UNITED STATES – CANADA
MEMORANDUM OF INTENT
ON
TRANSBOUNDARY AIR POLLUTION

ATMOSPHERIC MODELLING
INTERIM REPORT
FEBRUARY 1981

Work Group 2

This is an Interim Report prepared by a U.S./Canada Work Group in accordance with the Memorandum of Intent on Transboundary Air Pollution concluded between Canada and the United States on August 5, 1980.

This is one of a set of four reports which represent an initial effort to draw together currently available information on transboundary air pollution, with particular emphasis on acid deposition, and to develop a consensus on the nature of the problem and the measures available to deal with it. While these reports contain some information and analyses that should be considered preliminary in nature, they accurately reflect the current state of knowledge on the issues considered. Any portion of these reports is subject to modification and refinement as peer review, further advances in scientific understanding, or the results of ongoing assessment studies become available.

More complete reports on acid deposition are expected in mid 1981 and early 1982. Other transboundary air pollution issues will also be included in these reports.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL RESEARCH LABORATORIES

JAN 14 1981

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for Air, Noise and Radiation
U.S. Environmental Protection Agency
Washington, DC 20460

R. M. Robinson
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Environment Canada
Ottawa, Ontario
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Dear Messrs. Hawkins and Robinson:

We are pleased to transmit under cover of this letter the final interim report of Work Group 2 (Atmospheric Modeling) as required by our terms of reference and work plan. We believe that this report satisfies, in a scientifically responsible manner, our Phase I objectives.

Sincerely,

Lowell Smith for

Lester Machta,
U.S. Chairman,
Work Group 2

H. L. Ferguson

Howard Ferguson
Canadian Chairman
Work Group 2

cc: S.E. Ahmad
E.G. Lee

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WORK GROUP 2

ATMOSPHERIC MODELLING

INTERIM REPORT

SUMMARY

As outlined in the Memorandum of Intent, the Atmospheric Modeling Work Group was charged with describing the transport of air pollutants from their sources to final deposition, especially deposition in sensitive ecological areas. The first phase of the work has been completed with the submission of this report. The overall purpose of the report is to describe the development of state-of-the-art, source-receptor relationships based on available model results and measured deposition values from monitoring networks. Though this exercise is in a preliminary stage, it is believed that the activities of the Group have produced the best available information to guide transboundary air pollution control strategies in both countries.

Several models have been developed in both Canada and the U.S. which could be used for long-range transport studies. The Group decided to use only models that met certain criteria. In general, the models had to be fully operational, numerically practical, flexible enough to include new data and other such factors. Features of the individual models are reviewed in this report.

The long-range transport models selected for intercomparison in this report have several important features. These models use emission and meteorological data, and meteorological,

chemical and empirical parameters to calculate the transport of a given pollutant to a sensitive area. To date the models have been successful in describing sulfur deposition on an annual basis. Hydrogen and nitrate ion deposition, two important factors in acid rain, have not yet been successfully incorporated in the models. Initial source-receptor relationships for sulfur have been determined using model calculations.

If the models are to be useful to satisfy the requirements of the Memorandum of Intent, a quantitative relationship between pollution emissions and deposition in sensitive areas must be established. To do this, a transfer matrix approach has been adopted. Theoretically, by using this method, a change in a source strength can be tied to a change in the deposition amount of the given pollutant in a sensitive area. Preliminary transfer matrix results are discussed in this report, but these results are subject to future changes, possibly significant, as modeling techniques are refined. Though preliminary in nature, the report sets up the needed framework to produce a more accurate transfer matrix during Phase II.

In order to check the accuracy of the models, field measurements of the deposition from the existing monitoring networks in both countries are required. At present, wet deposition/acid rain is being measured reasonably well.

Dry deposition, an important factor in ecological effects, can not yet be measured on a routine basis. Existing deposition data will be used to evaluate the selected models utilized by the Group throughout its Phase II effort.

Though the long-range transport models do have restrictions on their usefulness, they are an important and possibly the only guide to establishing source receptor relationships. Their further development and intercomparison will be an ongoing activity of the Group in Phase II.

LIST OF CONTRIBUTORS

This Phase I report was prepared by members of Work Group 2 as listed below. Authors carried the primary responsibility for chapters and monitors provided writing and reviewing assistance. Reviewers provided comment on final draft sections. In all cases Canadian and U.S. Work Group members worked closely on the preparation of individual chapters and on the final construction of the complete report. Drs. L. Smith and D. M. Whelpdale were responsible for coordinating the preparation of the report.

Chapter	Title	Author(s)	Monitor(s)	Reviewer(s)
1	Introduction	D. Whelpdale L. Smith		P. Choquette J. Blanchard
2	The Role of Modeling in the Development of Emission Control Strategies	A. Venkatram	B. Niemann	P. Choquette R. Morris
3	Summary of Selected Models	B. Niemann J. Young	M. Olson J. Miller	G. Paulin K. Demerjian K. W. Yeh
4	Source Region and Sensitive Area Development and Transfer Matrix Operation	L. Smith B. Niemann	D. Whelpdale	G. Paulin B. Silverman K.W. Yeh
5	Source-Receptor Relationships	P. Altshuller P. Summers		P. Choquette R. Kane
6	Monitoring	J. Miller	D. Whelpdale	G. Paulin F. Burmann
7	Conclusions, Recommendations and Phase II Work	G. Van Volkenburgh J. Miller		

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Chapter 1

INTRODUCTION

The Atmospheric Modeling Work Group was established under the Memorandum of Intent in order to provide information, based on cooperative atmospheric modeling and analysis of monitoring network and other data, which would lead to a further understanding of the transport of air pollutants between source regions and sensitive areas. In addition, the Group was to prepare proposals for the "Research, Modeling and Monitoring" element of an agreement. The Terms of Reference of the Group and Work Group membership are contained in Appendices 1 and 2, respectively.

The purpose of this Phase I report is to provide as complete a response as possible to all the scientific and technical areas identified in the Terms of Reference and as specified in its approved work plan. During Phase I the Work Group has devoted its efforts to:

(1) Preparing a work plan for the first two phases;

(2) Identifying required inputs from and outputs to other Work Goups;

(3) Developing data bases and analytical methods which will be required in subsequent work;

(4) Developing preliminary source-receptor relationships based on available modeling results which can be utilized in Phase II by other Work Groups; and

(5) Developing a glossary of terms which all Work Groups can use (see Appendix 3).

During Phase II, the Work Group will:

(1) Endeavor to evaluate several selected models against available monitoring data sets and to intercompare further these models and their results with one another;

(2) Review the science of atmospheric transport and deposition of pollution in order to understand better the applicability and limitation of available models to predict the response in ambient pollutant concentrations and deposition rates to changes in emission rates; and

(3) Review and improve the source-receptor relationships to be used in the Phase III Work Group effort.

In this regard it is expected that some revision of designated sensitive areas and source areas to be used following Phase II will be accomplished by the appropriate Work Groups during Phase II.

Many advances in understanding the regional and long-range transport of air pollutants have been gained in recent years, in large part due to an expansion of basic research efforts coupled with the development and use of large mathematical models to integrate available scientific information. Even so, it is not possible to describe fully all aspects of air pollution transport on a regional or continental scale. Consequently, many simplifications have been made in the analyses of results presented in this report. A major effort will be made during Phase II to review available research results, both published and unpublished, in order to specify more precisely the validity and range of uncertainty that characterize the methodologies utilized and results presented in this and subsequent reports.

Although many substances may undergo transboundary atmospheric transport and have harmful effects upon either the atmosphere or surface receptors, acid deposition is the phenomenon of primary concern for the first two phases of our Work Group activities. As a consequence, highest priority has been given to the study of oxides of sulfur and nitrogen, the main precursors of acid precipitation. During this first phase, emphasis has also been placed on the development of the "transfer matrix" concept. It is this application of establishing quantitative relationships between sources and sensitive receptors for which mathematical models are uniquely suited, and the development of useful, comprehensible display of this information is of great importance.

This first report is structured to follow closely the terms of reference for the Group. The following two chapters describe the role of models in the particular application at hand, and those models which have been selected for use in Canada and the United States. In Chapter 4 source region and sensitive area development and the source-receptor matrix concept are presented. The fifth chapter, perhaps the most important of this Phase I report, presents source-receptor matrices from the five models for a variety of concentration and deposition parameters. Although these results are of a preliminary nature, they provide a good indication of the values and limitations of the approach, as well as some first estimates of the relative importance of various source regions. Chapter 5 will form the basis for refinements in Phase II, and for the work of Work Groups 3A and 3B. Chapter 6 is a brief survey of available field data, which provide valuable comparisons for the modeling results. The final chapter of this report, "Conclusions, Recommendations, and Work Plan", is of a preliminary nature, but does chart the future course of action of the Work Group. It is intended that the Phase II report will primarily be an elaboration upon this Phase I report; for this reason the report structure will remain the same, with upgrading of information and additions being made as necessary.

A large amount of reference material is available for the modeling work described in this report. This work draws heavily upon what was accomplished in the Canada-United States Research Consultation Group on the Long Range Transport of Air Pollutants as described in their recent reports.* Complete documentation of the models used herein is available, as are references to much other modeling work underway at the present time.

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* Altshuller, A.P. and McBean, G.A., 1980. Second report of the United States-Canada Research Consultation Group on the Long-Range Transport of Air Pollutants. U.S. State Department, Canada Department of External Affairs, November 1980, 40 pp.

Smith. L.F. and Whelpdale, D.M., 1980. Atmospheric Transport and Deposition Modeling· Inventory, Analysis and Recommendations. Report to the United States - Canada Research Consultation Group on LRTAP. December 1980, 123 pp.

These two reports can be obtained from:

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Chapter 2

THE ROLE OF MODELING IN THE DEVELOPMENT OF EMISSION CONTROL STRATEGIES

Goals

Work Group 2 will provide several major output products to Groups 3A and 3B. One of these, a review of experimentally observed atmospheric loadings for hydrogen and sulfate ion, is discussed in Chapter 6 of this report. These loadings will be used by Group 3B as the starting point for planning strategies to reduce loadings in sensitive areas. A second major output is the transfer matrices (i.e., source-receptor relationships) for acid-deposition-related species. These matrices will be the major tool which Groups 3A and 3B will employ to develop strategies for the control of acid deposition species and precursors. Chapters 2 through 5 of this report discuss the development of these matrices in some detail in order that the present and future utility of this tool is well understood.

What is a Long Range Transport Model

Before introducing the concept of a transfer matrix, the concept of modeling in general will be reviewed.

A model is essentially a description of physical or chemical processes in the language of mathematics. Relationships between the variables of the system being modeled are replaced by logical connections or equations in the mathematical model. The model can be used to study the complex cause-effect relationships by well defined rules of mathematics. The long-range transport (LRT) model is a combination of submodels of the physical and chemical processes involved in long-range transport of various species under consideration. In order to keep the computing effort manageable, the submodels of a LRT model are often simplified by parameterization. This means that the LRT model may not reflect the degree of understanding we actually have of long-range transport. However, it is generally believed that the errors introduced by parameterization are not significant when the model outputs are averaged over time scales of the order of several months.

The basic components of a LRT model are

(1) A submodel for the transport of pollutants;

(2) A submodel for the chemical transformations of the pollutants to other (secondary) pollutants; and

(3) A submodel for the wet and dry removal of primary and secondary pollutants as they are transported.

The main inputs to an LRT model are

(1) Emission inventory of pollutants;

(2) Meteorological data such as wind speed, precipitation, boundary layer height and solar radiation;

(3) Ground cover data on the region of interest. This data might include variables such as surface roughness,

vegetative cover, type of surface (land, water), etc.; and

(4) Parameter values.

The precise nature of the input data requirements is a function of the complexity of the long-range transport model and its application.

The main uses and advantages of LRT models include the following:

(1) A model is a vital component of data interpretation. For example, parameters such as the oxidation rate of SO_2 to particulate-sulfate material can be inferred by fitting model results to measurements.

(2) A model can be used to interpolate between monitored observation points. This application is important in the computation of deposition over an area covered by a limited number of monitors.

(3) A model is an invaluable tool in the planning of large scale field experiments and in the design of monitoring networks. Sensitivity studies can be done to determine the relative importance of physical variables to be measured. Also, simulations can be used to estimate the optimal location of monitors.

(4) The computer simulation is the only way to estimate the relative contribution of many different source areas to the deposition at a receptor of interest.

For this last application, the contributions to the depositions or ambient concentrations at a series of receptor areas of interest from a series of specified source regions can be displayed conveniently in matrix form. This format of presentation is called a "transfer matrix" because each element of the matrix expresses, quantitatively, the physical relationship between a specified receptor area and a specified source area for the species and variable of interest. One can thus relate source to receptor, or "transfer" the effect of a change at source to the receptor. The matrix elements can be made independent of source strength, but they are functions of the chemical species, the variable chosen, and the averaging time used.

A transfer matrix is a convenient format in which to display changes in concentration or deposition patterns, corresponding to various emission reduction scenarios. Details of the use of the transfer matrix are given in Chapter 4. The impacts of emission reduction scenarios depend upon the formulation of the matrix, and the matrix in turn is only valid within the limitations of the LRT model used in its construction.

Present Limitations of LRT Models

Our incomplete understanding of the physical and chemical process involved in long-range transport as well as limitations on computing resources prevent us from constructing a "perfect" model. The necessary simplifications introduced into most available models will lead to errors in model outputs. Those areas in which simplifications are most likely to affect model results and which are currently being improved are

(1) The relationship between the H^+ ion and precursor sulfur compounds, especially SO_2;

(2) The characterization of the nitrogen-oxidants cycle in connection with H^+ ion; and

(3) The representation of the wet removal of pollutants via scavenging processes during rain or snow events.

The availability, accuracy and resolution of field measurements also limit both our ability to make reliable model predictions (when the data are used as model inputs) and our ability to assess the degree of uncertainty in model outputs (when the data are used for comparison purposes). In addition, the evaluation of model simulations of total and dry deposition are difficult because dry deposition cannot yet be measured reliably.

Typically, on an annual basis, model estimates and reliable field observations are expected to agree to within a factor of two. It is expected that this range of uncertainty will be narrowed in the future.

The above discussion points out the need for caution when using small differences in model results as a basis for choosing between alternate emission reduction scenarios. For example, a small percentage difference in the deposition contribution from two source regions could not be considered significant; similarly, a small percentage difference at the same receptor using different emission scenarios could not be considered significant.

Phase I Transfer Matrices

In Phases II and III, LRT model limitations will be critically analyzed in terms of current research, and it is expected that some limitations will be removed, and others quantitatively defined. While the "transfer matrices" given in this report must not be used as "final" in the strategy development exercise, it is the opinion of this Work Group that the present matrices can be used by Groups 3A and 3B to begin to consider the major elements of strategies which will alleviate excessive acid deposition. The present matrices can be considered to be qualitatively correct, based on evaluation work done to date by the various modeling groups. Only by having information (albeit qualitative) begin to flow among all the parties concerned in strategy development, can the entire process begin to function in an integrated fashion.

Chapter 3

SUMMARY OF SELECTED MODELS

Types of Models Available

There are two basic types of LRT Models: Lagrangian (trajectory) and Eulerian (grid).

A Lagrangian Model solves the conservation equations in a coordinate system fixed to each moving air parcel.

An Eulerian Model solves the conservation equations in a fixed coordinate system through which air masses are advected and diffused. The computation points are usually arranged in a fixed grid.

All models are then variations of these two basic approaches. One can have, for example, a statistical Lagrangian model or an analytical Eulerian model, the choice being made by the modeler to allow a certain form of output or to use a given form of input data.

The basic types of LRT models can be applied to both short-term (multi-day episodes) and long-term (monthly, seasonal, and annual) simulation periods, and outputs of both can be displayed as point values, areal values, or gridded values.

Work Group II decided that the annual time period should be the primary focus for modeling source-receptor relationships and fluxes for Phases I and II due to the large amount of preparatory work required to provide adequate shorter time period modeling results. A survey of modeling groups (see Appendix 4) revealed that there are about fifteen active modeling efforts in the U.S. and Canada and that the majority of the models are of the Lagrangian type and have been applied to monthly-to-annual time periods. The effort on Eulerian and episode type models has increased during the past year, providing more balance in the overall modeling effort.

Discussion of Models Selected

The models selected for this exercise fulfilled several important criteria, namely:

(1) They are fully operational;

(2) They are numerically practical;

(3) They can be expanded as the knowledge base increases;

(4) They can be used over the geographical and temporal time scales of interest; and

(5) They have each been at least partially evaluated through comparison with measurements.

Two regional air quality simulation models developed in Canada and three developed in the United States were selected for Phase I. It is conceivable that additional Canadian and/or U.S. developed models could be added to or replace this initial group of models as a result of the Phase II work effort. Appendices 4 and 5 summarize current North American modeling efforts and describe more fully those models used in Phase I analysis.

AES-LRT Model

The Atmospheric Environment Service of Canada (AES) has developed and applied a Lagrangian box model to simulate ambient concentrations and deposition patterns of sulfur throughout eastern North America (Olson et al., 1979). The AES-LRT model is based on trajectories, at approximately 600 meters above the surface, which are calculated from each designated receptor four times a day using analyzed winds on the standard numerical weather predicton grid covering North America. As the air parcels follow the trajectories towards the receptor points, sulfur dioxide emissions (1976-1980), mixing heights and precipitation amounts along the path are determined from gridded arrays. The transformation and deposition processes are parameterized linearly. The concentrations at each receptor are combined to form daily, monthly, and annual average concentrations and depositions. An evaluation of the model is being conducted using measured data from several American and Canadian networks for 1978.

OME-LRT Model

The Ontario Ministry of the Environment (OME) has developed and applied a simple statistical model to simulate long term ambient concentration and wet deposition patterns on a regional scale for eastern North America (Venkatram et al., 1980). The dispersion and removal of pollutants and the required meteorological parameters in the OME model are specified in terms of the statistics of these physical processes from wind and precipitation data. The source emission inventory corresponds to the year 1977. The OME model estimates compare quite favorably to measurements of annual wet deposition taken from Canadian and U.S. networks for 1977. The OME model also has been used to calculate the relative contribution from U.S. and Canadian SO_2 emission sources to the sulfur concentrations and wet deposition over eastern North America.

ENAMAP-1 Model

SRI International has developed a trajectory-type regional air quality simulation model (Bhumralkar et al., 1980). This model calculates monthly and annual average concentrations and dry and wet depositions of SO_2 and SO_4. The basic element of the ENAMAP-1 model is the emission of puffs of SO_2 at equal time intervals from all source areas. The puffs are assumed to be well mixed in the horizontal and vertical and to be transported by the mixed layer wind field.

The wind field is determined by objective analysis of available upper-air observations approximately 1500 m above mean sea level. Removal and transformation of the pollutant mass is treated linearly.

SO_2 emissions from the SURE program were used in ENAMAP-1 model simulations. The months of January, April, August, and October 1977 were chosen for model evaluation.

ASTRAP Model

The Argonne National Laboratory has developed the Advanced Statistical Trajectory Regional Air Pollution Model (ASTRAP) under the MAP3S Program for simulating regional sulfur concentrations and depositions on a monthly and annual basis (Shannon, 1980).

The ASTRAP model takes a statistical approach to long-term regional modeling rather than a day-by-day simulation technique. The ASTRAP model is based on the assumption that for long-period averages, i.e., one month or longer, horizontal and vertical dispersion processes can be separated.

The long term horizontal dispersion of individual puffs is represented by dispersion statistics. Vertical dispersion is simulated by numerically integrating the standard one-dimensional diffusion equation to a height of 2100 m.

The transformation and dry deposition processes are linearly parameterized. The wet deposition is a one-half power relationship of precipitation rate. In the ASTRAP Model, seasonal and daily variations in all parameters are taken into account. A wind field is developed from National Weather Service (NWS) data at 1000 metres in the winter and 1800 metres in the summer.

Preliminary model runs have been made in the eastern United States and Canada using 1974 and 1975 meteorological data. The emission inventory (MAP3S) consisted of both point and area sources emissions in the eastern United States and Canada. The model results were then compared with measurements from the SURE data network for 1977 and 1978.

RCDM Model

The Regional Climatological Dispersion Model (RCDM) of Teknekron Research, Inc., (TRI) is an application of the basic model developed by Fay and Rosenzweig (1980). Analytical solutions to the coupled diffusion equations for sulfur dioxide and sulfate concentrations are found through the use of simplifying assumptions. The horizontal eddy diffusivity and conversion and removal rates are uniform in space.

The TRI formulation of RCDM attempted to apply temporal and spatial averaging of the wind data sufficient to eliminate most of the detailed fluctuations while preserving the mean transport field that results from a large number of trajectories. The compromise utilized was to create a seasonal and annual resultant wind vector for each emission cell (state, province or subunit thereof) by averaging available upper air wind data for the eastern U.S. and southeastern Canada (Niemann, et al., 1980).

The conversion and removal parameters used in the RCDM are the same as those used by Fay and Rosenzweig from the literature with an annual mixing height of 1000 metres. The RCDM uses a simple deposition velocity technique to calculate dry and wet depositions of sulfur dioxide, sulfate and total sulfur. The RCDM has been evaluated against historical ambient data and current sulfur dioxide and ambient sulfate and wet sulfur deposition data.

<u>Discussion of Input Parameters Used</u>

Table 3-1 outlines the parameter values for the meteorological and chemical processes used in these models.

The sulfur dioxide transformation rate to sulfate is set at 1%/hour in most models with some seasonal variability allowed.

The sulfur dioxide dry deposition velocity for the Canadian models and ASTRAP is set near 0.5 cm/s and double that for RCDM and ENAMAP. The sulfate dry deposition velocity used varies from 0.05 cm/s (OME-LRT) to 0.4 cm/s (ASTRAP) with most models using 0.1 cm/s.

The parameterization of wet removal shows the greatest variability. Some models use percentage removal as a function of rainfall rate (with 100% removal occurring at rates ranging from 0.67 to 14 mm/h), while others use a constant removal rate during precipitation (with 100% removal occurring in 27.6 to 2.8 hours).

TABLE 3-1. REGIONAL MODEL PARAMETER VALUES FOR EASTERN NORTH AMERICA TRANSPORT SIMULATIONS

PARAMETER	RCDM	ENAMAP - 1	ASTRAP	OME	AES
SO_2 transformation rate (%/hour)	2.4×10^5 [f]	1.0	Diurnal Cycle Summer 1.1 Winter 0.55	1.0	1.0
SO_2 dry deposition velocity (cm/s)	0.83 [h] (1.7×10^5)[g]	1.0	Summer 0.4 (avg.) Winter 0.25 (avg.)	0.5	0.5
$SO_4^=$ dry deposition velocity (cm/s)	0.63 [h]	0.2	Summer 0.4 (avg.) Winter 0.25 (avg.)	0.05	0.1
SO_2 wet removal rate (%/hour)	(1.2×10^5)[g]	28P(t) [a]	$100(h/4)^{1/2}$; $h \leq 4$ [b]	10.8 [e]	30,000 [c]
$SO_4^=$ wet removal rate (%/hour)	(1.6×10^5)[g]	7P(t) [a]	100 ; $h > 4$ [b]	36 [e]	850,000 [c]
Mixing depth (m)	1000	Winter 1150 Spring 1300 Summer 1450	up to 2100 (10 levels)	1000	Climatological [d] by month (mean = 1200m)
Wind Data	resultant average vector wind field, $\overline{U}$ = 3.2m/s $\overline{\theta}$ = 265° True	80 x 80 km grid; representative grid square average $\overline{U} = 0.75\, U_{850mb}$ $\overline{\theta} = \theta_{850mb} - 15°$	191 x 191 km grid, $1/R^2$ analyzed to grid points	long term wind statistics $\sigma_x = U_m T$ $\sigma_y = V_m T$ U_m = 10 m/s V_m = 6 m/s	objectively analyzed at 4 levels on 381 x 381 km grid
		(1977)	(1975)		(1978)

[a] Precipitation rate, P(t) in mm/hr.

[b] Precipitation rate, h, in mm/6 hr.

[c] Scavanging ratio

[d] Based on Portelli (1977) & Holzworth (1967)

[e] Function of average length of wet and dry periods (applies during wet period only)

[f] Chemical conversion time scale (seconds)

[g] Total wet and dry depletion time scale (seconds)

[h] Dry and wet combined

The wind data varies from long-term statistical to 6-hourly, objectively analyzed fields* on grids ranging in size from 80 km x 80 km to 381 km x 381 km. Mixing depth varies from climatological arrays through actual calculated values (from upper air ascents) to fixed values between 1000-1500 metres.

Appendix 5 gives a more detailed description of each of the five selected models and a summary of some preliminary comparisons with measured data.

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* Objective analysis routines variously use inverse-square averaging, arithmetic averaging within a grid square, and a 3-dimensional data assimilation scheme that incorporates hydrostatic and height-wind balance routines.

Chapter 4

SOURCE REGION AND SENSITIVE AREA DEVELOPMENT AND TRANSFER MATRIX OPERATION

The application of LRT models to the development of quantitative relationships between pollution source areas and sensitive receptor areas in the form of transfer matrices requires the identification of appropriate geographical groupings of sources and the identification of sensitive receptor areas.

The transfer matrix application is immediately amenable to control strategy development in that manipulation of source contributions to sensitive areas is easily carried out. Because control strategies (i.e., emission limitations or reductions) would most likely be implemented on a state or sub-state basis in the U.S., and on a province or sub-province basis in Canada, a thoughtful geographical aggregation of sources or grid elements on such a basis is required for model calculations.

This need was recognized early in the EPA/DOE Acid Rain Mitigation Study (ARMS) when areas from the 80 km x 80 km SURE emission grid were aggregated into 60 larger areas which approximated state and provincial areas or represented selected areas thought to be sensitive to acid deposition. These 60 areas were constructed to reproduce total state

SO_2 emissions and boundaries as closely as possible. A table that compares the state and grid-aggregate SO_2 emission totals along with percentage differences is presented in Appendix 6. In most cases differences were less than + 15% and the largest was 32%.

For the present application the SURE grid has been expanded (from 30 x 36 to 40 x 42 elements) to the north and east to include more of southeastern Canada. The expanded grid is now includes 63 aggregated SURE areas (see Figure 4.1), ten of which have been selected to represent major sensitive areas. The total SO_2 emissions in the SURE inventory for the eastern U. S. are thought by EPA to be too high and this situation is presently being reviewed by comparing the SURE SO_2 emissions for the utility sector with those computed using the EPA AIR-TEST program. As a result of this review, revisions in the U.S. emissions inventory are likely to occur during Phase II.

In Phase I and planned Phase II activities, U.S. and Canadian modeling efforts have used different grid systems and areas to generate source-receptor (transfer) matrices. Canadian efforts, similarly based upon the aggregation of sources, have resulted in the delineation of 11 regions. Because of this difference, the 11 Canadian regions, which are based on an aggregation of sources on a 127 km x127 km polar stereographic grid, were projected onto the 63 U.S.

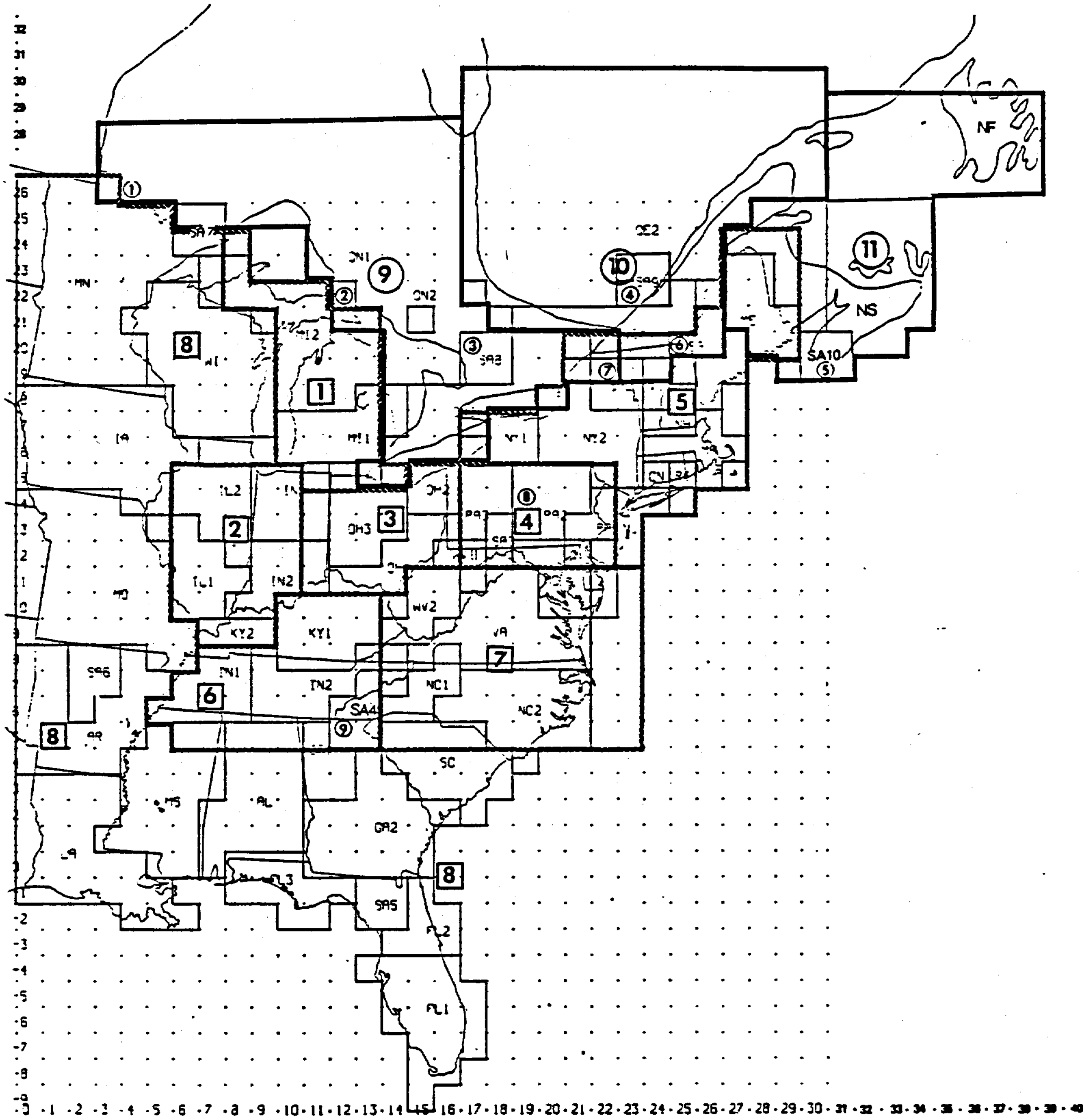


Figure 4.1: Map of eastern North America showing the two sets of geographical regions used in Work Group 2 modeling. Light and heavy (solid in Canada; slashed in U.S.) lines outline regions used by U.S. and Canadian models, respectively. U.S. aggregate SURE grid regions are identified by 2 or 3 character alpha-numeric labels (light), with sensitive areas having 'SA' as the first two characters. Canadian-model source regions are identified by large numbers, in boxes in the U.S. and in circles in Canada, and sensitive areas are identified by small numbers in circles. (See Appendix 6.)

areas, which are based on the 80 km x 80 km Transverse Mercator grid. This projection was necessarily done in an approximate way and some mechanical difficulties and uncertainties still exist in relating the 11 Canadian regions to the 63 U.S. areas.

SO_2 emissions in the 11 Canadian regions and in the 63 U.S. areas are given for comparative purposes in Appendix 6. In addition, a comparison was made between SO_2 emissions used in the Ontario Ministry of the Environment (OME) and the Atmospheric Environment Service (AES) models. Basically, the OME model used emissions that were about 80% of the total emissions used in the AES model for the 8 regions in the U.S., while the emissions used for the 3 regions in Canada were approximately equivalent.

It is expected that early in Phase II, Work Group 2 will be provided with an "agreed" and "unified" Canada/U.S. emissions data base which will be made available to all participating modeling groups. Such a common inventory could be expected to lead to improved agreement in model results.

The Work Group will develop a common basis for specification of source and sensitive areas during Phase II for use in the development of refined transfer matrices for application in Phase III and beyond. This effort will be coordinated with other Work Groups as appropriate for their particular areas of responsibility.

The specification of sensitive areas is primarily the responsibility of Work Group 1, in coordination with Work Group 2. However, in order to commence modeling work, Work Group 2 chose sensitive areas that had been previously identified in the work of ARMS and of the RCG.

The Canadian sensitive receptor areas, which are actually specified as points by latitude and longitude coordinates, and the ARMS sensitive areas are listed in Appendix 6. Six of the 9 Canadian receptor areas fall within the 10 ARMS sensitive areas; two of the Canadian receptor areas are close to ARMS sensitive areas; and two of the ARMS sensitive areas are not included in the Canadian list (Arkansas and Florida). The ARMS sensitive areas were purposely selected to include at least several SURE grid squares (usually 4) and to include areas in which adverse ecological impacts from acid deposition had been detected or were considered probable. (The principal reason for selection of each of the 10 ARMS sensitive areas is provided in Appendix 6).

For future work during Phases II and III Work Group 2 expects that Work Group 1 will provide a list of candidate sensitive areas together with their sensitivities and target sulfur deposition objectives. It is expected that many of these sensitive areas will coincide with those already selected for initial analysis.

The development of quantitative relationships between the sources and receptors identified above is an application for which LRT models are uniquely suited. Specifically, this entails computing how much pollution, in terms of concentration or deposition, arrives at a specified receptor area from a variety of source regions. This information can be presented in matrix form for all parameters of interest, as absolute values, percentages, or normalized values.

Mathematically, the transfer matrix concept may be expressed as

$$D_j = f_{ij} Q_i$$

where D_j is the deposition (or concentration) of the parameter of interest at receptor 'j'; Q_i is the strength of source 'i'; and f_{ij} is an element of the transfer matrix which describes the relationship between the two. The LRT models are used to determine the transfer matrix, examples of which are presented in Chapter 5.

An important future application would involve the estimation of the reduction in D_j (concentration or deposition) due to a reduction in emissions Q_i. Examples of the manipulations which can be undertaken with the relationship include:

(1) The maximization of the reduction in deposition with given constraints on emission reductions.

(2) The minimization of the cost of emission reduction given constraints on the deposition reduction.

These applications are described in more detail in Appendix 7.

Because of the large amount of data to be handled in transfer matrix operations and due to the complexity of the operations themselves, an integrated transfer matrix processing system is under development. This system will be accessed by Work Groups 3A and 3B during Phase II and beyond in order to provide the rapid-response analyses required to support the negotiations following Phase II. The integrated matrix processing system has been designed to handle a variety of inputs and to provide the specific outputs needed by Work Groups 2, 3A, and 3B. At present the integrated processing system consists of five computer programs which format, intercompare, plot, and manipulate the matrices. It is expected that the integrated matrix processing system will be refined and that the operations in program five (least-cost, source-receptor optimization) will be specified by Work Group 3B in Phase II. This system is described in more detail in Appendix 7.

Chapter 5

SOURCE-RECEPTOR RELATIONSHIPS

Introduction

Several long-range transport models are currently available for predicting sulfur deposition and for developing source-repector relationships; these were described in Chapter 3. No models are currently available for predicting either acidity or nitrate deposition.

Eastern North America can be divided up in a variety of ways for purposes of source-receptor modeling as described in Chapter 4. In the United States many modelers have used a basic 80 km grid with the cells aggregated into 63 geographical areas. The ASTRAP and ENAMAP models have been run using the original ARMS 60 areas to produce a 60 by 60 transfer matrix. Of particular interest in the present context is the impact of individual or combined source areas on the ten areas designated as sensitive receptor areas. At a later date when other potential effects (e.g. on agriculture or buildings) are being considered, different sets of receptor areas may be considered.

The Canadian approach has been to aggregate into 11 large source regions, 8 U.S. and 3 Canadian, and 9 receptor areas. Most of the receptor areas selected are the same as those used by the U.S.

The source-receptor relationships

a) United States Models

The results of running the three U.S. models are contained in separate computer print-out files on a 60 by 60 matrix. The matrices are to be consolidated into the eleven source areas used for the Canadian models. These matrices also can be reduced in size by selecting out the columns representing the sensitive receptor areas from the set of all 60 areas. The values are to be presented in the same three ways discussed below for the Canadian models.

For the purpose of illustrating their use, a selected portion of one of the U.S. 60 x 60 matrices is shown in Table 5.1. The three largest U.S. emission source regions (Southern Ohio, Southern Michigan and Southern Indiana) and the largest Canadian emission source region (Sudbury) were chosen, and 10 of the 60 regions were selected as receptors because of their known sensitivity to acid deposition.

This resulted in the 4x10 matrix shown in Table 5.1, and its use can be illustrated as follows. If one is interested in the impact of a given source, for example S Ohio, one reads down the column headed "46 S. Ohio" and the annual deposition of sulfur at each receptor is given. Conversely, if one is interested in the contribution to a given receptor area, for example Adirondack, one reads across the row headed "8 Adirondack".

Table 5.1 Total Annual Sulfur Deposition as Computed from the ASTRAP Model ($KgSha^{-1}\ yr^{-1}$)

	Selected Major Source Areas			
	45 S. Ind.	46 S. Ohio	49 S. Mich.	55 Sudbury
Sensitive Receptor Areas	AST[b]	AST	AST	AST
2. New Hampshire	0.63	1.3	1.6	1.0
8. Adirondack	0.91	2.0	2.5	1.3
15. Pennsylvania	2.3	9.0	2.8	0.15
25. S. Appalachia	2.2	2.2	0.17	0.01
33. Florida	0.08	0.06	0.01	0.0
39. Arkansas	0.38	0.15	0.06	0.0
53. Boundary Waters	0.11	0.11	0.20	0.01
56. Ontario	1.1	2.0	5.1	6.4
58. Quebec	0.61	1.1	2.2	3.5
1. S.N.S.[a]	0.43	0.88	1.1	0.83

a Sulfur deposition in Southern Nova Scotia sensitive area assumed same as for Maine.

b Annual average: computed from winter and summer months.

b) Canadian models

The results from the Canadian models are presented in Appendix 8 in 11 x 9 transfer matrices; for each model annual values of each of the following five variables are given:

(1) ambient SO_2 concentrations

(2) ambient SO_4 concentrations

(3) dry deposition of sulfur

(4) wet deposition of sulfur

(5) total deposition of sulfur

In each case information on the variable is presented in three ways:

(1) normalized to a unit emission from each source

(2) as a percentage contribution from each source

(3) as an absolute value

This gives a total of 15 tables so that there is maximum flexibility in how the results can be used. To provide an example, and to illustrate the use of source-receptor matrices for the Canadian models, Table A8-10 from Appendix 8 is reproduced below as Table 5-2. While the sensitive receptor areas match fairly closely those used by the U.S. modelers, the source regions differ and are much larger. Thus, a direct comparison cannot be made between the results presented in Tables 5-1 and 5-2.

Table 5-2 is used in exactly the same way as Table 5-1. For example, if one is interested in the impact of a given source region such as Ohio, one reads across the row headed "3. Ohio".

Table 5.2: Example of transfer matrix from Appendix 8.
Total annual sulfur deposition in kg ha^{-1} yr^{-1}
(Table A8-10)

		Receptor Areas								
Source Regions	Models	B.Waters (1)	Alg. (2)	Msk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (9)
1 Mich.	MOE	0.10	0.75	1.8	0.58	0.66	1.0	1.6	3.4	0.19
	AES	0.30	4.5	6.7	1.7	0.60	1.6	2.2	4.7	0.30
2 Ill. Ind.	MOE	0.28	1.3	1.8	0.78	0.93	1.2	1.7	4.5	2.8
	AES	0.30	3.5	3.4	0.80	0.40	0.90	1.4	4.2	4.3
3 Ohio	MOE	0.16	0.65	1.4	0.77	1.2	1.4	2.2	10.2	1.0
	AES	0	0.90	6.7	1.8	1.2	3.9	5.9	28.9	2.2
4 Penn.	MOE	0.06	0.26	0.65	0.46	0.91	0.90	1.4	11.8	0.24
	AES	0	0.40	1.9	1.2	0.70	2.8	4.3	26.0	0.20
5 N.York to Maine	MOE	0.05	0.18	0.52	0.66	2.8	1.6	2.3	0.93	0.11
	AES	0	0.40	1.2	2.5	6.5	4.7	6.1	1.1	0
6 Kent. Tenn.	MOE	0.07	0.23	0.35	0.21	0.31	0.33	0.44	1.3	5.0
	AES	0	0.30	1.3	0.10	0.20	0.40	0.90	3.6	15.2
7 W.Virg. to N.C.	MOE	0.08	0.27	0.57	0.46	1.0	0.83	1.1	3.7	0.62
	AES	0	0.10	0.50	0.60	0.50	1.5	2.0	7.3	1.5
8 Rest of (USA) Fld to Mo. to Minn.	MOE	0.22	1.1	0.94	0.37	0.36	0.51	0.68	1.1	2.9
	AES	2.5	4.2	1.8	0.40	0.30	0.50	0.90	3.4	18.7
9 Ontario	MOE	0.14	1.2	3.7	2.3	1.2	2.4	2.6	1.2	0.09
	AES	0.10	3.9	13.2	3.1	1.3	3.8	5.4	3.1	0.10
10 Quebec	MOE	0.06	0.25	0.46	2.3	1.0	3.6	0.86	0.17	0.03
	AES	0.10	0.50	1.2	4.3	1.5	7.2	2.5	0.20	0
11 Atlantic Provinces	MOE	0	0.01	0.02	0.07	0.35	0.07	0.04	0.02	0
	AES	0	0	0	0.10	3.2	0.10	0	0	0
Western Canada	AES	0.60	0.20	0.20	0	0	0	0.20	0	0
Total Concen- tration	MOE*	1.2	6.2	12.2	8.9	10.8	13.8	14.9	38.3	13.0
	AES	3.9	18.8	38.1	16.7	16.3	27.4	31.8	82.5	42.6

*Note: In order to calculate the total deposition at each site, the deposition resulting from background in the amount of 0.2 g.m-2.yr-1 (or 2.0 kg.ha-1.yr-1) should be added to this row.

Conversely, the contributions at a given receptor such as Muskoka can be seen by reading down the column headed "Muskoka".

A comparison of the predictions of the two Canadian models shows that, whilst they agree reasonably well with each other, the AES model generally predicts larger values than the OME model for the absolute values and the emission-normalized values in Tables A8-1 through A8-10.

<u>Comparison of matrix outputs with each other and observations</u>

Each of the models discussed in this Chapter has been compared with observations as described in Appendix 5. But, since the observations consist only of the deposition or ambient concentration at a monitoring station due to all sources, there is no way that each of the contributions in the matrices can be directly verified. However, the total contribution of all sources at each receptor predicted by the models can be compared with the observations. If these do not agree, then clearly there is no justification for using the models further. If the predicted and observed depositions do agree reasonably well, then in the absence of any evidence to the contrary, it can be assumed that the individual contributions in the matrices will probably also be realistic.

Table 5.3 - Comparison of the predicted annual wet deposition of sulfur (kgSha^{-1}yr^{-1}) from selected LRT models compared to the measured values

	Sensitive Areas	Model predictions* Canadian MOE	AES	United States† ASTRAP	RCDM	Observed Values**
1	Boundary Waters	2.6	1.5	< 5+	5	6
2	Algoma	4.7	10.4	10	17	10
3	Muskoka	7.1	17.6	22	20	18
4	Quebec - Montmorency	5.9	9.0	15	13	20
5	Southern Nova Scotia	6.8	5.9	5	6	12
6	New Hampshire	7.9	13.1	15	13	9
7	Adirondack - Whiteface	8.3	15.7	19	18	12
8	Pennsylvania - Penn State	17.2	33.5	>25	26	19
9	Southern Appalachians	7.4	16.7	9	18	12
10	Florida			< 5	8	9
11	Arkansas			< 5	10	9

* Modeled values include wet deposition of SO_2 and SO_4 expressed as S.

** See Table 6.1

\+ Uncertainty due to limited number of isopleths of model predictions.

† Final ENAMAP and ASTRAP results were not available when the report was finalized.

In Table 5.3, the variations among the model predictions are immediately obvious and are due to many diffences such as: the variations in emission inputs; the differing meteorology in the years chosen to run the models; the differences in the values chosen for SO_2 to SO_4 conversion rates and wet and dry deposition. Resolution of these differences will be the subject of a detailed model intercomparison by Work Group 2 as part of Phase II.

The most detailed and reliable deposition observations are for the wet component. The results presented in Chapter 6 for the estimated wet deposition rate at the sensitive sites are compared in Table 5.3 with the predictions of the models obtained from Appendix 8, Table A8-9, and from the U.S. model outputs.

For many of the sensitive areas, the predictions of the two Canadian models agree with the observations reasonably well, with the AES model tending to overpredict and the MOE model tending to underpredict.

We recognize the importance of advising the reader about the confidence with which one can make use of the transfer matrices in this chapter and Appendix 8. These matrices have not yet been thoroughly verified or intercompared, so that it is difficult to assign a quantitative measure of uncertainty to the matrix elements. The differences among model estimates for individual matrix elements are perhaps the best indication of the uncertainty in these values at the present time. On the whole, the matrix elements representing transport between major source areas and those receptor areas within reasonable transport range of the source areas are in relatively good agreement across the models. Where obvious differences exist, efforts have been initiated to determine the cause for disagreement. These efforts are expected to help us understand the reasons for most of the major differences before the end of Phase II.

In the meantime all the model results must be regarded as preliminary. The results are presented here primarily to indicate the type of information and the format that can be provided for use by others. The results also give some useful indications, or trends, regarding the <u>relative</u> importance of various source regions on the sensitive receptor areas presently of interest. But at this time the absolute values of the numbers in the matrices should not be given too much importance and certainly the results of any one model should not be taken in preference to the others. It is expected that Work Group 2 in Phase II and beyond will provide "best estimates" of the values in matrices based on the results of all models, and that other Work Groups will still be advised not to use results of individual models as definitive.

Chapter 6

MONITORING

Whether needed for the study of atmospheric transport or ecological and other effects, the measurement of atmospheric pollutants and precipitation composition and deposition is a vital aspect of understanding long-range transport and acid rain. Modeling research and applications require ground truth measurements with which calculations can be compared. Ecological and other impact studies require the amount of atmospheric input to relate quantitatively loadings to effects. A multistage monitoring program is a necessity to understand both the transport and chemistry in air and their trends as well as the ecological consequences of atmospheric deposition.

In addition, during future Phases, two potential applications of monitoring networks will require evaluation. These are the possible use of monitoring networks to assess the efficacy of control strategies, and the possible use of meteorological and air quality networks as a supplemental part of control strategies.

Monitoring, at least of the chemistry of precipitation, has not been consistently maintained in North America. European scientists began a large international network in the mid-1950's which has been continued more or less intact to the present. Only in recent years have limited commitments been made to long-term monitoring in Canada and the United States.

Precipitation chemistry monitoring networks in Canada and the United States are of three types: global background, national trends and research support. The small number of global background sites are located in remote areas where there is little or no local or even regional pollution. Such sites include American Samoa, Barrow, Alaska, and others. These stations identify long-term trends in the global spread of pollution.

Currently the national trends networks measure the composition of precipitation and wet deposition using wet-only collectors for both atmospheric and ecological purposes. They are long-term, country-wide, national networks: the Canadian Network for Sampling Precipitation (CANSAP), and the National Atmospheric Deposition Program (NADP), a cooperative program involving several U.S. agencies. Several other networks with similar objectives, including those of the Tennessee Valley Authority, EPA Region V, the Ontario Ministry of the Environment and the Great Lakes Precipitation Chemistry Network, are more regionally oriented.

Other networks, such as those of the Electric Power Research Institute (ERPI), of the Multi-State Atmospheric Power Production Pollution Study (MAP3S), Ontario Hydro and the Air and Precipitation Monitoring Network (APN), fall into the third category - research support networks. They are designed primarily to support studies in atmospheric transport, chemistry, and modeling.

As a result of the increased activity in monitoring during the last five years, a combined set of data for North America is now emerging from the Canadian and U.S. networks. Combining several network data sets from 1976 to 1979, Figure 6.1 shows a map of hydrogen ion (H^+) deposition over the North American continent (Wisniewski and Keitz, 1980). The 50 and 10 mg m^{-2} lines represent approximately 4.3 and 5.0 pH lines, respectively. The map shows large acidic deposition in the northeastern part of the United States and southeastern part of Canada. It has been postulated that the geographic extent of increasing rain acidity is spreading toward the southeast and midwest with all states east of the Mississippi River now receiving some degree of rain acidity. Some west-coast sites in both countries also show relatively large hydrogen ion deposition based on recent measurements.

Since it will be some time before models will be able to calculate hydrogen ion deposition, the sulfur deposition values in precipitation may be the best data for comparison with model results. A map of the wet deposition values of sulfur for 1977 in eastern North America is given in Figure 6.2. (Galloway and Whelpdale, 1980). The problem of comparing model results with such data is obvious in view of the complexity of the deposition field. Deposition fields of other substances (e.g., nitrate and ammonium ion) are also necessary for a more complete description of the acid deposition phenomenon. In

Figure 6.1 : Mean annual hydrogen ion (H^+) deposition in precipitation for period 1976-1979 (mg m^{-2} y^{-1}). Deposition values are derived from mean pH and mean annual precipitation. Adapted from Wisniewski and Keitz (1980).

