1988

Annual Report

To the President and Congress

NAPAP

NATIONAL ACID PRECIPITATION ASSESSMENT PROGRAM

Interagency Task Force on Acid Precipitation

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Miss Donna Fitzpatrick	Department of Energy
Mr. A. Alan Hill	Council on Environmental Quality
Mr. T Ary	Department of the Interior
Dr. William E. Evans	Department of Commerce

Other Agency Task Force Members:

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Mr. John F. Fitzgerald	Department of State
Dr. David T. Kingsbury	National Science Foundation
Dr. Ralph R. Reed	Department of Health and Human Services
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Dr. Ralph M. Perhac	Electric Power Research Institute

National Laboratory Representatives:

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Dr. Bernard Manowitz	Brookhaven National Laboratory
Dr. Chester R. Richmond	Oak Ridge National Laboratory
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1988 ANNUAL REPORT

National Acid Precipitation Assessment Program

Department of Agriculture ◦ Department of Commerce

Council on Environmental Quality ◦ Department of Energy

Environmental Protection Agency ◦ Department of Health and Human Services

Department of the Interior ◦ National Aeronautics and Space Administration

National Oceanic and Atmospheric Administration ◦ National Science Foundation

Department of State ◦ Tennessee Valley Authority

National Acid Precipitation Assessment Program
Office of the Director
722 Jackson Place, N.W.
Washington, DC 20503

January 13, 1989

NAPAP Task Group Chairmen

Task Group	Name	Affiliation
Emissions and Controls	Ms. Denise Swink	DOE
Atmospheric Chemistry	Mr. Bruce Hicks	NOAA
Atmospheric Transport and Modeling	Dr. Robin Dennis	NOAA
Atmospheric Deposition and Air Quality Monitoring	Mr. F. Paul Kapinos	DOI
Terrestrial Effects	Dr. Paul H. Dunn	USDA
Aquatic Effects	Dr. Daniel McKenzie	EPA
Effects on Materials and Cultural Resources	Dr. Philip Baedecker	DOI

NAPAP Office of the Director

Director:	Dr. James R. Mahoney
Scientific Staff:	Dr. Ruth H. Allen Dr. Patricia M. Irving Dr. John L. Malanchuk Mr. Ronald J. Nesse Dr. David S. Renne
Technical Staff:	Ms. Donna C.Connell Mr. Robert J. Downing Mr. Charles N. Herrick Ms. Judy L. Hickey Ms. Gloria D. Robinson Ms. Barbara R. Symons Ms. Denise Vines

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INTRODUCTION

The Acid Precipitation Act of 1980 (Title VII of the Energy Security Act of 1980, Public Law 96-294) established the Interagency Task Force on Acid Precipitation to develop and implement the National Acid Precipitation Assessment Program (NAPAP). The purpose of NAPAP is to increase our understanding of the causes and effects of acidic deposition, and to produce scientific information to support decisionmaking regarding acidic deposition control and abatement strategies.

The Task Force is required by law to issue an annual report to the President and Congress describing the progress and accomplishments of the National Acid Precipitation Assessment Program. This Report, the Program's seventh, is divided into three major sections. The first section describes the Program's organizational structure, external coordination activities, peer reviews, and budgetary status. It also includes a discussion of the NAPAP assessment process, and provides a synopsis of NAPAP's plan and schedule for 1989 and 1990 assessment reports. The second section is a Task Group-by-Task Group breakdown of the Program's 1988 research and assessment accomplishments and its plans for future deliverables. The last section is a list of NAPAP's 1988 publications.

NAPAP ORGANIZATION

The Task Force that implements NAPAP is jointly chaired by the Environmental Protection Agency (EPA); the Departments of Agriculture (USDA), Energy (DOE), and the Interior (DOI); the National Oceanic and Atmospheric Administration (NOAA); and the Council on Environmental Quality (CEQ). Other statutory members include the Department of Commerce (DOC), the Department of Health and Human Services (HHS), the Department of State (DOS), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the Tennessee Valley Authority (TVA). The Task Force includes four Presidential appointees as well as representatives from DOE's Argonne, Brookhaven, Oak Ridge, and Pacific Northwest National Laboratories.

Appointed by the Joint Chairs Council (JCC), the NAPAP Director is responsible for program planning, management, and coordination, and for recommending research and assessment initiatives to the Joint Chairs and the Task Force. The participating agencies work with the NAPAP Office of the Director at several levels. The Interagency Science Committee (ISC), comprised of senior scientific managers from each agency, works with the Director and his staff to develop, implement, and evaluate programmatic research, assessment, and budgetary requirements. The Interagency Policy Committee (IPC), comprised of senior policy officials from the agencies, is responsible for the review of NAPAP research and assessment activities to ensure that they are fully responsive to policy needs.

NAPAP's program of research is divided among seven Task Groups dealing with the following categories: 1) Emissions and Controls, 2) Atmospheric Chemistry, 3) Atmospheric Transport and Modeling, 4) Atmospheric Deposition and Air Quality Monitoring, 5) Terrestrial Effects, 6) Aquatic Effects, and 7) Effects on Materials and Cultural Resources. Senior scientists from the funding agencies are appointed by the Director and the ISC to serve as Task Group Leaders. These individuals are responsible for the direct oversight of NAPAP research and assessment activities.

External Coordination and Research Interaction

A large part of NAPAP's activity is devoted to coordination among the various sectors of the acidic deposition research and assessment communities. NAPAP managers meet regularly with representatives from other National programs, state government agencies, the private sector, environmental and resource conservation organizations, and academia. In addition, NAPAP draws on state, academic, and private sector scientists for the purpose of peer review. NAPAP's 1988 peer review panels included scientists and technical specialists from California, Minnesota, Pennsylvania, the Northeast States for Coordinated Air Use Management (NESCAUM), six privately-funded research organizations, and ten universities.

Also important are NAPAP's frequent contacts with scientists and assessment specialists from other nations. NAPAP's formal associations with Canada and the Federal Republic of Germany are ongoing and extensive, involving collaboration in the areas of deposition monitoring, emissions inventories, materials effects data, atmospheric processes, forestry, and agricultural crops. Other contacts and exchanges have involved Australia, Chile, China, Czechoslovakia, England, France, Holland, Mexico, the Netherlands, Norway, Scotland, and Sweden. NAPAP's 1988 peer review panels included scientists from Canada, England, Norway, and the Netherlands.

NAPAP's broad-scaled interaction helps to assure that 1) all researchers, assessors, and policy officials have access to current information; 2) the costly duplication of efforts is avoided; and 3) research and assessment results are disseminated to end-users in a timely and efficient manner.

Peer Reviews

The process of third-party review and evaluation is an integral aspect of the conduct of the NAPAP research and assessment program. Through the peer review process, external experts from academic institutions, the private sector, state and federal government agencies, and the international scientific community are provided with the opportunity to critically evaluate the technical quality, relevance, and completeness of NAPAP's various research projects. NAPAP consults with state and Canadian research program managers about the design of its reviews, the selection of reviewers, and their interest in presenting projects from their programs during these reviews. Reviewers are asked to evaluate not only the quality of individual projects, but also to consider the interrelatedness of groups of projects in light of NAPAP's programmatic objectives.

The following NAPAP-sponsored peer reviews were conducted in 1988:

- projects conducted by the Emissions and Controls Task Group in February 1988,
- projects conducted by the Atmospheric Chemistry Task Group in March 1988,
- projects conducted by the Atmospheric Deposition and Air Quality Monitoring Task Group in April 1988, and

- projects conducted by the Atmospheric Transport and Modeling Task Group in May 1988.

In each case, detailed comments from the reviewers are sent to the appropriate agency managers and researchers. The Task Force and its member agencies use the information generated by the reviews to help guide the National Program's decisions on research and assessment directions and project funding. Summary reports from each of the peer reviews are available from the NAPAP Office of the Director.

NAPAP FY 1988 Budget

For fiscal 1988, the National Acid Precipitation Assessment Program's budget was $82.46 million. Funding for NAPAP has remained roughly level over the past three years, after increasing from 1982 through 1986 as the program implemented its various long-term research efforts (see Figure 1).

As in years past, the NAPAP budget apportionment has been drawn from six federal agencies. The Environmental Protection Agency provided approximately 62.8 percent of the Program's funding; the Departments of Agriculture and Energy were responsible for 14.2 and 10.5 percent, respectively; and the Department of the Interior (6.6 percent), the National Oceanic and Atmospheric Administration (5.1 percent), and the Tennessee Valley Authority (1.0 percent) contributed the remainder (Table 1).

As is indicated in Table 1, the total NAPAP apportionment of $82.46 million was divided among research categories as follows: Aquatic Effects, $21.8 million; Terrestrial Effects, $18.5 million; Atmospheric Chemistry, $12.4 million; Atmospheric Transport and Modeling, $9.9 million; Atmospheric Deposition and Air Quality Monitoring, $9.6 million; Emissions and Controls, $4.7 million; and Effects on Materials and Cultural Resources, $3.7 million.

FIGURE 1. NAPAP Funding History *(in millions)*

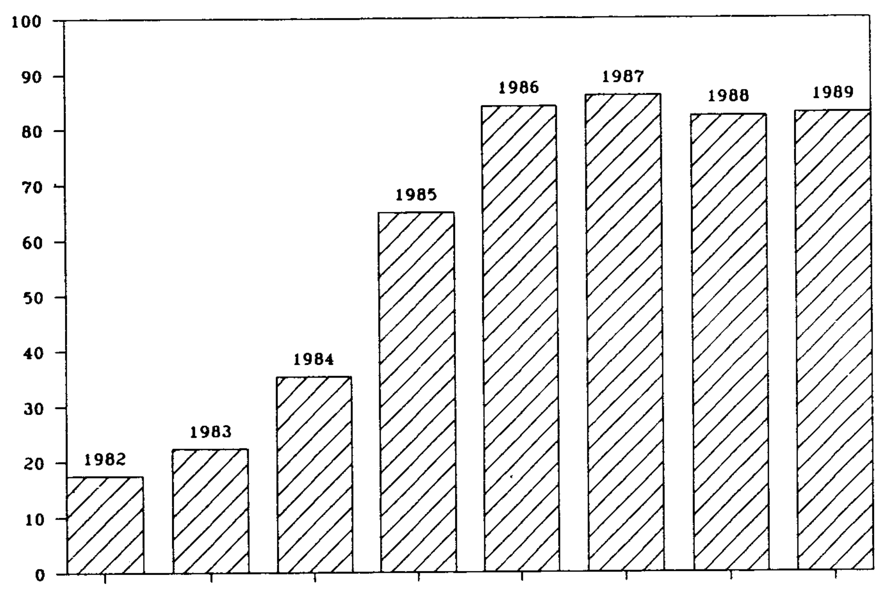


TABLE 1. NAPAP 1988 Current Budget *($ K)*

Task Group	EPA	USDA: CSRS	USDA: ARS	USDA: FS	NOAA	DOE	DOI: NPS	DOI: USGS	DOI: FWS	DOI: BLM	TVA	TOTAL	TG%
I EMISSIONS & CONTROLS	3,985					750						4,735	5.7%
II ATMOSPHERIC CHEMISTRY	4,194				2,806	4,999					400	12,399	15.0%
III ATMOSPHERIC TRANSPORT	8,672				940	280						9,892	12.0%
IV ATMOSPHERIC DEPOSITION & AIR QUALITY MONITORING	5,919	567		146	430	452	117	1,816		100	40	9,587	11.6%
V TERRESTRIAL EFFECTS	8,198	2,130	284	7,550		40					304	18,506	22.4%
VI AQUATIC EFFECTS	18,121			1,005		250	393	1,044	955		75	21,843	26.5%
VIII MATERIAL EFFECTS	2,670						825	155				3,650	4.4%
Assessment						1,850						1,850	2.2%
		2,697	284	8,701			1,335	3,015	955	100			
TOTALS:	51,759		11,682		4,176	8,621		5,405			819	$82,462	100.0%
Agency %:	62.8%		14.2%		5.1%	10.5%		6.6%			1.0%	100.0%	

NAPAP ASSESSMENTS

The central focus of NAPAP's 1988 activities revolved around the conception and development of a plan for an integrated series of assessment reports, to be released in 1989 and 1990. Formalization of the Plan began in April when the Office of the Director conducted a week-long workshop to discuss the general orientation and approach that NAPAP will adopt for assessment development. This meeting involved over 100 scientists and technical experts from Federal and State government agencies, academia, and the private sector.

During the April meeting, attendees divided into ten working groups based on the following categories: Assessment Methodology, Emissions and Controls, Atmospheric Processes, Atmospheric Deposition and Air Quality Monitoring, Terrestrial Effects, Aquatic Effects, Effects on Materials and Cultural Resources, Human Health, Atmospheric Visibility, and Economics. Each of these groups were requested to 1) define assessment questions, 2) identify pertinent data sources and methodological approaches, and 3) develop preliminary outlines for reports detailing the state of acidic deposition science within each of the areas of concern. During the months of May and June, each of the ten groups met separately with the Office of the Director to further refine their perspectives; and on July 7-8 all ten groups reconvened to compare their products and to develop priorities for an assessment plan.

The draft assessment plan was compiled in an iterative manner and involved three review and revision phases during July through September. Final revisions were completed during the first week of September, and the NAPAP Joint Chairs Council approved a public review draft of the Assessment Plan on October 6, 1988. The resulting document, entitled, "Plan and Schedule for

NAPAP Assessment Reports," was released for public review on October 12 along with an invitation to attend and make comments at a public review meeting scheduled for November 17, 1988. The public meeting was attended by over 200 individuals. Speakers included representatives from the Canadian Government, environmental organizations, utility groups, and various state and provincial governments. All comments received at the public meeting, as well as comments received in writing before December 1, 1988, were recorded and will be considered in a revision of the Plan that will be released in January 1989. In addition, NAPAP will publish a summary of public comments and indicate how it responded to these comments in its revision of the Assessment Plan. The revised plan may be obtained through the NAPAP Office of the Director.

The Assessment Plan

The NAPAP Assessment Plan is intended to be a major element in the technical dialogue essential for the preparation of a useful integrated assessment of acidic deposition causes, effects, and control measures. The necessary dialogue is both internal (within the Task Force) and external (between NAPAP and potential users of the Assessment). Acidic deposition issues involve significant complexity and uncertainty. To be of maximum benefit in resolving such issues, the Assessment must be based on a framework well understood by all of its preparers and users.

The expected users of the NAPAP Assessment include the President, members of Congress and their staff; policy, technical, and regulatory officials within the Executive Branch; representatives of state and local government units; representatives of provincial and federal government units in Canada; representatives of environmental, health, and other public-interest groups; representatives of industry, utility, coal, and economic development organizations; representatives of labor organizations; representatives of control technology developers and vendors; interested scientists and engineers; and interested representatives of international organizations and other government units.

Approach for the Assessment

NAPAP's assessment will be developed in two principal parts: 1) a series of State-of-Science/Technology (SOS/T) Reports - comprehensive analyses and discussions of relevant technical information prepared for specialist readers, and 2) the Integrated Assessment - a structured compilation of policy-relevant technical information presented in a form suitable to assist policymakers and the public in evaluating the key questions concerning acidic deposition causes, effects, and control strategies (see Figure 2).

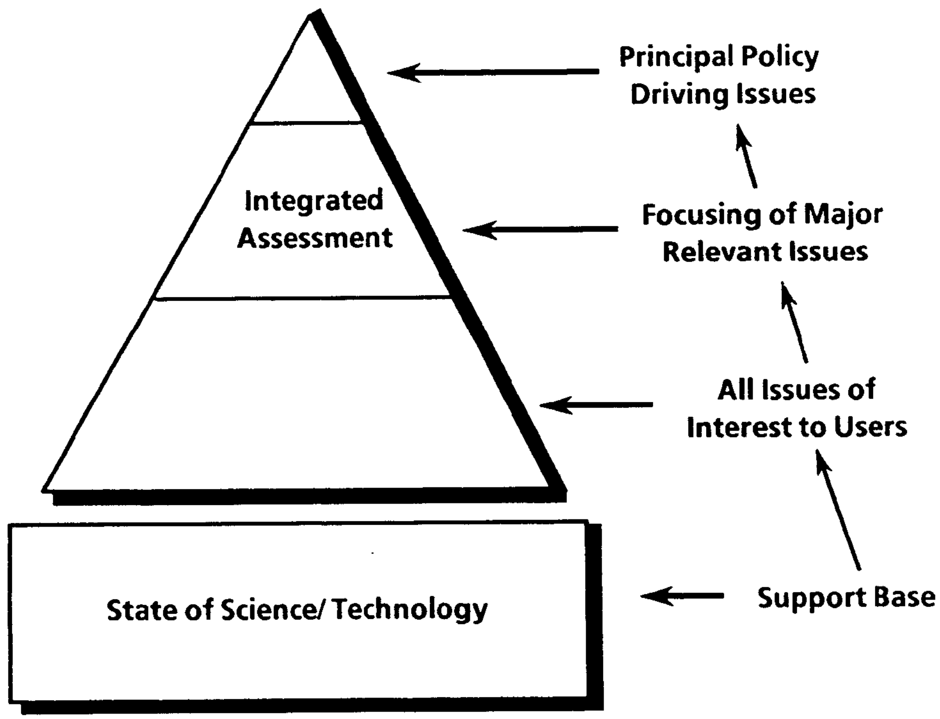
Plan Update: Details of Future Scenario Cases

NAPAP's assessment methodology incorporates a survey of present conditions and a comparative approach for evaluating future scenarios. The number of plausible scenarios that might be evaluated is prohibitively large to allow comprehensive treatment. NAPAP is currently developing specifications of illustrative scenarios for evaluation in the Integrated Assessment. The illustrative scenarios will conform to the three key guidelines below.

o The scenarios will be based on plausible combinations of emission reduction strategies.

o The scenarios will reflect the range of emission reduction strategies commonly discussed in the national debate about acidic deposition. NAPAP, however, will not analyze specific legislative or other public proposals.

FIGURE 2. Schematic Illustration of the Relationship Between the State-of-Science/Technology Reports and the Integrated Assessment



NAPAP data and methods will be available for specialized analysis by other investigators.

o The scenarios will be selected to address a wide range of situations in order to allow adequate briefing relating to questions such as, "How much difference (in control costs, effects patterns, etc.) does it make to adopt one strategy as opposed to another?"

NAPAP plans to report on the specification of illustrative scenarios for analysis in the Integrated Assessment in an "Assessment Plan Update" document to be published in July 1989.

State-of-Science/Technology Reports

The SOS/T Reports are intended to provide a comprehensive statement of the technical information concerning acidic deposition from all available sources, i.e., both NAPAP-sponsored studies and all other relevant studies reported in the technical literature. Review drafts of these surveys will be published in mid- and late 1989 and will be subjected to several levels of review: interagency review by the NAPAP cooperating agencies, peer review by independent scientists, and open review by all interested persons at an international scientific meeting convened specifically to evaluate the reports. Following this extensive review, the SOS/T Reports will be published in final form in 1990, and, in combination with the updated Assessment Plan, will be used as the basis for the technical findings, analysis methods, and projection and comparison methodologies that are the key elements of the Integrated Assessment. The emphasis on full reporting and extensive external review of the SOS/T Reports is intended to ensure that the Integrated Assessment is based on the broadest available, fully reviewed technical information. Also, a lay summary of each of the SOS/T Reports will be prepared (with scientific and public review), to ensure that the principal information is available to a wider audience of interested readers. The summaries will also serve as resources for scholastic and public educational programs dealing with acidic deposition issues.

Currently, 27 Reports, prepared by approximately 100 specialist authors, are planned to provide a survey of all the pertinent SOS/T areas. The scope of the documents will include 1) emissions, transport, transformation, air concentrations, and deposition of acidic and associated pollutants; 2) effects of acidic deposition and associated pollutants in all principal areas of concern (surface waters, forests, agricultural crops, exposed materials, human health, and visibility in the atmosphere); and 3) economic and technological evaluation of control and mitigation measures and economic evaluation methods relevant to acidic deposition effects.

Integrated Assessment

The Integrated Assessment is intended to translate scientific information, with its associated uncertainties, into results that can be used to address relevant questions for the policymaking audience. The Integrated Assessment will aid public officials and other interested individuals by focusing the scientific and technical information on the principal issues of concern, and by interpreting the importance of available technical information. The Integrated Assessment will be structured around five key questions that address both present knowledge (Questions I and II) and future projections (Questions III, IV, and V).

<u>Present Knowledge</u>

o Question I: What are the effects of concern, and what is the relationship between current levels of acidic deposition/air pollutant concentrations and these effects?

o Question II: What is the relationship between emissions of the precursor pollutants and acidic deposition/air pollutant concentrations currently observed in North America?

