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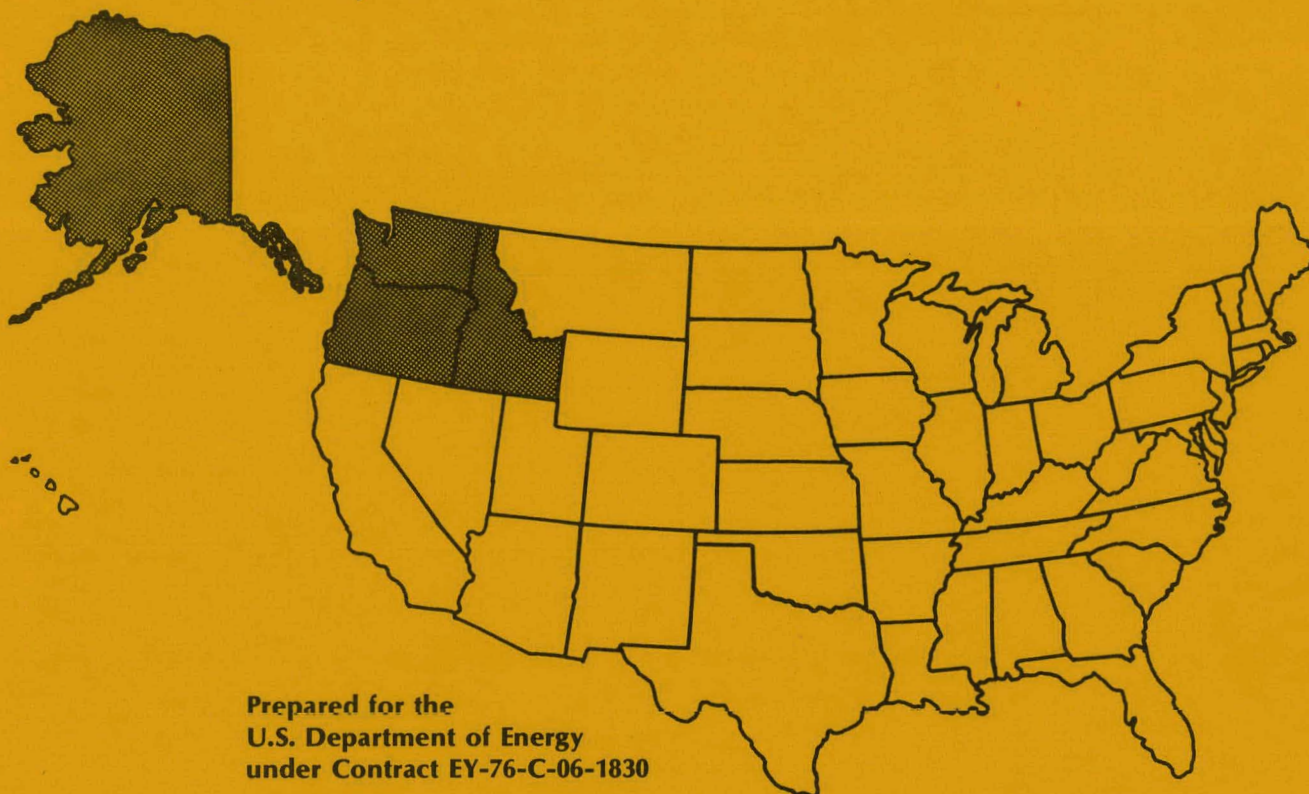
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REGIONAL ASSESSMENT PROGRAM

# Long-Range Transport of Sulfur in the Western United States

January 1979



Prepared for the  
U.S. Department of Energy  
under Contract EY-76-C-06-1830

Pacific Northwest Laboratory  
Operated for the U.S. Department of Energy  
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LONG-RANGE TRANSPORT OF SULFUR  
IN THE WESTERN UNITED STATES

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## SUMMARY

Pollutants, such as SO<sub>2</sub> and sulfate, emitted from both utility and industrial coal burning processes have long residence time in the atmosphere. Therefore, the long-range atmospheric transport and diffusion of these pollutants must be considered in any environmental assessment of proposed plant operation. The most useful tool in predicting the long-range transport of pollutants is a computer simulation technique for the Gaussian diffusion equation. Meteorological data input to the model consist of rawinsonde wind data that can be supplemented with available pilot wind data. Also required are hourly precipitation values for wet deposition and rainfall pH calculations.

Information produced by the model includes: SO<sub>2</sub> and sulfate ground-level air concentrations, the amount of SO<sub>2</sub> and sulfate deposited on the ground surface, the minimum pH value in the rainfall, and the budget of SO<sub>2</sub> and sulfate material over the diffusion grid. This information on air quality impact initially allows one to determine if certain provisions of the Clean Air Act of 1977 can be met (e.g., National Ambient Air Quality Standards, and the Prevention of Significant Deterioration (PSD)). This information may also be required for an assessment of the Provisions for the Protection of Visibility.

These calculations require information on siting and emissions. For this study siting was based on projected coal use in 1985 and 1990 based on a two-thirds increase in coal production. Emission data assumed facilities met standards of New Source Performance Standards (NSPS), or would be required to implement the best available control technology (BACT).

Results of the modeling for the western United States indicate that the maximum incremental ground-level air concentrations for SO<sub>2</sub> are 8.4 and 14 µg/m<sup>3</sup> for utility and industrial sources, respectively. Maximum predicted incremental ground-level sulfate concentrations for utility and industrial sources are 0.8 and 1.2 µg/m<sup>3</sup>, respectively. The minimum calculated pH values for both utility and industrial sulfur emission were 5.3. Maximum SO<sub>2</sub> deposition amounts range from 0.5 to 0.8 gm/m<sup>2</sup> for both the utility and industrial coal use scenarios. The largest sulfate deposition amounts range from a factor of 55 to 24 smaller than SO<sub>2</sub> deposition amounts.

Modeling of carbon monoxide (CO), nitrogen dioxide, and hydrocarbon (HC) emissions was not performed. Instead, data based on current air quality trends are provided.



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## CONCLUSION AND RECOMMENDATIONS

Based on predicted incremental concentrations given in this report, ambient air quality standards for  $\text{SO}_2$  will not be violated in the western U.S. However, Prevention of Significant Deterioration (PSD) limits may be exceeded for those Class I areas near large utility and industrial emitters. For example, this may occur in the Los Angeles, western Washington, and the Four Corners area. Whether or not PSD limits will be exceeded can only be answered after definite siting of facilities. However, a buffer zone where no industrial or utility sources may be sited may be required around all Class I areas.

Sulfate concentrations do not appear constraining to future industrial or facility siting. This conclusion would be accurate even if the analysis had been performed with double the  $\text{SO}_2$ -to-sulfate transformation rate.

Impacts associated with  $\text{NO}_x$ , CO, and hydrocarbon emissions, although not directly modeled, appear insignificant. Non-utility or industrial emission sources, e.g., mobile sources, refineries, contribute to the majority of the emission inventory. However, continuing and future emission control regulations are expected to further reduce pollutant emissions.

Particulate emissions from both utility and industrial sources are not expected to produce significant air quality impact based on the reduced emission levels of efficient control technology. Future technological improvements in coal combustion techniques should also reduce these emissions.

Deposition amounts of sulfur, both  $\text{SO}_2$  and sulfate, should improve local soil content. For the most part, soils in the western U.S. are sulfur deficient. Thus, local agriculture may benefit from future coal combustion.

In view of the results presented in this report, future air quality studies in the west should be directed toward mesoscale studies. After identifying a potential plant site, a mesoscale transport model that incorporates complex terrain effects can be applied. This is important in

the western U.S. since a majority of the existing sites are located in areas of non-uniform terrain. This model should also incorporate a variable mixing height and atmospheric stability descriptor as well as a non-linear function for the transformation of  $\text{SO}_2$  to sulfate.

## INTRODUCTION

The Department of Energy (DOE) is currently completing a National Coal Utilization Assessment (NCUA), which is part of the overall National Energy Program (NEP) designed to direct the U.S. toward energy independence. However, before NEP is implemented it must be determined if future coal use will be environmentally acceptable.

The purpose of this report is to determine the air quality impact resulting from coal combustion in the western U.S. Since high ambient concentrations of sulfur may produce undesirable health effects, sulfur pollutants are the primary concern of this report. Other pollutants investigated with a passing interest were: particulates, carbon oxides, nitrogen oxides, and hydrocarbons. Our scale of interest is the long-range transport of sulfur dioxide ( $\text{SO}_2$ ) and subsequent transformation to sulfate.

To analyze the long-range transport of sulfur, a regional-scale transport and diffusion model was used. This model accounts for the diffusion in the vertical by a Gaussian plume model. Diffusion in the horizontal, however, is simulated by the spatial and temporal variation in the wind field. This technique requires the use of upper-air wind data obtained from the National Weather Service (NWS). A linear transformation of  $\text{SO}_2$  to sulfate is included along with a technique to deplete the pollutant by wet and dry deposition.

Emission data for two siting scenarios were obtained from the Brookhaven National Laboratory (BNL). Their data were based on siting information generated by the Oak Ridge National Laboratory (ORNL). Thus, this analysis represents a multi-laboratory effort.

Predicted incremental concentrations of  $\text{SO}_2$  or sulfate are compared to federal or state annual ambient air quality standards. This report also determines if the limits for the Prevention of Significant Deterioration (PSD) for Class I and II land areas will be exceeded. BNL will use PNL's sulfate concentrations, which will be integrated with results obtained by BNL for the eastern United States, to develop a population dose-response function to sulfate.

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## AIR QUALITY ISSUES

This study discusses regional climate, the Clean Air Act Amendments of 1977, and existing air quality in the study area. These three issues are discussed separately. In addition, the discussion of the Clean Air Act Amendments of 1977 is divided into four sections: National Ambient Air Quality Standards (NAAQS), regulations regarding the Prevention of Significant Deterioration (PSD), New Source Performance Standards (NSPS), and Provisions for the Protection of Visibility.

### REGIONAL CLIMATE

A diverse topography and climatology characterize the western United States. Two major mountain ranges--the Coast Range and the Cascades, located in the states of Washington, Oregon, and California--produce orographic rainfall from persistent storm-frontal passages during the late fall and early winter. To a lesser extent the Sierra Nevada mountain range produces the same effect. The Rocky Mountain range also produces orographic precipitation from Pacific frontal systems moving inland; however, the Rocky Mountain range tends to steer arctic frontal systems through the Plains States and onward to the eastern U.S. Since the western region is not only affected by frequent frontal passages in the late fall and early winter but also by convective storm activity in the spring and summer, adequate air ventilation generally occurs. However, between these frontal passages high-pressure ridges that limit ventilation can settle over parts of the region, particularly in basins bound by major mountain ranges and in interior mountain valleys. These stagnation periods can last for several weeks in the late summer and early fall to longer periods during midwinter. Holzworth<sup>(1)</sup>, in his analysis of Standard National Weather Service upper-air data, summarized the frequency of stagnation periods and their average length, based on specific atmospheric criteria.

Because of the variation in the climate and topography over the western U.S., the location of any major emission facility would require careful siting studies. However, such a siting was beyond the scope of this long-range transport analysis. Instead, the regional climate for a 1-mo period was used to investigate air quality impacts that may constrain future utility and industrial development within certain regions.

#### CLEAN AIR ACT AMENDMENTS OF 1977

The Clean Air Act Amendments of 1977 promulgated air quality standards for six pollutants: carbon monoxide, nitrogen dioxide, particulate matter, sulfur dioxide, hydrocarbons, and photochemical oxidants.

#### National Ambient Air Quality Standards

In this study, only sulfur dioxide ( $\text{SO}_2$ ) emissions from coal-fired power plants and coal-burning industrial facilities were studied. The National Ambient Air Quality Standards (NAAQS) for all pollutants are given in Table 1.

Section 109 of the Clean Air Act Amendments of 1977 requires that no later than December 31, 1980, EPA establish an independent scientific committee to review air quality criteria and the existing NAAQS and to recommend revisions as appropriate in the criteria standards. An independent scientific committee is also required to review the NAAQS at intervals not to exceed five years from December 31, 1980. Section 109 also requires EPA to promulgate a short-term (less than 3-hr) primary standard for nitrogen dioxide ( $\text{NO}_2$ ) within 1 yr after enactment.

Undoubtedly, section 109 will generate a revision in the current suspended particulate standard. Such a revision could involve a standard based on the size distribution of respirable particulate emissions. This could be especially important to western states where fugitive dust emissions frequently contribute to suspended particulate violations.

TABLE 1. National Ambient Air Quality Standards

Pollutant	Primary ( $\mu\text{g}/\text{m}^3$ )	Secondary $\mu\text{g}/\text{m}^3$ (a)
Particulate		
Annual average	75	60
24-hr maximum	260	150
SO <sub>2</sub>		
Annual average	80	
24-hr maximum	365	
3-hr maximum		1300
NO <sub>2</sub>		
Annual average	100	100
CO		
8-hr maximum	10	
1-hr maximum	40	
Photochemical oxidant		
1-hr maximum	160	
Hydrocarbons		
30-hr maximum	160	

(a) Secondary standards for CO, photochemical oxidant and hydrocarbons are identical to the primary standards.

The EPA has noted in its states attainment review<sup>(2)</sup> that greater health impacts occur from fugitive dust in urban areas than in rural areas. The rationale for this position is: rural wind-blown dust is not significantly contaminated by industrial pollutants. Therefore, for suspended particulate attainment designations, any rural area experiencing total suspended particulate (TSP) violations that could be attributed to fugitive dust was designated as attainment with regard to the TSP NAAQS.

## Prevention of Significant Deterioration

The Prevention of Significant Deterioration (PSD) is potentially more constraining than NAAQS to coal-fired power plants and industrial development, particularly in the western U.S. The EPA promulgated PSD in December 1974 after a suit was filed against the Administrator in June of 1972. The suit stated that no State Implementation Plan (SIP) was designed to protect areas where air quality was cleaner than that required by ambient air quality standards. As a result, regulations to protect these areas were incorporated into the Clean Air Act Amendments of 1977. These regulations specify that each state must designate all regions into one of three classes:

- Class I allows little or no industrial growth as only very limited air quality deterioration may occur.
- Class II allows moderate, well-controlled industrial growth.
- Class III allows concentrated industrial growth, as long as air quality is not degraded beyond the secondary NAAQS.

Class I areas include all international parks, national wilderness areas, national memorial parks larger than 5000 acres, and national parks larger than 6000 acres, which are in existence on August 7, 1977. Currently all states, with the exception of some areas of Montana, are designated Class II, excluding mandatory Class I areas. A list of all federally mandated Class I areas was published in the Federal Register.<sup>(3)</sup> In general, Class I areas for the western U.S. are concentrated in the region's three major mountain ranges: the Coast Range, the Cascades, and the Rockies (see Figure 1).