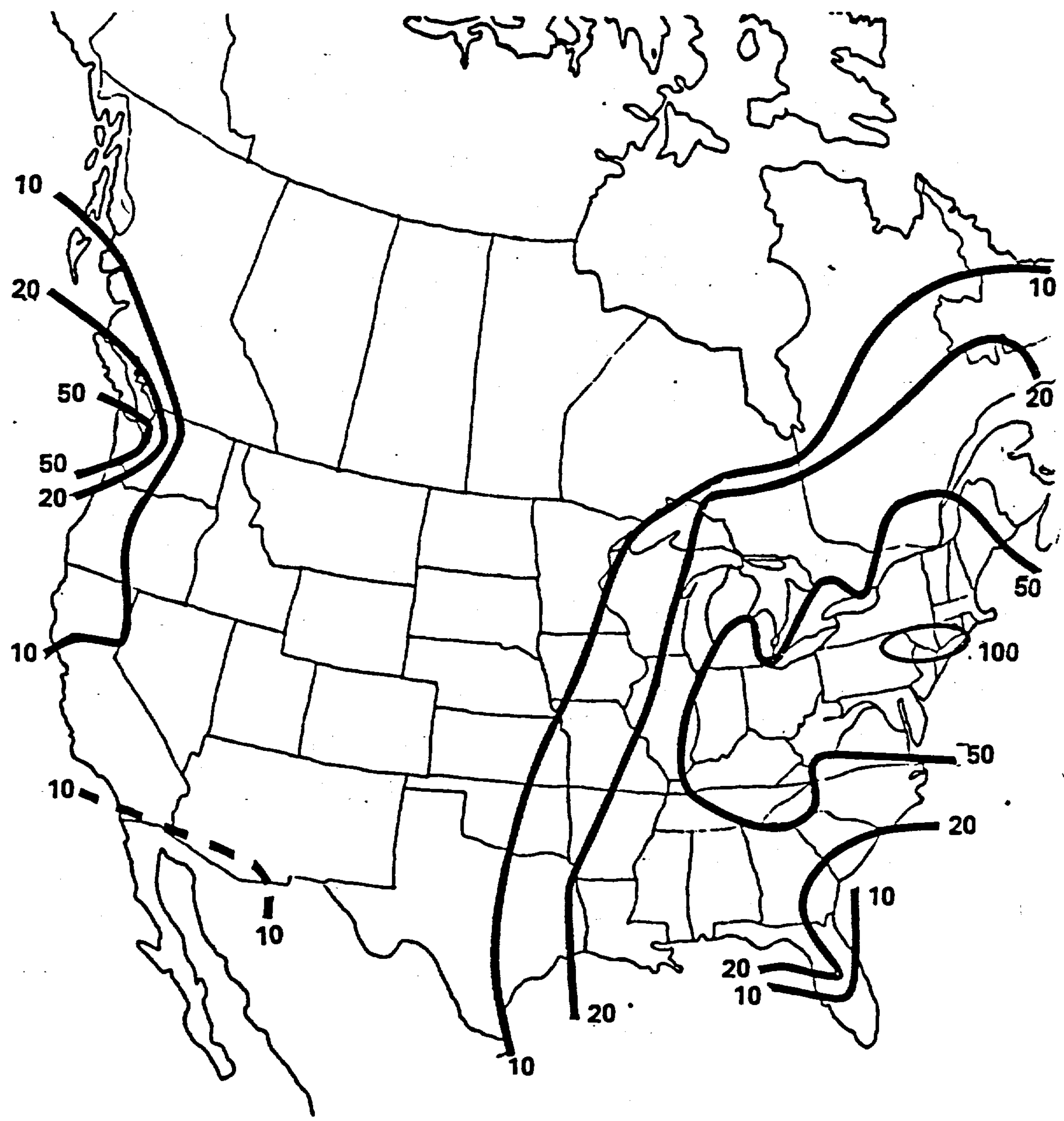
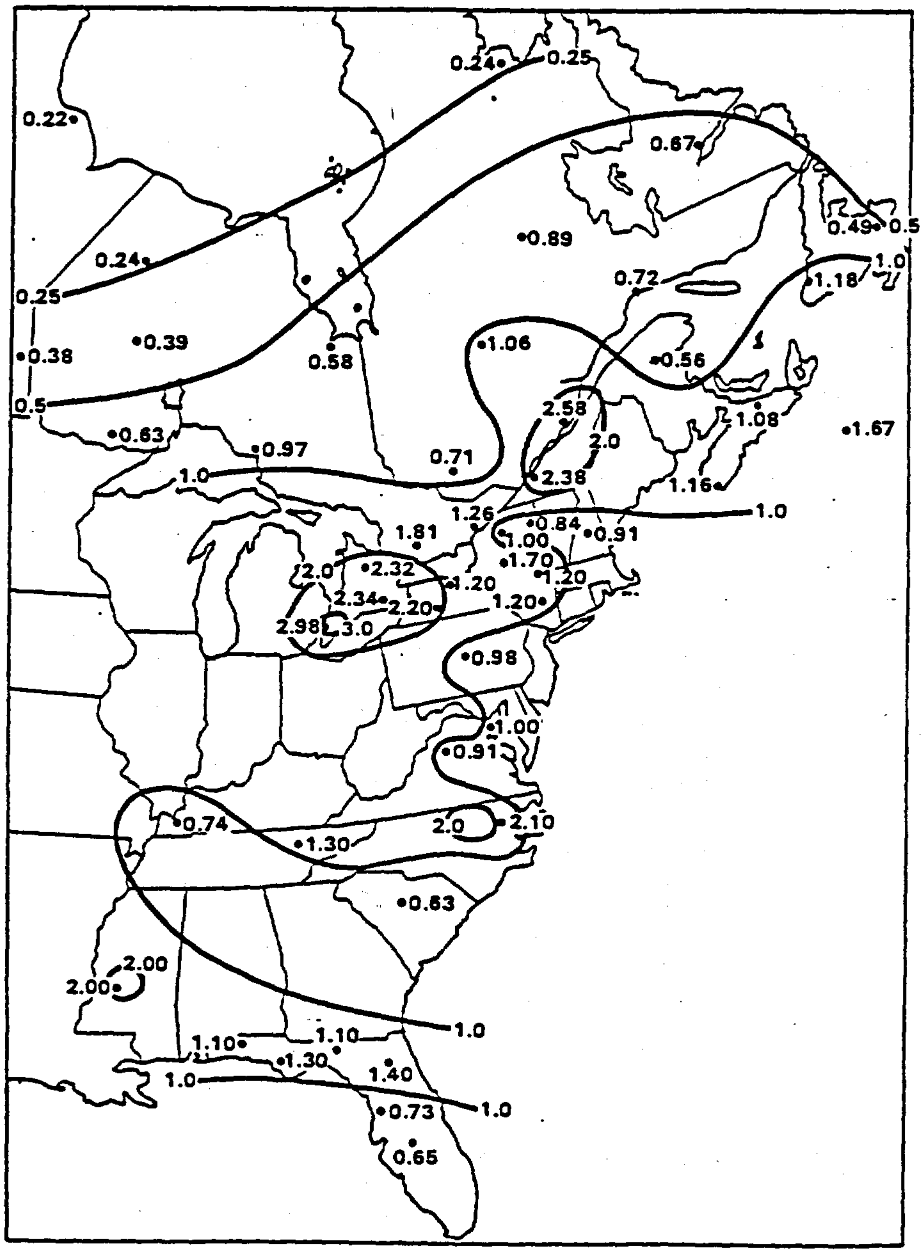


Figure 6.2 : Wet deposition of sulfate (SO_4) in precipitation in eastern North America for 1977 ($g\ S\ m^{-2}\ y^{-1}$). Adapted from Galloway and Whelpdale (1980).



any given year deposition patterns could be quite different from a long-term average due to variations in meteorological parameters, such as the wind and precipitation fields.

Besides the natural variability of precipitation chemistry, the methods used to collect, transport, store, and analyze samples contribute to possible errors in the final data. The isopleths shown in Figures 6.1 and 6.2 were based on data from networks with different measurement techniques. Also, the level of quality assurance varied from network to network. With these considerations in mind, a rough estimate of error for individual data points used in the figures and for values in Table 6.1 can be made of hydrogen deposition to be as high as +50% and of sulfur deposition to be as high as ±25%. As better quality assurance techniques are applied and a large statistical base established, error estimates can be refined.

One of the goals of this Canada - U.S. study is the quantitative evaluation of transport of material through the atmosphere and deposition on sensitive areas. The amount of wet deposition to sensitive areas can be estimated from recent monitoring data collected since 1977. Some such estimates of annual wet deposition of hydrogen and sulfate ion to specified sensitive areas are given in Table 6.1. As a more extensive record of measurements is compiled, both our confidence in average annual deposition values and our awareness of possible deviations of individual yearly values will increase.

Table 6.1 Estimated annual wet deposition of hydrogen and sulfate ion to specified sensitive areas. <u>These data must be considered preliminary</u>. Errors in H^+ and SO_4 values are estimated to be as high as $\pm$50% and $\pm$25%, respectively.

Sensitive Area*	Annual Wet Deposition: H^+ (mg H $m^{-2}y^{-1}$)	SO_4 (g S $m^{-2}y^{-1}$)**
Boundary Waters	10	0.6
Algoma	30	1
Muskoka	70	1.8
Quebec - Montmorency	40	2.0
Southern Nova Scotia	30	1.2
New Hampshire	50	0.9
Adirondack - Whiteface	50	1.2
Pennsylvania - Penn State U.	90	1.9
Southern Appalachians	60	1.2
Florida	30	0.9
Arkansas	30	0.9

* See Figure 4.1 and Appendix 6 for sensitive area locations.

** To convert sulfate loading expressed in terms of S (as shown in table) to loading in terms of SO_4, multiply by 3.

Seasonal and monthly deposition values may vary widely because the amounts deposited depend not only on the varying composition of the rain but also on the highly variable amount of rain that falls.

The measurement of the dry deposition component is at present not possible because there exists no generally accepted method for routine monitoring of dry deposited material.

Chapter 7

CONCLUSIONS, RECOMMENDATIONS, AND PHASE II WORK

Conclusions

Work Group 2 has reviewed the modeling, monitoring and research aspects of the atmospheric behavior of acid-forming pollutants, particularly sulfur, between their source regions and deposition areas. The role, capabilities and applications of selected transport models from both Canada and the U.S. have been described. As a part of the Phase I work, "first cut" transfer matrices to describe source-receptor relationships have been constructed by the Group. Comparisons of model results were made with deposition data collected by networks in both countries.

The following are the major conclusions of the Group

(1) The source-receptor matrices obtained to date are of an interim nature, and must be viewed as only a first attempt to quantify relationships. Revisions and refinements will be made in the transfer matrices during future Phases.

(2) Monitoring data of high quality are crucial for the evaluation of models, and, at present, significant uncertainties exist in these data. The continuation of existing monitoring networks, and of strong quality assurance programs are essential to ensure that valid monitoring data will be available for future in-depth comparisons with model calculations.

(3) The above uncertainties notwithstanding, the results from the models and the monitoring networks which have been presented can serve for the initial development of pollution control stratagies.

(4) A strong research and development effort is essential for the continuing upgrading of routine modeling and monitoring activities, and for the further development of a sound base of scientific knowldge for the agreement.

Recommendations

The first set of recommendations pertains to matters requiring consultation or clarification among the various Work Groups. Work Group 2 recommends that:

- there be continuing consultation with Work Group 2 regarding the uses, results, and significance of the Phase I transfer matrices;
- a common glossary of terms be developed to insure uniformity of technical language in all Groups (see Appendix 3 to this report);
- common units of measurement be used, preferably the SI (International System) units;
- field, analysis, and interpretive activities of Work Groups 1 and 2 be coordinated, as far as possible, in order to gain maximum benefit from the efforts invested.

The second set of recommendations is directed to clarifying aspects of Phase II (and beyond) work. We recommend that:

- the relative importance of hydrogen and sulfate ion deposition, as a measure of damage, be examined and resolved, as far as possible at this time;
- key atmospheric parameters, from an effects point of view, be identified;
- the urgency/importance of investigating nitrogen oxide deposition be discussed and resolved, as far as possible at this time;
- the need for investigating the various time scales of adverse effects from acid deposition, and associated Work Group 1 priorities, be established;
- the priority of considering the long-range transport of other materials (e.g., metals, synthetic organics, particulates) be established;
- the need to model past emissions and deposition of sulfur and other species be reviewed, in view of the paucity and uncertainty of past data, and the likelihood of a poor return for our efforts;
- the number and type of emission scenarios to be run in future Phases be clarified;
- the name of Work Group 2 be changed to "Atmospheric Sciences and Analysis Work Group" to reflect more accurately our charge;

- the following be added to our terms of reference:

  " - evaluate and employ available field measurements, monitoring data and other information;";
- a critical path analysis of tasks and information needs be completed by the Coordinating Committee or Work Group 3A and distributed to ensure a coordinated effort;

The third set of recommendations are more general in nature and concern the broader aspects of the acid deposition problem. We recommend that:

- a long-term commitment be made by governments to the operation of national and regional precipitation chemistry networks, specifically CANSAP and NADP, with increased effort and resources being allocated to quality assurance/control and data analysis/ interpretation aspects;
- efforts be made to develop more comprehensive deposition information, including that on nitrate and ammonium ion, alkaline constituents, and dry deposition;
- communications within and coordination of scientific programs in the two countries continue and be enhanced. (The structure for this exists: MOI Work Groups provide the near-term reporting function; the RCG is structured to provide a longer-term coordination function; and the NAS-RSC panel can be expected to provide the important review function.)

Phase II Work

The work plan of Work Group 2, prepared during Phase I, outlined the major tasks of the Group and their timing. Table 7.1 shows, as a bar graph, a slightly revised set of tasks and timing for Phase II and beyond.

In order to proceed in Phase II with a number of its tasks, Work Group 2 requires, in addition to those items identified as recommendations, several specific inputs from other Work Groups. These are needed before further revision of the transfer matrices is undertaken. They are

- a current, agreed, 'unified' sulfur emissions inventory for North America, on an annual and seasonal basis by February 1, 1981 (from WG 3B);
- agreement on the number and delineation of source regions in the two countries for use in transfer matrix calculations (input from WG's 3A and 3B);
- agreement on sensitive receptor areas in both countries (from WG 1).

TABLE 7.1

WORK GROUP 2 ACTIVITY SCHEDULE (REVISED 80/12/19)

	ACTIVITY	Nov 15	Jan 15	Mar 30	May 15	Oct 81	Jan 82
1	Receive unified U.S./Canada present S inventory (annual) from 3B	--------	----?				
2	Receive unified U.S./Canada present S inventory (seasonal) from 3B	--------	----?				
3	Receive past/future S inventories (annual and seasonal) from Group 3B	--------	----?				
4	Receive unified U.S./Canada N and HC inventories from Group 3B	--------	----?				
5	Final choice of source and receptor areas from Group I, 3A, and 3B	--------	----?				
6	Settle meteorological period for verification	complete					
7	Settle meteorological period for general use	--------	-------	---x			
8	Choose selected models	complete					
9	Review and document model parameters	complete					
10	Demonstrate model output	complete					
11	Demonstrate model use	complete					
12	Evaluate and intercompare selected models	--------	-------	------	------	----x	
13	Glossary	complete					
14	Assess and use measured data	--------	---x---	------	----x-	------	-------x
15	Develop and demonstrate transfer matrix	--------	----x--	------	----x		
16	Run reference scenarios	--------	-------	------	----x-	------	-------x
17	Review of selected atmospheric science topics	--------	-------	------	----x		
18	Formulate proposals for agreement	--------	----x--	------	----x-	------	-------x
	Timing of Phases	Phase I		Phase II		Phase III	

Comments on the status of each of the tasks listed in Figure 7.1 is given below.

Tasks 1-5: Inputs required from other Work Groups

Task 6: The year 1978 was chosen. See Appendix 9.

Task 7: To be completed early in Phase II.

Task 8: Completed. See Chapter 3.

Task 9: Completed. See Appendix 5.

Task 10: Completed. See Chapter 5 and Appendices 5 and 8.

Task 11: Completed. See Chapter 5 and Appendices 5 and 8.

Task 12: A major Phase II activity. This will be the subject of a series of workshops. See Appendix 9 for a report of the first workshop.

Task 13: Completed, but can be ammended. See Appendix 3.

Task 14: Completed for Phase I. See Chapter 6. This is a continuing activity throughout all phases.

Task 15: Completed as an interim step. See Chapter 5 and Appendix 8. Refinements will occur during Phase II.

Task 16: To be done in Phases II and III as determined in consultation with Work Groups 3A and 3B.

Task 17: Initial reviews to be done during Phase II for four topics: (i) the parameterization of chemical processes in LRT models; (ii) historical trends in precipitation composition and deposition data; (iii) wintertime deposition and chemical processes; and (iv) global and western North America rain pH.

Task 18: Ongoing.

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VOLDNER, E.C., M.P. OLSON, K. OIKAWA, and M. LOISELLE, 1980: Comparison between measured and computed concentrations of sulfur compounds in Eastern North America, to appear in Journal of Geophysical Research Procedings of CACGP Symposium on Trace Gases and Aerosols, August 1979.

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Appendix 1

Work Group 2

Terms of Reference

and Additional Guidance

Terms of Reference from the MOI

The Group will provide information based on cooperative atmospheric modeling activities leading to an understanding of the transport of air pollutants between source regions and sensitive areas, and prepare proposals for the "Research, Modeling and Monitoring" element of an agreement. As a first priority the Group will by October 1, 1980 provide initial guidance on suitable atmospheric transport models to be used in preliminary assessment activities.

In carrying out its work, the Group will:*

- identify source regions and applicable emission data bases;
- evaluate and select atmospheric transport models and data bases to be used.
- relate emissions from the source regions to loadings in each identified sensitive area;
- calculate emission reductions required from source regions to achieve proposed reductions in air pollutant concentration and deposition rates which would be necessary in order to protect sensitive areas;

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* proposed additional term of reference:
" - evaluate and employ available field measurements, monitoring data and other information;"

- assess historic trends of emissions, ambient concentrations and atmospheric deposition to gain further insights into source-receptor relationships for air quality, including deposition; and
- prepare proposals for the "Research, Modeling and Monitoring" element of an agreement.

Additional Guidance from the Chairman of WG 3B

Each Work Group will be responsible individually for the following.

a. Develop data needs and analysis methods for their Work Group; identify required inputs from other Work Groups; (due to the size of the Work Groups, the Chairmen will have to very carefully orchestrate the Group's activities in order to accomplish their tasks).
b. The technical review (including peer review as necessary) of their work products.
c. Maintaining agreed upon work schedules with prompt notification to 3A Chairman in the event of any significant deviation from Work Plan.
d. Responsible for coordination with their counterparts from the other country in conducting full cooperative analyses in order to fulfill the terms of reference.
e. Responsible for fulfilling requests for information from other work groups in a timely fashion.

f. Be prepared to draft language for portion of agreement that pertains to their tasks as directed by Coordinating Committee.

Appendix 2

Membership of Work Group 2

1. <u>United States</u>

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	Franz Burmann Environmental Monitoring Systems Laboratory Environmental Protection Agency Research Triangle Park, NC 27711
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Appendix 3

Glossary of Terms

Introductory Comments

During the preparation of this glossary, use has been made of terminology and definitions found in, *inter alia*, the first two annual reports of the United States-Canada Research Consultation Group on the Long Range Transport of Air Pollutants, and the draft Federal Acid Rain Assessment Plan. An obvious need exists for uniformity in terminology amongst all Work Groups and others involved in activities related to the Memorandum of Intent and subsequent developments. It is anticipated that this glossary will grow and be refined as further contributions from specialists in various disciplines are received.

<u>Acid Deposition:</u> Collectively, the processes by which acidic and acidifying materials are removed from the atmosphere and deposited at the surface of the earth. Also, the amount of material so deposited. (Units: $ML^{-2}T^{-1}$.)

<u>Acid Precipitation:</u> A more precise term than acid rain, it usually refers to all types of precipitation with pH less than 5.6.

<u>Acid Rain:</u> A popular term used to describe precipitation that is more acidic than "clean" rain (pH ~ 5.6). It is also used more generally to describe other atmospheric deposition phenomena involving acidity.

<u>Analytical Model:</u> A mathematical model in which the solution to the system of governing equations is expressed in terms of analytical functions. As such, these models are simplifications of Lagrangian, Eulerian or statistical models.

<u>Anthropogenic:</u> Produced by man's activity.

<u>Bulk Deposition:</u> The term applied to atmospheric deposition collected in a collector which is open at all times. Bulk deposition consists of wet deposition, plus an unknown fraction of the dry particulate deposition, plus an unknown and probably very small fraction of the dry gaseous deposition.

<u>Dry Deposition:</u> Collectively, the processes, excluding precipitation processes, by which materials are removed from the atmosphere and deposited at the surface of the earth. Processes include sedimentation of large particles, the turbulent transfer

to the surface of small particles and gases, followed, respectively, by impaction and sorption or reaction. Also, the amount of material so deposited. (Units: $ML^{-2}T^{-1}$.)

<u>Ensemble Mean</u>: The average over a number of individual model runs in which only one or a few adjustable parameters are allowed to change.

<u>Eulerian Model</u>: A mathematical model in which computations are made successively at fixed points in space (as opposed to Lagrangian models where computations are made following an air parcel). Computation points are usually arranged in a fixed grid, and the model is also known as a grid model.

<u>Flux</u>: A physical quantity, the amount (mass) of material passing through a unit area in a unit of time. (Units: $ML^{-2}T^{-1}$.)

<u>Individual Realization</u>: The result from a single model run with a given set of input parameters.

<u>Inventory</u>: A listing of emission source strengths of a particular pollutant for a specified time period. Inventories and parameters are normally organized on a point-source basis, an area-source basis, or a combination of the two. Area sources may be represented on a grid, urban-area, county, state, province, or national basis.

<u>Isopleth</u>: A line drawn on a field of values which joins points of equal value in time or space.

<u>Lagrangian Model:</u> A mathematical model in which computations are made successively in the same air parcel(s) as it moves along a trajectory. Because this type of model is based on following an air parcel, it is also known as a trajectory model.

<u>Loading (atmospheric)</u>: The amount of a pollutant in the atmosphere expressed in mass or concentration units. (May also be expressed on a per unit time and/or area basis.)

<u>Loading Surface:</u> A term used interchangeably with deposition.

<u>LRTAP:</u> The long-range transport of air pollutants refers to the processes, collectively, by which pollutants are transported, transformed and deposited, on a regional scale (of the order of hundreds to thousands of km).

<u>Mb (Millibar) Level:</u> A surface of constant pressure in the atmosphere, identified by the pressure expressed in mb. (Common pressure levels used in air quality modeling are 925 and 850 mb levels.)

<u>Mixing Height:</u> The height above the earth's surface of a boundary layer inversion which is usually the upper limit of turbulent mixing activity, and which inhibits upward flux of pollutant.

<u>Model:</u> A quantitative simulation of the behaviour of a portion of the environment.

Model Evaluation: A procedure by which the validity and sensitivity of a model is assessed. Usually the validity is ascertained by comparing model outputs with measurements, and the sensitivity assessed through a series of model runs in which input parameter values are altered in sequence, and the results intercompared.

Model Intercomparison: A procedure of comparing the results of several models which have been run on specified data bases and with (usually) specified values of model parameters.

Model Resolution: The ability of a model to distinguish (utilize) small spatial or temporal changes in input variables.

Model Sensitivity: A model characteristic which is described by the response of an output parameter to a unit change in an input variable or a model parameter.

Model Validation: The part of model evaluation in which modeled results are compared with measured values.

Oxides of Nitrogen: This term usually denotes the sum of nitric oxide (NO) and nitrogen dioxide (NO_2). Other forms are nitrate (NO_3), nitrous oxide (N_2O), and dinitrogen pentoxide (N_2O_5).

Oxides of Sulfur: This term usually denotes sulfur dioxide (SO_2). Other forms are sulfur trioxide (SO_3) which is uncommon, and sulfate (SO_4).

Parameterization: The representation of a physical, chemical or other process by a convenient mathematical expression containing quantities (parameters) for which measurements or estimates are usually available.

<u>Receptor</u>: An organism, ecosystem or object which is the direct or indirect recipient of atmospheric deposition.

<u>Scavenging:</u> The processes by which materials are incorporated into precipitation elements and (usually) brought to the earth's surface.

<u>Scenario:</u> In the modeling context, a set of specified conditions (usually emissions inventory) for input to the model which usually reflect some anticipated future situation (e.g., energy use or pollution emissions).

<u>Sensitive Area</u>: A geographical area in which a receptor (or receptors) exhibit damage in response to a (pollution-imposed) stress.

<u>Sensitivity Receptor</u>: The degree to which a receptor exhibits an adverse effect from a (pollution-imposed) stress.

<u>Source-Receptor Relationship</u>: An expression of how a pollution-source area and a receptor region are quantitatively linked.

<u>Spatial Resolution:</u> The minimum distance in space over which meaningful differences in results can be determined (using a particular model.) (For example, a model based on a 381-km grid will provide no significantly different information for two receptor points separated by less than approximately 381 km.)

<u>Statistical Model</u>: A mathematical model which uses statistical values of parameters as inputs for the computations.

Surrogate: The term applied to a parameter which is used to represent another. (For example, modeling hydrogen ion behavior in the atmosphere is difficult, so that sulfate ion is used as a substitute.)

Susceptibility: A receptor or receptor area is said to be susceptible if it is both sensitive, and receiving a pollutant loading or stress.

Temporal Resolution: The minimum time during which meaningful differences in results can be determined (using a particular model). (For example, models using upper air data which are only available every six hours are limited in their temporal resolution to about 6 hours.)

Trajectory: The path or track of an air parcel through the atmosphere. It can be calculated from observed or gridded wind data either forward or backward from a point (source or receptor, respectively).

Transfer Matrix: A presentation of source-receptor relationships in a matrix form. Matrix elements can be expressed as percentage values, as absolute values, or as values normalized by source strength.) Such a presentation provides a means of easy comparison of the impact of a variety of sources on a variety of receptors.

Transformation (chemical): The processes by which chemical species are converted into other chemical species (in the atmosphere).

<u>Variance:</u> A measure of variability. It is denoted by σ^2 and defined as the mean-square deviation from the mean, that is, the mean of the squares of the differences between individual values of x and the mean value $\bar{x}$.

$\sigma^2 = E[(x-\bar{x})^2]$, where E denotes the expected value.

<u>Wet Deposition:</u> Collectively, the processes by which materials are removed from the atmosphere and deposited at the surface of the earth by precipitation elements. The processes include in-cloud and below-cloud scavenging of both gaseous and particulate materials. Also, the amount of material so deposited. (Units: $ML^{-2}T^{-1}$.)

Appendix 4

Inventory of Available Models

Table 1. Summary of Principal Regional Air Quality Simulation Models in the United States and Canada

Name of Organization	Model Acronym	Type of Model	Time Period	Principal References
Batelle-Pacific Northwest Labs	RAPT	Lagrangian	monthly to annual	McNaughton (1980)
Brookhaven National Labs	AIRSOX	Lagrangian	monthly to annual	Kleinman et al (1980)
Argonne National Labs	ASTRAP*	Lagrangian	monthly to annual	Shannon (1980)
ERT, Inc.	SURAD	Eulerian	episodes	Lavery et al (1980)
ERT, Inc.	MESOPUFF	Lagrangian	episodes	Bass (1980)
Teknekron Research, Inc.	RCDM*	Analytical Eulerian	annual	Fay and Rosenzweig (1980) Niemann et al (1980)
Teknekron Research, Inc.	REGMOD	Eulerian	episodes	Prahm and Christensen (1977) Niemann et al (1980)
Washington University	CAPITA-Monte Carlo	Statistical Lagrangian	monthly to annual	Patterson et al (1980)
SRI International	ENAMAP-1*	Lagrangian	monthly to annual	Bhumralkar et al (1980)
EPA Meterology Lab	RPAQSM	Eulerian	episodes	Lamb (1980)
Atmospheric Environ. Service	AES-LRT*	Lagrangian	monthly to annual	Voldner et al (1980)
Ministry of the Environment	OME-LRT*	Statistical Lagrangian	annual	Venkatram et al (1980)
NOAA/ARL	ATAD	Lagrangian	monthly	Heffter (1980)
Colorado State University	RADM	Lagrangian	monthly	Henmi (1980)
University of Wisconsin	ATM-SOX	Statistical Eulerian	monthly	Wilkening and Ragland (1980)
MEP, Ltd.	LRT	Lagrangian	seasonal	Weisman (1980)
Environnement Québec	TGD-EQ	Statistical Lagrangian	seasonal to annual	Lelièvre (1981)

* Models selected for use by Work Group 2 as of January 15, 1981.

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HENMI, J., 1980: Long-Range Transport Model of SO2 and Sulfate and its Application to the Eastern United States, Journal of Geophysical Research, 85, C8, 4436 - 4442, August 20.

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LAMB, R.G., 1980: A Regional Scale (1000 km) Model of Photochemical Air Pollution - Part I: Theoretical Formulation, draft report from the Meteorology and Assessment Division, EPA Environmental Sciences Laboratory, Research Triangle Park, N.C.

LAVERY, T.L., et al, 1980: Development and validation of a regional model to simulate atmospheric concentrations of sulfur dioxide and sulfate, paper in Proceedings of the Second Joint AMS/APCA Conference on Air Pollution Meteorology, March 24-27, New Orleans, LA, 236-247.

LELIEVRE, C., 1981: Modèle simple de transformation chimique du soufre lors de son transport dans l'atmosphère, Rapport Interne, Service de la Metéorologie, Ministère de l'Environnement du Québec.

McNAUGHTON, D.J., 1980: Time series comparisons of regional model predictions with sulfur oxide observations from the SURE program, Paper 80-54.5 presented at the 73rd Annual Meeting of the Air Pollution Control Association, Montreal, Quebec, June 22-27, 1980.

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PRAHM, L.V. and O. CHRISTENSEN, 1977: Long-range Transmission of Pollutants Simulated by a Two-Dimensional Pseudo-Spectral Dispersion Model, J. Appl. Meteor., 16,9, 896-910.

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Appendix 5

Descriptions of Selected Models

TABLE OF CONTENTS

FIGURE AND TABLE DESCRIPTIONS

Model: ASTRAP (Advanced Statistical Trajectory Regional Air Pollution Control Model)

Modeling Group: Argonne National Laboratory, Jack Shannon

Model Type: Statistical Lagrangian

Emission Data: Point Sources or gridded virtual sources for a normalized 60 x 60 transition matrix (emission height can be variable)

Wind Data: uses 1/2 NMC* (191 km). Calculate mean transport speed and direction from surface to 1800 metres summer (1000 m. winter) for each Rawinsonde Station. Use inverse distance squared to get value at grid point (starting at radius = 381 km and increase until at least two observing stations).

Precipitation Data: 6 hour amount within 1/4 NMC grid square (95 km). Used average precipitation from those reporting precipitation, within a 1/4 square, and those reporting zero to assign percentage removed (i.e. 3 of 5 reporting precipitation means up to 60% removal is allowed).

Mixing Height: not used directly - numerical integration to 2100 metres using a diurnal pattern of growth of a nocturnal stable layer followed by breakup during the day to a maximum afternoon value and repeating on an actual rawinsonde ascent.

Chemistry: first order SO_2/SO_4, with diurnal variation.

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* National Meteorological Center

Dispersion: - horizontal from Lagrangian simulated tracers in the mean wind field*

- vertical by one-dimensional numerical integration (11 layers)

Removal Processes: Wet and dry deposition of SO_2 and SO_4, diurnal and seasonal variations.

- wet removal rate proportional to 1/2 power of 6-hourly precipitation amount (4 mm in 6 hours removes everything whereas 1 mm/hour removes 50%).

Model Outputs: Long term regional patterns of SO_2 and SO_4 surface concentration and cumulative wet and dry deposition of total S.

Resolution: Monthly and 1/4 of an NMC grid (95 km).

Area of Application: Eastern North America

Parameter Values: Wind/Precipitation - 1975 Summer (July, August)

Winter (Jan., Feb.)

Average VD_{SO2} and SO_4 = 0.4 cm/sec. (summer)

= 0.25 cm/sec. (winter)

Conversion SO_2/SO_4 = 1.1%/hour (summer)

= 0.55%/hour (winter)

---

* calculation done on ensemble parameters only.

Descriptive Material:

Seasonal and diurnal cycles in the deposition velocities of SO_2 and SO_4 produced by vertical mixing and plant stomatal activity are also provided for in the model. Sulfate deposition velocities used are the same order of magnitude as SO_2 velocities rather than an order of magnitude less as in other modeling studies.

Wet removal is taken into account using the scavenging ratio approach. This method relates wet deposition to the ratio of field measurements of concentration of pollutant measured in the air to that measured in rainfall at the same time. Argonne National Laboratory has found that scavenging rates are relatively constant, and sulfur deposition by wet processes is a function of the half power of the amount of precipitation.

The mixed layer is divided into 11 layers for the vertical numerical integration. A wind field is developed at a specified level in the atmosphere based on NWS data. Winds are interpolated between data points using a radius of influence inverse square relationship.

Comparisons With Data:

The model results were compared with measurements from the SURE data network for 1977 and 1978. The average two-month summer and winter sulfate fields show there are major discrepencies, particularly in the western part of the eastern

U.S. It must be kept in mind, however, that meteorology for a different year was used in the model. The ASTRAP simulations of wet deposition of total sulfur were scaled to a one-year period and compared with observations during 1977 of annual accumulations of sulfate in precipitation, expressed as total sulfur. There is some general agreement, but the data shows a more complex distribution than that indicated by the ASTRAP model results. On an annual basis, an estimated 5.4 million metric tons were deposited on the eastern United States. Wet and dry removal were approximately equally important. By season, dry deposition was equal to wet deposition in the summer, but wet removal was approximately twice dry removal in the winter.

Figures A5-1 through A5-3 show output from the ASTRAP Model.

Figure A5-1 Comparison of cumulative sulfate in rain, expressed as total sulfur for 1977 with ASTRAP simulations (isopleths) (Galloway and Whelpdale).

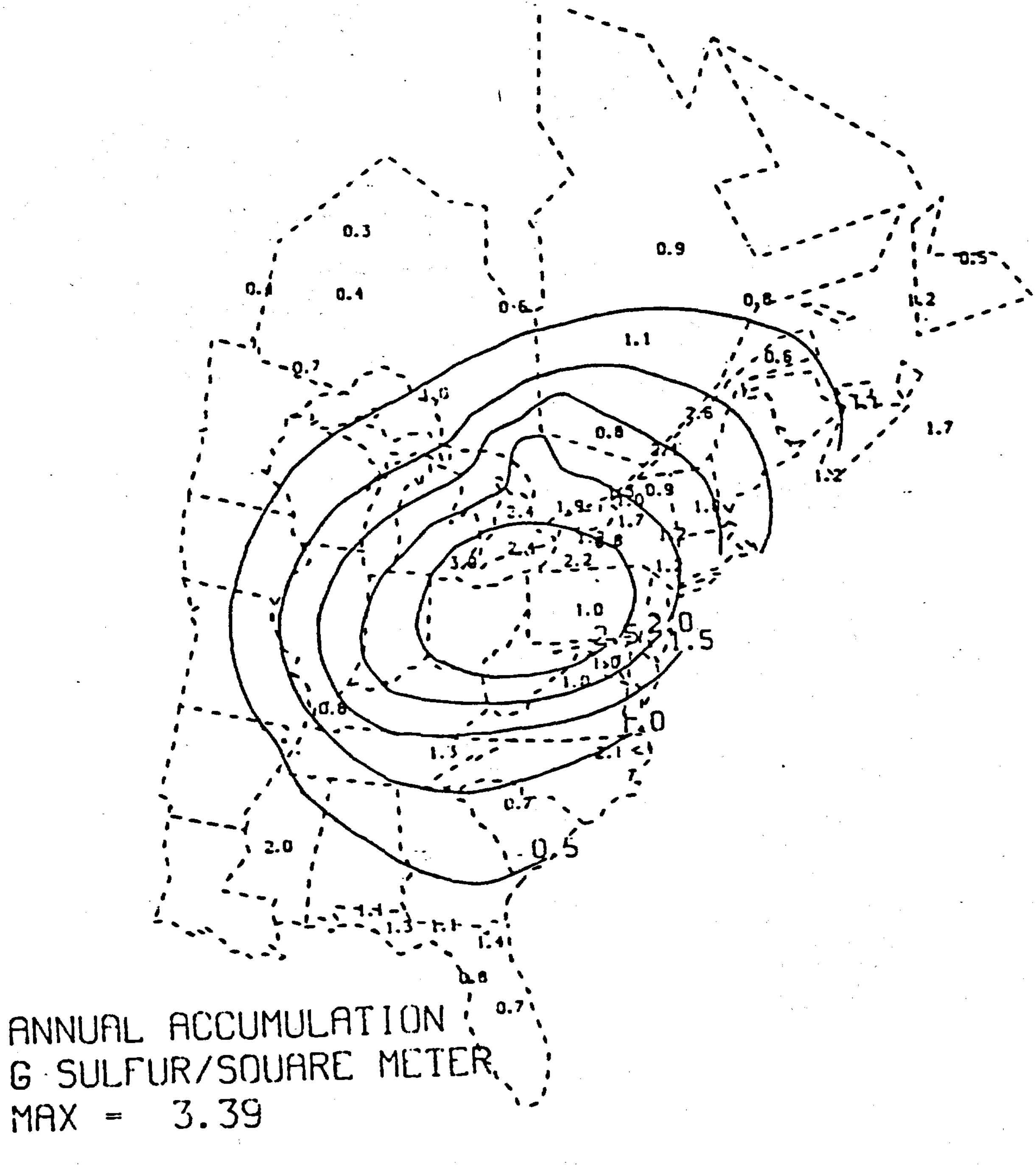


Figure A5-2 Comparison of Jan-Feb 1978 SURE average sulfate measurements (number) with ASTRAP simulations (isopleths) using Jan-Feb 1975 meteorology. (Shannon)

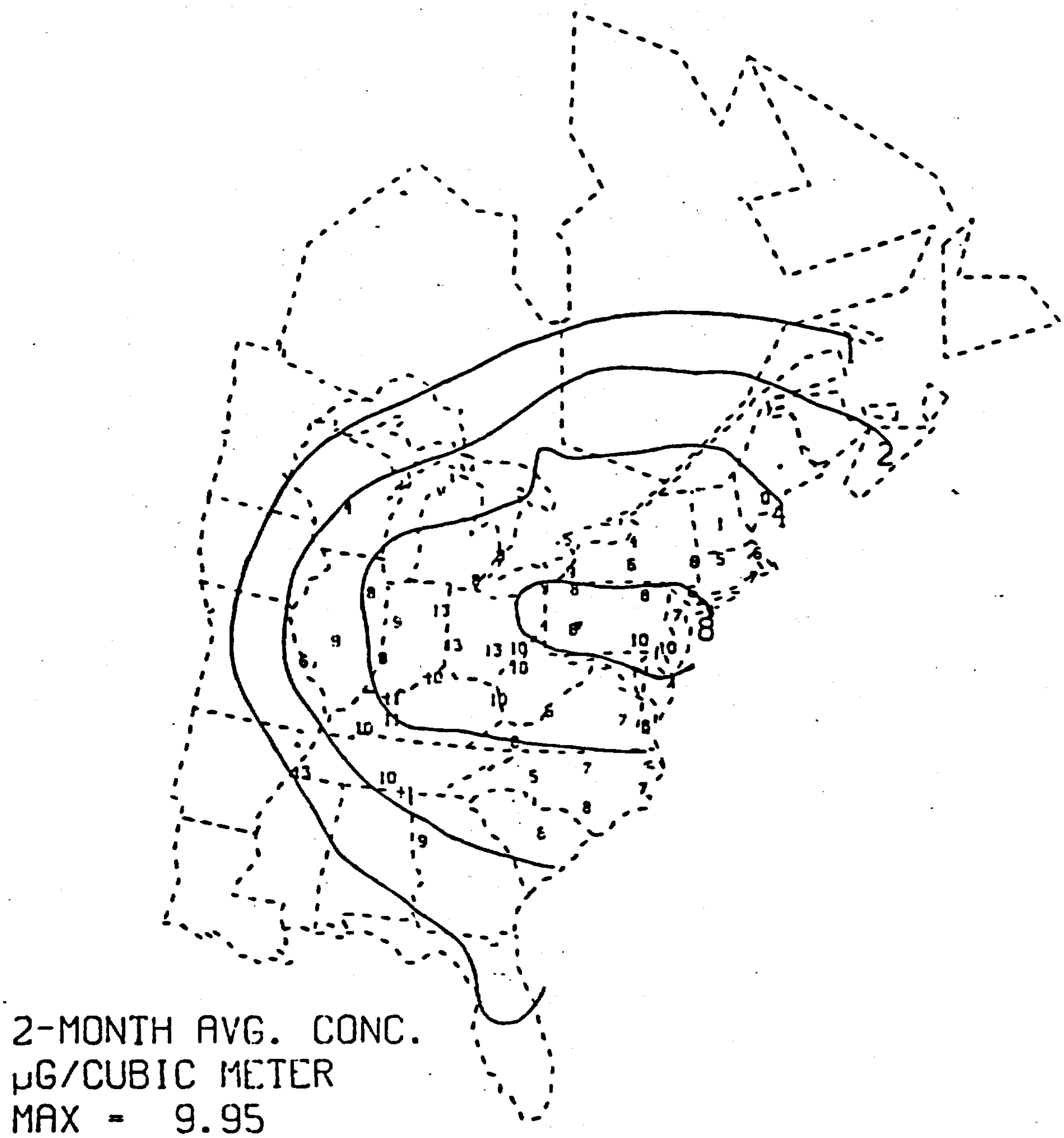
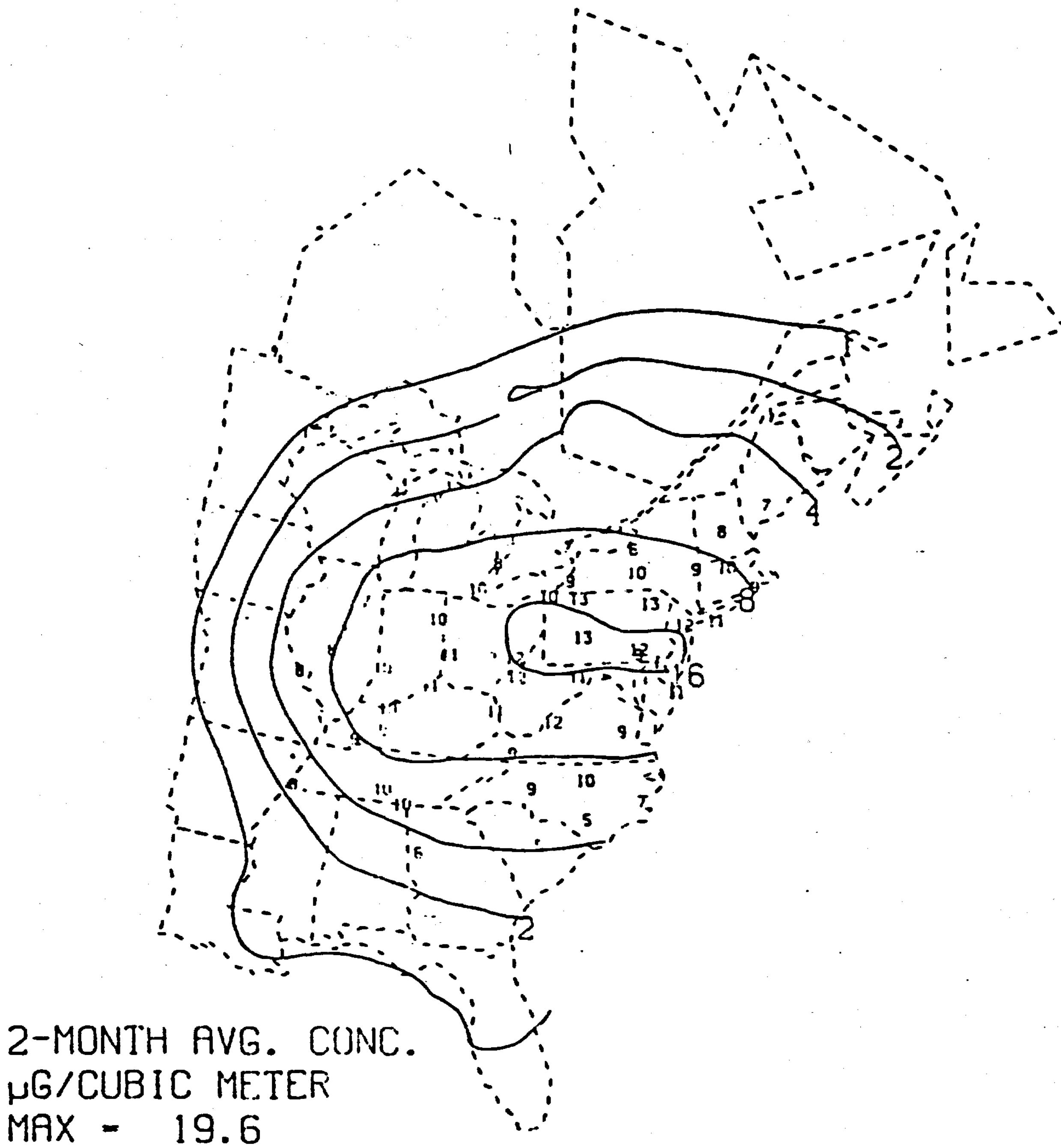


Figure A5-3 Comparison of August 1977 SURE average sulfate measurements (numbers) with ASTRAP simulations (isopleths) using July-August 1975 meteoroglogy. (Shannon)



Model: ENAMAP-1 (Eastern North America Model of Air Pollution)

Modeling Group: SRI International, Chandrakant Bhumralker and EPA/ESRL, Ken Demerjian

Model Type: Lagrangian Puff

Emission Data:
- 80 km x 80 km UTM SURE grid extended
- SURE and NEDS
- average (annual and seasonal)
- 12 hour puff

Wind Data: historical (retaining original temporal and spatial detail) (1977)
- 3 hour time steps using objectively* analyzed wind fields from surface (6 hour intervals) & upper air data (12 hr. intervals) on 80 x 80 grid.

$\overline{U} = 0.75\ U\ (850mb)$; $\overline{\theta} = \theta\ (850mb) - 15°$

Precipitation Data: - objectively* analyzed onto 80 x 80 grid using observed data.

Mixing Height: seasonal dependence varying from 1.15 km in winter to 1.45 km in summer.

Chemistry: SO_2/SO_4 first order

Dispersion:
- Fickian ($t^{1/2}$)
- horizontal - uniform
- vertical - mixing (instantaneous) to top of the boundary layer

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* least squares polynomial fit using at least 3 data points within a radius of influence.

Removal Processes: first order

Model Outputs: (1) SO_2, SO_4 Concentrations

(2) dry and wet deposition

(3) interregional exchanges

Resolution: monthly, 70 x 70 km grid square

Area of Application: Eastern North America

Parameter Values: SO_2/SO_4 1%/hour

$L = 1.3 - 0.15$ km

where = + 1 in winter; -1 in summer and 0 in spring & fall

SO_2: dry deposition = 0.037 hr^{-1}

SO_2: wet deposition = 0.28R hr^{-1}

where R = mm/hr. of precipitation

SO_4 : dry deposition = 0.007 hr^{-1}

SO_4 : wet deposition = 0.07R hr^{-1}

Descriptive Material:

ENAMAP-1 was originally developed for the Federal Republic of Germany (as EURMAP-1) and has been adapted to the Eastern North America region and renamed ENAMAP-1.

The wind field is determined by objective analysis of available upper-air observations at the 850-mb level (approximately 1500 m above mean sea level). The resulting field wind speeds are decreased by 1/4, and the wind directions are rotated 15° counterclockwise to account for surface layer friction effects. The wind fields are then interpolated every 3 hours between 12-hour data intervals.

The SO_2 transformation rate, the SO_2 and SO_4 dry deposition velocities and the mixing heights used in the ENAMAP-1 are generally similar to those used in other regional models. The SO_2 and SO_4 wet removal rates are different than those used in other regional models.

Comparisons with Data:

SO_2 emissions from the SURE program and NEDS were used in ENAMAP-1 model simulations. The months of January and August 1977 were chosen for model evaluation, and the results were compared with SURE and SAROAD air quality data. ENAMAP-1 predicted high sulfate in the northeastern states and relatively low values elsewhere in January 1977. The observed concentration field was similar in the East but measured values were higher than predicted in the Midwest. The model results for August 1977 were in better agreement with observations.

Figures A5-4 through A5-14 are seasonal and annual verification outputs from the ENAMAP-1 Model. Comparisons of modeled SO_4 against observed SURE data show very good agreement.

