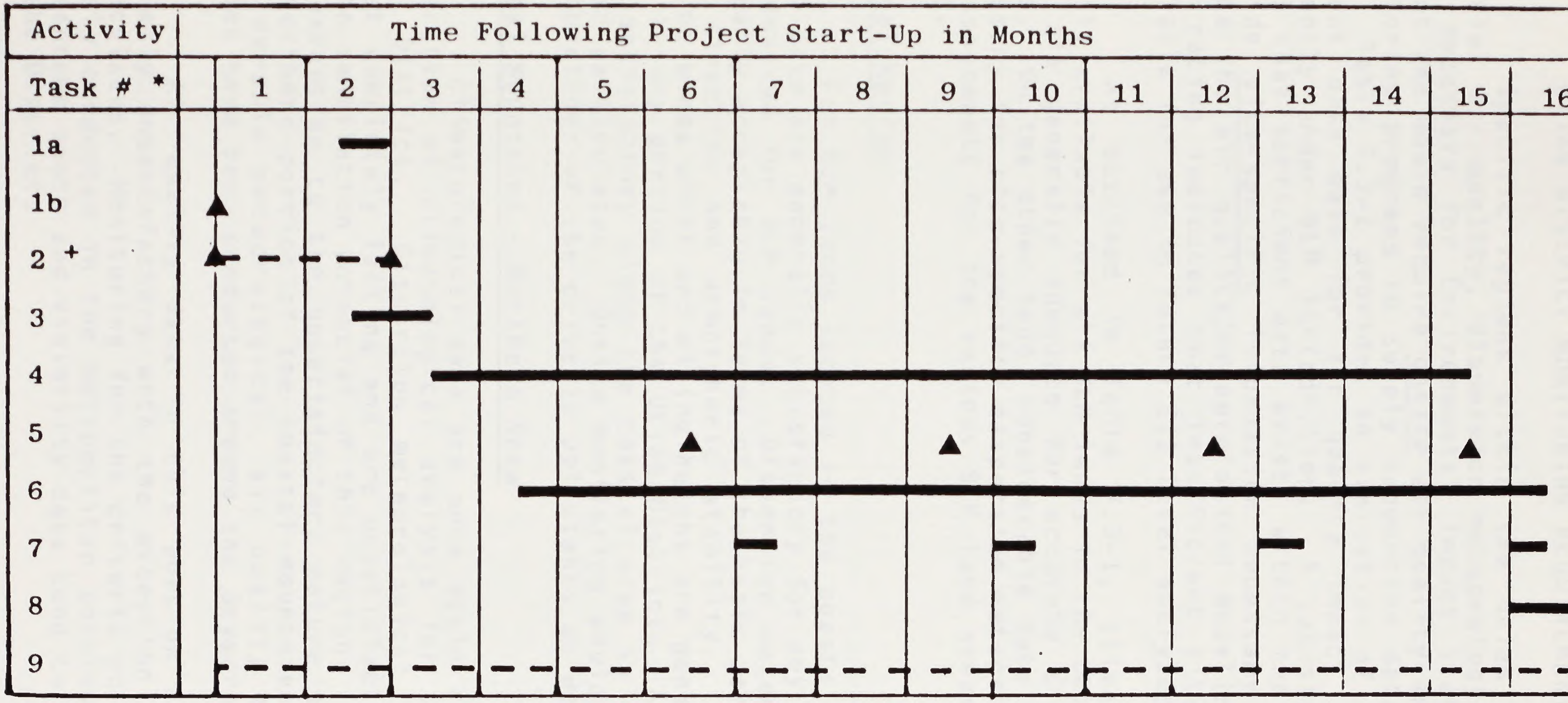
Table 7.2-3

Summary of Monitoring Program Costs

Site Selection	~$1000
System Design	~$ 500 - $3000
Equipment Selection and Purchase	~$2000 - $100,000
Installation and Initial Calibration	~$ 500 - $5000
Onsite Surveillance, Maintenance and Repair	~$5000 - $50,000
Quarterly Calibrations	~$ 500 - $5000
Data Handling, Reduction, Summarization and Analysis	~$1000 - $10,000
Quality Assurance	~$ 500 - $5000
Report Preparation	~$1000 - $10,000

