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LONG-RANGE TRANSPORT OF POLLUTANTS IN THE PACIFIC NORTHWEST

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INTRODUCTION Our Congress is currently attempting to formulate a workable National Energy Plan (NEP) that will minimize our dependence on foreign oil. One plan of the NEP is a two-thirds increase in coal production. To put this plan in effect the NEP would provide for taxes on the use of oil and natural gas to encourage conversion to coal by industries and utilities.

On August 7, 1977, the President signed into law the Clean Air Act Amendments of 1977. This amendment reaffirmed the goal "to protect and enhance the Nation's air resources so as to promote the health and welfare of its population". Numerous new and more stringent requirements were imposed upon operators of major emitting facilities. These requirements can increase the difficulty in obtaining permits for new or expanded facilities. One notable requirement is the regulation for the Prevention of Significant Deterioration (PSD). This regulation is intended to prevent long-term degradation of air quality by specifying allowable increments of concentrations of sulfur dioxide (SO_2) and particulates. This regulation is extremely important to the Pacific Northwest, since a large majority of the land area can only tolerate the lowest pollutant increment. Because air quality regulations have been strengthened, significant conflicts may arise in implementing the NEP and enhancing the air quality. This complex situation is being investigated at the Pacific Northwest Laboratory (PNL) through the Regional Assessment Program (RAP) for the western United States (land area west of 100° longitude). The air quality impact of various NEP scenarios are being studied as a major objective of this study.

The objective of this study is to investigate incremental air quality impacts resulting from the long-range transport, transformation, and removal of sulfur and particulate emissions from both utility and industrial sources. Future facility siting was based on the "business as usual" scenario of energy demand and supply.

Ground-level air concentrations and surface depositions of sulfur dioxide (SO_2), sulfate ($SO_4^=$) and particulates have been computed for major emission sources in the Pacific Northwest (Washington, Oregon, and Idaho). Meteorological data consisted of upper air and precipitation data for April 1974. Emission data for utility and industrial sources is based on either individual state implementation plans (SIP) or the current EPA policy on the best available control technology (BACT). Emission sources could be coal, oil, or gas fueled.

This paper focuses on the modeling techniques and results of the impacts on air quality for projected emissions in 1985. These results provide a comparison to a study of sulfur emissions in the western U.S. that were based on increased coal use (Sandusky and Renne, 1979).

REGIONAL MODELING A regional scale transport, transformation, and removal model developed by Wendell, et.al., (1976) and adapted for use in the western United States by Renne, et. al., (1978) and Sandusky, et.al., (1978) is being utilized to obtain estimates of incremental ground-level air concentrations and surface depositions of SO_2, sulfates, and particulates. Pollutant transport is determined from the spatial and temporal variations of the upper level rawinsonde and pibal winds interpolated to a uniformly spaced grid over the region. Wind data is averaged over a specified layer to provide a "layered-average" transport. Gridded wind fields are produced for each hour by interpolating between the routine 12-hour observations. Pollutant transport is simulated by a plume centerline approximated by the trajectories of massless particles released once each hour from specified source locations. The release is at a specified height above ground level that accounts for plume rise. Average monthly ground-level air concentrations and surface depositions are computed by sampling the plumes over an array of grid squares.

The vertical dispersion parameter, σ_z, is estimated from the formulations of Eimutis and Konicek (1972). Horizontal dispersion about the plume centerline is accounted for by the spatial and temporal variations in the wind field. The atmospheric stability time was dependent on time of day.

A linear oxidation reaction rate of SO_2 to sulfate is assumed. A source depletion technique is utilized for computing dry removal scavenging of airborne SO_2, sulfates and particulates. The washout is directly proportional to the precipitation rate for SO_2 and particulate removal and proportional to a power of the precipitation rate for sulfate removal.