After consulting with the federal land manager, states can redesignate Class II lands to Class I or to Class III. National monuments, national primitive areas, national preserves, national wild and scenic rivers, national wildlife refuges, national lakeshores, national seashores, new national parks, national wilderness areas and any new areas created in these categories cannot be redesignated to Class III if the area in question is larger than 10,000 acres.



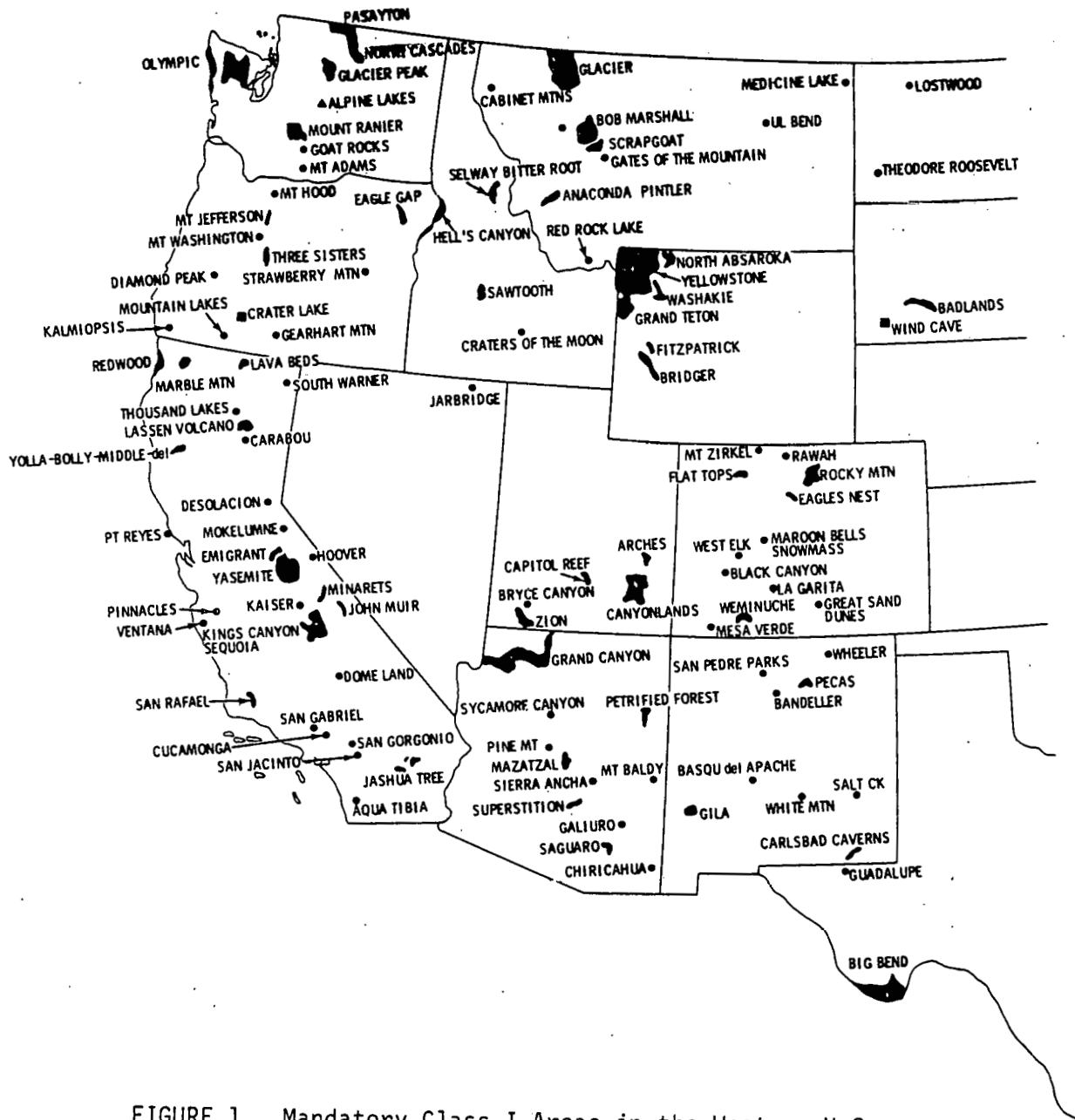


FIGURE 1. Mandatory Class I Areas in the Western U.S.

In addition, the federal land manager is to review national monuments, national primitive areas, and national preserves and to recommend, where appropriate, redesignation of any areas to Class I to protect air quality related values.

Air quality in each class cannot exceed certain specified incremental increases as summarized in Table 2. In no case may the air quality exceed the national ambient secondary standard. Sulfur dioxide and TSP are currently regulated, but within 1 yr of the enactment each state must submit to EPA plans that establish increments, or other means of preventing significant deterioration from nitrogen oxides, hydrocarbons, carbon monoxide, and oxidants. If the state plan is rejected, EPA must propose a plan for the state within 4 mo of the rejection.

TABLE 2. Allowable Air Quality Increments Specified in Clean Air Act Amendments of 1977

Pollutant	Averging Time	Allowable Increments $\mu\text{g}/\text{m}^3$		
		Class I	Class II	Class III
SO <sub>2</sub>	Annual	2	20	40
	24-hr maximum	8	91	182
	3-hr maximum	25	512	700
TSP	Annual	5	19	37
	24-hr maximum	10	37	75

If an area is designated as nonattainment, the designation will have limited significance for new source preconstruction review, since new sources, wherever they propose to locate, will be reviewed for their impact on all surrounding areas as well as on the area in which they locate. In addition, PSD rules apply to any area where at least one NAAQS is attained. Since nearly every area in the country shows attainment for at least one pollutant, the PSD review will be a requisite virtually nationwide. Finally, a new source review will be required on a

case-by-case basis to insure that an area with a particular designation may not encompass "pockets" that do not have the same designation.

### Standards of Performance for New Stationary Sources

Section 111 of the Clean Air Act Amendments of 1977 requires the EPA Administrator to promulgate revised standards of performance for new or modified stationary sources. A stationary source is any source having the potential to emit 100 tons/yr of any pollutant. For fossil-fuel-fired stationary sources these standards require the best system of continuous emission reduction regardless of fuel quality. This requirement is known as the best available control technology (BACT).

The current provision goes far beyond the New Source Performance Standards (NSPS) for fossil-fuel-fired steam generators. NSPS was promulgated after the Clean Air Act was amended in 1970. At that time, the standards as published in the Federal Register<sup>(4)</sup> reflected the reasonable-available-control technology. The 1971 standards eliminated the variability in heat and sulfur content of coal supplies and indicated the upper regulatory limit for emissions from new facilities. However, with the Clean Air Act Amendments of 1977, BACT now prevails.

BACT is one of the major unresolved issues of this assessment. In a study of western coal reserves, Renne<sup>(5)</sup> found that roughly half of all stripable and mineable resources in Montana and Wyoming could be burned without controls and not exceed the NSPS. Nevertheless, the Clean Air Act Amendments of 1977 specified that BACT must be applied to all new facilities; in the West, BACT could result in an additional reduction in SO<sub>2</sub> emissions of as much as 90% beyond that of the NSPS. Considering the economic costs of applying such strict controls on facilities that are already burning low-sulfur coal, a case-by-case review of each proposed facility should be conducted to determine the level of control required. Because of the uncertainties concerning how BACT will be interpreted and how the NSPS may be revised, calculations in this study when applied to emissions were based on 90% control technology for coal

typically burned in each western state. If less-stringent emission controls are placed on western low-sulfur coal, the calculations presented here may underestimate actual concentrations.

### Provisions for the Protection of Visibility

In the Clean Air Act Amendments of 1977, Congress declared the maintenance of good visibility in mandatory Class I areas as a national goal. Visibility impairment is defined as reduction in visual range and atmospheric discoloration. Section 169A of the Act requires the Secretary of the Interior to identify all mandatory federal Class I areas where visibility is an important consideration.

In addition, the Administrator, after consulting with the Secretary of the Interior is required to promulgate within 1 yr of the date of enactment a list of Class I areas to receive visibility protection provided by the Act. The Administrator is also required to report to Congress, within 18 mo after enactment, the results of a study that:

- establishes methods for determining and measuring visibility impairment
- establishes modeling techniques or other methods for determining the contribution of manmade air pollution to visibility impairment
- reports on methods for controlling air pollution that results in visibility impairment
- identifies categories of sources and types of air pollutants that may cause or contribute significantly to impairment of visibility.

Within 24 mo from enactment, the Administrator is required to promulgate regulations to assure reasonable progress towards meeting the national goal for adequate visibility.

The visibility provisions state that existing fossil-fuel power plants operating in the vicinity of Class I areas will have to retrofit their stacks with cleaning devices if their emissions are impairing the

visibility of the federal Class I areas. However, facilities with lower than a 750 MWe capacity may be exempt from this rule.

#### EXISTING AIR QUALITY

Prevention of Significant Deterioration (PSD) regulations are applied to all attainment areas. Attainment means that all national ambient air quality standards, both short-and-long term, are being met. Nonattainment areas have one or more criteria pollutants that exceed existing standards. Siting facilities in these areas require emission reduction of nonattainment pollutants of old sources, which just meet the proposed new source emissions. Other emissions must meet PSD limits.

Recently, the EPA classified all portions of each state and most territories as attainment or nonattainment for each criteria pollutant. In most cases, the states determined the classification, although the EPA reversed several classifications. These classifications are important for this study as they identify areas where PSD regulations for SO<sub>2</sub> apply. Figure 2 shows those areas of the western U.S. where counties have been classified as nonattainment with regard to SO<sub>2</sub> standards. Based on current EPA policy for SO<sub>2</sub> standards, the county is generally the smallest unit for nonattainment status; however, this is not the case for other criteria pollutants.

The nonattainment counties generally have large coal-fired power plants or nonferrous smelters located within their boundaries. In the study area, only the states of Oregon, Colorado, and Wyoming do not have at least one nonattainment county. The large area of southern Arizona classified as nonattainment is due to smelter operations in the region.

Figure 3 gives 1975 mean annual SO<sub>2</sub> ground-level concentration values.<sup>(9)</sup> No areas in the study region exceed the NAAQS. The highest reported values occur in the Los Angeles, California area; the northern Puget Sound area; near Spokane, Washington and around the Lewiston, Idaho/Clarkston, Washington area. The high value near Yakima, Washington may be anomalous, or it may result from drainage flow into the Columbia and Snake river basins.

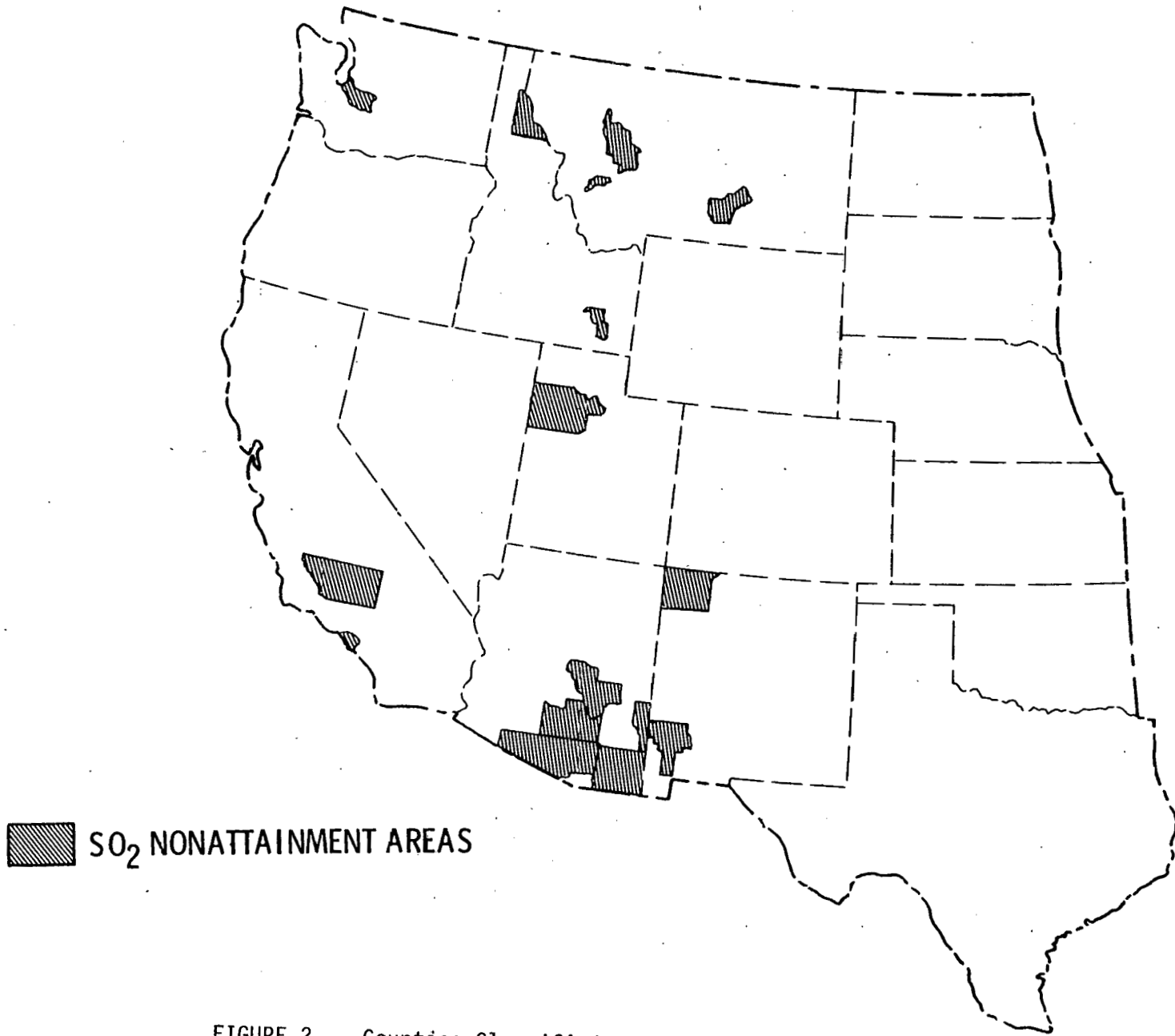


FIGURE 2. Counties Classified as Nonattainment with Regard to SO<sub>2</sub> NAAQS