Figure 7.2-20

Proposed Project Schedule



Tasks

1. Task Organization
   a) Job Procedure (JP) and Quality Assurance (QA) Manuals
   b) Site Visit
2. Equipment Ordering and Initial Calibration
3. Installation and Initial Calibration
4. Onsite Surveillance
5. Quarterly Calibrations
6. Data Reduction
7. Quarterly Reports
8. Final (Annual) Report
9. Task Management

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7.3 UKIAH DISTRICT MONITORING REQUIREMENTS

Specific regions within the Ukiah District lack substantial air quality, dispersion meteorology and climatological data necessary for Environmental Impact Statement (EIS) development and would require onsite air quality and/or meteorological monitoring programs to supply supportive data for future analyses. Table 7.3-1 provides an evaluation of the adequacy of the current data base for air quality impact analyses for lands currently under BLM jurisdiction. A satisfactory rating indicates that sufficient data exists within the particular area to provide site-specific information necessary to accurately describe the air quality/meteorological baseline. An unsatisfactory rating indicates that insufficient site-specific data are available for use in future EIS level analyses.

As outlined in Table 7.3-1, climatological data are readily available for all BLM lands in the Ukiah District. These data are generally adequate for accurate site-specific assessments. On the other hand, considerable data resolution would be necessary for site-specific dispersion meteorology and air quality assessments for the various BLM land areas in the Ukiah District.

Coastal Region

For BLM lands located in the coastal region, climatological data are generally satisfactory for any analysis that would be required for BLM lands. Dispersion meteorological data are generally acceptable in terms of the basic parameters wind speed, wind direction and atmospheric stability. More sophisticated data on winds aloft and mixing height are generally not satisfactory in any portion of the Ukiah District. Air quality data are only satisfactory along the coastal area in terms of total suspended particulates. Onsite monitoring would be recommended for the remainder of the criteria pollutants as well as visibility.

Coastal Mountains - Northern Area

Climatological data are once again satisfactory for the preparation of climatological analysis for this portion of the Ukiah District. Dispersion meteorological data, however, are almost completely lacking and are unsatisfactory for an analysis of the ventilation potential of this region. The Geysers KGRA is one exception to the unsatisfactory nature of the data base in the northern portion of the coastal mountains. In this region, considerable meteorological, air quality and gaseous tracer studies have been conducted around the Geysers thermal area.

Air quality data in this portion of the District are generally unsatisfactory with the exception of total suspended particulates. Monitoring for the criteria pollutants is generally only conducted in the metropolitan portion of the Distict in the extreme south and visibility data tend to be lacking throughout the District.

Table 7.3-1
Summary of the Adequacy of Climatological, Dispersion Meteorological and Air Quality Data for BLM Lands in the Ukiah District

Parameters	BLM Land Areas A: Coastal	BLM Land Areas B: Coastal Mountains Northern Area	BLM Land Areas C: Coastal Mountains Southern Area
Climatology			
Temperature	Satisfactory	Satisfactory	Satisfactory
Precipitation	Satisfactory	Satisfactory	Satisfactory
Others	Satisfactory	Satisfactory	Satisfactory
Dispersion Meteorology			
Wind Speed	Satisfactory(1)	Unsatisfactory(2)	Satisfactory(1)
Wind Direction	Satisfactory(1)	Unsatisfactory(2)	Satisfactory(1)
Stability	Satisfactory	Unsatisfactory(2)	Satisfactory
Winds Aloft	Unsatisfactory	Unsatisfactory	Unsatisfactory
Mixing Height	Unsatisfactory	Unsatisfactory	Unsatisfactory
Air Quality			
TSP	Satisfactory	Satisfactory	Unsatisfactory(3)
SO_2	Unsatisfactory	Unsatisfactory	Unsatisfactory(4)
NO_x	Unsatisfactory	Unsatisfactory	Unsatisfactory(4)
O_3	Unsatisfactory	Unsatisfactory	Satisfactory
CO	Unsatisfactory	Unsatisfactory	Unsatisfactory(4)
Visibility	Unsatisfactory	Unsatisfactory	Unsatisfactory

Satisfactory - Sufficient site-specific data to accurately describe a particular parameter for future EIS analyses.

Unsatisfactory - Insufficient site-specific data to accurately describe a particular parameter for future EIS analyses.

[1] Local terrain features will result in dispersion characteristics not well defined by the available data.

[2] Primarily for BLM Lands in northern Mendocino and eastern Humboldt Counties.

[3] Unsatisfactory in Colusa County.

[4] Satisfactory in Napa County.