<u>Future Projections</u>

o Question III: What does available technical information indicate about the sensitivity to change for the relationship between (a) emissions and future conditions related to economic, energy, and technological developments; (b) control costs and changes in emissions levels; (c) emissions levels and resulting deposition/air concentration levels; and (d) air concentrations/deposition levels and effects?

o Question IV: What are the estimates of future conditions (emissions, deposition, and effects) with and without additional emissions reductions strategies?

o Question V: What differences emerge from comparative evaluations of future scenarios?

Guiding Principles and Scope for the Assessment

NAPAP plans to complete its assessment activities within the ten-year Congressionally mandated reporting period, resulting in publication of its Integrated Assessment in September 1990. NAPAP will receive comments after publication of the Integrated Assessment, and will conclude all program activity with a document summarizing and responding to issues raised in the public response to the Assessment. Publication of this supplementary document is scheduled for December 1990.

During the next two years, NAPAP will conduct several parallel activities: 1) completion and documentation of its program of sponsored research; 2) production and review of the series of State-of-Science/Technology Reports; and 3) completion of assessment analyses, involving scientific, technological, and economic evaluations.

NAPAP's Integrated Assessment is intended to provide users with comprehensive scientific, technological, and economic information on the causes and effects of acidic deposition and on the effectiveness of various illustrative control measures in mitigating the adverse effects. NAPAP has the responsibility to provide users with objective, broadly reviewed data and analyses, which can serve as a basis for policy considerations. The Assessment will not make "public value" recommendations (such as, "What are the trade-offs between imposing stricter emissions controls in the near future vs. waiting for the implementation of new, cleaner technologies over the longer term?"), although it will provide the technical information and analyses that assist such public value decisions. NAPAP's assessment methodology is intended to facilitate the development of useful information for a wide range of state-, regional-, and national-level policy questions.

NAPAP has adopted several operating principles for the development of the Integrated Assessment.

o Based on SOS/T Reports - The SOS/T Reports are intended to cover the technical basis for the Assessment. This ensures that the technical information used in the Assessment will be extensively peer reviewed and available to all users of the Assessment.

o Based on responses to structured questions - The Assessment will be developed in the form of responses to a specific set of high priority questions, allowing users of the Assessment to review the questions being posed and to suggest other formulations if needed.

o Explicit treatment of scientific confidence level - Unavoidable scientific uncertainty precludes complete resolution of many key cause-effect issues. Although NAPAP-sponsored and other research has greatly improved understanding of many acidic deposition issues in recent years, uncertainties will remain in 1990. The Assessment will explicitly report NAPAP's best estimate of the level of confidence associated with various statements (ranging from characterizations such as "unsupported hypothesis" to "generally supported by data, generally agreed by investigators"). Reporting of scientific confidence level, after extensive peer review, will aid policy officials in assigning weight to various statements in the Assessment.

o Avoidance of oversimplification - Because of the complexities involved, there is a tendency to develop assessments of acidic deposition causes, effects, and controls in the form of simplified, parameterized analyses. NAPAP has adopted an approach that excludes oversimplified dose-response relationships and integration methods. This approach precludes development of an assessment that can express results in the form of a few key parameters. NAPAP's assessment, based on evaluation of changes in control costs and effects patterns compared to a reference case, will require more complicated interpretation, but will better reflect the full body of scientific and technical knowledge.

o Three-part analysis of benefits - NAPAP's authorizing statute requires economic analysis of benefits, as well as control costs. NAPAP will fully review economic analysis methods for valuing environmental benefits in the appropriate SOS/T reports. In the Integrated Assessment, however, NAPAP will not report all benefit valuations in economic form. Instead, three general categories of benefits will be reported: 1) health-related; 2) economically denominated (i.e., those for which an agreed economic analysis methodology is available); and 3) conservation-related (including important resource conservation categories for which acceptable economic valuation methods are not generally agreed).

o Assessment based on comparisons to a future case - Most of the technical data and projection models available for use in the NAPAP Assessment (e.g., air quality models, aquatic system response models) are better suited to comparative evaluation than to absolute value projections. Thus, a comparative approach allows significantly improved confidence in the Assessment findings, relative to absolute projections. Moreover, most of the relevant policy questions also are comparative. For example, "How would deposition vary with strategies that reduce emissions uniformly across the eastern states vs. in the Ohio Valley?"

Scope of the State-of-Science/Technology Reports

The 27 SOS/T reports that are currently planned will summarize and critically evaluate all the scientific and technical information available in each relevant discipline. Titles, detailed outlines, and authors nominated for these reports are presented in Part 2 of the Plan. Guidelines for authors, including a description of the review process and international scientific meeting, are also presented in the Plan. The following section provides a brief summary of the purpose and emphasis for the SOS/T reports within each discipline.

Major Scientific and Technological Areas for State-of-Science/Technology Reports

o Emissions: The first SOS/T report will describe the sources, magnitudes, and spatial/temporal patterns of emissions contributing to acidic deposition and involved in acidic deposition formation processes.

o Atmospheric Processes: Extensive efforts have been made, both within and outside NAPAP, to observe and to model individual atmospheric processes that affect acidic deposition. The second SOS/T report will describe the physical and chemical processes of the atmosphere pertinent to the formation and deposition of acidic species, oxidants, and aerosols, and will present approaches for modeling these processes.

The third report will describe how the information presented in Report 2 is represented in the current science of regional deposition and air concentration modeling. The Report will show how regional atmospheric models form a hierarchy with a range of applications. This report will also discuss procedures for aggregating episodic model outputs to produce long-term average deposition and air quality information of relevance to the effects analyses.

The fourth report will provide a comprehensive description of the Regional Acid Deposition Model (RADM). The purpose of RADM and its attendant aggregation scheme is to provide the estimates of current and future deposition and air patterns.

The fifth report will present a summary of evaluation and intercomparison studies for regional acidic deposition and air concentration models. A particular focus of this report will be the program designed to provide field data for evaluation of regional models, such as RADM. Evaluation results will be presented, including the interim evaluation of RADM and the sulfur-only Engineering Model.

o Atmospheric Deposition and Air Quality Monitoring: Reports 6 and 7 will describe and analyze the data available from wet and dry deposition and air quality monitoring programs. Data from programs designed for research purposes, long-term trends monitoring, and geographic analysis will be included, along with advances in quality assurance and data base management.

o Source-Receptor Relationships: Report 8 will consolidate the information contained in the emissions, atmospheric processes, and deposition and air quality monitoring reports to present our current understanding of source-receptor linkages. Associations between historical and current emissions and observed deposition and air quality patterns will be described at three levels: 1) descriptive (such as through the use of maps and charts), whereby spatial and temporal emissions data will be compared against spatial and temporal deposition data; 2) statistical (such as through use of regression and trend analysis); and 3) model-based (such as through use of linear and Eulerian model formulations), whereby deposition and air concentration patterns and trends are linked to emissions patterns and trends through simulation of atmospheric processes.

o Aquatic Effects: A series of seven reports (9-15) will present the current state of knowledge regarding the chronic and episodic effects of acidic deposition on aquatic resources. Historical status and methods for forecasting future change in status also will be addressed.

Report 9 will summarize the current chemical condition of surface waters in five regions of the United States, evaluate the spatial distribution of their chemical characteristics, and examine the associations of surface water chemistry with watershed characteristics and wet deposition chemistry. Results for the United States will be compared with those for Canada, Norway, and other nations having temperate climates.

Report 10 will focus on what is known about natural watershed processes, both aquatic and terrestrial, that affect chronic acid-base chemistry in lakes and streams. Processes related to hydrology and biogeochemistry in watersheds and in lakes and streams, and those associated with changes in land use will be examined. How acidic deposition interacts with these natural processes, and the implications for surface water and soil acidification or recovery, will be presented. Results from case studies of soil and water acidification, conducted internationally and in the United States, will be compared for natural systems with and without acidic deposition and for a number of experimentally acidified systems.

Report 11 will be an overview of the state of knowledge regarding natural and anthropogenic factors that influence the acid-base chemistry of surface waters and how these factors might influence the occurrence and detection of historical change. Methods for investigating historical change (historical water chemistry measurements, paleolimnological reconstructions, comparisons between high and low deposition areas, and models) and their associated uncertainties will be discussed. Results from several distinct lines of investigation will be integrated to provide historical estimates of change for lakes in the Adirondacks, and possibly for drainage lakes in the Northeast and Upper Midwest and seepage lakes in Florida.

The current understanding of episodic acidification of surface waters will be summarized in Report 12. The relationships of episodes to chronic acidification and the hydrologic cycle, their chemical characteristics and biological significance, and the processes that control them will be discussed. The extent and severity of episodic acidification will be presented, with data limitations clearly identified, for the United States, and compared when appropriate with European and Canadian information. This report concludes with a discussion of modeling approaches for regional estimates of the magnitude, duration, frequency, and extent of episodes (and associated uncertainties).

Report 13 will identify the chemical parameters that influence the effects of changes in acid-base chemistry on biological communities and processes. Methods for quantitatively evaluating the relationship between changes in acid-base chemistry and regional effects on fish populations will be presented, along with associated uncertainties. Qualitative discussions will include the effects of surface water acidification on aquatic organisms other than fish, e.g., benthic invertebrates, amphibians, waterfowl, and mammals.

Methods for forecasting changes in acid-base chemistry of surface waters and their associated uncertainties will be presented in Report 14. Three general types of models - steady-state, empirical time-varying, and dynamic system models - will be evaluated. Prior model applications in the United States, other North American regions, and Europe will be summarized. Each model will be discussed with regard to its structure, assumptions and limitations, sensitivity and behavioral analyses, and verification/validation studies. Error analyses, linkages to deposition estimates and inputs to biological models, and procedures for extrapolation to obtain regional estimates will be discussed.

The last report on aquatic effects (Report 15) will be an evaluation of the mitigative (surface water acid neutralization) approaches to restore and protect surface waters from acidification. This report will include a description of previously applied mitigative strategies and the effects of these mitigation techniques on ecosystem structure and function.

o Terrestrial Effects: Three SOS/T reports will evaluate terrestrial effects. Two reports (16, 17) will discuss the forest and agricultural crop resources in the United States. They will examine factors that influence forest and crop health and productivity, forming the basis for interpreting the influences from air pollutants that will be presented in the third report for this area. Aspects of extending interpretation of experimental results to estimate pollutant impacts on growth, production, and management will also be discussed. The third report (18) will discuss the theoretical basis for air pollution effects on plants, experimental results, and our level of understanding regarding the mechanisms of plant response to pollutant exposure.

o Materials Effects: The current state of knowledge regarding the incremental effects of acidic deposition on the degradation of metals, carbonate stone, paint, and other finishing systems will be reviewed in Report 19. Patterns of urban deposition to structures will be discussed in Report 20. Methodologies for preparing inventories of cultural and construction materials exposed to acidic deposition for the assessment of materials damage will be discussed in Report 21, along with a review of the available data bases.

o Human Health Effects: Scientific issues related to both direct and indirect health effects of air pollutants associated with acidic deposition precursors will be discussed in separate SOS/T reports. Report 22 on direct health effects will examine the effects of particulate matter, sulfur dioxide, acidic aerosols, ozone, and nitrogen dioxide. It will include a presentation of ambient exposures and deposition of the pollutants in the lungs, but the focus will be on health effects and concentrations/times of exposures that will cause these effects. Factors that affect susceptibility to these pollutants, such as exercise and pre-existing disease, also will be covered.

Report 23 on the indirect health effects of acidic deposition will discuss how acidic deposition can influence exposure of humans to pollutants through mechanisms such as acidity-dependent leaching of pollutants in some drinking water systems and food-chain accumulation of pollutants. Susceptibility factors will also be discussed. Given the nature of the data base, this report will focus on lead, mercury, and asbestos; however, other relevant metals such as cadmium, arsenic, aluminum, copper, and zinc will also be reviewed.

o Visibility Effects: This report, number 24, will present a thorough review of aerosol impacts on atmospheric visibility. The document will describe pertinent theory, results of controlled experiments, and analysis of ambient observations. To the degree possible, the chain of relationships between emissions sources, pollutant concentrations, and perceived visibility will be discussed.

o Control Measures: Report 25 will discuss the performance, costs, and applicability of available and emerging technologies and other techniques for emissions reduction. Report 26 will describe models for projecting future emissions and estimating control costs and will present results of selected sensitivity runs of those models.

o Economic Evaluations: Report 27 will be divided into two sections. The first section will provide a general review of the methods used to estimate the economic values associated with environmental changes. The second section will focus on models, methods, and issues specific to valuing acidic deposition effects.

Scope of the Integrated Assessment

The Integrated Assessment will structure the scientific information from the SOS/T Reports to focus on the principal policy-driving issues. These issues will be raised in a series of questions organized into five principal categories that will be addressed in the Assessment. The approach, assumptions, information sources, and uncertainties associated with answering these questions are described in Part 3 of the Plan. The guidelines for contributors to the Integrated Assessment, including a description of the review process and the protocol for evaluating the confidence level of the answers, are also provided in the Plan. The Integrated Assessment will be developed by the same technical specialists who have been involved in the production of the Plan and by the authors of the SOS/T Reports. The purpose, approach, and major focus for each of the five principal questions to be addressed in the Assessment are described below.

Question I: What are the effects of concern and what is the relationship between acidic deposition/air pollutant concentrations and these effects?

The basis for concern about acidic deposition is its possible effects. Thus, the Integrated Assessment will begin with a summary of the effects that have been hypothesized and an evaluation of the role of acidic deposition and associated pollutants in causing the effects currently observed. The evaluation will be conducted in a sequence of steps, beginning with a description of the current status and rate of change for aquatic resources, forest health, crop production, materials resources, human health, and visibility. The approach, assumptions, and information sources that will be used to provide this information for each effects category are given in Part 3 of the Plan. The predicted level of confidence in the information is also provided. The important hypotheses that relate the effects of concern to acidic deposition and associated pollutants are then listed along with an estimated confidence level for the information available to test each hypothesis.

The approach, assumptions, and information available to test each hypothesis are grouped into categories of evidence from exposure-response studies and evidence from correlative studies (such as epidemiological studies). These two categories of evidence are then integrated and assessed, along with information on the role of other stress factors, to determine the cause(s) of the effects of concern. A well-established cause-and-effect relationship can be developed only when there is a strong pattern of consistency and responsiveness, and a proven mechanism between observed effects and the suspected causal factor. The answers to this question are meant to document systematically the determination of causality for the effects of concern.

Question II: What is the relationship between acidic deposition, air quality, and emissions?

Question II is meant to explain deposition and air concentration patterns and the linkage between emissions sources and deposition. The first part of Question II will relate to the current status of deposition and air quality relevant to the effects discussed in Question I, and will rely on current measurements of deposition and air pollutant concentrations and on surrogates for measurement data to provide a historical perspective of long-term trends. Because historical deposition data are lacking, long-term emissions and visibility trends may be used to infer historical deposition trends. The second part of Question II will relate to source-receptor linkages, based on knowledge derived from observations and models. The third part of Question II will provide information on changes in deposition and air quality that may result from changes in emissions.

Question III: What is the sensitivity to change?

The ability to estimate future impacts is an important aspect of environmental assessment. In order to evaluate the potential for future changes, a general methodology must be available for examining a wide range of relevant factors. For acidic deposition, this methodology involves the use of models and other methods to describe functional relationships. Three major categories of models to be used in the Assessment are 1) emissions projection, 2) source-receptor, and 3) dose-response. These models range from very simple empirical relationships to integrated series of functions.

The answers to Question III will describe the sensitivity in model output to incremental changes over a wide range of input factors. This analysis will also evaluate the relative importance of key input parameters. This question is intended to provide the transition between the current state of knowledge, as summarized in Questions I and II, and future projections, as summarized in Questions IV and V.

The sensitivity of effects to changes in emissions will be evaluated for four areas: 1) emissions, using different assumptions for future conditions; 2) control costs, with emissions changes for a selected set of emission-reduction strategies; 3) deposition/air quality, with incremental emissions changes; and 4) effects, with incremental deposition/air quality changes. For the purposes of this question, effects sensitivity will not be linked directly to the sensitivity analyses for emissions and deposition/air concentrations. This linkage will be developed in the answers to Questions IV and V.

Question IV: What are the estimates of future conditions?

A two-part answer to this question will be provided: 1) estimates of future conditions without changes in current policy and legislation directed at acidic deposition control, and 2) estimates of future conditions with illustrative emissions reduction strategies for SO_2, NO_x, and VOCs.

Looking at the future allows us to estimate, under various sets of assumptions, what emissions levels, source-receptor relationships, and effects might be. An evaluation of changes in effects expected to result from a wide range of scenarios will allow focus on the more effective sets of options. This evaluation will also include calculations of costs for each control option. The models used in the sensitivity analyses for Question III will be linked together to project future changes in effects for Question IV. While the output of these linked models may not have a high level of confidence in absolute terms, comparative analyses based on changes from reference cases will generally allow higher confidence levels.

The inherently uncertain nature of future conditions will cause the answers developed for Question IV of the Assessment to have a lower level of confidence than those developed for Questions I and II, which rely directly on current measurements. The uncertainties about future conditions are different from those encountered in Questions I and II; in most cases they can only be resolved over time, rather than by more research. Because of these uncertainties, many assumptions affecting future scenarios that will be used to answer Question IV will be based on conditions that remain constant over time (e.g., land-use patterns, natural emissions, tree populations in forests). For comparative purposes, though, the answers to Question IV should allow a reasonable level of confidence in evaluating future conditions.

Question V: What differences emerge from comparative evaluations of future scenarios?

The objective of Question V is to compare and contrast the results of various future scenarios with and without additional future acidic deposition control and mitigation measures. This comparison will be performed through an evaluation of a set of policy-relevant issues regarding the need for additional controls, the costs and effectiveness of various levels of control and mitigation, the timing of implementing such measures, and the environmental changes that are expected to result. This information will help define further analyses of key issues. As previously discussed, NAPAP will not develop recommendations regarding optimal control strategies, nor will the analysis be aggregated into a comprehensive benefit-cost framework.

Examples of these issues include the following:

- What future trends of emissions and effects, compared to current conditions, are possible if current Clean Air Act authorities are not changed?

- Given the geographic regions of concern for all effects areas, is it most effective to implement a control scenario uniformly for all 31 eastern states or are other scenarios more effective?

- Is current damage sufficiently low and the rate of natural resource change sufficiently slow to warrant delaying implementation to await commercialization of new, lower-emitting or possibly more cost-effective technology rather than relying on existing retrofit technology?

A more comprehensive list of issues selected for analysis will be reported in the July 1989 Plan Update.

The answers to these questions will be based on quantitative answers from Question IV, as well as information from the SOS/T Reports and other Integrated Assessment questions. In many cases, the answers to Question IV will not provide complete information on the results of the strategies. However, comparisons among strategies will incorporate all available information about effects, including levels of uncertainty, as well as using deposition and control cost information.

Information on the effect changes will be categorized according to health effects, conservation effects, and economic effects. Health effect changes are considered separately because of their general importance and their prominence within regulatory statutes. Conservation effects are related to maintaining or preserving the natural or cultural environment. Economic effects include those that can be expressed in economic terms, by generally agreed methodologies.

EMISSIONS AND CONTROLS

1988 Research Highlights

Current Emissions Trends

A preliminary report of current emissions trends through 1987 indicated that sulfur dioxide, nitrogen oxide, and VOC emissions did not change substantially from 1986. The report provides an additional year of current trends data with which to gauge the status of current Clean Air Act emission reductions and provides a basis for the comparison of emissions and economic activity. Recent emissions data will also be utilized in the evaluation of emissions projections models and regional acid deposition models.

Transportation Emissions Modeling

Emissions from light duty vehicles constitute a major area source in the NAPAP data base. A recent study assessed the uncertainties associated with emissions estimates derived from the MOBILE 3 model. The model outputs were found to be quite sensitive to input parameters such as average speed by road type and temperature.

Model Set Integration Review and Workshop

A third party review and subsequent workshop were conducted on the model set integration and the Commercial/Residential Sector Emission Projection Model (CRESS). The panel of independent reviewers emphasized the need for consistent integration and recommended some specific improvements. This will provide NAPAP with a consistent set of emissions models to project future emissions and to evaluate the effectiveness and cost of illustrative control scenarios.

AUSM Review

An independent review of the Advanced Utility Simulation Model (AUSM) was carried out by the Massachusetts Institute of Technology. The review results are being used to strengthen the AUSM's methodology. In particular, inputs from the review have resulted in revisions to the AUSM that enhance its analytical capability as a tool to evaluate future generating technologies.