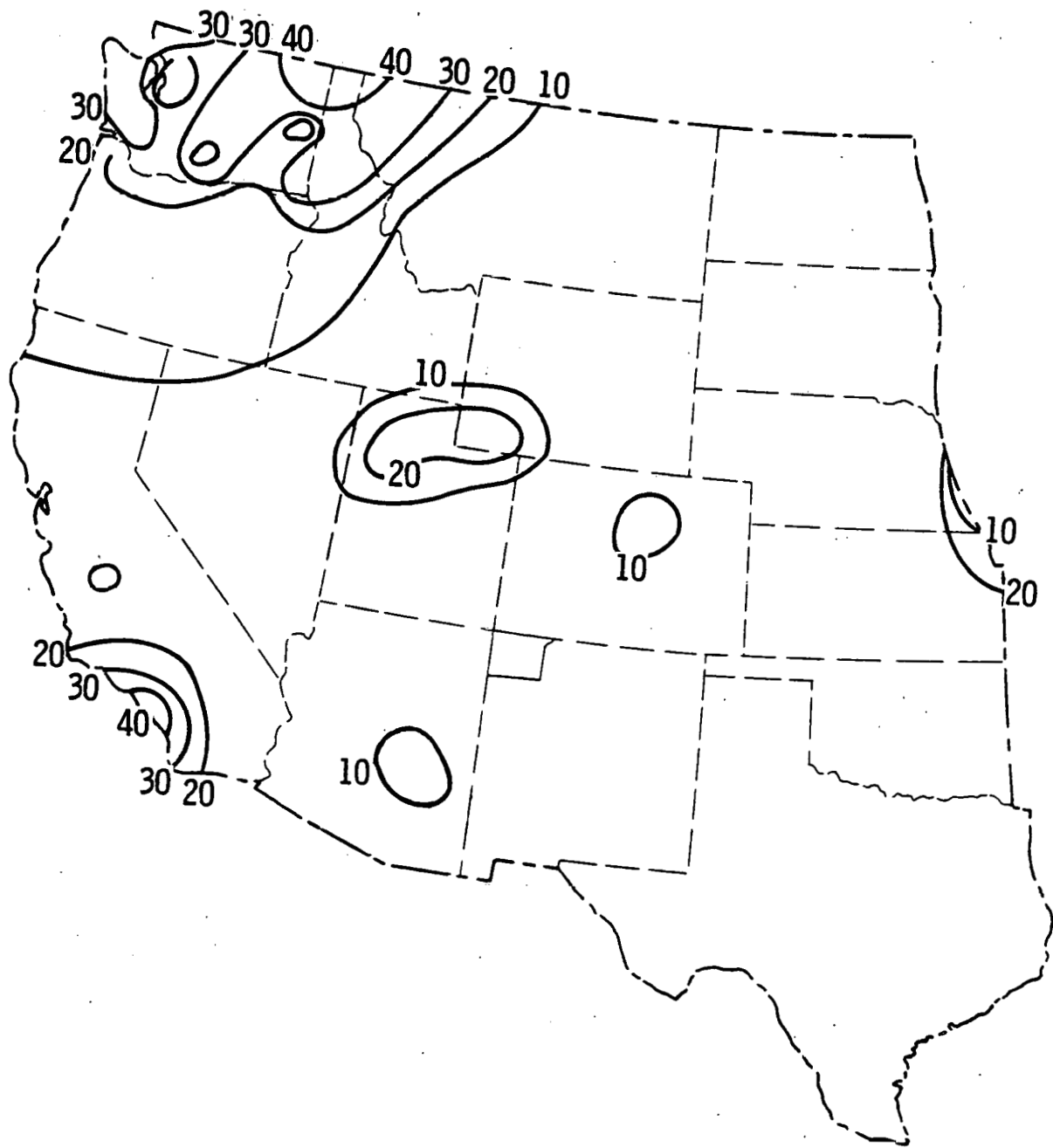


FIGURE 3. 1975 Annual Ground-Level Concentrations of SO<sub>2</sub> in µg/m<sup>3</sup>

Figure 2 and 3 show a large portion of the western U.S. has clean air; however, the more polluted air is found in the regions of existing industrial operation. Since mean annual SO<sub>2</sub> concentrations in all areas are below existing standards, nonattainment designations were based on violations of short-term standards. This nonattainment classification is generally related to the persistence of poor atmospheric dispersion conditions.



## LONG-RANGE MODELING

The computer simulation technique used in long-range transport and dispersion of  $\text{SO}_2$  is basically the same as that used in earlier regional assessments.<sup>(10)</sup> Several of the model parameters, however, have changed as a result of current research. Therefore, information in this section is given on the model's features, required meteorological data, and the sensitivity of results to input parameters.

### MODEL FEATURES

Wendell et al.<sup>(7)</sup> initially developed the computer model used to obtain estimates of regional ground-level air concentrations and surface deposition of  $\text{SO}_2$  and sulfate. This model has been modified by Renne, et al.<sup>(10)</sup> to incorporate multiple source locations throughout the western U.S. so that air quality impacts from any combination of scenarios, e.g., emission strengths and source locations, may be analyzed. An elaborate graphical display package has also been developed to readily illustrate the model's output results.

One feature of the model is its capability to account for spatial and temporal variations in the wind field. An objective analysis scheme of upper-air data collected by the National Weather Service or other government or military agencies generates the gridded wind-field maps. This technique allows for curved trajectory path.

Vertical pollutant dispersion is accounted for by the normal Gaussian formulation. A vertical lid of 1000 m is imposed. Horizontal dispersion about the plume centerline is accounted for by the spatial and temporal variations in the wind field in order to simulate plume meander.

Other model features include a linear oxidation/reaction rate for the transformation of  $\text{SO}_2$  to sulfate, which has a constant value of 1/2% hr, and the ability to account for wet- and dry-removal mechanisms. Wet-removal calculations require either time-averaged or gridded hourly precipitation data. Appendix A includes a more complete description of the long-range transport model.

## SOURCES OF METEOROLOGICAL DATA

Gridded wind maps, as mentioned in the previous section, are required to calculate the transport and diffusion of the emitted pollutant. For each hour of the study period, July 1974, wind maps were generated from rawinsonde and pibal data collected over the western U.S. Since rawinsonde data are routinely obtained at 12-hr intervals, the hourly values had to be interpolated. Pibal wind data either supplemented coincident rawinsonde observation or provided data at intermediate time intervals.

The wind data from the rawinsonde observation were averaged over a specified layer to provide a "layered-average" transport. For most stations a layer between 100 and 1000 m above the ground was used to estimate the pollutant transport. However, for rawinsonde stations located in mountain valleys or sheltered basins some distance from the emission sources, layered winds from 1000 to 2000 m were used. Location of the rawinsonde and pibal data used in the study is given in Figure 4 and listed in Table 3.

Precipitation data for this study was obtained from the National Climatic Center. These values were also gridded on an hourly basis. Since the precipitation was reported in hourly intervals, no interpolation in time was required. The precipitation grid is a factor of 16 smaller than the wind grid.

## SENSITIVITY OF RESULTS TO INPUT PARAMETERS

Sensitivity of results to input parameters for this long-range transport analysis was partially based on the findings of Powell and McNaughton<sup>(6)</sup> who studied utility and industrial sources in the eastern U.S. This study used the same model for long-range transport analysis as this report. Their sensitivity analysis was performed to indicate (1) which physical processes needed to be specified with greater sophistication, (2) which modeling approximations were more tolerable than others, and (3) which clues would help to correlate predicted and observed values.

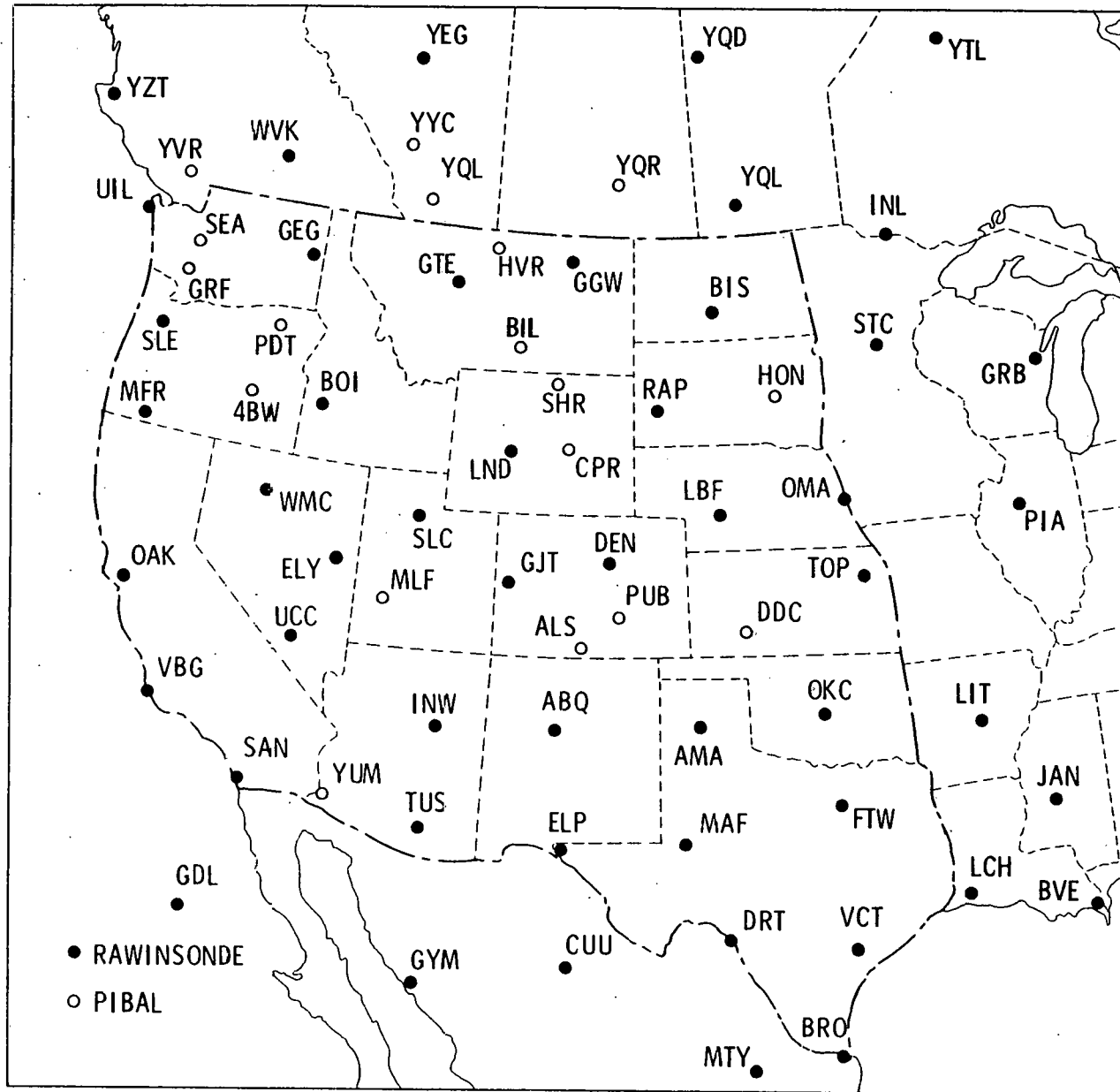


FIGURE 4. Location of Rawinsonde and Pibal Data Stations

TABLE 3. Meteorological Stations Used in the Interpolation Scheme

Station Symbol	Station Name <sup>(a)</sup>	Station Symbol	Station Name <sup>(a)</sup>
DDC	Dodge City, KS	DRT	Del Rio, TX
DEN	Denver, CO	MAF	Midland, TX
GJT	Grand Junction, CO	ELP	El Paso, TX
ELY	Ely, NV	TUC	Tucson, AR
LBF	North Platte, NB	SAN	San Diego, CA
CPR	Casper, WY	AMA	Amarillo, TX
SLC	Salt Lake City, UT	ABQ	Albuquerque, NM
LND	Lander, WY	INW	Winslow, AR
WMC	Winnemucca, NV	UCC	Yucca Flat, NV
MFR	Medford, OR	VBG	Vandenburg AFB, CA
HON	Huron, SD	TOP	Topeka, KS
SHR	Sheridan, WY	OAK	Oakland, CA
BIL	Billings, MT	OMA	Omaha, NB
BOI	Boise, ID	STC	St. Cloud, MN
4BW	Burns, OR	OKC	Oklahoma City, OK
PDT	Pendleton, OR	YUM	Yuma, AR
SLE	Salem, OR	ALS	Alamosa, CO
BIS	Bismarck, ND	PUB	Pueblo, CO
GGW	Glasgow, MT	MIF	Milford, UT
GTE	Great Falls, MT	YYC	Calgary, Alta.
HVR	Havre, MT	INL	International Falls, NM
GEG	Spokane, WA	BVE	Bootaville, LA
SEA	Seattle, WA	JAN	Jackson, MS
UIL	Quillayute, WA	LCA	Lake Charles, LA
YWG	Winnipeg, Man.	BRO	Brownsville, TX
YBR	Brandon, Man.	LIT	Little Rock, AR
YQR	Regina, Sask.	PIA	Peoria, IL
YQL	Lethbridge, Alta.	GRB	Green Bay, WI
YVR	Vancouver, B.C.	YQL	Camp Shilo, Man.
YZT	Port Hardy, B.C.	YQD	The Pas, Man.
WVK	Vernon, B.C.	YEG	Edmonton, Alta.
GRF	Tacoma, WA	YTL	Trout Lake, Ont.
CVT	Victoria, TX	CUU	Ciudad, Chiluahua
FTW	Fort Worth, TX	GYM	Guaymas, Sonora
		MTY	Guadalupe Island

(a) All stations have a specified layer-averaged wind of 100 m to 1000 m except Grand Junction, CO; Salt Lake City, UT; Lander, WY; Medford, OR; Vernon, B.C.; San Diego, CA; Albuquerque, NM; and Oakland, CA which have a 1000 m to 2000 m layer.

The following separate sensitivity tests were performed on the long-range transport model:<sup>(6)</sup>

- use of a fixed mixing depth instead of a variable one
- use of neutral stability during all time periods
- study of the effects of changes in the dry-deposition velocity for  $\text{SO}_2$  and sulfate
- study of the effects of changes in the wet-removal coefficient for  $\text{SO}_2$  and sulfate
- study of variations in the  $\text{SO}_2$ -to-sulfate transformation rate.

The results of these tests are discussed in separate sections below.

#### Mixing Depth

The effect of a fixed mixing depth as opposed to a variable one was most notable in sulfate values. Utility sources produced concentrations that were increased about 20% over a source with a variable mixing depth. Sulfate deposition, however, increased approximately 3% for all sources.

#### Neutral Stability

Probably the most interesting comparison was for constant (neutral) stability and a stability which varied within a given 24 hr, but was identical for each 24-hr period. The utility  $\text{SO}_2$  ground-level air concentration and deposition for the constant stability case increased about 28%, while the sulfate air concentration increased 68%. The sulfate deposition, however, increased only 3%. This difference occurred because the varying stability analysis incorporated unstable conditions, which allowed more rapid plume dispersion.

#### Dry-Deposition Velocity

Increasing the dry-deposition velocity for either  $\text{SO}_2$  or sulfate produced the expected effect. Doubling the dry-deposition velocity for  $\text{SO}_2$  decreased the sulfate deposition values as well as the  $\text{SO}_2$  and sulfate

ground-level air concentration, while it increased the  $\text{SO}_2$  deposition. Doubling the dry-deposition velocity for sulfate increased the deposition values while decreasing sulfate ground-level air concentration values.