EMISSION INVENTORY Projected utility and industrial pollutant emissions (sulfur and particulates) were based on certain assumptions regarding fuel characteristics as well as appropriate emission standards. For industrial sources State Implementation Plan (SIP) values were used for existing and new, non major fuel burning (MFB) installations (i.e., plants smaller than 100×10^6 BTU/hr). Best available control technology (BACT)

limited emissions for new MFBI's. If the SIP has no emission requirements, then Federal New Source Performance Standards (NSPS) applyed. For utility sources the year of plant start-up determined emission characteristics. For existing plants, emissions were considered to be uncontrolled based on FPC coal characteristics data for 1976. For new or recent plants (start-up after 1975), the Federal NSPS applied. For plants with start-up dates beyond 1983, BACT was assumed that required 85% annual average SO_2 removal with an 0.2 lb $SO_2/10^6$ BTU emissions floor.

Other assumptions included heat rate for coal and oil, and the characteristics of coal burned in the region. For the EPA Federal Region X (Washington, Oregon, Idaho) these values were 0.53% and 15.2% for percent of sulfur and fly ash in the coal.

The assumptions employed in computation of the emissions are considered to be valid for this initial assessment. The implementation of BACT and possible future revision to NSPS are certainly important issues. Primary sulfate emissions are assumed to be 2% of the total SO_2 emissions.

The actual siting scenarios by counties was developed within the Oak Ridge National Laboratory (ORNL) Regional Studies Program. Factors considered in the siting, among others, were water availability, existing air quality, and relationship to existing load centers for utility sources. In this assessment the actual site location is considered to be the geographic centroid of the county.

METEOROLOGICAL DATA AND MODEL FEATURE Both rawinsonde and upper air pilot balloon wind observations (pibals) are used to generate the gridded wind fields. Maximum data coverage was sought to eliminate as much as possible the large-scale topographic influences on the wind field. This is particularly important in much of the Pacific Northwest since this area is dominated by complex terrain. Figure 1 shows the upper air network of rawinsonde and pibal stations used in this assessment. Those pibal stations located in isolated mountain valleys or sheltered locations were not used for this analysis.

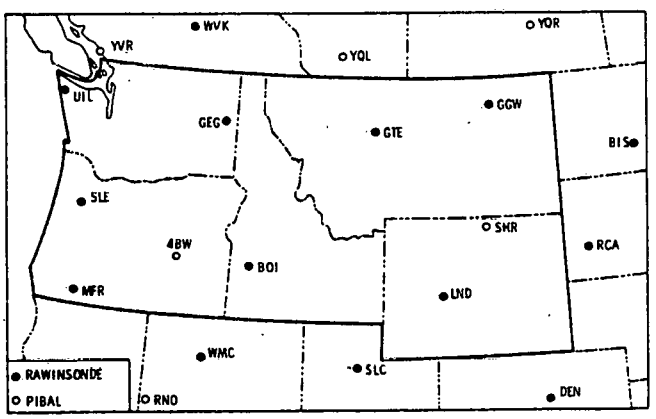

Figure 1. U.S. and Canadian Meteorological Stations Utilized in the Interpolated Wind Fields. Additional Stations Off the Grid are Used for Interpolating Winds Near the Grid Boundaries.

For most of the stations, winds averaged over a layer between 100 and 1000 m above the ground were used to estimate the pollutant transport. In some cases, however, emission source may be located on a broad plateau while the nearest upper air station is in a confined valley. Under these conditions averaged winds between 1000 to 2000 m for the nearby stations were used so as to allow the interpolated winds to be above the influence of the local topography.

A model feature employed to approximate the effects of the complex terrain on pollutant transport and removal was to vary dry deposition according to terrain height. This approach has been used in other regional assessments (Elliott and Renne, 1977). Specifically the deposition velocity is increased by a specified factor depending on terrain type. Factors range from 2 for forested terrain to 10 for very mountainous terrain.

Summary of Model Input The input parameters used in the assessment model are shown in Table 1.