Transportation Emissions Projections Model

A third party review and subsequent workshop were conducted on the Transportation Emissions Projection Model (TEEMS). Input from the workshop and review will be used to improve the TEEMS model. The transportation sector is the largest emitter of nitrogen oxides and a large source of volatile organic compounds. Improvements in this model will help to provide a more accurate portrayal of future nitrogen oxide and volatile organic compound emissions.

Advanced Utility Simulation Model

In special studies of the Advanced Utility Simulation Model (AUSM), the model's forecasts are being compared to historical emissions data from 1980-1985 and to future emissions projected by the Coal Electric Use Model (CEUM), operated by ICF, Inc. The characterization of the extent to which the model can reproduce historical emissions data and compares favorably with other models will contribute to an evaluation of the preformance of the model.

Utility Reference File

Emissions, facility, and generation data for all electric utilities in the United States were compiled in the National Utility Reference File (NURF) from data submitted to EPA and DOE. NURF data are used as input to NAPAP's Advanced Utility Simulation Model.

Sulfur Dioxide, Nitrogen Oxide, and Volatile Organic Compounds Projection Models

Two industrial SO_2/NO_x and a national VOC emission and cost projection model were completed and tested. The Industrial Combustion Emissions (ICE) Model (version 6.0), the Process Model Projection Technique (PROMPT, version 3.0), and the Volatile Organic Compound (VOC) Model (version 1.8) were released for agency use. Each of the models uses a 1980 baseline year, and future versions will employ a 1985 baseline year. Magnetic tapes or floppy disks and published reports were released to the National Technical Information Service for public distribution.

1985 NAPAP Emissions Inventory

United States' anthropogenic point and area source SO_x, NO_x, and VOC emissions were complied into the 1985 NAPAP Emissions Inventory. The 1985 emissions inventory is highly resolved in space, time, and chemical species. These intensive requirements were designed to meet the needs of atmospheric modelers. The emissions inventory will be essential in NAPAP assessment activities, as well as atmospheric chemistry studies using RADM and other models.

MAJOR DELIVERABLES

DELIVERABLE	DATE	SIGNIFICANCE
1989 Emissions of SO_x, NO_x, and VOC (Flash Report): These emissions data will provide decisionmakers and researchers with the latest trend information in man-made emissions.	Yearly updates through March 1990	Coupled with deposition and ambient trends data since 1975, these data provide information for developing or evaluating transformation and transport hypotheses. Emissions trends data are also helpful to decisionmakers who wish to gauge the impact of current Clean Air Act legislation and energy and economic shifts. The March 1990 update will provide the latest available emissions trends information to support the NAPAP State of Science/Technology Reports and Integrated Assessment.
Utility File Updates (Codes and Report): Updates are made of the EPA/NAPAP Reference File to incorporate the yearly utility inputs from sources such as the DOE/EIA 767, 759, and 423 files; the North American Electric Reliability Council (NERC) files; and the DOE Generating Unit Reference Files (GURF) and Flue Gas Desulfurization Information System Files (FGDIS).	Early 1989	The 1989 update will be utilized to update the 1985 data base in the Advanced Utility Simulation Model.

DELIVERABLE	DATE	SIGNIFICANCE
1985 Detailed Inventory (Code and Reports): Provides estimates of 1985 emissions of some 59 man-made species of interest with regard to acidic deposition formation and neutralization. The inventory will be based on 20 by 20 km grid cells with temporal profiles on an hourly basis for weekdays, Saturdays and Sundays, for each season, and contains a high degree of source identification.	Early 1989	The 1985 detailed inventory will characterize emissions sources in the United States and Canada, and will provide input for driving the RADM atmospheric transport and transformation model. The 1985 data will support the Emissions State of Science/Technology Report and the integrated assessment activities involving RADM.
Integrated Projection Model Set: This interconnected set of sector models and energy/economic drivers will be used to project future emissions of SO_2, NO_x, and VOC as a function of assumptions regarding future economic, energy, technology, operational, and control scenarios; and for estimating the primary and secondary costs of illustrative control scenarios in the NAPAP Integrated Assessment.	Early 1989 (updates in early 1990)	The Integrated Projection Model Set will play a major role in answering key questions in the NAPAP Integrated Assessment with respect to potential future emissions patterns and how and at what costs these patterns might be altered.

DELIVERABLES	DATE	SIGNIFICANCE
Site-Specific Utility SO_2/NO_x Control Report: This report will describe the methods and costs associated with the retrofit reduction of SO_2 emissions from typical utility units. A detailed evaluation of 15 plants will form the basis for a more generalized evaluation of the remaining top 200 emitters of SO_2.	Early 1990	This report will provide an improved source of information on the cost of accomplishing emission reductions from the utility sector, because it will be based on site-specific information as opposed to "generic" cost information. Information, including retrofit difficulty estimates, gathered in the development of the report will be used in the Advanced Utility Simulation Model, and will also be utilized in analyses to be contained in the scenario comparisons of the NAPAP Integrated Assessment.
Emerging Technology (Cost, Performance, and Emissions Report): This report will analyze the present and future state of industrial sectors and emerging energy technologies, and describe factors which will determine technological penetration and the resultant emission patterns.	Early 1990	The report will provide important information for integrated assessment activities with regard to what future emissions patterns may result because of the penetration of new energy technologies in new plant or repowering/reboiler modes. The report will be used in analyses to be contained in the future conditions and scenario comparison parts of the Integrated Assessment.

ATMOSPHERIC CHEMISTRY

1988 RESEARCH HIGHLIGHTS

Natural Emissions

o NO_x emission rates from soils have been refined.

The emission of nitrogen oxides from soils is a source of atmospheric NO_x, but the magnitude of this source is difficult to assess. A major goal of recent field studies has been to reduce the uncertainty associated with NO_x emission measurements, and to improve methods for estimating emission rates from areas of the size of RADM grid cells.

During the last year, NO and NO_2 emission rates have been measured at several sites including an ungrazed grassland site in Colorado, an uncultivated, ungrazed forest clearing in the eastern United States, and an agricultural area in the eastern U.S. Results of these studies and of controlled tests on synthetic soil samples have been used to relate emission rates to soil nitrate concentrations, soil temperature, soil type, moisture, and pH. Emission rates appear to be independent of ammonium levels, for the soils that have been studied; the emission algorithm that has been developed depends only on soil temperature and nitrate level, for reasonable levels of soil moisture. The results confirm that soil emissions account for an average of about 5 percentof all NO_x emissions in the eastern U.S. Ongoing work is focused on the need to refine this estimate and to provide uncertainty bounds for it.

o Systems for measuring ammonia (NH_3) in air have been improved.

Ammonia is the the only basic gas in the troposphere with concentrations that are readily measurable, yet can act as an acidifying agent in soils as a result of its incorporation in biota and the release of nitrogen in soil. Ammonia is known to be derived from the decay of plant and animal matter, at average rates that are presently poorly specified. An assessment of acid deposition requires an understanding of the scope of this problem. Definitive measurements of ambient concentrations of ammonia in key regions would permit such an estimate. Since gas phase ammonia is particularly difficult to measure reliably, work has started by emphasizing instrument development, assessment of field reliability, and pilot field measurements.

An automated metal oxide annular denuder system has been developed for gas phase ambient ammonia measurements; this design represents an advance in ammonia sampling technology. The system is based on the adsorption of ammonia on molybdenum oxide, followed by its release (upon heating) as nitric oxide which can then be measured using chemiluminescence detectors. Field tests have been conducted at Niwot Ridge and the Pawnee Grassland research sites in Colorado.

Gas Phase Chemistry

o Field tests of alternative measurement techniques have continued.

As a continuation of the effort reported last year, two additional field campaigns were devoted specifically to comparing the performances of four of the most popular techniques currently being used to measure NO_2 concentrations, with the intent to demonstrate the advantages and disadvantages of each. The most common technique relies on the detection of NO produced by catalytic reduction of NO_2; these methods were found to be susceptible to interference by other compounds which are also affected by the catalyst. Methods based on the measurement of luminescence produced by reaction of NO_2 with organic dyes (usually luminol) offer a small and convenient package, but can also suffer from interferences. A more specific but more complicated method is based on the conversion of NO_2 to NO by ultraviolet light followed by the detection of the NO by chemiluminescence. The most advanced method is based on the use of tunable diode lasers; this was found to be both sensitive and precise, but too elaborate for routine use. In general, the results of the comparisons permit more confident selection of measurement methods for field programs.

o A major field investigation of interactions of NO_x, volatile organic compounds, and oxidants was conducted.

An intensive study was conducted during the summer of 1988, at the Scotia Range site in central Pennsylvania, operated by Pennsylvania State University. Measurements were made of of a wide range of oxidants and nitrogen compounds, including organic nitrates. Measurements were also made of the emission of isoprene from the forest.

An imbalance between the total of the reactive nitrogen oxides (NO_x) and the sum of the individual components (NO + NO_2 + PAN + HNO_3) was observed over a wide range of conditions. The sum of the individual measured components was less than the total reactive NO_y, sometimes approaching 20 percent, greater than had been encountered previously. The implications of this imbalance are to be explored further during 1989, especially in regard to the uncertainty of predictions of models.

o Reaction rates of volatile organic compounds with NO_x were measured.

The rate constant for the reaction of NO_3 with hydrocarbons derived from forests (isoprene, and alpha-pinene) and with acetaldehyde were measured as a function of temperature in a series of laboratory studies. Isoprene and alpha-pinene are emitted by trees and are thought to be the most important natural nonmethane hydrocarbon emissions; they influence the formation of oxidants and hence affect the production of acids. Acetaldehyde is one of the principal products of the oxidation of anthropogenic hydrocarbons and is an important compound in the clear-air reactions that oxidize sulfur dioxide and NO_x to form acids.

o A new model has been developed to describe the interaction between photochemical reactions and vertical transport in the lower atmosphere.

The impact of natural volatile organic compounds (VOC) on the oxidation of NO_x and SO_2 and on the formation of O_3 in rural air has been studied using a one-dimensional photochemical model with more detailed vertical transport than in previous simulations. Such detailed vertical resolution may be important because the high reactivity of natural VOC causes their concentrations to decrease rapidly with height; in comparison, in rural situations anthropogenic VOC are relatively well-mixed in the lower atmosphere. The model shows that the effects of natural VOC on the concentrations of oxidants in the lower atmosphere can be substantial. Potential consequences extend to the gas-phase oxidation of NO_x and SO_2 and the aqueous-phase oxidation of SO_2; the H_2O_2 produced by the gas-phase reactions provides much of the fuel for the aqueous-phase oxidation, and hence natural VOC's influence both gas-phase and aqueous-phase chemistry.

Preliminary conclusions drawn from this model, in combination with knowledge of aqueous-phase chemistry, are as follows:

(1) Natural VOC increase the rate of formation of peroxides and ozone in rural air.

(2) The aqueous-phase oxidation of SO_2 is enhanced by natural VOC.

(3) In relatively clean air, gas-phase oxidation rates of NO_x and SO_2 are also affected. This effect is less evident in air with elevated NO_x levels.

These results on the importance of natural VOC's in producing oxidants in rural areas differ somewhat from other model results. Research is underway to investigate the basis for these differences.

Precipitation Scavenging

o The 3CPO/PRECP VI field study was conducted.

A field study of scavenging by midwestern convective storms was completed during June, 1988. The goal was to provide the strongest possible data base for evaluation of the convective-storm scavenging portion of the Scavenging Module of the Regional Acid Deposition Model (RADM). Data are currently under analysis, and will be applied along with PRECP V data for module evaluation during the coming year.

o Analysis of the PRECP I and PRECP II data was completed.

PRECP I's data analysis has been concluded; a final series of computer simulations is now being performed at the Universities of Kentucky and Iowa. Diagnostic model runs for the PRECP II study are nearing completion and will be published in the open literature during 1989. Efforts on PRECP II will conclude with this step. In addition, data from PRECP III and PRECP IV have been compiled for use in model evaluation.

o Advanced cloud-physics models have been developed.

On the basis of the field studies conducted thus far (identified above), several advanced cloud-physics parameterizations have been developed for use in conjunction with the scavenging modules of RADM. In essence, the advanced models will be used to test the adequacy of the simpler parameterizations used in RADM, and will provide an objective evaluation of the uncertainties involved.

o The collection of gas-phase reactants by ice particles and by water droplets was studied and reported.

Many chemical conversions in the atmosphere take place on surfaces or in liquid drops; it has been estimated that half of the SO_2 emitted by industry is oxidized to sulfuric acid in liquid drops by peroxides. A laboratory study was conducted to measure the ability of liquid droplets and ice particles to absorb various trace gases. The collection of SO_2, H_2O_2, O_3, NO_3, and NO_2 by ice particles, and the subsequent reactions, were measured and have been reported. Nitric acid exhibits the highest affinity for ice surfaces, with a retention of greater than 95 percent in all cases. Hydrogen peroxide shows a variable affinity, indicating a retention ranging between 50 percent and 80 percent, and the remaining gases are less than 1 percent retained. There is a strong reaction between hydrogen peroxide and ozone on ice surfaces; this has strong implications for future modeling efforts involving in-cloud SO_2 oxidation.

Dry Deposition Processes

o The CORE/satellite dry deposition research network was extended.

The extension of research data on dry deposition rates, at selected "CORE" sites, to satellite stations where simpler measurements are made continued; a new satellite site in central New York is now being set up.

o Dry deposition data obtained routinely were compared against results using research methods.

"Benchmarking" efforts continued in 1988, with field studies at Oak Ridge, Tennessee, and State College, Pennsylvania. Results indicate that the routine "inferential" method consistently overestimated the deposition rate of O_3 by 20-40 percent; the cause appears to lie in an inadequate parameterization of cuticular uptake. The inferential model of dry deposition was revised by updating the descriptions of stomatal and cuticular resistance in the program.

o Dry deposition was compared to wet deposition.

Estimates of the dry deposition rates of relevant components (SO_2, SO_4, NO_3, HNO_3, and the base cations reported in wet deposition programs) were calculated for all 12 satellite research sites up to September 1987. These data were combined with wet deposition data at or near the satellite locations to determine the relative contributions from dry or wet deposition for each chemical species. For most locations, dry deposition of sulfur accounted for about half of the total deposition while the dry deposition of nitrogen compounds accounted for slightly more. The contribution by dry deposition to the total deposition of base cations (present as small particles) was substantially smaller with values ranging from 0.05 to 0.2. The role of large particles is presently being assessed, for both base cations and nitrate.

o Probability distributions of air concentrations were computed.

Weekly average air concentration data derived using the NOAA satellite-site filterpack network were in general found to be log-normal. This result will permit interpolation among the limited array of dry deposition research stations now in operation.

o Dry deposition to a forest floor was measured.

In an experiment in April 1988, the uptake of SO_2 and O_3 by the floor of a mixed-species forest near Oak Ridge, Tennessee, was measured. Preliminary results indicate that deposition velocities to the forest floor are on the order of 0.1 cm/s for both SO_2 and O_3, substantially lower than values appropriate for the forest as a whole. A major goal is to examine the role of soil moisture on the uptake of O_3 and SO_2.

o The role of surface moisture was explored in field studies.

Experiments continue to reveal that dry deposition is closely linked to surface moisture. A major limitation of current models of dry deposition lies in their crude consideration of surface moisture; when plants are short of water, transpiration is limited and dry deposition rates are lower than if water is plentiful. When foliage is wet, very high rates of exchange of sulfur dioxide (in particular) are known to occur. Detection of surface water and inclusion of moisture in the description of the dry deposition process is an important factor. The wetness sensor deployed in the satellite network has been tested in a comparison study involving several alternatives. The results indicated that the sensors should be placed as close to the top of the canopy as possible, since strong gradients in humidity exist at night.

o Initial evaluations of the effects of surface heterogeneity on dry deposition have been conducted.

The spatial variability of dry deposition was examined for an 80 km x 80 km area in central Pennsylvania. This was accomplished by estimating and comparing dry deposition to individual 1 km x 1 km squares within the larger area. In this initial study, uniform meteorological conditions were assumed across the entire area. However, the nature of the surface, which controls the rate of pollutant uptakes, was allowed to vary and was characterized using satellite imagery. For both SO_2 and O_3, the spatially averaged deposition was estimated to be about twice that which would be computed if the surface were assumed to be covered by maize only, and about 20 percent lower than if it were grass.

o Throughfall methods were tested using sulfur isotopes.

During 1988, experiments were conducted using ^{35}S tracers with mature trees to determine that foliar leaching of sulfate is generally insignificant relative to the total flux of sulfate in forest throughfall. This has important implications for NAPAP model evaluations of sulfate deposition, suggesting that fluxes in throughfall primarily reflect total wet plus dry deposition of sulfate. Studies at a new site in the Smoky Mountains indicate that cloudwater fluxes may also be measured in this manner.

MAJOR DELIVERABLES

DELIVERABLE	DATE	SIGNIFICANCE
Report on the annular denuder method for measuring ammonia.	Early 1989	Estimates of ammonia emissions from natural sources require accurate measurement of ammonia in air.
Report on field measurements of natural nitrogen compounds.	Mid-1989	NO emissions from soil add to emissions from anthropogenic sources. This report will document emission rates from soils across the eastern U.S.
Inventory of natural aerosol fluxes, elemental analysis,solubility and mean time	Early 1990	Soil-derived particles tend to neutralize rain acidity. Assessment of the consequences of reducing emissions require accurate estimates of background neutralizing capacity.
Refined inventory of nitrogen emissions from soils in the continental U.S.	Early 1990	The NAPAP assessment reports require an inventory of natural sources of NO_x, since these add to industrial emissions.

DELIVERABLE	DATE	SIGNIFICANCE
Report on natural hydrocarbon emission inventory for the continental U.S.	Early 1990	The NAPAP assessment requires background VOC data. VOC's interact with other chemicals in the air, and influence the production rates of acids.
Report on background NH_3 levels representative of major biomes in the U.S.	Mid-1990	The NAPAP assessment requires background ammonia data, because ammonia can neutralize atmospheric acids in the air and still act as an acidifying agent in the soil.
Report on comparisons of methods for measuring NO_2.	Early 1989	High-quality field measurements are required to test model predictions and guide module development, yet some methods are not reliable.
Report on the key photochemical and transport processes that control the budget of atmospheric oxidants.	Mid-1989	The report will help assess uncertainties in modeling the oxidation of sulfur and nitrogen oxides in the lower atmosphere.
A model of natural background ozone distribution and natural oxidation capacities	Late 1989	Modeling the consequences of reductions in emissions requires that the background situation be well understood as well as that in polluted air.
Report comparing H_2O_2 and organic peroxide concentrations in Colorada and Pennsylvania.	Late 1989	The report will quantify differences between the oxidizing capacities of polluted and clean air.
Report on chamber simulation of single day H_2O_2 chemistry - simple hydrocarbons/NO_x mixtures.	Late 1989	Data from smog chambers will provide a basis to refine model formulations and assess modeling uncertainties.
Report on regional budgets of odd-hydrogen species, H_2O_2 and O_3	Early 1990	Background concentrations are needed to provide a baseline for RADM predictions.

DELIVERABLE	DATE	SIGNIFICANCE
Report on comparisons of methods for measuring VOC's.	Late 1990	High-quality data are required for model testing and for module development, yet some methods are not reliable. It is suspected that VOC's may presently be underestimated.
Report on chamber simulation of single day H_2O_2 chemistry -comples hydrocarbon/NO_x mixtures.	Late 1990	The report is needed to provide an independent basis for testing model formulations.
Completion of subgrid evaluation of reaction kinetics and scavenging modules.	Mid-1989	These results will be of direct importance for interpreting the validity of the regional model(s).
Installation and application of source attribution and emission-change software in regional acid deposition model(s).	Mid-1989	This methodology will be employed as a model-based tool for direct application to the 1990 assessment.
Completion of processing of PRECP III-PRECP VI data bases for model evaluation purposes.	Late 1989	These data provide a basis for direct comparison of RADM predictions against field observations.
Report on sticking coefficients for water surfaces, related to atmospheric oxidant concentration.	Late 1989	Much of the oxidation of NO_x and SO_2 occurs in droplets. The rate of oxidation depends on the rate of transfer from the air into the droplet of gas-phase reactants.
Completion of statistical analysis of precipitation chemistry spatial/temporal variability.	Early 1990	This analysis will have direct importance for the application of historical and special-purpose precipitation-chemistry data for refined RADM model evaluation.
Summary of wet and dry deposition data by location and by season.	Early 1989	These data are required as input to effects computations and for testing models such as RADM.