#### Wet-Removal Coefficient

Increasing the wet-removal coefficient for  $\text{SO}_2$  emissions resulted in the same effects as increasing the dry-deposition velocity. The deposition values of  $\text{SO}_2$  increased as  $\text{SO}_2$  ground-level air concentrations and sulfate ground-level air concentration and deposition values decreased. Decreasing the wet-removal coefficient for sulfate increased the ground-level air concentration of sulfate while it decreased sulfate deposition values.

#### Transformation Rate of $\text{SO}_2$ to Sulfate

A sensitivity study was performed to investigate the effect of doubling the  $\text{SO}_2$ -to-sulfate transformation rate. Ground-level air concentration and deposition values of  $\text{SO}_2$  decreased slightly from the base case. Sulfate ground-level air concentration and deposition values, as expected, increased approximately 50%. This result is in agreement with the work of Powell and McNaughton.<sup>(6)</sup>

## LONG-RANGE TRANSPORT OF SULFUR DIOXIDE AND SULFATE

Based on supplied emission and siting information, incremental ground-level air concentrations of  $\text{SO}_2$  and sulfate were predicted for two utility and coal use scenarios. Emissions data was supplied by the Brookhaven National Laboratory Regional Studies program (BNL), which was based on the siting information prepared by Oak Ridge National Laboratory (ORNL).

The techniques used by BNL in the emissions data preparation are given below. The information, for both utility and industrial sources, depended on the siting data prepared by ORNL.

The concentration and deposition values given are for the U.S. land area west of approximately  $90^\circ$  longitude; however, these values result from emission in the 11 states west of approximately  $100^\circ$  longitude. The overlapping procedure allows ample space for emissions near  $100^\circ$  longitude to be transported and diffused and allows the Pacific Northwest Laboratory (PNL) results to overlap the BNL grid to insure a complete national assessment of  $\text{SO}_2$  emissions.

### PROJECTED EMISSIONS

Projected utility and industrial emissions are based on current and projected pollution control equipment and continued use of the present coal supplies. The latter assumption is based on one interpretation of BACT.

#### Utility Sources

The ORNL siting data specify Btu electric for conventional and advanced coal boilers (in the equation below,  $g_1$  and  $g_2$ , respectively) for each scenario considered. Conventional boilers have three possible configurations: no flue gas desulfurization (FGD) system, solid-waste-producing FGD system, and regenerable FGD systems. (These three configurations are represented by the subscript  $j = 1, 2, \text{ and } 3$ , respectively.)

The advanced coal boilers, assumed to be fluidized bed combustion, are represented by  $j = 4$ .

The electrical output (Btuout) for each scenario in each of these four configurations is expressed by

$$\text{Btuout}_j = \lambda_j g_1; \quad j = 1, \dots, 3$$

$$\text{Btuout}_4 = g_2$$

where

$$\lambda_1 = 1 - \lambda_2 - \lambda_3 = \text{fraction without FGD}$$

$$\lambda_2 = \text{fraction with nonregenerable FGD}^{(a)}$$

$$\lambda_3 = \text{fraction with regenerable FGD}^{(a)}$$

The following expression gives annual emissions of  $\text{SO}_2$  in lb/yr for each county.

$$A = \sum_{j=1}^4 \frac{\text{Btuout}_j}{H_\ell} \cdot S_\ell \cdot \frac{1}{100} \cdot 1.988(1-f_j)$$

where

$H_\ell$  = heat content of coal, in Btu/lb, for the  $\ell$ -th state

$S_\ell$  = sulfur content, wt%, for the  $\ell$ -th state

$f_j$  = fraction of  $\text{SO}_2$  removed in technology  $j$

---

<sup>(a)</sup> Values for  $\lambda_2$  and  $\lambda_3$  were generated by BNL.



$$f_1 = 0.0$$

$f_2 = f_3 = f_4 = 0.81$  corresponding to one possible definition of BACT requiring 90% sulfur removal at 90% availability.

The heat content and S percentages in each state's coal supplies were derived from 1976 Federal Power Commission data and are listed in Table 4. Data for estimating emissions correspond to those expected under BACT, which will probably emphasize locally available coal.

Figure 5 provides utility siting data for the 1985 and 1990 scenarios. A list of the sites, by number, is provided in Appendix B.

TABLE 4. Coal Characteristics Data

<u>State</u>	<u>Avg Wt, %</u>		<u>Avg Heat Value, (Btu/lb)</u>
	<u>Sulfur</u>	<u>Ash</u>	
New Mexico	0.66	22.3	8,929
Montana	0.72	8.5	8,338
Wyoming	0.53	9.4	8,766
Utah	0.52	12.4	11,600
Colorado	0.49	8.0	9,797
Nevada	0.42	9.5	11,118
Arizona	0.48	10.8	10,551
California	0.45	10.2	10,835
Washington	0.53	15.2	8,100
Oregon	0.53	15.2	8,100
Idaho	0.53	15.2	8,100

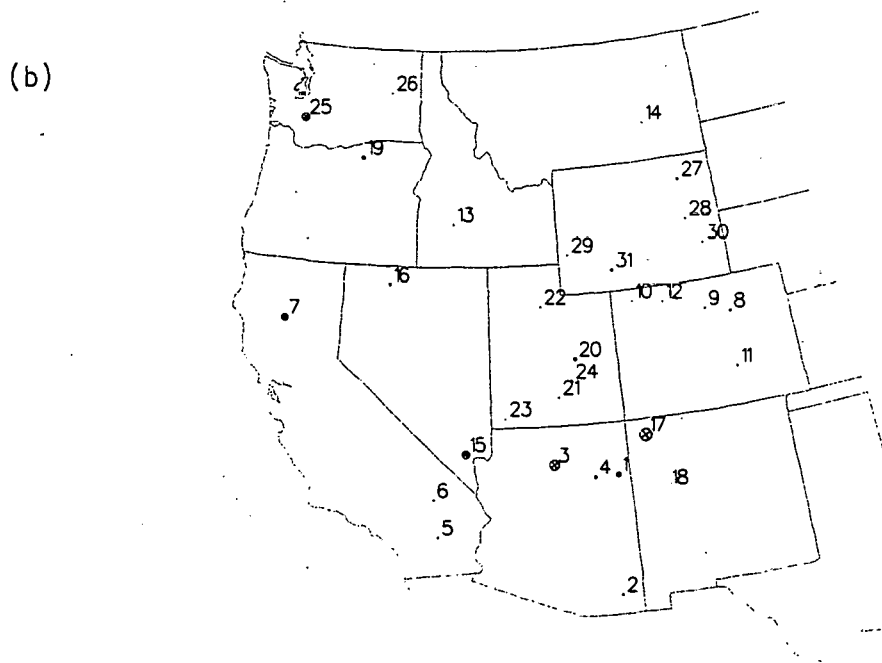
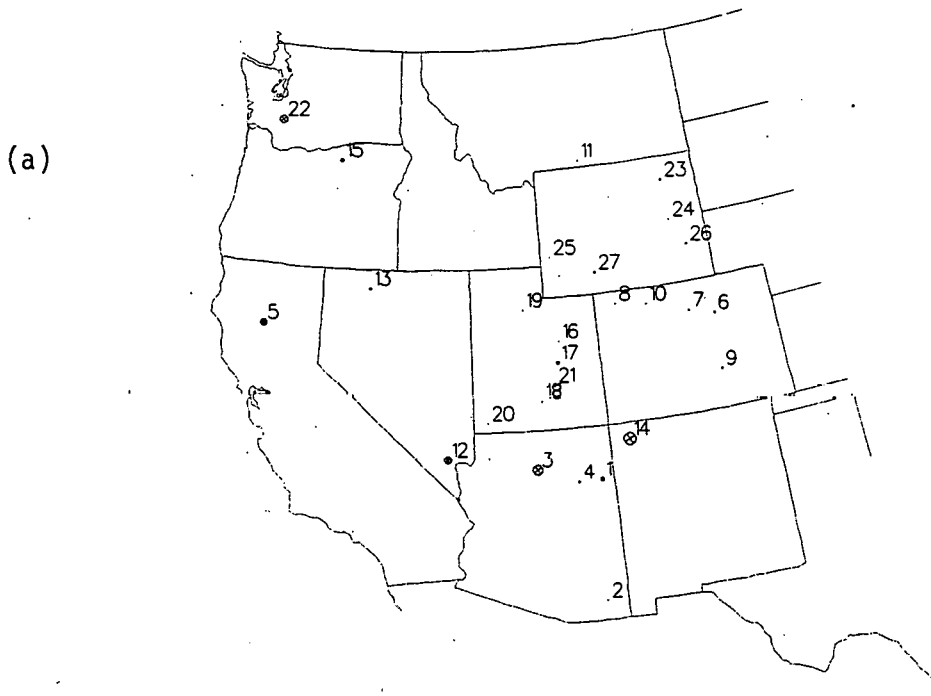


FIGURE 5. Source Strengths and Locations for (a) 1985 and (b) 1990 Utility Coal Use Scenarios

### Industrial Sources

Since industries use a type of coal similar to that used in the utility sector, emission data by county level were calculated using a method similar to that used for the utility sector. Information on fuel use, boiler vintage distribution, and type of present emission control was obtained from a Federal Energy Administration Major Fuel Burning Installations (MFBI) tape. For each county an average stack height, based on a weighted mean of all stack heights, was computed.

Figure 6 provides industrial siting data for the 1985 and 1990 scenarios. A list of the sites, by number, is provided in Appendix C.

### SO<sub>2</sub> CONCENTRATIONS

Two scenarios of SO<sub>2</sub> concentrations for the western U.S. are described: utility and industrial coal use in 1985, and utility and industrial coal use in 1990. For each case, incremental values above background are given to determine if PSD limits are being met. The estimates may understate actual conditions since mobile and small stationary sources (<1 kiloton SO<sub>2</sub> emissions/yr) have not been included. Because of low transformation rate of SO<sub>2</sub> to sulfate and efficient removal by natural processes and terrain types, maximum values occur near the emission sources.

### Utility Sources

Figure 7 illustrates SO<sub>2</sub> concentrations from two utility coal use scenarios. The largest predicted incremental concentration for each scenario is 8.4 µg/m<sup>3</sup>, which occurs in the four corners area of Arizona, Utah, New Mexico, and Colorado. The PSD limits for Class II is met; however, because of the regional-scale interaction, a possibility exists for exceeding PSD limits at Class I areas near the four corners area.

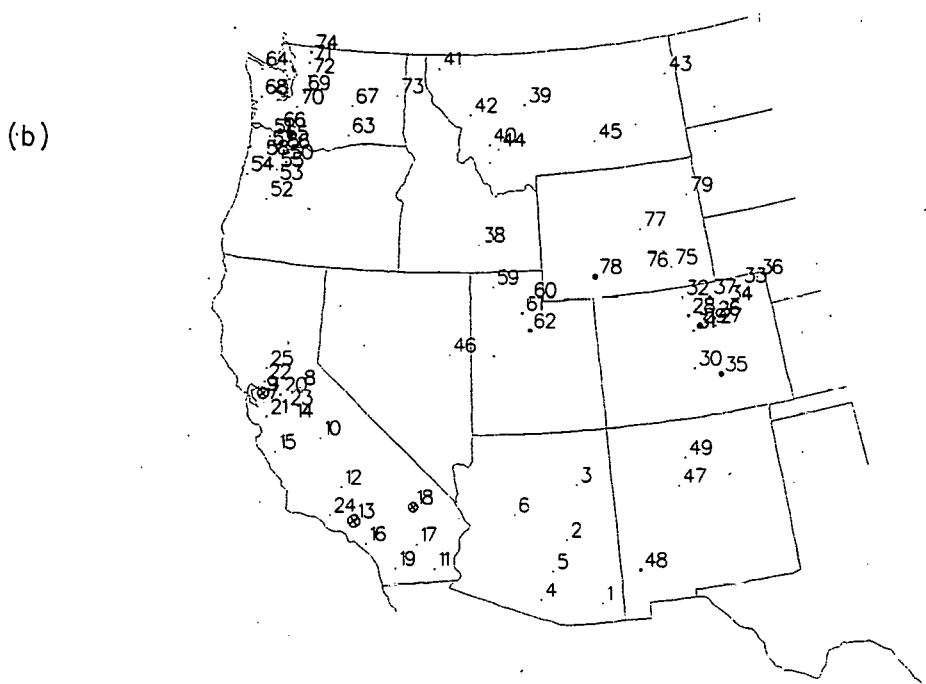
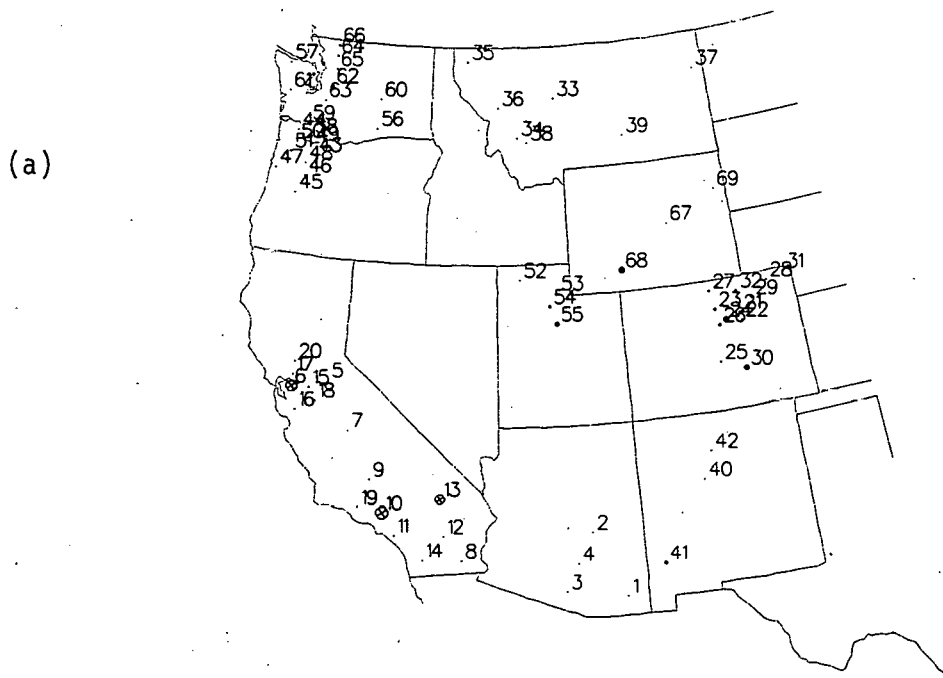
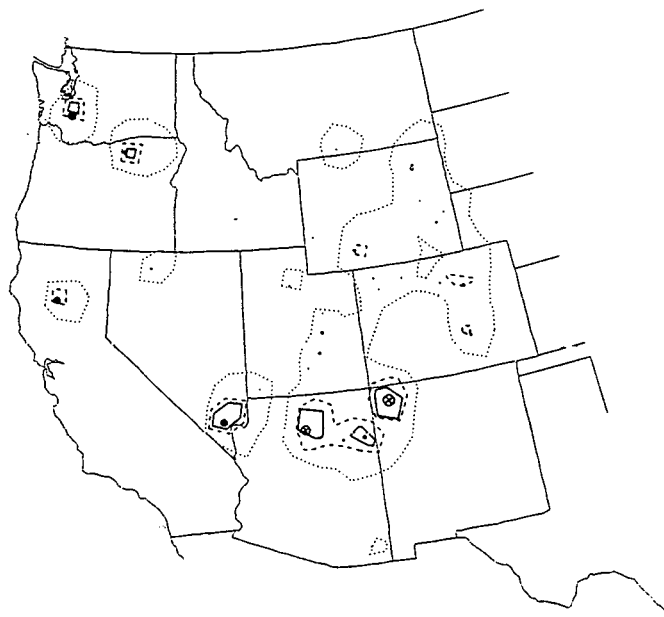
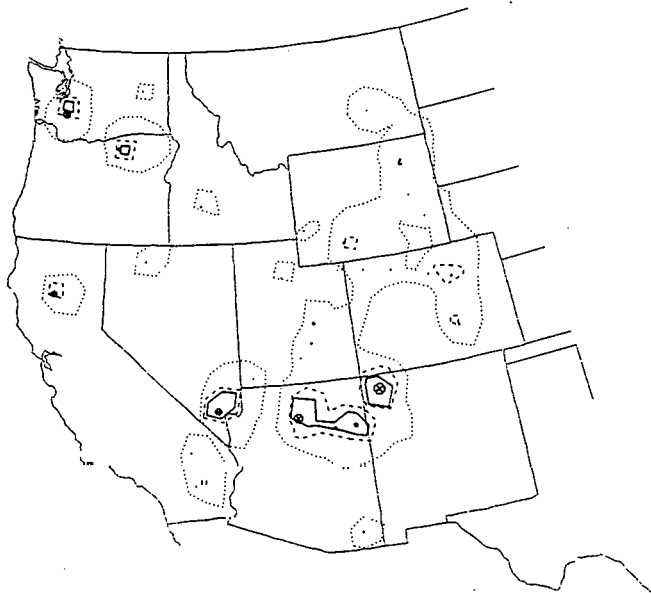