Figure A5-4 SO_2 concentrations (ug/m^3) for January 1977 from ENAMAP-1

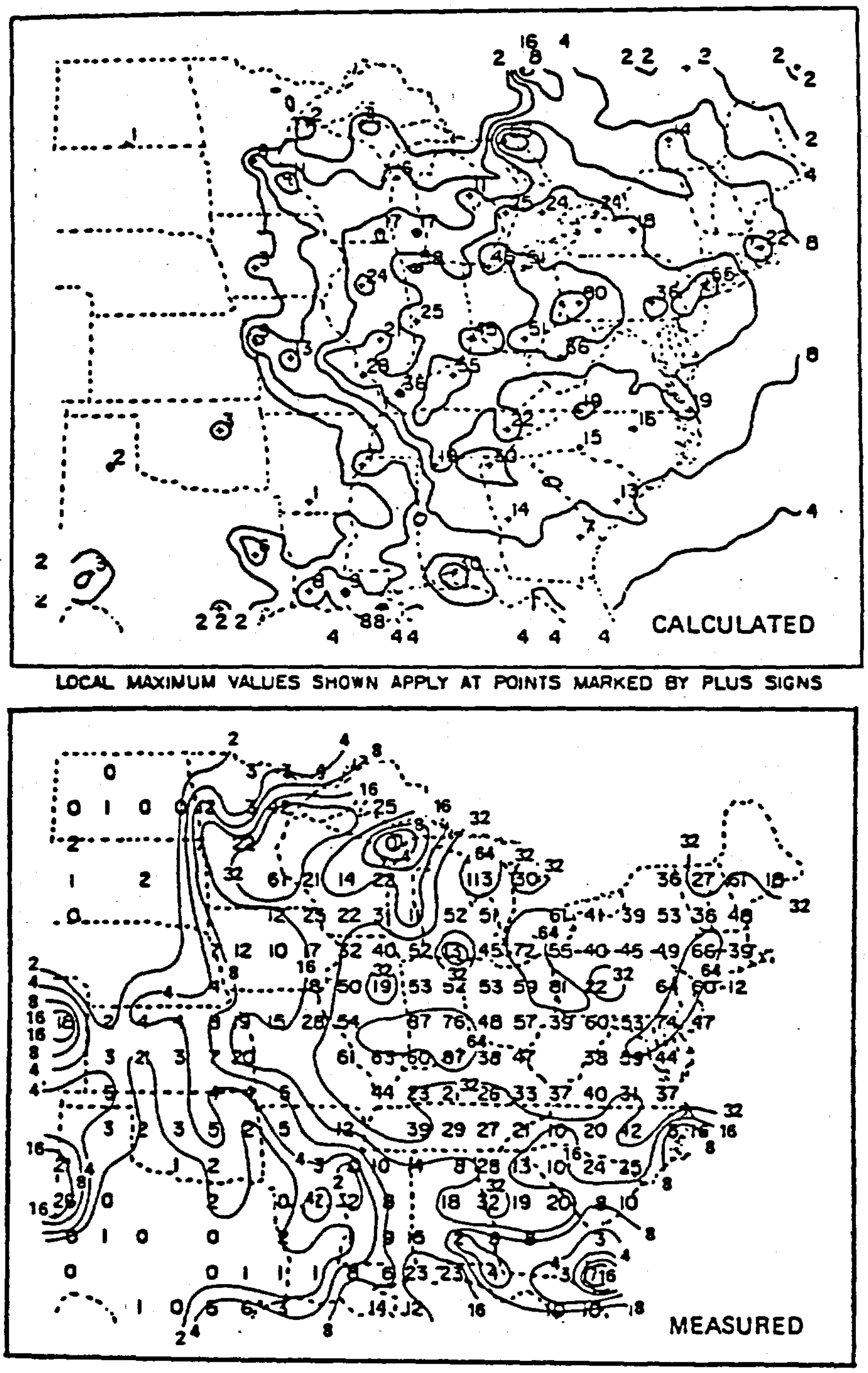
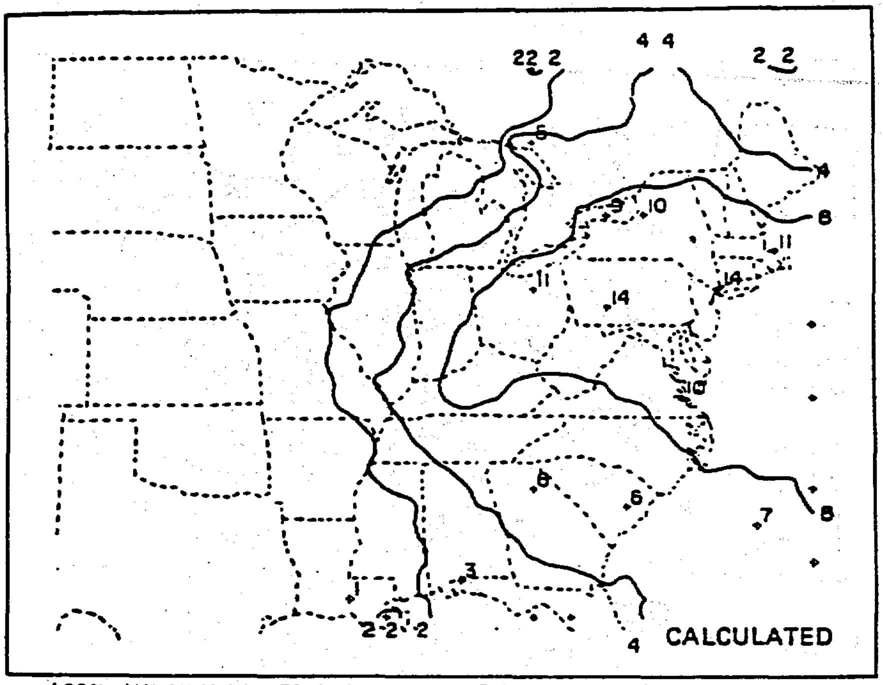


Figure A5-5 SO_4 concentrations (ug/m^3) for January 1977 from ENAMAP-1



LOCAL MAXIMUM VALUES SHOWN APPLY AT POINTS MARKED BY PLUS SIGNS

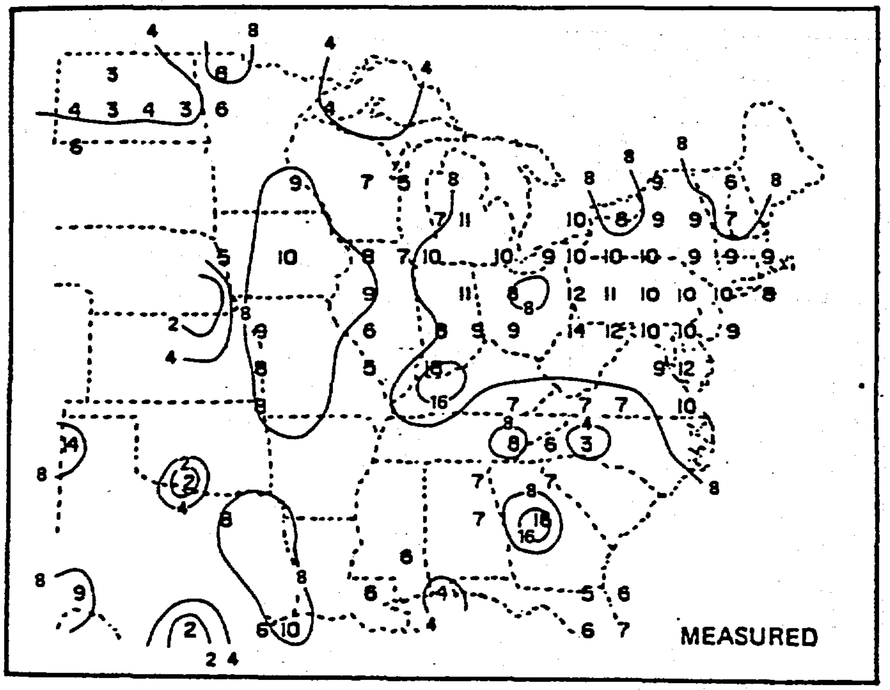
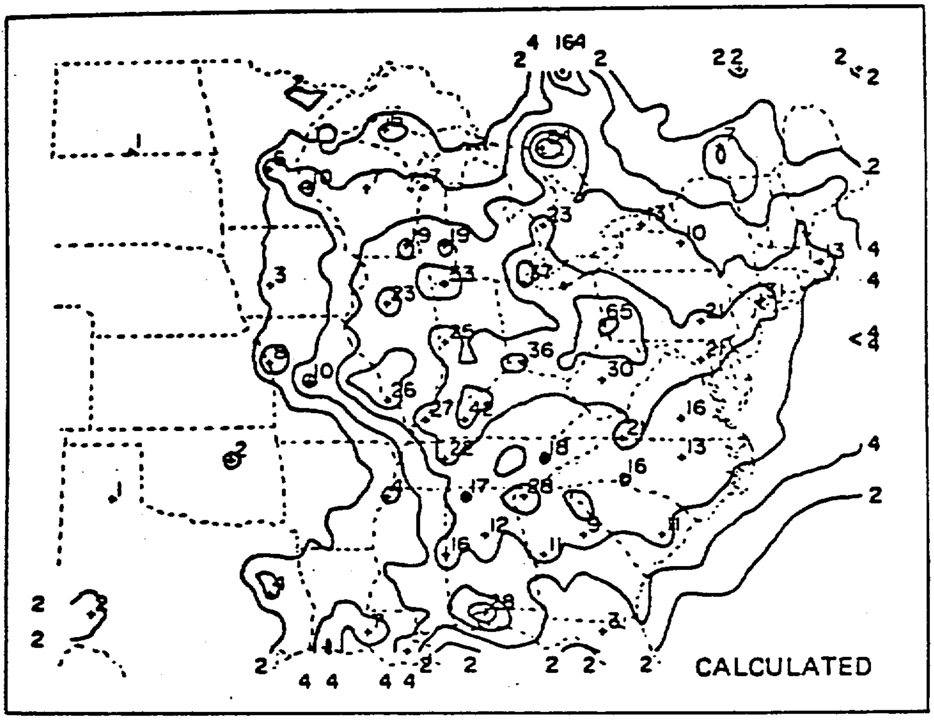


Figure A5-6 SO_2 concentrations (ug/m^3) for April 1977 from ENAMAP-1



LOCAL MAXIMUM VALUES SHOWN APPLY AT POINTS MARKED BY PLUS SIGNS

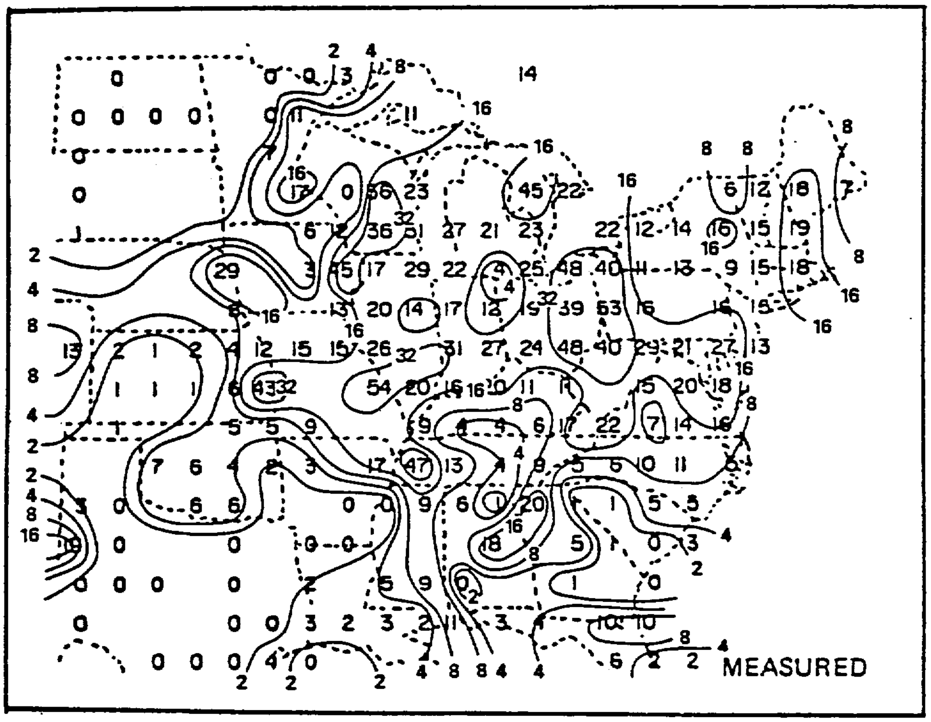


Figure A5-7 SO_4 concentrations (ug/m^3) for April 1977 from ENAMAP-1

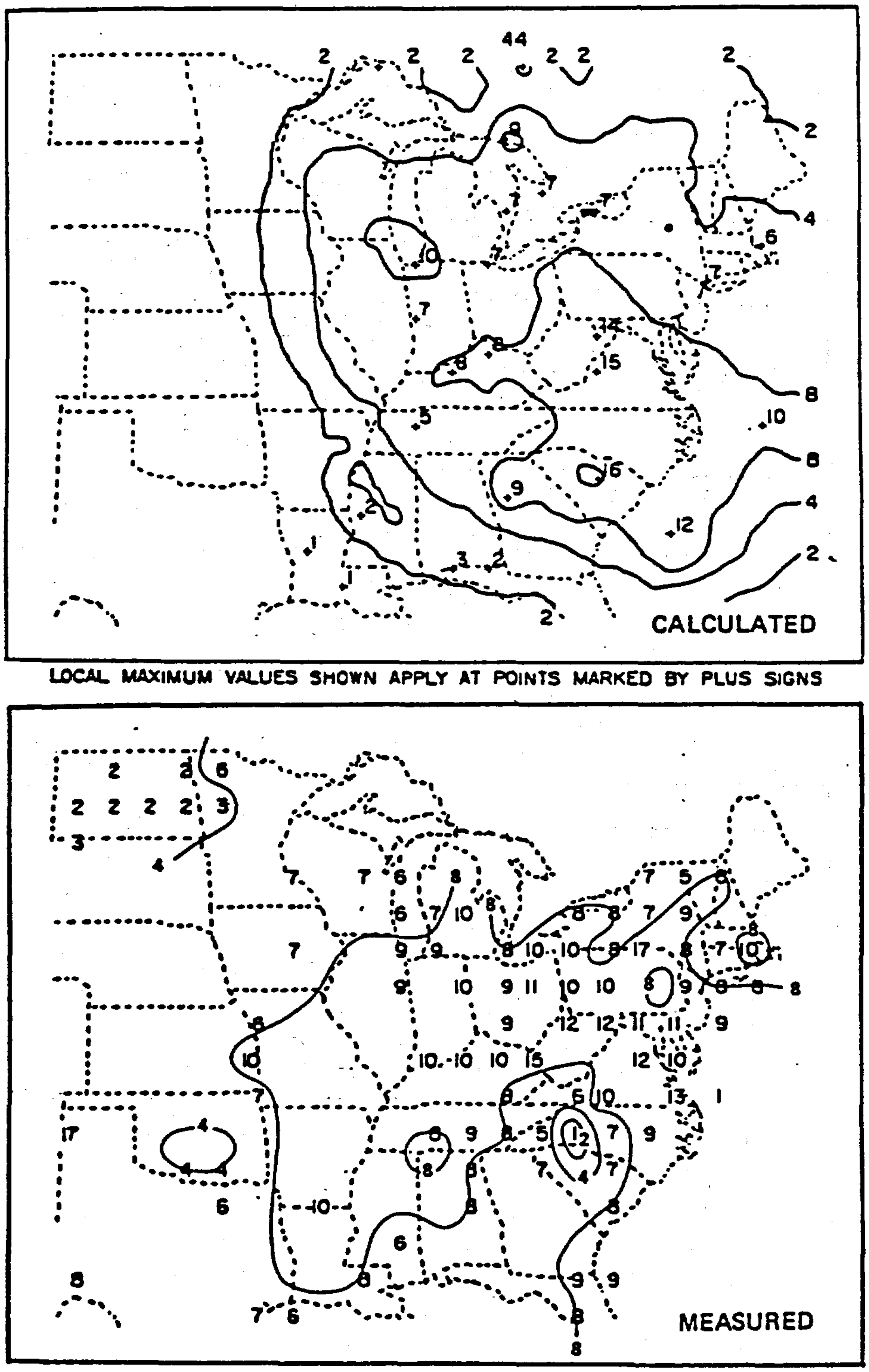
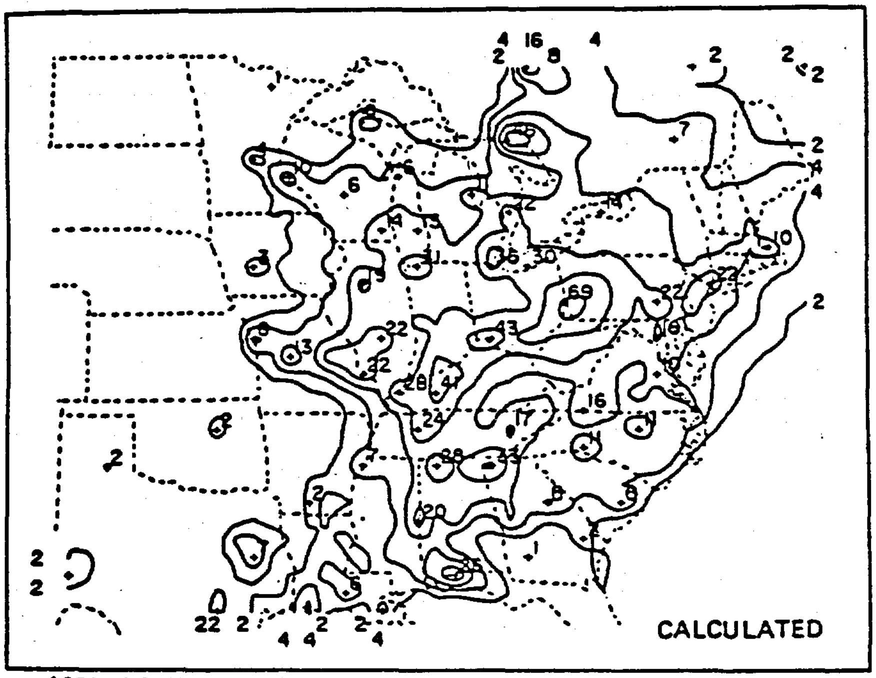


Figure A5-8 SO_2 concentrations (ug/m^3) for August 1977 from ENAMAP-1



LOCAL MAXIMUM VALUES SHOWN APPLY AT POINTS MARKED BY PLUS SIGNS

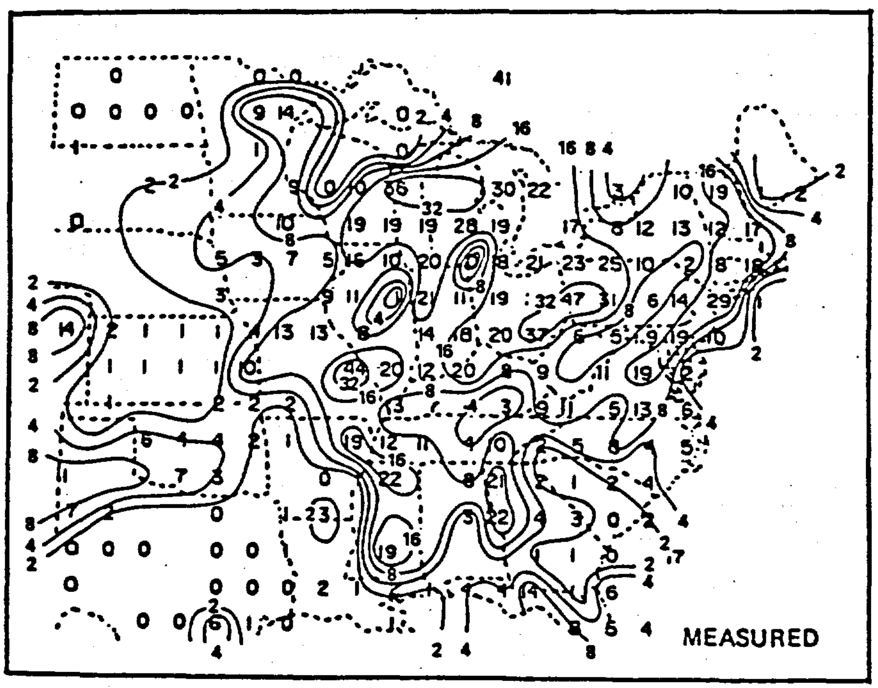
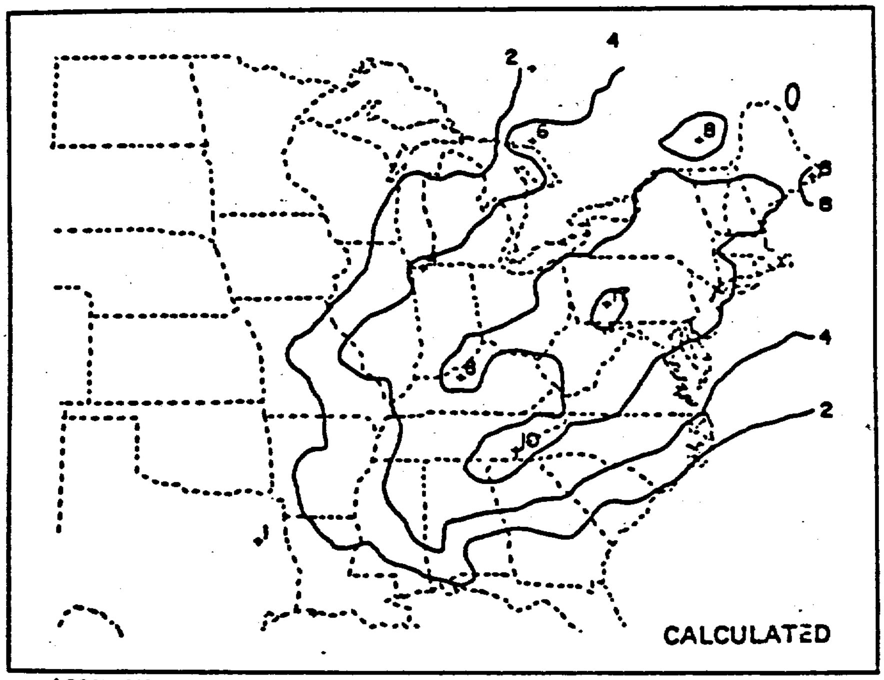


Figure A5-9 SO_4 concentrations (ug/m^3) for August 1977 from ENAMAP-1



LOCAL MAXIMUM VALUES SHOWN APPLY AT POINTS MARKED BY PLUS SIGNS

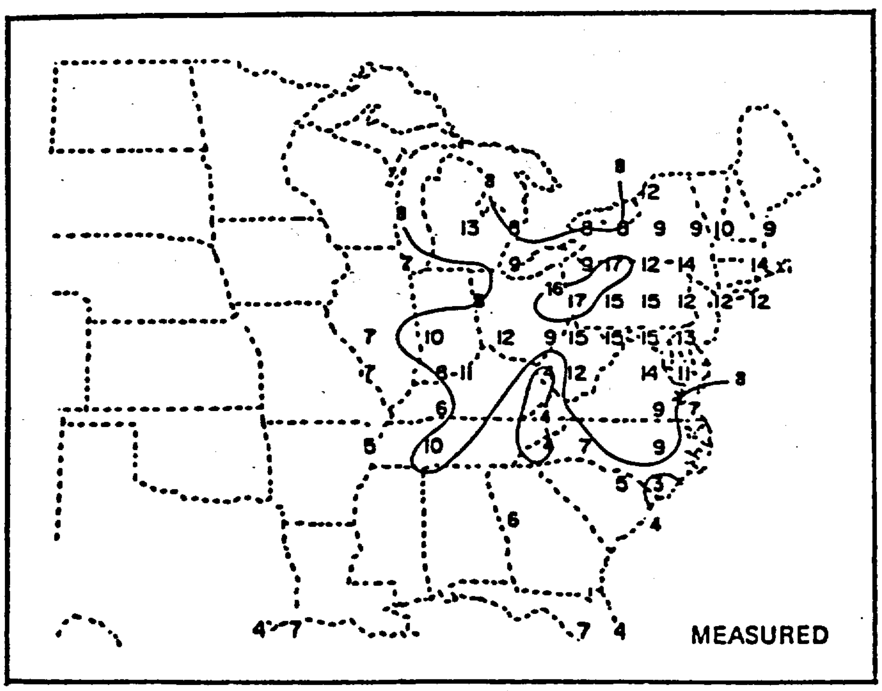


Figure A5-10 SO_2 concentrations (ug/m^3) for October 1977 from ENAMAP-1

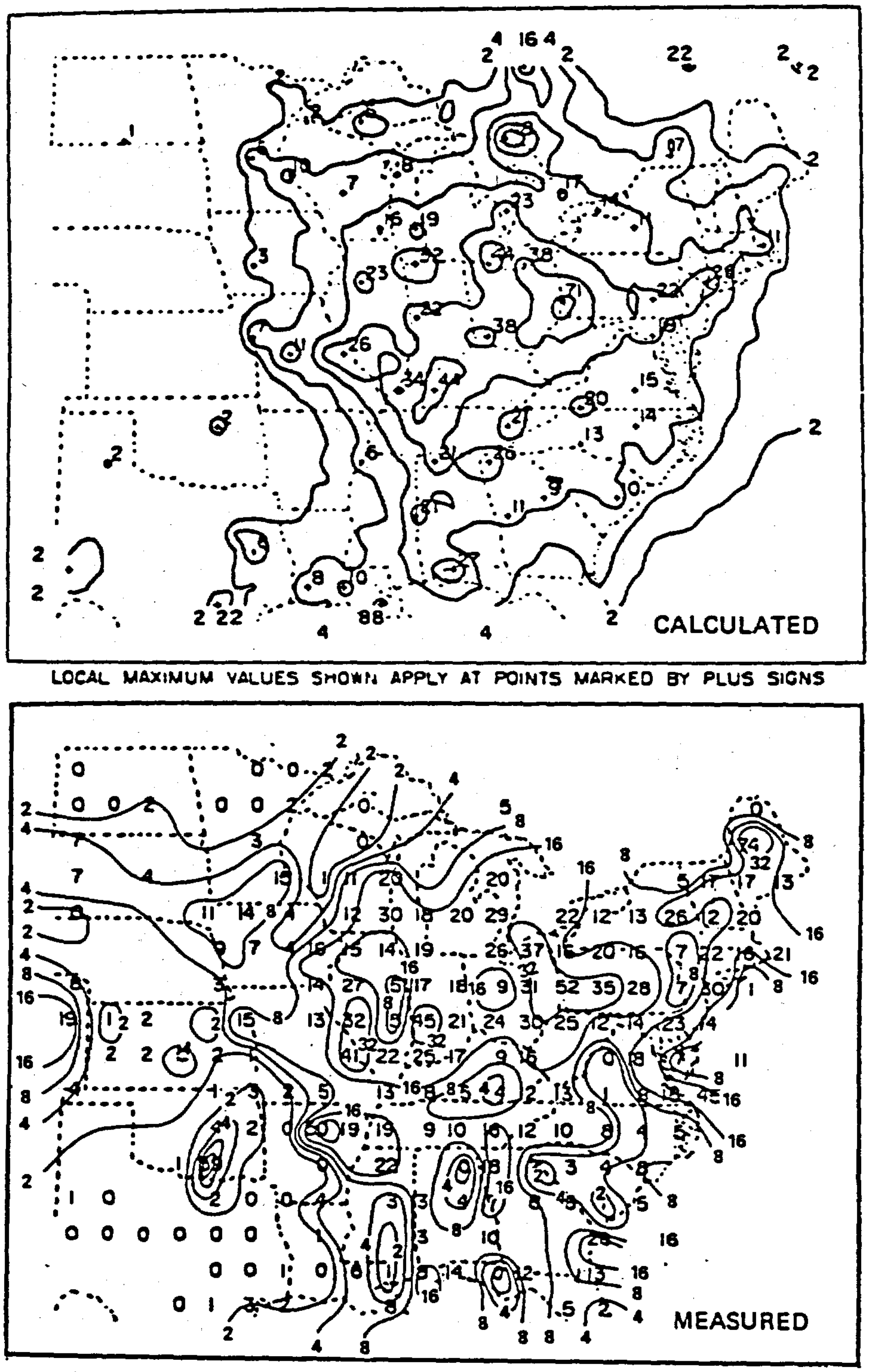


Figure A5-11 SO_4 concentrations (ug/m^3) for October 1977 from ENAMAP-1

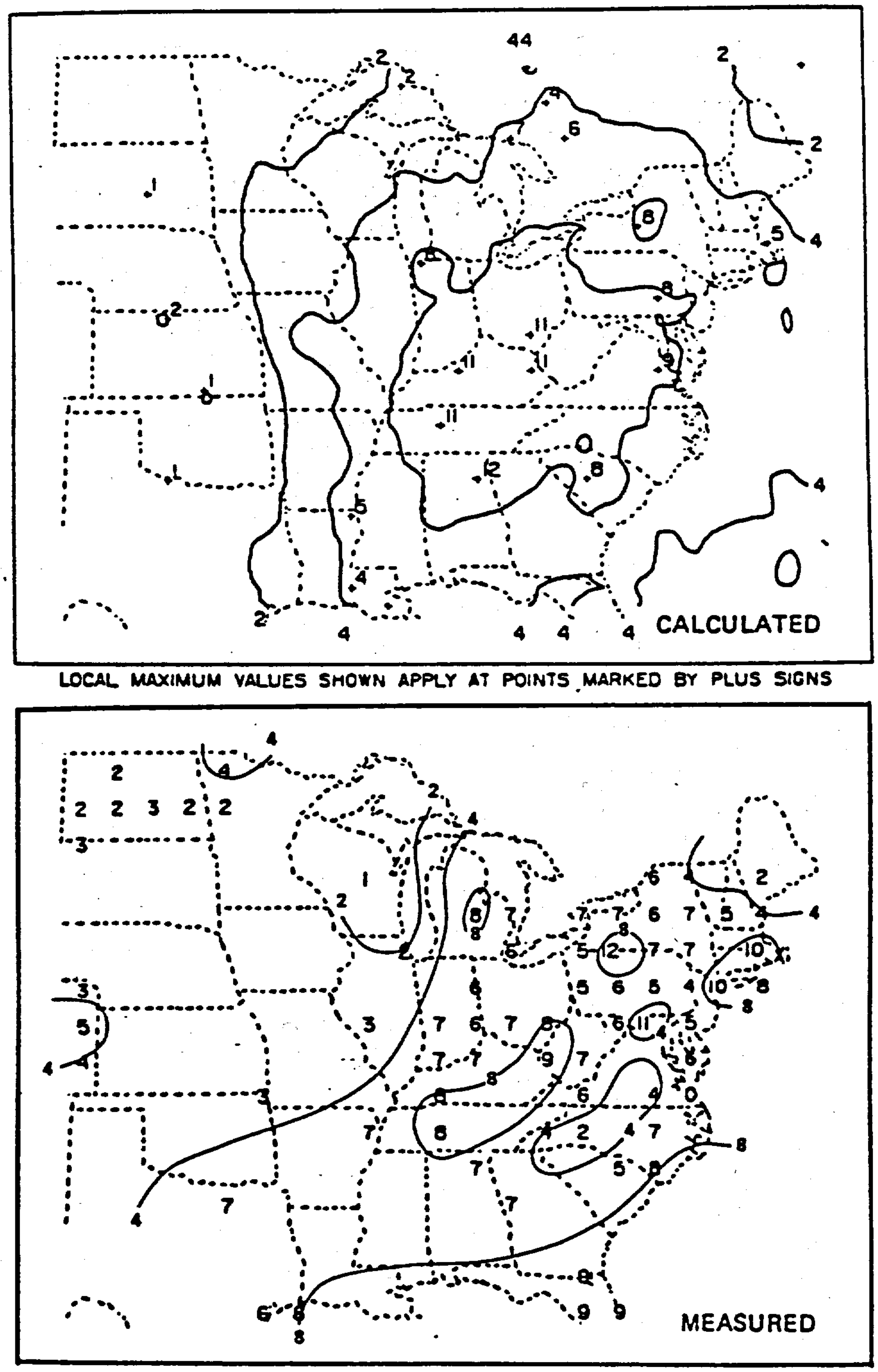
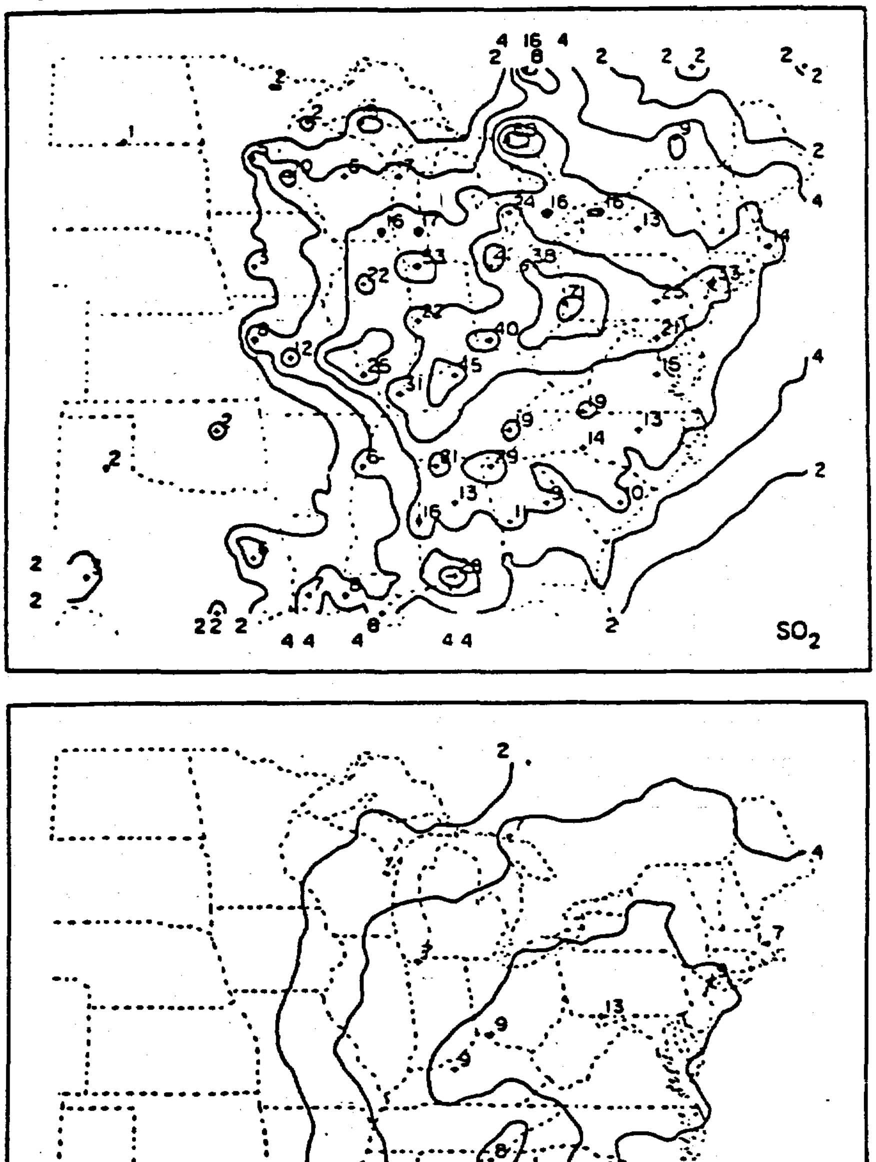
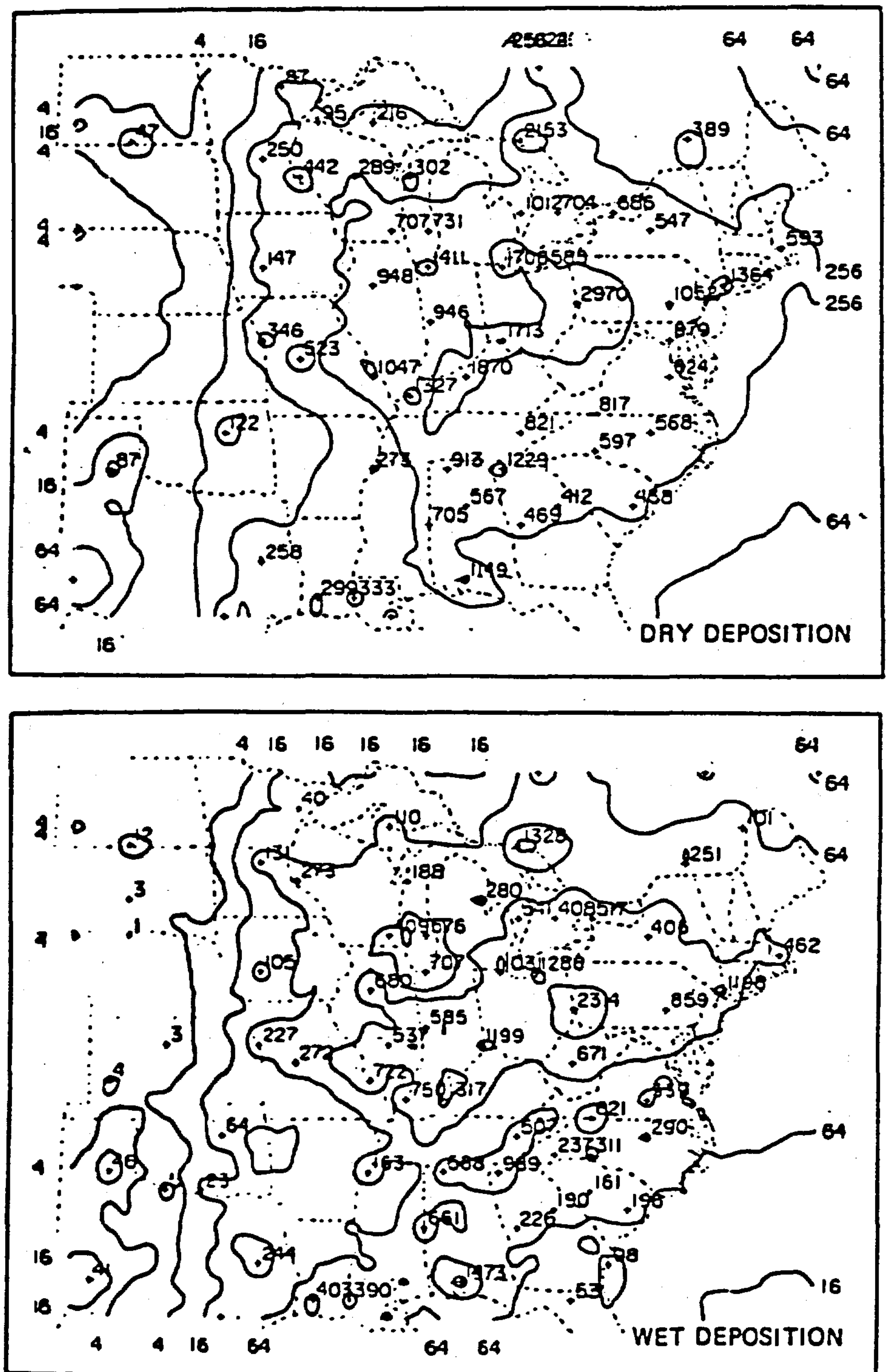


Figure A5-12 Calculated annual concentrations of SO_2 and SO_4 (ug/m^3) for 1977 from ENAMAP-1



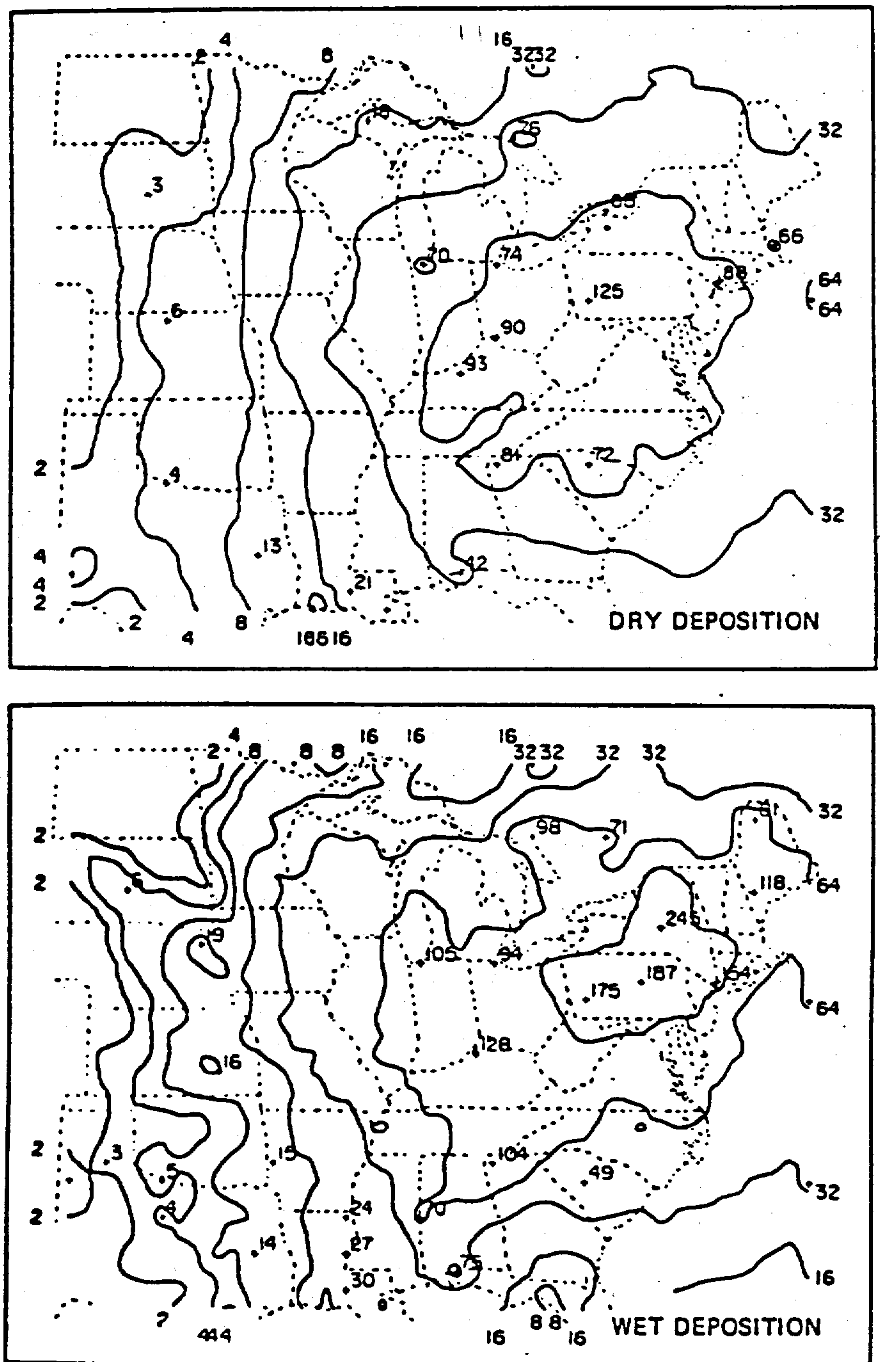
LOCAL MAXIMUM VALUES SHOWN APPLY AT POINTS MARKED BY PLUS SIGNS

Figure A5-13 Calculated annual dry and wet depositions of SO_2 ($10\ mg/m^2$) for 1977 from ENAMAP-1



LOCAL MAXIMUM VALUES SHOWN APPLY AT POINTS MARKED BY PLUS SIGNS

Figure A5-14 Calculated annual dry and wet depositions of SO_4 (10 mg/m^2) for 1977 from ENAMAP-1



LOCAL MAXIMUM VALUES SHOWN APPLY AT POINTS MARKED BY PLUS SIGNS

Model: AES-LRT

Modeling Group: Atmospheric Environment Service, Marvin Olson and Eva Voldner

Model Type: Lagrangian

Emission Data: 127 km 127 km - polar stereographic CMC* grid

Wind Data: upper air observations, objectively** analyzed at 6 hourly intervals at 4 levels on 381 x 381 km CMC grid (1978)

Precipitation Data: 24 hour amount, objectively analyzed on 127 x 127 km CMC grid

Mixing Height: climatological (Portelli, Holzworth) as a function of month averaged onto 127 x 127 km CMC grid (mean daily = (morn. min. + aft. max.) /2)

Chemistry: first order SO_2/SO_4

Dispersion: - instantaneously in a grid box (127 x 127 km)
- individual trajectories (96-hour backward)

Removal Processes: wet and dry deposition of SO_2 and SO_4

Model Outputs: (1) concentration and deposition fields for SO_2, SO_4
(2) source receptor matrix (11 x 9)

Resolution: 1 month, 127 km square.

Area of Application: Eastern North America

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* Canadian Meteorological Centre

** 3-D data assimilation scheme that incorporated hydrostatic and height-wind balance routines

Parameter Values: SO_2/SO_4 = 1%/hour

$VDSO_2$ = 0.5 cm/sec.

$VDSO_4$ = 0.1 cm/sec.

Scavenging ratio: SO_2 = 30,000 ($.3 \times 10^5$)

SO_4 = 850,000 (8.5×10^5)

Descriptive Material:

Wet deposition is parameterized by using the scavenging ratio approach and the 24-hour precipitation amount.

Dry deposition is parameterized through the use of fixed deposition velocities.

Trajectories are calculated using winds interpolated to the 925 mb level and using computed vertical motions.

Comparisons with Data:

Preliminary results indicate some overprediction of sulfur dioxide concentrations and some underprediction of wet deposition, but generally the overall concentration patterns and episode occurrences agree quite well with measurements (correlations between 0.4 and 0.9).

Figures A5-15 through A5-18 compare daily average measured and computed concentrations and ratios of computed to measured monthly concentrations.

Figure A5-15 AES-LRT computed and measured daily mean SO_2 concentrations during October 1977 at Albany, N.Y. (measured-solid, computed-dashed)

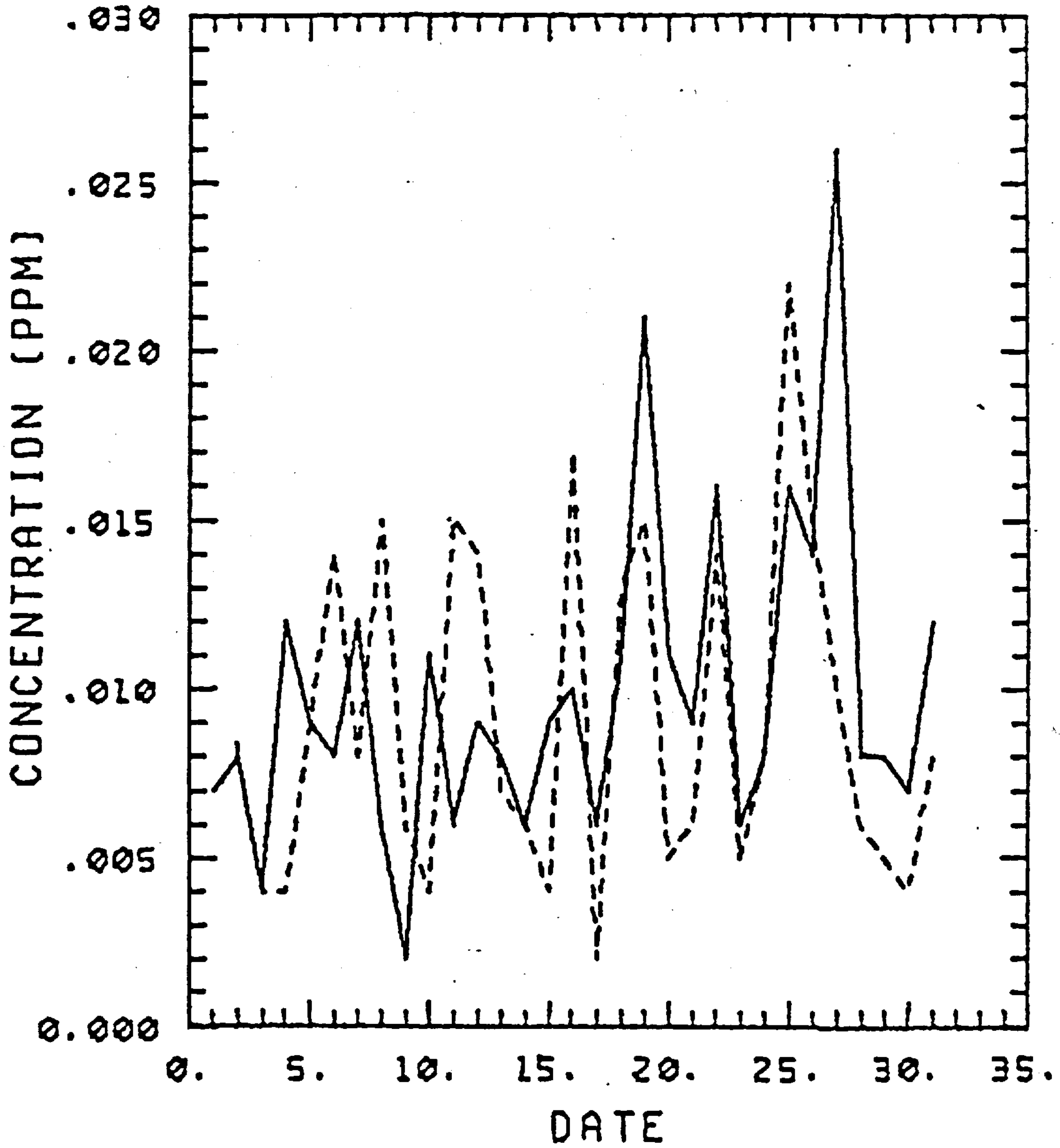


Figure A5-16 AES-LRT computed and measured daily mean sulfate concentrations during October 1977 at Port Huron, Mich. (measured-solid, computed-dashed)

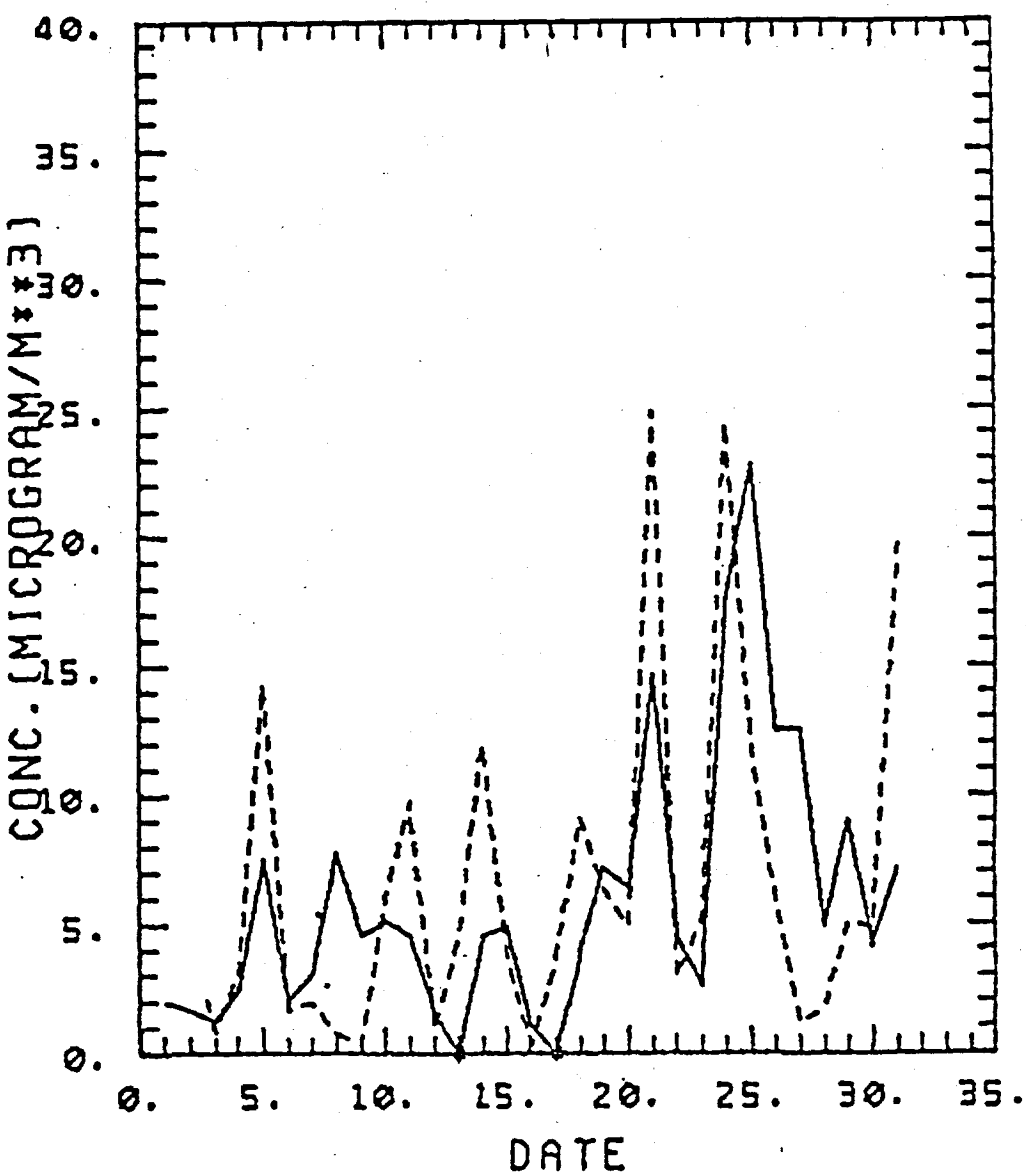


Figure A5-17 Ratios of AES-LRT computed to measured monthly precipitation weighted sulfate concentrations in the rain and percent contribution from direct sulfate scavenging (in parentheses) for October 1977.

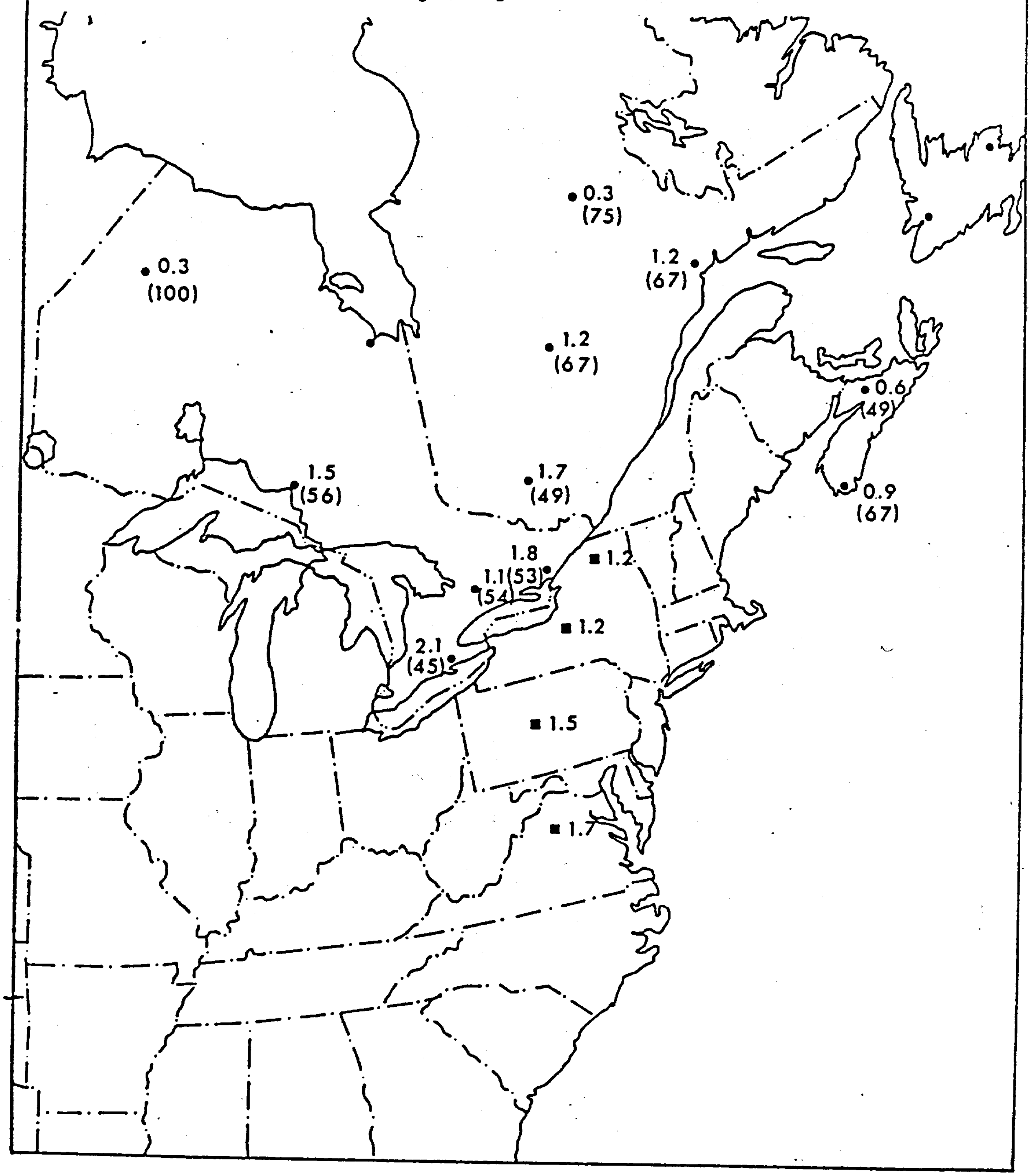
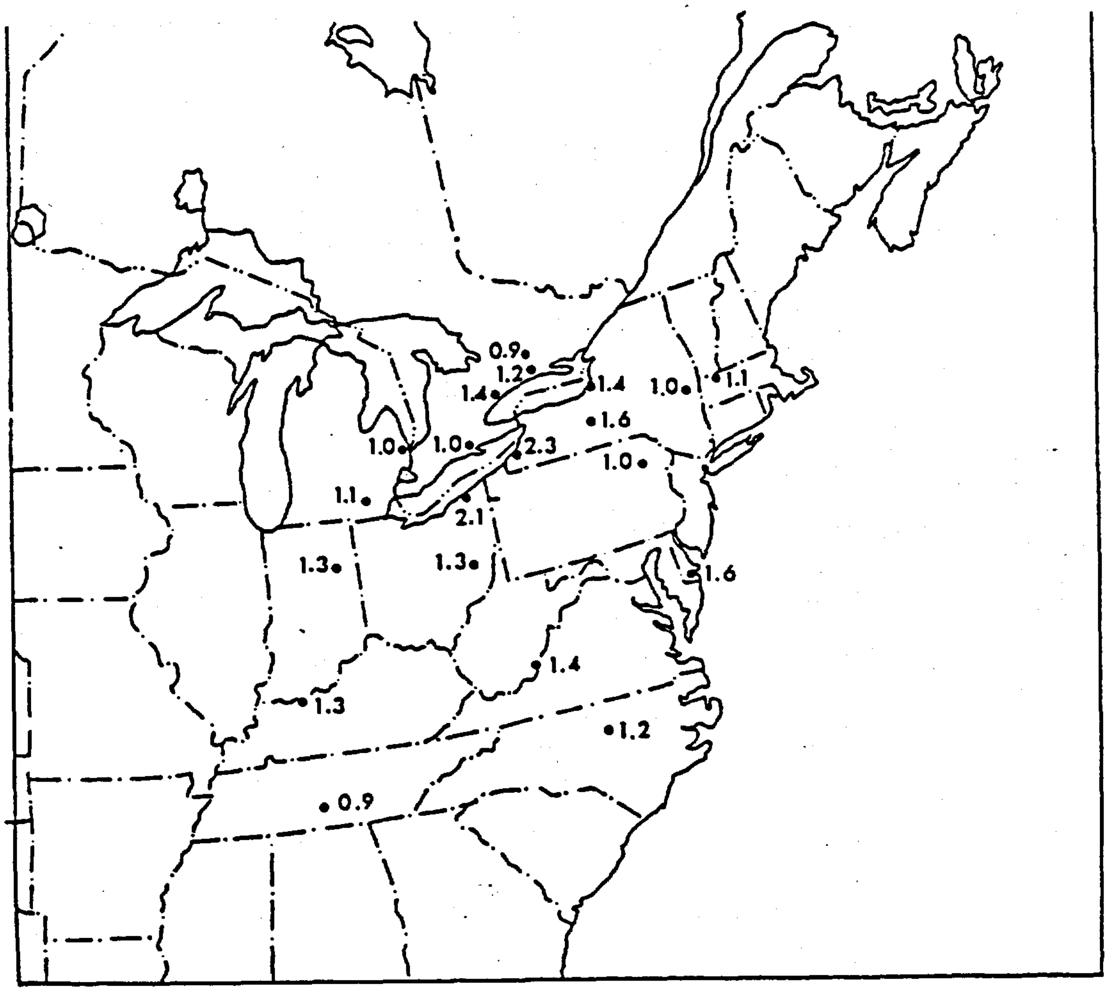


Figure A5-18 Ratios of AES-LRT computed to measured monthly mean sulfate concentrations in the air for October 1977



Model: OME-LRT

Modeling Group: Ontario Ministry of the Environment, Akula Venkatram

Model Type: Statistical Trajectory

Emission Data: - point source: a function of height
- area sources: in the form of effective point source at emission weighted geometric mean co-ordinates.

