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to the
President and Congress

National Acid Precipitation Assessment Program
Washington, D.C.

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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Executive Summary

This statutory Annual Report to the President and the Congress by the Interagency Task Force on Acid Precipitation marks the end of the first full year of an integrated research effort by the Federal agencies. The National Acid Precipitation Assessment Program is coordinated by the Task Force and focuses federally-funded research on the timely development of a firmer scientific basis for policy decisions.

This report summarizes the major research findings and accomplishments of the National Program's first year, with particular emphasis on their bearing on acid precipitation policy questions. It provides a brief overview of the available scientific information relevant to policy formulation. As the National Program progresses, future annual reports will provide updates and increasingly better information to assist decisionmakers and the public in continuing to resolve the "acid rain" issue. The program will integrate findings from diverse research areas in order to arrive at successively better answers to key questions, such as:

- What are the current and potential effects of acid deposition within each region, and to what extent could these be ameliorated by lower deposition levels or other mitigation methods?
- What is the quantitative relationship between the release of certain pollutants into the atmosphere and the amount of acidic materials that are deposited?
- What are the costs and environmental impacts of these effects, as well as the costs and benefits of controlling pollutant releases?

In accordance with the Acid Precipitation Act of 1980 (P.L. 96-294), the Task Force is vigorously implementing a comprehensive research program. Federally-funded acid deposition research has doubled, from about $11 million in FY 1980 to $22.3 million for FY 1983. The National Program is producing results at an increasing rate, disseminating them as soon as they become available. However, as recognized in the Act, it will take a systematic effort over a number of years to adequately address all the major uncertainties about the causes, effects, and management of acid deposition.

STATE OF THE SCIENCE

This overview on the current state of the science is based on information from all available sources, including research supported by Federal agencies, States, environmental organizations, private sector groups, and other nations.

Causes

Man-made atmospheric pollutants are probably the major contributors to acid deposition in northeastern North America. The approximate coincidence of the region of highest precipitation acidity with the areas of greatest sulfur dioxide and nitrogen oxides emissions provides circumstantial evidence to support this assertion. This conclusion is also supported by preliminary meteorological studies tracking the physical movement of one pollutant (sulfur dioxide) from sources of emission to suspected areas of deposition.

The National Program is also studying another contributory pollutant (oxides of nitrogen) and chemical substances suspected of being factors in controlling acid deposition. Current data and available methods, however, are not sufficient to quantify relationships between pollutant emissions and acid deposition on a regional scale, or under varying conditions. Nor is it yet possible to identify the specific change in acid deposition patterns that would result from a given change in precursor emissions.

In addition to man-made sources, natural sources of acid precursors are known to exist. On a global scale, it is roughly estimated that half the sulfur in the atmosphere is from natural emissions. Regionally, preliminary findings suggest that natural sources might contribute significantly to the acidity of precipitation in some areas, such as the southeastern United States. In the northeastern United States natural sources are believed to be minor contributors to acid deposition. The National Program includes research to increase our meager knowledge of the strengths, character, and distribution of natural sources of sulfur and nitrogen that can contribute to acidity as well as alkaline dusts that neutralize acids in precipitation. This information will be used to assess the potential significance of these sources in contributing to acid deposition in sensitive areas.

Source/Receptor Relationships

To formulate scientifically based control strategies, the relationship between emission of precursor pollutants and deposition of acidic material at sensitive receptors should be reliably established.

The ability of current generation models to predict source/receptor relationships with adequate resolution and accuracy is an unresolved issue. A study on the ability of eight models to predict the deposition of sulfur emissions in eastern North America found only a few suitable monitoring data points. While a method is now available to properly evaluate model performance, more data (quality assured and available as a time series) is needed to quantify the uncertainties in model predictions. In addition there are widely differing views of the relative importance of local sources (acid deposition from nearby sources of pollution) and long-range transport (acid deposition from far-removed sources of pollution) on the receptors in the local region.