FIGURE 6. Source Strengths and Locations for (a) 1985 and (b) 1990 Industrial Coal Use Scenarios

(a)



(b)



— 2  $\mu\text{g}/\text{m}^3$   
- - - 1  
· · · 0.1

FIGURE 7.  $\text{SO}_2$  Air Concentrations for (a) 1985 and (b) 1990 Utility Coal Use

### Industrial Sources

Figure 8 illustrates SO<sub>2</sub> concentrations resulting from the two coal use scenarios. The largest predicted incremental concentrations are 9 and 14 µg/m<sup>3</sup> for the 1985 and 1990 scenarios, respectively. Because the largest pollutant sources are near Los Angeles, both maximum values occur in southern California. This analysis shows small regional-scale interaction. Again the PSD limit for a Class II area is met, but some possibility does exist for exceeding PSD limits at Class I areas near the Los Angeles basin.

### SULFATE CONCENTRATIONS

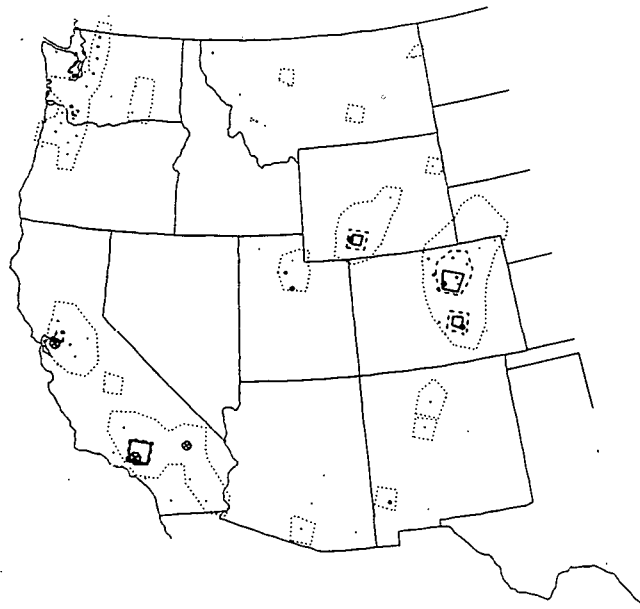
The low SO<sub>2</sub>-to-sulfate transformation rate used in the analysis limits the regional-scale interaction of sulfate concentrations. A majority of the emitted pollutants remains as SO<sub>2</sub> and are rapidly depleted by deposition processes before being transformed to sulfate. Since 2% of the emitted material is considered to be sulfate, the maximum concentrations occur near the source.

NAAQS for sulfates have not been established. However, some evidence indicates that sulfates can cause health problems. This information has led some states to establish their own standard, e.g., Montana and North Dakota, where the maximum allowable annual sulfate concentration is 4 µg/m<sup>3</sup>.

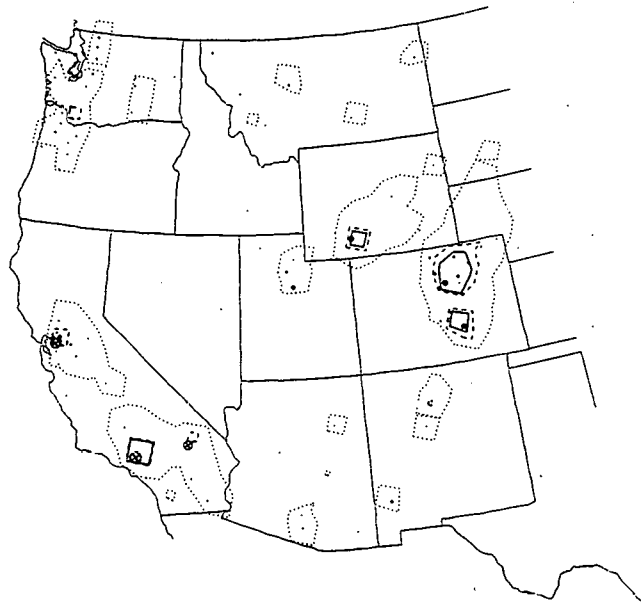
### Utility Sources

Sulfate concentration values are given in Figure 9 for the two utility coal use scenarios. Maximum predicted incremental values were 0.8 µg/m<sup>3</sup> for each scenario, respectively. Montana and North Dakota's ambient sulfate standards are not violated.

(a)



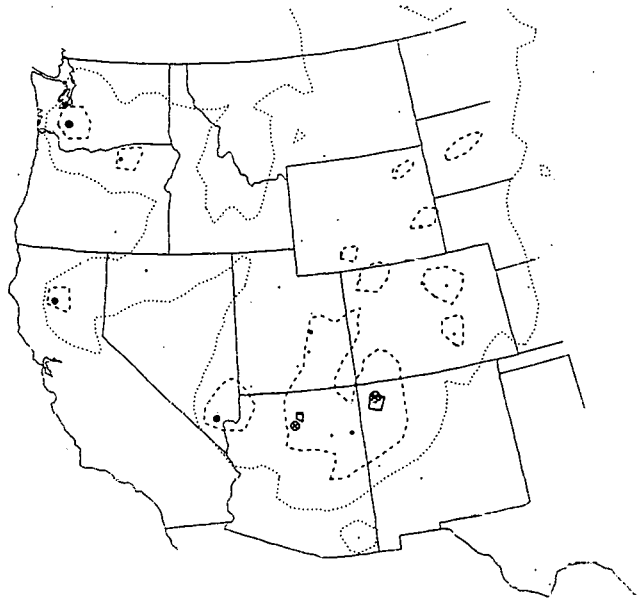
(b)



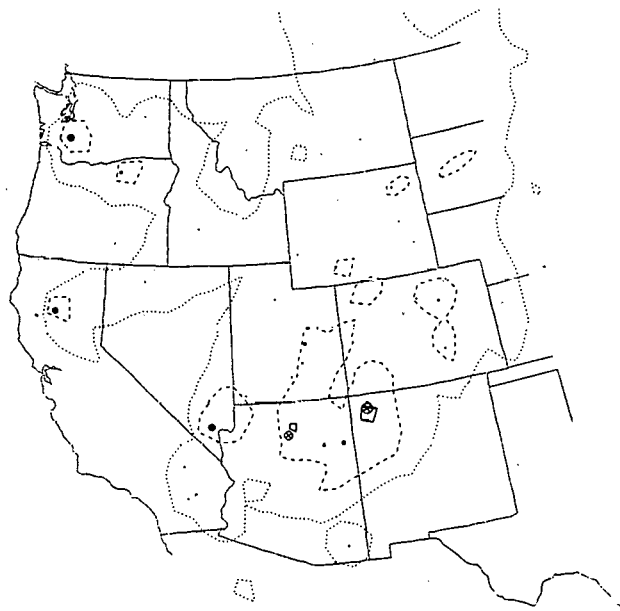
— 2  $\mu\text{g}/\text{m}^3$   
- - - 1  
· · · 0.1

FIGURE 8. SO<sub>2</sub> Air Concentrations for (a) 1985 and (b) 1990 Industrial Coal Use

(a)



(b)



— 0.5  $\mu\text{g}/\text{m}^3$   
..... 0.1  
- - - 0.01

FIGURE 9. Sulfate Concentrations for (a) 1985 and (b) 1990 Utility Coal Use



### Industrial Sources

Figure 10 illustrates sulfate concentrations resulting from the two coal use scenarios. Maximum predicted incremental values are 0.8 and 1.2  $\mu\text{g}/\text{m}^3$  for the 1985 and 1990 scenarios, respectively. Montana and North Dakota's ambient sulfate standards are not violated.

### SO<sub>2</sub> AND SULFATE DEPOSITIONS

SO<sub>2</sub> and sulfate deposition values from utility and industrial coal emissions are given below. These values represent the amounts deposited on the surface for the test period, July 1974. Large variation in the sulfate deposition patterns are expected primarily due to seasonal variations in precipitation throughout the western U.S.

#### Utility Sources

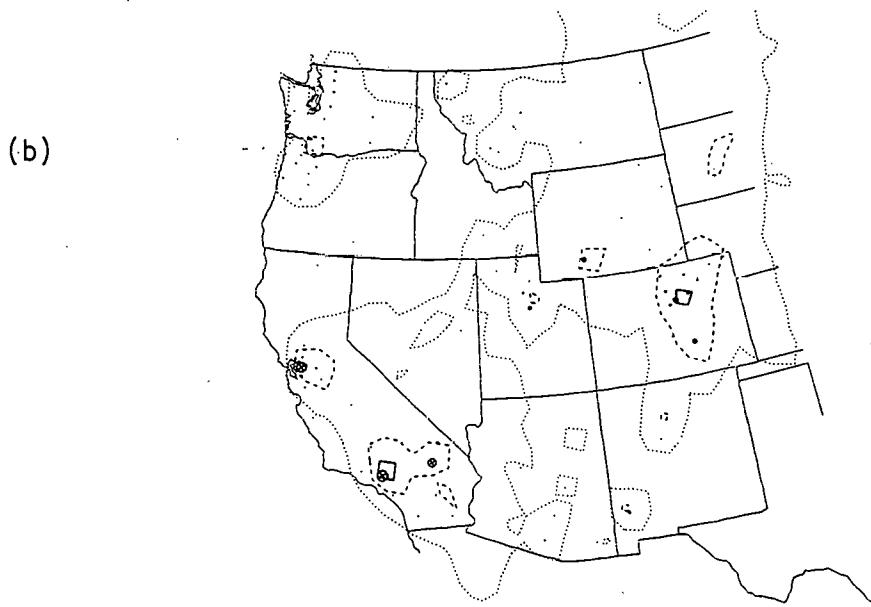
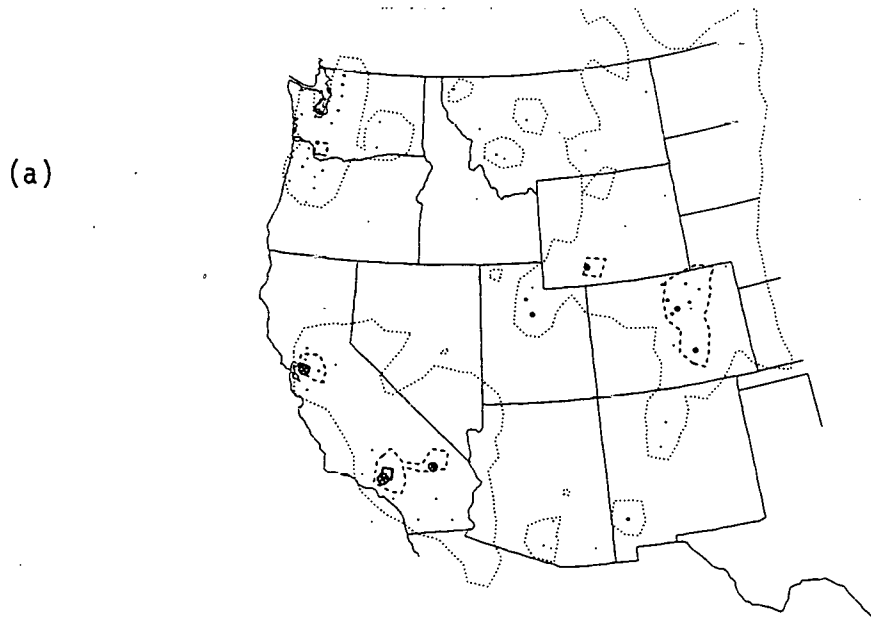
SO<sub>2</sub> and sulfate deposition values are given in Figures 11 and 12 for the two utility coal use scenarios. The maximum sulfur amount (both SO<sub>2</sub> and sulfate) deposited in the terrestrial environment for either scenarios is 0.5  $\mu\text{g}/\text{m}^2$  or 4.4 lb/acre.

The largest sulfate depositions for each scenario are a factor of 24 smaller than that of SO<sub>2</sub> depositions, because much of the SO<sub>2</sub> is deposited by wet and dry processes before being transformed to sulfate.