Wind Data: statistics of σ_u and σ_v from Tennekes (long term average only)

Precipitation Data: duration and frequency of wet and dry periods (Slinn, 1979)

Mixing Height: constant value of 1000 metres

Chemistry: first order SO_2/SO_4

Dispersion: - instantaneous mixing
- solution of the Lagrangian dispersion equation
- function of trajectory spread

Removal Processes: Stochastic scavenging - wet and dry removal of SO_2 & SO_4

Model Outputs: (1) concentration and deposition fields for SO_2 & SO_4
(2) source receptor matrix (11 regions)

Resolution: Annual, 100 km.

Area of Application: North America

Parameter Values: $\sigma_x = U_m T$

$\sigma_y = V_m T$

where $U_m = 10$ m/s

$V_m = 6$ m/s

SO_2/SO_4 = 1%/hour (dry & wet)

Effective washout rate for $SO_2 = 3 \times 10^{-5}$ 1/sec.

Precipitation scavenging of $SO_4 = 1 \times 10^{-4}$ 1/sec.

$VDSO_2 = 0.5$ cm/s

$VDSO_4 = 0.05$ cm/s

$T_d = 46$ hours - Langrangian dry period

$T_w = 7$ hours - Lagrangian wet period

$\bar{L} = 1000$ m

$\bar{U} = 10$ m/s

Ratio of SO_2 to SO_4 at the Source = 0.98/0.02

Descriptive Material:

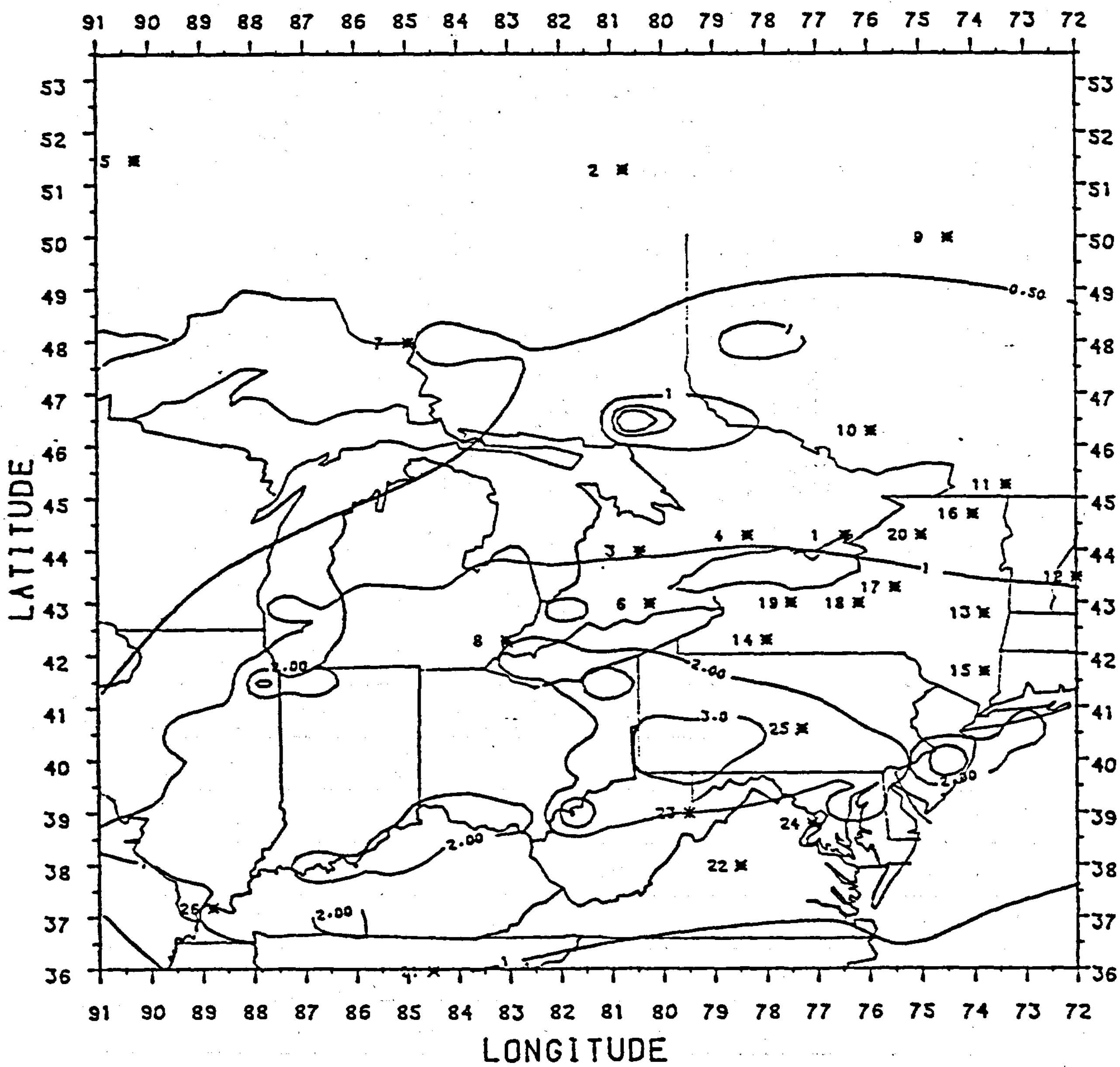
The horizontal dispersion of pollutants is based on a Gaussian puff whose mean motion follows that of large scale synoptic flows. The standard deviations of the Gaussian puff are related to the statistics of trajectories from the source of interest. Scavenging of pollutants is treated with a stochastic model which accounts for the distinctly different probabilities of rain in synoptically dry and wet regions. The model also allows for different SO_2 to SO_4 conversion rates in wet and dry periods. The statistical LRT model is a "convolution" of the dispersion and scavenging sub-models.

Comparisons with Data:

Figure A5-19 shows modeled total wet deposition of sulphur for 1977.

Table A5-1 details the verification data and correlation coefficients for various agglomerations of sources from the OME-LRT Model.

Figure A5-19 OME-LRT model predictions of annual wet deposition of sulfur in $gm/m^2/year$. Stars in figure correspond to monitors in the CANSAP and U.S. networks. Numbers next to stars are station codes referred to in Table A5-1



Station No	Receptor Name	OBS	PRED	Wet sulfur deposition OBS/PRED
		$(g/m^2/yr)$		
1	Kingston, Ont	1.26	0.93	1.35
2	Moosonee, Ont	0.58	0.33	1.76
3	Mount Forest, Ont	2.32	0.96	2.42
4	Peterbough, Ont	1.81	0.94	1.93
5	Pickel Lake, Ont	0.39	0.28	1.39
6	Simcoe, Ont	2.34	1.49	1.57
7	Wawa, Ont	0.91	0.52	1.75
8	Windsor, Ont	2.98	2.00	1.49
9	Chibougamau, Que	1.06	0.42	2.52
10	Maniwaki, Que	0.71	0.75	0.95
11	Montreal, Que	2.35	0.88	2.67
12	Merrimach Cnty, N.Y.	0.91	0.93	0.98
13	Albany Cnty, N.Y.	1.20	1.21	0.99
14	Allegany Cnty, N.Y.	2.20	1.58	1.39
15	Dutchess Cnty, N.Y.	1.20	1.48	0.81
16	Essex Cnty, N.Y.	0.84	0.84	1.00
17	Oneida Cnty, N.Y.	1.70	1.08	1.57
18	Onondaga Cnty, N.Y.	0.79	1.19	0.66
19	Ontario Cnty, N.Y.	1.20	1.34	0.90
20	St. Law. Cnty, N.Y.	1.00	0.89	1.12
21	Oak Ridge, Tenn	1.30	1.04	1.25
22	Charlottesville Vir	0.91	1.31	0.69
23	Tucker Cnty, W.V.	2.00	1.94	1.03
24	Washington, D.C.	1.00	1.83	0.55
25	Lewistown, Penn	0.98	2.21	0.44
26	Paducah, Kentucky	0.57	1.29	0.44

LINEAR ANALYSIS: OBSERVED DEPOSITION = a + b* PREDICTED DEPOSITION

Receptor Location	r^2	$a(g/m^2/yr)$	b	Receptor Excluded
Canada	0.76	0.24	1.49	
Canada	0.84	0.16	1.48	11
U.S.	0.09	0.73	0.34	
U.S.	0.47	0.05	0.98	24, 25, 26
All PT	0.19	0.67	0.58	
All PT	0.51	0.24	1.04	11, 24, 25, 26
All PT Can Obs Reduced 30%	0.70	0.12	0.97	11, 24, 25, 26

Table A5-1 Comparison of OME-LRT model predictions with observations of wet deposition of sulfur for 1977 (Galloway and Whelpdale, 1980).

Model: RCDM (Regional Climatological Dispersion Model)

Fay and Rosenzweig

Modeling Group: Teknekron Research Inc., Brand Niemann and Carl Benkeley

Model Type: Analytical Eulerian

Emission Data:
- single or multiple point and area sources
- SURE inventory

Wind Data: - resultant average vector wind field

Precipitation Data: seasonal, regional average

Mixing Height: use seasonal value at receptor point

Chemistry: slow and irreversible (eg. SO_2/SO_4) or fast and reversible (e.g. NO/NO_2)
- linear decay or equilibrium mass coefficient

Dispersion:
- steady state diffusion equation (two-dimensional)
- regional scale diffusivity

Removal Processes:
- uniform in space
- wet and dry
- first order rate constant

Model Outputs:
(1) Long term average pollutant concentrations and deposition patterns
(2) Gridded field
(3) Transfer matrix (arbitrary number of areas)

Resolution: >50 km from sources, regional scale.

Area of Application: Eastern North America

Parameter Values: $\bar{L}$ = 1000 m

$\bar{u}$ = 3.2 m/s

θ = 265° True

VD_{SO_2} = .01 m/s

Tw = 3×10^5 seconds

= net depletion time = 10^5 seconds

D_H = Diffusivity = 6.4×10^5 m^2/sec.

Descriptive Material:

Fay and Rosenzweig assumed that the longer period sulfur dioxide and sulfate concentrations from a point source can be described by the 2-dimensional steady state advection-diffusion equation in which the horizontal eddy diffusivity and conversion and removal rates are uniform in space.

The RCDM is an appropriate compromise between the original Fay and Rosenzweig application which used only one wind speed and direction for the entire eastern U.S. and the NOAA/ARL and ASTRAP models which use the highest temporal and spatial resolution available in upper air data.

The compromise decided upon was to use the seasonal and annual resultant wind vectors at all the upper air stations in the eastern U.S. and southeastern Canada.

Comparisons with Data:

Fay and Rosenzweig found generally good agreement between sulfur dioxide predictions from their analytical model and numerical predictions from the NOAA/ATDL trajectory model.

The sulfate predictions from the steady state model are in general agreement with those from the ASTRAP model which uses high resolution meteorological data to compute an ensemble average of trajectory statistics.

Sensitivity analysis of the RCDM show in general that SO_2 concentrations are most sensitive to the mixing height and the inverse total depletion rate while the sulfate concentrations are most sensitive to mixing height and the inverse chemical conversion rate. The RCDM has been evaluated against historical sulfate data and current sulfur dioxide and sulfate data. The RCDM predictions were found to be in generally good agreement with regional sulfate concentrations during 1960-1974 and with current sulfur dioxide and sulfate concentrations. Both the historical and current regional sulfate concentrations show a regional pattern of elevated sulfate concentrations which are roughly symmetrical about the 11 contiguous states with the highest sulfur dioxide emissions.

The RCDM also gives generally good agreement with winter and summer season regional sulfur dioxide and sulfate concentrations when the seasonal mixing heights from climatological data are used and the inverse chemical conversion rate (i.e., SO_2 residence time) is decreased slightly for the summer and increased slightly for the winter over the annual value.

The predicted wet sulfur deposition values are in general agreement with those computed from the MAP3S and EPRI precipitation chemistry networks in the region of highest SO_2 emissions. However, the RCDM does not predict the observed maxima in wet sulfur deposition in regions like southeastern Canada beyond the region of highest SO_2 emissions in the eastern U.S.

Figures A5-20 through A5-26 illustrate the verification data available for this model.

Figure A5-20 Isopleths of annual SO_2 concentrations (ug/m^3) simulated by the RCDM

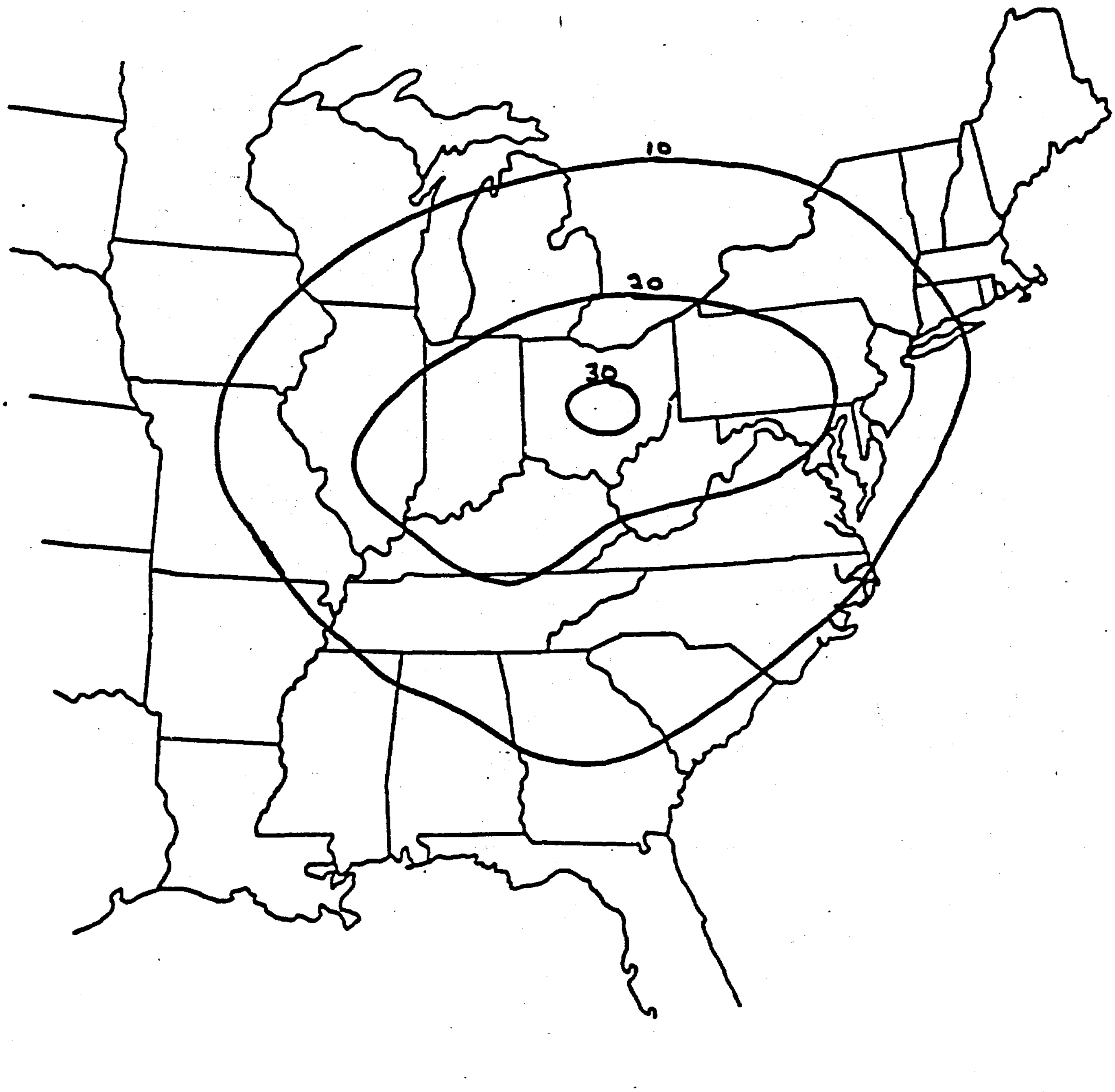


Figure A5-21 Isopleths of annual sulfate concentrations (ug/m^3) simulated by the RCDM

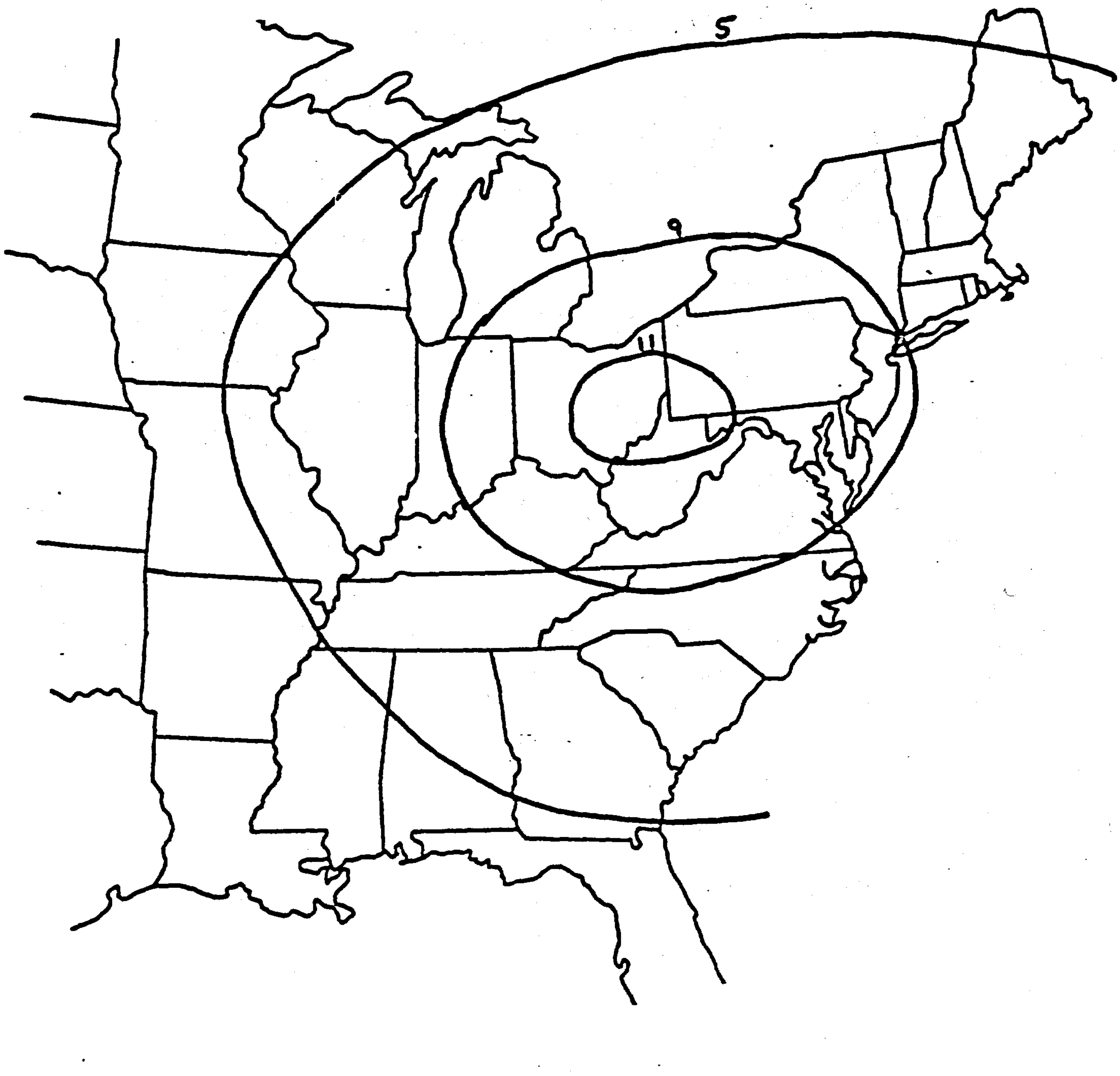


Figure A5-22 Three-year average (1975-1977) of AQCR average sulfate concentrations (ug/m^3)

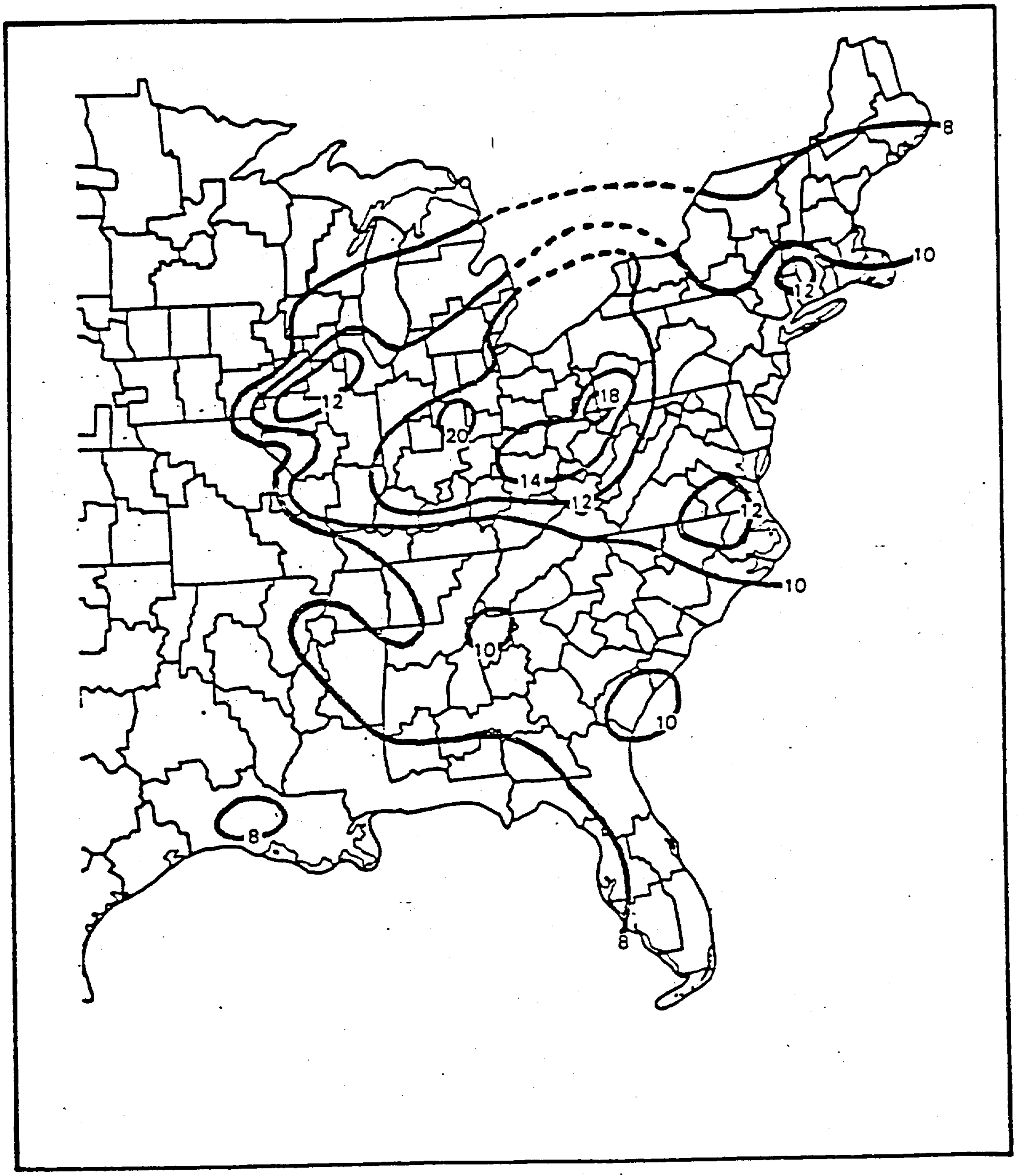


Figure A5-23 Annual average sulfate concentrations (ug/m^3) at Ontario Hydro monitors in 1978

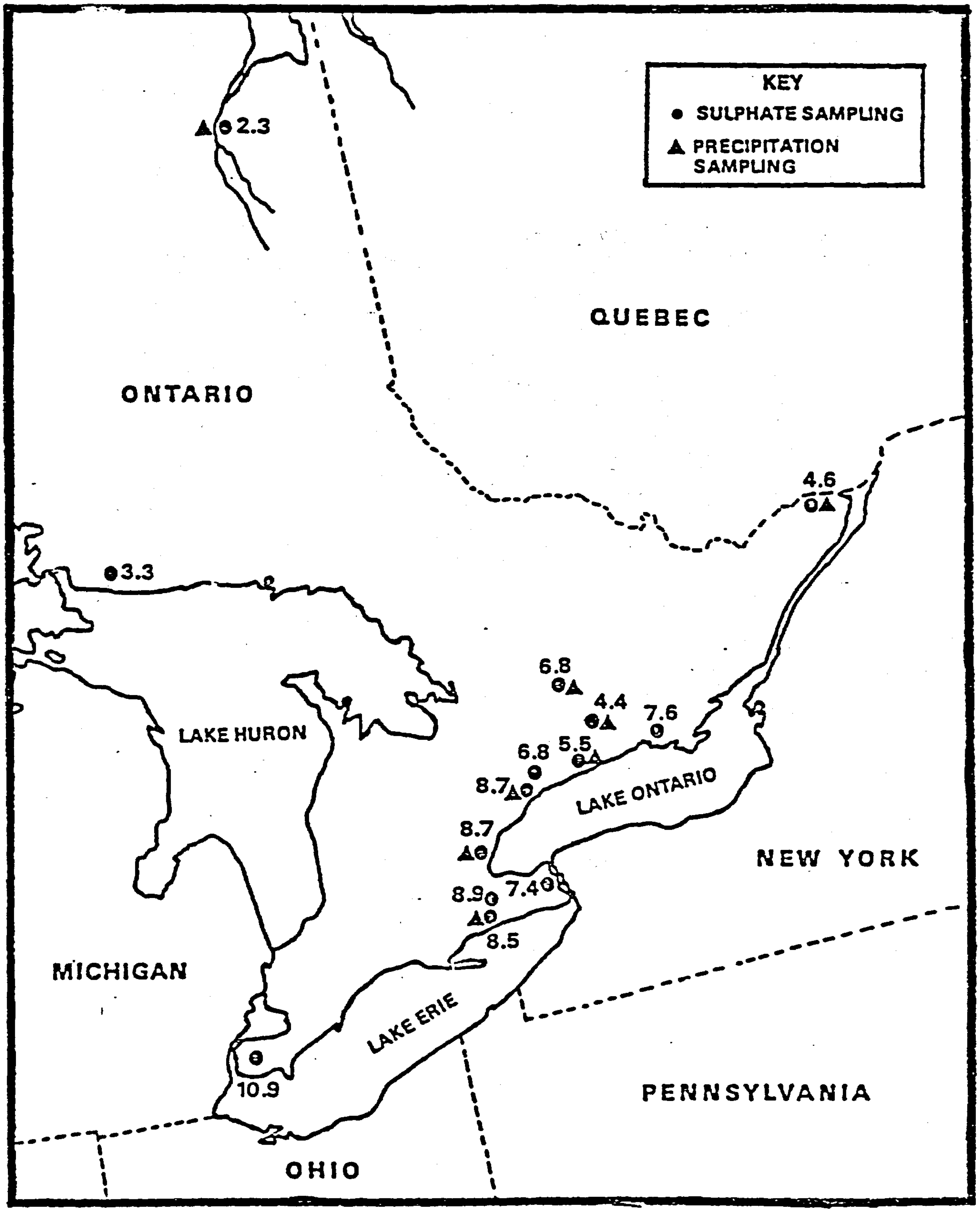


Figure A5-24 "Annual average" sulfate concentrations (ug/m^3) at the SURE monitors

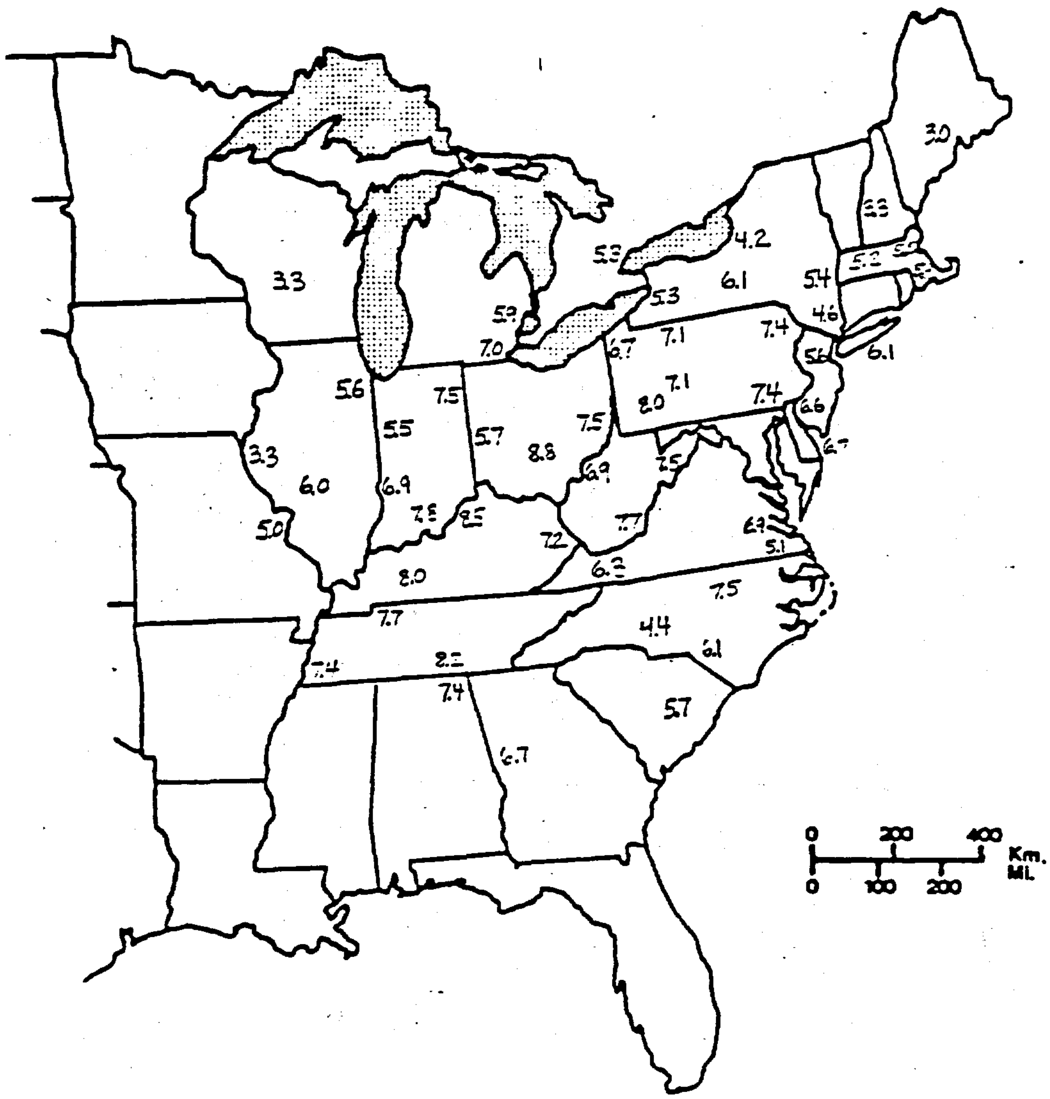


Figure A5-25 Isopleths of wet sulfur deposition (g/m^2yr) simulated by the RCDM

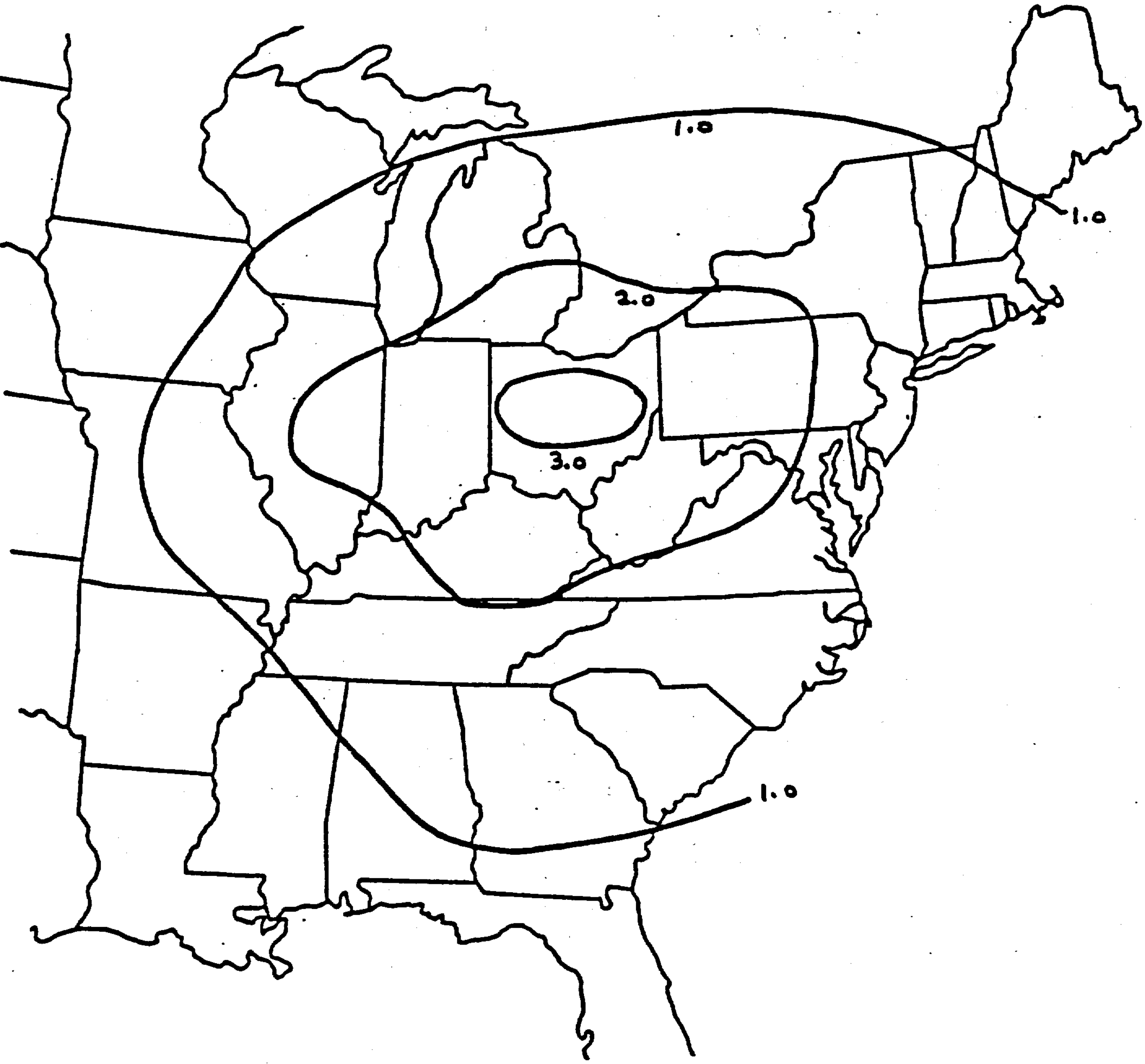
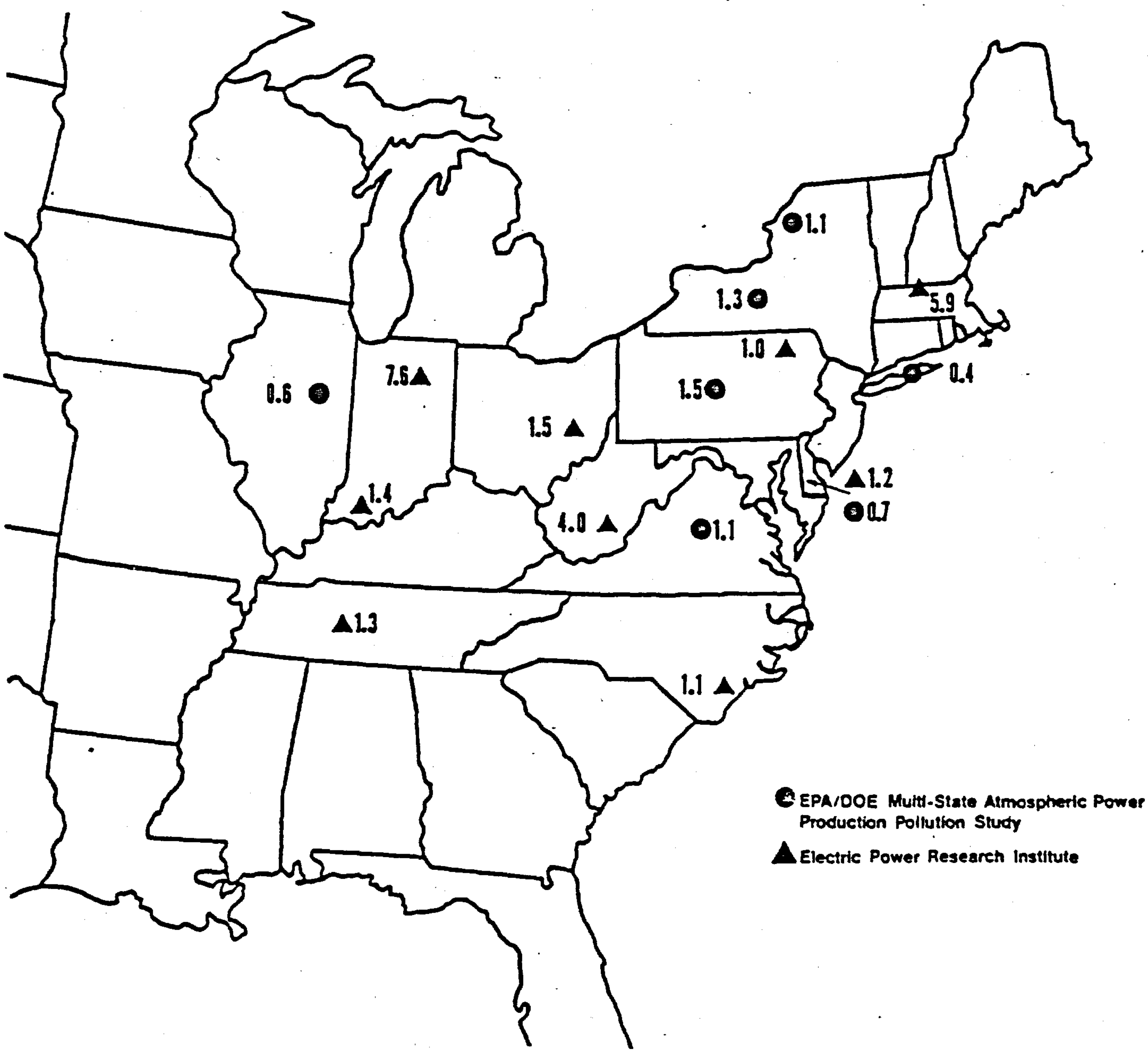


Figure A5-26 Wet sulfur deposition (g/m^2yr) at event monitoring sites in the northeastern U.S. (1976-1979)



Appendix 6

Source Region and Inventory Description

NOTE: An addendum to this appendix containing more detailed information has been produced and will be updated periodically.

LIST OF FIGURES AND TABLES

A6.1 A Description of the SURE II Extended Grid: Source Regions and Sensitive Receptor Areas

The 80km grid cells in the Sulfate Regional Experiment (SURE) Phase II emission inventory have been aggregated to define 63 distinct areas. These 63 areas have been selected to include logical source regions or sensitive receptor areas. Each entire SURE II grid cell (undivided) has been assigned to one of the 63 areas with attention being paid to matching state emission totals and state boundaries as closely as possible.

TABLE A6-1 Comparison of State Emissions Totals and Aggregate - Grid Totals (based on SURE Phase II Inventory)

State	Emissions (1000s tons/year) SURE Data Files	Aggregate of Grid Squares	Difference (Grid Aggregate - Data Base) 1000 tons/year	Percent
Alabama	1290	1209	-81	-6
Arkansas	79	90	+11	+14
Connecticut	66	45	-21	-32
Delaware	129	131	+2	+2
Florida	1788	1798	+10	+1
Georgia	916*	942*	+26	+3
Illinois	2344	1994	-350	-15
Indiana	2189	2545	+356	+16
Iowa	535	557	+22	+4
Kentucky	1824	1809	-15	-1
Louisiana	636	614	-22	-3
Maine	337	339	+2	+1
Maryland & D.C.	352	455	+103	+29
Massachusetts	666	670	+4	+1
Michigan	2292	2627	+355	+13
Minnesota	521	508	-13	-2
Mississippi	447	501	+54	+12
Missouri	1288	1291	+3	0
New Hampshire	169	173	+4	+8
New Jersey	555	692	+137	+25
New York	974	698	-276	-28
N. Carolina	984*	1004*	+20	+2
Ohio	4533	4759	+226	+5
Pennsylvania	2480	2150	-330	-15
Rhode Island	43	33	-10	-23
S. Carolina	459	429	-30	-7
Tennessee	1332*	1360*	+28	+2
Vermont	7	6	-1	-14
Virginia	695	644	-51	-7
West Virginia	1349	1355	+6	0
Wisconsin	937	935	-2	0
Ontario (part)	2228	2088	-140	-6
Quebec (part)	1017	1020	+3	0
	35509	35519	+10	0.03%

* Emissions in S. Appalachain sensititve area excluded

The SURE-II Extended Grid

The grid has an 80-km mesh, with 41 cells east-west and 42 north-south; because it is an extension of an earlier version, the cells are numbered 0 to 40 and -9 to 32 in the X and Y, or east and north, directions respectively.

If the 0 to 30 E-W index is denoted I, and the -9 to 32 N-S index denoted J, the one-dimensional index used is IDX = I+ 41 * (J-1).

The grid is "centered" around 81^{0} west longitude, 39^{0} 38' latitude, which corresponds to x=500.0km, and y=4407.02 km in the transverse mercator (TM) system used for the grid. This corresponds to the following TM coordinates for the grid lines:

42 N-S lines at -780, -700,..............., +2420, +2500 km

43 E-W lines at 2687.02, 2767.02,.............. 5967.02, 6047.02 km

TABLE A6-2 SURE II SO_2 Emissions Allocated to Grid Aggregate Areas.

Area	SO_2 Emissions 1000s tons per year	AREA CENTROID X	AREA CENTROID Y	EMISSION CENTROID X	EMISSION CENTROID Y
1. Maine	332.0	27.36	20.79	26.92	19.45
2. New Hampshire SA*	41.7	25.50	20.00	25.16	19.40
3. Vermont	5.8	24.00	18.50	24.00	18.29
4. Southern New Hampshire	138.4	24.67	17.33	24.90	17.28
5. Massachusetts	670.1	25.67	16.00	25.80	15.98
6. Rhode Island	33.2	25.00	15.00	25.00	15.00
7. Connecticut	45.1	24.00	15.00	24.00	15.00
8. Adirondack SA*	12.0	22.50	18.50	22.75	18.54
9. Western New York	307.1	18.20	16.40	18.54	16.88
10. Southeastern New York	378.9	21.46	16.69	21.83	16.08
11. New Jersey	691.7	23.00	13.00	22.85	13.64
12. Southeastern Pennsylvania	569.0	21.67	13.33	21.83	13.35
13. Central Pennsylvania	476.9	19.88	14.13	20.00	13.46
14. Western Pennsylvania	1075.8	17.40	14.20	17.09	13.42
15. Pennsylvania SA*	55.2	18.00	12.50	18.00	12.51
16. Maryland & DC	428.2	20.17	11.00	19.98	11.11
17. Delaware	130.5	21.67	11.00	21.34	11.66
18. Virginia	643.8	18.35	9.06	19.13	8.91
19. Northeastern West Virginia	1086.3	16.67	11.67	16.26	11.89
20. Southwestern West Virginia	268.3	15.17	10.00	15.01	10.11
21. Eastern Kentucky	753.9	11.58	9.17	10.58	9.87
22. Western Kentucky	1054.6	8.00	9.00	8.11	9.00
23. Western Tennessee	726.2	6.89	6.78	7.52	7.17
24. Eastern Tennessee	633.2	10.80	7.00	11.32	7.42
25. Southern Appalachain SA*	72.8	12.83	6.00	13.14	6.35
26. Central North Carolina	512.4	15.20	6.80	15.34	7.12
27. Eastern North Carolina	473.2	18.94	5.94	18.20	6.25
28. South Carolina	423.0	16.07	3.86	15.97	3.96
29. Northwestern Georgia	620.8	11.40	3.80	11.08	4.40
30. Southeastern Georgia	321.4	13.21	1.42	13.66	1.74
31. Southern Florida	647.7	15.33	-5.89	14.75	-4.59
32. Northern Florida	179.8	15.17	-2.33	14.81	-2.57
33. Florida SA*	59.6	13.50	-1.50	13.61	-1.52
34. Western Florida	911.8	9.80	-0.90	8.38	-0.31
35. Alabama	1208.5	8.67	2.67	8.59	3.64
36. Mississippi	500.6	5.30	2.65	6.24	2.28
37. Louisiana	614.1	2.20	0.44	3.01	-0.20
38. Arkansas	67.4	1.95	5.85	2.63	5.24
39. Arkansas SA*	10.6	2.40	7.20	2.40	6.66
40. Missouri	1290.5	2.58	11.06	3.38	11.00
41. Iowa	524.8	2.78	16.30	3.56	16.10

42.	Southern Illinois	1065.6	6.44	11.44	6.31	11.15
43.	Northern Illinois	959.9	7.42	14.42	6.97	14.43
44.	Northern Indiana	751.4	10.00	14.00	9.37	14.55
45.	Southern Indiana	1793.2	9.63	11.13	9.69	11.06
46.	Southern Ohio	3014.2	14.14	11.86	14.58	12.07
47.	Northeastern Ohio	1108.8	15.50	14.50	15.32	14.54
48.	Northwestern Ohio	635.9	12.78	13.33	13.06	13.07
49.	Southern Michigan	2310.5	12.17	16.67	12.71	16.16
50.	Northern Michigan	316.4	10.50	20.54	10.20	20.27
51.	Wisconsin	935.5	6.84	19.36	7.36	18.34
52.	Minnesota	487.3	2.15	20.51	3.54	20.91
53.	Boundary Waters SA*	20.2	6.20	24.60	6.00	24.00
54.	Central Ontario	433.5	12.52	23.57	16.00	20.99
55.	Sudbury	1060.8	15.00	21.00	15.00	21.00
56.	Ontario SA*	8.2	17.50	19.50	17.34	19.12
57.	Southern Ontario	585.4	17.12	17.76	16.25	17.27
58.	Quebec SA*	14.5	23.50	22.50	23.50	22.50
59.	Southern Quebec	273.0	22.69	21.00	23.10	20.66
60.	Central Quebec	732.9	23.66	24.33	19.12	24.23
61.	Southern Nova Scotia*	2.9	30.50	19.50	30.50	19.50
62.	Nova Scotia	--	32.00	21.50	32.00	21.50
63.	Newfoundland	--	37.00	28.00	37.00	28.00

*SA = Sensitive Area

NOTE: Canadian emissions in areas 54-60 are also from the SURE inventory.