Because of the urgent need to improve our ability to make predictions that reasonably estimate the change in amounts of acid deposition expected from decreases in pollution levels, the National Program includes several simultaneous approaches:

1. For near-term assessments, modifying current-generation models to refine their accommodation of chemical and physical factors over shorter periods of time;
2. Constructing a new generation of models to more effectively treat the physical movement of pollutants in the atmosphere, as well as the mechanisms for their conversion to acids and deposition;
3. Designing a series of field experiments to provide empirical, quantitative evidence of the relationship of pollution source to acid deposition; and
4. Upgrading and evaluating a suitable local/mesoscale model to quantify the relative contribution of local versus long-range transport on receptors.

Intensive efforts underway in the National Program and elsewhere should enhance our ability to project the consequences of changes in emission patterns.

Impacts

Among the possible effects of acid deposition, aquatic impacts are currently of greatest concern because of the sensitivity of certain surface waters to acidification and the known potential for damage to fish and other organisms. Initial surveys indicate that a small number of lakes concentrated in the sensitive regions of northeastern North America have been acidified, and their biota have changed.

In the Adirondacks, one of the most sensitive regions in North America, the State of New York has classified 3.6 percent of lake area as in "critical" condition (7,466 acres of 246,388 acres total) and 14 percent endangered; 84 percent were surveyed. Acid deposition is probably the major contributor to this acidification, but the rates of change and the factors controlling it are still poorly understood.

Many of the reported cases that suggest acid deposition is the cause of some observed change in an aquatic ecosystem are based on circumstantial evidence and lack documentation of the mechanisms linking cause and effect. At present, the extent of actual aquatic damages is not well established. The question of long-term trends in freshwater acidification also remains uncertain.

The National Program produced maps in FY 1982 depicting the regions where surface waters could be most susceptible to acidification. Studies underway will better define the factors that control acidification, and improved regional monitoring and testing programs will produce more detailed and reliable inventories of the extent of damages and the location and value of resources at risk.

Beyond the alteration of the chemistry and biology of certain sensitive surface waters, the other effects of acid deposition in North America are undetermined. There is concern about possible effects on crops, forests, wetlands, soils, building materials, and indirect effects on human health (through drinking water or food). Although mechanisms for such effects are known, evidence has not yet demonstrated that they are widely occurring under ambient acid deposition in North America. For instance, although experimental studies with simulated acid rain have shown both positive and negative effects on crop species, effects on crops growing under actual field conditions have not been determined.

Similarly, although a dieback of spruce trees on mountain sites in New England is observable, the relative contribution of potential causes—acid deposition, drought, disease, and other pollutants—is still undetermined. In contrast to acid deposition, the effects of ozone and other air pollutants on crops and forests are well documented. The National Program is speeding up investigations and analyses to determine the actual effects of acid deposition.

RESEARCH PROGRESS AND OUTLOOK

In addition to the preceding synopsis of the state of knowledge about acid deposition, the "Research Progress and Outlook" part of this report describes in more detail current findings in each subject area. It also outlines many of the major research accomplishments of the National Program.

National Program FY 1982 Accomplishments

Some selected highlights of progress in FY 1982 for each research area follow.

A. Natural Sources:

- Developed and tested instruments for reliable field measurement of sulfur and nitrogen emissions from natural sources.
- Obtained preliminary measurements of natural sulfur compounds in the ocean that suggest emissions from marine sources may contribute significantly to atmospheric acidity in some areas.

B. Man-made Sources:

- Completed preliminary study on emission sources that suggested that nearby petroleum combustion and local and distant coal combustion could significantly affect local acid deposition.

• Continued development of models to predict the cost and emissions changes from utilities and industries based on various possible control strategies.

• Developed specifications for emissions inventories with improved spatial, temporal, and source-type resolution, and initiated studies to better characterize the man-made sources of acid precursor pollutants.

C. Atmospheric Processes:

• Obtained initial observations that confirm the importance of clouds in transforming sulfur dioxide to acidic sulfates.