#### Industrial Sources

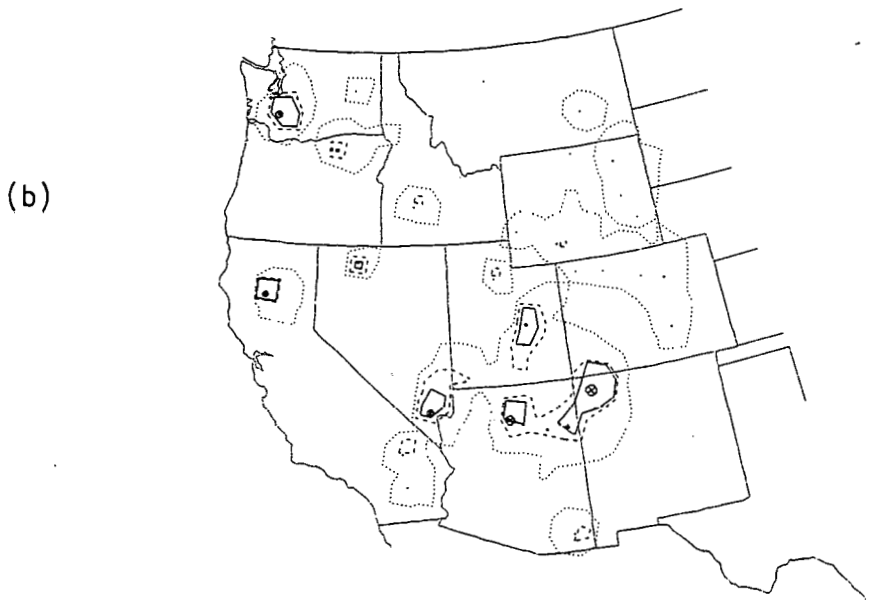
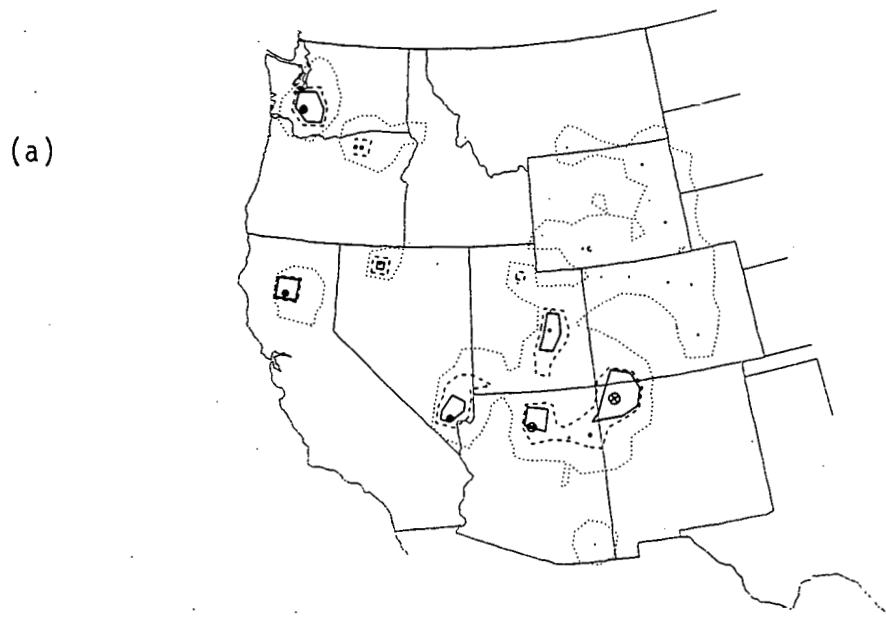
SO<sub>2</sub> and sulfate deposition values are given in Figures 13 and 14 for the two coal use scenarios. The maximum sulfur amount deposited in the terrestrial environment for either scenario is 0.8  $\text{gm}/\text{m}^2$  or 7 lb/acre. Increased sulfur to the soil could benefit agriculture in some regions.

The largest sulfate depositions for each scenario are a factor of 55 smaller than SO<sub>2</sub> depositions. This results because much of the SO<sub>2</sub> is deposited by wet and dry processes before being transformed to sulfate.



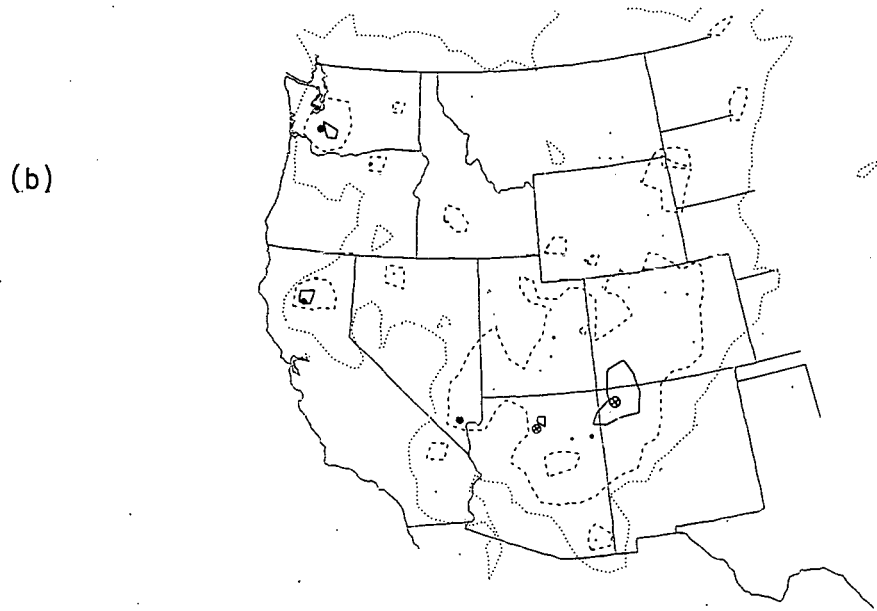
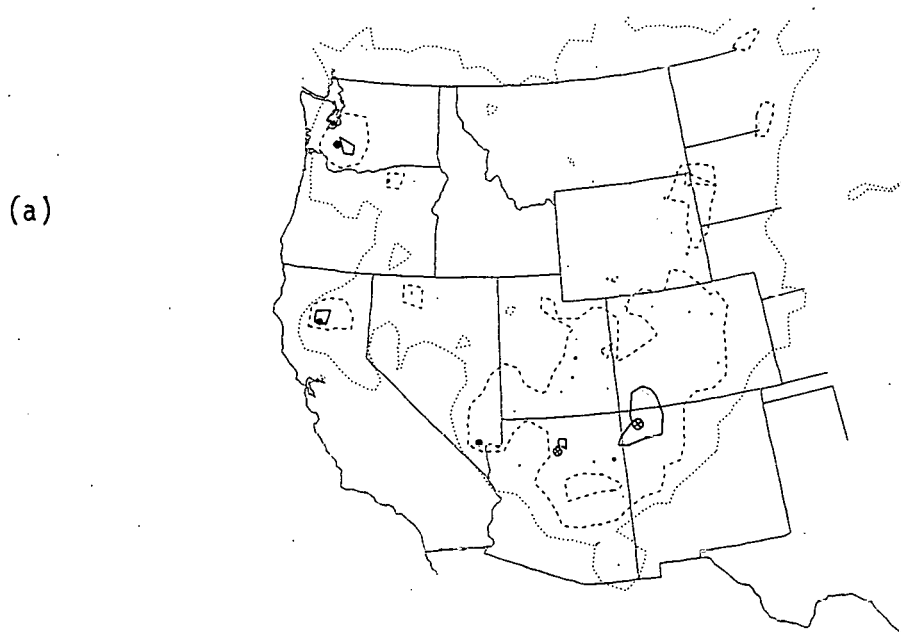
— 05  $\mu\text{g}/\text{m}^3$   
- - - 01  
..... 001

FIGURE 10. Sulfate Air Concentrations for (a) 1985 and (b) 1990 Industrial Coal Use



— 100 mg/m<sup>2</sup>  
 ..... 50  
 5

FIGURE 11. SO<sub>2</sub> Deposition Amounts for (a) 1985 and (b) 1990 Utility Coal Use



-----  
—— 5 mg/m<sup>2</sup>  
..... 1  
..... 0.1

FIGURE 12. Sulfate Deposition Amounts for (a) 1985 and (b) 1990 Utility Coal Use

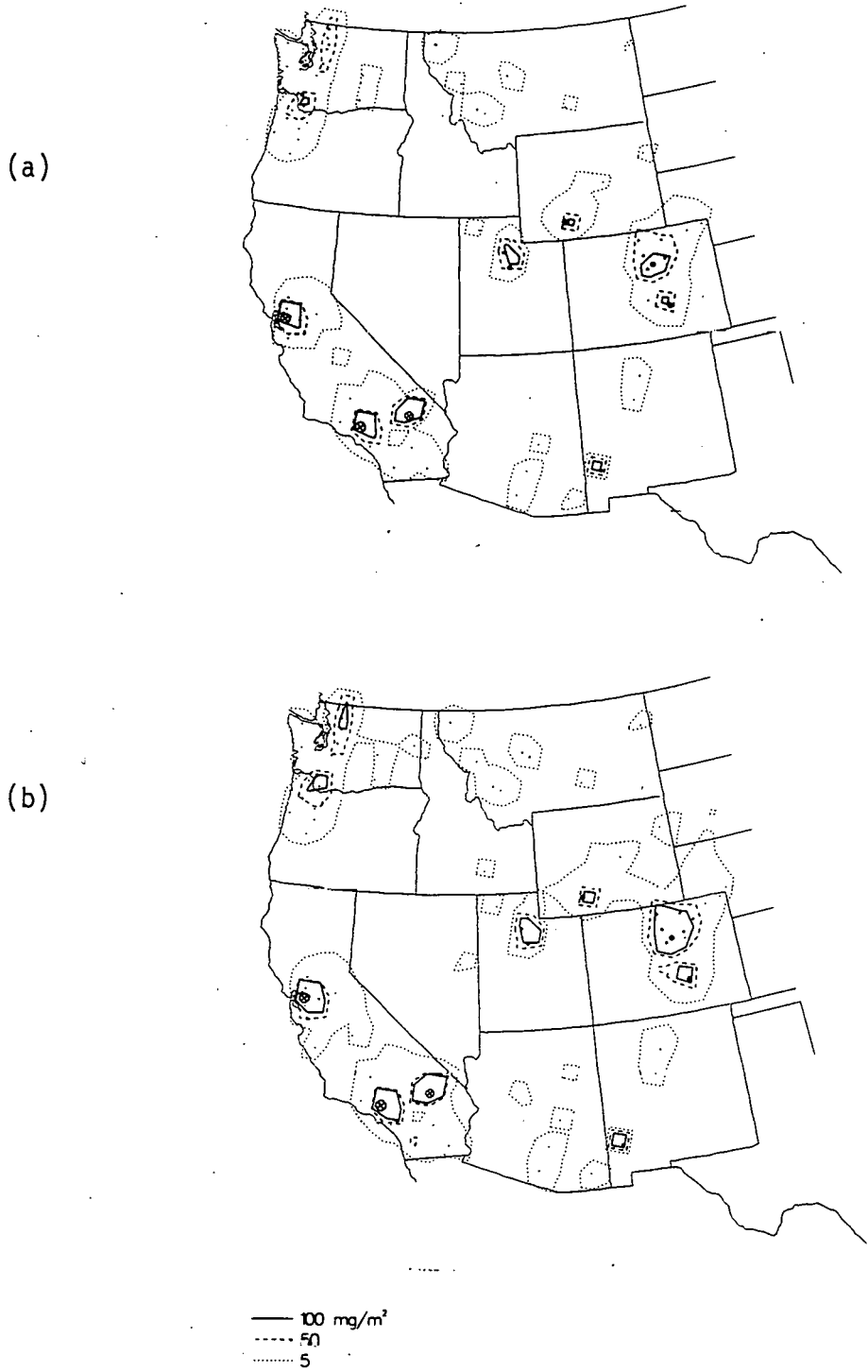
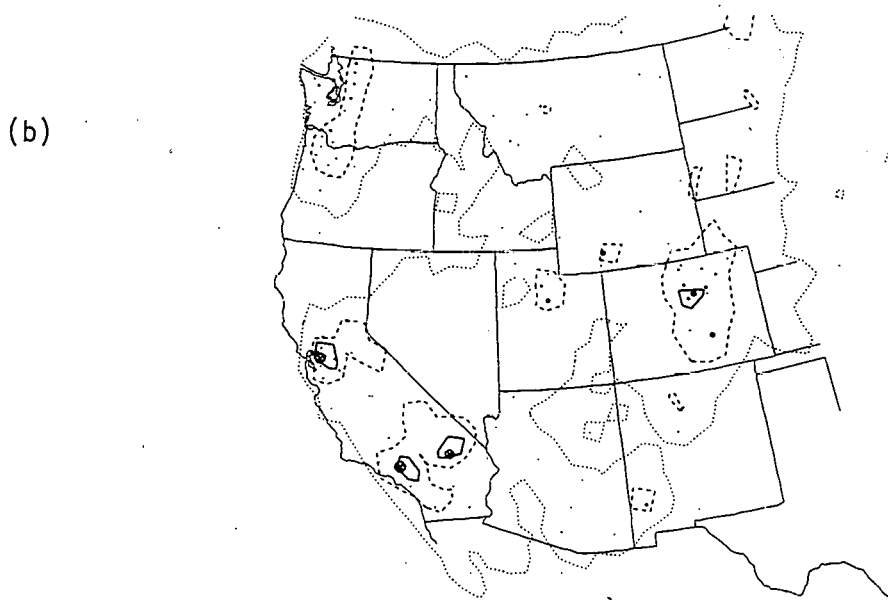
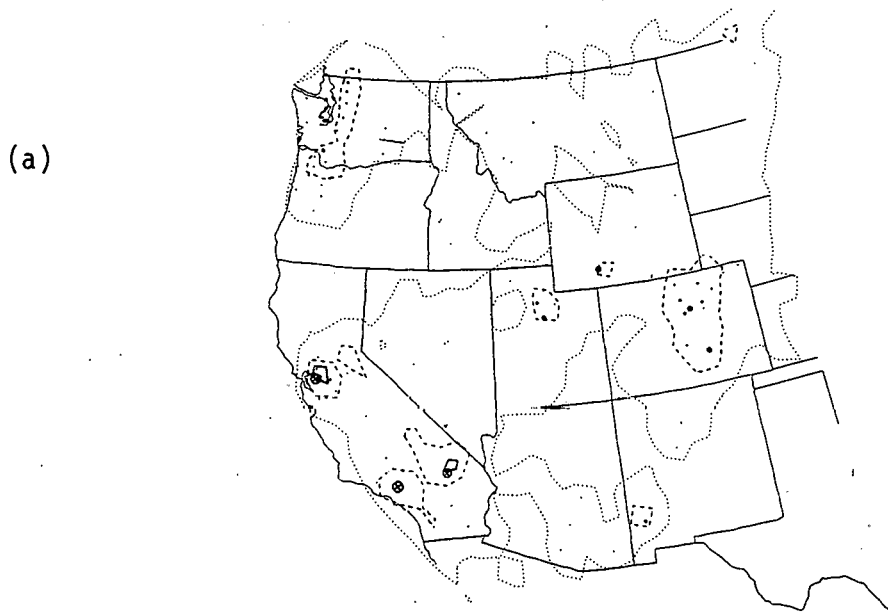


FIGURE 13. SO<sub>2</sub> Deposition Amounts for (a) 1985 and (b) 1990 Industrial Coal Use



— 5 mg/m<sup>2</sup>  
- - - 1  
· · · 0.1

FIGURE 14. Sulfate Deposition Amounts for (a) 1985 and (b) 1990 Industrial Coal Use

## SO<sub>2</sub> AND SULFATE BUDGETS

SO<sub>2</sub> and sulfate budgets allow determination of the final location of the emitted pollutant. It can remain in the air, deposited on ground surfaces, or transported off the sampling grid.