TABLE A6-3 SURE II SO_2 Emissions Allocated to Grid Aggregate Areas Subdivided by by Stack Height

Area Number	STACK HEIGHT <100m	100m - 300m	>300m	TOTAL (10^3 tons)
1	45	4	0	49
2	0	0	0	0
3	0	0	0	0
4	34	17	0	51
5	74	233	0	307
6	6	8	0	14
7	18	13	0	31
8	0	0	0	0
9	94	60	0	154
10	141	25	0	166
11	169	60	0	229
12	193	97	0	290
13	131	202	0	333
14	279	424	170	873
15	30	0	0	30
16	81	173	0	254
17	43	22	0	65
18	192	38	0	230
19	40	536	443	1019
20	45	109	0	154
21	170	413	0	583
22	217	561	248	1026
23	200	198	231	629
24	54	281	125	460
25	16	0	0	16
26	110	271	0	381
27	165	96	0	261
28	186	60	0	246
29	0	260	277	537
30	63	12	41	116
31	196	238	0	434
32	62	64	0	126
33	14	0	0	14
34	36	6	0	42
35	286	542	69	897
36	269	57	0	326
37	263	126	0	389
38	11	2	0	13
39	0	0	0	0
40	139	856	0	995
41	193	19	0	212

Area Number	<100m	STACK HEIGHT 100m - 300m	>300m	TOTAL (10^3 tons)
42	204	713	0	917
43	138	325	0	463
44	240	176	0	416
45	233	1254	0	1487
46	211	2048	403	2662
47	519	123	0	642
48	94	170	0	264
49	534	1253	0	1787
50	96	78	0	174
51	170	355	0	525
52	38	285	0	323
53	20	0	0	20
54	162	264	1059	1485
55	0	0	0	0
56	0	0	0	0
57	27	345	0	372
58	0	0	0	0
59	89	0	0	89
60	36	650	0	686
	7,076	14,122	3,066	24,264

FIGURE A6-1 SO_2 Emission Rate with Height (SURE II Inventory)

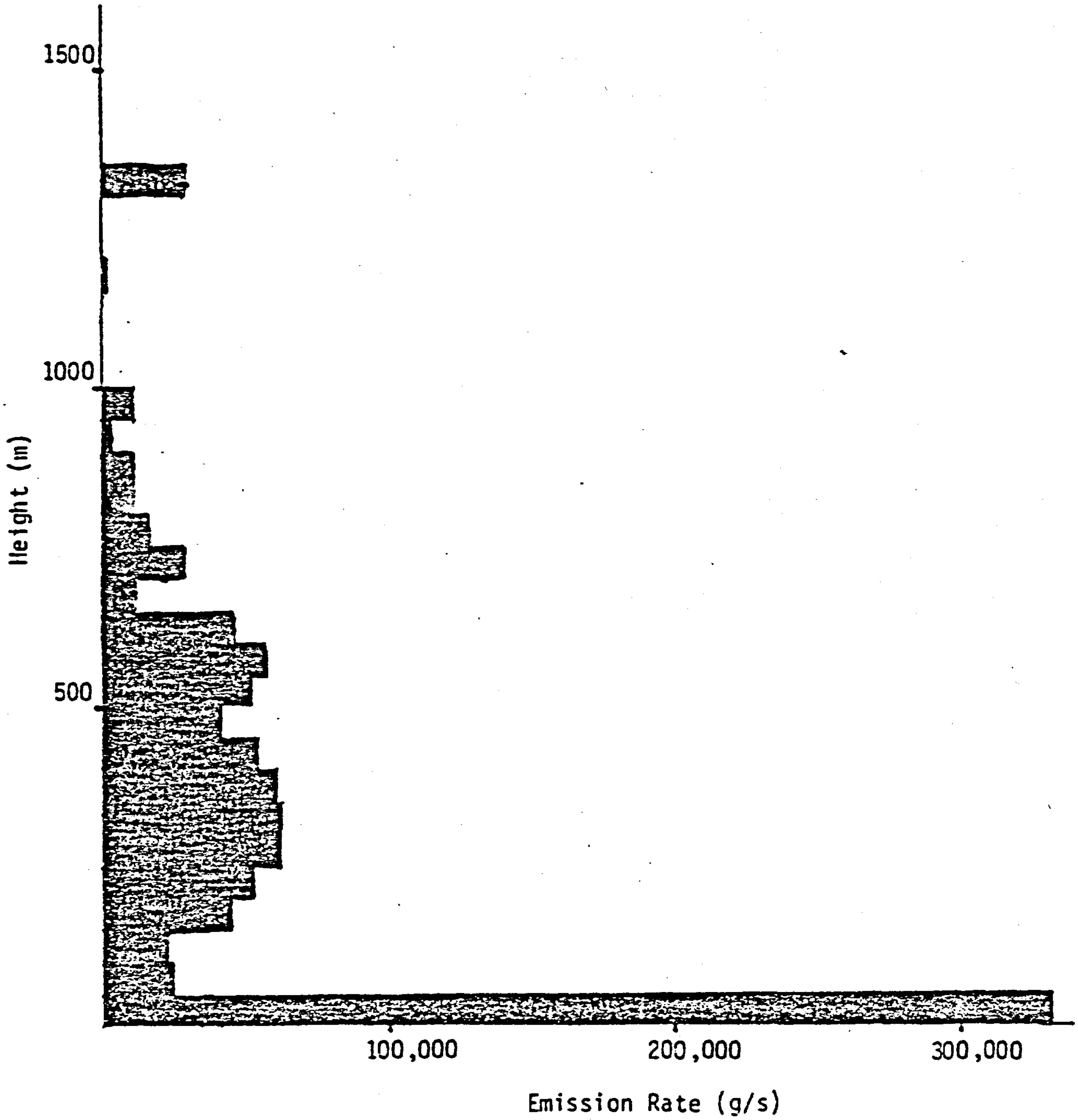


TABLE A6-4

Principal Reason for Selection of Sensitive Areas

AREA NUMBER	PRINCIPAL REASON
2	Hubbard Brook Studies by Likens et al
8	Lake Studies by Scofield, EPRI, etc.
15	River and Stream Studies by Arnold et al
25	Great Smoky Mountain National Park
33	Lake and Swamp Studies by Brezonik et al
39	Ozark Mountain Soils and Forests and Hot Springs National Park
53	Lake Studies by Gary Glass et al
56	Lake Studies by Canadians
58	Lake Studies by Canadians
61	Lake Studies by Canadians

TABLE A6-5 Relationship Between Area Numbers and Abbreviations on Large Map

Area Number	Map Designation	Area Number	Map Designation
1	ME	31	FL1
2	SA1	32	FL2
3	VT	33	SA5
4	NH	34	FL3
5	MA	35	AL
6	RI	36	MS
7	CN	37	LA
8	SA2	38	AR
9	NY1	39	SA6
10	NY2	40	MO
11	NJ	41	IA
12	PA1	42	IL1
13	PA2	43	IL2
14	PA3	44	IN1
15	SA3	45	IN2
16	MD	46	OH1
17	DE	47	OH2
18	VA	48	OH3
19	WV1	49	MI1
20	WV2	50	MI2
21	KY1	51	WI
22	KY2	52	MN
23	TN1	53	SA7
24	TN2	54	ON1
25	SA4	55	ON2
26	NC1	56	SA8
27	NC2	57	ON3
28	SC	58	SA9
29	GA1	59	QE1
30	GA2	60	QE2
		61	SA10
		62	NS
		63	NF

TABLE A6-6 Relationship Between Canadian Regions and the 63 Aggregated SURE Grid Areas

Canadian Region #	Area Represented	Canadian SO_2 Emissions(1) (kT/yr)	Canadian SO_2 Emissions(2) (kT/yr)	SURE SO_2 Emissions(3) (kt/yr)	Principal SURE Areas
1	Michigan	1946	1566	2627	49-50
	(South Michigan)	(1762)		(2311)	(49)
2	Illinois, Indiana	3874	5072	4570	42-45
	(Southern Illinois)	(1050)		(1066)	(42)
3	Ohio	4762	3961	4759	46-48
	(Southern Ohio)	(3092)		(3014)	(46)
	(Northeast Ohio)	(1286)		(1109)	(47)
4	Pennsylvania	2056	2039	2177	12-15
	(Western Pennsylvania)	(1067)		(1076)	(14)
5	New York, New Jersey to Maine	2408	2281	2656	1-11
6	Kentucky, Tennessee	2835	2400	3241	21-25
	(Western Kentucky)	(740)		(1055)	(22)
7	West Virginia, Virginia, N. Carolina, Delaware, Maryland,	2446	3400	2557	16-20
	and D.C.			985	26-27
	(Northern W. Virginia)	(476)		(1086)	(19)
8	Rest of Eastern United States	7485	2387	8803	28-41, 51, 52
	(Missouri)	(1316)		(1291)	(40)
	(Alabama)	(1525)		(1209)	(35)
	TOTAL EASTERN U.S.	27,812	23,106	32,375	
9	Ontario	1970	1809	2108	53-57
	(Sudbury)	(1001)		(1061)	(55)
10	Quebec	1037	1186	1021	58-60
11	Atlantic Provinces	469	368		
	TOTAL EASTERN CANADA	3,476	3,363	3129	

1 kT = 1.1 kt

1 Used in AES-LRT Model
2 Used in OME-LRT Model
3 Used in ENAMAP, ASTRAP, and RCDM Models

TABLE A6-7 Relationship Between Canadian Receptor Areas and ARMS Sensitive Areas

ARMS Sensitive Area	Name	Canadian Receptor Point	Area Represented	Comments
1	New Hampshire	6	New Hampshire	
2	Adirondacks	7	Adirondack (Whiteface)	
3	Pennsylvania	8	Pennsylvania (Penn State)	in PA 2
4	Southern Appalachia	9	Southern Appalachia (Smokies)	
5	Florida			
6	Arkansas			
7	Boundary Waters	1	Boundary Waters	Northwest of SA 7
8	Ontario	3	Muskoka	
9	Quebec	4	Quebec City (Montmorency)	
10	Nova Scotia	5	Southern Nova Scotia	
		2	Algoma	

A6.2 Canadian Emissions - Current Data Base

The data base for current emission rates in Canada represents a mixture of information covering the period 1976 through 1980. For sulphur dioxide, all area source data represent 1976 annual emission rates (1). Major point sources are at their 1979 annual emission rate and the most important copper-nickel smelter complex, representing about twenty percent of eastern Canada emissions, is shown at its 1980 emission rate (2). On a weighted emissions basis the aggregated SO_2 data base closely represents actual emissions for the year 1979.

In the case of nitrogen oxides all area source type emissions are from the 1976 base year (1) and major point sources are at their 1979 annual emission rate (2). On a weighted emissions basis the aggregated Canadian NO_x data base probably represents actual emission rates in 1977.

The eastern Canada (including Manitoba) data is further prorated on a grid array of 127 km x 127 km squares which is the basic dimension for the emissions and meteorological data used in the AES long-range transport model.

On a national basis the overall accuracy of the current Canadian SO_2 emissions inventory is estimated to be + 30% at a 75% confidence level (2). The accuracy varies widely for each sector of emissions and within each sector, and is far greater for the major point sources (e.g. Cu-Ni smelters), which together represent more than half of total Canadian emissions, than for sources of lesser significance. An uncertainty analysis has not been carried out for NO_x emissions.

Seasonal variations data for use in detailed air quality analysis have been developed for both SO_2 and NO_x emissions for all contributing sectors (2). Nationwide inventories of the natural emissions of sulphur and nitrogen compounds have also been prepared (3,4)

References

1. Environment Canada, Air Pollution Control Directorate, A Nationwide Inventory of Emissions of Air Contaminants (1976), Report EPS-3-AP-80-1 (December 1980).
2. Environment Canada, Air Pollution Control Directorate, Data Analysis Division (Unpublished information) (December 1980)
3. Environment Canada, Air Pollution Control Directorate, National Inventory of Natural Sources and Emissions of Sulphur Compounds, Report EPS 3-APA-79-2 (February 1980)
4. Environment Canada, Air Pollution Control Directorate, National Inventory of Natural Sources and Emissions of Nitrogen Compounds, Report EPS 3-AP-80-4 (January 1981)

Appendix 7

Matrix Operations

A. MATRIX MANIPULATION PROGRAMS

The integrated analysis framework outlined in Table A7.1 has three major characteristics:

1. The ability to selectively combine information from various sources such as emission inventories and transport model transfer matrices to provide estimates of resulting concentrations and depositions.
2. The ability to support comparison and evaluation of different data bases and models by converting their results to common units and output formats.
3. The ability to combine emission projections with cost implications data in order to identify cost-effective answers to questions concerning how to reduce atmospheric loadings and/or deposition.

With regard to the first characteristic, the integrating framework could be used to combine utility, industrial, combustion, and area source emission estimates from different models in order to produce integrated emission estimates from all sectors. The emissions can then be combined with transfer matrices in order to estimate deposition.

With regard to the second characteristic, the integrating framework can be used in converting data from different sources to common units. For example, ENAMAP and ASTRAP results have been converted to common units and comparison tables and scatter diagrams prepared.

Table A.7-1 Integrated ARMS/RCG/MOI

SO_x Source - Receptor Matrix Processing System

External - prepare inputs	Work Group 2 - analyze and intercompare	Work Groups 3A and 3B - develop least cost control strategy
Emissions and control costs		Program 4 - Format Emissions (4) and Costs
Utility - USM, ICF, EPA		
Industrial - ICF, IFCAM	Run models with emissions to meet specified target loadings in sensitive areas.	Program 5 - Least-Cost Source-Receptor Optimization (5)
Other - EPA Mobile, SEAS - DOE Canada - Work Group 3B	Re-run models to confirm efficacy of emission reduction scenarios to meet specified target loadings in sensitive areas.	
LRTAP model matrices	Program 1 - Format Matrices (1)	Program 3 - Compute Concentrations and Depositions (3)
Canadian - AES, OME (11x9x5)	Program 2 - Intercompare Matrices (2)	
U.S. - ENAMAP, ASTRAP* RCDM* (63x63x VAR)	2A Convert: U.S. to Canada	
Other - CAPITA*, REGMOD (episode), BWA, PNL, BNL	2B Plot Scatter Figures	
	Program 3 - Same as for Work Group 3A and 3B	

* NO_x in progress

Status: (1) on-line
(2) in-process
(3) on-line
(4) to be developed
(5) modify existing program

The final characteristic permits the combined assessment of emissions, costs of controling emissions, and resulting deposition. The development of cost-effective control strategies is done using a nonlinear optimization model which is being extended to consider regional scale problems. The optimization model identifies a least-cost solution which meets a combined set of emission quantity, ambient air quality, and/or deposition constraints.

B. TECHNIQUE FOR IDENTIFYING CANDIDATE AREAS FOR EMISSION REDUCTION

The deposition of sulphur D_j (or acid) at a receptor due to a source can be expressed as

$$D_j = Q_i f_{ij} \tag{1}$$

where Q_i is the strength of source 'i', and 'j' refers to the receptor. The transfer function f_{ij} establishes the physical relationship between the locations of the source and receptor. It is essentially the deposition at 'j' due to unit emissions at 'i' and is dependent on the scavenging and dispersion processes which affect the pollutants transported from 'i' to 'j'. f_{ij} is the most important model result from the point of view of emission control strategy.

The reduction in deposition $\widetilde{\Delta} D_j$ due to a source reduction ΔQ_i follows from (1)

$$\widetilde{\Delta} D_j = \Delta Q_i f_{ij} \tag{2}$$

The deposition reduction associated with a number of sources can be written as

$$\underset{i}{\Delta} D_j = \sum_i \Delta Q_i f_{ij} \qquad (3)$$

Equation (3) can be conveniently written for several receptors in matrix notation

$$\Delta D = F^T \Delta Q \qquad (4)$$

where ΔD and ΔQ are column vectors and F is the so-called transfer matrix and F^T is its transpose.

APPLICATIONS OF EQUATION (4)

There are any number of ways of looking at emission reduction scenarios. Some possible methods are

1) Maximize the reduction in deposition given constraints on emission reduction. This is a problem in linear programming and can be stated as:

$$\text{Maximize} \quad \Delta D = \sum_j \sum_i \Delta Q_i f_{ij} a_j \qquad (5a)$$

$$\text{Given} \quad \sum a_j \Delta Q_i \leq Q_{Tj}; \quad j = 1,2....N \qquad (5b)$$

where Q_{Tj} is the specified emission constraint and N is the number of constraints. The number a_j reflects the importance assigned by the decision maker to the receptor j. For example, the Ontario Ministry of the Environment might want to give Ontario receptors three times more importance than the other receptors of interest. Then we take $a_j = 3$ for Ontario receptors and $a_j = 1$ for the others.

2) Minimize cost of emission reduction given constraints on deposition reduction. This is also a problem in linear programming which can be stated as

$$\text{Minimize } \Delta C = \sum_i b_i \Delta Q_i \tag{6a}$$

$$\text{Given } \sum_i a_{ij} \Delta D_i > \Delta D_{Tj};\ j = 1,2....N \tag{6b}$$

where b_i relates cost to emission reduction. A possible constraint corresponding to (6b) is

$$\Delta D_i \geq \Delta D_{Ti} \tag{7}$$

Equation (7) states that the deposition reduction at each receptor should be greater than or equal to a specified value. Note that ΔD_i in (6b) is related to ΔQ_j through (2).

This discussion illustrates the importance of the transfer matrix F in any emission reduction strategy.

Another important "effect" variable is the frequency with which a concentration or deposition is exceeded at a receptor of interest. If we denote this frequency by $F_{ij}(c)$ we can write

$$F_{ij}(c) = \Psi(Q_i, D_{ij}) \tag{8}$$

Note that F_{ij} is not expected to be a linear function of Q_i. D_{ij} is the physical relationship between 'i' and 'j' which can derived from Lagrangian model results for time scales for which the concentration is important. Clearly the use of (8) in emission control strategy requires non-linear optimization techniques.

Appendix 8

Transfer Matrices

NOTE: An addendum to this appendix containing the ASTRAP, ENAMAP, and RCDM model matrices is in process.

Table A8-1 Transfer Matrix of:

Annual Sulfur Dioxide Concentration (ug/m^{-3})
per unit emission (Tg.S.yr^{-1})

Source Regions	Models	Emiss. (Tg.S)	B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (9)
1	MOE	0.784	0.08	0.70	1.7	0.50	0.57	0.91	1.5	3.3	0.16
Mich.	AES	0.973	0.16	2.9	4.4	0.80	0.38	1.0	1.4	3.8	0.16
2 Ill.	MOE	2.538	0.07	0.34	0.49	0.19	0.22	0.31	0.46	1.3	0.80
Ind.	AES	1.937	0.07	0.72	0.77	0.15	0.11	0.26	0.42	1.2	1.6
3	MOE	1.983	0.04	0.22	0.51	0.25	0.40	0.48	0.78	4.0	0.37
Ohio	AES	2.381	0	0.14	1.2	0.40	0.32	0.71	1.3	9.0	0.80
4	MOE	1.021	0.03	0.17	0.46	0.30	0.62	0.63	0.99	9.2	0.16
Penn.	AES	1.028	0	.06	0.71	0.47	0.44	1.3	2.2	21.7	0.12
5 N.York	MOE	1.143	0.02	0.10	0.33	0.40	1.9	1.0	1.6	0.62	0.06
to Maine	AES	1.204	0.01	0.12	0.56	0.91	4.2	2.0	3.2	0.58	0.04
6 Kent.	MOE	1.202	0.03	0.12	0.19	0.10	0.15	0.17	0.23	0.74	3.2
Tenn.	AES	1.418	0	0.07	0.27	0.04	0.04	0.12	0.22	1.3	9.3
7 W.Virg.	MOE	1.703	0.02	0.10	0.22	0.17	0.40	0.33	0.46	1.7	0.26
to N.C.	AES	1.223	0	0.02	0.16	0.16	0.18	0.38	0.64	3.0	0.90
8 Rest of	MOE	1.196	0.12	0.68	0.55	0.20	0.18	0.28	0.38	0.62	1.9
(USA) Fld to Mo. to Minn.	AES	3.743	0.53	0.61	0.27	0.05	0.03	0.07	0.13	0.45	3.0
9	MOE	0.906	0.10	1.0	3.2	1.9	0.91	2.0	2.2	0.96	0.06
Ontario	AES	0.985	0.11	2.5	12.4	1.7	0.78	2.6	4.2	2.4	0.08
10	MOE	0.595	0.06	0.30	0.57	3.0	1.3	4.7	1.1	0.18	0.03
Quebec	AES	0.519	0.08	0.91	1.9	6.7	2.3	13.1	3.9	0.29	0.02
11 Atlantic	MOE	0.187	0.01	0.03	0.07	0.26	1.5	0.26	0.15	0.05	0.01
Provinces	AES	0.235	0	0	0.04	0.26	13.6	0.13	0.09	0	0

Table A8-2 Transfer Matrix of:

Annual Sulfate Concentration (ug/m^{-3}) per unit emission (TgS.yr^{-1})

Source Regions	Models	Emiss. (Tg.S)	Receptor Areas: B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (9)
1 Mich.	MOE	0.784	0.08	0.27	0.56	0.32	0.38	0.46	0.61	0.86	0.13
	AES	0.973	0.10	0.45	1.8	0.55	0.46	0.80	0.94	1.5	0.25
2 Ill. Ind.	MOE	2.538	0.08	0.22	0.29	0.18	0.22	0.25	0.31	0.57	0.36
	AES	1.937	0.02	0.37	0.41	0.12	0.11	0.22	0.34	0.72	1.3
3 Ohio	MOE	1.983	0.06	0.15	0.26	0.20	0.30	0.30	0.38	0.88	0.19
	AES	2.381	0	0.04	0.59	0.16	0.31	0.41	0.63	2.3	0.63
4 Penn.	MOE	1.021	0.05	0.12	0.23	0.21	0.37	0.33	0.41	1.1	0.12
	AES	1.028	0	0.03	0.29	0.20	0.34	0.50	0.91	2.5	0.11
5 N.York to Maine	MOE	1.143	0.04	0.08	0.15	0.22	0.61	0.35	0.38	0.19	0.06
	AES	1.204	0.01	0.08	0.22	0.31	1.2	0.55	0.70	0.18	0.02
6 Kent. Tenn.	MOE	1.202	0.05	0.12	0.16	0.12	0.17	0.17	0.20	0.38	0.07
	AES	1.418	0	0.04	0.12	0.01	0.04	0.06	0.11	0.56	2.6
7 W.Virg. to N.C.	MOE	1.703	0.04	0.09	0.16	0.15	0.28	0.22	0.26	0.42	0.13
	AES	1.223	0	0	0.07	0.05	0.13	0.17	0.27	0.90	0.70
8 Rest of (USA) Fld to Mo. to Minn.	MOE	1.196	0.09	0.27	0.29	0.17	0.19	0.22	0.26	0.35	0.44
	AES	3.743	0.12	0.27	0.20	0.05	0.05	0.08	0.13	0.29	1.2
9 Ontario	MOE	0.906	0.08	0.23	0.67	0.66	0.49	0.69	0.69	0.34	0.07
	AES	0.985	0.05	0.67	2.3	1.0	0.79	1.4	1.9	1.0	0.11
10 Quebec	MOE	0.595	0.06	0.14	0.22	0.72	0.51	.75	0.34	0.14	0.04
	AES	0.519	0.14	0.42	0.85	1.3	1.2	1.9	1.4	0.17	0.04
11 Atlantic Provinces	MOE	0.187	0.02	0.04	0.06	0.13	0.33	0.13	0.10	0.06	0.03
	AES	0.235	0	0	0	0.13	0.55	0.04	0.04	0	0

Table A8-3 Transfer Matrix of:

Annual Dry Deposition of Sulfur ($kg.ha^{-1}.yr^{-1}$) per unit emission ($Tg.S.yr^{-1}$)

Source Regions	Models	Emiss. (Tg.S)	Receptor Areas: B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (9)
1 Mich.	MOE	0.784	0.07	0.56	1.4	0.41	0.46	0.73	1.2	2.6	0.13
	AES	0.973	0.10	2.3	3.7	0.72	0.31	0.92	1.2	3.1	0.10
2 Ill. Ind.	MOE	2.538	0.05	0.28	0.39	0.16	0.18	0.25	0.37	1.0	0.64
	AES	1.937	0.10	0.62	0.62	0.16	0.10	0.21	0.36	1.0	1.4
3 Ohio	MOE	1.983	0.04	0.18	0.41	0.20	0.32	0.39	0.62	3.1	0.30
	AES	2.381	0	0.13	0.97	0.29	0.29	0.63	1.1	7.4	0.67
4 Penn.	MOE	1.021	0.03	0.14	0.36	0.24	0.49	0.50	0.79	7.2	0.13
	AES	1.028	0	0.10	0.58	0.39	0.39	1.1	1.8	17.4	0.10
5 N.York to Maine	MOE	1.143	0.02	0.08	0.26	0.32	1.5	0.82	1.2	0.49	0.05
	AES	1.204	0	0.08	0.50	0.75	3.4	1.7	2.7	0.50	0
6 Kent. Tenn.	MOE	1.202	0.03	0.10	0.15	0.08	0.13	0.14	0.19	0.59	2.5
	AES	1.418	0	0.07	0.21	0	0.07	0.07	0.21	1.1	7.6
7 W.Virg. to N.C.	MOE	1.703	0.02	0.08	0.18	0.14	0.32	0.26	0.37	1.3	0.21
	AES	1.223	0	0	0.16	0.16	0.16	0.33	0.48	2.5	0.74
8 Rest of (USA) Fld to Mo. to Minn.	MOE	1.196	0.10	0.54	0.44	0.16	0.15	0.22	0.31	0.50	1.5
	AES	3.743	0.43	0.51	0.24	0.05	0.03	0.05	0.11	0.37	2.5
9 Ontario	MOE	0.906	0.08	0.79	2.5	1.5	0.73	1.5	1.7	0.76	0.05
	AES	0.985	0.10	2.0	9.9	1.4	0.71	2.2	3.4	2.0	0.10
10 Quebec	MOE	0.595	0.05	0.24	0.45	2.3	1.0	3.7	0.86	0.15	0.02
	AES	0.519	0	0.77	1.7	15.4	1.9	10.6	3.3	0.19	0
11 Atlantic Provinces	MOE	0.187	0.01	0.03	0.05	0.21	1.2	0.21	0.12	0.04	0.01
	AES	0.235	0	0	0	0.43	10.6	0	0	0	0

Table A8-4 Transfer Matrix of:

Annual Wet Deposition of Sulfur ($kg.ha^{-1}.yr^{-1}$)
per unit emission ($Tg.S.yr^{-1}$)

			Receptor Areas								
Source Regions	Models	Emiss. (Tg.S)	B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (9)
1 Mich.	MOE	0.784	0.07	0.40	0.93	0.34	0.39	0.56	0.86	1.7	0.12
	AES	0.973	0.21	2.4	3.2	1.0	0.31	0.72	1.1	1.7	0.21
2 Ill. Ind.	MOE	2.538	0.06	0.23	0.32	0.15	0.18	0.23	0.31	0.76	0.47
	AES	1.937	0.05	1.2	1.1	0.31	0.10	0.30	0.36	1.1	0.77
3 Ohio	MOE	1.983	0.04	0.15	0.32	0.19	0.28	0.32	0.47	2.0	0.23
	AES	2.381	0	0.25	1.8	0.46	0.21	1.0	1.3	4.7	0.25
4 Penn.	MOE	1.021	0.03	0.12	0.28	0.21	0.40	0.39	0.57	4.4	0.11
	AES	1.028	0	0.29	1.3	0.68	0.29	1.8	2.2	7.9	0.10
5 N.York to Maine	MOE	1.143	0.02	0.07	0.19	0.25	1.0	0.56	0.80	0.33	0.05
	AES	1.204	0	0.17	0.50	1.3	2.0	2.2	2.4	0.42	0
6 Kent. Tenn.	MOE	1.202	0.03	0.10	0.14	0.09	0.13	0.14	0.18	0.46	1.6
	AES	1.418	0	0.14	0.71	0.07	0.07	0.21	0.42	1.5	3.1
7 W.Virg. to N.C.	MOE	1.703	0.03	0.08	0.15	0.13	0.28	0.22	0.29	0.85	0.16
	AES	1.223	0	0	0.33	0.33	0.25	0.90	1.1	3.5	0.49
8 Rest of (USA) Fld to Mo. to Minn.	MOE	1.196	0.09	0.39	0.34	0.15	0.15	0.20	0.26	0.40	1.0
	AES	3.743	0.24	0.61	0.24	0.05	0.03	0.08	0.13	0.53	2.5
9 Ontario	MOE	0.906	0.08	0.51	1.6	1.0	0.57	1.1	1.2	0.53	0.05
	AES	0.985	0.10	1.8	3.3	1.7	0.61	1.6	2.0	1.2	0
10 Quebec	MOE	0.595	0.06	0.18	0.32	1.5	0.73	2.3	0.59	0.13	0.03
	AES	0.519	0	0.19	0.58	2.9	0.96	3.3	1.5	0.19	0
11 Atlantic Provinces	MOE	0.187	0.01	0.03	0.05	0.16	0.74	0.16	0.10	0.05	0.01
	AES	0.235	0	0	0	0.43	2.6	0	0	0	0

Table A8-5 Transfer Matrix of:

Annual Total Deposition of Sulfur $(kg.ha^{-1}.yr^{-1})$
per unit emission $(Tg.S.yr^{-1})$

Source Regions	Models	Emiss. (Tg.S)	Receptor Areas B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (9)
1 Mich.	MOE	0.784	0.13	0.96	2.3	0.74	0.84	1.3	2.0	4.3	0.25
	AES	0.973	0.31	4.6	6.9	1.7	0.62	1.6	2.3	4.8	0.31
2 Ill. Ind.	MOE	2.538	0.11	0.50	0.71	0.31	0.37	0.48	0.68	1.8	1.1
	AES	1.937	0.16	1.8	1.8	0.41	0.21	0.47	0.72	2.2	2.2
3 Ohio	MOE	1.983	0.08	0.33	0.72	0.39	0.61	0.71	1.1	5.2	0.52
	AES	2.381	0	0.38	2.8	0.76	0.50	1.6	2.5	12.1	0.92
4 Penn.	MOE	1.021	0.06	0.26	0.64	0.45	0.89	0.88	1.4	11.6	0.24
	AES	1.028	0	0.39	1.8	1.2	0.68	2.7	4.2	25.3	0.20
5 N.York to Maine	MOE	1.143	0.04	0.16	0.46	0.57	2.5	1.4	2.0	0.82	0.10
	AES	1.204	0	0.33	1.0	2.1	5.4	3.9	5.1	0.91	0
6 Kent. Tenn.	MOE	1.202	0.06	0.19	0.30	0.17	0.26	0.27	0.37	1.0	4.2
	AES	1.418	0	0.21	0.92	0.07	0.14	0.28	0.64	2.5	10.7
7 W.Virg. to N.C.	MOE	1.703	0.04	0.16	0.33	0.27	0.60	0.49	0.66	2.2	0.37
	AES	1.223	0	0.08	0.41	0.49	0.41	1.2	1.6	6.0	1.2
8 Rest of (USA) Fld to Mo. to Minn.	MOE	1.196	0.19	0.93	0.78	0.31	0.30	0.43	0.57	0.90	2.4
	AES	3.743	0.67	1.1	0.48	0.11	0.08	0.13	0.24	0.91	5.0
9 Ontario	MOE	0.906	0.16	1.3	4.1	2.5	1.3	2.6	2.9	1.3	0.10
	AES	0.985	0.10	4.0	13.4	3.1	1.3	3.8	5.5	3.1	0.10
10 Quebec	MOE	0.595	0.11	0.42	0.77	3.8	1.7	6.1	1.5	0.28	0.05
	AES	0.519	0.19	0.96	2.3	8.3	2.9	13.9	4.8	0.39	0
11 Atlantic Provinces	MOE	0.187	0.02	0.06	0.11	0.36	1.9	0.37	0.23	0.09	0.02
	AES	0.235	0	0	0	0.43	13.6	0.43	0	0	0

Table A8-6 Transfer Matrix of:

Annual Sulfur Dioxide Concentration ($ug.m^{-3}$)

Source Regions	Models	B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (9)
		Receptor Areas								
1 Mich.	MOE	0.06	0.55	1.4	0.39	0.44	0.71	1.2	2.6	0.12
	AES	0.16	2.8	4.3	0.78	0.37	1.0	1.4	3.7	0.16
2 Ill. Ind.	MOE	0.18	0.87	1.2	0.48	0.57	0.78	1.2	3.3	2.0
	AES	0.14	1.4	1.5	0.29	0.21	0.50	0.81	2.3	3.2
3 Ohio	MOE	0.08	0.43	1.0	0.50	0.79	0.95	1.5	7.9	0.73
	AES	0	0.33	2.8	0.88	0.77	1.7	3.2	21.5	1.9
4 Penn.	MOE	0.03	0.17	0.46	0.30	0.63	0.63	1.0	9.4	0.16
	AES	0	0.06	0.73	0.48	0.45	1.3	2.3	22.3	0.12
5 N.York to Maine	MOE	0.02	0.11	0.37	0.46	2.1	1.2	1.8	0.71	0.07
	AES	0.01	0.15	0.68	1.1	5.1	2.4	3.9	0.70	0.05
6 Kent. Tenn.	MOE	0.04	0.14	0.22	0.12	0.18	0.20	0.28	0.89	3.9
	AES	0	0.10	0.38	0.06	0.06	0.17	0.31	1.8	13.2
7 W.Virg. to N.C.	MOE	0.04	0.17	0.38	0.29	0.68	0.56	0.78	2.8	0.44
	AES	0	0.02	0.20	0.19	0.22	0.46	0.78	3.7	1.1
8 Rest of (USA) Fld to Mo. to Minn.	MOE	0.15	0.81	0.66	0.24	0.22	0.33	0.45	0.75	2.2
	AES	2.0	2.3	1.0	0.17	0.13	0.26	0.47	1.7	11.4
9 Ontario	MOE	0.09	0.91	2.9	1.7	0.82	1.8	2.0	0.87	0.05
	AES	0.11	2.5	12.2	1.7	0.77	2.6	4.1	2.4	0.08
10 Quebec	MOE	0.04	0.18	0.34	1.8	0.76	2.8	0.65	0.11	0.02
	AES	0.04	0.47	1.0	3.5	1.2	6.8	2.0	0.15	0.01
11 Atlantic Provinces	MOE	0	0.01	0.01	0.05	0.27	0.05	0.03	0.01	0
	AES	0	0	0.01	0.06	3.2	0.03	0.02	0	0
Western Canada	AES	0.48	0.14	0.06	0.01	0.01	0.02	0.01	0	0
Total Concen- tration	MOE	0.73	4.4	8.9	6.3	7.5	10.0	10.9	29.4	9.7
	AES	2.9	10.3	24.9	9.2	12.5	17.3	19.3	60.3	31.2

Table A8-7 Transfer Matrix of:

Annual Sulfate Concentration (ug m-3)

Source Regions	Models	Receptor Areas B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (9)
1	MOE	0.06	0.21	0.44	0.25	0.30	0.36	0.48	0.67	0.10
Mich.	AES	0.10	0.44	1.8	0.54	0.45	0.78	0.91	1.5	0.24
2 Ill.	MOE	0.20	0.54	0.75	0.46	0.56	0.63	0.79	1.4	0.91
Ind.	AES	0.04	0.71	0.79	0.24	0.21	0.42	0.65	1.4	2.5
3	MOE	0.11	0.30	0.52	0.40	0.59	0.60	0.76	1.7	0.38
Ohio	AES	0	0.10	1.4	0.39	0.74	0.97	1.5	5.5	1.5
4	MOE	0.05	0.13	0.23	0.22	0.38	0.34	0.42	1.2	0.12
Penn.	AES	0	0.03	0.30	0.20	0.35	0.51	0.93	2.6	0.11
5 N.York	MOE	0.04	0.09	0.17	0.25	0.70	0.40	0.44	0.21	0.07
to Maine	AES	0.01	0.09	0.26	0.37	1.5	0.66	0.84	0.22	0.02
6 Kent.	MOE	0.06	0.14	0.20	0.15	0.20	0.20	0.24	0.46	0.84
Tenn.	AES	0	0.05	0.17	0.01	0.06	0.08	0.16	0.80	3.7
7 W.Virg.	MOE	0.06	0.16	0.26	0.26	0.47	0.38	0.44	0.72	0.23
to N.C.	AES	0	0	0.09	0.06	0.16	0.21	0.33	1.1	0.86
8 Rest of	MOE	0.11	0.32	0.34	0.21	0.22	0.26	0.31	0.42	0.52
(USA) Fld to Mo. to Minn.	AES	0.44	1.0	0.74	0.18	0.17	0.28	0.48	1.1	4.3
9	MOE	0.07	0.21	0.60	0.60	0.45	0.63	0.62	0.31	0.06
Ontario	AES	0.05	0.66	2.3	0.98	0.78	1.4	1.9	1.0	0.11
10	MOE	0.04	0.08	0.13	0.43	0.31	0.44	0.20	0.08	0.03
Quebec	AES	0.07	0.22	0.44	0.66	0.63	0.98	0.75	0.09	0.02
11 Atlantic	MOE	0	0.01	0.01	0.02	0.06	0.02	0.02	0.01	0
Provinces	AES	0	0	0	0.03	0.13	0.01	0.01	0	0
Western Canada	AES	0.40	0.20	0.09	0.07	0.06	0.06	0.04	0.03	0
Total Concen-	MOE	0.80	2.2	3.7	3.3	4.3	4.3	4.7	7.2	3.3
tration	AES	1.1	3.5	8.4	3.7	5.2	6.4	8.5	15.3	13.3

Table A8-8 Transfer Matrix of:

Annual Dry Deposition of Sulfur ($kg.ha^{-1}.yr^{-1}$)

Source Regions	Models	Receptor Areas: B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (9)
1	MOE	0.05	0.44	1.1	0.32	0.36	0.57	0.93	2.0	0.10
Mich.	AES	0.10	2.2	3.6	0.70	0.30	0.90	1.2	3.0	0.10
2 Ill.	MOE	0.13	0.70	0.99	0.40	0.47	0.63	0.94	2.6	1.6
Ind.	AES	0.20	1.2	1.2	0.30	0.20	0.40	0.70	2.0	2.8
3	MOE	0.08	0.35	0.81	0.41	0.64	0.77	1.2	6.2	0.58
Ohio	AES	0	0.30	2.3	0.70	0.70	1.5	2.7	17.6	1.6
4	MOE	0.03	0.14	0.37	0.24	0.50	0.51	0.80	7.3	0.13
Penn.	AES	0	0.10	0.60	0.40	0.40	1.1	1.9	17.9	0.10
5 N.York	MOE	0.02	0.09	0.30	0.37	1.7	0.94	1.4	0.56	0.05
to Maine	AES	0	0.10	0.60	0.90	4.1	2.0	3.2	0.60	0
6 Kent.	MOE	0.03	0.12	0.18	0.10	0.15	0.16	0.23	0.71	3.1
Tenn.	AES	0	0.10	0.30	0	0.10	0.10	0.30	1.5	10.8
7 W.Virg.	MOE	0.03	0.14	0.31	0.24	0.55	0.45	0.63	2.2	0.35
to N.C.	AES	0	0	0.20	0.20	0.20	0.40	0.60	3.0	0.90
8 Rest of	MOE	0.12	0.65	0.53	0.19	0.18	0.27	0.37	0.60	1.8
(USA) Fld to Mo. to Minn.	AES	1.6	1.9	0.9	0.20	0.10	0.20	0.40	1.4	9.5
9	MOE	0.08	0.71	2.2	1.3	0.66	1.4	1.6	0.69	0.04
Ontario	AES	0.10	2.0	9.8	1.4	0.70	2.2	3.4	2.0	0.10
10	MOE	0.03	0.14	0.27	1.4	0.60	2.2	0.51	0.09	0.01
Quebec	AES	0	0.40	0.90	2.8	1.0	5.5	1.7	0.10	0
11 Atlantic	MOE	0	0	0.01	0.04	0.22	0.04	0.02	0.01	0
Provinces	AES	0	0	0	0.10	2.5	0	0	0	0
Western Canada	AES	0.40	0.10	0.10	0	0	0	0	0	0
Total Concen-	MOE	0.60	3.5	7.1	5.0	6.0	7.9	8.6	23.0	7.7
tration	AES	2.4	8.4	20.5	7.7	10.3	14.3	16.1	49.1	25.9

Table A8-9 Transfer Matrix of:

Annual Wet Deposition of Sulfur ($kg.ha^{-1}.yr^{-1}$)

Source Regions	Models	B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (9)
1 Mich.	MOE	0.05	0.31	0.73	0.26	0.30	0.44	0.67	1.3	0.09
	AES	0.20	2.3	3.1	1.0	0.30	0.70	1.1	1.7	0.20
2 Ill. Ind.	MOE	0.15	0.58	0.81	0.39	0.46	0.58	0.79	1.9	1.2
	AES	0.10	2.4	2.2	0.60	0.20	0.50	0.70	2.2	1.5
3 Ohio	MOE	0.08	0.30	0.63	0.37	0.56	0.63	0.93	4.0	0.45
	AES	0	0.60	4.4	1.1	0.50	2.4	3.2	11.3	0.60
4 Penn.	MOE	0.03	0.12	0.28	0.21	0.41	0.40	0.58	4.5	0.11
	AES	0	0.20	1.3	0.70	0.30	1.8	2.3	8.1	0.10
5 N.York to Maine	MOE	0.03	0.09	0.22	0.29	1.2	0.64	0.91	0.38	0.06
	AES	0	0.20	0.60	1.6	2.4	2.7	2.9	0.50	0
6 Kent. Tenn.	MOE	0.04	0.12	0.17	0.11	0.16	0.16	0.21	0.55	2.0
	AES	0	0.20	1.0	0.10	0.10	0.30	0.60	2.1	4.4
7 W.Virg. to N.C.	MOE	0.04	0.13	0.26	0.22	0.47	0.38	0.50	1.5	0.27
	AES	0	0	0.40	0.40	0.30	1.1	1.4	4.3	0.60
8 Rest of (USA) Fld to Mo. to Minn.	MOE	0.10	0.46	0.41	0.18	0.18	0.24	0.31	0.47	1.1
	AES	0.90	2.3	0.90	0.20	0.10	0.30	0.50	2.0	9.2
9 Ontario	MOE	0.07	0.46	1.4	0.94	0.52	0.97	1.1	0.48	0.05
	AES	0.10	1.8	3.3	1.7	0.60	1.6	2.0	1.2	0
10 Quebec	MOE	0.03	0.11	0.19	0.90	0.43	1.4	0.35	0.08	0.02
	AES	0	0.10	0.30	1.5	0.50	1.7	0.80	0.10	0
11 Atlantic Provinces	MOE	0	0.01	0.01	0.03	0.14	0.03	0.02	0.01	0
	AES	0	0	0	0.10	0.60	0	0	0	0
Western Canada	AES	0.20	0.20	0.10	0	0	0	0.20	0	0
Total Concen-tration	MOE*	0.62	2.7	5.1	3.9	4.8	5.9	6.3	15.2	5.4
	AES	1.5	10.4	17.6	9.0	5.9	13.1	15.7	33.5	16.7

*Note: In order to calculate the total deposition at each site, the deposition resulting from background in the amount of 0.2 $g.m^{-2}.yr^{-1}$ (or 2.0 $kg.ha^{-1}.yr^{-1}$) should be added to this row.

Table A8-10 Transfer Matrix of:

Total Annual Sulfur Deposition ($kg.ha^{-1}.yr^{-1}$)

		Receptor Areas								
Source Regions	Models	B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (9)
1 Mich.	MOE	0.10	0.75	1.8	0.58	0.66	1.0	1.6	3.4	0.19
	AES	0.30	4.5	6.7	1.7	0.60	1.6	2.2	4.7	0.30
2 Ill. Ind.	MOE	0.28	1.3	1.8	0.78	0.93	1.2	1.7	4.5	2.8
	AES	0.30	3.5	3.4	0.80	0.40	0.90	1.4	4.2	4.3
3 Ohio	MOE	0.16	0.65	1.4	0.77	1.2	1.4	2.2	10.2	1.0
	AES	0	0.90	6.7	1.8	1.2	3.9	5.9	28.9	2.2
4 Penn.	MOE	0.06	0.26	0.65	0.46	0.91	0.90	1.4	11.8	0.24
	AES	0	0.40	1.9	1.2	0.70	2.8	4.3	26.0	0.20
5 N.York to Maine	MOE	0.05	0.18	0.52	0.66	2.8	1.6	2.3	0.93	0.11
	AES	0	0.40	1.2	2.5	6.5	4.7	6.1	1.1	0
6 Kent. Tenn.	MOE	0.07	0.23	0.35	0.21	0.31	0.33	0.44	1.3	5.0
	AES	0	0.30	1.3	0.10	0.20	0.40	0.90	3.6	15.2
7 W.Virg. to N.C.	MOE	0.08	0.27	0.57	0.46	1.0	0.83	1.1	3.7	0.62
	AES	0	0.10	0.50	0.60	0.50	1.5	2.0	7.3	1.5
8 Rest of (USA) Fld to Mo. to Minn.	MOE	0.22	1.1	0.94	0.37	0.36	0.51	0.68	1.1	2.9
	AES	2.5	4.2	1.8	0.40	0.30	0.50	0.90	3.4	18.7
9 Ontario	MOE	0.14	1.2	3.7	2.3	1.2	2.4	2.6	1.2	0.09
	AES	0.10	3.9	13.2	3.1	1.3	3.8	5.4	3.1	0.10
10 Quebec	MOE	0.06	0.25	0.46	2.3	1.0	3.6	0.86	0.17	0.03
	AES	0.10	0.50	1.2	4.3	1.5	7.2	2.5	0.20	0
11 Atlantic Provinces	MOE	0	0.01	0.02	0.07	0.35	0.07	0.04	0.02	0
	AES	0	0	0	0.10	3.2	0.10	0	0	0
Western Canada	AES	0.60	0.20	0.20	0	0	0	0.20	0	0
Total Concen-tration	MOE*	1.2	6.2	12.2	8.9	10.8	13.8	14.9	38.3	13.0
	AES	3.9	18.8	38.1	16.7	16.3	27.4	31.8	82.5	42.6

*Note: In order to calculate the total deposition at each site, the deposition resulting from background in the amount of 0.2 $g.m^{-2}.yr^{-1}$ (or 2.0 $kg.ha^{-1}.yr^{-1}$) should be added to this row.

Table A8-11 Transfer Matrix of:

Percent Contribution to Annual Sulphur Dioxide Concentration

Source Regions	Models	Receptor Areas: B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (10)
1	MOE	8.2	12.6	15.7	6.2	5.9	7.1	11.0	8.8	1.2
Mich.	AES	5.4	27.2	17.3	8.5	3.0	5.8	7.2	6.1	0.5
2 Ill.	MOE	24.7	19.8	13.4	7.6	7.6	7.8	11.0	11.2	20.6
Ind.	AES	4.8	13.6	6.0	3.2	1.7	2.9	4.2	3.8	10.3
3	MOE	11.0	9.8	11.2	7.9	10.6	9.5	13.8	26.9	7.5
Ohio	AES	0	3.2	11.2	9.6	6.2	9.8	16.6	35.7	6.1
4	MOE	4.1	3.9	5.2	4.8	8.4	6.3	9.2	32.0	1.7
Penn.	AES	0	0.6	2.9	5.2	3.6	7.5	11.9	37.0	0.4
5 N.York	MOE	2.7	2.5	4.2	7.3	28.0	12.0	16.5	2.4	0.7
to Maine	AES	0.3	1.5	2.7	11.9	40.8	13.9	20.2	1.2	0.1
6 Kent.	MOE	5.5	3.2	2.4	1.9	2.4	2.0	2.6	3.0	40.2
Tenn.	AES	0	1.0	1.5	0.7	0.4	1.0	1.6	3.0	42.3
7 W.Virg.	MOE	5.5	3.9	4.3	4.6	9.1	5.6	7.2	9.5	4.5
to N.C.	AES	0	0.2	0.8	2.1	1.7	2.7	4.0	6.1	3.5
8 Rest of	MOE	20.5	18.5	7.4	3.8	2.9	3.3	4.1	2.6	22.7
(USA) Fld to Mo. to Minn.	AES	68.0	22.3	4.0	1.9	1.0	1.5	2.4	2.8	36.5
9	MOE	12.3	20.7	32.5	26.9	11.0	18.0	18.3	3.0	0.5
Ontario	AES	3.7	24.3	49.0	18.4	6.2	15.0	21.2	4.0	3.0
10	MOE	5.5	4.1	3.8	28.5	10.1	28.0	6.0	0.4	0.2
Quebec	AES	1.4	4.6	4.0	38.0	9.6	39.3	10.4	0.3	0
11 Atlantic	MOE	0	0.2	0.1	0.8	3.6	0.5	0.3	0	0
Provinces	AES	0	0	0	0.7	25.6	0.2	0.1	0	0
Western Canada	AES	16.3	1.4	0.3	0.1	0.1	0.1	0.1	0	0
Eastern U.S.A.	MOE	82.2	74.2	63.8	44.1	74.9	53.6	75.4	96.4	99.1
Contri. bution	AES	78.5	69.6	46.4	43.1	58.4	45.1	68.1	95.7	99.7
Total Canadian	MOE	17.8	25.0	36.4	56.2	24.7	46.5	24.6	3.4	0.7
Contri. bution	AES	21.4	30.3	53.3	57.2	41.5	54.6	31.8	4.3	0.3

Table A8-12 Transfer Matrix of:

Percent Contribution to Annual Sulfate Concentration

Source Regions	Models	B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (10)
		Receptor Areas								
1	MOE	7.5	9.6	12.0	7.7	7.1	8.5	10.2	9.3	3.1
Mich.	AES	9.0	12.6	21.5	14.5	8.6	12.2	10.7	10.0	1.8
2 Ill.	MOE	25.0	24.6	20.6	14.2	13.2	14.8	16.7	19.5	27.9
Ind.	AES	3.6	20.3	9.4	6.4	4.0	6.6	7.7	9.0	18.6
3	MOE	13.8	13.6	14.3	12.3	13.9	14.1	16.1	23.7	11.7
Ohio	AES	0	2.9	16.7	10.5	14.1	15.2	17.9	35.8	11.0
4	MOE	6.2	5.9	6.3	6.8	9.0	8.0	8.9	16.7	3.7
Penn.	AES	0	0.9	3.6	5.4	6.7	8.0	11.0	16.9	0.8
5 N.York	MOE	5.0	4.1	4.7	7.7	16.5	9.4	9.3	2.9	2.2
to Maine	AES	0.9	2.6	3.1	9.9	28.6	10.3	9.9	1.4	0.1
6 Kent.	MOE	7.5	6.4	5.5	4.6	4.7	4.7	5.1	6.4	25.8
Tenn.	AES	0	1.4	2.0	0.3	1.2	1.3	1.9	5.2	27.7
7 W.Virg.	MOE	7.5	7.3	7.1	8.0	11.1	8.9	9.3	10.0	7.1
to N.C.	AES	0	0	1.1	1.6	3.1	3.3	3.9	7.1	6.5
8 Rest of	MOE	13.7	14.6	9.3	6.5	5.2	6.1	6.6	5.9	16.0
(USA) Fld to Mo. to Minn.	AES	39.6	28.6	8.8	4.8	3.2	4.4	5.7	6.9	32.3
9	MOE	8.8	9.6	16.4	18.5	10.6	14.8	13.1	4.3	1.8
Ontario	AES	4.5	18.9	27.5	26.3	14.9	21.9	21.9	6.8	0.8
10	MOE	5.0	3.6	3.5	13.2	7.3	10.3	4.2	1.1	0.9
Quebec	AES	6.3	6.3	5.3	17.7	12.0	15.4	8.8	0.6	0.2
11 Atlantic	MOE	0	0.5	0.3	0.6	1.4	0.5	0.4	0.1	0
Provinces	AES	0	0	0	0.8	2.5	0.2	0.1	0	0
Western Canada	AES	36.0	5.7	1.0	1.8	1.1	1.0	0.5	0.2	0
Eastern U.S.A.	MOE	86.2	86.1	79.8	67.8	80.7	74.5	82.2	94.4	97.5
Contri. bution	AES	53.1	69.3	66.2	53.4	69.5	61.3	68.7	92.3	98.8
Total Canadian	MOE	13.8	13.7	20.2	32.3	19.3	25.6	17.7	5.5	2.7
Contri. bution	AES	46.8	30.9	33.8	46.7	30.5	38.5	31.3	7.6	1.0

Table A8-13 Transfer Matrix of:

Percent Contribution to Annual Sulfur Dry Deposition

Source Regions	Models	Receptor Areas: B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (10)
1 Mich.	MOE	8.3	12.6	15.5	6.4	6.0	7.2	10.8	8.7	1.3
	AES	4.2	26.2	17.6	9.2	2.9	6.3	7.5	6.1	0.4
2 Ill. Ind.	MOE	21.7	20.0	14.0	8.0	7.8	8.0	10.9	11.3	20.7
	AES	8.3	14.3	5.9	4.0	1.9	2.8	4.4	4.1	10.8
3 Ohio	MOE	13.3	10.0	11.4	8.2	10.6	9.7	13.9	27.0	7.5
	AES	0	3.6	11.2	9.2	6.8	10.5	16.8	35.8	6.2
4 Penn.	MOE	5.0	4.0	5.2	4.8	8.3	6.4	9.3	31.7	1.6
	AES	0	1.2	2.9	5.3	3.9	7.7	11.8	36.4	0.4
5 N.York to Maine	MOE	3.3	2.6	4.2	7.4	28.3	11.9	16.3	2.4	0.6
	AES	0	1.2	2.9	11.8	39.8	14.0	19.9	1.2	0
6 Kent. Tenn.	MOE	5.0	3.5	2.6	2.0	2.5	2.0	2.6	3.1	40.2
	AES	0	1.2	1.5	0	1.0	0.7	1.9	3.1	41.5
7 W.Virg. to N.C.	MOE	5.0	4.0	4.4	4.8	9.1	5.7	7.3	9.6	4.5
	AES	0	0	1.0	2.6	1.9	2.8	3.7	6.1	3.5
8 Rest of (USA) Fld to Mo. to Minn.	MOE	20.0	18.6	7.5	3.8	3.0	3.4	4.3	2.6	23.3
	AES	66.7	22.6	4.4	2.6	1.0	1.4	2.5	2.9	36.5
9 Ontario	MOE	13.3	20.4	31.0	26.0	11.0	17.7	18.6	3.0	0.5
	AES	3.8	23.8	47.8	18.4	6.8	15.4	21.1	4.1	0.4
10 Quebec	MOE	5.0	4.1	3.8	28.0	10.0	27.8	5.9	0.4	0.1
	AES	0	4.8	4.4	36.8	9.7	38.5	10.6	0.2	0
11 Atlantic Provinces	MOE	0	0	0.1	0.8	3.6	0.5	0.2	0	0
	AES	0	0	0	1.3	24.3	0	0	0	0
Western Canada	AES	16.7	1.1	0.4	0	0	0	0	0	0
Eastern U.S.A. Contribution	MOE	81.6	75.3	64.8	45.4	75.6	54.3	75.4	96.4	99.7
	AES	79.2	70.3	47.4	44.7	59.2	46.2	68.5	95.7	99.3
Total Canadian Contribution	MOE	18.3	24.5	34.9	54.8	24.6	46.0	24.7	3.4	0.6
	AES	20.5	29.7	52.6	56.5	40.8	53.9	31.7	4.3	0.4

Table A8-14 Transfer Matrix of:

Percent Contribution to Annual Sulfur Wet Deposition

Source Regions	Models	Receptor Areas: B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (10)
1 Mich.	MOE	8.1	11.5	14.3	6.7	6.2	7.5	10.6	8.6	1.7
	AES	13.3	22.1	17.6	11.1	5.1	5.3	7.0	5.1	1.2
2 Ill. Ind.	MOE	24.2	21.5	15.9	10.0	9.6	9.9	12.5	12.5	22.3
	AES	6.7	23.1	12.5	6.7	3.4	3.8	4.5	6.6	9.0
3 Ohio	MOE	12.9	11.1	12.3	9.5	11.6	10.7	14.8	26.3	8.3
	AES	0	5.8	25.0	12.2	8.5	18.3	20.4	33.7	3.6
4 Penn.	MOE	4.8	4.5	5.5	5.4	8.5	6.8	9.2	29.6	2.1
	AES	0	2.9	7.4	7.8	5.1	13.7	14.7	24.2	0.6
5 N.York to Maine	MOE	4.8	3.3	4.3	7.4	25.0	10.9	14.4	2.5	1.1
	AES	0	1.9	3.4	17.8	40.7	20.6	18.5	1.5	0
6 Kent. Tenn.	MOE	6.5	4.5	3.3	2.8	3.3	2.7	2.3	3.6	37.1
	AES	0	1.9	5.7	1.1	1.7	2.3	3.8	6.3	26.4
7 W.Virg. to N.C.	MOE	6.5	4.8	5.1	5.6	9.8	6.5	7.9	9.9	5.0
	AES	0	0	2.3	4.4	5.1	8.4	8.9	12.8	3.6
8 Rest of (USA) Fld to Mo. to Minn.	MOE	16.1	17.1	8.0	4.6	3.7	4.1	4.9	3.1	20.4
	AES	60.0	22.1	5.1	2.2	1.7	2.3	3.2	6.0	55.1
9 Ontario	MOE	11.3	17.0	27.4	24.1	10.8	16.5	17.5	3.2	0.9
	AES	6.7	17.3	18.8	18.9	10.0	12.2	12.7	3.6	0
10 Quebec	MOE	4.8	4.1	3.7	23.1	8.9	23.7	5.6	0.5	0.4
	AES	0	1.0	1.7	16.7	8.5	13.0	5.1	0.3	0
11 Atlantic Provinces	MOE	0	0.4	0.2	0.8	2.9	0.5	0.3	0.1	0
	AES	0	0	0	1.1	10.2	0	0	0	0
Western Canada	AES	13.3	1.9	0.5	0	0	0	1.2	0	0
Eastern U.S.A. Contribution	MOE	83.9	78.3	68.7	52.0	77.7	59.1	76.6	96.1	98.0
	AES	80.0	79.8	79.0	63.3	71.3	74.7	81.0	96.2	99.5
Total Canadian Contribution.	MOE	16.1	21.5	31.3	48.0	22.6	40.7	23.4	3.8	1.3
	AES	20.0	20.2	21.0	36.7	28.7	25.2	19.0	3.9	0

Table A8-15 Transfer Matrix of:

Percent Contribution to Total Annual Sulfur Deposition

Source Regions	Models	Receptor Areas: B.Waters (1)	Alg. (2)	Musk. (3)	Que. (4)	S. N.Sc. (5)	Vt. NH. (6)	Adir. (7)	Penn. (8)	Smokies (10)
1 Mich.	MOE	8.2	12.2	14.7	6.5	6.1	7.2	10.7	8.9	1.5
	AES	7.7	23.9	17.6	10.2	3.7	5.8	6.9	5.7	0.7
2 Ill. Ind.	MOE	23.0	21.1	14.8	8.7	8.7	8.7	11.4	11.8	21.5
	AES	7.7	18.6	8.9	4.8	2.4	3.3	4.4	5.1	10.1
3 Ohio	MOE	13.1	10.5	11.5	8.6	11.1	10.1	14.8	26.6	7.7
	AES	0	4.8	17.6	10.8	7.3	14.2	18.6	35.0	5.2
4 Penn.	MOE	4.9	4.2	5.3	5.1	8.5	6.5	9.4	30.8	1.8
	AES	0	2.1	5.0	7.2	4.3	10.2	13.5	31.4	0.5
5 N.York to Maine	MOE	4.1	2.9	4.2	7.4	26.0	11.6	15.4	2.4	0.8
	AES	0	2.1	3.2	15.0	39.9	17.1	19.2	1.2	0
6 Kent. Tenn.	MOE	5.7	3.7	2.9	2.3	2.9	2.4	2.9	3.4	38.5
	AES	0	1.6	3.4	0.6	1.2	1.5	2.8	4.4	35.6
7 W.Virg. to N.C.	MOE	6.6	4.4	4.6	5.1	9.3	6.0	7.4	9.7	4.8
	AES	0	0.5	1.3	3.6	3.0	5.5	6.3	8.8	3.5
8 Rest of (USA) Fld to Mo. to Minn.	MOE	18.0	17.8	7.7	4.1	3.4	3.7	4.5	2.9	22.3
	AES	64.1	22.3	4.7	2.4	1.8	1.8	2.8	4.1	43.8
9 Ontario	MOE	11.5	19.5	30.3	25.8	11.1	17.4	17.4	3.1	0.7
	AES	2.6	20.7	34.7	18.6	8.0	13.9	17.0	3.8	0.2
10 Quebec	MOE	4.9	4.0	3.8	25.8	9.3	26.1	5.8	0.4	0.2
	AES	2.6	2.6	3.2	25.8	9.2	26.3	7.9	0.2	0
11 Atlantic Provinces	MOE	0	0.1	0.1	0.8	3.3	0.5	0.3	0	0
	AES	0	0	0	0.6	19.6	0.4	0	0	0
Western Canada	AES	15.3	1.0	0.5	0	0	0	0.6	0	0
Eastern U.S.A. Contribution	MOE	83.6	76.8	65.7	47.8	76.0	56.2	76.5	96.5	98.9
	AES	79.5	75.9	61.7	54.6	63.6	59.4	74.5	95.7	99.4
Total Canadian Contribution	MOE	16.4	23.6	34.2	52.4	23.7	44.0	23.5	3.5	0.9
	AES	20.5	24.3	38.4	45.0	36.8	40.6	25.5	4.0	0.2

Appendix 9

Workshop Summary Reports:

Atmospheric and Science Reviews

Modeling Evaluation and Intercomparison

(16-17 December 1980, Washington, D.C.)