• Initiated field studies that suggest the importance of man-made aerosols in cloud formation.

• Completed planning and initial testing for a major field experiment to be performed in FY 1983 that will track the movement of tracer gases over hundreds of miles after their release in the Midwest.

• Improved atmospheric models and used them to gain a better understanding of the movement and conversion of pollutants and the deposition of acidic material.

D. Deposition Monitoring:

• Produced the first comprehensive maps describing the distribution of major chemical substances over North America.

• Completed design for the National Trends Network, which will be established in FY 1983 building on existing National Atmospheric Deposition Program (NADP) sites and others that meet specific criteria.

• Established four research sites to test improved methods of monitoring wet and dry deposition.

• Compared field measurements of dry deposition obtained from different prototype methods and continued efforts to develop reliable techniques for routine measurement of dry deposition.

E. Aquatic Effects:

• Produced a nationwide map indicating regions where surface waters are likely to be most sensitive to acidification.

• Began long-term monitoring of aquatic resources (chemistry and biota) in key sensitive regions.

• Completed preliminary survey of drinking water in the Northeast that indicates some reservoirs and their watersheds have limited ability to buffer acid deposition.

• Developed better understanding of factors controlling the susceptibility of surface waters to acidification and evaluated models for predicting acidification.

• Evaluated existing information on mitigation strategies (liming), and initiated field and laboratory studies to examine their effectiveness and limitations.

• Began studies of acid deposition effects in the southeastern United States.

F. Terrestrial Effects:

• Initiated extensive long-term studies to determine whether acid rain has caused changes in rate of growth and species composition in forests.

• Completed a study evaluating whether acid rain predisposes pine seedlings to succumb to stress factors. It did not show increased susceptibility to insect or disease attack; some seedlings showed increased resistance to disease.

• Conducted agricultural experiments using simulated acid rain that did not indicate injury to potato plants or two forage plants, but decreased the yield in soybeans and corn under some conditions and had no effect under others.

• Performed soil studies in the Southeast, mid-Atlantic coast, and Northeast that showed response to acid rain varied according to mobilization of toxic metals and leaching of nutrients.

• Conducted studies indicating that southeastern watersheds are accumulating sulfur. The importance of this change on the chemical and biological characteristics of surface waters is not clearly understood.

• Completed several studies showing that forest ecosystems alter the acidity of rain traveling through them.

G. Effects on Materials and Cultural Resources:

• Began work to determine possible damage to historical monuments that is related to acid deposition.

• Established several field sites for testing materials and estimating the relationship of deterioration rates to acid deposition.

• Began analyzing available materials deterioration data and documenting the performance of possible protective treatments for masonry.

• Tested a simplified deposition monitor for application to materials damage research.

H. Control Technologies: (FY 1982 developments outside the National Acid Precipitation Assessment Program under preexisting agency pollution control hardware programs relevant to acid deposition)

• Successfully tested developmental prototype of low-cost, retrofitable technology (LIMB) that can simultaneously decrease sulfur dioxide and nitrogen oxides emissions from utilities by 50 percent. (EPA)

• Developed burner systems to decrease nitrogen oxides emissions by 75 percent in large coal-fired boilers. (EPA)

• Assembled data on the characteristics of U.S. coals to aid in determining their emission control potential. (EPA, DOE)

• Evaluated improved wet and dry sulfur dioxide scrubbing (removal) processes. (DOE, TVA, EPA)

I. Assessments and Policy Analysis:

• Prepared the "Critical Assessment Document: The Acidic Deposition Phenomenon and Its Effects" requested by the Clean Air Science Advisory Committee prior to formation of the National Program. Several chapters review acid deposition and its impacts. Contributors include 54 scientists from many institutions in this country and abroad. The document is now undergoing public review and final revision.

• Initiated work on developing methodologies for conducting integrated assessments of the significance of various scientific and economic information.

• Developed the preliminary version of a model for assessing sulfur dioxide emissions from the utility sector.