DELIVERABLE	DATE	SIGNIFICANCE
Benchmark inferred dry deposition data against more direct measurements at CORE and selected other sites.	Mid-1989	These data are needed to verify deposition deposition estimates from routine methods. Such tests are conducted every year.
Report on spatial and temporal distributions of dry/wet ratios.	Early 1990	Assessment of total deposition to effects areas can be based on assumed dry/wet ratios. The assumptions need to be tested.
Report on the application of throughfall methods to measure cloud droplet and dry deposition.	Early 1990	This report will present data on the total deposition of sulfate in wet deposition, droplet interception, and dry particle deposition at high altitude locations.
Benchmark inferred dry deposition data against more direct measurements at core and selected other sites.	Mid-1990	Confidence in dry deposition estimates based on indirect routine methods is based on comparisons against independent measurements at shared sites. Comparisons are made every year.
Assess the uncertainty in sub- regional estimates of dry deposition from measurement sites and modeling.	Late 1990	It is needed to assess the error involved in using point measurements to represent areas and vice versa. The RADM produces spatial average estimates, whereas measurement programs yield local quantifications.

ATMOSPHERIC TRANSPORT AND MODELING

1988 Research Highlights

Model Development

The version of the Regional Acid Deposition Model to be used in NAPAP's 1990 Assessment, RADM II, was completed at SUNY-Albany. This version contains important advances over earlier versions of the RADM: (1) an improved advection scheme which significantly reduces diffusion introduced artifically through the mathematical solver; (2) an updated dry deposition module; (3) improvements to the aqueous chemistry and wet scavenging module which resulted from testing against the scavenging module delivered from Pacific Northwest Laboratory to SUNY and; (4) a significantly enhanced gas-phase chemistry module. RADM II is undergoing final testing and will be transferred to EPA for use by NAPAP in January 1989.

A "tagged species" Engineering Model, based on the full RADM, was developed by EPA in cooperation with SUNY-Albany, and implemented on a VAX computer system. The tagging of certain emitted sulfur species allows for source attribution to be studied. Under conditions when oxidants are limited in the atmosphere, which can result in non-linear source-receptor relationships, the linear-chemistry modeling assumption that the effects of different sources of emissions can be treated independently and then superposed is not valid. Consequently, the contribution of emissions from specified sources need to be determined "in situ" with the other emission sources. The Engineering Model version of RADM, operating on an Eulerian framework, is ideally suited to meet this analysis need.

Model Evaluation

The Central United States RADM Test and Assessment Intensives (CURTAIN) are a series of aircraft measurements designed to obtain data along the inflow boundary of the RADM modeling domain used in applications. These data can also be used to establish seasonal trends in critical chemical and physical varibles to guide the setting of chemical concentrations at the RADM boundaries. Further, the data can be used to provide critical chemical measurements for use in the RADM so that observed concentration patterns can be compared with RADM predictions. Flights were made in each of four seasons along a path near the Mississippi River between Iowa and the Gulf of Mexico. The data show significantly higher hydrogen peroxide concentrations in summer than in winter. Consistent with 1987 results, spring and summer ozone concentrations were higher than the fall and winter. Both hydrogen peroxide and ozone are important oxidants that transform sulfur dioxide into sulfuric acid. No significant altitude dependence was observed for hydrogen peroxide. The seasonal patterns were duplicated by a photochemical model, indicating that the increase in solar radiation and absolute water vapor from winter to summer contributed to the increase in oxidant level. Conversely, hydrocarbon concentrations were minimized during the summer. Sulfur dioxide concentrations peaked in both winter and summer at low altitude, but at high altitude little seasonal trend was evident. Based on the observed ratios between hydrogen peroxide and sulfur dioxide, the in-cloud conversion of sulfur dioxide to sulfate in this region is not expected to be oxidant limited during the summer. There may be oxidant limitations during other seasons.

The ACID-MODES surface monitoring network was installed and made operational in June 1988. ACID-MODES is a project in support of a two-year regional acidic deposition model evaluation program. This EPA-sponsored surface network is coordinated with three other networks under the sponsorship of the Electric Power Research Institute, the Atmospheric Environment Service of Canada, and the Ontario Ministry of the Environment. These four networks comprise more than 100 sites distributed across eastern North America for use in the operational evaluation of the models. As a part of the model evaluation field study program, intensive sampling from additional research-grade surface sites and from aircraft was conducted during the period of August 15 through October 7. This intensive program is designed to provide data for the diagnostic evaluation of regional acidic deposition models. Although no results of the intensive data collection program are available as of yet, the aircraft program was successful in completing all planned flight missions for obtaining data for use in specific diagnostic model tests.

Model Application

Measurements of dry deposition data throughout the eastern United States are limited, yet can be an important factor in perfoming assessments of the acidification of aquatic resources. As a means of interpolating limited measurements and estimating dry deposition levels for the eastern United States, the Regional Lagrangian Model of Air Pollution (RELMAP) was tested against observational data from twelve monitoring sites in the northeastern Unites States and southeastern Canada. The results of this test suggest that RELMAP underpredicted dry deposition near sources and overpredicted dry deposition at longer distances from sources, and as a consequence, did not replicate the strong dry deposition spatial variations indicated by the available data. Modifications to the RELMAP were made. In addition, the first generation version of RADM (RADM I) was applied to the study. The results indicate that the revised RELMAP and the RADM I both provide reasonably good replications of the observed dry deposition fields. This indicates that the revised RELMAP and the RADM I might be used as a means of interpolating actual dry deposition measurements, once model calculations have been "anchored" to actual observations. This technique of using models to interpolate limited data sets could be an important methodology for providing the information needed for effects assessments.

Special Studies: Characteristics of Regional Transport

The Across North America Tracer Experiment (ANATEX) was a field study conducted in early 1987 to provide experimental data on the meteorological influence on the transport and dispersion of pollutants over scales of hundreds to thousands of kilometers. By releasing tracer material at two different ground level locations in the central United States and tracking the material as it spreads eastward, data which demonstrate the ability of long-range transport models to represent the regional transport of pollutants released at ground level can be obtained. Further, the data can be used to characterize meteorological influences on regional transport.

Although the analyses are somewhat limited since tracer observations are based on 24-hour averages, preliminary results show that the behavior of the tracer material after release is in part a function of the release relative to large scale weather patterns. For example, several cases indicate that the material remained within the airmass into which it was released, particularly behind a frontal system, for extended periods. The position of the material remained stationary relative to troughs and ridges, and horizontal transport was accomplished by movement of these troughs and ridges relative to the ground. This illustrates the classic case of fronts acting as barriers to the pollutant. However, there were also cases where material was released in the vicinity of a front, and found behind the front in subsequent sampling periods, or was dissipated by the passage of the front, presumably due to strong vertical mixing and wind shear aloft. These preliminary observations suggest that pollutants released at ground level may not always behave in a classic sense near frontal systems. This may be of considerable importance for the development and evaluation of long-range transport models, which incorporate a variety of assumptions regarding the flow of pollutants in the vicinity of air mass boundaries.

Special Studies: Washington Mesoscale Field Study

The Washinton D.C. Mesoscale Field Study, like its predecessor the Philadelphia Study, was designed to provide observational information on the relative importance of industrial and transportation emissions within the "urban plume" on the wet deposition of pollutants on the mesoscale. The intention is to provide insight on the amount of urban emissions available for long-range transport, which is directly relevant for the evaluation of models such as the RADM. Results from four storm measurement periods in the Washington study confirmed findings from the Philadelphia study: When wind directions remain relatively uniform throughout the storm event, clear upwind-downwind differences in rain chemistry are observed. Downwind nitrate wet deposition increases considerably above background. The study further indicates that mesoscale circulations embedded within the storms can have a significant influence on deposition patterns.

MAJOR DELIVERABLES

DELIVERABLE	DATE	SIGNIFICANCE
A report on an analysis of emissions change and source attribution using the RADM II and the Engineering Model.	Late 1989	The report will provide an assessment of source attribution using the new models, incorporating the effects of nonlinearity.
A report on an analysis of nonlinearity based on the applications of RADM and the Engineering Model.	Late 1989	This report will provide an assessment of the importance of nonlinearity in the acidic deposition system, involving transport and transformation. It will also provide a reference against which to judge earlier estimates of the effect of emissions changes in a given source region on deposition to receptor areas.
A report covering 1987 ANATEX results.	Mid-1989	This report will provide a data base for testing the estimates from mathematical models of inert gas transport under more complex meteorological conditions.
A report on the preliminary evaluation of RADM II against the first six months of field study data.	Early 1990	The report will provide a first evaluation of the RADM II. It will also provide an assessment of the degree of confidence associated with the use of RADM for NAPAP's assessment activities.
A report on CURTAIN program boundary condition measurements for use by RADM.	Late 1989	The report will provide an important data base for reducing uncertainties in setting boundary conditions for the RADM model.

ATMOSPHERIC DEPOSITION AND AIR QUALITY MONITORING

1988 RESEARCH HIGHLIGHTS

o The annual data summary of precipitation chemistry in the United States for 1987 was published by the NADP/NTN Coordinator's Office at Colorado State University. The annual mean pH data for 1987 are shown in Figure IV-1. Network data suggest no striking changes in the pH of precipitation during the past several years since NAPAP has been producing these maps. Several organizations, including the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (EPA), are involved in analyzing and summarizing data from the NADP/NTN in preparation for the NAPAP assessment.

o A LOWESS (locally weighed scatterplot smoothing) analysis of the NADP/NTN blind-audit data was performed by the USGS for all data from 1980 to 1987. This evaluation indicates that during the 7-year period, contamination of the samples by sampling-materials has decreased for calcium, magnesium, chloride, and sulfate. The annual average contamination in samples of calcium, magnesium, chloride, and sulfate is, respectively, 0.05 mg/L, 0.02 mg/L, 0.04 mg/L,

FIGURE IV-1. pH of Wet Deposition in 1987. (Precipitation-weighted Annual Average) Based on NADP/NTN Data. Isolines omitted in West due to sparceness of data points.

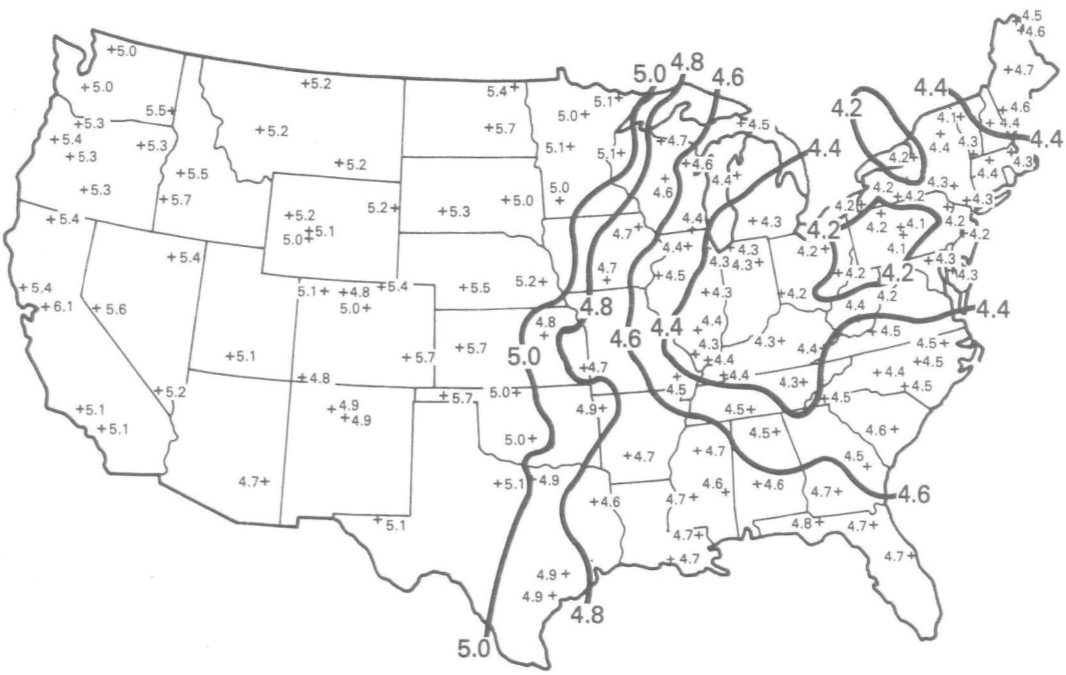


FIGURE IV-2. NDDN Monitoring Sites. Continental United States. *(Through Fiscal Year 1988)*

and 0.09 mg/L. Sodium contamination of the samples by the same sources generally decreased until 1986 and increased during 1987. Hydrogen-ion neutralization appears to have decreased until about 1986 and has been steady since that time. This recognition of sample contamination is important because it permits more accurate data evaluation and deposition computation.

o A 52-station National Dry Deposition Network (NDDN) has been designed (Fig. IV-2) and is in the process of deployment. Basically a long-term trends network, the first thirty-five sites have been placed in operation in the eastern United States in support of an international model evaluation program sponsored by the EPA, Electric Power Research Institute, Atmospheric Environment Service of Canada, and the Ontario Ministry of the Environment. Field, laboratory, and data management procedures have been developed to permit rapid delivery of validated data. As the first broad-scale dry deposition network established in the U.S., data from the NDDN will be used to determine the contribution of dry deposition to total deposition in the East.

The current database is limited to 35 sites, some of which have less than 1-year's data; however, important patterns have begun to emerge. First, the seasonal variability of SO_4^{-2} is high relative to that to HNO_3 and NO_3^-. Average SO_4^{-2} concentrations decrease by a factor of 2 from summer to winter, while SO_2 concentrations increase by a factor of 2, except in the midwest. HNO_3 is reasonably constant from season to season, while NO_3^- exhibits what appears to be site-specific variability. Second, annual average rural ozone concentrations for 1987 show little variability across the network (range is from 30 to 34 ppb). On a monthly basis, however, significant seasonal variability is apparent. In general, the southwestern Virginia site and the site southwest of Chicago, Illinois, exhibit the highest and lowest monthly ozone values, respectively. Diurnal variability, or the lack thereof, appears to explain much of the difference between these two extremes.

o The Global Trends Network (GTN) was established in 1980 to measure precipitation chemistry in areas far from manmade sources. Between May 1980 and August 1985, 190 precipitation events were sampled on Amsterdam Island, a GTN site located in the central Indian Ocean, and samples were subsequently analyzed for major chemical constituents. Iosbaric back trajectories were calculated for each event and a cluster analysis technique was used to identify patterns in the multivariate data sets for both chemistry and transport. The cluster analysis technique represents a relatively objective alternative to the more subjective method of classifying trajectories according to compass sector, or stratifying chemical concentrations into evenly spaced ranges. In this analysis two chemical clusters were identified; one representing 141 samples and the other having 21 samples. Storms in the smaller chemical cluster occurred mainly in the spring and were associated with significantly greater deposition of H^+, NH_4^+, NO_3^-, and non-sea-salt (nss) SO_4^{-2}. Samples in the larger subset were very clean. Four distinct transport clusters revealed no significant differences for either concentrations or per-event depositions of any of the major chemical constituents suggesting that transport is not an important factor in controlling the chemical composition of precipitation on the island. Although a continental influence on some air masses was suggested from both back trajectories and data for ^{222}Rn and CO_2, a signal in terms of major ions in associated precipitation events was not discernible from the marine background after the mean 3.5 day transport over the ocean. A significant seasonal signal in nss SO_4^{-2}, NH_4^+ and H^+ is consistent with the hypothesis of stronger source strengths of marine emissions and enhanced photochemistry during warmer months.

o A major intercomparison program has been undertaken at the Pennsylvania State University Atmospheric Chemistry Research Site. Installation of an instrumentation trailer and new precipitation and air sampling equipment proceeded throughout the spring of 1988. Complete operations began in June and are scheduled to last approximately 2 years. The purpose of the project is to intercompare collectors and protocols for sampling and analysis used by all of the major measurements programs involved in NAPAP. In addition to program intercomparisons, most of the programs have set up duplicate sampling equipment in order to obtain data from which measurement precisions can be estimated. This large intercomparison project follows and extends an earlier project, which began in October 1988 and is coordinated by the USGS, to compare the sampling methodologies of CAPMoN and NADP/NTN. Preliminary results of this initial study reveal minor differences in some parameters, specifically NO_3^- and NH_4^+, but overall agreement is within about 10 percent. Extensive analysis of the complete data sets from all of the programs involved, to be conducted toward the end of the 2-year measurement phase, should provide a quantitative means of assessing the quality of the data on which validation of the acidic deposition models will depend.

o Daily precipitation samples are collected at nine sites of the Multistate Atmospheric Power Production and Pollution Study (MAP3S) network in the eastern United States. An analysis of the distribution of event deposition at these sites has shown that while a significant fraction of the deposition of the major ionic species is contributed by relatively few events, the MAP3S network sites are not as strongly "episodic" as are sites in remote areas. The deposition distributions for the major species are quite uniform spatially: the highest 20 percent of deposition events contribute about 55 percent of the annual deposition of sulfate, whereas the highest 20 percent of the precipitation events contribute only 40 percent of the annual precipitation amount. This indicates that high deposition episodes are in part caused by relatively high ionic concentrations and are not exclusively due to high precipitation amounts. Therefore, the study of ecosystem responses to acidic wet deposition must consider the effects of high concentration events as well as episodic deposition amounts.

o MAP3S data have been analyzed for evidence of temporal trends. At some sites the data record now extends beyond ten years. Statistically significant ($p=0.05$) linear trends were found in the annual precipitation-weighted mean ionic concentrations for only a few species at a few sites. Concentrations of H^+ decreased with time at both Ithaca, New York and Oxford, Ohio, but only at Oxford did the concentration of SO_4^{-2} also decrease significantly. Except for NH_4^+, which has increased with time at Ithaca, no other significant trends over the MAP3S data period from 1977 to 1986 were found for any of the other major ions at any other sites.

o An analysis of pre- and post-event, gas-phase concentrations of ammonia at Pennsylvania State University found that below-cloud scavenging contributed less than 50 percent of the ammonium found in rainwater at this MAP3S site. In spite of the high solubility of ammonia in water, the limited rate of diffusion of ammonia to raindrops prevents the drops from achieving equilibrium with gas-phase ammonia during their transit from cloud base to the surface. Therefore, the majority of the ammonium ion found in rainwater must be incorporated via in-cloud processes.

MAJOR DELIVERABLES

DELIVERABLE	DATE	SIGNIFICANCE
1988 precipitation chemistry data for all NADP/NTN stations.	Mid-1988	These data will be available for interpretation by NAPAP scientists and used for NAPAP assessment activities.
A report on the temporal and spatial trends analyses of wet deposition data.	Late 1989	This report will provide an interpretation of spatial and temporal changes in wet deposition over the last 10 years.
An issue paper addressing spatial interpolation techniques for wet deposition.	Mid-1989	This paper weighing the pros and cons of a variety of interpolation techniques will be presented and recommendations made on how best to present data for NAPAP Assessment.
A data report and analysis from the National Dry Deposition Network, 1984-1988.	Mid-1989	This report will describe and analyze the first four years of data from the National Dry Deposition Network.
A summary report on 1987 MAP3S network data.	Late 1989	This report will provide an update on precipitation chemistry statistics and trends through 1987.
A summary report on MAP3S network research activities.	Late 1989	This report will provide an overview of all of the research accomplishments produced by the MAP3S community since the start of the network in 1976.

DELIVERABLE	DATE	SIGNIFICANCE
Several journal articles will be published on the higher moments of the distributions of event precipitation chemistry.	Mid-1989	These articles will provide information on the shape of the frequency distributions of ionic concentrations in precipitation that can be compared to results from computer simulations of acidic deposition processes.
A journal article on the use of multiple regression techniques to classify western NADP/NTN sites in terms of the relative importance of SO_4 and NO_3 as acidifying influences on precipitation.	Early 1989	This publication will identify local and regional sources of air pollution which dominate acidic deposition at specific monitoring sites.

TERRESTRIAL EFFECTS

1988 RESEARCH HIGHLIGHTS - CROPS

Soybean Response to Acidic Rain

Controlled experiments utilizing simulated acidic rain indicate that ambient and even greater-than-ambient levels of rain acidity have no direct effects on the growth and productivity of the cultivars examined. Studies of two soybean cultivars (Williams and Cutler 71) demonstrated no significant differences in growth or seed yield in treatments groups receiving simulated rain at pH levels of 3.0, 3.5, 4.0, and 5.0.

These experimental results are consistent with other studies and do not appear to support earlier reports that acidic rain may reduce soybean yield although further studies of cultivar differences may be necessary to fully evaluate this conclusion.