Atmospheric Science Review

At a Work Group 2 workshop meeting held in Washington, DC on December 16, 1980, a wide-ranging discussion occurred regarding the most important areas in the atmospheric sciences which were closely connected with the use of long range transport models. From that discussion emerged several topics on which Work Group 2 would prepare reviews for their May 15, 1981, Phase II report. The purpose of these reviews would be to highlight the state of knowledge in the particular topic areas, and to indicate how that knowledge is reflected in various models being used by this Work Group. The reviews are to be brief, comprehensive, reflect recent literature and work in progress, and written in a manner which is comprehensible to the educated layman.

The initial topics chosen are described briefly below, and the lead authors are identified. First drafts of the write-ups will be distributed to all Work Group 2 members for discussion in the last half of February, 1981.

1) Sulfur and Nitrogen Chemistry in LRT Models

(A.P. Altshuller) Homogeneous and heterogeneous reaction mechanisms will be reviewed. The degree to which models can treat sulphur chemistry as being first-order and independent of other atmospheric cycles (e.g., oxidants, nitrogen, particulates, visibility) will be discussed. Seasonal differences will be mentioned. The ways in which SO_2 is converted into sulphuric acid, as opposed to other sulfate products, will be emphasized in all parts of the report.

It is known that nitrogen chemistry is more complex than sulphur chemistry, and that in many situations it is not first-order. Additionally, other key species involved in nitrogen chemistry are often not being measured. This discussion will review the above issues, as well as the aspects mentioned above for sulfur. Finally, the possibility of crudely modeling nitrogen reactions in a pseudo-first order way in existing Lagrangian models will be discussed.

2) <u>Trends in precipitation composition and deposition</u> (J. Miller) What data sets are available which have not been discussed to date? Are the data sets reliable? Is there any way to relate trends, which these and newer sets of data may show, to estimates of past and present emissions of SO_2; should the comparison even be made in view of the different spatial distribution of the sources, the different release heights of the SO_2, etc.

3) <u>Deposition processes for sulphur and nitrogen compounds</u> (G. Van Volkenburg) Once atmospheric reactions have occurred, how does one measure and model the various pathways of deposition, both wet and dry? Are the mechanisms and amounts of deposition radically different because of seasonal changes? What is the role of changing

meteorological conditions (e.g., mixing height, temperature, type of storm, amount of precipitation) and surface conditions (wet, snow-covered, vegetation-covered, etc.)? How valid are the parameterigation of deposition being used in models currently?

4) Global and western North American measurements of precipitation pH (P. Summers) The strength of the assumption of "unpolluted" rain having a pH of 5.6 will be compared to recent global background measurements, and these measurements will be interpreted in light of current assumptions about residence times of acid precursor compounds and scavenging mechanisms for these compounds ovér oceans, coastal regions, and over land. Recent measurements from western North America will be examined thoroughly.

2. <u>Evaluation and Intercomparison of Selected Models</u>

On December 17, 1980, the first workshop of Group 2 was convened to plan a comprehensive model evaluation and intercomparison program for the five-month period up to May 1981. The follwing items wre agreed upon:

1) <u>Management:</u> J.W.S. Young and B. Niemann were appointed as the Canadian and U.S. "whips", respectively, to insure that, to the maximum extent possible, data, manpower, and funding would be made available for this exercise by the various agencies involved.

Agreement was reached among EPA (US), and AES and OME (Canada) that if required, support for a contractor to assist in assembling data sets would be made available.

2) <u>Task scheduling:</u> Once tasks had been outlined and agreed to, it was agreed that the sponsoring agencies would hold workshops to discuss progress on the tasks, at approximately monthly intervals. The second workshop was scheduled for January 13-14, 1981 in Washington, and the third for the last half of February in Toronto.

3) <u>Provision of an "Agreed", "Unified" North American Sulfur Inventory:</u> The crucial need for a current, unified sulfur inventory for North America was raised again. It is understood that Work Group 3B is responsible for the provision of this inventory. It is to be published as a

tabulation, identifying for each point and area source: location, most recent annual and seasonal emissions, and other stack paramenters (where appropriate). Using the inventory breakouts of emissions totals for point and area sources will be undertaken for various georgraphical regions, including continental, country, the 11 Canadian source regions, the SURE approximations to states and provinces, and the 63 SURE source regions.

4) Meteorological Year for Test Use: 1978 was chosen. Annual, winter (Jan.-March), summer (July-September), and monthly slices from seasons (January and July) will be used.

5) Meteorological Year for Greneral Use: To be decided at second workshop. P. Summers will produce notes for discussion.

6) Input data sets for testing: The 1978 data sets from CANSAP, MAP3S, SURE, Ontario Hydro, and SAROAD archives will be employed.

7) Parameters to be modeled for sulphur: Wet deposition, and SO_2 and SO_4 concentrations will be the three primary outputs. Estimates of dry and total deposition are of lower priority because they can not be validated against field observations and they are, therefore, more uncertain.

8) Methods of Parameterization: A. Venkatram and J. Shannon will write a position paper for the January 13-14 workshop to stimulate discussion on which, and how, parameters should be "tuned" to data sets. Can statistics be generated from this exercise which say anything about the confidence of the models?

9) Methods of Validation: A. Venkatram will prepare, for the January workshop, a position paper for discussion which indicates how the models can be validated in a uniform manner, and how the measure of validity can be expressed from model to model in a uniform manner.

10) Amount of Model "Production, Usage": The chairman of Work Group 2 will extract from the chairmen of Work Group 3B the number of "full scenarios" to be run in Phase II. This number, along with estimates of model usage for validation and intercomparison, will identify the level of effort required by each modeler.

Addendum to Appendix 6

Source Region and Inventory Description

of the

Phase I Report on

Atmospheric Modeling

by

Work Group 2

Preface

The purpose of this addendum is to provide more detailed documentation of the emissions and their geographical assignments than was possible in Appendix 6 of the Phase I report. The information in this addendum is being used by the atmospheric transport modelers in Phase II for model intercomparisons, evaluations, and production runs. It is expected that the material in this addendum will be updated and supplemented from time to time.

A large (30" x 40") map of the SURE grid system, 63 SURE aggregate areas, and 11 Canadian regions, superimposed on State and provincial boundaries is available for use with this appendix. Inquiries should be directed to:

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U. S. Environmental Protection Agency
RD-681 Room 641 West Tower
401 M Street, S. W.
Washington, D. C. 20460
202 426-9434

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1. Relationships Between U. S. Counties, SURE Grids, 63 Aggregated SURE Grid Areas, and the 11 Canadian Regions

1.1 Counties and Sources in SURE Grids

STATE	COUNTY	FIPS ST	FIPS CITY	SURE II	GRID	NUMBER	ARMS REGION
AL	AUTAUGA	1	1	9	2	351	35
AL	BALDWIN	1	3	7	0	287	35
AL	BARBOUR	1	5	10	1	321	35
AL	BIBB	1	7	8	3	381	35
AL	BLOUNT	1	9	9	4	413	35
AL	BULLOCK	1	11	10	2	352	35
AL	BUTLER	1	13	9	1	320	35
AL	CALHOUN	1	15	10	4	414	35
AL	CHAMBERS	1	17	11	3	384	29
AL	CHEROKEE	1	19	10	5	445	35
AL	CHILTON	1	21	9	3	382	35
AL	CHOCTAW	1	23	7	2	349	35
AL	CLARKE	1	25	7	1	318	35
AL	CLAY	1	27	10	3	383	35
AL	CLEBURNE	1	29	10	4	414	35
AL	COFFEE	1	31	10	1	321	35
AL	COLBERT	1	33	8	5	443	35
AL	CONECUH	1	35	8	1	319	35
AL	COOSA	1	37	9	3	382	35
AL	COVINGTON	1	39	9	1	320	35
AL	CRENSHAW	1	41	9	1	320	35
AL	CULLMAN	1	43	9	5	444	35
AL	DALE	1	45	10	1	321	35
AL	DALLAS	1	47	8	2	350	35
AL	DEKALB	1	49	10	5	445	35
AL	ELMORE	1	51	9	2	351	35
AL	ESCAMBIA	1	53	8	0	288	34
AL	ETOWAH	1	55	10	4	414	35
AL	FAYETTE	1	57	8	4	412	35
AL	FRANKLIN	1	59	8	5	443	35
AL	GENEVA	1	61	10	0	290	34
AL	GREENE	1	63	7	3	380	36
AL	HALE	1	65	8	3	381	35
AL	HENRY	1	67	10	1	321	35
AL	HOUSTON	1	69	10	0	290	34
AL	JACKSON	1	71	10	5	445	35
AL	JEFFERSON	1	73	9	4	413	35
AL	LAMAR	1	75	7	4	411	36
AL	LAUDERDALE	1	77	8	6	474	23
AL	LAWRENCE	1	79	8	5	443	35
AL	LEE	1	81	10	2	352	35
AL	LIMESTONE	1	83	9	6	475	24
AL	LOWNDES	1	85	9	2	351	35
AL	MACON	1	87	10	2	352	35

Grid Square SO_2 Emission Data in the SURE II Inventory - Utility Sector in the Major Point Source file

Sample Output

Individual Source Parameters

SURE-2 SO2 AND EMISSIONS
BY GRID NUMBER(IN GRAMS/SEC)

GRIDNUM=699

OBS	GRIDX	GRIDY	STATE	COUNTY	PLNTCDE	PNTCDE	SOURCE	UTMX	UTMY	STACKHGT	SO2EMIS
626	13	16	OHIO	540	5002	5	UT	520.5	4417.5	259.1	145.95
627	13	16	OHIO	540	5002	6	UT	520.5	4417.5	259.1	185.12
628	13	16	OHIO	540	5002	7	UT	520.5	4417.5	259.1	186.77
629	13	16	OHIO	540	5002	8	UT	520.5	4417.5	259.1	176.77
630	13	16	OHIO	540	5002	9	UT	520.5	4417.5	259.1	276.27
631	13	16	OHIO	540	5002	10	UT	520.5	4417.5	259.1	298.70
632	13	16	OHIO	540	5002	11	UT	520.5	4417.5	259.1	773.50
633	13	16	OHIO	540	5002	12	UT	520.5	4417.5	259.1	792.50
634	13	16	OHIO	3160	5002	1	UT	530.0	4455.8	251.8	2066.10
635	13	16	OHIO	3160	5002	5	UT	529.9	4455.6	251.5	1629.20
636	13	16	OHIO	3160	5002	6	UT	529.9	4455.6	274.3	433.63
637	13	16	OHIO	3160	5010	7	UT	531.7	4485.5	153.6	531.90
638	13	16	OHIO	3160	5010	8	UT	531.7	4485.5	153.6	760.87
639	13	16	OHIO	3160	5010	9	UT	531.7	4485.5	153.6	1001.82
640	13	16	OHIO	3160	5010	10	UT	531.7	4485.5	153.6	1001.82
641	13	16	OHIO	3160	5010	11	UT	531.7	4485.5	259.1	1634.90
642	13	16	OHIO	3160	5010	12	UT	531.7	4485.5	259.1	3493.70
643	13	16	OHIO	3160	5010	13	UT	531.7	4485.5	304.8	3346.70
644	13	16	OHIO	3160	5012	1	UT	533.5	4481.8	198.1	345.62
645	13	16	OHIO	3160	5012	2	UT	533.5	4481.8	198.1	501.60
646	13	16	OHIO	3160	5012	3	UT	533.5	4481.8	198.1	501.05
647	13	16	PENNSYLVANIA	9200	7	1	UT	588.3	4452.8	58.8	30.85
648	13	16	PENNSYLVANIA	9200	7	2	UT	588.3	4452.8	58.8	30.80
649	13	16	PENNSYLVANIA	9200	7	3	UT	588.3	4452.8	58.8	30.80
650	13	16	PENNSYLVANIA	9200	7	4	UT	588.3	4452.8	70.1	1284.50
651	13	16	PENNSYLVANIA	9200	12	1	UT	592.1	4456.1	82.9	330.52
652	13	16	PENNSYLVANIA	9200	12	2	UT	592.1	4456.1	82.9	350.72
653	13	16	PENNSYLVANIA	9200	12	3	UT	592.1	4456.1	82.9	380.75
654	13	16	PENNSYLVANIA	9200	12	4	UT	592.1	4456.1	89.0	587.70

1.2 Grids in Aggregated Grid Areas

Explanation of Format

Column	Definition	Range	Format
1	X index (west-east)	1:31	I5
2	Y index (south-north)	1:36	I5
3	Grid Scalor Index	1:1116(1)	I5
4	X* index (west-east)	0:30	I5
5	Y* index (south-north)	- 9:26	I5
6	ARMS area	0:60(2)	I5
7	Sum of major point sources SO_2		F10.1
8	Sum of all sources SO_2		F10.1

(1) 1 is in the southwest corner of the entire grid system

(2) 0 is the ocean

* Original SURE Grid Numbering System

1	1	1	0	-9	0	0.0	0.0
2	1	2	1	-9	0	0.0	0.0
3	1	3	2	-9	0	0.0	0.0
4	1	4	3	-9	0	0.0	0.0
5	1	5	4	-9	0	0.0	0.0
6	1	6	5	-9	0	0.0	0.0
7	1	7	6	-9	0	0.0	0.0
8	1	8	7	-9	0	0.0	0.0
9	1	9	8	-9	0	0.0	0.0
10	1	10	9	-9	0	0.0	0.0
11	1	11	10	-9	0	0.0	0.0
12	1	12	11	-9	0	0.0	0.0
13	1	13	12	-9	0	0.0	0.0
14	1	14	13	-9	0	0.0	0.0
15	1	15	14	-9	0	0.0	0.0
16	1	16	15	-9	31	0.0	1.6
17	1	17	16	-9	0	0.0	0.0
18	1	18	17	-9	0	0.0	0.0
19	1	19	18	-9	0	0.0	0.0
20	1	20	19	-9	0	0.0	0.0
21	1	21	20	-9	0	0.0	0.0
22	1	22	21	-9	0	0.0	0.0
23	1	23	22	-9	0	0.0	0.0
24	1	24	23	-9	0	0.0	0.0
25	1	25	24	-9	0	0.0	0.0
26	1	26	25	-9	0	0.0	0.0
27	1	27	26	-9	0	0.0	0.0
28	1	28	27	-9	0	0.0	0.0
29	1	29	28	-9	0	0.0	0.0
30	1	30	29	-9	0	0.0	0.0
31	1	31	30	-9	0	0.0	0.0
1	2	32	0	-8	0	0.0	0.0
2	2	33	1	-8	0	0.0	0.0
3	2	34	2	-8	0	0.0	0.0
4	2	35	3	-8	0	0.0	0.0
5	2	36	4	-8	0	0.0	0.0
6	2	37	5	-8	0	0.0	0.0
7	2	38	6	-8	0	0.0	0.0
8	2	39	7	-8	0	0.0	0.0
9	2	40	8	-8	0	0.0	0.0
10	2	41	9	-8	0	0.0	0.0
11	2	42	10	-8	0	0.0	0.0
12	2	43	11	-8	0	0.0	0.0
13	2	44	12	-8	0	0.0	0.0
14	2	45	13	-8	0	0.0	0.0
15	2	46	14	-8	0	0.0	0.0
16	2	47	15	-8	31	0.0	.5
17	2	48	16	-8	31	0.0	11.0
18	2	49	17	-8	0	0.0	0.0
19	2	50	18	-8	0	0.0	0.0
20	2	51	19	-8	0	0.0	0.0
21	2	52	20	-8	0	0.0	0.0

22	2	53	21	-8	0	0.0	0.0
23	2	54	22	-8	0	0.0	0.0
24	2	55	23	-8	0	0.0	0.0
25	2	56	24	-8	0	0.0	0.0
26	2	57	25	-8	0	0.0	0.0
27	2	58	26	-8	0	0.0	0.0
28	2	59	27	-8	0	0.0	0.0
29	2	60	28	-8	0	0.0	0.0
30	2	61	29	-8	0	0.0	0.0
31	2	62	30	-8	0	0.0	0.0
1	3	63	0	-7	0	0.0	0.0
2	3	64	1	-7	0	0.0	0.0
3	3	65	2	-7	0	0.0	0.0
4	3	66	3	-7	0	0.0	0.0
5	3	67	4	-7	0	0.0	0.0
6	3	68	5	-7	0	0.0	0.0
7	3	69	6	-7	0	0.0	0.0
8	3	70	7	-7	0	0.0	0.0
9	3	71	8	-7	0	0.0	0.0
10	3	72	9	-7	0	0.0	0.0
11	3	73	10	-7	0	0.0	0.0
12	3	74	11	-7	0	0.0	0.0
13	3	75	12	-7	0	0.0	0.0
14	3	76	13	-7	0	0.0	0.0
15	3	77	14	-7	0	0.0	0.0
16	3	78	15	-7	31	0.0	.8
17	3	79	16	-7	31	0.0	19.3
18	3	80	17	-7	31	22.8	51.5
19	3	81	18	-7	[illegible]	0.0	0.0
20	3	82	19	-7	0	0.0	0.0
21	3	83	20	-7	0	0.0	0.0
22	3	84	21	-7	0	0.0	0.0
23	3	85	22	-7	0	0.0	0.0
24	3	86	23	-7	0	0.0	0.0
25	3	87	24	-7	0	0.0	0.0
26	3	88	25	-7	0	0.0	0.0
27	3	89	26	-7	0	0.0	0.0
28	3	90	27	-7	0	0.0	0.0
29	3	91	28	-7	0	0.0	0.0
30	3	92	29	-7	0	0.0	0.0
31	3	93	30	-7	0	0.0	0.0
1	4	94	0	-6	0	0.0	0.0
2	4	95	1	-5	0	0.0	0.0
3	4	96	2	-5	0	0.0	0.0
4	4	97	3	-5	0	0.0	0.0
5	4	98	4	-6	0	0.0	0.0
6	4	99	5	-5	0	0.0	0.0
7	4	100	6	-5	0	0.0	0.0
8	4	101	7	-5	0	0.0	0.0
9	4	102	8	-6	0	0.0	0.0
10	4	103	9	-6	0	0.0	0.0
11	4	104	10	-6	0	0.0	0.0
12	4	105	11	-5	0	0.0	0.0
13	4	106	12	-6	0	0.0	0.0
14	4	107	13	-5	0	0.0	0.0
15	4	108	14	-5	31	0.0	1.1
16	4	109	15	-6	31	0.0	3.8
17	4	110	16	-5	31	0.0	7.9
18	4	111	17	-6	31	10.7	31.2
19	4	112	18	-5	0	0.0	0.0
20	4	113	19	-5	0	0.0	0.0
21	4	114	20	-6	0	0.0	0.0
22	4	115	21	-6	0	0.0	0.0
23	4	116	22	-5	0	0.0	0.0
24	4	117	23	-6	0	0.0	0.0
25	4	118	24	-6	0	0.0	0.0

26	4	119	25	-6	0	0.0	0.0
27	4	120	26	-6	0	0.0	0.0
28	4	121	27	-5	0	0.0	0.0
29	4	122	28	-6	0	0.0	0.0
30	4	123	29	-5	0	0.0	0.0
31	4	124	30	-5	0	0.0	0.0
1	5	125	0	-5	0	0.0	0.0
2	5	126	1	-5	0	0.0	0.0
3	5	127	2	-5	0	0.0	0.0
4	5	128	3	-5	0	0.0	0.0
5	5	129	4	-5	0	0.0	0.0
6	5	130	5	-5	0	0.0	0.0
7	5	131	6	-5	0	0.0	0.0
8	5	132	7	-5	0	0.0	0.0
9	5	133	8	-5	0	0.0	0.0
10	5	134	9	-5	0	0.0	0.0
11	5	135	10	-5	0	0.0	0.0
12	5	136	11	-5	0	0.0	0.0
13	5	137	12	-5	0	0.0	0.0
14	5	138	13	-5	0	0.0	0.0
15	5	139	14	-5	31	0.0	6.0
16	5	140	15	-5	31	0.0	3.8
17	5	141	16	-5	31	1.0	15.2
18	5	142	17	-5	31	0.0	0.0
19	5	143	18	-5	0	0.0	0.0
20	5	144	19	-5	0	0.0	0.0
21	5	145	20	-5	0	0.0	0.0
22	5	146	21	-5	0	0.0	0.0
23	5	147	22	-5	0	0.0	0.0
24	5	148	23	-5	0	0.0	0.0
25	5	149	24	-5	0	0.0	0.0
26	5	150	25	-5	0	0.0	0.0
27	5	151	26	-5	0	0.0	0.0
28	5	152	27	-5	0	0.0	0.0
29	5	153	28	-5	0	0.0	0.0
30	5	154	29	-5	0	0.0	0.0
31	5	155	30	-5	0	0.0	0.0
1	6	156	0	-4	0	0.0	0.0
2	6	157	1	-4	0	0.0	0.0
3	6	158	2	-4	0	0.0	0.0
4	6	159	3	-4	0	0.0	0.0
5	6	160	4	-4	0	0.0	0.0
6	6	161	5	-4	0	0.0	0.0
7	6	162	6	-4	0	0.0	0.0
8	6	163	7	-4	0	0.0	0.0
9	6	164	8	-4	0	0.0	0.0
10	6	165	9	-4	0	0.0	0.0
11	6	166	10	-4	0	0.0	0.0
12	6	167	11	-4	0	0.0	0.0
13	6	168	12	-4	0	0.0	0.0
14	6	169	13	-4	31	44.0	47.3
15	6	170	14	-4	31	238.9	342.8
16	6	171	15	-4	31	1.6	42.8
17	6	172	16	-4	31	56.1	61.1
18	6	173	17	-4	0	0.0	0.0
19	6	174	18	-4	0	0.0	0.0
20	6	175	19	-4	0	0.0	0.0
21	6	176	20	-4	0	0.0	0.0
22	6	177	21	-4	0	0.0	0.0
23	6	178	22	-4	0	0.0	0.0
24	6	179	23	-4	0	0.0	0.0
25	6	180	24	-4	0	0.0	0.0
26	6	181	25	-4	0	0.0	0.0
27	6	182	26	-4	0	0.0	0.0
28	6	183	27	-4	0	0.0	0.0
29	6	184	28	-4	0	0.0	0.0

30	6	185	29	-4	0	0.0	0.0
31	6	186	30	-4	0	0.0	0.0
1	7	187	0	-3	0	0.0	0.0
2	7	188	1	-3	0	0.0	0.0
3	7	189	2	-3	0	0.0	0.0
4	7	190	3	-3	0	0.0	0.0
5	7	191	4	-3	0	0.0	0.0
6	7	192	5	-3	0	0.0	0.0
7	7	193	6	-3	0	0.0	0.0
8	7	194	7	-3	0	0.0	0.0
9	7	195	8	-3	0	0.0	0.0
10	7	196	9	-3	0	0.0	0.0
11	7	197	10	-3	0	0.0	0.0
12	7	198	11	-3	0	0.0	0.0
13	7	199	12	-3	0	0.0	0.0
14	7	200	13	-3	0	0.0	0.0
15	7	201	14	-3	32	29.5	34.4
15	7	202	15	-3	32	76.8	97.4
17	7	203	16	-3	32	0.0	.4
18	7	204	17	-3	0	0.0	0.0
19	7	205	18	-3	0	0.0	0.0
20	7	206	19	-3	0	0.0	0.0
21	7	207	20	-3	0	0.0	0.0
22	7	208	21	-3	0	0.0	0.0
23	7	209	22	-3	0	0.0	0.0
24	7	210	23	-3	0	0.0	0.0
25	7	211	24	-3	0	0.0	0.0
26	7	212	25	-3	0	0.0	0.0
27	7	213	26	-3	0	0.0	0.0
28	7	214	27	-3	0	0.0	0.0
29	7	215	28	-3	0	0.0	0.0
30	7	216	29	-3	0	0.0	0.0
31	7	217	30	-3	0	0.0	0.0
1	8	218	0	-2	0	0.0	0.0
2	8	219	1	-2	0	0.0	0.0
3	8	220	2	-2	0	0.0	0.0
4	8	221	3	-2	0	0.0	0.0
5	8	222	4	-2	37	0.0	.1
6	8	223	5	-2	37	5.1	27.7
7	8	224	6	-2	37	0.0	4.1
8	8	225	7	-2	0	0.0	0.0
9	8	226	8	-2	0	0.0	0.0
10	8	227	9	-2	0	0.0	0.0
11	8	228	10	-2	34	0.0	.6
12	8	229	11	-2	34	0.0	0.0
13	8	230	12	-2	0	0.0	0.0
14	8	231	13	-2	33	0.0	5.4
15	8	232	14	-2	33	0.0	25.3
16	8	233	15	-2	32	8.5	17.0
17	8	234	16	-2	32	0.0	.2
18	8	235	17	-2	0	0.0	0.0
19	8	236	18	-2	0	0.0	0.0
20	8	237	19	-2	0	0.0	0.0
21	8	238	20	-2	0	0.0	0.0
22	8	239	21	-2	0	0.0	0.0
23	8	240	22	-2	0	0.0	0.0
24	8	241	23	-2	0	0.0	0.0
25	8	242	24	-2	0	0.0	0.0
26	8	243	25	-2	0	0.0	0.0
27	8	244	26	-2	0	0.0	0.0
28	8	245	27	-2	0	0.0	0.0
29	8	246	28	-2	0	0.0	0.0
30	8	247	29	-2	0	0.0	0.0
31	8	248	30	-2	0	0.0	0.0
1	9	249	0	-1	37	0.0	0.0
2	9	250	1	-1	37	0.0	.1

3	9	251	2	-1	37	1.5	3.1
~~4~~	~~9~~	~~252~~	~~3~~	~~-1~~	~~37~~	~~.1~~	~~18.9~~
5	9	253	4	-1	37	80.8	125.1
6	9	254	5	-1	37	25.4	70.5
~~7~~	~~9~~	~~255~~	~~6~~	~~-1~~	~~0~~	~~0.0~~	~~0.0~~
8	9	256	7	-1	0	0.0	0.0
9	9	257	8	-1	34	8.4	186.0
~~10~~	~~9~~	~~258~~	~~9~~	~~-1~~	~~34~~	~~0.0~~	~~.6~~
11	9	259	10	-1	34	34.9	55.5
12	9	260	11	-1	34	0.0	16.1
~~13~~	~~9~~	~~261~~	~~12~~	~~-1~~	~~34~~	~~0.0~~	~~21.0~~
14	9	262	13	-1	33	14.4	18.0
15	9	263	14	-1	33	0.0	10.9
~~16~~	~~9~~	~~264~~	~~15~~	~~-1~~	~~32~~	~~11.5~~	~~3[illegible].4~~
17	9	265	16	-1	0	0.0	0.0
18	9	266	17	-1	0	0.0	0.0
~~19~~	~~9~~	~~267~~	~~18~~	~~-1~~	~~0~~	~~0.0~~	~~0.0~~
20	9	268	19	-1	0	0.0	0.0
21	9	269	20	-1	0	0.0	0.0
~~22~~	~~9~~	~~270~~	~~21~~	~~-1~~	~~0~~	~~0.0~~	~~0.0~~
23	9	271	22	-1	0	0.0	0.0
24	9	272	23	-1	0	0.0	0.0
~~25~~	~~9~~	~~273~~	~~24~~	~~-1~~	~~0~~	~~0.0~~	~~0.0~~
26	9	274	25	-1	0	0.0	0.0
27	9	275	26	-1	0	0.0	0.0
~~28~~	~~9~~	~~276~~	~~27~~	~~-1~~	~~0~~	~~0.0~~	~~0.0~~
29	9	277	28	-1	0	0.0	0.0
30	9	278	29	-1	0	0.0	0.0
~~31~~	~~9~~	~~279~~	~~30~~	~~-1~~	~~0~~	~~0.0~~	~~0.0~~
1	10	280	0	0	37	0.0	0.0
2	10	281	1	0	37	103.4	122.4
~~3~~	~~10~~	~~282~~	~~2~~	~~0~~	~~37~~	~~3.0~~	~~4.7~~
4	10	283	3	0	37	94.4	134.0
5	10	284	4	0	37	0.0	7.5
~~6~~	~~10~~	~~285~~	~~5~~	~~0~~	~~36~~	~~0.0~~	~~15.3~~
7	10	286	6	0	36	10.0	73.4
8	10	287	7	0	35	78.1	127.7
~~9~~	~~10~~	~~288~~	~~8~~	~~0~~	~~34~~	~~0.0~~	~~541.5~~
10	10	289	9	0	34	0.0	83.6
11	10	290	10	0	34	0.0	6.9
~~12~~	~~10~~	~~291~~	~~11~~	~~0~~	~~33~~	~~0.0~~	~~10.2~~
13	10	292	12	0	30	0.0	1.8
14	10	293	13	0	30	0.0	6.0
~~15~~	~~10~~	~~294~~	~~14~~	~~0~~	~~30~~	~~0.0~~	~~3.6~~
16	10	295	15	0	30	20.9	42.2
17	10	296	16	0	0	0.0	0.0
~~18~~	~~10~~	~~297~~	~~17~~	~~0~~	~~0~~	~~0.0~~	~~0.0~~
19	10	298	18	0	0	0.0	0.0
20	10	299	19	0	0	0.0	0.0
~~21~~	~~10~~	~~300~~	~~20~~	~~0~~	~~0~~	~~0.0~~	~~0.0~~
22	10	301	21	0	0	0.0	0.0
23	10	302	22	0	0	0.0	0.0
~~24~~	~~10~~	~~303~~	~~23~~	~~0~~	~~0~~	~~0.0~~	~~0.0~~
25	10	304	24	0	0	0.0	0.0
26	10	305	25	0	0	0.0	0.0
~~27~~	~~10~~	~~306~~	~~26~~	~~0~~	~~0~~	~~0.0~~	~~0.0~~
28	10	307	27	0	0	0.0	0.0
29	10	308	28	0	0	0.0	0.0
~~30~~	~~10~~	~~309~~	~~29~~	~~0~~	~~0~~	~~0.0~~	~~0.0~~
31	10	310	30	0	0	0.0	0.0
1	11	311	0	1	37	0.0	0.0
~~2~~	~~11~~	~~312~~	~~1~~	~~1~~	~~37~~	~~0.0~~	~~1.0~~
3	11	313	2	1	37	62.3	63.3
4	11	314	3	1	36	0.0	13.4
~~5~~	~~11~~	~~315~~	~~4~~	~~1~~	~~36~~	~~0.0~~	~~.7~~
6	11	316	5	1	36	0.0	36.5

7	11	317	6	1	36	11.0	43.2
8	11	318	7	1	35	0.0	35.4
9	11	319	8	1	35	0.0	12.2
10	11	320	9	1	35	0.0	10.5
11	11	321	10	1	35	0.0	8.1
12	11	322	11	1	30	7.3	8.0
13	11	323	12	1	30	0.0	30.4
14	11	324	13	1	30	0.0	3.4
15	11	325	14	1	30	0.0	.8
16	11	326	15	1	30	24.1	38.3
17	11	327	16	1	0	0.0	0.0
18	11	328	17	1	0	0.0	0.0
19	11	329	18	1	0	0.0	0.0
20	11	330	19	1	0	0.0	0.0
21	11	331	20	1	0	0.0	0.0
22	11	332	21	1	0	0.0	0.0
23	11	333	22	1	0	0.0	0.0
24	11	334	23	1	0	0.0	0.0
25	11	335	24	1	0	0.0	0.0
26	11	336	25	1	0	0.0	0.0
27	11	337	26	1	0	0.0	0.0
28	11	338	27	1	0	0.0	0.0
29	11	339	28	1	0	0.0	0.0
30	11	340	29	1	0	0.0	0.0
31	11	341	30	1	0	0.0	0.0
1	12	342	0	2	37	0.0	0.0
2	12	343	1	2	37	0.0	1.4
3	12	344	2	2	37	0.0	1.1
4	12	345	3	2	37	0.0	.4
5	12	346	4	2	36	14.5	22.4
6	12	347	5	2	36	0.0	16.7
7	12	348	6	2	36	0.0	9.2
8	12	349	7	2	35	11.1	20.0
9	12	350	8	2	35	0.0	6.5
10	12	351	9	2	35	0.0	3.8
11	12	352	10	2	35	0.0	8.1
12	12	353	11	2	30	0.0	5.4
13	12	354	12	2	30	0.0	4.6
14	12	355	13	2	30	0.0	1.7
15	12	356	14	2	30	0.0	6.1
16	12	357	15	2	30	0.0	33.5
17	12	358	16	2	30	0.0	2.7
18	12	359	17	2	28	0.0	2.5
19	12	360	18	2	0	0.0	0.0
20	12	361	19	2	0	0.0	0.0
21	12	362	20	2	0	0.0	0.0
22	12	363	21	2	0	0.0	0.0
23	12	364	22	2	0	0.0	0.0
24	12	365	23	2	0	0.0	0.0
25	12	366	24	2	0	0.0	0.0
26	12	367	25	2	0	0.0	0.0
27	12	368	26	2	0	0.0	0.0
28	12	369	27	2	0	0.0	0.0
29	12	370	28	2	0	0.0	0.0
30	12	371	29	2	0	0.0	0.0
31	12	372	30	2	0	0.0	0.0
1	13	373	0	3	37	0.0	0.0
2	13	374	1	3	37	0.0	1.0
3	13	375	2	3	37	3.3	9.7
4	13	376	3	3	37	0.0	18.0
5	13	377	4	3	36	.1	4.6
6	13	378	5	3	36	0.0	.6
7	13	379	6	3	36	0.0	.7
8	13	380	7	3	36	291.0	291.9
9	13	381	8	3	35	0.0	11.0
10	13	382	9	3	35	159.7	161.3

11	13	383	10	3	35	12.3	27.1
12	13	384	11	3	29	113.6	127.6
13	13	385	12	3	29	13.6	25.6
14	13	386	13	3	30	63.8	71.6
15	13	387	14	3	30	.1	48.8
16	13	388	15	3	29	0.0	2.9
17	13	389	16	3	29	13.0	29.4
18	13	390	17	3	28	100.5	115.8
19	13	391	18	3	28	0.0	.4
20	13	392	19	3	0	0.0	0.0
21	13	393	20	3	0	0.0	0.0
22	13	394	21	3	0	0.0	0.0
23	13	395	22	3	0	0.0	0.0
24	13	396	23	3	0	0.0	0.0
25	13	397	24	3	0	0.0	0.0
26	13	398	25	3	0	0.0	0.0
27	13	399	26	3	0	0.0	0.0
28	13	400	27	3	0	0.0	0.0
29	13	401	28	3	0	0.0	0.0
30	13	402	29	3	0	0.0	0.0
31	13	403	30	3	0	0.0	0.0
1	14	404	0	4	39	0.0	0.0
2	14	405	1	4	38	0.0	8.1
3	14	406	2	4	38	0.0	11.6
4	14	407	3	4	39	0.0	1.6
5	14	408	4	4	36	0.0	1.4
6	14	409	5	4	35	0.0	.8
7	14	410	6	4	35	0.0	.8
8	14	411	7	4	35	0.0	1.6
9	14	412	8	4	35	115.3	121.7
10	14	413	9	4	35	0.0	76.7
11	14	414	10	4	35	12.9	3[illegible].8
12	14	415	11	4	29	28.8	39.6
13	14	416	12	4	29	0.0	24.3
14	14	417	13	4	30	0.0	2.3
15	14	418	14	4	28	0.0	12.4
16	14	419	15	4	28	46.3	52.5
17	14	420	16	4	28	37.2	49.6
18	14	421	17	4	28	0.0	12.7
19	14	422	18	4	28	7.8	9.4
20	14	423	19	4	27	0.0	6.0
21	14	424	20	4	0	0.0	0.0
22	14	425	21	4	0	0.0	0.0
23	14	426	22	4	0	0.0	0.0
24	14	427	23	4	0	0.0	0.0
25	14	428	24	4	0	0.0	0.0
26	14	429	25	4	0	0.0	0.0
27	14	430	26	4	0	0.0	0.0
28	14	431	27	4	0	0.0	0.0
29	14	432	28	4	0	0.0	0.0
30	14	433	29	4	0	0.0	0.0
31	14	434	30	4	0	0.0	0.0
1	15	435	0	5	38	0.0	0.0
2	15	436	1	5	38	0.0	.8
3	15	437	2	5	38	9.5	12.9
4	15	438	3	5	38	0.0	1.5
5	15	439	4	5	38	3.9	5.8
6	15	440	5	5	36	0.0	3.8
7	15	441	6	5	35	0.0	2.5
8	15	442	7	5	35	0.0	1.1
9	15	443	8	5	35	25[illegible].6	269.0
10	15	444	9	5	35	48.2	63.2
11	15	445	10	5	35	2[illegible]9.0	215.4
12	15	446	11	5	29	392.1	403.7
13	15	447	12	5	25	0.0	2.2
14	15	448	13	5	25	0.0	6.2

15	15	449	14	5	28	14.8	35.6
16	15	450	15	5	28	1.7	46.4
17	15	451	16	5	28	0.0	17.6
18	15	452	17	5	28	5.9	35.8
19	15	453	18	5	27	10.9	17.3
20	15	454	19	5	27	20.6	59.6
21	15	455	20	5	27	0.0	2.1
22	15	456	21	5	27	0.0	.4
23	15	457	22	5	0	0.0	0.0
24	15	458	23	5	0	0.0	0.0
25	15	459	24	5	0	0.0	0.0
26	15	460	25	5	0	0.0	0.0
27	15	461	26	5	0	0.0	0.0
28	15	462	27	5	0	0.0	0.0
29	15	463	28	5	0	0.0	0.0
30	15	464	29	5	0	0.0	0.0
31	15	465	30	5	0	0.0	0.0
1	16	466	0	6	38	0.0	0.0
2	16	467	1	6	38	0.0	.5
3	16	468	2	6	38	0.0	4.7
4	16	469	3	6	38	0.0	8.1
5	16	470	4	6	38	0.0	6.0
6	16	471	5	6	23	81.9	99.1
7	16	472	6	6	23	0.0	6.4
8	16	473	7	6	23	0.0	19.3
9	16	474	8	6	23	0.0	1.7
10	16	475	9	6	24	0.0	4.4
11	16	476	10	6	24	0.0	4.7
12	16	477	11	6	24	13.2	45.6
13	16	478	12	6	25	0.0	9.4
14	16	479	13	6	25	9.4	21.0
15	16	480	14	6	26	20.9	69.5
16	16	481	15	6	26	100.7	136.6
17	16	482	16	6	27	23.0	51.9
18	16	483	17	6	27	0.0	3.3
19	16	484	18	6	27	0.0	16.9
20	16	485	19	6	27	44.4	55.7
21	16	486	20	6	27	29.9	40.1
22	16	487	21	6	27	0.0	.7
23	16	488	22	6	0	0.0	0.0
24	16	489	23	6	0	0.0	0.0
25	16	490	24	6	0	0.0	0.0
26	16	491	25	6	0	0.0	0.0
27	16	492	26	6	0	0.0	0.0
28	16	493	27	6	0	0.0	0.0
29	16	494	28	6	0	0.0	0.0
30	16	495	29	6	0	0.0	0.0
31	16	496	30	6	0	0.0	0.0
1	17	497	0	7	38	0.0	0.0
2	17	498	1	7	39	0.4	1.4
3	17	499	2	7	39	0.0	1.2
4	17	500	3	7	39	0.0	3.6
5	17	501	4	7	39	0.0	2.9
6	17	502	5	7	33	0.0	4.5
7	17	503	6	7	23	0.0	2.6
8	17	504	7	7	23	0.0	3.0
9	17	505	8	7	23	316.1	346.3
10	17	506	9	7	24	1.5	25.5
11	17	507	10	7	24	0.0	1.0
12	17	508	11	7	24	0.0	7.0
13	17	509	12	7	24	158.1	223.6
14	17	510	13	7	25	6.7	12.2
15	17	511	14	7	25	0.0	21.8
16	17	512	15	7	26	0.0	15.4
17	17	513	16	7	26	0.0	23.4
18	17	514	17	7	27	13.9	43.3

19	17	515	18	7	27	135.2	128.2
20	17	516	19	7	27	0.0	19.5
21	17	517	20	7	27	10.3	16.0
22	17	518	21	7	27	0.0	2.2
23	17	519	22	7	0	0.0	0.0
24	17	520	23	7	0	0.0	0.0
25	17	521	24	7	0	0.0	0.0
26	17	522	25	7	0	0.0	0.0
27	17	523	26	7	0	0.0	0.0
28	17	524	27	7	0	0.0	0.0
29	17	525	28	7	0	0.0	0.0
30	17	526	29	7	0	0.0	0.0
31	17	527	30	7	0	0.0	0.0
1	18	528	0	8	38	0.0	0.0
2	18	529	1	8	38	0.0	1.4
3	18	530	2	8	39	0.0	.5
4	18	531	3	8	33	0.0	.6
5	18	532	4	8	38	0.0	.3
6	18	533	5	8	40	0.0	1.3
7	18	534	6	8	40	0.0	3.2
8	18	535	7	8	23	0.0	11.5
9	18	536	8	8	23	230.5	236.3
10	18	537	9	8	24	154.2	170.4
11	18	538	10	8	21	0.0	.7
12	18	539	11	8	21	0.0	.7
13	18	540	12	8	21	33.4	42.4
14	18	541	13	8	24	61.7	66.1
15	18	542	14	8	24	55.9	84.9
16	18	543	15	8	18	0.0	3.1
17	18	544	16	8	25	25[illegible].8	267.5
18	18	545	17	8	18	0.[illegible]	40.5
19	18	546	18	8	18	0.0	4.3
20	18	547	19	8	18	0.0	37.8
21	18	548	20	8	18	8.0	13.5
22	18	549	21	8	18	23.5	117.2
23	18	550	22	8	0	0.0	0.0
24	18	551	23	8	0	0.0	0.0
25	18	552	24	8	0	0.0	0.0
26	18	553	25	8	0	0.0	0.0
27	18	554	26	8	0	0.0	0.0
28	18	555	27	8	0	0.0	0.0
29	18	556	28	8	0	0.0	0.0
30	18	557	29	8	0	0.0	0.0
31	18	558	30	8	0	0.0	0.0
1	19	559	0	9	40	0.0	0.0
2	19	560	1	9	40	0.0	.6
3	19	561	2	9	40	0.0	1.3
4	19	562	3	9	40	0.0	.3
5	19	563	4	9	40	0.0	.5
6	19	564	5	9	40	0.0	1.6
7	19	565	6	9	40	0.0	4.1
8	19	566	7	9	22	422.1	445.2
9	19	567	8	9	22	43.8	46.1
10	19	568	9	9	22	553.8	563.3
11	19	569	10	9	21	0.0	1.7
12	19	570	11	9	21	0.0	1.0
13	19	571	12	9	21	0.0	2.7
14	19	572	13	9	21	0.0	6.8
15	19	573	14	9	20	0.0	7.4
16	19	574	15	9	20	0.0	3.9
17	19	575	16	9	18	20.4	25.5
18	19	576	17	9	18	35.4	53.4
19	19	577	18	9	18	0.0	14.2
20	19	578	19	9	18	34.1	104.0
21	19	579	20	9	18	18.9	78.6
22	19	580	21	9	13	34.6	46.8

23	19	581	22	9	0	0.0	0.0
24	19	582	23	9	0	0.0	0.0
25	19	583	24	9	0	0.0	0.0
26	19	584	25	9	0	0.0	0.0
27	19	585	26	9	0	0.0	0.0
28	19	586	27	9	0	0.0	0.0
29	19	587	28	9	0	0.0	0.0
30	19	588	29	9	0	0.0	0.0
31	19	589	30	9	0	0.0	0.0
1	20	590	0	10	40	54.9	54.9
2	20	591	1	10	40	0.0	.8
3	20	592	2	10	40	0.0	8.7
4	20	593	3	10	40	0.0	2.9
5	20	594	4	10	40	0.0	6.2
6	20	595	5	10	40	78.1	96.9
7	20	596	6	10	42	340.0	350.5
8	20	597	7	10	42	0.0	7.7
9	20	598	8	10	45	33.2	70.7
10	20	599	9	10	45	352.2	378.6
11	20	600	10	10	21	39[illegible].0	497.9
12	20	601	11	10	21	75.7	79.0
13	20	602	12	10	21	8.8	12.9
14	20	603	13	10	21	0.0	19.5
15	20	604	14	10	21	71.2	89.0
16	20	605	15	10	20	153.6	212.1
17	20	606	16	10	20	0.0	3.1
18	20	607	17	10	18	0.0	3.6
19	20	608	18	10	18	13.0	22.8
20	20	609	19	10	18	0.0	22.8
21	20	610	20	10	16	59.3	82.0
22	20	611	21	10	16	0.0	3.0
23	20	612	22	10	17	0.0	.9
24	20	613	23	10	0	0.0	0.0
25	20	614	24	10	0	0.0	0.0
26	20	615	25	10	0	0.0	0.0
27	20	616	26	10	0	0.0	0.0
28	20	617	27	10	0	0.0	0.0
29	20	618	28	10	0	0.0	0.0
30	20	619	29	10	0	0.0	0.0
31	20	620	30	10	0	0.0	0.0
1	21	621	0	11	40	0.0	0.0
2	21	622	1	11	40	0.0	.9
3	21	623	2	11	40	185.7	186.1
4	21	624	3	11	40	0.0	6.0
5	21	625	4	11	40	272.4	290.9
6	21	626	5	11	40	236.1	352.4
7	21	627	6	11	42	148.6	226.1
8	21	628	7	11	42	0.0	11.9
9	21	629	8	11	42	29.3	44.6
10	21	630	9	11	45	232.4	279.6
11	21	631	10	11	45	0.0	9.1
12	21	632	11	11	45	485.6	495.3
13	21	633	12	11	46	451.6	510.3
14	21	634	13	11	46	7.8	36.2
15	21	635	14	11	46	558.8	576.1
16	21	636	15	11	20	0.0	34.2
17	21	637	16	11	20	0.0	7.6
18	21	638	17	11	19	106.0	115.2
19	21	639	18	11	18	0.0	13.4
20	21	640	19	11	18	37.3	42.3
21	21	641	20	11	16	125.6	184.6
22	21	642	21	11	16	13.8	26.4
23	21	643	22	11	17	29.6	42.9
24	21	644	23	11	0	0.0	0.0
25	21	645	24	11	0	0.0	0.0
26	21	646	25	11	0	0.0	0.0

27	21	647	26	11	0	0.0	0.0
28	21	648	27	11	0	0.0	0.0
29	21	649	28	11	0	0.0	0.0
30	21	650	29	11	0	0.0	0.0
31	21	651	30	11	0	0.0	0.0
1	22	652	0	12	40	0.0	0.0
2	22	653	1	12	40	133.8	172.7
3	22	654	2	12	40	0.0	20.1
4	22	655	3	12	40	0.0	6.3
5	22	656	4	12	40	0.0	5.0
6	22	657	5	12	41	5.6	6.4
7	22	658	6	12	42	81.7	90.7
8	22	659	7	12	42	232.7	235.6
9	22	660	8	12	43	16.7	17.5
10	22	661	9	12	45	222.7	284.2
11	22	662	10	12	45	150.8	243.6
12	22	663	11	12	45	0.0	32.1
13	22	664	12	12	48	22.7	127.3
14	22	665	13	12	48	43.8	115.7
15	22	666	14	12	45	33.5	62.2
16	22	667	15	12	46	451.3	504.6
17	22	668	16	12	13	751.1	800.0
18	22	669	17	12	13	162.0	171.1
19	22	670	18	12	15	19.3	26.8
20	22	671	19	12	16	0.0	36.0
21	22	672	20	12	16	55.4	96.2
22	22	673	21	12	17	35.7	85.7
23	22	674	22	12	11	61.9	112.1
24	22	675	23	12	11	0.0	1.6
25	22	676	24	12	0	0.0	0.0
26	22	677	25	12	0	0.0	0.0
27	22	678	26	12	0	0.0	0.0
28	22	679	27	12	0	0.0	0.0
29	22	680	28	12	0	0.0	0.0
30	22	681	29	12	0	0.0	0.0
31	22	682	30	12	0	0.0	0.0
1	23	683	0	13	40	0.0	0.0
2	23	684	1	13	40	0.0	20.2
3	23	685	2	13	40	0.0	6.2
4	23	686	3	13	40	0.0	.5
5	23	687	4	13	41	28.4	31.9
6	23	688	5	13	42	4.5	12.4
7	23	689	6	13	42	80.9	86.1
8	23	690	7	13	43	33.7	39.9
9	23	691	8	13	43	29.4	65.7
10	23	692	9	13	44	0.0	48.6
11	23	693	10	13	44	5.2	46.8
12	23	694	11	13	44	0.0	50.0
13	23	695	12	13	48	9.1	43.8
14	23	696	13	13	48	0.0	51.6
15	23	697	14	13	48	0.0	18.0
15	23	698	15	13	46	315.1	343.8
17	23	699	16	13	46	846.0	981.0
18	23	700	17	13	14	578.9	674.5
19	23	701	18	13	15	11.1	28.4
20	23	702	19	13	13	0.0	8.7
21	23	703	20	13	13	226.0	263.0
22	23	704	21	13	12	43.4	99.0
23	23	705	22	13	12	111.1	269.2
24	23	706	23	13	11	0.0	23.9
25	23	707	24	13	0	0.0	0.0
26	23	708	25	13	0	0.0	0.0
27	23	709	26	13	0	0.0	0.0
28	23	710	27	13	0	0.0	0.0
29	23	711	28	13	0	0.0	0.0
30	23	712	29	13	0	0.0	0.0