• Began investigation of estimating uncertainty in models and the implications for formulating management strategies.

J. International Activities:

• Established basis and mechanisms for increased cooperation between the United States and Canada on research and monitoring activities.

• Began developing specific proposals for joint research efforts with other nations.

• Published *International Directory of Acid Rain Researchers,* listing 1,600 scientists in 32 countries.

This annual report contains more details of the accomplishments in the various research categories in Sections A through J of the "Research Progress and Outlook" chapter. The Task Force also has made significant progress in FY 1982 in integrating and focusing Federal activities and coordinating them more effectively with private sector, State, and international acid deposition research efforts. In FY 1982 the Task Force met with representatives of these key groups to increase coordination. These accomplishments are described in the "Organization and Management Activities" chapters.

Outlook

In the next several years the research under the National Program will produce a number of important results. From FY 1983 to FY 1985 the Task Force agencies expect to accomplish several goals:

• Produce a report estimating how effective control of sulfur oxides, nitrogen oxides, and/or volatile organic compounds would be in reducing acid deposition for different regions.

• Complete assessments of the potential significance of alkaline dusts and natural sulfur and nitrogen emissions in influencing precipitation acidity over sensitive regions.

• Begin applying advanced models to predict utility emissions and develop a preliminary model to estimate industrial combustion emissions.

• Complete a major transport experiment (CAPTEX) to help determine long-range pollutant transport patterns and facilitate evaluation of atmospheric models.

• Develop a model capable of estimating local/mesoscale atmospheric deposition.

• Complete the National Trends Network, to provide adequate coverage to produce reliable annual maps of acid deposition for North America.

• Develop and begin applying improved techniques for monitoring dry deposition.

• Complete inventories and detailed regional maps of the extent of sensitive and currently acidified surface water.

• Prepare a comprehensive report on the status of drinking water supplies.

• Finish a broad assessment of the potential effects of acid deposition on soils.

• Establish dose-response information on corn and soybeans in eastern and midwestern regions of the United States.

• Complete initial determination of the effect of acid deposition on the susceptibility of forests to drought and other stresses.

• Prepare a report on historical rates of deterioration of building material and complete inventory of materials at risk in the Northeast.

• Complete initial assessment of the scope of material damages caused by acid deposition.

• Finish report on historical trends in emissions, deposition, and effects.

• Develop and apply advanced integrated assessment methods to evaluate the optimal strategies for managing acid deposition and its effects.

These and the many other achievements of the National Program will significantly improve our understanding of acid deposition and help develop sound policies to address the problem.

The National Acid Precipitation Assessment Program made an ambitious start and broad progress during its first year. The groundwork has been laid for continued progress in answering the scientific questions associated with acid deposition. A framework has been established to organize and integrate research results to address policy questions. The National Program's recurring assessments will provide a successively refined scientific basis for decisionmaking as well as opportunities to reexamine research directions.

Organization and Management Activities

HISTORY

The Interagency Task Force on Acid Precipitation was established by the Acid Precipitation Act of 1980 (P.L. 96-294) to plan and manage the National Acid Precipitation Assessment Program. Planning for the National Program began in October 1980, when the Task Force was first organized. In accordance with the Act, the Task Force drafted a National Acid Precipitation Assessment Plan, outlining the proposed research effort. That plan underwent extensive public review and the final version was submitted to Congress in June 1982.

The Task Force developed its first interagency budget for the Program in January 1981 and submitted it to Congress as part of the President's FY 1982 budget request. In January 1982, the Task Force issued its first annual report, outlining initial progress in the organization and planning of the National Program. The National Program's integrated research effort began in October 1981 with the beginning of FY 1982.