Table 1

Model Input Data

Time period for meteorological data	1-30 April 1974
Advection grid spacing (60°N Lat.)	269 Km
Grid spacing for precipitation data, terrain types, and sampling of results (34°N Lat.)	38.4 Km
Effective stack height for utility sources	200 m
Mixing height	Variable
Stability	Variable
Dry deposition velocities[a]	
SO_2	1.4 cm/sec
Sulfates	0.23 cm/sec
Wet removal coefficients[b]	
SO_2	0.058 P/hr
Sulfates	.38 $P^{.73}$/hr
Transformation rate of SO_2 to sulfates	0.005/hr
Percentage of emissions as primary sulfates	0.02 (2% of emission)

[a] These were values for low roughness terrain. Deposition velocities were varied over different terrain types.

[b] P = rainfall rates mm/hr. Temporal and spacial variation in P were determined from hourly precipitation data.

RESULTS Average incremental ground-level air concentrations and surface depositions of SO_2 sulfates, and particulates from sited utility and industrial pollutant emissions were computed for a one month data period. The April 1974 data

period was chosen to provide a conservative estimate of annual incremental air concentrations values. Deposition values, however, are for a one month period only.

Predicted incremental concentrations are compared to the PSD values allowed under the Clean Air Act Amendments of 1977. No National Ambient Air Quality Standards (NAAQS) or PSD limits for sulfate currently exist. However, the air quality standard for sulfate that has been adopted by Montana and North Dakota will be used as a basis for comparison. For those states the maximum allowable annual sulfate concentration is 4 $\mu g/m^3$.

SO_2 Concentrations Annual average incremental concentrations of SO_2 are shown in Figures 2 and 3 for utility and industrial sources considering the 1985 siting scenario. Maximum values in both cases are localized. Terrain effects are more obvious for the industrial siting scenario.

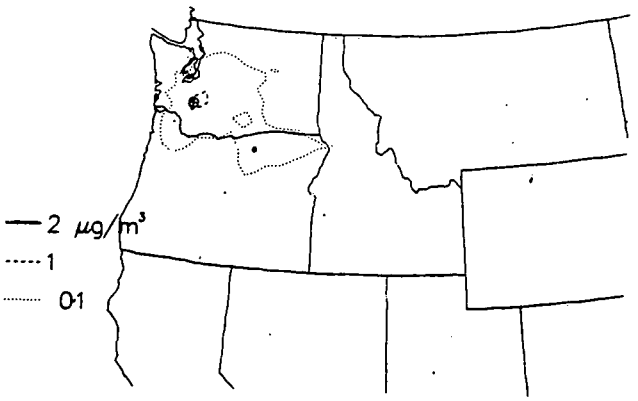

Figure 2. Incremental SO_2 Air Concentrations for 1985 Utility Siting

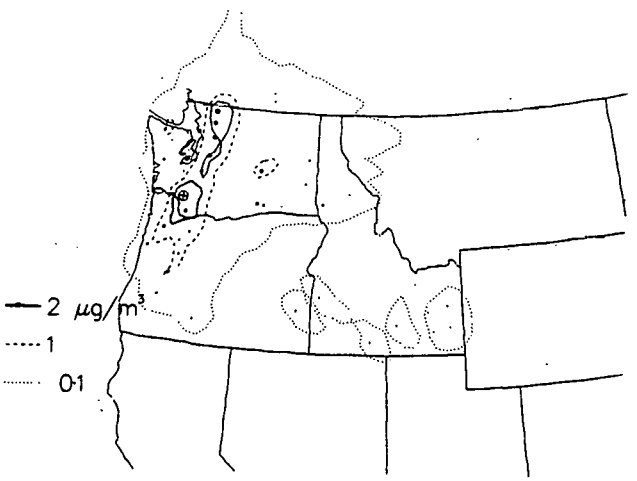

Figure 3. Incremental SO_2 Air Concentrations for Industrial Siting

For the industrial siting analysis the actual facility stack height, if greater than 100 meters, was used as the effective release height. If the actual stack height was less than 100 meters it was set to 100 meters. Therefore increasing deposition velocity due to terrain roughness depleted the plume rapidly east of the Seattle-Portland emissions corridor. Utility emissions, having an effective release height of 200 m, are transported over larger distances.