31	23	713	30	13	0	0.0	0.0
1	24	714	0	14	40	0.0	0.0
2	24	715	1	14	40	0.0	.5
3	24	716	2	14	40	0.0	.5
4	24	717	3	14	40	0.0	.6
5	24	718	4	14	41	.7	7.9
6	24	719	5	14	41	22.6	48.6
7	24	720	6	14	43	237.6	375.8
8	24	721	7	14	43	0.0	22.7
9	24	722	8	14	43	0.0	22.7
10	24	723	9	14	44	0.0	4.2
11	24	724	10	14	44	0.0	23.8
12	24	725	11	14	44	0.0	22.8
13	24	726	12	14	44	0.0	19.5
14	24	727	13	14	48	11.0	34.9
15	24	728	14	14	43	178.1	217.1
16	24	729	15	14	47	135.6	297.5
17	24	730	16	14	47	89.2	210.6
18	24	731	17	14	14	233.3	272.1
19	24	732	18	14	14	77.0	82.8
20	24	733	19	14	13	13.3	39.4
21	24	734	20	14	13	94.2	110.3
22	24	735	21	14	13	0.0	42.3
23	24	736	22	14	12	135.9	236.8
24	24	737	23	14	11	169.7	542.3
25	24	738	24	14	11	0.0	11.8
26	24	739	25	14	0	0.0	0.0
27	24	740	26	14	0	0.0	0.0
28	24	741	27	14	0	0.0	0.0
29	24	742	28	14	0	0.0	0.0
30	24	743	29	14	0	0.0	0.0
31	24	744	30	14	0	0.0	0.0
1	25	745	0	15	41	0.0	0.0
2	25	746	1	15	41	0.0	3.6
3	25	747	2	15	41	0.0	.4
4	25	748	3	15	41	14.4	16.0
5	25	749	4	15	41	0.0	3.1
6	25	750	5	15	41	15.6	57.1
7	25	751	6	15	43	21.4	32.0
8	25	752	7	15	43	6.0	57.8
9	25	753	8	15	43	53.8	188.9
10	25	754	9	15	44	412.3	526.0
11	25	755	10	15	44	.9	33.9
12	25	756	11	15	44	0.0	15.3
13	25	757	12	15	48	0.0	8.0
14	25	758	13	15	49	588.9	671.0
15	25	759	14	15	57	0.0	15.2
16	25	760	15	15	47	346.7	460.1
17	25	761	16	15	47	102.0	140.6
18	25	762	17	15	14	15.1	34.7
19	25	763	18	15	14	0.0	11.7
20	25	764	19	15	13	0.0	2.0
21	25	765	20	15	13	0.0	2.4
22	25	766	21	15	13	0.0	8.8
23	25	767	22	15	10	0.0	6.2
24	25	768	23	15	10	54.4	92.2
25	25	769	24	15	7	31.4	45.1
26	25	770	25	15	6	13.2	33.2
27	25	771	26	15	5	111.7	138.2
28	25	772	27	15	0	0.0	0.0
29	25	773	28	15	0	0.0	0.0
30	25	774	29	15	0	0.0	0.0
31	25	775	30	15	0	0.0	0.0
1	26	776	0	16	41	5.0	5.0
2	26	777	1	16	41	0.0	.6
3	25	778	2	15	41	31.9	69.4

4	26	779	3	15	41	5.4	29.2
~~5~~	~~26~~	~~780~~	~~4~~	~~15~~	~~41~~	~~3.6~~	~~51.4~~
6	26	781	5	15	41	0.0	24.0
7	26	782	6	15	41	50.1	52.6
~~8~~	~~26~~	~~783~~	~~7~~	~~15~~	~~43~~	~~0.0~~	~~51.4~~
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10	26	785	9	15	43	0.0	11.6
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12	26	787	11	15	49	0.0	55.7
13	26	788	12	15	49	97.4	122.3
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15	26	790	14	15	57	99.3	112.6
16	26	791	15	16	57	0.0	2.7
~~17~~	~~26~~	~~792~~	~~16~~	~~16~~	~~57~~	~~0.0~~	~~.8~~
18	26	793	17	15	9	0.0	.8
19	26	794	18	15	9	0.0	24.4
~~20~~	~~26~~	~~795~~	~~19~~	~~15~~	~~9~~	~~11.0~~	~~13.1~~
21	26	796	20	15	10	44.8	51.3
22	26	797	21	15	10	11.5	14.2
~~23~~	~~26~~	~~798~~	~~22~~	~~15~~	~~10~~	~~.6~~	~~26.1~~
24	26	799	23	16	10	0.0	70.2
25	26	800	24	15	5	20.4	68.7
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27	26	802	26	15	5	56.6	184.4
28	26	803	27	15	5	78.5	79.4
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30	26	805	29	15	0	0.0	8.0
31	26	806	30	15	0	0.0	0.0
~~1~~	~~27~~	~~807~~	~~0~~	~~17~~	~~41~~	~~42.8~~	~~42.8~~
2	27	808	1	17	41	0.0	.6
3	27	809	2	17	41	0.0	10.4
~~4~~	~~27~~	~~810~~	~~3~~	~~17~~	~~41~~	~~0.0~~	~~2.6~~
5	27	811	4	17	41	0.0	17.2
6	27	812	5	17	41	0.0	9.3
~~7~~	~~27~~	~~813~~	~~6~~	~~17~~	~~51~~	~~36.5~~	~~62.0~~
8	27	814	7	17	51	31.0	52.3
9	27	815	8	17	51	207.6	242.4
~~10~~	~~27~~	~~816~~	~~9~~	~~17~~	~~51~~	~~0.0~~	~~2.9~~
11	27	817	10	17	49	219.5	247.0
12	27	818	11	17	49	0.0	9.6
~~13~~	~~27~~	~~819~~	~~12~~	~~17~~	~~49~~	~~0.0~~	~~20.1~~
14	27	820	13	17	49	.4	43.0
15	27	821	14	17	49	335.9	358.3
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17	27	823	16	17	57	145.5	160.6
18	27	824	17	17	57	11.2	43.8
~~19~~	~~27~~	~~825~~	~~18~~	~~17~~	~~9~~	~~0.0~~	~~114.0~~
20	27	826	19	17	9	142.7	154.8
21	27	827	20	17	10	30.3	66.6
~~22~~	~~27~~	~~828~~	~~21~~	~~17~~	~~10~~	~~0.0~~	~~5.6~~
23	27	829	22	17	10	0.0	1.5
24	27	830	23	17	10	25.1	36.6
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26	27	832	25	17	4	17.7	85.4
27	27	833	26	17	5	40.1	121.8
~~28~~	~~27~~	~~834~~	~~27~~	~~17~~	~~0~~	~~0.0~~	~~0.0~~
29	27	835	28	17	0	0.0	0.0
30	27	836	29	17	0	0.0	0.0
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2	28	839	1	13	41	0.0	8.0
~~3~~	~~28~~	~~840~~	~~2~~	~~13~~	~~41~~	~~0.0~~	~~22.4~~
4	28	841	3	13	41	5.2	25.1
5	28	842	4	13	41	0.0	2.7
~~6~~	~~28~~	~~843~~	~~5~~	~~13~~	~~41~~	~~9.5~~	~~23.8~~
7	28	844	6	13	51	50.5	54.9

8	28	845	7	13	51	0.0	.9
~~9~~	~~28~~	~~846~~	~~8~~	~~13~~	~~51~~	~~0.0~~	~~18.9~~
10	28	847	9	13	51	64.4	68.1
11	28	848	10	13	50	0.0	3.6
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13	28	850	12	13	50	52.1	70.3
14	28	851	13	13	49	148.9	167.0
~~15~~	~~28~~	~~852~~	~~14~~	~~13~~	~~49~~	~~13.9~~	~~16.0~~
16	28	853	15	13	57	0.0	1.4
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19	28	856	18	13	57	0.0	6.6
20	28	857	19	13	57	0.0	2.6
~~21~~	~~28~~	~~858~~	~~20~~	~~13~~	~~10~~	~~0.0~~	~~.9~~
22	28	859	21	13	10	0.0	4.8
23	28	860	22	13	9	0.0	1.5
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25	28	862	24	13	3	0.0	4.1
26	28	863	25	13	4	33.8	39.4
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28	28	865	27	13	0	0.0	0.0
29	28	866	28	13	0	0.0	0.0
~~30~~	~~28~~	~~867~~	~~29~~	~~13~~	~~0~~	~~0.0~~	~~0.0~~
31	28	868	30	13	0	0.0	0.0
1	29	869	0	13	52	0.0	0.0
~~2~~	~~29~~	~~870~~	~~1~~	~~13~~	~~52~~	~~0.0~~	~~.5~~
3	29	871	2	13	52	0.0	10.8
4	29	872	3	13	52	0.0	2.9
~~5~~	~~29~~	~~873~~	~~4~~	~~13~~	~~52~~	~~0.0~~	~~17.3~~
6	29	874	5	13	51	24.5	30.8
7	29	875	6	13	51	0.0	40.7
~~8~~	~~29~~	~~876~~	~~7~~	~~13~~	~~51~~	~~15.6~~	~~57.9~~
9	29	877	8	13	51	7.4	44.2
10	29	878	9	13	51	70.2	83.7
~~11~~	~~29~~	~~879~~	~~10~~	~~13~~	~~50~~	~~0.0~~	~~7.0~~
12	29	880	11	13	50	0.0	10.2
13	29	881	12	13	50	0.0	5.8
~~14~~	~~29~~	~~882~~	~~13~~	~~13~~	~~50~~	~~0.0~~	~~7.9~~
15	29	883	14	13	54	0.0	0.0
15	29	884	15	13	54	0.0	.4
~~17~~	~~29~~	~~885~~	~~16~~	~~13~~	~~54~~	~~0.0~~	~~2.1~~
18	29	886	17	13	56	0.0	4.5
19	29	887	18	13	56	0.0	2.7
~~20~~	~~29~~	~~888~~	~~19~~	~~13~~	~~57~~	~~15.4~~	~~17.2~~
21	29	889	20	13	57	0.0	3.3
22	29	890	21	13	10	0.0	2.7
~~23~~	~~29~~	~~891~~	~~22~~	~~13~~	~~9~~	~~0.0~~	~~1.5~~
24	29	892	23	13	5	0.0	5.0
25	29	893	24	13	3	0.0	1.7
~~26~~	~~29~~	~~894~~	~~25~~	~~13~~	~~2~~	~~0.0~~	~~25.2~~
27	29	895	26	13	1	0.0	35.8
28	29	896	27	13	1	15.4	73.5
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30	29	898	29	13	0	0.0	0.0
31	29	899	30	13	0	0.0	0.0
~~1~~	~~30~~	~~900~~	~~0~~	~~20~~	~~52~~	~~0.0~~	~~0.0~~
2	30	901	1	20	52	0.0	.6
3	30	902	2	20	52	.6	4.3
~~4~~	~~30~~	~~903~~	~~3~~	~~20~~	~~52~~	~~20.2~~	~~45.4~~
5	30	904	4	20	52	154.4	180.7
6	30	905	5	20	51	0.0	13.7
~~7~~	~~30~~	~~906~~	~~6~~	~~20~~	~~51~~	~~0.0~~	~~10.4~~
8	30	907	7	20	51	13.1	87.7
9	30	908	8	20	51	1.0	11.0
~~10~~	~~30~~	~~909~~	~~9~~	~~20~~	~~51~~	~~4.9~~	~~11.6~~
11	30	910	10	20	50	0.0	0.0

12	30	911	11	20	53	0.0	14.4
~~13~~	~~30~~	~~912~~	~~12~~	~~20~~	~~53~~	~~0.0~~	~~18.5~~
14	30	913	13	20	53	19.0	21.4
15	30	914	14	20	54	0.0	0.0
~~16~~	~~30~~	~~915~~	~~15~~	~~20~~	~~54~~	~~0.0~~	~~.4~~
17	30	916	16	20	54	0.0	.4
18	30	917	17	20	55	0.0	.9
~~19~~	~~30~~	~~918~~	~~18~~	~~20~~	~~56~~	~~0.0~~	~~.1~~
20	30	919	19	20	57	0.0	.2
21	30	920	20	20	57	0.0	1.9
~~22~~	~~30~~	~~921~~	~~21~~	~~20~~	~~57~~	~~0.0~~	~~19.3~~
23	30	922	22	20	59	2.5	6.3
24	30	923	23	20	59	31.2	109.4
~~25~~	~~30~~	~~924~~	~~24~~	~~20~~	~~59~~	~~0.0~~	~~4.7~~
26	30	925	25	20	2	0.0	10.0
27	30	926	26	20	2	0.0	6.2
~~28~~	~~30~~	~~927~~	~~27~~	~~20~~	~~1~~	~~0.0~~	~~25.8~~
29	30	928	28	20	1	10.6	56.4
30	30	929	29	20	1	0.0	.9
~~31~~	~~30~~	~~930~~	~~30~~	~~20~~	~~0~~	~~0.0~~	~~0.0~~
1	31	931	0	21	52	0.0	0.0
2	31	932	1	21	52	0.0	3.8
~~3~~	~~31~~	~~933~~	~~2~~	~~21~~	~~52~~	~~0.0~~	~~5.9~~
4	31	934	3	21	52	105.5	118.3
5	31	935	4	21	51	0.0	5.1
~~6~~	~~31~~	~~936~~	~~5~~	~~21~~	~~51~~	~~0.0~~	~~.7~~
7	31	937	6	21	51	0.0	.5
8	31	938	7	21	51	0.0	3.0
~~9~~	~~31~~	~~939~~	~~8~~	~~21~~	~~51~~	~~0.0~~	~~.3~~
10	31	940	9	21	50	0.0	6.1
11	31	941	10	21	50	0.0	7.7
~~12~~	~~31~~	~~942~~	~~11~~	~~21~~	~~50~~	~~0.0~~	~~1.1~~
13	31	943	12	21	50	0.0	2.5
14	31	944	13	21	50	0.0	.1
~~15~~	~~31~~	~~945~~	~~14~~	~~21~~	~~54~~	~~0.0~~	~~.5~~
16	31	946	15	21	55	1058.4	1060.8
17	31	947	16	21	54	425.7	427.2
~~18~~	~~31~~	~~948~~	~~17~~	~~21~~	~~54~~	~~0.0~~	~~2.4~~
19	31	949	18	21	54	0.0	.2
20	31	950	19	21	59	0.0	1.2
~~21~~	~~31~~	~~951~~	~~20~~	~~21~~	~~59~~	~~0.0~~	~~.4~~
22	31	952	21	21	59	0.0	0.0
23	31	953	22	21	59	0.0	4.5
~~24~~	~~31~~	~~954~~	~~23~~	~~21~~	~~59~~	~~45.2~~	~~127.4~~
25	31	955	24	21	59	0.0	8.8
25	31	956	25	21	59	0.0	1.3
~~27~~	~~31~~	~~957~~	~~26~~	~~21~~	~~2~~	~~0.0~~	~~.3~~
28	31	958	27	21	1	0.0	21.3
29	31	959	28	21	1	0.0	12.6
~~30~~	~~31~~	~~960~~	~~29~~	~~21~~	~~1~~	~~0.0~~	~~.8~~
31	31	961	30	21	60	0.0	0.0
1	32	962	0	22	52	0.0	0.0
~~2~~	~~32~~	~~963~~	~~1~~	~~22~~	~~52~~	~~0.0~~	~~2.6~~
3	32	964	2	22	52	0.0	1.7
4	32	965	3	22	52	0.0	1.5
~~5~~	~~32~~	~~966~~	~~4~~	~~22~~	~~52~~	~~0.0~~	~~4.7~~
6	32	967	5	22	51	0.0	10.7
7	32	968	6	22	51	0.0	21.1
~~8~~	~~32~~	~~969~~	~~7~~	~~22~~	~~50~~	~~0.0~~	~~2.9~~
9	32	970	8	22	50	67.7	75.1
10	32	971	9	22	50	24.6	45.8
~~11~~	~~32~~	~~972~~	~~10~~	~~22~~	~~50~~	~~0.0~~	~~3.7~~
12	32	973	11	22	50	0.0	.5
13	32	974	12	22	50	0.0	.2
~~14~~	~~32~~	~~975~~	~~13~~	~~22~~	~~54~~	~~0.0~~	~~0.0~~
15	32	976	14	22	54	0.0	0.0

16	32	977	15	22	54	0.0	0.0
17	32	978	16	22	54	0.0	0.0
18	32	979	17	22	54	0.0	0.0
19	32	980	18	22	60	0.0	0.0
20	32	981	19	22	59	0.0	0.0
21	32	982	20	22	58	0.0	0.0
22	32	983	21	22	60	0.0	.5
23	32	984	22	22	60	0.0	0.0
24	32	985	23	22	59	0.0	2.8
25	32	986	24	22	59	4.6	10.9
26	32	987	25	22	59	5.8	9.3
27	32	988	26	22	1	0.0	.4
28	32	989	27	22	1	0.0	.8
29	32	990	28	22	1	0.0	9.3
30	32	991	29	22	60	0.0	0.0
31	32	992	30	22	60	0.0	0.0
1	33	993	0	23	52	0.0	0.0
2	33	994	1	23	52	0.0	1.8
3	33	995	2	23	52	0.0	1.2
4	33	996	3	23	52	0.0	.5
5	33	997	4	23	52	0.0	7.7
6	33	998	5	23	52	0.0	13.6
7	33	999	6	23	52	0.0	.1
8	33	1000	7	23	50	0.0	0.0
9	33	1001	8	23	50	0.0	2.5
10	33	1002	9	23	54	0.0	0.0
11	33	1003	10	23	54	0.0	0.0
12	33	1004	11	23	54	0.0	0.0
13	33	1005	12	23	54	0.0	0.0
14	33	1006	13	23	54	0.0	.2
15	33	1007	14	23	54	0.0	0.0
16	33	1008	15	23	54	0.0	0.0
17	33	1009	16	23	54	0.0	0.0
18	33	1010	17	23	60	0.0	.1
19	33	1011	18	23	60	0.0	0.0
20	33	1012	19	23	58	0.0	0.0
21	33	1013	20	23	58	0.0	0.0
22	33	1014	21	23	60	0.0	0.0
23	33	1015	22	23	60	0.0	0.0
24	33	1016	23	23	60	0.0	.8
25	33	1017	24	23	60	0.0	0.0
26	33	1018	25	23	60	0.0	26.2
27	33	1019	26	23	60	0.0	.8
28	33	1020	27	23	1	0.0	3.5
29	33	1021	28	23	1	0.0	8.6
30	33	1022	29	23	60	0.0	0.0
31	33	1023	30	23	60	0.0	0.0
1	34	1024	0	24	52	0.0	0.0
2	34	1025	1	24	52	0.0	2.2
3	34	1026	2	24	52	0.0	.4
4	34	1027	3	24	52	0.0	.2
5	34	1028	4	24	52	31.0	34.1
6	34	1029	5	24	52	10.9	20.6
7	34	1030	6	24	53	19.9	20.2
8	34	1031	7	24	53	0.0	0.0
9	34	1032	8	24	54	0.0	0.0
10	34	1033	9	24	54	0.0	0.0
11	34	1034	10	24	54	0.0	0.0
12	34	1035	11	24	54	0.0	0.0
13	34	1036	12	24	54	0.0	0.0
14	34	1037	13	24	54	0.0	0.0
15	34	1038	14	24	54	0.0	0.0
16	34	1039	15	24	54	0.0	0.0
17	34	1040	16	24	54	0.0	0.0
18	34	1041	17	24	60	581.2	583.0
19	34	1042	18	24	60	0.0	.3

20	34	1043	19	24	60	0.0	1.3
21	34	1044	20	24	60	0.0	0.0
22	34	1045	21	24	60	0.0	0.0
23	34	1046	22	24	60	0.0	0.0
24	34	1047	23	24	60	0.0	0.0
25	34	1048	24	24	60	0.0	0.0
26	34	1049	25	24	60	0.0	0.0
27	34	1050	26	24	60	0.0	1.7
28	34	1051	27	24	60	0.0	0.0
29	34	1052	28	24	60	0.0	0.0
30	34	1053	29	24	60	0.0	0.0
31	34	1054	30	24	60	0.0	0.0
1	35	1055	4	25	52	0.0	0.0
2	35	1056	1	25	52	0.0	1.1
3	35	1057	2	25	52	0.0	.3
4	35	1058	3	25	52	0.0	1.0
5	35	1059	4	25	52	0.0	1.2
6	35	1060	5	25	53	0.0	0.0
7	35	1061	6	25	53	0.0	0.0
8	35	1062	7	25	53	0.0	0.0
9	35	1063	8	25	54	0.0	0.0
10	35	1064	9	25	54	0.0	0.0
11	35	1065	10	25	54	0.0	0.0
12	35	1066	11	25	54	0.0	0.0
13	35	1067	12	25	54	0.0	0.0
14	35	1068	13	25	54	0.0	0.0
15	35	1069	14	25	54	0.0	0.0
16	35	1070	15	25	54	0.0	0.0
17	35	1071	16	25	54	0.0	0.0
18	35	1072	17	25	60	0.0	.3
19	35	1073	18	25	60	0.0	.4
20	35	1074	19	25	60	0.0	1.0
21	35	1075	20	25	60	0.0	0.0
22	35	1076	21	25	60	0.0	0.0
23	35	1077	22	25	60	0.0	0.0
24	35	1078	23	25	60	0.0	.3
25	35	1079	24	25	60	5.1	10.2
26	35	1080	25	25	60	22.0	24.6
27	35	1081	26	25	60	0.0	.5
28	35	1082	27	25	60	0.0	2.2
29	35	1083	28	25	60	0.0	0.0
30	35	1084	29	25	60	0.0	0.0
31	35	1085	30	25	60	0.0	0.0
1	36	1086	4	26	52	0.0	0.0
2	36	1087	1	26	52	0.0	.2
3	36	1088	2	26	52	0.0	.1
4	36	1089	3	25	52	0.0	0.0
5	36	1090	4	26	54	0.0	0.0
6	36	1091	5	25	54	0.0	0.0
7	36	1092	6	26	54	0.0	0.0
8	36	1093	7	26	54	0.0	0.0
9	36	1094	8	26	54	0.0	0.0
10	36	1095	9	26	54	0.0	0.0
11	36	1096	10	25	54	0.0	0.0
12	36	1097	11	26	54	0.0	0.0
13	36	1098	12	26	54	0.0	0.0
14	36	1099	13	26	54	0.0	0.0
15	36	1100	14	26	54	0.0	0.0
16	36	1101	15	26	54	0.0	0.0
17	36	1102	16	26	54	0.0	0.0
18	36	1103	17	25	60	0.0	0.0
19	36	1104	18	26	60	0.0	0.0
20	36	1105	19	26	60	0.0	0.0
21	36	1106	20	26	60	0.0	0.0
22	36	1107	21	26	60	0.0	0.0
23	36	1108	22	26	60	0.0	0.0
24	36	1109	23	26	60	0.0	0.0
25	36	1110	24	25	60	0.0	0.0
26	36	1111	25	26	60	0.0	0.0
27	36	1112	26	25	60	0.0	0.0
28	36	1113	27	26	60	3.5	10.0
29	36	1114	28	25	60	0.0	.9
30	36	1115	29	26	60	0.0	0.0
31	36	1116	30	25	60	59.6	69.6

AREA 1 ME MAINE

AREA CENTROID (X,Y) = 27.36, 20.79
EMISSION CENTROID = 26.92 19.45

GRID CELLS INCLUDED:

864(26,18) 895(26,19) 896(27,19) 927(27,20) 928(28,20)
929(29,20) 958(27,21) 959(28,21) 960(29,21) 988(26,22)
989(27,22) 990(28,22) 1020(27,23) 1021(28,23)

AREA 2 SA1 NEW HAMPSHIRE SENSITIVE AREA

AREA CENTROID (X,Y) = 25.50, 20.00
EMISSION CENTROID = 25.66 19.40

GRID CELLS INCLUDED:

894(25,19) 925(25,20) 926(26,20) 957(26,21)

AREA 3 VT VERMONT

AREA CENTROID (X,Y) = 24.00, 18.50
EMISSION CENTROID = 24.00 18.29

GRID CELLS INCLUDED:

862(24,18) 893(24,19)

AREA 4 NH SOUTHERN NEW HAMPSHIRE

AREA CENTROID (X,Y) = 24.57, 17.33
EMISSION CENTROID = 24.90 17.28

GRID CELLS INCLUDED:

831(24,17) 832(25,17) 863(25,18)

AREA 5 MA MASSACHUSETTS

AREA CENTROID (X,Y) = 25.57, 16.00
EMISSION CENTROID = 25.80 15.99

GRID CELLS INCLUDED:

771(26,15) 800(24,16) 801(25,16) 802(26,16) 803(27,16)
833(26,17)

AREA 6 RI RHODE ISLAND

AREA CENTROID (X,Y) = 25.00, 15.00
EMISSION CENTROID = 25.00 15.00

GRID CELLS INCLUDED:

770(25,15)

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AREA  7  CN   CONNECTICUT
                                    AREA CENTROID (X,Y) =     24.00, 15.00
                                    EMISSION CENTROID =       24.00  15.00
  GRID CELLS INCLUDED:
    769(24,15)

AREA  8  SA2  ADIRONDACKS SENSITIVE AREA
                                    AREA CENTROID (X,Y) =     22.50, 18.50
                                    EMISSION CENTROID =       22.75  18.54
  GRID CELLS INCLUDED:
    860(22,18)     861(23,18)     891(22,19)     892(23,19)

AREA  9  NY1  WESTERN NEW YORK
                                    AREA CENTROID (X,Y) =     18.20, 16.40
                                    EMISSION CENTROID =       18.54  16.88
  GRID CELLS INCLUDED:
    793(17,16)     794(18,16)     795(19,16)     825(18,17)     826(19,17)

AREA 10  NY2  SOUTHEASTERN NEW YORK
                                    AREA CENTROID (X,Y) =     21.46, 16.69
                                    EMISSION CENTROID =       21.83  16.08
  GRID CELLS INCLUDED:
    767(22,15)     768(23,15)     796(20,16)     797(21,16)     798(22,16)
    799(23,16)     827(20,17)     828(21,17)     829(22,17)     830(23,17)
    858(20,18)     859(21,18)     890(21,19)

AREA 11  NJ   NEW JERSEY
                                    AREA CENTROID (X,Y) =     23.00, 13.00
                                    EMISSION CENTROID =       22.85  13.64
  GRID CELLS INCLUDED:
    674(22,12)     675(23,12)     706(23,13)     737(23,14)     738(24,14)

AREA 12  PA1  SOUTHEASTERN PENNSYLVANIA
                                    AREA CENTROID (X,Y) =     21.67, 13.33
                                    EMISSION CENTROID =       21.83  16.08
  GRID CELLS INCLUDED:
    704(21,13)     705(22,13)     735(22,14)
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AREA 13   PA2   CENTRAL PENNSYLVANIA
                                       AREA CENTROID (X,Y) =      19.85, 14.13
                                       EMISSION CENTROID =        20.00   13.46
   GRID CELLS INCLUDED:
      702(19,13)       703(20,13)       733(19,14)       734(20,14)       735(21,14)
      764(19,15)       765(20,15)       766(21,15)

AREA 14   PA3   WESTERN PENNSYLVANIA
                                       AREA CENTROID (X,Y) =      17.48, 14.20
                                       EMISSION CENTROID =        17.09   13.48
   GRID CELLS INCLUDED:
      700(17,13)       731(17,14)       732(18,14)       762(17,15)       763(18,15)

AREA 15   SA3   PENNSYLVANIA SENSITIVE AREA
                                       AREA CENTROID (X,Y) =      18.00, 12.50
                                       EMISSION CENTROID =        18.00   12.51
   GRID CELLS INCLUDED:
      670(18,12)       701(18,13)

AREA 16   MD    MARYLAND + DC
                                       AREA CENTROID (X,Y) =      20.17, 11.00
                                       EMISSION CENTROID =        19.98   11.11
   GRID CELLS INCLUDED:
      610(20,10)       611(21,10)       641(20,11)       642(21,11)       671(19,12)
      672(20,12)

AREA 17   DE    DELAWARE
                                       AREA CENTROID (X,Y) =      21.67, 11.00
                                       EMISSION CENTROID =        21.34   11.66
   GRID CELLS INCLUDED:
      612(22,10)       643(22,11)       673(21,12)

AREA 18   VA    VIRGINIA
                                       AREA CENTROID (X,Y) =      18.35,  9.06
                                       EMISSION CENTROID =        19.13   8.91
   GRID CELLS INCLUDED:
      543(15, 8)       545(17, 8)       546(18, 8)       547(19, 8)       548(20, 8)
      549(21, 8)       575(16, 9)       576(17, 9)       577(18, 9)       578(19, 9)
      579(20, 9)       580(21, 9)       607(17,10)       608(18,10)       609(19,10)
      639(18,11)       640(19,11)
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AREA 19 WV1 NORTHEASTERN WEST VIRGINIA
AREA CENTROID (X,Y) = 16.57, 11.67
EMISSION CENTROID = 16.26 11.99

GRID CELLS INCLUDED:
638(17,11) 668(16,12) 669(17,12)

AREA 20 WV2 SOUTHWESTERN WEST VIRGINIA
AREA CENTROID (X,Y) = 15.17, 10.00
EMISSION CENTROID = 15.01 10.11

GRID CELLS INCLUDED:
573(14, 9) 574(15, 9) 605(15,10) 606(16,10) 636(15,11)
637(16,11)

AREA 21 KY1 EASTERN KENTUCKY
AREA CENTROID (X,Y) = 11.58, 9.17
EMISSION CENTROID = 10.84 9.87

GRID CELLS INCLUDED:
538(10, 8) 539(11, 8) 540(12, 8) 569(10, 9) 570(11, 9)
571(12, 9) 572(13, 9) 600(10,10) 601(11,10) 602(12,10)
603(13,10) 604(14,10)

AREA 22 KY2 WESTERN KENTUCKY
AREA CENTROID (X,Y) = 8.00, 9.00
EMISSION CENTROID = 8.11 9.00

GRID CELLS INCLUDED:
566(7, 9) 567(8, 9) 568(9, 9)

AREA 23 TN1 WESTERN TENNESSEE
AREA CENTROID (X,Y) = 5.89, 6.78
EMISSION CENTROID = 7.52 7.17

GRID CELLS INCLUDED:
471(5, 6) 472(6, 6) 473(7, 6) 474(8, 6) 503(6, 7)
504(7, 7) 505(8, 7) 535(7, 8) 536(8, 8)

AREA 24 TN2 EASTERN TENNESSEE
AREA CENTROID (X,Y) = 10.80, 7.00
EMISSION CENTROID = 11.32 7.42

GRID CELLS INCLUDED:
475(9, 6) 476(10, 6) 477(11, 6) 506(9, 7) 507(10, 7)
508(11, 7) 509(12, 7) 537(9, 8) 541(13, 8) 542(14, 8)

AREA 25 SA4 SOUTHERN APPALACHAIN SENS AREA

AREA CENTROID (X,Y) = 12.83, 6.00
EMISSION CENTROID = 13.14 6.35

GRID CELLS INCLUDED:

447(12, 5)	448(13, 5)	478(12, 6)	479(13, 6)	510(13, 7)
511(14, 7)				

AREA 26 NC1 CENTRAL NORTH CAROLINA

AREA CENTROID (X,Y) = 15.20, 6.80
EMISSION CENTROID = 15.48 7.12

GRID CELLS INCLUDED:

480(14, 6)	481(15, 6)	512(15, 7)	513(16, 7)	544(16, 8)

AREA 27 NC2 EASTERN NORTH CAROLINA

AREA CENTROID (X,Y) = 18.34, 5.94
EMISSION CENTROID = 19.28 6.25

GRID CELLS INCLUDED:

423(19, 4)	453(18, 5)	454(19, 5)	455(20, 5)	456(21, 5)
482(16, 6)	483(17, 6)	484(18, 6)	485(19, 6)	486(20, 6)
487(21, 6)	514(17, 7)	515(18, 7)	516(19, 7)	517(20, 7)
518(21, 7)				

AREA 28 SC SOUTH CAROLINA

AREA CENTROID (X,Y) = 16.07, 3.86
EMISSION CENTROID = 15.97 3.96

GRID CELLS INCLUDED:

359(17, 2)	388(15, 3)	389(16, 3)	390(17, 3)	391(18, 3)
418(14, 4)	419(15, 4)	420(16, 4)	421(17, 4)	422(18, 4)
449(14, 5)	450(15, 5)	451(16, 5)	452(17, 5)	

AREA 29 GA1. NORTHWESTERN GEORGIA

AREA CENTROID (X,Y) = 11.40, 3.80
EMISSION CENTROID = 11.68 4.40

GRID CELLS INCLUDED:

384(11, 3)	385(12, 3)	415(11, 4)	416(12, 4)	446(11, 5)

AREA 30 GA2 SOUTHEASTERN GEORGIA

AREA CENTROID (X,Y) = 13.21, 1.42
EMISSION CENTROID = 13.66 1.74

GRID CELLS INCLUDED:

291(11, 0)	292(12, 0)	293(13, 0)	294(14, 0)	295(15, 0)
322(11, 1)	323(12, 1)	324(13, 1)	325(14, 1)	326(15, 1)
353(11, 2)	354(12, 2)	355(13, 2)	356(14, 2)	357(15, 2)
358(16, 2)	386(13, 3)	387(14, 3)	417(13, 4)	

AREA 31 FL1 SOUTHERN FLORIDA

AREA CENTROID (X,Y) = 15.33, -5.89

EMISSION CENTROID = 14.75 -4.57

GRID CELLS INCLUDED:

16(15,-9)	47(15,-8)	48(16,-8)	78(15,-7)	79(16,-7)
80(17,-7)	108(14,-6)	109(15,-6)	110(16,-6)	111(17,-6)
139(14,-5)	140(15,-5)	141(16,-5)	142(17,-5)	169(13,-4)
170(14,-4)	171(15,-4)	172(16,-4)		

AREA 32 FL2 NORTHERN FLORIDA

AREA CENTROID (X,Y) = 15.17, -2.33

EMISSION CENTROID = 14.81 -2.57

GRID CELLS INCLUDED:

201(14,-3)	202(15,-3)	203(16,-3)	233(15,-2)	234(16,-2)
264(15,-1)				

AREA 33 SA5 FLORIDA SENSITIVE AREA

AREA CENTROID (X,Y) = 13.50, -1.50

EMISSION CENTROID = 13.61 -1.52

GRID CELLS INCLUDED:

231(13,-2)	232(14,-2)	262(13,-1)	263(14,-1)

AREA 34 FL3 WESTERN FLORIDA

AREA CENTROID (X,Y) = 9.80, -.90

EMISSION CENTROID = 8.38 -.81

GRID CELLS INCLUDED:

228(10,-2)	229(11,-2)	257(8,-1)	258(9,-1)	259(10,-1)
260(11,-1)	261(12,-1)	288(8, 0)	289(9, 0)	290(10, 0)

AREA 35 AL ALABAMA

AREA CENTROID (X,Y) = 9.67, 2.67

EMISSION CENTROID = 8.51 3.64

GRID CELLS INCLUDED:

287(7, 0)	318(7, 1)	319(8, 1)	320(9, 1)	321(10, 1)
349(7, 2)	350(8, 2)	351(9, 2)	352(10, 2)	381(8, 3)
382(9, 3)	383(10, 3)	412(8, 4)	413(9, 4)	414(10, 4)
443(8, 5)	444(9, 5)	445(10, 5)		

AREA 36 MS MISSISSIPPI

AREA CENTROID (X,Y) = 5.30, 2.65
EMISSION CENTROID = 6.24 2.28

GRID CELLS INCLUDED:

285(5, 0)	286(6, 0)	314(3, 1)	315(4, 1)	316(5, 1)
317(6, 1)	346(4, 2)	347(5, 2)	348(6, 2)	377(4, 3)
378(5, 3)	379(6, 3)	380(7, 3)	408(4, 4)	409(5, 4)
410(6, 4)	411(7, 4)	440(5, 5)	441(6, 5)	442(7, 5)

AREA 37 LA LOUISIANA

AREA CENTROID (X,Y) = 2.20, .44
EMISSION CENTROID = 3.41 .20

GRID CELLS INCLUDED:

222(4,-2)	223(5,-2)	224(6,-2)	249(0,-1)	250(1,-1)
251(2,-1)	252(3,-1)	253(4,-1)	254(5,-1)	280(0, 0)
281(1, 0)	282(2, 0)	283(3, 0)	284(4, 0)	311(0, 1)
312(1, 1)	313(2, 1)	342(0, 2)	343(1, 2)	344(2, 2)
345(3, 2)	373(0, 3)	374(1, 3)	375(2, 3)	376(3, 3)

AREA 38 AR ARKANSAS

AREA CENTROID (X,Y) = 1.35, 5.85
EMISSION CENTROID = 3.63 5.24

GRID CELLS INCLUDED:

404(0, 4)	405(1, 4)	406(2, 4)	407(3, 4)	435(0, 5)
436(1, 5)	437(2, 5)	438(3, 5)	439(4, 5)	466(0, 6)
467(1, 6)	469(3, 6)	470(4, 6)	497(0, 7)	498(1, 7)
501(4, 7)	502(5, 7)	528(0, 8)	529(1, 8)	532(4, 8)

AREA 39 SAS ARKANSAS SENSITIVE AREA

AREA CENTROID (X,Y) = 2.40, 7.20
EMISSION CENTROID = 2.46 6.66

GRID CELLS INCLUDED:

468(2, 6)	499(2, 7)	500(3, 7)	530(2, 8)	531(3, 8)

AREA 40 MO MISSOURI

AREA CENTROID (X,Y) = 2.58, 11.06
EMISSION CENTROID = 3.39 11.10

GRID CELLS INCLUDED:

533(5, 8)	534(6, 8)	559(0, 9)	560(1, 9)	561(2, 9)
562(3, 9)	563(4, 9)	564(5, 9)	565(6, 9)	590(0,10)
591(1,10)	592(2,10)	593(3,10)	594(4,10)	595(5,10)
621(0,11)	622(1,11)	623(2,11)	624(3,11)	625(4,11)
626(5,11)	652(0,12)	653(1,12)	654(2,12)	655(3,12)
656(4,12)	657(5,12)	683(0,13)	684(1,13)	685(2,13)
686(3,13)	687(4,13)	714(0,14)	715(1,14)	716(2,14)
717(3,14)				

AREA 41 IA IOWA

AREA CENTROID (X,Y) = 2.73, 16.30
EMISSION CENTROID = 3.56 16.10

GRID CELLS INCLUDED:

718(4,14)	719(5,14)	745(0,15)	746(1,15)	747(2,15)
748(3,15)	749(4,15)	750(5,15)	776(0,16)	777(1,16)
778(2,16)	779(3,16)	780(4,16)	781(5,16)	782(6,16)
807(0,17)	808(1,17)	809(2,17)	810(3,17)	811(4,17)
812(5,17)	838(0,18)	839(1,18)	840(2,18)	841(3,18)
842(4,18)	843(5,18)			

AREA 42 IL1 SOUTHERN ILLINOIS

AREA CENTROID (X,Y) = 6.44, 11.44
EMISSION CENTROID = 6.31 11.15

GRID CELLS INCLUDED:

596(6,10)	597(7,10)	627(6,11)	628(7,11)	629(8,11)
658(6,12)	659(7,12)	688(5,13)	689(6,13)	

AREA 43 IL2 NORTHERN ILLINOIS

AREA CENTROID (X,Y) = 7.42, 14.42
EMISSION CENTROID = 6.97 14.43

GRID CELLS INCLUDED:

660(8,12)	690(7,13)	691(8,13)	720(6,14)	721(7,14)
722(8,14)	751(6,15)	752(7,15)	753(8,15)	783(7,16)
784(8,16)	785(9,16)			

AREA 44 IN1 NORTHERN INDIANA

AREA CENTROID (X,Y) = 10.00, 14.00
EMISSION CENTROID = 9.87 14.55

GRID CELLS INCLUDED:

692(9,13)	693(10,13)	694(11,13)	723(9,14)	724(10,14)
725(11,14)	754(9,15)	755(10,15)	756(11,15)	

AREA 45 IN2 SOUTHERN INDIANA

AREA CENTROID (X,Y) = 9.53, 11.13
EMISSION CENTROID = 9.69 11.06

GRID CELLS INCLUDED:

598(8,10)	599(9,10)	630(9,11)	631(10,11)	632(11,11)
661(9,12)	662(10,12)	663(11,12)		

AREA 46 OH1 SOUTHERN OHIO

AREA CENTROID (X,Y) = 14.14, 11.86
EMISSION CENTROID = 14.58 12.7

GRID CELLS INCLUDED:

633(12,11)	634(13,11)	635(14,11)	666(14,12)	667(15,12)
698(15,13)	699(16,13)			

AREA 47 OH2 NORTHEASTERN OHIO

AREA CENTROID (X,Y) = 15.50, 14.50
EMISSION CENTROID = 15.32 14.64

GRID CELLS INCLUDED:

729(15,14)	730(16,14)	760(15,15)	761(16,15)

AREA 48 OH3 NORTHWESTERN OHIO

AREA CENTROID (X,Y) = 12.78, 13.33
EMISSION CENTROID = 13.06 13.67

GRID CELLS INCLUDED:

664(12,12)	665(13,12)	695(12,13)	696(13,13)	697(14,13)
726(12,14)	727(13,14)	728(14,14)	757(12,15)	

AREA 49 MI1 SOUTHERN MICHIGAN

AREA CENTROID (X,Y) = 12.17, 16.67
EMISSION CENTROID = 12.71 16.16

GRID CELLS INCLUDED:

758(13,15)	786(10,16)	787(11,16)	788(12,16)	789(13,16)
817(10,17)	818(11,17)	819(12,17)	820(13,17)	821(14,17)
851(13,18)	852(14,18)			

AREA 50 MI2 NORTHERN MICHIGAN

AREA CENTROID (X,Y) = 10.50, 20.54
EMISSION CENTROID = 10.30 20.87

GRID CELLS INCLUDED:

848(10,18)	849(11,18)	850(12,18)	879(10,19)	880(11,19)
881(12,19)	882(13,19)	910(10,20)	911(11,20)	912(12,20)
913(13,20)	940(9,21)	941(10,21)	942(11,21)	943(12,21)
944(13,21)	969(7,22)	970(8,22)	971(9,22)	972(10,22)
973(11,22)	974(12,22)	1000(7,23)	1001(8,23)	

AREA 51 WI WISCONSIN

AREA CENTROID (X,Y) = 6.34, 19.36
EMISSION CENTROID = 7.36 18.34

GRID CELLS INCLUDED:

813(6,17)	814(7,17)	815(8,17)	816(9,17)	844(6,18)
845(7,18)	846(8,18)	847(9,18)	874(5,19)	875(6,19)
876(7,19)	877(8,19)	878(9,19)	905(5,20)	906(6,20)
907(7,20)	908(8,20)	909(9,20)	935(4,21)	936(5,21)
937(6,21)	938(7,21)	939(8,21)	967(5,22)	968(6,22)

AREA 52 MN MINNESOTA

AREA CENTROID (X,Y) = 2.15, 22.51
EMISSION CENTROID = 3.54 20.91

GRID CELLS INCLUDED:

869(0,19)	870(1,19)	871(2,19)	872(3,19)	873(4,19)
900(0,20)	901(1,20)	902(2,20)	903(3,20)	904(4,20)
931(0,21)	932(1,21)	933(2,21)	934(3,21)	962(0,22)
963(1,22)	964(2,22)	965(3,22)	966(4,22)	993(0,23)
994(1,23)	995(2,23)	996(3,23)	997(4,23)	998(5,23)
999(6,23)	1024(0,24)	1025(1,24)	1026(2,24)	1027(3,24)
1028(4,24)	1029(5,24)	1055(0,25)	1056(1,25)	1057(2,25)
1058(3,25)	1059(4,25)	1086(0,26)	1087(1,25)	1088(2,26)
1089(3,26)				

AREA 53 SA7 BOUNDARY WATERS SENS AREA

AREA CENTROID (X,Y) = 6.20, 24.60
EMISSION CENTROID = 6.00 24.60

GRID CELLS INCLUDED:

1030(6,24)	1031(7,24)	1060(5,25)	1061(6,25)	1062(7,25)

```
AREA 54  ON1  CENTRAL ONTARIO
                                       AREA CENTROID (X,Y) =    12.52, 23.57
                                       EMISSION CENTROID =      16.00  20.77
  GRID CELLS INCLUDED:
     883(14,19)     884(15,19)     885(16,19)     914(14,20)     915(15,20)
     916(16,20)     945(14,21)     946(15,21)     947(16,21)     948(17,21)
     949(18,21)     975(13,22)     976(14,22)     978(15,22)     979(17,22)
    1002( 9,23)    1003(10,23)    1004(11,23)    1005(12,23)    1006(13,23)
    1007(14,23)    1008(15,23)    1009(16,23)    1032( 8,24)    1033( 9,24)
    1034(10,24)    1035(11,24)    1036(12,24)    1037(13,24)    1038(14,24)
    1039(15,24)    1040(16,24)    1063( 8,25)    1064( 9,25)    1065(10,25)
    1066(11,25)    1067(12,25)    1068(13,25)    1069(14,25)    1070(15,25)
    1071(16,25)    1090( 4,26)    1091( 5,26)    1092( 6,26)    1093( 7,26)
    1094( 8,26)    1095( 9,26)    1096(10,26)    1097(11,26)    1098(12,26)
    1099(13,26)    1100(14,26)    1101(15,26)    1102(16,26)

AREA 55  ON2  SUDBURY SOURCE AREA
                                       AREA CENTROID (X,Y) =    15.00, 21.00
                                       EMISSION CENTROID =      15.00  21.00
  GRID CELLS INCLUDED:
     977(15,22)

AREA 56  SA8  ONTARIO SENSITIVE AREA
                                       AREA CENTROID (X,Y) =    17.50, 19.50
                                       EMISSION CENTROID =      17.34  19.12
  GRID CELLS INCLUDED:
     886(17,19)     887(18,19)     917(17,20)     918(18,20)

AREA 57  ON3  SOUTHERN ONTARIO
                                       AREA CENTROID (X,Y) =    17.12, 17.76
                                       EMISSION CENTROID =      16.25  17.37
  GRID CELLS INCLUDED:
     759(14,15)     790(14,16)     791(15,16)     792(16,16)     822(15,17)
     823(16,17)     824(17,17)     853(15,18)     854(16,18)     855(17,18)
     856(18,18)     857(19,18)     888(19,19)     889(20,19)     919(19,20)
     920(20,20)     921(21,20)

AREA 58  SA9  QUEBEC SENSITIVE AREA
                                       AREA CENTROID (X,Y) =    19.50, 22.50
                                       EMISSION CENTROID =      19.50  22.50
  GRID CELLS INCLUDED:
     981(19,22)     982(20,22)    1012(19,23)    1013(20,23)
```

AREA 59 QE1 SOUTHERN QUEBEC

AREA CENTROID (X,Y) = 22.69, 21.00
EMISSION CENTROID = 23.18 24.66

GRID CELLS INCLUDED:

922(22,20)	923(23,20)	924(24,20)	950(19,21)	951(20,21)
952(21,21)	953(22,21)	954(23,21)	955(24,21)	956(25,21)
985(23,22)	986(24,22)	987(25,22)		

AREA 60 QE2 CENTRAL QUEBEC

AREA CENTROID (X,Y) = 23.66, 24.33
EMISSION CENTROID = 19.12 24.13

GRID CELLS INCLUDED:

961(30,21)	980(18,22)	983(21,22)	984(22,22)	991(29,22)
992(30,22)	1010(17,23)	1011(18,23)	1014(21,23)	1015(22,23)
1016(23,23)	1017(24,23)	1018(25,23)	1019(26,23)	1022(29,23)
1023(30,23)	1041(17,24)	1042(18,24)	1043(19,24)	1044(20,24)
1045(21,24)	1046(22,24)	1047(23,24)	1048(24,24)	1049(25,24)
1050(26,24)	1051(27,24)	1052(28,24)	1053(29,24)	1054(30,24)
1072(17,25)	1073(18,25)	1074(19,25)	1075(20,25)	1076(21,25)
1077(22,25)	1078(23,25)	1079(24,25)	1080(25,25)	1081(26,25)
1082(27,25)	1083(28,25)	1084(29,25)	1085(30,25)	1103(17,26)
1104(18,26)	1105(19,26)	1106(20,26)	1107(21,26)	1108(22,26)
1109(23,26)	1110(24,26)	1111(25,26)	1112(26,25)	1113(27,26)
1114(28,26)	1115(29,26)	1116(30,26)		

1.3 Aggregrated Grid Areas in 11 Canadian Regions

Relationship Between U.S. 63 Areas
and Canadian 11 Regions

Canadian Region Number	Canadian SO_2 Emissions (kT/yr)	SURE Aggregate Areas	Area Number	SURE SO_2 Emissions (kt/yr)	% Difference*
1	1946	MI1	49	2311	
		MI2	50	316	
		Subtotal		2627	
				(2388)	+19
2	3874	IL1	42	1066	
		IL2	43	960	
		IN1	44	751	
		IN2	45	1793	
		Subtotal		4570	
				(4154)	+ 7
3	4762	OH1	46	3014	
		OH2	47	1109	
		OH3	48	636	
		Subtotal		4759	
				(4326)	-10
4	2056	PA1	12	569	
		PA2	13	477	
		PA3	14	1076	
		SA3	15	55	
		Subtotal		2177	
				(1979)	-4
5	2408	NY1	9	307	
		NY2	10	379	
		VT	3	6	
		NH	4	138	
		MA	5	670	
		RI	6	33	
		CN	7	45	
		SA2	8	12	
		NJ	11	692	
		SA1	2	42	
		ME	1	332	
		Subtotal		2656	
				(2415)	0

(continued)

Canadian Region Number	Canadian SO_2 Emissions (kT/yr)	SURE Aggregate Areas	Area Number	SURE SO_2 Emissions (kT/yr)	% Difference*
6	2835	KY1	21	754	
		KY2	22	1055	
		TN1	23	726	
		TN2	24	633	
		SA4	25	73	
		Subtotal		3241	
				(2946)	+4
7	2446	DE	17	131	
		MD	16	428	
		NC1	26	512	
		NC2	27	473	
		VA	18	644	
		WV1	19	1089	
		WV2	20	268	
		Subtotal		3542	
				(3220)	+24
8	7485	SC	28	423	
		GA1	29	621	
		GA2	30	321	
		SA5	33	60	
		FL1	31	648	
		FL2	32	180	
		FL3	34	912	
		AL	35	1209	
		MS	36	501	
		LA	37	614	
		AR	38	67	
		SA6	39	11	
		MO	40	1291	
		IA	41	525	
		WI	51	936	
		MN	52	487	
		SA7	53	20	
		Subtotal		8826	
				(8024)	+7
Total Eastern U.S.	27,812			32,398	
				(29,453)	+6

(continued)

Canadian Region Number	Canadian SO_2 Emissions (kT/yr)	SURE Aggregate Areas	Area Number	SURE SO_2 Emissions (kT/yr)	% Difference*
9	1970	ON1	54	434	
		ON2	55	1061	
		ON3	57	585	
		SA8	56	8	
		Subtotal		2088	
				(1898)	-4
10	1037	QE1	59	287	
		QE2	60	734	
		SA9	58	0	
		Subtotal		1021	
				(928)	-12
11	469	NS	62	--	
		NF	63	--	
		Subtotal		0	
Total Eastern Canada	3,476			3,109	
				(2826)	-23
TOTAL	31,288			35,507	
				(32,279)	+3

$* \frac{\text{US - CAN}}{\text{US}} \times 100$

Number in parenthesis are in units of kT/yr where 1 kT = 1.1 kt

2. Comparison of U. S. SURE, Canadian SURE, and NEDS 1976 on a State Basis

Table. Comparison of U. S. SURE, Canadian SURE, NEDS 1976 on a State Basis

States	SURE Major Point (kt)(1)	SURE Major Point (kt)(2)	SURE Total(kt)	NEDS 1976(kt)
Alabama	939	944	1290	1028
Arkansas	13	13	79	111
Connecticut	39	45	66	92
Dist. Columbia	0	0	0	40
Delaware	65	65	129	166
Florida	605	630	1788	969
Georgia	587	643	916*	710
Illinois	1635	1650	2344	2771
Indiana	1601	1610	2189	1977
Iowa	228	234	535	344
Kentucky	1613	1621	1824	1644
Louisiana	377	391	636	303
Maine	50	49	337	152
Maryland	248	252	352	363
Massachusetts	306	307	666	332
Michigan	1294	1686	2292	1221
Minnesota	339	343	521	349
Mississippi	209	281	447	227
Missouri	975	995	1288	1395
New Hampshire	52	51	169	121
New Jersey	194	214	555	317
New York	383	398	974	1129
North Carolina	645	651	984*	620
Ohio	3310	3423	4533	3342
Pennsylvania	1795	1812	2480	2443
Rhode Island	0	0	43	28
South Carolina	242	246	459	265
Tennessee	1046	1075	1332	1281
Vermont	0	0	7	8
Virginia	261	263	695	403
West Virginia	1086	1099	1349	1211
Wisconsin	512	521	937	674
TOTAL	20,644	21,512	32,216	26,036