Response of Corn to Acidic Rain and Drought

Preliminary results from a third year of study to examine the possible interaction of rain acidity and drought stress on corn are supportive of the second year's results which indicated no significant interaction. This outcome suggests that an apparent interaction between the two stresses observed for one of two corn cultivars during the first year of study cannot be easily explained or readily repeated. Studies at another research institute suggest a possible mechanism for such an interaction but corroborating studies have failed to provide additional support.

These results tend to minimize early speculation that an acidic rain event during pollination and after prolonged drought stress may be an important mechanism by which corn yield is reduced during periods of drought stress.

Acidic Rain and Ozone Effects on the Rhizosphere

Studies using sorghum x sudangrass hybrid seedlings in a soil-sand mix were completed to examine the effects of ozone and acidic rain on rhizosphere microorganisms. Opposing effects of the two types of pollutants (generally inhibitory at the highest O_3 level and stimulatory at the highest rain acidity level) contributed to a significant O_3 x acidity interaction with respect to shoot growth.

Ozone and acidic rain also generally caused different changes in the rhizosphere, but an interaction was observed for only one of eight assays. Conclusions regarding pollutant effects on rhizosphere ecology must be considered in the context of specific pollutants and microorganisms.

Acidic Fog Effects in California

Strawberry plants exposed to several repeated simulated fog events at pH levels of 1.6 had reduced yield compared to plants exposed to higher fog pH values; however, pH levels of 2.0 did not result in yield impacts after ten weeks of treatment although visible injury was evident. Injury of the calyx at pH 2.8 and lower suggests that crop marketability may be affected at these lower pH levels.

These studies indicate that further research and monitoring activities are needed to examine the magnitude and extent of low acidity fog events in the south coast of California and their possible effects on crop yield and quality.

Acidic Deposition Effects on a Forage Plant/Soil System

The response of a forage ecosystem to different deposition acidity levels over the short term was examined to determine possible impacts on an agricultural system regarded to be potentially sensitive to acidic deposition. In experiments using simulated rain for two acidic, low CEC unfertilized soils, orchardgrass seedling viability and dry weights were significantly enhanced by the two most acidic treatments (pH 3.1 and 2.5) compared to pH 3.7 and 4.3. The composition of the soil solution was also affected by the acidity of the rain treatments; nutrient levels, acidity, and ionic strength increased while the Ca/Al activity ratio decreased with increasing rainfall acidity.

Agricultural soils lacking natural buffering ability and receiving relatively low intensity management may be particularly sensitive to acidic deposition, yet these studies with an orchardgrass forage system indicate that simulated rain at high acidity levels can have a positive effect on seed germination and growth even though soil solution chemistry is changed.

Effects on Soil Through Foliar Applications of Acids

Foliar application of sulfuric acid (pH 3.2) to recently germinated alfalfa, corn, fescue, and soybean had little influence on the acidity of the soil adjacent to the roots of these plants when compared to plants treated with a control solution (pH 5.6), except for corn where soil pH adjacent to the root was reduced by 0.1 unit. Regardless of treatment, there was a trend for pH differences in the vicinity of roots to increase as bulk soil pH increased from 4.0 to 6.2.

There is little evidence that application of acidic solutions to foliar surfaces changes the acidity level of root exudates to the degree that soil pH is affected, except possibly for corn growing in nearly neutral soil.

Interactive Effects of Ozone and Sulfur Dioxide

Exposure to very high concentrations of sulfur dioxide (as high as 0.4 ppm for 4 hrs per day, 5 days per week for 4 weeks) did not produce any visible injury symptoms in three watermelon cultivars in greenhouse experiments. However, foliar injury resulting from 0.1 ppm ozone for the same exposure times was significantly increased when combined with simultaneous sulfur dioxide exposures that had no effect when they occurred in the absence of ozone.

Further research at lower pollutant concentrations is indicated to determine if ambient levels of sulfur dioxide and ozone interact synergistically to affect watermelon growth and yield as is reported for the higher concentrations used in this study.

Ambient Ozone Affects Melons in Indiana

Additional observations of field-grown melons in Indiana indicate that apparent foliar injury from ambient levels of ozone was more prevalent in watermelon than in muskmelon and that early maturing varieties were more susceptible to injury than late-maturing varieties, perhaps because higher levels of ozone occurred during susceptible growth periods of the early-maturing varieties. Both muskmelons and watermelons had lower yields in plants exposed to non-filtered air compared to plants grown in open-top chambers with filtered air that removed ambient ozone.

Differential ozone sensitivity in melon cultivars may be related to differences in maturity times and periods of high ambient ozone concentrations during susceptible life stages. Ambient ozone apparently reduces the yield of some melons in southwestern Indiana.

Use of EDU to Examine Ozone Effects

In field experiments using the antioxidant EDU to protect plants from ambient levels of ozone, five white potato cultivars were differentially susceptible to ambient ozone with respect to foliar injury and yield reduction. Significant effects on yield were observed in two of three cultivars in New Jersey in 1980 when foliar injury was 75 percent or greater and cumulative ozone dose was 110 ppm hr. A similar approach to examine soybean cultivars during 1982 through 1985 did not indicate significant effects from ambient levels of ozone as high as 101 ppm hr.

Further studies of EDU effects on soybeans are needed to determine effective doses and to reconcile apparent differences in these results with those of several other studies that have predicted negative impacts on yields of soybeans at ozone concentrations similar to those causing no effect in these EDU studies.

Ozone Effects on Photosynthetic Processes

In experiments using isolated soybean cells, ozone reduced post-treatment photosynthesis when ozone was administered in the light or in the dark.

The results indicate that ozone can affect photosynthesis independently of affecting stomatal activity and that the damage can occur when the cell is not actively photosynthesizing. This provides significant new information on possible mechanisms of ozone damage.

Indirect Effects of Ozone on Soil Organisms

Experiments to determine the effects of ozone on beneficial root-infecting microorganisms indicated that ozone exposure induces an alteration of the carbon relations among subterranean clover and its two microbial symbionts, rhizobia and an endomycorrhizal fungus. Ozone suppressed the proportion of plant nitrogen that had been fixed from the air.

The results indicate that the direct effects of ozone on carbon allocation in plants may have indirect effects on associated soil organisms which result in further changes to the ecosystem. More research is necessary on this important aspect of potential air pollution damage to terrestrial ecosystems.

Survival of Ozone-Resistant Plants Within a Population

Clones of ladino clover that survived two years of exposure to high doses of ozone in the field were generally much more resistant to subsequent short-term ozone exposure than those surviving two years of exposure to low ozone levels.

Thus, individual plants within a perennial crop population that survive exposure to high levels of ozone may be genetically predisposed to resist the damage caused by ozone and are therefore less sensitive to subsequent ozone episodes than a population of unexposed plants. This suggests that under polluted conditions ozone-resistant individuals within a population have an advantage and that over time this may result in lower ozone sensitivity in naturally reproducing populations.

Varietal Differences in Response to Ozone

Results of initial experiments with two varieties of snapbean indicated physiological and developmental characteristics that might account for observed differences in their growth response to ozone. The sensitive variety may absorb ozone at a much higher rate and also appears to allocate a greater proportion of its total photosynthate to reproductive growth, perhaps leading to a reduced ability to compensate for pollution-induced leaf tissue injury than more resistant varieties.

These studies provide additional information that sensitivity to ozone is genetically determined and is related to metabolic rates and strategies of carbon allocation.

Ozone-Drought Interaction

Experiments performed with soybeans at two different laboratories did not detect a significant interactive effect on yield between drought and ozone stress, although both ozone and drought reduced yields. In one of the experiments root growth was stimulated by drought stress but reduced by elevated ozone, whereas, in well-watered plots ozone had little effect on root growth.

A number of experiments have indicated an interactive effect of ozone and drought stress on crop plants. Definitive conclusions cannot yet be reached, however, because, as these studies indicate, the results have not been totally consistent. More information on the influence of the timing and magnitude and the two stresses may resolve the inconsistencies.

1988 RESEARCH HIGHLIGHTS - FORESTS

SOUTHERN COMMERCIAL FORESTS

Dose-Response Studies

Open-top chamber studies of loblolly pine seedlings found no apparent effects of simulated acid precipitation through the first year of treatment. However, a small but significant growth increase was seen after 18 months at the pH 3.5 treatment. This stimulation in growth may be a fertilization effect from added nitrogen in the simulated acid precipitation.

Soil Characteristics

Based on a critical analysis of information on soils, it is expected that up to 30 percent of southern forest soils will show major changes in soil chemistry within the next 50 years. Many southern soils are not expected to retain deposited sulfur in the future. However, virtually all deposited nitrogen will be retained by the forest ecosystem. These projections will be vital inputs to NAPAP terrestrial assessment activities. This analysis was based on: (1) a synthesis of available literature on the biogeochemical impacts of sulfate and nitrate, (2) an examination of empirical evidence relating to the effects of sulfate and nitrogen on southern forest ecosystems, and (3) simulation models exploring soil sensitivity to sulfate deposition.

EASTERN HARDWOOD FORESTS

Minnesota-to-Michigan Deposition Gradients

A study of the relationships between various aspects of forest condition and atmospheric deposition concluded that there is a terrestrial sulfur gradient which increases from northeastern Minnesota to southeastern Michigan and corresponds to a gradient of atmospheric wet sulfate deposition. This conclusion was based on chemical analysis of forest floor and mineral soil samples from 169 forested plots.

Sulfate deposition estimates for each plot were derived from NADP monitoring stations and weather stations. For sampling and sataistical purposes, the anthropogenic deposition gradient was divided into five zones from west to east corresponding approximately to the 1, 2, 4, and 8 kg/ha/yr total sulfate isolines of the acid sulfate deposition gradient. Estimated total average sulfate deposition levels ranged from 7.5 to 18.2 kg/ha/yr for plots in zone one (west) through zone five (east) and were significantly different ($p=<0.01$).

The study did not indicate a corresponding gradient in sulfur concentration in tree woody tissue based on chemical analysis of increment cores. The strongest relationships between diameter growth and sulfate deposition estimates were for jack pine, red pine, and sugar maple. The relationship was negative for the pines and positive for sugar maple.

Maple Decline

A joint United States and Canadian research program on the causes of sugar maple decline is underway. Field plots have been established in both commercial sugar bushes and natural stands of sugar maple in Ontario, Quebec, New Brunswick, Maine, Michigan, New Hampshire, New York, Vermont, Massachusetts, and Wisconsin. Initial tree vigor ratings were made using a field manual prepared by the study team. Subsequent ratings in 1989 and 1990 will establish the rate of change in tree condition in relation to: (1) high vs. low pollutant (sulfate and nitrate) deposition zones, (2) commercial sugar bush vs. natural stands, and (3) initial vigor rating. Also underway is a feasibility study for sampling root feeding insects which have been implicated in maple decline.

Hardwood Decline

A case history study of hardwood decline in the eastern United States has been completed. This literature review found that many hardwood species have experienced declines and mortality events during the last few decades. This may be due to intensified reporting and to the maturation of the forest. Most of the mortality events have been attributed to various abiotic and biotic stress factors such as weather, management practices, and damage by insects and diseases. Firm evidence of atmospheric pollutant damage is present from point-source pollution such as smelters and from ozone damage on white pine. No consistent evidence was found in these reported studies for an association between patterns of hardwood mortality and regional atmospheric pollution.

Sensitivity Testing

A seedling exposure study to screen 12 important eastern hardwood species for relative sensitivity to acid rain, sulfur dioxide, and ozone, singly and in combination, has been completed. Ozone was by far the most toxic of the three compounds, as measured by foliar symptoms to seedlings. The more sensitive species in terms of foliar injury or growth response include white ash, yellow birch, sweetgum, red maple, yellow poplar, and sugar maple. White oak, shagbark hickory, and American beech were more tolerant. Increase in rain acidity from pH 4.2 to 3.0 caused white ash to decrease height growth by 6 percent and leaf dry weight, leaf area and new growth dry weight by 20 percent. This same change in rain pH caused an increase in yellow birch leaf area by 4 percent and height by 8 percent. The chlorotic leaf stippling, characteristic of ozone symptoms on leaves, was not affected by acid rain treatments. The sulfur dioxide response of these hardwood species seedlings was unclear. Ongoing work will evaluate atmospheric deposition effects on root and top growth of hardwood seedlings, including drought interaction. Atmospheric deposition effects on photosynthesis, water relations, and carbohydrate reserves will also be examined.

WESTERN CONIFEROUS FORESTS

Cloud Chemistry

A study of cloud chemistry and SO_4 and NO_3 deposition in the Rocky Mountains of Colorado found that, during the summer months, deposition from clouds was of the same magnitude as that from precipitation, and greater than that from dry deposition. A few cloud events sampled during the study period showed pH values similar to those for the northeastern United States. However, on average, the cloud samples from the Rockies were ten times less acidic than cloud sample values reported for the Northeast. The study demonstrated that accurate estimates of acidic deposition to high elevation forests in the West cannot be achieved without determining the contribution from cloud deposition.

Acid Mist and Foliar Leaching

For solution-cultured Douglas-fir seedlings with intermediate nutrient availability (0.1 x full strength nutrient solution), foliar leaching was higher for pH 3.1 acid mist exposures than for pH 5.6. However, the amount of nutrients removed was small relative to daily root uptake rates. None of the seedlings exposed to 24 low-pH fog events showed measurable deficiency symptoms or reductions in either biomas production or foliar nutrient concentration.

Ponderosa Pine Growth Trends

A study of ponderosa pine increment cores from 56 mixed conifer stands throughout the Sierra Nevada found no evidence of recent, large-scale regional growth reduction. Regionally, precipitation is the main variable influncing growth rates. Some sites in the southern Sierra Nevada showed recent reduced growth rates correlated with foliar ozone damage.

EASTERN SPRUCE-FIR FORESTS

High Elevation -- North

A 100 percent mapping of dead spruce and fir for all the high elevation forests in the northeast has been completed. Results indicate that, at elevations over 800 meters (2,600 feet) in the Adirondacks, Green, and White Mountains, red spruce mortality in the past 25 years has greatly reduced the number of trees. There is a decreasing gradient in damage from west-to-east with several mountains in the Adirondacks having 50 percent or more standing dead trees. Percent standing dead red spruce in the Green Mountains is less than that in the Adirondacks and less still in the White Mountains. Mortality has occurred in stands of differing age and disturbance history and there is high variability in mortality from mountain to mountain within each geographic area. Current regeneration of spruce in the Northeast appears to be within normal stocking levels.

A region-wide abrupt reduction of growth began in the early 1960s in stands of differing age and disturbance history. This reduction in growth seems to be associated with a change in the historical climate/growth relationship. An exception to this region-wide phenomenon is Mount

Moosilauke, where the growth decline does not appear to be synchronous because starting dates vary from 1954 to 1980.

historical climate/growth relationship. Regeneration is found at all elevations, with abundance proportional to overstory species composition.

High-Elevation -- South

Twenty-four percent of high elevation spruce-fir forests in the southern Appalachian Mountains have greater than 70 percent standing dead timber. This is accounted for, in part, by balsam woolly adelgid-caused mortality in Fraser fir. The percent standing dead for red spruce alone ranges from 5 to 13 percent with no relationship between elevation and mortality.

Crown condition (foliar thinning) and growth reductions have been found to be the only important indicators of poor red spruce health in the southern Appalachians. At high elevations there is evidence of an unusual reduction in radial increment that has been associated with a breakdown of the

Winter Injury

It has been hypothesized that a fertilization effect due to increased nitrogen deposition might play a role in high elevation spruce decline by reducing frost hardiness and thus resulting in increased winter injury. However, experimental work has shown that nitrogen fertilization does not reduce frost hardiness in red spruce. Under experimental conditions, one study did reveal that exposure to ozone resulted in delayed development of frost hardiness in red spruce seedlings, while a separate study found delayed frost hardiness following exposure to simulated acidic cloud water.

MAJOR DELIVERABLES - CROPS AND FORESTS

DELIVERABLE	DATE	SIGNIFICANCE
Evaluation of the effects of ambient levels of ozone for various crop species in several locations in the U.S. through studies using the antioxidant, EDU, which may protect plants from ozone injury when used as a foliar spray or soil drench.	Late 1989	The use of an antioxidant may provide an alternative methodology to open top chambers for investigating the effects of ambient ozone on crop production. When EDU and open-top chambers are used in combination, possible "chamber effects" and/or "EDU" effects can be examined.

DELIVERABLE	DATE	SIGNIFICANCE
Publication of the results of an international cooperative experiment in which similar experimental protocol was used to evaluate the effects of ambient levels of ozone in ten different countries on visible injury, growth and yield of the same crop species. Two different sites in the U.S. participated in the 1988 experiment.	Mid-1989	This first year of international cooperation was meant to demonstrate the interest in and feasibility of conducting coordinated and integrated experiments on an international scale to evaluate crop loss from air pollutants.
Determination of the role of free-radical oxygen scavenging enzymes in protecting plants against ozone injury through the measurements of three of such enzymes in ozone-treated and untreated plants and through studies of biotypes with genetically induced differences in these enzymes.	Mid-1990	Will provide information on the possible mechanism by which ozone damages plants.
Differences in ozone sensitivity will be examined for several soybean cultivars under varying short-term ozone profiles by measuring gas exchange and free-radical scavenging.	Mid-1990	Possible mechanisms of genetic tolerance to ozone will be determined along with the influence of different exposure dynamics.
Further investigation of the effect of acidic rain on the structures, processes, temporal relationship, and dynamics of pollination and seed set in corn.	Mid-1990	Will provide additional information to evaluate preliminary results that suggest that acidic rain may reduce the yield of field corn by affecting reproduction processes when the plant is under stress by other factors.

DELIVERABLE	DATE	SIGNIFICANCE
Quantification of changes in freezing resistance of citrus and avocado plants following exposure to chronic levels of ozone and acidic rain in a field study.	Early 1990	Provides information in an area where there are significant gaps in the knowledge base; that is, effects of pollutant combinations on perennial tree fruit crops. Also complements work being done in the forest response program.
Assessment of the possible interactive effects of ozone and elevated carbon dioxide levels on several field-grown soybean cultivars through measurements of plant water relations and photosynthate partitioning.	Mid-1990	Examines the possible repercussions of one aspect of global climate change (elevated carbon dioxide) in combination with current levels of ozone on an important crop plant and possible genetic differences in the response to such change. Few studies have examined this combination of pollutants, although both are by-products of fossil fuel combustion.
Publication describing the effects of acidic rain on soil fauna in corn and soybean fields in different locations and with different soil types.	Mid-1989	Provides information on the possible indirect effects of acidic deposition on annual crops through impacts on beneficial and detrimental soil organisms.
Examination of the effects of ambient levels of ozone and sulfur dioxide on watermelon in the indus-trial midwest where pollutant levels are generally high.	Early 1990	Will aid in the determination of the cause for the foliar injury and yield decreases recently observed in watermelons in Indiana.
Investigation of fungal and bacterial disease progression in celery and lettuce exposed to acidic fog.	Early 1990	Provides information to estimate the influence of acidic fog on disease management in California crops exposed to winter fogs having high acidity levels.

DELIVERABLE	DATE	SIGNIFICANCE
Completion of a field study to determine the relative impact of ozone on soybean physiology and yield when chronic exposures occur during different growth stages.	Early 1989	Determination of ozone-sensitive growth stages in soybean to assess the importance of temporal aspects of pollutant exposures.
Results of phytotron studies to determine the importance of peak ozone episodes on plant response.	Early 1990	Will help to separate the influence of short-term exposures to high levels of ozone versus long-term exposures at lower concentrations. Results from the above two studies may influence the selection of control strategies to reduce ozone damage to crops.
Further investigations of possible mechanisms of the direct effects of ozone on Geranium reproduction.	Mid-1989	Provides information on possible effects of ozone on reproductive processes in plants.
Completion of greenhouse studies of tomato plants to determine the effect of simulated rain acidity and duration of rain event on visible injury, vegetative growth, and fruit numbers.	Early 1989	Provides needed information on the importance of rainfall duration in affecting plant response to rainfall acidity since previous experimental designs have principally consisted of short-duration rain events.
Evaluation of near real-time variations, peak pollutant concentrations, and physical characteristics of the high elevation cloud/atmospheric environment.	Early 1990	Near real-time cloud chemistry characterization will be useful in assessing signifcance of cloud processes in deposition and resulting canopy interactions.
Electronically accessible monthly summaries of existing monitoring data (1978-1986) for the Ohio Valley corridor (including quality assurance information).	Early 1989	Will provide summaries from forested areas at monthly intervals which may be more meaningful for studies of forest effects than hourly averages or 7-hour means.