Coastal Mountains - Southern Area

As described for the other two portions of the Ukiah District, climatological data are once again satisfactory. Dispersion meteorological data are satisfactory in terms of the basic parameters wind speed, wind direction and atmospheric stability but are unsatisfactory for the more sophisticated parameters winds aloft and mixing height. These latter parameters are generally only available at major National Weather Service stations and as a result of site specific studies conducted by applicants for major power development projects. Air quality data in this region are again largely unsatisfactory with the exception of ozone for which sufficient data exists.

Future Monitoring

The monitoring requirements required in support of air quality permit applications are an oblibligation of the Applicant. The data have been presented to inform the Federal Land Manager (FLM) of monitoring requirements, as the role of the FLM in the protection of air quality has increased in recent years. The 1977 Amendments require the FLM To take an active role in EPA's PSD permit process. In addition, the FLM must actively protect the "air quality related values", primarily visibility, of Class I Areas (i.e., national parks, monuments and wilderness areas [See Section 6.4]).

The FLM is charged with ensuring "reasonable progress" toward meeting the national goal of remedying impairment to visibility in Class I Areas. To do this, a visibility baseline must be established. BLM is presently entering into a Cooperative Agreement with the EPA which will begin visibility baseline studies for Class I areas in California. This program will be an expansion of the EPA's Western Fine Particulate Network which includes forty stations uniformly distributed throughout Montana, North Dakota, Wyoming, South Dakota, Utah, Colorado, Arizona and New Mexico. The purpose of this study is to determine the impacts of western energy resource development. Particulate samples are taken twice weekly and undergo mass concentration and trace element analysis.

The visibility monitoring program will include two initial site locations. One site will be located in the Susanville District and one within a desert area of the Riverside District as mandated by the EPA. The objective of the program is to measure visibility, aerosal characteristics and climatology in remote areas influenced by industrial expansion and population growth. The program is also to differentiate between natural and man-made contributions to visibility degradation.

In addition to sophisticated visibility measurements by telephotometers, nephelometers and color photography, size segregated particulate sampling will be conducted with subsequent trace element analysis. The measurement program will be supported by basic meteorological monitoring including wind speed and direction, temperature and relative humidity.

Baseline visibility is poorly defined in the Ukiah District. However, monitoring programs should emphasize those areas that incorporate or are adjacent to Class I areas. Therefore, visibility monitoring would be recommended near either the Point Reyes National Seashore or the Redwood National Park.

7.4 GLOSSARY OF TERMS

Accuracy	The closeness of the instrument output to the true value of the parameter.
Anisotropic Turbullence	Turbulence which is directionally dependent.
Bi-Vane	A wind direction instrument designed to rotate around a vertical axis to measure the azimuth and elevation angle of the wind.
Chemiluminescence	The use of a photomultiplier detector to measure the luminescence produced in a gas phase reaction between two species.
Chromatograph	Analyzers used for the separation and measurement of volatile compounds and of compounds that can be quantitatively converted into volatile derivatives.
Colorimetry	The measurement or analysis of shade, tint, value, brightness and purity of a color.
Conductivity	The property or power of conducting or transmitting heat, electricity, etc.
Constant Level Balloons	Constant level balloons are used to determine the trajectory of an air parcel at a desired pressure level during a given time interval.
Coulometry	A method used in microanalysis to determine quantities in solutions by measuring the amount of electricity required to effect a chemical change.
Durabilty	The ability of an instrument to survive vibrations and shock encountered in transportation, rough handling and normal operating conditions.
Dustfall	The simple collection of dust due to gravitational settling.
Dynamic Response	The real time reaction of an instrument.
Flame Ionization	The ionization of gas samples through their introduction into an air hydrogyn flame. Species specific ions are then measured by a detector which measures ion intensity resulting from the flame ionization of any organic compound.