TASK FORCE

The Task Force oversees the planning and implementation of the National Acid Precipitation Assessment Program. The 20 members include one high-level representative from each of the 12 Federal entities in the Program, the directors of Argonne, Brookhaven, Oak Ridge, and Pacific Northwest National Laboratories, and four Presidential appointees. The Task Force is jointly chaired by the National Oceanic and Atmospheric Administration (NOAA), the Department of Agriculture (DOA), and the Environmental Protection Agency (EPA). Other participating Federal entities include the Departments of Interior (DOI), Health and Human Services (HHS), Commerce (DOC), Energy (DOE), and State (DOS); the National Aeronautics and Space Administration (NASA); the Council on Environmental Quality (CEQ); the National Science Foundation (NSF); and the Tennessee Valley Authority (TVA).

The primary responsibilities of the Task Force are:

- Plan and manage the National Acid Precipitation Assessment Program.
- Provide annual reports on the National Program's progress.
- Produce an annual interagency budget for the National Program.
- Coordinate the National Program with the research and monitoring activities of the private sector groups, environmental organizations, States, and other nations.
- Maintain an inventory of federally-funded acid precipitation research projects.
- Disseminate research results and assessments of their implications.

The role of the Task Force in planning the interagency budget for the National Program is a highly effective and unique aspect of the Federal effort. By working together through the Task Force, the agencies have established a research program that addresses national needs while building on the research expertise of the individual agencies. This strong interagency planning process avoids unnecessary duplication and eliminates crucial omissions in the National Program.

The Task Force sets the research goals for the National Acid Precipitation Assessment Program, identifies the projects needed to meet these goals, and decides which agencies are best suited to conduct the necessary work. The result is a comprehensive program of interlocking projects, with each agency contributing to specific aspects of the overall national effort.

During FY 1982 the Task Force met six times to review and approve the final National Acid Precipitation Assessment Plan, develop and approve the FY 1984 budget request, review and approve plans for the First Annual Review Meeting, and begin developing a detailed technical Operating Research Plan for the National Program. Appendix II lists all major Task Force activities with their dates and purposes.

TECHNICAL TASK GROUPS

The Task Force has 10 working-level Task Groups, one for each of the National Program's nine research categories and one for international activities. These technical groups include program managers and experts from all the participating Federal agencies and National Laboratories. They are responsible for detailed planning

and work in their assigned areas. A Coordinating Agency serves as the contact point within each Task Group. The Task Groups and their Coordinating Agencies are:

Task Group	Coordinating Agency
A. Natural Sources	NOAA
B. Man-made Sources	DOE
C. Atmospheric Processes	NOAA
D. Deposition Monitoring	DOI
E. Aquatic Effects	EPA
F. Terrestrial Effects	DOA
G. Effects on Materials and Cultural Resources	DOI
H. Control Technologies	EPA
I. Assessments and Policy Analysis	EPA
J. International Activities	DOS

These Task Groups met numerous times throughout FY 1982 and provided the material used in developing this report.

RESEARCH COORDINATION COUNCIL

The Research Coordination Council (RCC) oversees and integrates the efforts of the various Task Groups and develops draft reports, program plans, budgets, and other recommendations for consideration by the full Task Force. The joint chairs designated the Task Force's executive director to oversee its efforts. The RCC includes the leaders of all the task groups, the chairperson of the National Laboratory Consortium, and other appropriate agency representatives.

The Research Coordination Council met 10 times in 1982 and tackled many different tasks, including:

- Revising the National Acid Precipitation Assessment Plan;
- Drafting the Operating Research Plan;
- Planning the First Annual Review Meeting;
- Designing an inventory of Federal and State acid deposition research;
- Developing the FY 1984 interagency budget request;
- Drafting the 1982 Annual Report to the President and Congress.

The RCC will address many important management issues during the coming year, including plans for intensifying program review activities.

PROGRAM COORDINATION OFFICE

The Program Coordination Office staffs the Task Force and coordinates interagency activities. The office also disseminates information on the Program and is the primary liaison with States, private groups, the public, and other countries. The office is housed at CEQ and is funded by NOAA, EPA, DOA, DOI, and DOE.