DELIVERABLE	DATE	SIGNIFICANCE
Relative sensitivities of 10 eastern hardwood species to SO_2, O_3, and acid precipitation.	Early 1989	Seedling response under controlled conditions will provide means to evaluate response of trees along deposition gradients in the Northeast.
Interim report on rate of change in sugar maple condition ratings for years 1988-1990 on plots in Ontario, Quebec, New Brunswick, ME, MI, NH, NY, VT, MA, and WI.	Late 1989	Will evaluate the influence of SO_4 and sugaring (production of maple syrup or sugar) on reported maple decline.
Inventory of geographic variation in visual crown symptoms and frequency of occurence for red spruce and balsam fir in the Northeast. Vigor ratings based on (1) needle retention, (2) FDR damage classes, and (3) American Foliage and Tree Vigor Rating.	Early 1990	Will provide informatiion on the extent and magnitude of reported decline in NY, VT, NH, ME, MA, and WV.
Interim report quantifying loblolly, slash, and shortleaf pine response to acidic precipitation and ozone.	Mid-1990	Will provide information on the role of airborne pollutants in forest health (growth, nutrition, and physiology).
Evaluation of effects of acidic deposition on forest nutrient cycling (slash pine and commercial red spruce).	Mid- and Late 1990	Will address two proposed mechanisms by which sulfur and/or nitrogen pollutants might affect forests: (1) increased leaching of foliar nutrients and (2) increased leaching of soil nutrients.

DELIVERABLE	DATE	SIGNIFICANCE
Evaluation of the effect of ambient ozone (between 20 and 134 ppb) and water stress on net carbon exchange and growth of 11-year old loblolly pine branches using a branch cuvette fumigation system.	Mid-1990	Use of branch chambers will provide a link between responses observed in seedling exposure studies and those observed on established trees in the field.
Evaluation of relationship of sulfur, nitrogen, and acidity to frost hardiness of red spruce in the field along with model relating deposition to risk of frost injury for red spruce in the eastern United States.	Early 1990	Will adress the effect of sulfur and/or nitrogen pollution on red spruce through the mechanism of delayed cold hardening or early break in dormancy.
Interim report assessing long-term effect of precipitation chemistry on soil chemistry (high elevation spruce-fir).	Early 1990	Will address the effect of sulfur and/or nitrogen pollution on spruce-fir through the mechanism of direct toxicity to roots by mobilized metals in acidified soil water.
Dose/response function comparing effects of ozone and acid rain on photosynthesis and growth of red spruce seedlings and saplings.	Mid-1990	Will address the effect of airborne pollutants on red spruce through the mechanism of altered carbon allocation.
Interim report comparing phenological, physiological, biochemical, and morphological changes in foliage for controlled field experiments and uncontrolled field sites.	Early 1990	Will identify alterations in seasonal patterns of red spruce physiology that may be caused by exposure to ozone and/or acidic precipitation.
Report on the response of branch export of photosynthate to alternative deposition scenarios for red spruce, loblolly pine, and ponderosa pine.	Mid-1990	The report will synthesize the foliar effect of acidic deposition and examine sensitivity to pollution.

DELIVERABLE	DATE	SIGNIFICANCE
Sensitivity ranking of five western conifers to: (1) simulated acid fog/ozone exposure in seasonal interaction, and (2) simulated SO_2 exposure.	Early 1990	Will address the effect of airborne pollutants on western conifers through the mechanism of altered carbon allocation and leaching of foliar nutrients.
Evaluation of extent and magnitude of recent changes in forest condition.	Early 1990	Will address correlative assocations between natural factors such as climatic variation, stand maturation, and known pollutant deposition patterns.
Evaluation of the role of non-air pollution factors in growth reduction and visible decline.	Early 1990	Will address whether correlative associations between patterns of forest damage and patterns of pollutant exposure can reasonably be explained by natural ecological and environmental variables.
Quantitative estimates of seedling respone to sulfur, nitrogen, and associated pollutants at ambient conditions.	Mid-1989	Will integrate and interpret results of various controlled exposure experiments on forest tree seedlings.
Evaluation of the role of sulfur, nitrogen, and associated pollutants in forest damage.	Late 1989	This Forest Response Program analysis will compare response of species and/or regions and evaluate hypothesized mechanisms of decline (soil-mediated, foliar leaching, altered carbon allocation, and winter injury).
Interim reports on physiological and biomass response of red spruce seedlings to acidic cloud interception and/or ozone using field exposure chambers at Whitetop Mountain, VA.	Late 1989 and early 1990	Chronic ozone exposure and deposition of acidic cloud water increase with elevation in the Appalachian Mountains. These factors have been hypothesized as causal mechanisms for decline and mortality of red spruce at high elevations.

DELIVERABLE	DATE	SIGNIFICANCE
Interim report on comparison of the response of seedlings and mature branches of ponderosa pine and red spruce to air pollution.	Early 1990	Use of branch chambers will provide a link between effects observed in seedling exposure studies and those observed on mature trees in the field.

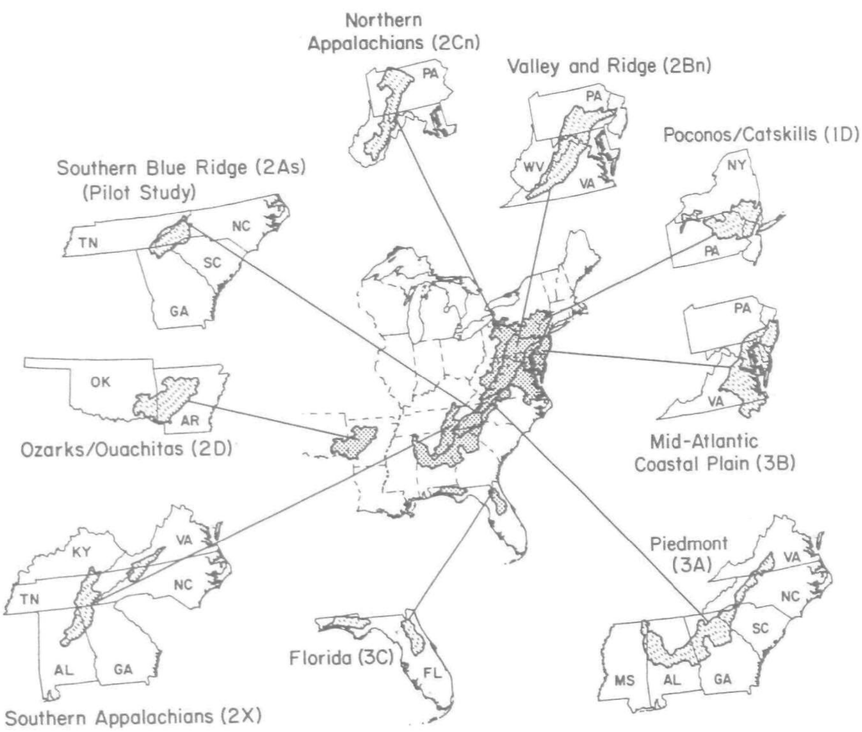
AQUATIC EFFECTS

1988 RESEARCH HIGHLIGHTS

Chemical Status of Surface Waters

The National Stream Survey-Phase I (NSS-I) was conducted in 1986 in the Mid-Atlantic and Southeast regions of the United States as part of the National Surface Water Survey. The NSS-I focused on regions of the United States where, on a national scale, (1) acidic deposition rates are relatively high, (2) the numbers of acidic streams and streams with low acid neutralizing capacity (ANC) were expected to be highest, and (3) the dominant aquatic resource was streams rather than lakes. Spring baseflow chemistry was measured in a probability sample of 504 stream reaches comprising approximately 1 percent of the total target population. This design allows population estimates to be made regarding characteristics of that population (64,300 reaches or 224,000 km total length). Nine subregions within the Mid-Atlantic and Southeast were surveyed (Figure VI-1). For the

FIGURE VI-1. Regions and Subregions Surveyed in Phase I of the National Stream Survey



purpose of data analysis, results from similar subregions were also combined to provide estimates for stream reaches in the Interior Mid-Atlantic and Interior Southeast.

The resource targeted within these regions included all streams with drainage areas less than 60 mi^2 (155km^2), but which are large enough to be represented as blue lines on 1:250,000-scale USGS topographic maps. Most streams in this size range have baseflow channel widths between 1 and 8 meters and depths between 7 and 50 centimeters. The target population was further restricted to exclude stream reaches with highly urbanized drainages, tidal impacts, no measurable flow, and those which are acidic due to acid mine drainage. The NSS-I estimates presented below are made from 478 sample reaches, representing this "refined" target population of approximately 57,000 reaches (201,000 km).

Acid neutralizing capacity is commonly used to examine the susceptibility of surface waters to acidification and was a key variable measured in the study. Regional and subregional ANC differences during spring baseflow were compared using the estimated percentages of stream length with ANC concentrations equal to or less than several reference values. Although the survey can be used to provide estimates for any reference value, four values and their definitions, used

TABLE VI-1. Population Estimates of the Percentage (Based on Stream Reach Length) of Target Reaches[1] with Spring Baseflow ANC Less than the Reference Values[2,3,4]

Subregion/Region (Code)	Total Length (km)	ANC (µeq/L) ≤0	≤50	≤100	≤200
Poconos/Catskills (1D)	15,144 (1,912)	3.6 (1.8)	10.6 (3.3)	23.8 (6.2)	36.2 (7.3)
N. Appalachians (2Cn)	21,738 (2,746)	7.0 (3.5)	17.1 (4.2)	31.9 (7.1)	59.5 (10)
Valley & Ridge (2Bn)	32,687 (4,492)	0.8 (0.6)	6.5 (3.0)	14.8 (6.3)	39.2 (10)
Mid-Atlantic Coastal Plain (3B)	40,296 (5,799)	6.3 (2.9)	23.9 (6.6)	27.0 (6.9)	52.3 (11)
S. Blue Ridge (2As)	9,036 (960)	<1.0 (-)	7.8 (2.8)	44.1 (8.3)	78.4 (10)
Piedmont (3A)	33,531 (4,402)	<1.0 (-)	7.1 (3.9)	21.0 (5.9)	40.4 (8.5)
S. Appalachians (2X)	21,892 (2,807)	0.5 (0.5)	3.5 (3.0)	12.7 (5.1)	28.0 (8.0)
Ozarks/Ouchitas (2D)	22,480 (2,507)	<1.0 (-)	0.9 (0.6)	19.2 (5.5)	67.1 (11)
Florida (3C)	3,848 (678)	12.0 (4.1)	61.2 (14)	69.4 (14.2)	76.4 (15)
Interior Mid-Atlantic [5]	69,569 (5,601)	3.3 (1.4)	10.7 (2.4)	22.1 (4.1)	44.9 (6.2)
Interior Southeast [6]	86,939 (5,871)	0.1 (0.1)	4.7 (1.5)	20.8 (3.1)	48.1 (4.9)
Mid-Atlantic [7]	109,865 (8,063)	4.4 (1.4)	15.5 (2.8)	23.9 (3.7)	47.6 (5.6)
Southeast [8]	90,787 (5,910)	0.6 (0.2)	7.1 (1.7)	22.9 (3.1)	49.3 (4.8)
Total	200,652 (9,996)	2.7 (0.8)	11.7 (1.7)	23.4 (2.4)	48.4 (3.8)

1 Target population is defined in the text.
2 Calculated using linear interpolation between upper and lower sampling sites on the reach (see text for explanation). Standard errors are shown in parentheses. The 95 percent upper confidence limit can be obtained by multiplying the standard error by 1.645 and adding the result to the estimate.
3 Population estimates of the percentage of stream length with ANC>200 µeq/L can be calculated by subtracting from 100% the percentage with ANC ≤200 µeq/L (the stated reference value).
4 This table excludes the streams whose acidity was proven to be attributed to acid mine drainage.
5 The Interior Mid-Alantic subregions are 1D, 2Cn, and 2Bn.
6 The Interior Southeast subregions are 2As, 3A, 2X, and 2D.
7 The Mid-Alantic includes the Interior Mid-Atlantic and subregion 3B.
8 The Southeast includes the Interior Southeast and subregion 3C.

TABLE VI-2. Population Estimates of the Percentage (Based on Stream Reach Length) of Target Reaches[1] with Spring Baseflow pH Less than the Reference Values[2,3]

Subregion/Region (Code)	Total Length (km)	pH ≤5.0	pH ≤5.5	pH ≤6.0
Poconos/Catskills (1D)	15,144 (1,912)	3.6 (1.9)	6.0 (2.8)	8.9 (3.4)
N. Appalachians (2Cn)	21,738 (2,746)	6.6 (3.2)	8.6 (3.2)	14.0 (4.2)
Valley & Ridge (2Bn)	32,687 (4,492)	0.8 (0.8)	5.9 (4.0)	12.6 (5.9)
Mid-Atlantic Coastal Plain (3B)	40,296 (5,799)	7.8 (3.3)	23.7 (7.5)	46.4 (11)
S. Blue Ridge (2As)	9,036 (960)	<1.0 (-)	<1.0 (-)	<1.0 (-)
Piedmont (3A)	33,531 (4,402)	<1.0 (-)	<1.0 (-)	7.1 (3.7)
S. Appalachians (2X)	21,892 (2,807)	<1.0 (-)	1.4 (1.4)	4.2 (2.5)
Ozarks/Ouchitas (2D)	22,480 (2,507)	<1.0 (-)	1.8 (1.3)	10.8 (4.4)
Florida (3C)	3,848 (678)	13.6 (6.5)	44.4 (12)	73.5 (16)
Interior Mid-Atlantic [4]	69,569 (5,601)	3.2 (1.1)	6.8 (2.4)	12.2 (3.4)
Interior Southeast [5]	86,939 (5,871)	<1.0 (-)	0.8 (0.5)	6.6 (1.9)
Mid-Atlantic [6]	109,865 (8,063)	4.9 (1.4)	13.0 (3.1)	24.8 (4.4)
Southeast [7]	90,787 (5,910)	0.6 (0.3)	2.7 (0.9)	9.5 (2.1)
Total	200,652 (9,996)	2.9 (0.8)	8.3 (1.7)	17.8 (2.6)

1 Target population is defined in the text.

2 Calculated using linear interpolation between upper and lower sampling sites on the reach (see text for explanation). Standa errors are shown in parentheses. The 95 percent upper confidence limit can be obtained by multiplying the standard error by 1.6 and adding the result to the estimate.

3 This table excludes the streams whose acidity was proven to be attributed to acid mine drainage.

4 The Interior Mid-Atlantic subregions are 1D, 2Cn, and 2Bn.

5 The Interior Southeast subregions are 2As, 3A, 2X, and 2D.

6 The Mid-Atlantic includes the Interior Mid-Atlantic and subregion 3B.

7 The Southeast includes the Interior Southeast and subregion 3C.

previously in other NAPAP analyses, are as follows: stream reaches with ANC ≤0 are acidic; those with ANC ≤50 µeq/L are generally agreed to be very sensitive; those with ANC ≤100 µeq/L are generally agreed to be sensitive; and those with ANC >200 µeq/L are generally agreed not to be sensitive to acidification.

The percentage of the total target stream reach length with ANC or pH below a given reference value, as shown in Tables VI-1 and VI-2, is estimated by linear interpolation between upstream and downstream ends (nodes) of sample reaches. These estimates depend upon the difference between upstream and downstream chemistry, the reach length, and the population weighting factor for each sample reach. Therefore, population percentages based on interpolation do not necessarily fall between those describing the percentage (by number) of upstream and downstream reach nodes. For example, the estimated percentage of stream reach length (based on the interpolated value) in the Valley and Ridge (2Bn) with ANC ≤0 is 0.8. Based on numbers using the upper and lower node samples, however, the percentages of acidic reaches are 5 percent and <1 percent, respectively.

Of the total estimated target length of eastern reaches, an estimated 48 percent (97,000 km) had ANC ≤200 μeq/L, 11.7 percent (23,000 km) had ANC ≤50 μeq/L, and 2.7 percent had ANC <0 μeq/L (5,400 km) (Table VI-1). The results also indicate notable differences between the Mid-Atlantic and Southeast with respect to the percentage of stream reach length that was acidic and that had ANC ≤50 μeq/L. Less than 1 percent of the surveyed acidic streams were in the surveyed portions of the Southeast, except in Florida, where most streams (including acidic streams) also contained high concentrations of dissolved organic carbon. The length of stream reaches that are acidic during spring baseflow was estimated to be 4.4 percent in the Mid-Atlantic and 0.6 percent in the Southeast. Nearly twice the percentage of stream length in the Mid-Atlantic (15.5 percent, 17,067 km) had ANC ≤50 μeq/L, compared to the Southeast where 7.1 percent (6,420 km) had ANC in this category. Estimates for ANC also varied among subregions. The lowest percentage of acidic reach length was found for the Southern Appalachians and the highest for the Northern Appalachians and Florida.

The estimated 2.7 percent (5400 km total length) of the streams in the NSS population that were acidic are of special interest to NAPAP. Not included in Table VI-1 are an additional 4600 km of acidic streams with high sulfate concentrations and evidence of mining activity. It is believed that mining activity is the source of the sulfate which is the major acid anion in these streams.

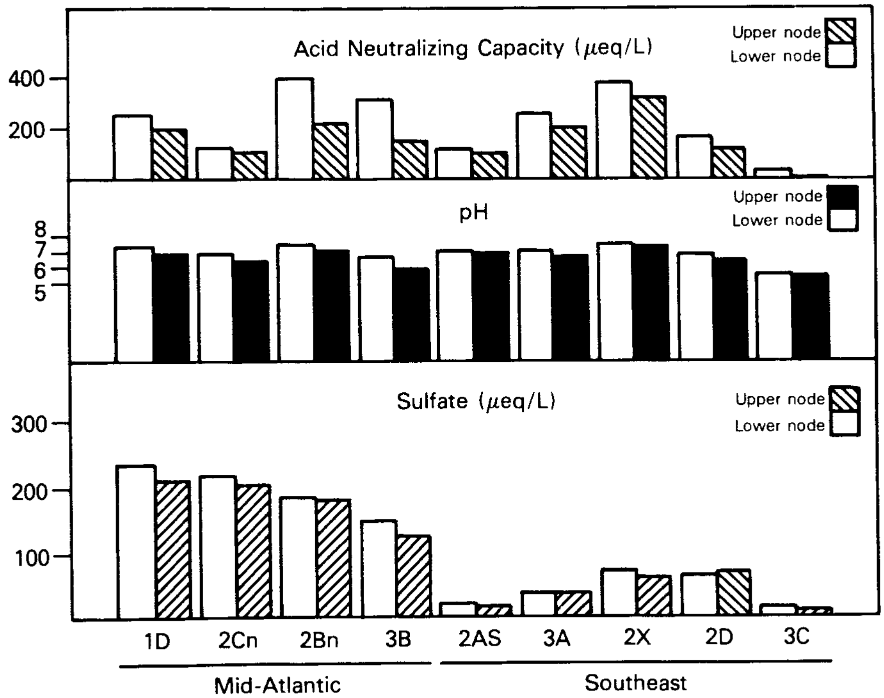
In the Florida Subregion, organic acids, presumably derived from decomposition, are surmised to play a dominant role in controlling the acidity of these streams. The acidic stream reaches observed there were largely low in sulfate (mean = 12 μeq/L) and high in DOC (mean = 77 mg/L). Organic anions (estimated from the Oliver model) dominated the anion balances in these reaches. Nitrate, sulfate, and naturally occurring organic acids are substantial contributors to the strong acid anion composition of streams in the Mid-Atlantic Coastal Plain.

In contrast to these findings in Florida and the Coastal Plain, sulfate is the major acid anion in the acidic reaches for the three Interior Mid-Atlantic subregions. These acidic streams were observed in upland, forested drainages of less than 20 km^2 and their pH ranged from 4.2 to 5.3. Sulfate was found at relatively high concentrations (mean = 153 μeq/L); concentrations of chloride (mean = 22 μeq/L), organic anion (mean = 14 μeq/L) and nitrate (mean = 8.7 μeq/L) were low and contribute only a small fraction of the total anion concentration. Thus, sulfate is by far the dominant acid anion in these acidic streams. In most cases, sulfate concentrations exceed the sum of base cation concentrations (after sea-salt correction), providing strong evidence for the presence of sulfuric acid.

The predicted steady-state streamwater sulfate concentrations in these three subregions, assuming only atmospheric deposition as a source, range from 158 μeq/L in the Poconos/Catskills to 214 μeq/L in the Valley and Ridge subregion. Given the mean observed sulfate concentration of only 153 μeq/L in these acidic streams, it is unlikely that substantial watershed (non-atmospheric) sources of sulfate were present. Therefore, acidic deposition is likely to provide the majority of sulfate to these streams.