Flame Photometry	The use of a hydrogen rich air flame to induce the emission of excited atoms specific to the pollutant being measured.
Griess-Saltzman Method	A continuous colorimetric method for NO_2 detection.
High-Volume	The collection of particulate matter on a filter medium through the collection of an air sample at a continuous standard rate.
Hydrothermograph	An instrument for the measurement of temperature and humidity through the use of human hairs which increase or shorten as a function of atmospheric moisture content.
Nephelometer	An instrument which indicates visibility impairment due to the presence of particulate matter in the atmosphere.
Net Radiation	The difference between the total incoming radiation and the outgoing terrestrial radiation.
Net Radiometer	An instrument for the measurement of net radiation.
Nondispersive Infrared Absorption	The use of the principal whereby gaseous compounds absorb infrared radiation at specific wave lengths. In nondispersive absorption, a detector is exposed to a wide wave length band of radiation.
Pilot Balloon	A method for the measurement of wind velocity and wind direction as a function of height using a gas filled free balloon.
Precision	The degree of closeness of a series of readings of an unchanging parameter.
Psychrometer	An instrument which combines a dry bulb and wet bulb thermometer for the subsequent calculation of humidity.
Pyranometer	An instrument used to measure direct radiation.
Pyrheliometer	An instrument used for the continuous measurement of direct solar radiation.
Radiosonde	The use of a free balloon to carry meteorological sensors and a radio transmitter aloft.

Rawinsonde	A method of measuring winds aloft using a gas filled free balloon and radio direction finding apparatus, usually radar.
Reliability	The ability of an air quality or meteorological instrument to provide reproduceable results.
Sensitivity	The smallest change in the measured variable that causes a detectable change in the output of the instrument.
Simplicity	Describes an instrument that can be operated by an individual through the use of Standard Operating Procedures.
T-Sonde	The use of a free balloon to carry a temperature sensor and radio transmitter aloft.
Theodolite	An optical system used to measure the azimuth and elevation angle of a pilot balloon.
Total Radiation	The direct radiation from the sun plus the diffuse radiation from the sky.
Transmissometer	An instrument used for the measurement of visibility through the measurement of the transmission of light over a fixed baseline. Usually on the order of 500 - 700 feet.
UVW Anemometer	An anemometer designed to measure wind speed in the horizontal (x and y directions) and vertical.