Largest annual average incremental SO_2 concentrations predicted by the model are 6.6 and 1.4 $\mu g \cdot m^{-3}$ for industrial and utility emissions, respectively. Therefore the PSD limits for a Class II area is not exceeded. However, since this value is an average for a 4100 km^2 grid, higher concentrations would be computed near the source using a short-range Gaussian plume model. This analysis does show that emissions from industrial emissions can be transported over large distances and impact areas where only small incremental increases (i.e., 2 $\mu g \cdot m^{-3}$ for Class I areas) in air concentration are allowed. Those Class I areas in the Pacific Northwest U.S. are given in Figure 4.

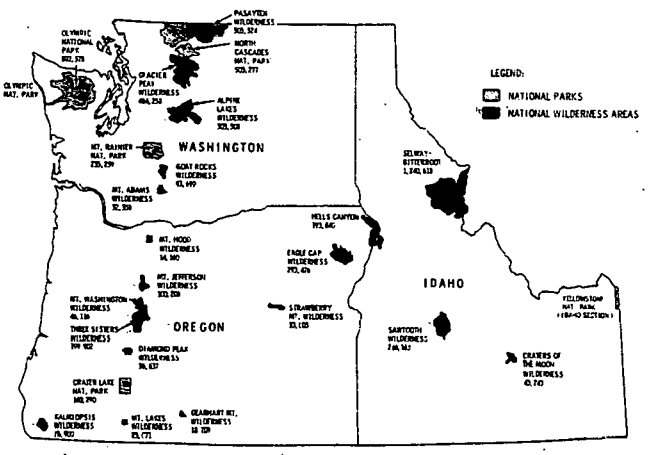

Figure 4. Mandatory Class I Areas in the Pacific Northwest

Sulfate Concentrations Our analysis that show the highest incremental sulfate values are near the emission sources. This is primarily due to the assumption of initial sulfate emission (i.e., 2% of total emission) and low transformation rate of SO_2 to sulfate. The lower concentrations of sulfate (i.e., 0.01 $\mu g\ m^{-3}$), however, cover large regions of the Pacific Northwest. Maximum annual average incremental concentrations of sulfate predicted by the model were 0.4 $\mu g\ m^{-3}$ for industrial emission and thus do appear constrained to future siting.

SO_2 and Sulfate Budgets Total SO_2 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 2 for both industrial and utility coal use. The budgets are based on 39 industrial and 4 utility source locations.

Table 2

Total SO_2 to Sulfate Budget for the Western United States

	Percent					
	Left in Air over Grid		Deposited on Surface of Grid		Transported Beyond Grid	
Source	SO_2	SO_4	SO_2	SO_4	SO_2	SO_4
Industrial	1.85	.58	85.28	6.32	.9	3.70
Utility	2.73	.74	87.32	9.74	.9	3.59

Sulfur dioxide emissions for these scenarios were respectively, 225.6 and 35.4 kilotons/yr. In general, variations in meteorological conditions and terrain characteristics affect the removal of SO_2 before it is transformed to sulfate. As this table shows, a large majority of the emitted SO_2 material is deposited on the grid surface. The low transformation rate (0.005 hr^{-1}) also limits sulfate formation before SO_2 removal. The percent of SO_2 deposited from industrial sources is slightly higher but undoubtedly due to the lower effective release height.

Particulate Concentrations The annual average incremental particulate concentration is shown in Figure 5 for industrial sources considering the 1985 siting scenario. As in the case for SO_2 concentrations the maximum values are localized.