Differences in median values for ANC, pH, and sulfate among subregions and regions were also evident (Figure VI-2). In general, upper nodes had lower median ANC values than did lower nodes, while sulfate and pH differences between the nodes were relatively small. Stream water sulfate concentrations were markedly higher in the four Mid-Atlantic subregions (medians from 125 to 138 μeq/L) than in the

FIGURE VI-2. Population Estimates for Median Acid Neutralizing Capacity, pH, and Sulfate Concentrations at Upper and Lower Sampling Sites (Nodes) in Stream Reaches for the National Stream Survey - Phase I. Data are for the target population of reaches as defined in the text. Median values for Florida (3C) are based on a special subset of streams with low acid neutralizing capacity and are not directly comparable to those for other subregions (see Kaufmann et al. 1988).

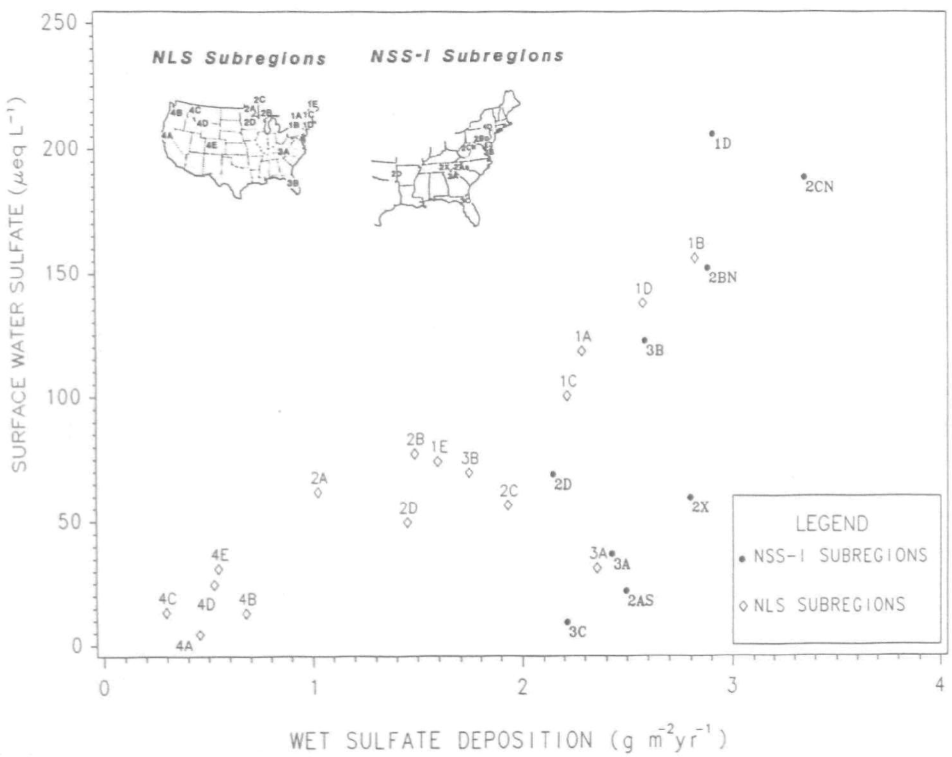


five Southeast subregions (10 to 71 μeq /L).

The relationship between median stream sulfate concentrations and sulfate deposition rates was examined across the nine subregions in a manner previously done for the National Lake Survey. For this analysis, those surface waters with the largest sources of terrestrial sulfate were excluded. For streams in the Mid-Atlantic Subregions (1D, 2Cn, 2Bn, 3B) and in the Ozarks/Ouchitas (2D), the regional pattern of increasing surface water sulfate concentration associated with increasing atmospheric sulfate loadings closely tracks that observed for lakes in the West, Upper Midwest, and East (Figure VI-3). The comparison with the lake data indicates that streams in the Southeast have lower sulfate concentrations than expected, given their sulfate deposition rates. This observation is consistent with other research showing substantial sulfate retention in some parts of the Southeast.

o Data from the National Surface Water Survey (NSWS) indicate that regional median sulfate concentrations in lakes reflect estimated median regional wet sulfur deposition levels in northern and western parts of North America. It is inferred from these data that surface water sulfate has increased since pre-industrial times in a manner roughly similar to changes in sulfur deposition in these areas.

FIGURE VI-3. Relationship Between Median Wet Sulfate Deposition (1980-1984) and Median Sulfate Concentration in Surface Waters With $SO_4^{2-} < 400$ µeq/L in Subregions for the National Surface Water Survey. This analysis is based on the target population as defined in the text, except that those streams with $SO_4^{2-} \geq 400$ µeq/L were eliminated for this analysis. Wet SO_4^{2-} deposition rates are derived from Wampler and Olsen (see Aquatic Effects Publications, 1987 NAPAP Annual Report).



Concerning within-lake and within-stream chemical relationships, examination of NSWS data on the total population of lakes and streams does not show a relationship between surface water sulfate and acidity. However, other analyses on a subset or subpopulation of low alkalinity lakes and streams show that sulfur deposition has influenced their chemistry and suggest that their acidity has increased. At least two of the NAPAP State of Science/Technology reports will examine approaches to quantifying the subpopulations of lakes and streams which respond to sulfur deposition by a change in acidity and estimating the magnitude and intensity of this response.

o The Episodic Response Project was initiated to examine episodic acidification and associated biological effects in streams of the Northern Appalachian Plateau of Pennsylvania and the Catskills and Adirondacks of New York. As part of the development of the project design, a two-box mixing model was used to estimate the potential influence of episodic acidification on regional estimates of surface water chemistry. Together with regional chemistry and deposition data, the results from application of the preliminary model indicated that acidic episodes are likely to be a chemically important regional phenomenon. Population estimates of the total proportion of acidic stream reaches would increase by 40-640 percent in six subregions of the eastern United States if episodes are taken into account. In addition, data from a small sample of lakes in the Adirondacks show that fall "index" ANC is an excellent predictor of the minimum episodic ANC measured at the outlets of these lakes during spring snowmelt. While 11 percent of the Adirondack lakes were estimated to be acidic at fall overturn based on National Lake Survey data, a preliminary linear regression model predicted that more than 35 percent would have been acidic at their outlets during the spring of 1986.

o Episodic acidification of surface waters in the Emerald Lake, California watershed has occurred following intense summer rainstorms. During these episodes surface water ANC has been reduced to zero. Similarly, ionic pulses have been detected during early spring snowmelt in the inflow streams concurrent with increases in concentrations of nitrate and sulfate.

Factors Controlling Surface Water Response

o Chemical weathering of minerals is a major process that provides long-term neutralization of acidic deposition. Organic compounds have been hypothesized to control weathering rates of primary minerals (and release rates of base cations) either by direct complexation reactions or indirectly by influencing solution pH. As part of the Watershed Manipulation Project in Maine, a series of laboratory studies has been completed. The studies have demonstrated that neither pH nor concentration of oxalic acid (a metal-binding organic compound) influence the weathering rates of two primary minerals, oligoclase and tremolite, found in low weathering environments. Extrapolation of these results to the field is premature at this time, but the research suggests that acidic deposition may have minimal effects on the weathering rate of (and rate of base cation supply from) these pure minerals. Nonetheless, mineral weathering does neutralize incoming precipitation acidity and adds to the alkalinity of the surface water.

o Alteration of precipitation chemistry by mature boreal conifer and hardwood forest canopies and by forest soil is being examined as part of an ongoing study in Isle Royale, Northern Michigan. The forest canopy significantly increased the concentration of calcium, magnesium, and potassium ions in throughfall and decreased the concentration of hydrogen ion beneath aspen-birch. For both forest types, concentrations of calcium, magnesium, and sodium ions and sulfate significantly increased and nitrate decreased in soil solution, relative to their concentrations in precipitation. Within the soil ecosystem, potassium ion, nitrate, and hydrogen ion were strongly conserved. Concentration of soil solution sulfate is higher, and its flux two-to threefold greater under conifers than hardwoods. This suggests the possibility that boreal conifer forests may be more susceptible than hardwood forests to cation leaching by mobile anions such as sulfate from atmospheric inputs, and may therefore contribute more base cations to surface waters.

o Research at Loch Vale Watershed in the Rocky Mountains has focused on tracing the hydrologic pathways of melting snow and summer rainstorms and on identifying crucial watershed-mediated processes along those pathways. Results indicate that organic acids in forest soils mobilize surprisingly high concentrations of potentially toxic aluminum. This research is also providing evidence that mineral weathering processes may be highly important in ameliorating episodic responses to acidic deposition. On an annual basis, much of the water moving through the watershed is related to the spring melting of the snowpack. It now appears that mineral weathering is active even in this early spring period. Further evidence of the importance of weathering is provided by summertime studies. Summer thunderstorms are, in general, much more acidic than winter snows and could cause episodes of acidic streamflow. To investigate this potential, researchers collected samples of streamwater runoff from a summer thunderstorm in the upper part of the watershed, which is above the treeline and is the area of the drainage that is most susceptible to acidic inputs. This alpine stream passes over bedrock and through talus fields with very little soil contact. The sampled stream runoff was almost 100 times less acidic than the rain water itself, indicating that weathering of granitic bedrock can substantially influence the acidity of storm water flowing into receiving surface waters.

Verifying Rates of Change in Surface Water Chemistry

o Sampling strategies for the detection of long-term trends in surface water acidification were analyzed as part of the Temporally Integrated Monitoring of Ecosystems Project. Several statistical techniques were tested on the basis of their power of trend detection for data sets typical of long-term monitoring programs dealing with acidic deposition effects. The performance of seven tests was compared over a range of conditions for eight statistical characteristics of temporal data sets, e.g., seasonal pattern of mean, trend magnitude, and lag-one autocorrelation coefficients. Detectable change in regional means was also examined for various combinations of numbers of sites, spatial correlation among sites, and length of record for various levels of power and significance. These results reduce uncertainty in monitoring network design for surface water acidification, by specifying the probability of trend detection for various combinations of numbers of sites and length of record, given estimated temporal variances for sites and constituents of interest. For example, for drainage lakes in the Northeast, the level of detectable change in regional ANC means over 10 years using four lakes with an average spatial correlation of 0.2 is 23 µeq/L, given that the probabilities of making Types I and II errors are both only 0.1. With the same assumptions, if 16 lakes are used, the detectable change is 17 µeq/L. For seepage lakes in the Upper Midwest, temporal variance is higher, and the equivalent levels of detectable change are 36 µeq/L for four lakes and 27 µeq/L for 16 lakes.

o Results of a detailed study of diatom remains in sediments of 30 lakes in the Sierra Nevada were used to establish a relationship between diatom communities and pH. This "calibration set" was then used to reconstruct the pH (using Pb^{210} from a "short" sediment core) and alkalinity history of Emerald Lake, in the Sequoia National Park, from 1825 to the present. Over the 150-year period the estimated pH variance was 6.1-6.6, with no obvious trends. Alkalinity ranged from 40-80 µeq/L, nearly within the current range of alkalinities recorded for Emerald Lake. Thus, these data show no apparent long-term trend toward chronic acidification of Emerald Lake.

Biological Effects

o Forty-nine lakes in the Upper Peninsula of Michigan (pH 4.4 to 8.2) were surveyed in summer 1987 to evaluate the status of fish communities in the region relative to potential effects from acidic deposition. The sampled lakes are all >4 ha in size and >1.5 m deep and had no major anthropogenic watershed disturbances or fish stocking likely to confound correlative analyses of fish population status and lake acidity. These lakes are a subset of those sampled for water chemistry in fall 1984 as part of Phase II of the Eastern Lake Survey. One or more species of fish were caught in 47 of the 49 lakes, which, when extrapolated to the target population, represents an estimated 99.4 percent of the lakes in the region. Yellow perch, which are quite acid tolerant and are commonly caught in waters with pH levels as low as 4.5, were the most common species, caught in 31 of the target lakes. Several minnow and darter species were notably absent from lakes with low pH (≤5.7-6.0), perhaps reflecting an intolerance of acidic conditions. This study provides a comprehensive survey of the present-day status of fish communities in a region of the country with a relatively high frequency of acidic lakes (an estimated 9.8 percent of the lakes have ANC ≤0) and with little existing data on fish community composition in lakes potentially sensitive to acidic deposition.

o Brood and duckling survival of ring-necked ducks was examined in wetland areas of Maine having a range of alkalinity and pH. Brood survival does not appear to be related to wetland pH or alkalinity. While duckling survival also did not differ among wetlands with high and low alkalinity, it does appear to be influenced by pH. The daily survival rate of ducklings was lower on low-pH (<6.0) wetlands than on high-pH (≥6.1) wetlands. Older ducklings (25-45 days old) appeared to be the most sensitive, having both the lowest survival rate when in wetlands with pH <5.5 and the highest survival rate when in wetlands with pH ≥6.5. The response of older ducklings on low-pH wetlands is most likely due to the effects of low pH on the invertebrate food source. The only difference found among the wetlands that could affect survival seems to be the quantity and quality of invertebrate foods. Diets of ducklings from high-pH wetlands were more diverse than those of ducklings on low-pH wetlands, which consumed smaller quantities of invertebrate food from fewer invertebrate taxa. When species diversity is low, ducklings may be forced to feed on less nutritious or more mobile species, and may spend more time and energy foraging to obtain sufficient nutrients for growth and survival. The effect of acidic deposition on the pH of wetlands is not clear at this time.

o Experiments performed by adding acids (nitric, sulfuric, and hydrochloric) and nutrients (phosphate) to large replicate bags suspended in Emerald Lake showed population changes in a number of zooplankton species. Two genera, *Diaptomus* and *Daphnia*, were eliminated from the bags in which the pH was lowered to 4.4. Other species, including *Bosmina* and *Keratella*, did better at intermediate pH levels (pH 5.2), which may indicate that some competitive species had been eliminated by the acid addition. Similarly, experimental acidification of stream channels showed that certain benthic invertebrates which are eaten by trout, e.g., *Baetis*, are adversely affected by low pH, comparable to those recorded in the outflow stream during spring snowmelt. Increased severity and frequency of episodic acidification might, through the loss of important dietary components, affect trout growth and survival in these food-limited systems.

o Completion of a second year of exposure to pH 5.1 produced additional changes in the biota of artificially acidified Little Rock Lake, a seepage lake in north-central Wisconsin. Shifts in invertebrate organism abundance have varied widely: upward and downward; changed in the second but not the first year of each pH increment (5.6 and 5.1); increased abundance but stable diversity among daphnids as compared to stable abundance and reduced diversity of rotifers. Unexpectedly, the *Mougeotia* algal mat and water transparency were reduced, and the growth rate of fishes was increased as compared to the previous year, perhaps related to the unusually warm and dry weather. Laboratory exposure, in situ field exposure, and field population data are providing a basis for comparison of various data types for estimating the effects of acidity on fish. All data indicate rock bass and black crappie are more vulnerable than largemouth bass and yellow perch, relationships first indicated by 30-day exposures of juvenile life stages. When comparing results from exposures of early-life stages (embryos and larvae), in situ data tend to overestimate and laboratory data to underestimate toxicity. Field data indicate rock bass are the most sensitive species and that acid stress might be reducing over-winter survival of young-of-the-year largemouth bass. Water column concentrations of calcium, manganese, aluminum and iron have increased. Lower bacterial numbers and microbial community activity have been associated with reduced decomposition of oak leaves.

Indirect Human Health Effects

o The effect of acidification on mercury accumulation in yellow perch inhabiting Little Rock Lake, Wisconsin, is being studied. Mercury concentrations in one-year old whole perch increased in response to whole-lake acidification from pH 6.1 to 5.6. Mean body burdens of mercury in these yellow perch were greater in the lake's treatment basin than in the reference basin. Acidification of the treatment basin may have increased the net production of methylmercury, the form of mercury that is most readily accumulated by fish. The influence of a decrease in pH on the direct uptake of methylmercury by fish remains unclear.

Ecological Effects of Mitigation

o Analysis of liming data on ten small lakes in New York has shown that dose rate alone is the best predictor of the initial dissolution efficiency of limestone applications to mitigate acidification in lakes. A number of dissolution model parameters were tested in this analysis. The study also examined lake flushing rate, mixing, and dissolution of calcite, all of which influence the rate of acidification. Dissolution rates declined exponentially, reaching undetectable levels within 2-3 years following treatment. Total limestone dissolution efficiencies in these lakes ranged from 17 to 59 percent, comparable to levels observed in Scandinavian lakes treated with similar materials. In another study on mitigation, a Minnesota lake was treated with five tons of powered limestone to study the duration of neutralization effects and ecological effects.

o Collection of baseline pretreatment data including biology, chemistry, and habitat characterization has been completed for stream studies in Massachusetts, West Virginia, and Tennessee. Stream liming will begin in fall 1988 based on dose rates that have already been calculated.

Forecasting Rates of Change in Surface Water Chemistry

o The Direct/Delayed Response Project is focusing on chronic sulfate deposition effects to determine the rate at which average annual surface water ANC might be expected to reach zero, given various rates of sulfate deposition. Forecasts are being made with three watershed acidification models. As part of this project, relative contributions of in-lake alkalinity generation to total basin alkalinity budgets for drainage lakes in selected regions of the eastern United States were estimated using two independent procedures. Projections from the two methods are comparable and show that for most drainage lakes in the Northeast, Southern Blue Ridge Province, and Upper Midwest, in-lake alkalinity generation is a minor contributor to net basin alkalinity production. Regional assessments of current or future effects of acidic deposition on surface water chemistry in the Northeast and Southern Blue Ridge Province, or in other areas dominated by drainage lakes with high watershed to lake area ratios, are not seriously compromised by use of models limited to consideration of terrestrial processes. For areas such as the Upper Midwest that contain high proportions of seepage lakes, or for lakes with long hydrologic residence times, in-lake processes and hydraulic influences must be considered. The accuracy of acidification forecasts will be enhanced by quantifying the relative importance of internal alkalinity generation to total basin alkalinity budgets.

o Regional-scale estimates of runoff are needed as input parameters in the watershed acidification models being used in the Direct/Delayed Response Project to forecast surface water acidification. Many of the sites being examined in this project do not have gauges installed, an important component in obtaining runoff estimates. Thus, to obtain regional estimates, interpolation methods must be used for ungauged sites. An analysis to quantify uncertainty associated with interpolating runoff to specific sites was conducted on 100 gauged watersheds using a runoff contour map by (1) hand interpolation to the watershed outlet, (2) a computer interpolation to the watershed outlet, and (3) hand interpolation to the watershed centroid. Interpolated values were then compared to the actual gauged values. On the average, interpolated values for runoff estimated at basin outlets were slightly less than gauged values. Results from the hand interpolation method were not significantly different from the computer interpolation method. Additionally, the absence of strong spatial correlations or regional patterns in the runoff interpolations indicated that no regional biases were introduced in the development of the contour map. Runoff can be estimated, on the average, to within approximately 15.0 percent of the measured value using the three methods. These results indicate that runoff contour maps can be used in regional studies to extrapolate runoff to ungauged systems with quantifiable uncertainty. The analysis of uncertainty in this component is one part of a more comprehensive uncertainty analysis underway.

MAJOR DELIVERABLES

DELIVERABLE	DATE	SIGNIFICANCE
Report on dynamic model forecasts for regional changes in acid neutralizing capacity in streams in the mid-Appalachians.	Early 1990	The report will provide a regional forecast with quantifiable certainty of the rate of change in acid neutralizing capacity for surface waters in two areas of the United States susceptible to acidic deposition.
Acid-base status of streams in the eastern United States--results of the National Stream Survey.	Late 1988	Interprets regional distribution of stream water chemistry as related to potential sources of acidity and current hypotheses on sulfate retention and delayed effects of acidic deposition.
Status and extent of acid mine drainage impacts and internal sulfate sources in the National Stream Survey target population.	Early 1989	Assess the location, number, and combined length of streams affected by acid mine drainage within the nine National Stream Survey subregions. Reduces uncertainty regarding effects attributable to weathering of sulfide minerals.
Geological controls on the acid-sensitivity of streams in a number of subregions of the eastern United States.	Early 1990	Clarifies the association between basin geology and streamwater acidity. Improves regional classification system and appropriate selection of models used to estimate historical change, future acidification and episodic change.
Watershed factors controlling water chemistry in streams of the National Stream Survey.	Late 1989	Examines factors controlling streamwater chemistry. Refines assessments of stream sensitivity to anthropogenic acidification, and helps explain the roles of deposition, hydrology, and geology.