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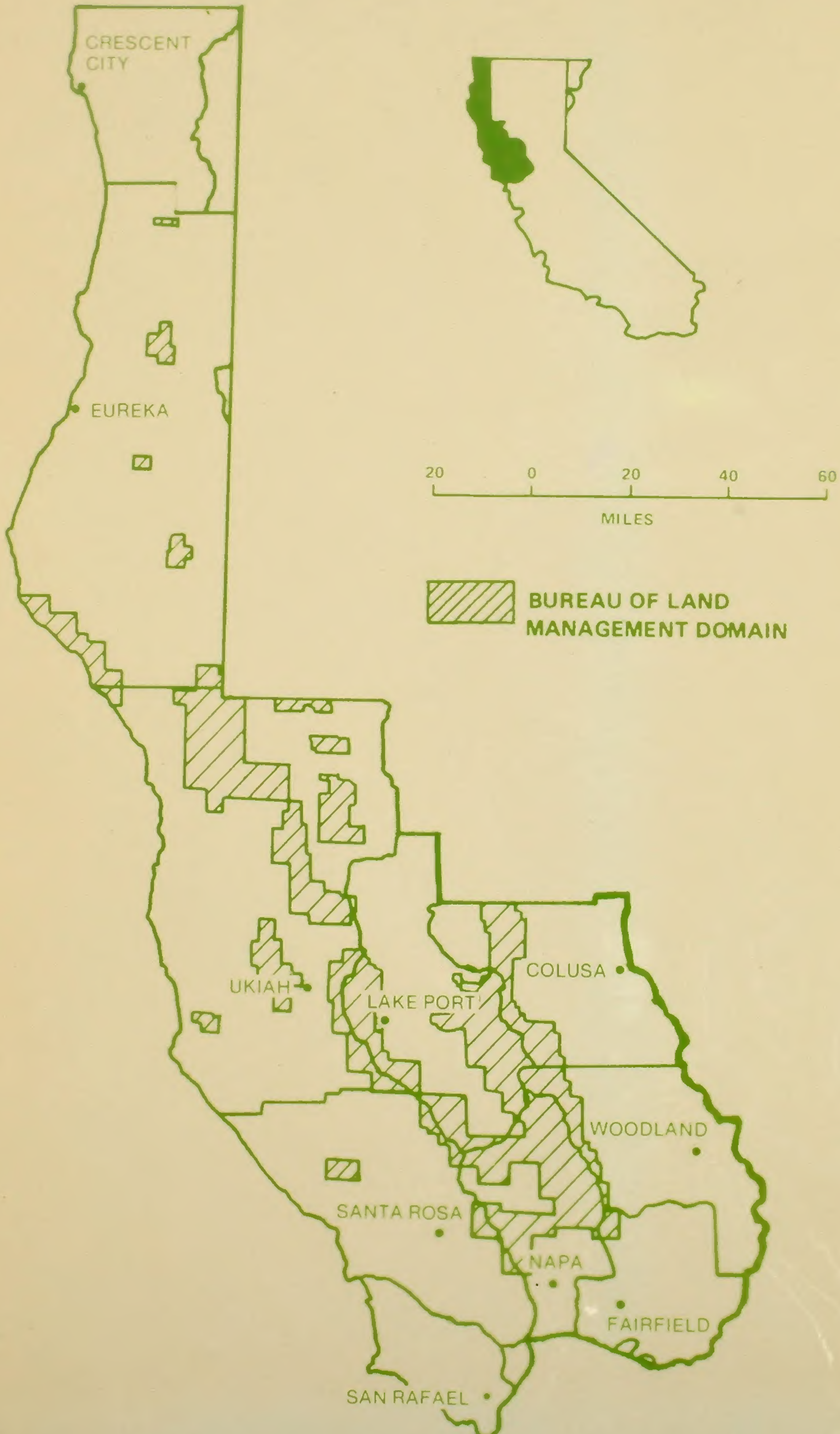