(1) Canadian Aggregation
(2) U.S. Aggregation
* Emissions in S. Appalachian sensitive area excluded

3. New U. S. Total and Utility SOx Emissions for the Aggregated Grid Areas in the United States

Table . New U. S. Total and Utility SOx Emissions for the Aggregated Areas in the United States (kt/yr)

Area	Total	Point	UTL	AIRTEST 80	New Total	Area	Total	Point	UTL	AIRTEST 80	New Total
1	332.0	49.3	96.5	25.6	261.3	33	59.6	14.4	25.4	9.1	43.3
2	41.7	0.0	20.7	0.0	21.0	34	911.9	43.3	57.5	184.0	1038.4
3	5.8	0.0	0.2	0.0	5.7	35	1208.4	897.9	822.3	508.3	894.4
4	138.6	51.5	86.9	50.0	101.7	36	500.1	325.9	94.3	230.5	636.3
5	670.7	307.4	410.7	189.1	449.1	37	614.1	391.2	243.0	27.1	398.2
6	33.2	13.1	15.2	2.0	20.0	38	67.6	13.4	28.0	27.1	66.7
7	45.1	31.4	27.4	12.3	30.0	39	10.6	0.0	2.4	0.3	8.5
8	12.1	0.0	0.0	2.6	14.7	40	1291.4	994.8	827.1	1357.9	1822.2
9	307.1	153.7	70.9	166.3	402.5	41	525.3	212.5	334.6	176.2	366.9
10	379.0	166.7	167.9	195.4	406.5	42	1065.5	917.4	858.8	961.1	1167.8
11	693.4	231.6	222.3	267.1	738.2	43	960.3	463.1	463.4	331.3	828.2
12	569.8	291.6	245.7	143.6	467.7	44	752.2	418.4	311.0	281.0	722.2
13	477.2	333.5	332.2	373.7	518.7	45	1794.0	1487.7	1547.5	1530.7	1777.2
14	1075.8	874.1	817.6	692.4	950.6	46	3014.3	2663.8	2626.6	2391.0	2778.7
15	55.3	30.4	13.4	2.0	43.9	47	1109.5	643.7	435.3	325.5	999.7
16	428.5	254.5	284.6	243.6	387.5	48	636.6	264.7	278.0	169.8	528.4
17	130.6	65.3	40.9	95.0	184.7	49	2311.7	1789.4	437.8	810.1	2684.0
18	644.2	231.1	172.7	211.3	682.8	50	316.5	173.5	6.7	31.2	341.0
19	1086.9	1019.5	1025.5	1039.0	1100.4	51	936.0	526.1	552.2	494.4	878.2
20	268.5	153.8	137.2	108.9	240.2	52	487.8	322.7	356.1	178.9	310.6
21	754.5	583.3	544.5	619.9	829.9	53	20.2	19.9	2.9	0.0	17.3
22	1054.3	1026.4	1026.9	838.2	865.6	54	433.8	425.7	0.0	0.0	433.8
23	727.0	629.5	600.1	724.9	851.8	55	1060.8	1058.4	0.0	0.0	1060.8
24	633.3	461.5	419.0	342.5	556.8	56	8.2	0.0	0.0	0.0	8.2
25	72.7	16.1	0.8	0.0	71.9	57	587.5	372.6	348.3	0.0	239.2
26	512.7	380.4	385.2	283.1	410.6	58	0.0	0.0	0.0	0.0	0.0
27	473.3	261.2	216.1	45.5	302.7	59	287.7	89.3	0.0	0.0	287.7
28	423.2	246.3	215.9	225.6	432.9	60	734.2	686.4	0.0	0.0	34.2
29	620.7	537.8	554.4	500.5	566.8	61					
30	321.4	115.9	139.4	65.5	247.5	62					
31	648.1	435.1	456.4	420.1	611.8	63					
32	179.8	126.2	127.5	151.8	204.1	TOTALS	35,504.6	24,293.9	19,533.9	18,063.0	33,147.6

NEW TOTAL = Total - UTL + AIRTEST 80

SENSITIVE AREA EMISSION RATES FOR SO2(IN KILOTONS)

AREA	AREA SOURCES INDUSTRIAL	UTILITY	COMMERCIAL	TRANSPORTATION	RESIDENTIAL	MAJOR POINT SOURCES INDUSTRIAL	UTILITY	TOTAL
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	169.8	79.2	25.7	1.4	6.8	32.0	17.3	332.2
2	18.4	20.7	1.7	0.3	0.6	0.0	0.0	41.7
3	1.8	0.2	2.3	0.1	1.4	0.0	0.0	5.9
4	30.2	35.7	16.5	1.5	3.2	0.3	51.2	138.6
5	128.9	103.7	106.1	10.4	12.2	0.4	307.0	670.7
6	12.0	3.4	2.5	0.5	1.7	1.3	11.8	33.2
7	2.9	0.3	0.6	2.6	7.4	4.3	27.1	45.1
8	8.7	0.0	1.1	0.8	1.5	0.0	0.0	12.1
9	124.7	15.0	3.7	7.9	2.1	47.8	55.9	307.1
10	143.3	32.3	9.9	15.7	11.1	31.1	135.6	379.0
11	153.2	26.8	214.6	43.6	23.7	36.1	195.5	693.4
12	158.4	16.5	54.0	29.7	18.7	67.4	229.2	569.6
13	70.3	17.8	21.8	12.6	21.2	19.1	314.4	477.2
14	164.7	5.8	15.5	10.0	5.6	62.2	611.6	1075.6
15	7.3	7.6	3.7	2.3	4.0	24.6	5.8	55.3
16	52.0	71.5	32.9	9.1	9.6	41.4	213.1	428.5
17	36.4	11.3	13.6	1.2	2.7	35.7	29.6	130.5
18	338.6	24.4	60.4	12.6	7.0	82.8	148.3	674.1
19	33.9	26.8	3.3	1.3	2.0	20.8	998.7	1086.8
20	95.9	12.6	2.1	2.0	2.1	29.2	124.6	268.5
21	139.9	12.5	7.7	8.4	2.7	51.3	532.0	754.5
22	24.6	0.5	1.0	1.5	0.3	0.0	1026.4	1054.3
23	88.5	0.9	2.6	5.2	0.4	30.2	599.2	727.0
24	138.1	12.4	9.0	9.2	3.1	54.9	406.6	633.3
25	47.8	0.8	2.6	3.6	1.8	16.1	0.0	72.7
26	112.3	4.9	5.5	5.6	3.9	0.1	380.3	512.7
27	174.3	1.0	19.1	11.8	6.1	46.0	215.1	473.3
28	152.6	8.4	7.9	5.5	2.5	38.8	207.5	423.2
29	46.3	16.6	9.2	8.6	0.3	0.0	537.8	620.7
30	139.9	48.4	8.0	8.9	0.3	24.9	91.0	321.4
31	152.4	28.8	9.7	12.1	0.0	7.5	427.6	696.1
32	23.2	24.0	2.2	4.2	0.0	22.7	103.5	179.8
33	18.9	20.0	4.9	1.4	0.0	9.0	5.4	59.6
34	833.7	28.5	4.4	2.1	0.0	14.3	29.0	911.9
35	260.2	18.6	22.0	9.3	0.3	94.2	603.7	1208.4
36	133.4	34.6	2.4	3.9	0.0	266.2	59.7	500.1
37	197.4	2.7	14.6	8.3	0.0	150.9	240.3	614.1
38	32.3	14.6	3.3	4.0	0.0	0.0	13.4	67.6
39	6.3	2.4	0.9	1.1	0.0	0.0	0.0	10.6
40	154.1	93.6	20.4	15.7	2.7	261.3	733.5	1291.4
41	142.9	153.2	4.3	8.2	4.1	31.1	161.4	525.3
42	85.3	35.0	17.7	8.6	1.6	93.6	623.8	1005.5
43	319.6	80.5	52.6	36.6	1.8	80.2	382.9	960.3
44	189.3	46.5	71.3	20.1	2.7	153.9	264.5	752.2
45	148.9	94.1	52.8	7.8	2.7	34.3	1453.4	1794.0
46	286.2	27.5	21.3	11.4	3.9	64.7	2599.1	3014.3
47	376.9	46.5	20.2	18.0	4.3	254.9	388.8	1109.5
48	198.0	84.3	63.9	20.1	6.5	71.0	193.7	636.6
49	447.1	6.6	27.0	34.6	12.0	1358.2	431.2	2311.7
50	127.2	4.5	2.6	5.0	3.8	171.3	2.2	316.5
51	302.7	68.7	16.2	10.6	11.8	42.6	463.5	936.0
52	73.9	53.7	16.7	10.0	10.9	20.3	302.4	487.6
53	0.0	0.2	0.0	0.0	0.1	17.2	2.7	20.2
54	2.0	0.0	1.4	3.6	1.1	425.7	0.0	433.8

SENSITIVE AREA EMISSION RATES FOR SO2(IN KILOTONS)

AREA	AREA SOURCES INDUSTRIAL	UTILITY	COMMERCIAL	TRANSPORTATION	RESIDENTIAL	MAJOR POINT SOURCES INDUSTRIAL	UTILITY	TOTAL
55	1.0	0.0	0.6	0.4	0.4	1058.4	0.0	1060.8
56	2.1	0.0	1.1	4.1	0.9	0.0	0.0	8.2
57	91.7	0.0	41.0	51.3	30.8	24.3	348.3	587.4
58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
59	95.2	0.0	56.2	17.1	40.0	69.3	0.0	277.7
60	14.7	0.0	14.4	8.4	10.2	686.4	0.0	734.2

4. New Canadian SOx Emissions for the Aggregated Grid Areas in Canada

In Process

5. Primary SOx Emissions for the Aggregated Grid Areas

SENSITIVE AREA EMISSION RATES FOR SO4(IN KILOTONS)

AREA	AREA SOURCES INDUSTRIAL	UTILITY	COMMERCIAL	TRANSPORTATION	RESIDENTIAL	MAJOR POINT SOURCES INDUSTRIAL	UTILITY	TOTAL
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	15.9	7.6	2.2	0.1	0.6	2.2	1.7	30.3
2	2.9	2.0	0.2	0.0	0.1	0.0	0.0	5.1
3	0.2	0.0	0.2	0.0	0.1	0.0	0.0	0.5
4	2.9	3.3	1.6	0.1	0.3	0.0	2.2	10.4
5	12.3	9.0	10.3	0.7	1.2	0.0	29.4	62.9
6	1.2	0.3	0.2	0.0	0.2	0.1	1.1	3.1
7	0.2	0.0	0.1	0.2	0.7	0.3	2.6	4.1
8	0.4	0.0	0.1	0.1	0.1	0.0	0.0	0.7
9	4.9	0.5	0.4	0.5	0.2	2.4	0.8	9.7
10	6.7	0.7	0.9	1.1	1.0	0.5	8.5	19.3
11	11.7	2.0	20.5	3.0	2.2	1.9	12.3	53.5
12	10.5	1.4	4.8	1.4	1.4	4.5	9.1	33.0
13	3.6	0.6	1.4	0.8	0.9	0.3	4.8	12.4
14	2.9	0.1	1.0	0.7	0.1	1.4	12.3	18.5
15	0.1	0.1	0.2	0.2	0.1	0.4	0.1	1.2
16	3.8	3.5	3.1	0.5	0.9	1.4	10.2	23.4
17	2.9	1.1	1.3	0.1	0.2	2.7	0.4	8.7
18	20.6	2.2	4.5	0.8	0.6	3.0	11.9	43.6
19	1.0	0.4	0.1	0.1	0.1	0.3	15.1	17.1
20	2.3	0.2	0.2	0.1	0.1	0.8	1.9	5.5
21	3.1	0.2	0.3	0.5	0.2	1.0	8.1	13.3
22	1.4	0.0	0.0	0.1	0.0	0.0	15.5	17.1
23	4.2	0.0	0.2	0.3	0.0	0.5	9.1	14.3
24	4.5	0.2	0.4	0.6	0.2	1.4	6.2	13.5
25	2.0	0.0	0.1	0.2	0.1	1.0	0.0	3.5
26	6.9	0.2	0.5	0.4	0.3	0.0	5.8	14.0
27	11.8	0.1	1.4	0.8	0.5	5.8	5.6	25.9
28	11.1	0.5	0.3	0.4	0.2	3.4	7.4	23.3
29	2.7	0.5	0.9	0.6	0.0	0.0	8.2	12.9
30	15.7	2.7	0.7	0.6	0.0	3.3	3.6	26.5
31	6.1	2.4	0.9	0.8	0.0	0.1	23.3	33.6
32	1.7	2.0	0.2	0.3	0.0	1.8	9.9	15.8
33	1.5	1.8	0.5	0.1	0.0	0.6	0.5	5.0
34	41.1	2.2	0.4	0.1	0.0	2.4	1.0	47.2
35	14.6	0.6	2.1	0.6	0.0	3.1	11.5	32.4
36	22.8	1.9	0.2	0.2	0.0	20.4	1.7	47.2
37	14.5	0.2	1.4	0.5	0.0	8.4	14.4	39.4
38	2.5	1.3	0.3	0.2	0.0	0.0	1.3	5.6
39	0.4	0.2	0.1	0.1	0.0	0.0	0.0	0.7
40	3.8	3.3	1.0	1.0	0.1	7.9	11.1	28.2
41	6.4	3.2	0.3	0.5	0.3	0.5	2.9	14.0
42	4.1	1.7	0.7	0.6	0.1	4.6	12.7	24.5
43	10.7	1.4	2.1	2.5	0.4	2.5	6.4	25.9
44	8.3	1.4	3.6	1.3	0.4	8.6	5.2	28.8
45	4.4	2.3	2.6	0.5	0.2	0.5	22.0	32.6
46	7.8	0.4	0.7	0.8	0.3	1.8	39.6	51.4
47	9.3	1.0	1.0	1.2	0.3	5.3	6.8	25.0
48	4.7	1.3	1.4	1.4	0.5	1.7	2.9	14.0
49	15.9	0.2	2.3	2.3	0.9	31.5	8.5	61.5
50	3.0	0.1	0.2	0.3	0.3	6.9	0.0	10.5
51	9.3	1.4	0.7	0.7	0.9	0.7	8.5	22.2
52	5.3	1.5	1.1	0.6	1.0	1.3	5.4	16.3
53	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3
54	0.2	0.0	0.1	0.2	0.1	33.4	0.0	34.0

SENSITIVE AREA EMISSION RATES FOR SO4(IN KILOTONS)

AREA	AREA SOURCES INDUSTRIAL	UTILITY	COMMERCIAL	TRANSPORTATION	RESIDENTIAL	MAJOR POINT SOURCES INDUSTRIAL	UTILITY	TOTAL
55	0.1	0.0	0.1	0.0	0.0	63.6	0.0	63.8
56	0.2	0.0	0.1	0.3	0.1	0.0	0.0	0.7
57	7.1	0.0	3.9	3.5	2.9	1.1	9.2	27.7
58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
59	5.0	0.0	4.6	1.1	3.1	6.7	0.0	20.6
60	0.9	0.0	1.2	0.6	0.8	52.5	0.0	55.9

6. NO_x and TEP Emissions for the Aggregated Grid Areas

SENSITIVE AREA EMISSION RATES FOR NO(IN KILOTONS)

AREA	AREA SOURCES INDUSTRIAL	UTILITY	COMMERCIAL	TRANSPORTATION	RESIDENTIAL	MAJOR POINT SOURCES INDUSTRIAL	UTILITY	TOTAL
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	18.3	16.6	4.0	14.7	2.4	4.9	3.5	64.4
2	2.7	3.2	0.3	4.2	0.2	0.0	0.0	10.6
3	0.4	0.1	0.5	1.6	0.5	0.0	0.0	3.0
4	6.6	6.7	4.1	15.9	1.9	0.1	21.5	56.7
5	39.1	61.0	36.7	111.7	9.9	1.5	89.0	348.9
6	4.0	2.3	1.2	4.9	0.8	0.2	8.4	21.9
7	5.1	0.1	3.7	28.3	3.0	1.0	23.9	65.2
8	0.1	0.1	0.3	9.4	0.6	0.0	0.0	10.5
9	3.3	3.9	2.0	92.1	3.5	21.0	9.9	135.7
10	17.4	6.0	3.7	183.4	6.7	4.1	36.2	257.5
11	58.0	21.9	60.1	491.0	16.3	29.7	228.8	905.6
12	74.8	13.7	18.9	226.9	9.3	17.0	74.0	434.7
13	15.4	8.5	5.7	146.2	4.5	2.5	38.7	221.4
14	28.6	0.9	4.9	114.6	3.4	8.8	105.4	266.7
15	3.0	1.2	1.1	27.3	0.8	3.2	0.9	37.5
16	13.6	36.3	10.3	76.2	5.4	21.4	55.7	218.9
17	6.7	4.0	2.5	12.8	1.1	2.4	4.5	36.0
18	68.0	5.9	11.4	137.6	3.1	14.1	39.7	279.7
19	8.1	3.7	0.7	14.3	0.5	3.0	185.9	216.2
20	19.2	3.2	0.9	19.7	0.8	1.3	43.3	88.4
21	30.5	5.1	4.3	86.6	2.3	10.2	67.5	206.5
22	5.6	0.0	0.3	16.5	0.3	0.0	174.7	197.5
23	24.3	0.3	1.3	53.6	0.7	17.3	64.7	162.2
24	30.3	5.1	5.5	98.5	1.3	20.2	95.1	256.1
25	11.6	0.3	2.4	44.1	0.7	4.5	0.0	63.6
26	37.9	1.2	1.2	66.9	1.4	0.3	113.9	222.8
27	47.3	0.9	4.3	139.0	2.4	4.6	57.7	256.1
28	48.7	5.2	2.4	65.9	1.4	10.9	70.6	205.2
29	17.2	0.9	1.3	135.3	1.1	0.0	66.6	192.4
30	29.2	20.1	1.4	109.9	1.0	6.7	25.5	193.7
31	30.2	25.7	2.6	132.4	0.2	12.1	79.1	282.3
32	9.9	2.3	0.8	47.0	0.1	6.7	16.0	82.8
33	5.1	1.6	0.8	16.4	0.0	2.6	2.0	28.5
34	16.4	11.9	1.0	22.9	0.1	7.5	7.6	67.5
35	46.9	6.7	5.1	97.1	1.2	18.7	140.8	306.6
36	43.5	15.1	2.3	43.7	0.6	72.1	18.2	195.6
37	96.1	19.6	4.6	81.7	1.8	75.7	186.3	465.9
38	20.4	14.4	1.8	34.5	0.7	0.0	14.2	86.0
39	4.7	1.6	0.4	9.3	0.2	0.0	0.0	16.2
40	39.0	20.7	10.6	162.0	4.3	8.1	135.2	379.6
41	34.2	31.9	3.4	85.5	3.0	8.9	52.2	219.0
42	16.3	8.4	3.6	92.0	2.1	19.7	188.1	330.1
43	59.4	18.3	20.7	383.6	9.5	15.2	110.9	617.5
44	48.7	6.9	13.9	213.6	6.3	110.3	107.6	507.3
45	34.5	14.4	8.7	84.8	2.6	5.2	205.3	355.5
46	43.3	7.8	4.9	126.5	3.4	20.3	337.2	543.3
47	29.0	5.1	6.6	197.6	5.5	39.1	63.6	346.5
48	41.4	25.7	12.3	225.6	5.6	10.9	24.2	345.7
49	130.0	20.8	12.4	392.7	10.5	208.2	65.0	839.5
50	31.8	6.7	1.1	61.3	1.7	35.5	0.5	138.6
51	75.3	19.8	6.4	118.8	6.2	11.1	89.2	326.9
52	24.8	23.0	7.9	103.6	4.9	3.4	120.5	288.2
53	0.0	0.1	0.0	0.4	0.0	3.3	2.4	6.1
54	0.8	0.0	0.4	47.4	0.2	0.0	0.0	48.8

SENSITIVE AREA EMISSION RATES FOR NO(IN KILOTONS)

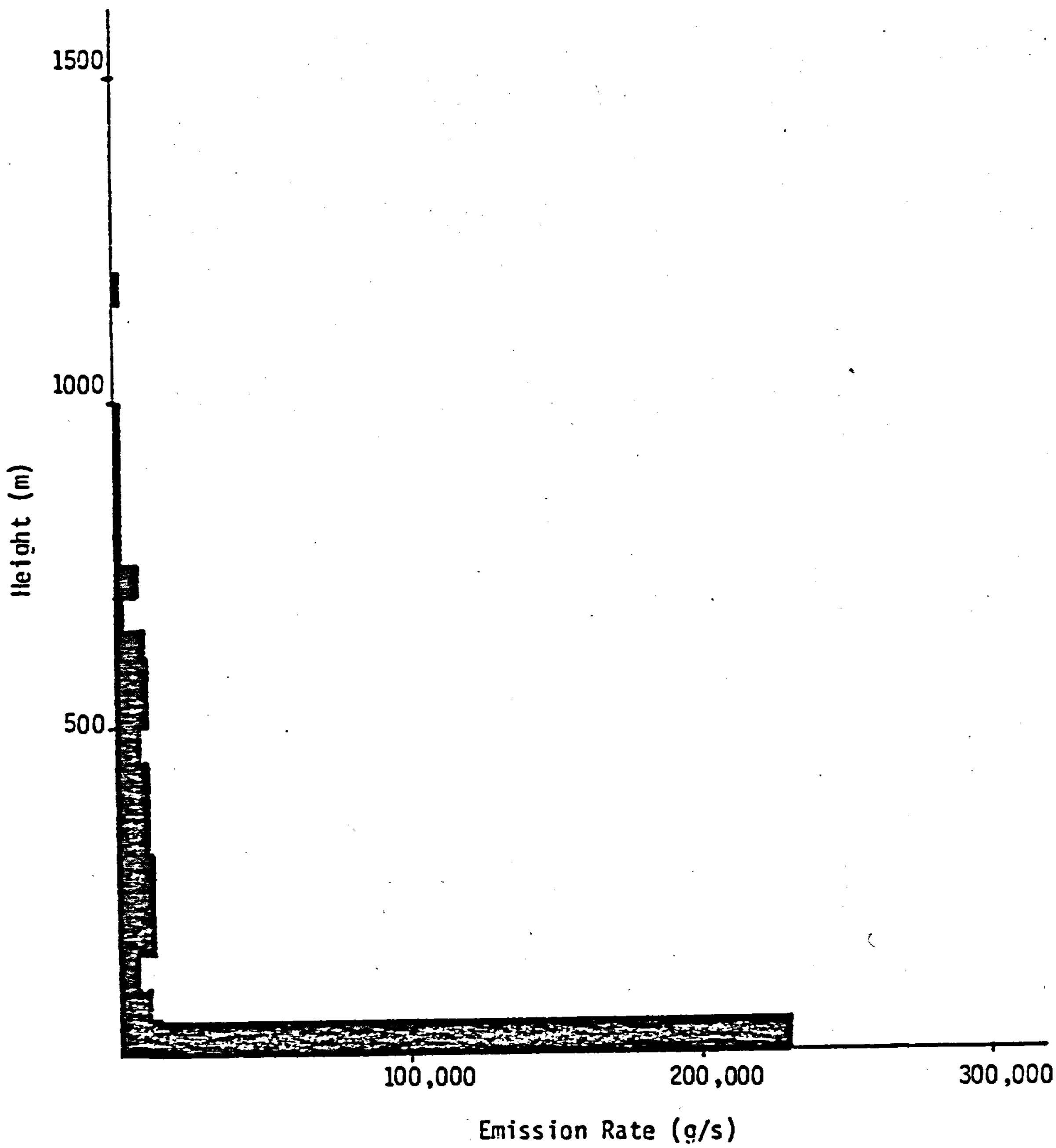
	AREA SOURCES					MAJOR POINT SOURCES		
AREA	INDUSTRIAL	UTILITY	COMMERCIAL	TRANSPORTATION	RESIDENTIAL	INDUSTRIAL	UTILITY	TOTAL
55	0.4	0.0	0.2	4.4	0.1	0.0	0.0	5.0
56	0.7	0.0	0.3	55.7	0.2	0.0	0.0	56.9
57	27.4	0.4	11.6	626.8	6.8	4.1	41.8	719.1
58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
59	24.3	0.0	8.1	193.1	4.2	12.0	0.0	241.7
60	5.1	0.0	2.0	106.7	1.0	5.5	0.0	120.2

SENSITIVE AREA EMISSION RATES FOR NO2(IN KILOTONS)

AREA	AREA SOURCES INDUSTRIAL	UTILITY	COMMERCIAL	TRANSPORTATION	RESIDENTIAL	MAJOR POINT SOURCES INDUSTRIAL	UTILITY	TOTAL
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.6	0.5	0.1	0.0	1.0	0.2	0.1	2.6
2	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.3
3	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.3
4	0.4	0.2	0.1	0.0	0.8	0.0	0.8	2.3
5	1.9	1.9	1.3	0.2	4.1	0.0	2.5	11.6
6	0.2	0.1	0.0	0.0	0.4	0.0	0.2	0.9
7	0.2	0.0	0.1	0.0	1.3	0.0	0.7	2.3
8	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3
9	0.2	0.1	0.1	0.1	1.4	0.8	0.4	3.1
10	0.7	0.2	0.1	0.3	2.7	0.2	1.2	5.4
11	2.8	0.8	2.2	0.8	6.7	3.4	5.8	22.5
12	3.7	0.5	0.8	0.3	3.8	0.7	2.6	12.6
13	1.7	0.3	0.2	0.2	1.8	0.1	1.5	5.6
14	1.6	0.0	0.2	0.2	1.3	0.4	4.1	7.9
15	0.2	0.0	0.0	0.0	0.3	0.1	0.0	0.6
16	0.8	1.0	0.4	0.1	2.2	0.6	1.8	7.0
17	0.4	0.1	0.1	0.0	0.5	0.1	0.2	1.4
18	2.1	0.2	0.4	0.2	1.3	1.1	1.2	6.4
19	0.3	0.1	0.0	0.0	0.2	0.1	7.3	8.2
20	0.8	0.1	0.0	0.0	0.3	0.1	1.7	3.0
21	2.8	0.2	0.2	0.1	0.9	0.4	2.7	7.3
22	0.3	0.0	0.0	0.0	0.1	0.0	6.9	7.3
23	1.2	0.0	0.1	0.1	0.3	0.3	2.7	4.6
24	2.4	0.2	0.3	0.1	0.5	4.0	3.7	11.4
25	1.0	0.0	0.1	0.0	0.3	0.2	0.0	1.6
26	1.9	0.0	0.0	0.1	0.6	0.0	4.5	7.2
27	4.3	0.1	0.2	0.2	1.0	0.2	2.4	8.3
28	3.0	0.3	0.1	0.1	0.6	0.4	2.9	7.3
29	0.9	0.1	0.0	0.1	0.4	0.0	2.9	4.4
30	2.4	1.1	0.0	0.1	0.4	6.2	1.0	11.1
31	1.1	1.2	0.1	0.2	0.1	0.2	3.0	5.9
32	0.4	0.1	0.0	0.1	0.0	0.2	0.5	1.3
33	0.2	0.0	0.0	0.0	0.0	0.3	0.1	0.7
34	1.6	0.6	0.0	0.0	0.0	1.7	0.3	4.3
35	4.9	0.4	0.2	0.1	0.4	2.9	4.9	13.8
36	2.7	0.7	0.1	0.0	0.2	10.3	0.6	14.9
37	4.7	1.1	0.2	0.1	0.7	8.8	10.1	25.6
38	1.6	0.9	0.1	0.0	0.3	0.0	0.7	3.5
39	0.3	0.1	0.0	0.0	0.1	0.0	0.0	0.4
40	10.3	1.1	0.6	0.2	1.7	0.5	6.2	20.5
41	2.8	1.5	0.2	0.0	1.2	0.8	2.4	8.9
42	0.9	0.3	0.1	0.1	0.8	1.5	7.6	10.7
43	9.8	1.0	1.2	0.6	3.7	8.0	4.4	28.7
44	2.8	0.3	0.6	0.3	2.5	6.0	4.5	17.0
45	3.0	0.7	0.4	0.1	1.1	5.1	8.1	18.5
46	4.5	0.5	0.2	0.2	1.3	0.9	13.2	20.6
47	1.5	0.2	0.4	0.3	2.2	2.1	2.5	9.0
48	2.4	1.0	0.6	0.3	2.2	0.5	1.0	7.4
49	6.5	0.3	0.7	0.6	4.1	9.2	3.0	24.5
50	1.7	0.1	0.0	0.1	0.7	2.0	0.0	4.6
51	3.9	1.1	0.3	0.1	2.5	0.5	3.6	12.1
52	1.3	1.0	0.4	0.1	2.0	1.6	4.7	11.1
53	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3
54	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.2

SENSITIVE AREA EMISSION RATES FOR NO2(IN KILOTONS)

	AREA SOURCES					MAJOR POINT SOURCES		
AREA	INDUSTRIAL	UTILITY	COMMERCIAL	TRANSPORTATION	RESIDENTIAL	INDUSTRIAL	UTILITY	TOTAL
55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
56	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.2
57	1.7	0.0	0.8	1.0	2.7	0.6	2.0	8.6
58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
59	1.0	0.0	0.4	0.3	1.7	0.6	0.0	4.0
60	0.2	0.0	0.1	0.2	0.4	0.2	0.0	1.0


1500
1000
500
Height (m)
100,000
200,000
300,000
Emission Rate (g/s)

SENSITIVE AREA EMISSION RATES FOR TEP(IN KILOTONS)

AREA	AREA SOURCES INDUSTRIAL	UTILITY	COMMERCIAL	TRANSPORTATION	RESIDENTIAL	MAJOR POINT SOURCES INDUSTRIAL	UTILITY	TOTAL
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	70.9	5.3	8.9	2.7	0.7	5.2	0.2	93.8
2	38.8	1.5	0.7	0.8	0.1	0.0	0.0	41.9
3	2.9	0.0	1.4	0.3	0.2	0.0	0.0	4.7
4	16.6	4.8	9.3	3.4	0.7	0.1	1.6	36.6
5	104.2	15.9	68.8	24.7	3.2	0.2	5.7	222.7
6	6.2	0.3	1.0	1.0	0.3	0.1	0.7	9.6
7	3.2	0.1	2.4	6.2	1.1	0.4	0.7	13.9
8	18.7	0.0	0.8	1.9	0.2	0.0	0.0	21.6
9	131.3	1.7	3.6	20.2	1.1	3.1	23.6	154.6
10	132.0	5.4	9.0	38.4	2.6	76.0	47.4	310.7
11	153.8	2.5	175.4	110.6	10.8	6.9	18.2	478.1
12	223.6	0.8	39.8	49.0	27.3	110.2	15.6	466.5
13	221.3	6.0	11.6	29.6	75.7	13.3	21.4	378.9
14	192.9	24.3	11.4	23.7	27.2	88.7	113.4	471.6
15	75.5	25.0	1.8	5.4	18.9	14.1	6.2	146.9
16	57.7	12.5	21.3	14.6	4.5	18.4	33.7	162.7
17	19.2	1.0	3.2	2.5	1.3	3.6	0.8	31.6
18	333.7	1.8	30.7	26.7	3.6	21.6	3.7	421.9
19	54.3	3.1	1.5	2.7	7.9	0.1	55.5	122.2
20	242.8	0.4	1.6	3.5	6.3	0.4	4.5	259.4
21	519.2	13.6	5.3	16.2	4.5	352.2	38.3	949.3
22	200.5	0.0	0.7	3.1	0.8	103.5	25.0	333.6
23	138.4	0.1	1.8	10.4	0.5	2.9	8.3	162.5
24	299.2	4.2	6.2	19.2	4.5	45.3	89.8	468.2
25	45.3	0.4	2.7	8.4	1.8	31.0	0.0	69.7
26	133.7	3.2	2.5	12.9	3.2	0.0	101.7	257.3
27	204.1	0.1	6.1	27.1	3.9	28.5	30.4	300.3
28	95.2	12.3	2.6	12.6	1.4	66.8	75.2	266.0
29	29.9	1.8	6.9	22.0	6.9	0.0	81.0	142.4
30	119.9	15.9	4.8	22.2	0.4	4.4	10.4	178.0
31	73.2	2.9	5.5	28.2	0.0	3.3	16.0	129.3
32	16.4	2.0	1.7	9.8	0.0	32.2	5.0	67.0
33	8.4	1.9	1.0	3.3	0.0	0.4	0.5	15.5
34	22.9	10.7	1.1	4.5	0.0	4.4	1.1	44.7
35	180.0	3.5	9.2	16.1	0.9	43.3	204.2	457.2
36	294.4	2.6	2.4	8.0	0.1	51.0	1.9	360.4
37	126.5	1.7	11.8	15.2	0.4	76.5	14.9	247.0
38	233.3	3.6	2.8	5.9	0.2	0.0	1.0	246.8
39	37.2	0.2	0.7	1.6	0.0	0.0	0.0	39.7
40	495.5	21.6	8.5	31.9	3.0	22.5	24.9	597.6
41	535.0	32.3	3.3	15.8	3.0	56.2	32.8	678.4
42	185.3	4.5	10.0	18.6	3.1	37.3	16.1	274.6
43	488.9	27.3	49.7	82.0	15.0	148.1	18.4	829.5
44	258.5	14.3	34.3	44.4	9.2	227.7	14.4	602.9
45	190.9	23.1	22.4	16.7	0.9	32.6	111.4	318.0
46	249.0	14.1	11.5	25.8	5.9	230.0	163.8	700.1
47	330.3	16.6	9.4	42.0	7.1	145.7	27.5	578.6
48	225.4	81.9	44.9	46.7	1.7	132.5	12.0	545.2
49	245.9	4.2	16.3	84.8	18.3	411.4	53.4	834.4
50	61.8	0.9	1.4	12.3	2.8	58.7	0.1	138.1
51	256.0	24.0	10.2	23.3	10.2	33.3	41.1	398.1
52	223.6	16.7	8.1	20.1	1.5	84.7	15.6	370.6
53	0.0	0.5	0.0	0.1	0.0	17.5	1.6	19.7
54	0.7	0.0	0.2	9.4	0.1	9.7	0.0	20.0

SENSITIVE AREA EMISSION RATES FOR TEF(IN KILOTONS)

	AREA SOURCES					MAJOR POINT SOURCES		
AREA	INDUSTRIAL	UTILITY	COMMERCIAL	TRANSPORTATION	RESIDENTIAL	INDUSTRIAL	UTILITY	TOTAL
55	0.3	0.0	0.1	0.9	0.0	7.5	0.0	8.8
56	0.5	0.0	0.1	11.0	0.0	0.0	0.0	11.6
57	294.4	0.7	5.5	127.1	1.8	11.2	7.9	448.6
58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
59	926.6	0.0	5.6	38.5	0.9	11.7	0.0	983.4
60	9.9	0.0	1.4	21.0	0.2	35.9	0.0	68.4

7. Listing of Historical and Current Emissions by State and County

The Phase I report of work Group III B contains sections on historical, current, and projected emissions in the eastern United States and Canada. Some of the historical and current emissions data from that report is included in this addendum for the convenience of the modelers.

The primary objective in developing historical emission trends is to recreate the emissions situations of several decades ago so that such data can be used in atmospheric models to provide an insight into sulfur deposition rates for those periods. These rates can then be compared to current deposition rates for an indication of the rate of degradation of the environment with time.

To examine emission trends on a regional basis in the United States, a data file has been constructd which also uses historical fuel usage fiqures to calculate emissions of SO_2 and NO_x from various categories of sources. The basis file contains emissions at the individual state level for the following source categories:

- Electric Utilities
- Industrial
- Commerical/Residential
- Pipelines
- Highway Vehicles
  - Gasoline-Powered
  - Diesel-Powered
- Miscellaneous
  - Railroads
  - Vessel
  - Misc. Off-Highway Mobile
  - Chemicals
  - Primary Metals
  - Mineral Products
  - Petroleum Refineries
  - Others

The file currently contains data for 33 eastern states plus the District of Columbia. Years on record for the file are 1950, 1960, 1965, 1970, 1975, and 1978.

For the electric utility sector, all power plants greater than 25 megawatts have been identified and located by the appropriate county within each state for each year of record. Emissions of SO_2 and NO_x have been determined for each year for all such power plants. Consequently, it is possible to identify power plants emissions on a county-by-county level for each year of record for all 33 states.

The file identifies each power plant by name, size, county location, and SO_2 and NO_x emissions from coal, oil, and natural gas consumption. The file also contains fuel usage information and has some limited data on stack height.

To distribute the non-power plant emissions to a county level, work is underway using historical census data to assign the statewide emissions to the county level. The technique to be used is to apportion the emissions to the county base on a historical population basis. The Brookhaven National Laboratory is currently conducting this work. A partial file is currently available from Carmen Benkovitz and it is expected that EPA/OAQPS will complete this file for Work Group 2. A paper describing the methodology is currently being prepared by a contractor for EPA/OAQPS.

As an example of the information from this file, a sample state and county are provided.

To assist in examining the historical emission trends on a regional scale, tables have been prepared in which the states are grouped according to the appropriate EPA regional offices (Regions I through V). Trends in SO_x and NO_x emissions for each state along with a summary for each grouping of the states (by regional office) are shown in the tables.

The current emission rates reported here for the United States are based on estimates of actual rates for numerous sectors of the economy. The values used in this summary are taken from National Air Pollution Emission Estimates (U.S. Environmental Protection Agency). Basically, the methodology for deriving these estimates used an inventory of sources, determinations of fuel consumption, and air pollution emission factors.

The inventory of sources, and associated fuel consumption rates, were taken from the National Emissions Data System (NEDS). The data in NEDS were provided by State agencies as an inventory of sources for each state. NEDS is constantly being updated and the version used here reflects values for 1978. However, NEDS is not complete and some source categories are more accurate than others. Estimates of the accuracy of this information are unavailable at this time.

The emissions factors used in developing these emission estimates are from the U.S. EPA report AP-42. The emission factor is an average estimate of the rate at which a pollutant is released to the atmosphere as a result of some activity. The emission factors are estimates based on source testing, process material balances, and engineering apparaisals. As a result, some emission factors are more accurate than others. In general, the emission factors are more ofter applied to regional or national emission estimates, than to single source estimates where the inaccuracies would be considerable.

SO_2 and NO_x emissions are shown on a state-by-state basis in the table. Only 33 states are represented in the table. Data for the 15 Western States and Alaska and Hawaii are unavailable at this time. The values in table represent 80% of the SO_2 and 76% of the NO_x emissions for the entire United States.

The emissions estimates can be further disaggregated to show emissions by source category for each state.

SO_x Emissions in 1000's of Tons

State of Kentucky

	1950	1955	1960	1965	1970	1975	1978
Non PP	34.5	153.6	262.3	310.7	198.4	117.7	108.8
Power Plant	28.6	251.2	368.8	603.3	1082.5	1349.1	1221.2
Total	63.1	404.8	631.1	914.0	1280.9	1466.8	1330.0

County of Jefferson, KY

Power Plant	1950	1955	1960	1965	1970	1975	1978
Canal	1.9	1.5	-	-	-	-	-
Cane Run	-	3.0	11.4	17.0	27.1	22.4	19.1
Mill Creek	-	-	-	-	-	17.8	21.0
Paddy's Run	7.4	10.4	9.4	4.1	3.5	.7	2.3
Waterside	.9	.8	-	-	-	-	-
Total PP	10.2	15.7	20.8	21.1	30.6	40.9	42.4

Non Power Plant - Jefferson County, KY

Work not complete on this portion of file as yet.

HISTORICAL TRENDS IN SO_2 EMISSIONS

in 1000's tons

State	1950	1955	1960	1965	1970	1975	1978
			EPA - REGION I				
Conn.	130.3	139.1	241.6	457.6	317.3	191.0	112
Maine	37.8	45.6	70.2	97.0	82.0	67.8	66
Mass.	906.4	956.7	374.6	443.2	584.4	362.2	402.2
New Hamp.	73.3	89.7	29.1	41.2	95.9	75.4	67.8
Rhode Island	67.7	80.2	87.3	41.2	60.1	24.3	19.7
TOTAL	1215.5	1311.3	802.8	1080.2	1139.1	720.7	667.7
			EPA - REGION II				
New York	847.0	1126.0	1427.4	1645.4	1455.0	1079.0	1041.1
New Jersey	*1308.8	*1486.2	482.6	623.4	590.2	341.0	323.7
TOTAL	*2155.8	*2612.20	1910.00	2268.8	2045.2	1420.0	1364.8
			EPA - REGION III				
Delaware	105.4	136.0	196.1	217.8	223.4	193.6	188.2
D.C.	32.4	31.0	38.5	47.9	78.0	27.1	17.6
Maryland	398.9	515.5	518.2	588.1	467.7	322.3	357.3
Penn.	* 970.2	2138.4	2362.2	2546.8	2245.7	2130.8	1900.0
Va.	157.2	277.4	171.4	188.1	475.2	381.0	359.9
West Va.	243.5	617.8	529.7	776.8	979.7	1220.0	1049.5
TOTAL	*1907.6	3716.1	3816.1	4365.5	4469.7	4274.8	3872.5
			EPA - REGION IV				
Alabama	139.5	522.7	613.5	892.3	979.1	986.5	762.1
Florida	225.5	350.5	341.1	501.6	862.3	827.9	685.9
Georgia	119.9	163.6	198.2	303.0	410.4	571.4	707.0
Mississippi	46.9	43.3	41.1	44.6	79.4	193.0	264.3
Kentucky	113.1	404.8	631.1	914.0	1280.9	1466.8	1330.0
North Carolina	306.1	347.4	232.4	294.4	533.2	500.5	562.3
South Carolina	44.5	84.3	115.9	121.7	185.4	202.3	288.6
Tenn.	97.3	369.2	731.2	771.5	988.1	1141.9	1162.8
TOTAL	1092.8	2285.8	2904.5	3843.1	5318.8	5890.3	5763.0

ƆRICAL TRENDS IN SO_2 EMISSIONS (Cont.)

State	1955	1960	1965	1970	1975	1978
		in 1000's tons				
		EPA - REGION V				
Illinois	*!172.1	2452.9	2791.4	2506.5	1950.6	1747.2
Indiana	.174.2	1840.8	2180.3	1941.5	1980.0	1848.2
Mich.	702.7	1085.5	1521.7	1520.9	1450.6	1117.8
Minn.	536.4	391.8	419.8	450.7	382.3	379.0
Ohio	*!344.9	2933.2	3181.2	3125.2	3271.2	3115.3
Wisc.	304.2	604.0	703.8	322.3	166.6	663.6
TOTAL	*:234.5	9308.2	10798.2	9867.1	9201.3	8871.1
		OTHER STATES				
Arkansas	36.7	26.1	29.9	37.0	68.6	121.6
Iowa	258.0	364.5	440.8	370.2	314.0	385.0
Louisiana	261.2	219.4	268.7	318.0	295.1	359.0
Missouri	!155.1	582.6	674.9	1107.3	1174.3	1307.7
Texas	:073.8	900.0	1074.3	1136.8	1123.8	1244.8

*Questionable Data

HISTORICAL TRENDS IN NO_x EMISSIONS

in 1000's tons

State	1950	1955	1960	1965	1970	1975	1978
			EPA - REGION I				
Conn.	85.7	100.0	152.6	169.0	202.0	182.0	183.0
Maine	44.6	46.7	49.1	60.2	75.8	72.7	76.7
Mass.	164.2	195.0	254.9	303.4	359.9	340.2	364.3
New Hamp.	18.2	22.6	31.1	39.7	63.7	67.5	66.9
Rhode Island	33.5	32.9	45.2	36.4	55.2	44.9	42.4
TOTAL	346.2	397.2	532.9	608.7	756.6	707.3	733.3
			EPA - REGION II				
New York	493.6	606.5	767.0	919.1	1000.3	869.3	908.9
New Jersey	281.5	319.1	362.7	439.1	538.3	462.0	494.4
TOTAL	775.1	925.6	1129.7	1358.2	1538.3	1331.3	1403.3
			EPA - REGION III				
Delaware	19.8	30.1	51.2	61.1	71.9	65.2	70.6
D.C.	30.8	34.3	35.0	38.1	58.3*	36.5	33.5
Maryland	108.9	138.5	222.9	292.5	298.8	294.9	313.9
Penn.	479.1	693.2	1020.2	1143.1	1089.2	1093.1	1120.7
Va.	183.8	228.0	259.9	361.8	433.5	420.8	435.2
West Va.	118.9	217.4	225.0	322.3	346.9	470.8	462.4
TOTAL	941.3	1341.5	1814.2	2218.9	2298.6	2381.3	2436.3
			EPA- REGION IV				
Alabama	172.6	367.0	308.6	448.3	416.1	580.8	473.0
Florida	206.8	263.4	321.5	420.8	552.1	733.2	777.4
Georgia	170.8	198.9	226.9	296.7	398.1	520.5	548.8
Kentucky	145.4	208.0	279.1	377.6	497.2	567.3	563.0
Mississippi	97.1	80.8	151.2	196.4	304.5	243.5	272.8
N.C.	192.0	210.7	290.0	376.2	546.4	568.0	591.0
S.C.	87.4	125.4	150.2	178.2	237.3	253.7	300.2
Tenn.	164.9	232.7	335.9	380.3	467.1	615.5	592.9
TOTAL	1237.0	1686.9	2063.3	2674.3	3418.8	4082.5	4119.1

HISTORICAL TRENDS IN NO_x EMISSIONS (Cont.)

State	1950	1955	1960	1965	1970	1975	1978
			in 1000's tons				
			EPA - REGION V				
Illinois	600.1	890.4	895.9	1063.7	1119.8	1129.1	1129.9
Indiana	296.6	447.2	584.9	555.2	576.4	631.7	600.6
Mich.	318.3	382.9	587.3	746.4	846.6	840.7	843.1
Minn.	164.7	187.6	240.1	275.5	331.3	370.0	399.6
Ohio	498.2	771.5	960.5	1082.3	1165.1	1221.0	1277.1
Wisc.	196.5	215.4	296.6	367.4	455.0	445.7	473.2
TOTAL	2074.4	2895.0	3565.3	4090.5	4494.2	4638.2	4723.5
			OTHER STATES				
Arkansas	112.6	122.9	115.9	147.6	193.2	171.4	217.9
Iowa	167.2	203.6	216.4	248.1	309.6	308.8	321.0
Louisiana	283.5	330.2	535.8	760.1	1016.9	1072.0	1593.7
Missouri	198.1	251.0	294.6	339.1	424.6	593.6	563.0
Texas	876.5	933.1	1658.0	2044.6	2551.3	2833.9	3309.5

*Questionable Data

Table. 1978 SO_2 and NO_x Emissions by State.
(kt/yr)

State	SO_2	NO_x
Alabama	762.1	473.0
Arkansas	121.6	217.9
Connecticut	112.0	183.0
Delaware	188.2	70.6
District of Columbia	17.6	33.5
Florida	685.9	777.4
Georgia	707.0	548.8
Illinois	1747.2	1129.9
Indiana	1848.2	600.6
Iowa	385.0	321.0
Kentucky	1330.0	563.0
Louisiana	359.0	1593.7
Maine	66.0	76.7
Maryland	357.3	43.9
Massachusetts	402.2	364.3
Michigan	1117.8	843.1
Minnesota	379.0	399.6
Mississippi	264.3	272.8
Missouri	1307.7	563.0
New Hamsphire	67.8	66.9
New Jersey	323.7	494.4
New York	1041.1	908.9
North Carolina	562.3	591.0
Ohio	3115.3	1277.1
Pennsylvania	1900.0	1207.7
Rhode Island	19.7	40.4
South Carolina	288.6	300.2
Tennessee	1162.8	592.9
Texas	1244.8	3309.5
Vermont	---	---
Virginia	359.9	435.2
West Virginia	1049.5	462.4
Wisconsin	663.6	473.2
TOTAL	23957.2	19420.6

1978 Emissions

Commercial/Residential

	TSP	SO_x	NO_x	HC	CO
National	353,760	23,406	100,672	742,054	2,152,169
Alabama	8,504	407	2,314	18,285	18,285
Arkansas	4,249	259	1,375	8,417	23,968
Connecticut	3,202	131	686	7,103	20,738
Delaware	640	53	229	1,064	29,089
Dist. of Columbia	612	179	214	477	7,482
Florida	65,291	1,126	1,870	9,906	28,251
Georgia	7,298	445	2,646	13,833	39,126
Illinois	16,606	1,186	2,981	39,490	116,353
Indiana	12,438	877	3,718	25,938	75,007
Iowa	8,324	634	2,134	17,083	49,374
Kentucky	5,927	398	2,192	11,170	32,107
Louisiana	5,739	287	1,723	11,753	33,316
Maine	2,719	182	776	5,579	16,072
Maryland	3,806	257	1,351	7,199	20,439
Massachusetts	7,794	420	1,501	17,869	52,370
Michigan	19,415	2,503	15,557	41,699	115,990
Minnesota	11,634	426	2,211	18,010	52,287
Mississippi	6,360	339	1,831	13,403	38,451
Missouri	10,158	429	2,100	23,533	68,831
New Hampshire	1,836	123	505	3,799	10,965
New Jersey	10,063	2,074	3,348	12,415	33,673
New York	16,216	1,453	4,718	27,866	79,280
North Carolina	11,159	865	4,106	20,296	57,248
Ohio	21,098	13,046	4,789	45,654	132,886
Pennsylvania	4,473	1,291	1,531	1,832	15,499
Rhode Island	1,187	48	208	2,856	8,403
South Carolina	7,676	390	2,230	16,185	46,695
Tennessee	9,366	507	2,601	20,165	59,487
Texas	12,820	784	3,539	26,742	76,609
Vermont	1,479	95	444	2,995	8,590
Virginia	6,786	590	2,547	12,661	35,788
West Virginia	3,947	237	1,434	7,505	21,236
Wisconsin	11,907	995	3,208	23,524	67,860

SOURCE: National Emissions Data System (NEDS).

1978 Emissions

Transportation

	TSP	SO_x	NO_x	HC	CO
National	6,286,087	955,767	9,355,943	12,549,131	97,801,165
Alabama	110,642	25,892	205,541	241,841	1,754,292
Arkansas	63,752	9,921	128,555	144,749	1,049,778
Connecticut	81,687	6,622	100,103	152,975	1,235,652
Delaware	16,283	2,823	28,039	35,773	275,377
Dist. of Columbia	15,214	1,197	17,111	24,235	202,223
Florida	298,690	30,889	362,730	557,336	4,269,119
Georgia	155,564	20,212	270,023	323,335	2,430,711
Illinois	286,009	30,472	398,479	518,854	4,112,325
Indiana	155,893	18,838	255,218	320,855	2,519,201
Iowa	60,897	9,805	135,773	157,697	1,218,841
Kentucky	90,950	14,480	189,160	204,932	1,508,128
Louisiana	113,812	43,953	202,170	240,994	1,754,474
Maine	23,288	3,727	50,419	59,136	428,545
Maryland	113,453	14,795	152,485	207,733	1,609,040
Massachusetts	158,713	10,765	161,017	278,951	2,314,969
Michigan	269,852	46,761	350,936	482,683	3,869,142
Minnesota	103,899	14,320	198,444	254,163	1,947,578
Mississippi	53,514	12,257	123,978	129,197	943,985
Missouri	151,023	17,041	235,436	306,040	2,367,375
New Hampshire	21,252	1,627	29,361	41,446	330,946
New Jersey	221,443	27,381	248,805	375,900	3,069,379
New York	340,260	34,575	419,157	634,875	5,114,336
North Carolina	143,885	19,485	284,714	334,094	2,477,393
Ohio	321,708	36,836	433,805	507,312	4,582,071
Pennsylvania	282,530	38,406	435,991	531,822	4,196,933
Rhode Island	28,389	1,679	29,380	53,827	444,384
South Carolina	76,807	9,897	136,873	173,858	1,258,446
Tennessee	129,396	19,506	250,647	274,032	2,038,819
Texas	455,232	111,334	704,565	897,667	6,744,339
Vermont	9,794	1,383	21,363	22,453	162,963
Virginia	135,464	19,047	237,600	286,300	2,147,509
West Virginia	17,147	5,663	69,521	51,699	326,512
Wisconsin	87,749	13,941	198,364	231,295	1,657,454

SOURCE: National Emissions Data System (NEDS).