### Industrial Sources

Total SO<sub>2</sub> and/to sulfate budgets (percent of total mass emitted that is deposited, remains in the air, or is transported off the grid), are presented in Table 5 for each industrial coal use scenario. The budgets are based on 69 and 79 source locations, respectively, for the two scenarios. Sulfur dioxide emissions for these scenarios were respectively, 278.9 and 428.8 kilotons/yr. Very little percentage change is noted between scenarios. In general, variations in meteorological conditions and terrain characteristics affect the removal of SO<sub>2</sub> before it is transformed to sulfate. As this analysis shows, a large majority of the emitted SO<sub>2</sub> material is deposited on the grid surface. The low transformation rate (0.005 hr<sup>-1</sup>) also limits sulfate formation before SO<sub>2</sub> removal.

### Utility Sources

Similar data on SO<sub>2</sub> and/to sulfate budgets for utility emissions are given in Table 6.

### ACID RAINFALL

The long-range transport model has the capability to calculate the pH balance of rainfall where precipitation scavenging of airborne SO<sub>2</sub> and sulfates occur. Information on the technique used in this analysis may be found in Powell's study.<sup>(12)</sup>

TABLE 5. Total SO<sub>2</sub> to Sulfate Budget  
for the Western United States  
from Industrial Emissions

<u>Period</u>	<u>Percent</u>						<u>Total</u>
	<u>Left in Air Over Grid</u>		<u>Deposited on Surface of Grid</u>		<u>Transported Beyond Grid</u>		
	<u>SO<sub>2</sub></u>	<u>SO<sub>4</sub></u>	<u>SO<sub>2</sub></u>	<u>SO<sub>4</sub></u>	<u>SO<sub>2</sub></u>	<u>SO<sub>4</sub></u>	
1985	.28	.11	96.17	3.26	.02	.14	99.98
1990	.28	.11	96.15	3.28	.02	.14	99.98

TABLE 6. Total SO<sub>2</sub> to Sulfate Budget  
for the Western United States  
from Utility Emissions

<u>Period</u>	<u>Percent</u>						<u>Total</u>
	<u>Left in Air Over Grid</u>		<u>Deposited on Surface of Grid</u>		<u>Transported Beyond Grid</u>		
	<u>SO<sub>2</sub></u>	<u>Sulfate</u>	<u>SO<sub>2</sub></u>	<u>Sulfate</u>	<u>SO<sub>2</sub></u>	<u>Sulfate</u>	
1985	.83	.26	94.02	4.69	.02	.16	99.97
1990	.80	.25	94.13	4.63	.02	.15	99.97

### Industrial Sources

Minimum pH values are calculated as low as 5.5 for both scenarios. These minimum values would occur in the Los Angeles area of California. However, the magnitude of this pH value is not expected to represent a significant impact.



### Utility Sources

Minimum pH values are calculated as low as 5.3 for either scenario. This value would occur in the Four Corners area.

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## PROBABLE IMPACTS FROM PARTICULATE EMISSIONS

Long-range transport and diffusion modeling of particulate emissions from utility and industrial sources was not made. Since pollutant transformation would not be involved and rapid pollutant deposition would occur, the resulting impact would be localized. When compared to SO<sub>2</sub> emissions, particulate emissions are small because of availability of more efficient control technology. However, existing ambient particulate concentrations, as compared to SO<sub>2</sub> levels, are generally higher, relative to established standards. Nevertheless, particulate concentrations should not be a serious problem for siting future coal facilities: This conclusion was also reached in an earlier air quality assessment for the western U.S. (10)

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## IMPACTS ASSOCIATED WITH EMISSION AND TRANSPORT OF NO<sub>x</sub>, HC AND CO

No prediction of incremental ground-level concentrations of NO<sub>x</sub>, HC, and CO was made because these pollutants, once released into the atmosphere, undergo a complex transformation process. In addition, mobile sources make up a large portion of the emission inventory and cannot be analyzed with our long-range transport model. Instead of predictions, a review of national emission and air quality trends was made, which allows some prediction of future concentrations.

Estimates of nationwide emissions for 1970 through 1975 are given in Table 7.<sup>(8)</sup> The information contained in this table covers a broader range of substances than are measured by routine ambient air monitoring equipment. As an example, the values given for particulates included all manmade particulate emissions, suspended and settled. However, a high-volume air sampler collects only suspended particulates that range from approximately 0.3 to 100  $\mu\text{m}$  in dia.

TABLE 7. Summary of National Emission Estimates  
1970 through 1975<sup>(8)</sup>

<u>Year</u>	<u>(10<sup>6</sup> tons/yr)</u>		
	<u>NO<sub>x</sub></u>	<u>HC</u>	<u>CO</u>
1970	22.7	33.9	113.7
1971	23.4	33.3	113.7
1972	24.6	34.1	115.8
1973	25.7	34.0	111.5
1974	25.0	32.9	103.3
1975	24.2	30.9	96.2

Sulfur dioxide and nitrogen dioxide ambient air monitors measure only those two specific compounds. All the oxides of nitrogen and sulfur are included in the emission estimates. In each case, the compound actually measured is the most prevalent constituent of its pollutant class. Oxidant emissions are not given because a majority of oxidants are secondary pollutants generated by photochemical reactions involving hydrocarbons.

#### EMISSION TRENDS

Most oxides of nitrogen emissions have increased from 1970 to 1975, primarily because of increased fuel consumption by electric utilities. Nitrogen oxides have also increased from highway and non-highway emissions.

Total hydrocarbon emission trends have not changed appreciably from 1970 to 1975. Although hydrocarbon emissions from highway mobile sources have been reduced since 1970, the decrease has been offset by the increase in industrial process emissions and evaporative losses from organic solvent use and petroleum-product manufacturing. These changes reflect the increased production of solvents for industrial uses.

Carbon monoxide emissions have decreased because of the controls applied to highway motor vehicles and the decrease in solid-waste burning. Industrial process emissions have also been reduced by decreases in production and by retirement of older high-polluting industrial processes.

#### AIR QUALITY TRENDS

Over the last several years CO, NO<sub>2</sub>, and oxidant concentrations have decreased. In some cases the reported values are still above standards although the downward trend should continue as new emission controls are developed as a result of revised NSPS.

In addition, the Clean Air Act Amendments of 1977 requires existing standards to be reviewed at 5-yr intervals. The Act also requires states, which do not currently meet standards, to develop methods to do so by December 31, 1987. Since the act may be further modified, predicting if standards will be met at all existing monitoring locations is difficult.

### Carbon Monoxide (CO)

Since the primary source of carbon monoxide (CO) emissions in most cities is the automobile, any location with sufficient traffic density may have a potential CO problem. The problem may be localized, spread throughout a city, or near transportation corridors. Improvements in ambient CO levels are directly related to the control of automobile emissions.

Data from 102 sites in 24 states indicate a downward trend in average CO concentrations. A majority of the sites were in California, thus reflecting a well-established air quality monitoring program in that state. However, the percentage of sites showing a downward trend in average CO concentrations is nearly identical for both California and non-California sites.

A study that involved measuring the carbonxyhemoglobin level in human blood<sup>(8)</sup> indicates similar results in the decrease of CO concentrations. Carbonxyhemoglobin levels for nonsmokers were reduced by 25% from 1970 to 1974. During the same period, the weighted average of CO emissions declined by 22.8%.

### Nitrogen Dioxide

Sufficient NO<sub>2</sub> data are available for trend evaluation at sites in California, New Jersey, Illinois, Colorado, and Oregon. The California data included measured concentrations from the Los Angeles Basin, San Diego Basin, and San Francisco Bay area. The New Jersey data included concentration values from three cities, while concentration values from Denver, Chicago, and Portland represented data from Colorado, Illinois, and Oregon, respectively.

Annual mean NO<sub>2</sub> levels in the Los Angeles Basin dropped from 170 to 140 µg/m<sup>3</sup> from 1970 through 1975. During the same period, the annual average of daily maximum 1-hr NO<sub>2</sub> concentrations dropped from 260 to 240

$\mu\text{g}/\text{m}^3$ . Although both values showed downward trends, the annual mean value was still above the NAAQS.

Examination of data from the San Francisco Bay Area also showed a downward trend in recorded concentration values from 1971 through 1975. Mean  $\text{NO}_2$  levels during these years remained at about  $50 \mu\text{g}/\text{m}^3$ , which is half the NAAQS for  $\text{NO}_2$ . San Diego Basin data for the same period showed no significant trend in the annual average of daily maximum  $\text{NO}_2$  concentrations.

The New Jersey data for 1971 had annual mean levels of  $\text{NO}_2$  ranging from 105 to  $80 \mu\text{g}/\text{m}^3$ . In 1975, the reported concentrations at the same sites ranged from 85 to  $60 \mu\text{g}/\text{m}^3$ . The reduced emissions may reflect the 1973/1974 fuel crisis coupled with the 1974/1975 economic recession.

Nitrogen dioxide trends in Denver were similar to those of the New Jersey sites. A 39% decrease in concentration values was found for the period 1973 to 1975. In contrast, long-term trends for Portland, Oregon, showed a steady increase in  $\text{NO}_2$  concentrations since 1972; however, these levels are still well below the annual standard. In Chicago,  $\text{NO}_2$  levels have fluctuated widely since 1969. No long-term trend is evident, but concentration levels remain above the annual standard.

#### Hydrocarbons/Oxidants

No specific information is provided for trends in hydrocarbon concentrations because no acceptable technique has been developed for measuring ambient hydrocarbon concentrations. Since a photochemical reaction involving hydrocarbons produces oxidants, and oxidant data are routinely measured, trends were investigated.

Data from California indicated a reduction of ambient oxidant concentrations from 1966 to 1975. Approximately 190 days a year the oxidant concentration exceeded  $200 \mu\text{g}/\text{m}^3$ . This figure has remained constant over the last five years, although some improvement was seen in the maximum value recorded.



## ISSUES REQUIRING FURTHER ANALYSIS

Present modeling aspects requiring future analysis are emission data, siting techniques, and model validation. Other potential issues may include air quality impacts resulting from secondary growth, visibility restrictions, and potential climatic change. Each of these items are discussed below.

### EMISSIONS DATA

Based on the technique outlined earlier a uniform emission rate was assumed. However, any seasonal or diurnal variation in emissions was not taken into account. Future studies should explore such variations as higher-than-average release rates combined with specific meteorological conditions that may produce large incremental ground-level concentrations.

### SITING TECHNIQUES

Because siting data from ORNL were computed according to counties the actual locations of emissions were assumed to be at the geographic centroid. This technique ignores water availability, population distribution, restricted area (national parks or wilderness areas) location, and projected land-use patterns. The long-range transport model can locate sites by latitude and longitude. Thus, a more refined siting analysis can be evaluated. The transport and diffusion model is designed to evaluate impacts on length scales exceeding 60 km. Therefore, impacts below this scale are more appropriately evaluated by local diffusion models.

### MODEL VALIDATION

Future studies of model validation are necessary since predicted concentration results are highly dependent on computer simulation performance. A meeting of government and industrial meteorologists was recently held to discuss the accuracy of models describing diffusion on the regional scale since few have undergone verification studies.<sup>(11)</sup> The

meeting concluded that although few experiments departed from estimates of more than a factor of 10, insufficient data exist upon which to base even a "scientific judgment" of estimates of accuracy.

#### SECONDARY GROWTH

Developing coal resources generates other industries that must accommodate the construction and operation work force. Pollutant emissions from construction and transportation place additional burdens on the local air quality. This problem will have to be addressed as soon as specific coal-resource sites are identified. Additionally, air quality impacts resulting from industrial process emissions should be investigated.

#### VISIBILITY RESTRICTIONS

Regulations regarding visibility, as noted earlier may place additional restraints on future power-plant siting, especially as the western U.S. has a large number of mandatory Class I areas. Although it is too early to tell what regulations will be imposed and how they will be regulated, an extensive analysis may be required once definite regulations are established.

## REFERENCES

1. G. C. Holzworth, Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. EPA Research Triangle Park, NC, 1972.
2. Environmental Protection Agency, "National Ambient Air Quality Standards-States Attainment Status." Federal Register, 43(43):8962, Part II, March 3, 1978.
3. Environmental Protection Agency, "1977 Clear Air Act Amendments to Prevent Significant Deterioration." Federal Register, 43(212):57459, November 3, 1977.
4. Environmental Protection Agency, "Standards of Performance for Fossil Fuel-Fired Steam Generators." Federal Register, 36(247):24778, Part II, Subpart D, December 23, 1971.
5. D. S. Renne, "Assessing Low Sulfur Coal Resources in Montana and Wyoming." J. Air Pollution Control Assoc., 26:12, December 1976.
6. D. S. Powell and D. J. McNaughton, "Sensitivity Testing of the MAP3S-PN Regional Model," In: Pacific Northwest Laboratory Annual Report for 1977 to the DOE Assistant Secretary for Environment, Part 3, Atmospheric Sciences, PNL-2500 PT3, Battelle, Pacific Northwest Laboratory, Richland, WA 99352, February 1978.
7. L. L. Wendell, D. C. Powell and R. L. Drake, "A Regional Scale Model for Computing Deposition and Ground Level Air Concentration of SO<sub>2</sub> and SO<sub>4</sub> from Elevated and Ground Sources." Presented at the Third Symposium on Atmospheric Turbulence, Diffusion and Air Quality of the American Meteorological Society, Raleigh, NC, October 19-22, 1976.
8. W. F. Hunt, Jr., ed, "National Air Quality and Emission Trends Report, 1975." EPA-450/1-76-002, November 1976.
9. Environmental Protection Agency, Air Quality Data-1975 Annual Statistics. EPA-450/2-77-002, May 1977.
10. D. S. Renne, W. J. Eadie and D. L. Elliott, "Air Quality Impacts." In: The Impact of Increased Coal Consumption in the Pacific Northwest, BNWL-RAP-21, Battelle, Pacific Northwest Laboratories, Richland, WA 99352, March 1978.
11. T. V. Crawford, Atmospheric Transport of Radionuclides. DP-MS-77-116, E. I. duPont de Nemours & Co., Savannah River Laboratory, Aiken, SC 29801, 1977.

12. D. C. Powell, "Calculation of Rainfall pH on a Multistate Scale,"  
In: Pacific Northwest Laboratory Annual Report for 1977 to the DOE  
Assistant Secretary for Environment, Part 3, Atmospheric Sciences,  
PNL-2500 PT3, February 1978.