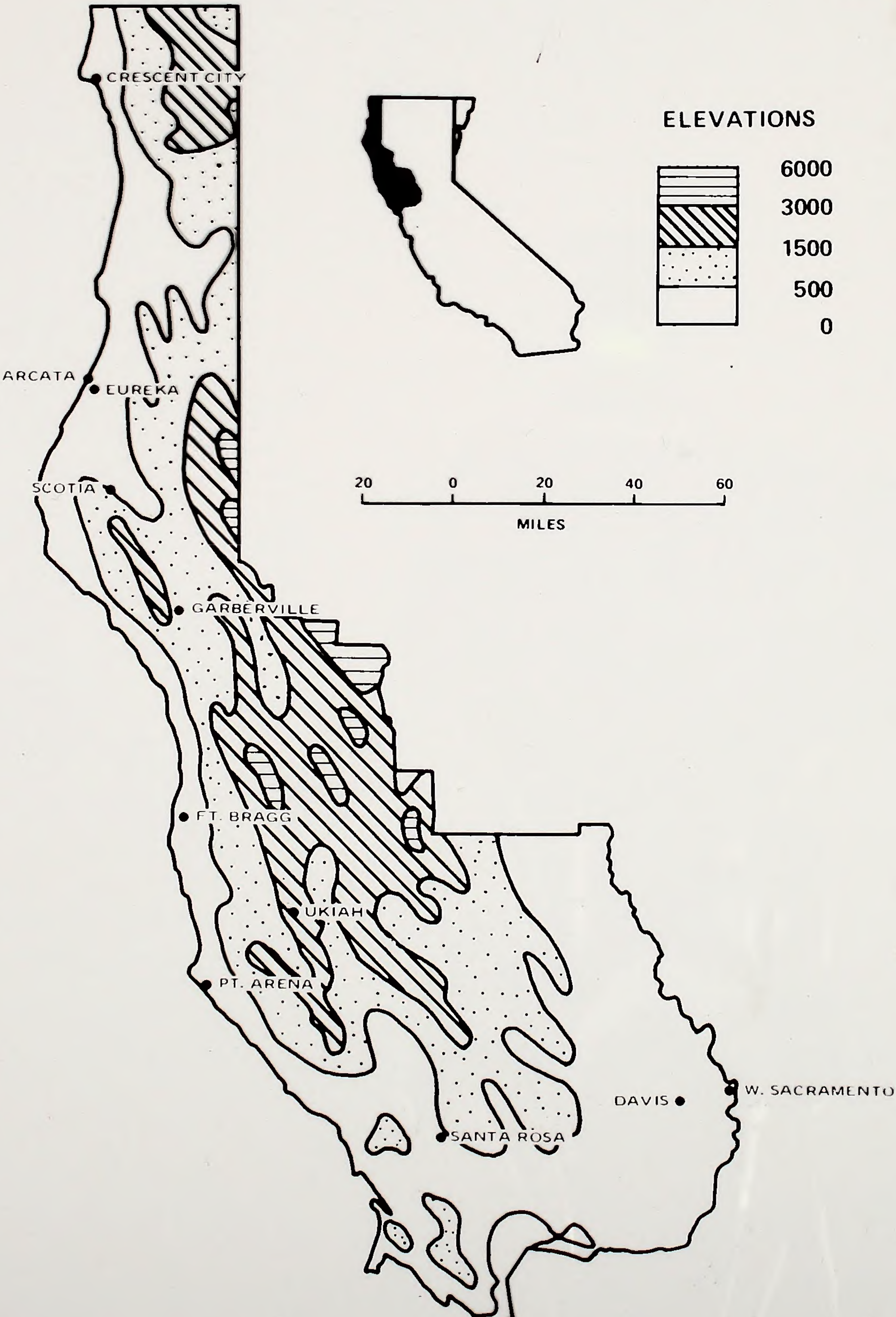
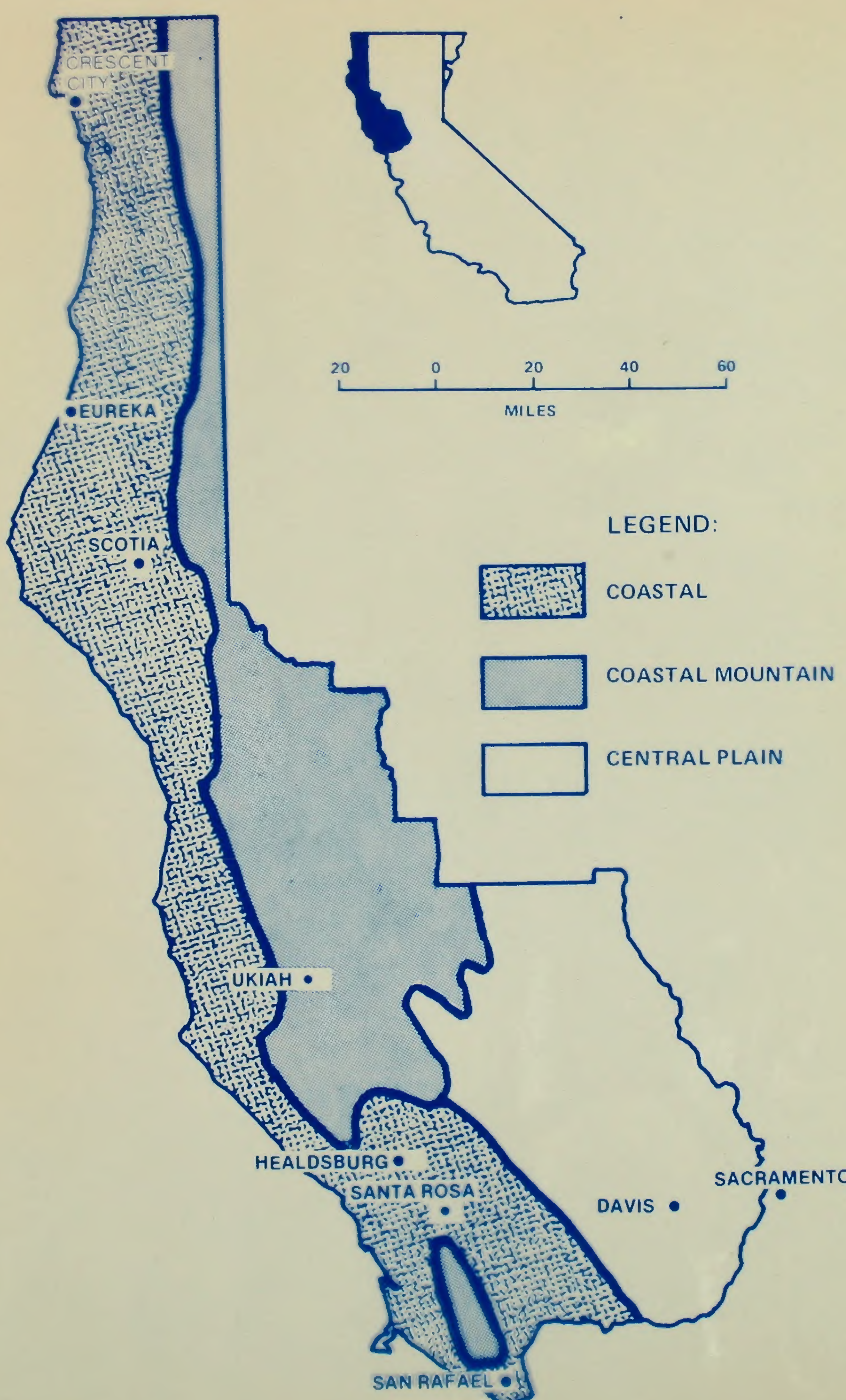
OVERLAY A
BLM LANDS UKIAH DISTRICT