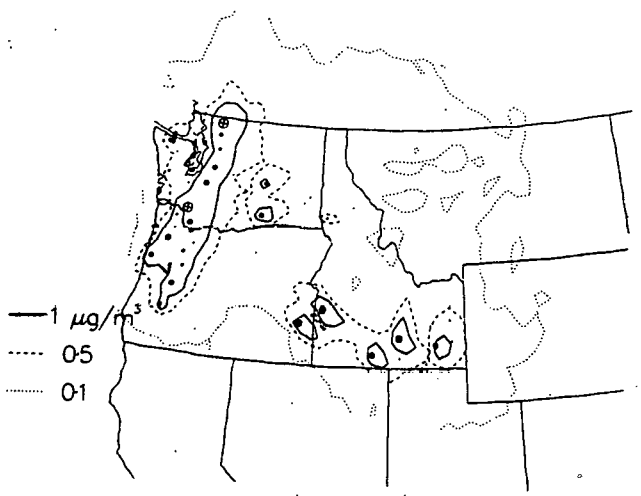

Figure 5. Incremental Particulate Concentrations for 1985 Industrial Siting

Largest annual average incremental particulate concentrations predicted by the model are 4.0 and 1.0 $\mu g \cdot m^{-3}$ for industrial and utility emissions, respectively. Particulate PSD limits for Class II areas are not exceeded. We would expect, however, that within the computational grid that higher values would exist.

SUMMARY AND CONCLUSION Air quality impacts associated with future utility and industrial siting as defined by the "business as usual" scenario have been analyzed. This analysis is based on assumptions regarding emission rates, implementation of BACT, siting data generated by the ORNL regional studies program, and a regional scale transport, transformation and removal model for SO_2, sulfates, and particulates. Results of this assessment show:

- Industrial siting in the Portland-Seattle area may be constrained due to regulations for Prevention of Significant Deterioration (PSD) in terms of both incremental SO_2 and particulate concentrations at sites near Class I areas. This assessment shows that both industrial and utility siting will not be constrained due to sulfate concentrations.
- Topography influences the concentration patterns of the pollutants. Generally, these patterns reflect the wind flow characteristics but are modified by dry deposition processes.
- Maximum predicted ground-level concentrations of SO_2, sulfate, and particulates occur with 63 km of the source.
- Over 80% of the sulfur emissions in the Pacific Northwest U.S. will ultimately be deposited within the region. The percentage deposited for industrial sources is slightly higher than utility sources due to the lower effective release height.

ACKNOWLEDGEMENTS This work was supported by the Division of Regional Assessment, U. S. Department of Energy.

REFERENCES

Eimutis, E. C. and M. G. Konicek, 1972. "Derivation of Continuous Functions for the Lateral and Vertical Atmospheric Dispersion Coefficient." Atm. Environ., 6, pp. 859-863.

Elliott, D. L. and D. S. Renne, 1977. Regional Air Quality Assessment for Coal-Related Energy Development in the Northwest. Preprints Joint Conference on Applications of Air Pollution Meteorology, Salt Lake City, UT, Amer. Meteor. Soc., p. 386.

Renne, D. S., W. J. Eadie and D. L. Elliott, 1978. "Air Quality Impacts." In: The Impact of Increased Coal Consumption in the Pacific Northwest, BNWL-RAP-21, Pacific Northwest Laboratory, Richland, WA 99352.

Sandusky, W. F., W. J. Eadie and D. R. Drewes, 1978. Long-Range Transport of Sulfur in the Western United States. PNL-RAP-26, Pacific Northwest Laboratory, Richland, WA 99352.

Sandusky, W. F. and D. S. Renne, 1979. Application of Long Range Transport Modeling to Assess Coal Development. Preprints Fourth Symposium on Turbulence, Diffusion, and Air Pollution, Reno, NV, Amer. Metecr. Soc., p. 555.

Wendell, L. L., D. C. Powell and R. L. Drake, 1976. A Regional Scale Model for Compuring Deposition and Ground Level Air Concentration of SO_2 and SO_4 from Elevated and Ground Sources. Preprints Third Symposium on Atmospheric Turbulence, Diffusion and Air Quality, Raleigh, NC, Amer. Meteor. Soc., 318 pp.