DELIVERABLE	DATE	SIGNIFICANCE
Estimated changes in lakewater chemistry in the Northeast from pre-1900 to the present based on paleoecological inferences.	Early 1989	Provides the first regional estimates of historical changes in lakewater chemistry based on paleoecological methods.
Components of variance in lakewater chemistry in a regional (Northeastern) assessment of lake characteristics.	Mid-1989	Reduces uncertainty in regional estimates of lake chemistry made during Phase I of the Eastern Lake Survey. Quantifies temporal and spatial variability associated with the single fall index sample.
Acid Deposition and Aquatic Ecosystems: Regional Case Studies.	Late 1989	Summarizes intercomparisons among ten regions of the United States and eastern Canada concerning what is known about the effects of acidic deposition on lakes and streams. Will assess the relative importance of processes controlling surface water chemistry in low-alkalinity lakes.
Chemical response of an alpine stream in Loch Vale Watershed to an intense summer rainstorm.	Late 1989	Documents effects of rapid inputs of acidic deposition on an alpine watershed-stream system. Explores relative importance of watershed processes in alkalinity generation.
Influence of experimental acidification on key chemical processes in a forested watershed.	Late 1989	Will improve process representations used in modeling sulfur fluxes through ecosystems, aluminum transport, soil and water responses affecting aluminum mobilization, changes in forest growth related to nitrogen reduction and release, and subsurface flow pathways at the hillslope scale.

DELIVERABLE	DATE	SIGNIFICANCE
Long-term depletion of calcium and other nutrients in eastern forests.	Late 1989	Reduces uncertainties regarding the impact of increased leaching of nutrient ions, particularly calcium, resulting from atmospheric deposition, which may affect aquatic chemistry and forest productivity.
Precipitation and streamwater chemistry from undisturbed watersheds in the Cascade Mountains of Oregon.	Late 1989	Provides deposition stream chemistry data from a research site that are comparable to date from sites that appear to be relatively unaffected by acidic deposition. Provides a reference point for comparison to watersheds subject to larger amounts of acidic deposition.
Biogeochemistry of two Appalachian deciduous forest sites in relation to episodic stream acidification.	Late 1989	Reduces uncertainty in the understanding of the importance of biochemical processes in controlling episodic acidification.
Throughfall chemistry, soil solution chemistry, and ionic budgets in a Sierra Nevada mixed conifer forest.	Late 1989 to Early 1990	Provides information on biogeochemical cycling mechanisms, including capacity of a forested ecosystem to buffer effects of acidic inputs, and processes influencing precipitation chemistry as it passes through the conifer canopy and major soil horizons.
Watershed processes related to buffering and concentrations of organic materials in surface waters of Loch Vale Watershed.	Early 1989 to Mid-1989	Elucidates mineral-water interactions, including weathering dynamics, that control production of alkalinity in a granite bedrock site with poor soil development. Helps explain the role of organic production in generating alkalinity and mobilizing metals during snowmelt.

DELIVERABLE	DATE	SIGNIFICANCE
Steam export, uptake rates, and cycling of sulfur and organic carbon in a pristine conifer-dominated watershed.	Early 1989 to Mid-1989	Presents site-specific data on input-output budgets for sulfate and nitrate from wet deposition. Estimates base-flow nitrate and hydrogen ion uptake which will serve as reference for surface water response at sites with high acidic deposition loads. Improves understanding of sources, cycling, and fates of sulfur and organic carbon.
Multiyear trends in snowpack ion accumulation and loss and pattern of solute movement from snowmelt episodes at Isle Royale, Northern Michigan.	Early 1989 to Mid-1989	Supports the hypothesis that longer-term patterns of snowmelt and pathways of ionic movement are important factors in determining whether streams undergo an ionic pulse upon snowmelt. Suggests that initial snowmelt dynamics have little effect on streamwater chemistry and that forest soils do not appear to enrich sulfate concentration in subsequent meltwaters. Nitrate concentrations in meltwater entering the stream, however, indicate that these forest soils are contributing nitrate.
Long-term monitoring analysis of temporal patterns and trends in a regionally diverse group of surface waters spanning a range of deposition gradients.	Mid-1989	Provides data on recent changes in surface water chemistry of low ANC surface waters potentially related to acidic deposition.
Chemical and biological responses to reduction in pH from 6.2 to 5.1 in an experimentally acidified seepage lake.	Mid-1989	Provides data on acid-stressed populations of freshwater organisms and on biogeochemical processes that will support development of acid impact models and help define regional and national effects.

DELIVERABLE	DATE	SIGNIFICANCE
Influence of experimental acidification on the biology and chemistry of a warmwater lake ecosystem (Little Rock Lake).	Early 1990	Examines the effects of progressive acidification on the structure and function of a warmwater seepage lake and evaluates the state of the art of predicting these effects.
Acid-sensitivity of cutthroat trout.	Late 1989	Describes the sensitivity of western salmonid species to low pH and elevated concentrations of aluminum, providing information necessary to assess potential effects of acidic deposition on fishery resources in the western United States.
Use of benthic macroinvertebrates as indicators of the sensitivity of stream communities to acidification.	Mid-1989	Describes a technique that uses the presence of certain macroinvertebrate taxa, individually and combined, to evaluate the biological sensitivity of stream communities in the Southern Blue Ridge Province to acidification.
Effect of cations mobilized by acidic precipitation on productivity and survival of terrestrial vertebrates.	Late 1989	Provides information on the food chain response to mobilized cations in acidified freshwater environments.
Fish communities in lakes in the Upper Peninsula of Michigan in relation to lake acidity.	Early 1989	Provides regional-level information on fish community response in potentially sensitive lakes. Results review fish community status as a function of water chemistry for a defined probability sample of lakes.
The potential effects of lake acidity on the bioaccumulation of mercury by fish in the Upper Peninsula of Michigan.	Mid-1989	Provides information on whether lake acidity and fish mercury content are significantly correlated. Estimates the number and extent of lakes in the Upper Peninsula of Michigan with enhanced fish mercury levels.

DELIVERABLE	DATE	SIGNIFICANCE
Effects of liming on fish populations.	Late 1989	Discusses the dose-response relationship between liming and surface water chemistry and freshwater organisms and the effects of liming on metals and nutrient flux. Contributes to understanding of the potential for mitigation techniques to benefit fish survival and health.
Effects of lime addition to lakes.	Late 1989 to Early 1990	Documents and models the effects of base addition on light attenuation and thermal stratification, which strongly influence lake biology.
Direct/Delayed Response Project (DDRP) model sensitivity and uncertainty analysis.	Early 1989	Evaluates three dynamic models of catchment acidification used to project the number of watersheds that may become acidic under current or altered deposition. Provides a means to estimate sensitivity and performance of models used for DDRP forecasts.
Dynamic model forecasts for regional changes in acid neutralizing capacity in surface waters in the Northeast, Southern Blue Ridge Province, and Mid-Appalachians.	Mid-1989 and Mid-1990	Provides regional forecasts with quantifiable certainty of the rate of change in acid neutralizing capacity for surface waters in three areas of the United States susceptible to acidic deposition.
Current status, historical changes, and episodic changes in surface water acid-base chemistry related to acidic deposition including watershed and lake processes affecting surface water response, biological effects, mitigation, and methods for forecasting future changes in surface water chemistry.	Mid-1990	Provides comprehensive state-of-science with quantified uncertainty, forming a partial basis for NAPAP's 1990 Integrated Assessment. Presents models for forecasting and hindcasting acid-base chemistry and biological effects based on various scenarios of acidic deposition loading.

EFFECTS ON MATERIALS AND CULTURAL RESOURCES

1988 RESEARCH HIGHLIGHTS

Atmospheric Corrosion Testing Of Zinc, Galvanized Steel And Other Metals

A preliminary dose-response function for predicting the corrosion of galvanized steel by wet and dry deposition has been developed from the thermodynamics and kinetics of atmospheric corrosion chemistry, supported by laboratory and controlled field experiments. The function mathematically expresses the competing reactions for the build up and dissolution of the basic zinc carbonate corrosion film with exposure time. The model quantitatively accounts for the following factors: (1) Basic zinc carbonate, formed by exposure to CO_2, is soluble in clean rain, and the removal rate depends on the residence time of the rain on the galvanized steel surface; (2) Rain acidity reacts stoichiometrically with the zinc coating; (3) The deposition of gaseous SO_2 during periods of wetness controls the rate of corrosion of galvanized steel structures; (4) During periods of surface wetness, SO_2 reaching the surface reacts stoichiometrically with the zinc.

The effects of acidic deposition on the corrosion of zinc, galvanized steel, and other metals is being investigated at five materials exposure sites, as well as in laboratory experiments using atmospheric exposure chambers. The annual corrosion rates estimated from the five-year exposure data were observed to vary by nearly a factor of three, with a ten-fold variation in sulfur dioxide concentration among the five sites. Measured deposition rates of sulfur dioxide to weathered zinc surfaces were observed to increase substantially with increasing exposure time, but decreased with time to weathered Cor-Ten A and 110 copper surfaces. These results indicate that the nature of the corrosion product formed on metal surfaces influences the rate at which sulfur dioxide is deposited.

Galvanized steel runoff experiments at the Research Triangle Park, North Carolina and Steubenville, Ohio sites have been completed. Runoff samples were collected on a rain-event basis from each panel followed by detailed chemical analysis of the collected solutions. Preliminary data analysis suggests that neutralization of acidic species by dry deposited coarse alkaline particles could be significant at the Ohio site. A study to determine how corrosion rates change with varying sample size and orientation is currently underway. Preliminary results suggest that the rate of uptake of SO_2 to galvanized steel surfaces depends on the size of the sample, with the deposition rate per unit area increasing with decreasing size.

The Effects of Acidic Deposition on Carbonate Stone

Acidic deposition to carbonate stone surfaces causes surface erosion through dissolution of stone exposed to rain, and causes gypsum deposits to form on surfaces sheltered from rain. Run-off experiments on limestone and marble slabs at four materials exposure sites can be used to partition the effects of hydrogen ion loading, the dry deposition of sulfur oxides and nitrogen oxides vis-a-vis the natural solubility of calcium carbonate in pH 5.6 rain. The excess sulfate and nitrate in the stone runoff solutions relative to corresponding glass blanks can be used as a measure of stone recession due to the loss of reaction products from the dry deposition of sulfur and nitrogen oxides. Data from three years of runoff experiments suggest that dry deposition accounts for 50-80 percent of the sulfate in runoff from quarry fresh marble and limestone surfaces. These data suggest that hydrogen ion accounts for approximately 10 percent of the stone recession at the exposure sites, while recession due to the reaction with sulfur oxides varies from 6 percent at the Adirondacks site to 20 percent at the downtown Washington, D.C. site. Sulfate accumulates on the sheltered undersides of the stone test samples. Estimates of annual sulfate accumulations based on four years of data agree within a factor of two with the cumulative measure of the excess sulfate removed from the quarry fresh marble and limestone slabs in the runoff experiments.

Additional experiments were initiated using samples of weathered marble and 80-year old limestone. The weathered surfaces, especially limestone, showed a higher concentration of gypsum (penetrating more than 1.5 mm into the stone) than was detected in fresh stone after four years of exposure at the field sites. The analysis of weathered stone in parallel with quarry fresh samples is expected to provide insight on the rate of gypsum accumulation and dissolution erosion over more typical lifespans of stone materials.

Progress was made in several laboratory studies addressing the deposition of pollutants to stone surfaces. Surface moisture is an important factor in determining dry deposition rates to stone surfaces. Wetting and drying characteristics of limestone briquettes have been analyzed through the use of a CAT scanning technique. The study was undertaken in order to better define the moisture cycling important to sulfur deposition, reaction, and crystallization. The experiments showed that rain water wetting limestone becomes uniformly distributed within the sample, presumably by capillary forces. After a rainfall, the sample dries uniformly throughout its entire volume. Solar radiation appears to have little or no effect on the interior drying pattern, although wind appears to result in preferential drying on the windward side of the briquette.

Laboratory Experiments on the Deposition of Acidic Pollutants to Paint Films, and the Effects on Polymer Coatings and at the Paint/Substrate Interface

Laboratory experiments are being conducted to determine the uptake of acid gases on paints covered with thin layers of moisture, the permeation of acid gases through polymers, and the effects on polymers and at the paint/substrate interface. An environmental test chamber, capable of exposing samples to SO_2, NO_2, and O_3, has been designed, built, and tested. Initial exposures of alkyd paints were made in 1-ppm SO_2. Some samples had previously been exposed to ultraviolet radiation. Samples were either kept at a constant temperature for dry deposition or were cyclically cooled for both wet and dry deposition. X-ray photoeletron spectroscopic (XPS) measurements of the surfaces revealed that S accumulation on dry surfaces was 3-10 times greater than on surfaces exposed under diurnal wet-dry cycle conditions. Surface moisture apparently allows deposited S to permeate the paint film, which has also been observed in samples immersed in diluted H_2SO_3. Studies are ongoing to confirm the permeation.

An in-situ electrochemical monitor capable of detection of paint degradation in atmospheric exposure via electrochemical impedance spectroscopy (EIS) has been developed. The electrochemical monitor will be utilized in the environmental exposure chamber and will represent the first technique which can be performed entirely in-situ to dectect coating deterioration. The additional benefit of the monitor lies in its applicability for EIS measurements, since EIS is capable of prediction/detection of coating deterioration at very early exposure times. It is expected that this technique will contribute to understanding of coating failure mechanisms and the early detection of coating failure.

Effects of Acidic Deposition on the Permeability and Chemical Structure of Paint Films

The leaching of extender components alters the characteristics of paint films, in particular affecting the moisture and pollutant transport through the film and, thus, the ability to protect the substrate. Paints without carbonate extenders lose considerably less weight after immersion in acid than those with carbonate. For paints containing $CaCO_3$, all of the $CaCO_3$ is removed by immersion in acid, with a rate that is dependent on pH. The leaching process affects the mechanical properties of the paint under certain temperature conditions. The kinetics of extender removal have been quantified from pH 2.0 to pH 5.6 for immersion in aqueous sulfurous acid solutions. The polymer itself is unaffected by immersion in acid.

Fourier-transform infrared spectroscopy, using the attenuated total reflectance sampling method (FTIR-ATR), has proven to be an invaluable technique for assessing the effects of acidic deposition on the chemical composition of paint films. Changes in the chemical structure of the base polymer have been noted after relatively short exposure periods to UV light + SO_2. Changes in the chemical composition of the paints, due to leaching or other removal processes, can be followed, and the kinetics of removal can be determined. The experiments completed to date have verified the feasibility of the ATR sampling method. Future experiments will be directed at in-situ monitoring of changes in the chemical structure and composition of the paints during exposure to pollutant gases and acidic environments.

The solubility and diffusivity of SO_2 in latex paints has been determined at room temperature and at varying pressures of SO_2. A linear relation has been confirmed between the partial pressure of SO_2 and its concentration in the polymer. Dissolution of SO_2 occurs only in the polymer, with the inorganic additives acting simply as impenetrable fillers. The base polymer in the paint absorbs about 13 percent by weight of SO_2 at an SO_2 pressure of 1 atm. The diffusivity of SO_2 in the paints can be measured, is pressure dependent, and when combined with the solubility (S), the permeability (P - SD) of the paints to SO_2 can be determined. This research has increased our understanding of the transport of SO_2 through paint films to the underlying substrate.

In Situ Studies of Materials Damage

The correlation between day-night timing of wetting/drying cycles and day-night variations in the concentrations and deposition of acidic pollutants has been investigated near a 150-year old marble-faced building in Philadelphia. The building has a variety of exposure situations that affect the wet and dry deposition of pollutants. It has previously been observed that the deterioration of stone building exteriors occurs at greatly differing rates on varying parts of the building. This observation is the basis for a series of measurements in which soluble deposits are sampled at various locations on the building exterior surfaces. These samples are collected in regions with varying degrees of sheltering from direct exposure to rain and with differences in visible surface accumulation and discoloration. The study of weathered marble on an actual building in an urban setting enhances our understanding of materials performance in an architecturally and historically important setting. The results are expected to augment the results of research directed toward the development of dose-response functions in laboratory and controlled field experiments, by the identification of the range of conditions that are the result of varying exposures on actual structures.

In a study conducted at Gettysburg National Military Park, Pennsylvania, field experiments have been conducted to investigate the dynamics of dry deposition to complex shapes. An equestrian statue was selected to provide a variety of shapes with different aerodynamic characteristics. The transport of acidic gases and particulates to the statue is being studied by using collection surfaces attached to the statue. Surrogate surfaces with aerodynamically well-defined boundary layer characteristics are also being exposed near the statue. Initial results indicate that greater fluxes of nitrate and sulfate correspond spatially to surfaces on the statue with greater degrees of corrosion.

MAJOR DELIVERABLES

DELIVERABLE	DATE	SIGNIFICANCE
Report on laboratory studies relating to carbonate dissolution processes.	Early 1989	The report will present the interpretation of kenetic experiment results and a geochemical model for pollutant damage to carbonate stone.
A report on laboratory studies relating to the deposition of atmospheric precursor gases to stone surfaces.	Early 1989	The report will describe the deposition of SO_2 and NO_x to the surfaces of freshly quarried and weathered carbonate stone under ambient environmental conditions. This data will assist in predicting stone damage from dry deposition.

DELIVERABLE	DATE	SIGNIFICANCE
A report on the analysis of sulfur compounds at the paint/wood interface after sulfuric acid treatment.	Early 1989	If sulfur is detected than it is possible that sulfuric acid can affect paint adhesion. On the other hand, if sulur is not detected, than it is unlikely that sufficient sulfuric acid can diffuse through an intact paint film to affect paint adhesion.
A report on damage functions for zinc and galvanized steel based on long-term field exposure data.	Mid-1989	The report will present an analysis of the data from long-term exposure (1-year and greater) of zinc and galvanized steel at the materials exposure sites. It will integrate the corrosion data base with the rain chemistry and aerometric data bases for each site.
A report on the micro/macro effects of acidic deposition on paint/substrate systems.	Mid-1989	The report will characterize the linkages between microscopic changes in paint films and macroscopic modes of paint failure. This information is required for economic assessment activities.
A report on a study conducted at Mesa Verde National Park, Colorado.	Late 1989	The report will define the effects of environmental exposure on the sandstone ruins, based on the results of four years of parallel monitoring of sandstone decay and environmental factors.
A report on a study conducted at Gettysburg National Military Park, Pennsylvania.	Late 1989	The report will describe the effects of acidic pollutants on bronze and carbonate stone monuments, based on the results of in-situ runoff experiments at this rural Pennsylvania site.

DELIVERABLE	DATE	SIGNIFICANCE
A report on the micro-damage of acrylic latex paint on wood substrates exposed to acidic deposition.	Late 1989	The report will discuss the development of coating mechanisms which will aid in the prediction of coating lifetimes under various exposure conditions.
A report on painted wood exposed for 18 months in an outdoor environment at sites in Steubenville, Ohio; Raleigh, North Carolina; and Madison, Wisconsin.	Early 1990	The report covers how samples will be evaluated for paint adhesion, chemical reactions at the paint/wood interface, and surface changes to the paint. The results of this experiment should allow the documentation of different weathering mechanisms and rates for various pollution levels.
A report on dose-response functions for carbonate stone.	Mid-1990	The report will discuss the algorithms to be used for the dose-response functions for carbonate building stone (including information on changes in surface composition, roughness, recession, and runoff chemistry) in an economic assessment of the effects of acidic deposition.
A series of reports on 5-year field exposure tests on carbonate stone.	Mid-1990	These reports will describe the results of mineralogical, surface chemistry, roughness/recession, weight loss, color change, and runoff measurements at five field sites in relation to environmental data supplied by EPA.
A report on dose-response functions for selected coating systems.	Mid-1990	This report will provide discussions of first generation dose-response functions produced under laboratory and field conditions for the effect of pH, sulfur dioxide, and oxides of nitrogen on polymeric surface coatings.

DELIVERABLE	DATE	SIGNIFICANCE
A report on the evaluation of chemical changes in lignin and carbohydrates in wood that has been exposed to dilute sulfuric, sulfurous, and nitric acids at room temperature.	Mid-1990	The elucidation of these chemical changes under laboratory conditions is expected to provide the background information which is necessary for evaluating specimens exposed in outdoor environments.
A report on monitoring studies conducted at Independence National Historical Park, Philadelphia, Pennsylvania.	Mid-1990	This document will describe the results of one year of parallel monitoring of marble decay and environmental factors on an historical marble building at an urban Philadelphia site. The study will describe the effects of orientation and sheltering on stone damage resulting from acidic deposition.

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EMISSIONS AND CONTROLS

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Kohout, E.J., C.L. Saricks, and D.J. Miller. 1988. Estimated Monthly Emissions of Sulfur Dioxide, Oxides of Nitrogen, and Volatile Organic Compounds for the 48 Contiguous States, 1987. ANL/EES-TM-322.

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