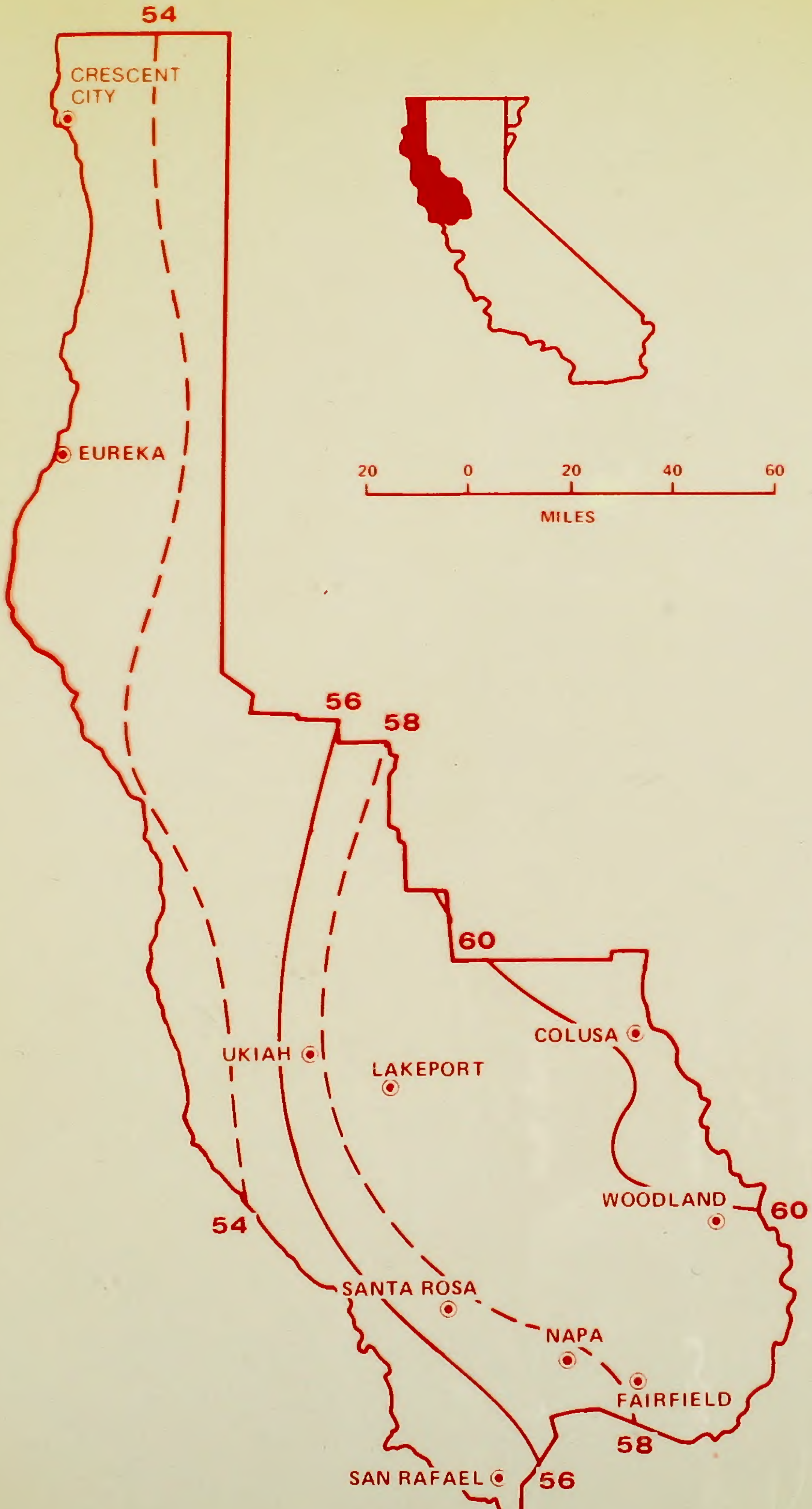
OVERLAY B
UKIAH DISTRICT TOPOGRAPHY



OVERLAY C
CLIMATIC ZONES FOR UKIAH DISTRICT



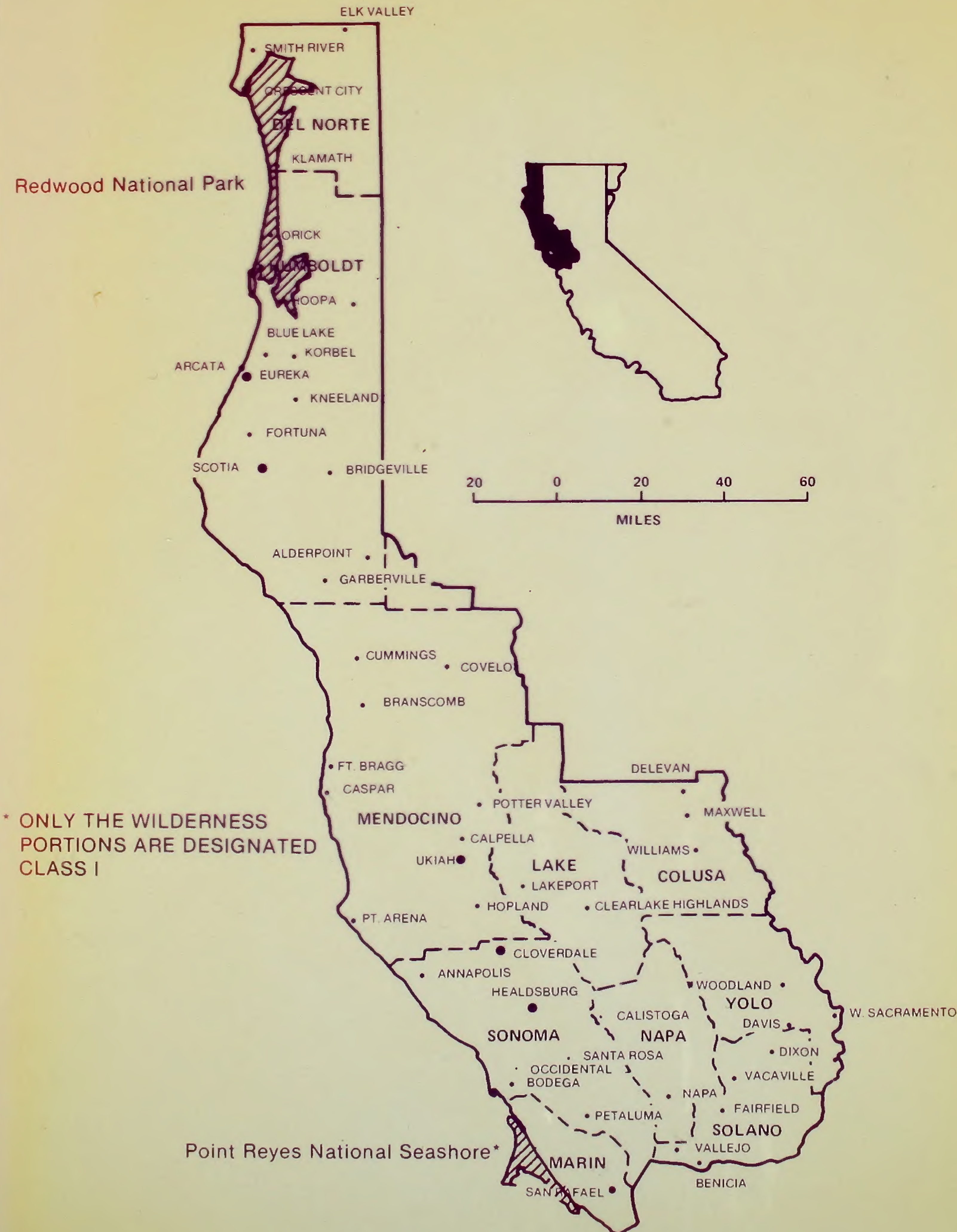
OVERLAY D
MEAN ANNUAL TEMPERATURE CONTOURS (°F)



OVERLAY E
MEAN ANNUAL PRECIPITATION (INCHES)

OVERLAY F
CALIFORNIA AIR BASINS IN THE UKIAH DISTRICT

OVERLAY G
MANDATORY CLASS I AREAS UNDER 1977 CLEAN AIR ACT AMENDMENTS



BIBLIOGRAPHY

OVERLAY G

MANDATORY CLASS I AREAS UNDER 1977 C

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