APPENDIX A

## APPENDIX A

### DESCRIPTION OF LONG-RANGE MODEL

The long-range transport model applied in this study computes ground-level air concentrations and surface depositions of SO<sub>2</sub> and sulfates, accounting for transport, chemical transformation, dry deposition, and precipitation scavenging. The regional model and techniques applied to approximate the effects of complex terrain on pollutant transport and removal are briefly described here. More complete descriptions of the model and techniques are available.<sup>(1,2,3)</sup>

Transport of the effluents is determined from the spatial and temporal variations of the observed upper-level rawinsonde and pibal winds interpolated to a uniformly spaced grid over the region. The winds are averaged over a specified layer to provide a "layer average" transport, and gridded wind fields are produced for each hour by interpolating between the routine 12-hr observations. Pollutant plume centerlines are simulated by the hourly sequential release of a series of particles from each source location into the wind fields. Average ground-level air concentrations and surface depositions are computed by sampling the plumes, hourly, over an array of grid squares.

The vertical dispersion parameter,  $\sigma_z$ , is computed using the formulas of Eimutis and Konicek.<sup>(4)</sup> In the present study, the vertical distribution factor for each plume element is calculated by assuming a Gaussian vertical distribution from an elevated release modified by reflections from the surface below and from the top of mixing layer above, until the plume element uniformly fills the mixed layer. Horizontal dispersion is accounted for by the spatial and temporal meandering of the plume elements in the wind fields. For the purposes of sampling, the mass associated with each plume element is uniformly distributed over the sampling grid box containing plume element.

A linear oxidation reaction rate is assumed for the transformation of  $\text{SO}_2$  to sulfate. For computing dry removal, the model uses the technique of source depletion. The removal rate is proportional to  $V_d/Z$ , where  $V_d$  is a dry deposition velocity and  $Z$  is a vertical distribution factor asymptotically approaching the depth of the mixing layer. The wet deposition of  $\text{SO}_2$  is assumed to be directly proportional to the precipitation rate, which is determined from hourly precipitational data. The wet deposition of sulfates is assumed to be proportional to the  $5/8$  power of the precipitation rate<sup>(5)</sup>.

Three techniques were used to approximate the effects of the complex terrain in the West on pollutant transport and removal. The first was to increase the network density of upper-air observations by incorporating stations with upper-air pilot balloon wind observations (pibal) at 0600 GMT and/or 1800 GMT. The second technique involved specifying the appropriate layer of winds for transporting the pollutant. For the majority of stations, winds averaged over a layer between 100 and 1000 m above the ground were used to estimate the pollutant transport. However, in mountain valleys and coastal locations the low-level winds are strongly influenced by mesoscale effects such as slope winds and sea breeze circulations. Thus, for rawinsonde stations located in mountain valleys or coastal locations away from the emission sources, 1000 to 2000 m layered winds were used to better approximate the long-range transport. The third technique involved varying dry deposition velocities with terrain types. Deposition velocities were increased by a factor of 2 for forested terrain and 5 for mountainous terrain.

Ground-level air concentrations and surface depositions of  $\text{SO}_2$  and sulfates associated with the 1985 and 1990 industrial and utility coal use emission scenarios were computed using July 1974 meteorological data. July was chosen as a typical worst case month to exemplify the maximum impact of coal-related emissions on air quality. This month is characterized by lighter mean wind speeds than the annual average over most of the United States. Although there were record amounts of precipitation on

the Oregon and Washington coastal regions, precipitation over much of the United States was light during July 1974.<sup>(6)</sup> Thus, the computed concentrations for July 1974 are assumed to equal or exceed typical annual average concentrations. Of course, the computed concentration and deposition patterns may vary somewhat from annual patterns, because of seasonal variations in prevailing wind directions and precipitation.

The verification of the model results with actual data has been examined in an assessment for the northeast United States.<sup>(3)</sup> However, the model results are certainly no more accurate than the collective assumptions of model, and the quantity of available meteorological data (e.g., density of upper-air stations). Nevertheless, the model predictions in this study should be fairly representative (as a first order approximation) of the long-range air quality impacts.

The model input parameters used in the long-range transport analysis for the Western States are shown in Table A-1.



TABLE A-1. Long-Range Transport Input Data

Time period for meteorological data	1 - 31 July 1974
Advection grid spacing (35°N Lat.)	321.2 km
Grid spacing for precipitation data, terrain types, and sampling of results (35°N Lat.)	64.2 km
Effective stack height for utility sources	200 m
Mixing Height (uniform and invariant)	1000 m
Stability (uniform and invariant)	Neutral
Dry deposition velocities <sup>(a)</sup>	
SO <sub>2</sub>	1.4 cm/sec
Sulfates	0.23 cm/sec
Wet Removal coefficients <sup>(b)</sup>	
SO <sub>2</sub>	0.005 P/hr
Sulfates	0.23 P <sup>5/8</sup> /hr
Transformation rate of SO <sub>2</sub> to sulfates	0.005/hr
Percentage of sulfates in original emissions	0.02 (2% of emission)

<sup>(a)</sup> These were values for low roughness terrain. Deposition velocities were varied over different terrain types.

<sup>(b)</sup> P = rainfall rates, mm/hr. Temporal and spacial variations in P were determined from hourly precipitation data.

## REFERENCES

1. D. S. Renne and D. L. Elliott, Regional Air Quality Assessment for Probable Near-Term Coal-Related Energy Development in the Northwest. BNWL-2084-RAP-9, Battelle, Pacific Northwest Laboratories, Richland, WA, October 1976.
2. L. L. Wendell, D. C. Powell and D. J. McNaughton, "A Multi-Source Comparison of the Effects of Real Time Precipitation Data on SO<sub>2</sub> and Sulfate Particulate Removal in a Regional Assessment Model." Preprints of the Joint Conference on Applications on Air Pollution, November 28-December 2, Salt Lake City, UT, 1977.
3. D. C. Powell, D. J. McNaughton, L. L. Wendell and R. L. Drake, "A Variable Trajectory Model for Regional Assessments of Air Pollution from Sulfur Compounds." PNL-2734, Battelle, Pacific Northwest Laboratories, Richland, WA, November 1978.
4. E. C. Eimutis and M. G. Konicek, "Derivations of Continuous Functions for the Lateral and Vertical Atmospheric Dispersion Coefficients." Atm. Environ., 6, 859-863, 1972.
5. B. C. Scott and M. T. Dana, "Wet Removal Rates for SO<sub>2</sub> Gas and SO<sub>4</sub> Aerosol." To be submitted for publication in Atmospheric Environment, Battelle, Pacific Northwest Laboratories, Richland, WA, 1978.
6. Climatological Data, National Climatic Center, Environmental Data Service, Asheville, NC.

## APPENDIX B

1985 Utility Emissions

Number	<u>Location</u> county, state	SO <sub>2</sub> Emission, kilotons/yr
1	Apache, AZ	21.5
2	Cochise, AZ	4.5
3	Coconino, AZ	58.7
4	Navajo, AZ	11.9
5	Tehema, CA	38.1
6	Adams, CO	10.0
7	Boulder, CO	7.6
8	Moffat, CO	5.0
9	Pueblo, CO	9.0
10	Routt, CO	4.9
11	Carbon, MT	4.8
12	Clark, NV	41.6
13	Humboldt, NV	10.8
14	San Juan, NM	72.7
15	Morrow, OR	18.8
16	Carbon, UT	2.0
17	Emery, UT	16.1
18	Garfield, UT	6.0
19	Salt Lake, UT	6.0
20	Washington, UT	2.5
21	Wayne, UT	12.1
22	Lewis, WA	45.0
23	Campbell, WY	10.8
24	Converse, WY	1.6
25	Lincoln, WY	1.6
26	Platte, WY	11.1
27	Sweetwater, WY	11.4

1990 Utility Emissions

Number	<u>Location</u> county, state	SO <sub>2</sub> Emission, kilotons/yr
1	Apache, AZ	25.9
2	Cochise, AZ	9.2
3	Coconino, AZ	58.7
4	Navajo, AZ	15.7
5	Riverside, CA	7.9
6	San Bernardino, CA	7.9
7	Tehama, CA	38.1
8	Adams, CO	12.1
9	Boulder, CO	7.6
10	Moffat, CO	2.9
11	Pueblo, CO	9.0
12	Routt, CO	4.9
13	Elmore, ID	7.7
14	Rosebud, MT	4.8
15	Clark, NV	43.8
16	Humboldt, NV	10.8
17	San Juan, NM	72.7
18	Valencia, NM	1.1
19	Morrow, OR	18.8
20	Emery, UT	18.2
21	Garfield, UT	6.0
22	Salt Lake, UT	6.0
23	Washington, UT	2.5
24	Wayne, UT	12.1
25	Lewis, WA	45.0
26	Lincoln, WA	3.9
27	Campbell, WY	10.8
28	Converse, WY	5.0
29	Lincoln, WY	5.0
30	Platte, WY	3.4
31	Sweetwater, WY	12.4

## APPENDIX C

1985 Industrial Emissions

Number	<u>Location</u> county, state	SO <sub>2</sub> Emission, kilotons/yr
1	Cochise, AZ	1.2
2	Gila, AZ	1.2
3	Pima, AZ	2.6
4	Pinal, AZ	1.6
5	Calaveras, CA	1.2
6	Contra Costa, CA	33.7
7	Fresno, CA	1.1
8	Imperial, CA	2.9
9	Kern, CA	2.5
10	Los Angeles, CA	37.8
11	Orange, CA	1.5
12	Riverside, CA	2.4
13	San Bernardino, CA	29.1
14	San Diego, CA	2.8
15	San Joaquin, CA	3.8
16	Santa Clara, CA	2.7
17	Solano, CA	2.9
18	Stanislaus, CA	2.4
19	Ventura, CA	1.1
20	Yolo, CA	2.9
21	Adams, CO	6.9
22	Arapahoe, CO	1.4
23	Boulder, CO	6.9
24	Denver, CO	15.5
25	Fremont, CO	3.4
26	Jefferson, CO	7.5
27	Larimer, CO	5.0
28	Logan, CO	2.3
29	Morgan, CO	4.2

1985 Industrial Emissions (cont.)

Number	<u>Location</u> county, state	SO <sub>2</sub> Emission, kilotons/yr
30	Pueblo, CO	15.0
31	Sedgwick, CO	1.2
32	Weld, CO	5.3
33	Cascade, MT	2.8
34	Deer Lodge, MT	3.1
35	Lincoln, MT	4.0
36	Missoula, MT	1.7
37	Richland, MT	1.4
38	Silver Bow, MT	1.3
39	Yellowstone, MT	1.3
40	Bernalillo, NM	1.9
41	Grant, NM	9.3
42	Los Alamos, NM	3.4
43	Clackamas, OR	2.7
44	Columbia, OR	1.7
45	Lane, OR	1.3
46	Lincoln, OR	1.8
47	Linn, OR	1.9
48	Marion, OR	1.3
49	Multnomah, OR	1.4
50	Washington, OR	2.0
51	Yamhill, OR	3.5
52	Box Elder, UT	1.1
53	Morgan, UT	1.2
54	Salt Lake, UT	7.3
55	Utah, UT	12.4
56	Benton, WA	2.3
57	Clallam, WA	2.6
58	Clark, WA	3.1
59	Cowitz, WA	8.1

1985 Industrial Emissions (cont.)

Number	<u>Location</u> county, state	SO <sub>2</sub> Emission, kilotons/yr
60	Grant, WA	1.7
61	Grays Harbour, WA	2.0
62	King, WA	4.0
63	Pierce, WA	2.4
64	Skagit, WA	4.6
65	Snohomish, WA	4.0
66	Whatcom, WA	5.5
67	Natrona, WY	1.0
68	Sweetwater, WY	17.6
69	Weston, WY	1.1

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1990 Industrial Emissions

Number	<u>Location</u> county, state	SO <sub>2</sub> Emission, kilotons/yr
1	Cochise, AZ	1.9
2	Gila, AZ	1.9
3	Navajo, AZ	1.3
4	Pima, AZ	4.0
5	Pinal, AZ	2.6
6	Yavapai, AZ	1.3
7	Alameda, CA	1.4
8	Calaveras, CA	1.8
9	Contra Costa, CA	51.6
10	Fresno, CA	1.9
11	Imperial, CA	4.4
12	Kern, CA	4.0
13	Los Angeles, CA	59.0
14	Merced, CA	1.0
15	Monterey, CA	1.2
16	Orange, CA	2.3
17	Riverside, CA	3.7
18	San Bernardino, CA	45.6
19	San Diego, CA	4.3
20	San Joaquin, CA	5.9
21	Santa Clara, CA	4.0
22	Solano, CA	4.4
23	Stanislaus, CA	3.8
24	Ventura, CA	1.6
25	Yolo, CA	4.2
26	Adams, CO	11.3
27	Arapahoe, CO	2.3
28	Boulder, CO	11.4
29	Denver, CO	25.6

1990 Industrial Emissions (cont.)

Number	Location county, state	SO <sub>2</sub> Emission, kilotons/yr
30	Fremont, CO	5.2
31	Jefferson, CO	11.5
32	Larimer, CO	8.3
33	Logan, CO	3.8
34	Morgan, CO	6.9
35	Pueblo, CO	23.0
36	Sedgwick, CO	2.0
37	Weld, CO	8.7
38	Minidoka, ID	1.1
39	Cascade, MT	5.8
40	Deer Lodge, MT	4.3
41	Lincoln, MT	5.1
42	Missoula, MT	2.4
43	Richland, MT	2.1
44	Silver Bow, MT	1.9
45	Yellowstone, MT	1.9
46	White Pine, NV	1.1
47	Bernalillo, NM	2.7
48	Grant, NM	12.5
49	Los Alamos, NM	4.8
50	Clackamas, OR	3.8
51	Columbia, OR	2.4
52	Lane, OR	2.0
53	Lincoln, OR	2.5
54	Linn, OR	2.8
55	Marion, OR	1.9
56	Multnomah, OR	2.0
57	Washington, OR	2.8
58	Yamhill, OR	4.9
59	Box Elder, UT	1.6

1990 Industrial Emissions (cont.)

Number	Location county, state	SO <sub>2</sub> Emission, kilotons/yr
60	Morgan, UT	1.7
61	Salt Lake, UT	9.3
62	Utah, UT	17.8
63	Benton, WA	2.2
64	Clallam, WA	3.9
65	Clark, WA	4.1
66	Cowitz, WA	10.6
67	Grant, WA	2.4
68	Grays Harbour, WA	2.6
69	King, WA	5.5
70	Pierce, WA	2.6
71	Skagit, WA	6.1
72	Smohomish, WA	5.6
73	Spokane, WA	1.2
74	Whatcom, WA	7.9
75	Albany, WY	1.4
76	Carbon, WY	1.0
77	Natrona, WY	3.0
78	Sweetwater, WY	23.4
79	Weston, WY	1.4

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