During FY 1982, the Program Coordination Office supervised planning for the Task Force's First Annual Review Meeting (held in September 1982), and worked with non-Federal groups in organizing the Acid Precipitation Research Coordination Workshop (held in November 1982). The Program Coordination Office actively distributed thousands of copies of Task Force documents and responded to hundreds of requests for information on the National Program.

NATIONAL LABORATORY CONSORTIUM

The four National Laboratories on the Task Force form the Consortium required by law to integrate their acid precipitation research efforts and assist the Task Force in planning and conducting research and assessment activities. Each year the Consortium elects a chairperson to serve on the Research Coordination Council.

During FY 1982 members of the National Laboratories participated in the activities of all the Task Groups and assisted the Task Force in drafting the Operating Research Plan. The National Laboratory Consortium is studying data management needs for the National Program and inventorying Federal and State acid rain research.

MAJOR FY 1982 PROGRAM DEVELOPMENT ACTIVITIES

In addition to regular meeting and planning activities, the Task Force has undertaken several major efforts to improve the management and coordination of the National Program, including:

1. **Improving Coordination with Non-Federal Activities.** The Task Force is committed to conducting a National Program that coordinates Federal efforts with the research and monitoring activities of State and local governments, the private sector, environmental organizations, and other countries. Several specific steps have been taken to develop and encourage such cooperation and more extensive joint planning activities are anticipated. Besides reviewing the draft National Plan, the Task Force's April 1981 workshop of non-Federal experts began a dialogue with State and private groups. The workshop report describes the participants' ideas concerning how coordination and cooperation can best be accomplished. The Task Force is implementing many of these suggestions and is actively pursuing continued exchanges of information with non-Federal groups.

At the First Annual Review Meeting of the Task Force (September 1982), approximately 30 non-Federal participants provided valuable ideas to discussions of interrelationships among research areas, using the draft Operating Research Plan as background. Substantial research on acid deposition is sponsored by the private sector, certain States, and Canada; Task Force representatives have met with these non-Federal groups. These meetings have focused on reviewing programs and establishing a basis for better understanding and closer coordination. During the last year, the two most significant such events were:

- *Task Force-Canadian Research Program Cooperation.* In April 1982, Task Force representatives met with the Canadian Federal/Provincial Research and Monitor-

ing Coordinating Committee (RMCC) to discuss bilateral scientific cooperation. Leaders of both the U.S. and Canadian research efforts emphasized the mutual value of greater cooperation and coordination of activities.

• *Task Force-State-Private Sector Coordination.* The Task Force initiated and encouraged joint sponsorship of an Acid Deposition Research Coordination Workshop in November 1982. The non-Federal sponsors included the Electric Power Research Institute, the American Petroleum Institute, the Gas Research Institute, the Coordinating Research Council, the National Council of the Paper Industry for Air and Stream Improvement, and the Keystone Center. The States, private sector, and the Federal Task Force were represented about equally. Environmental groups were also invited to participate.

The purpose of the workshop was to bring together key Federal and non-Federal managers of acid deposition research to review and discuss the management and coordination of their research planning efforts. Specifically, the two goals of the meeting were (1) to assess the scope of the nationwide acid deposition research effort, and (2) to initiate a continuing process for joint planning and coordination of Federal and non-Federal acid deposition research efforts.

In addition to developing joint statements on research needs and disseminating information, the State representatives agreed to organize by regions and to define their specific areas of expertise. The Task Force agreed to investigate ways to increase opportunities for State and private sector participation in the National Program planning and review groups. Followup activities include further discussion between the Task Force and the private sector and State representatives to work out the details.

2. **Developing a Detailed Operating Research Plan.** To ensure that diverse scientific findings are systematically organized to address the relevant policy questions, the Task Force is developing an Operating Research Plan. This detailed document supplements the more general National Acid Precipitation Assessment Plan (June 1982) and describes each project and how it relates to other activities and specific program outputs. This plan gives the technical and programmatic details on how the National Program's objectives will be met. The completed plan will be a dynamic document that will evolve with the Program and be updated annually to track the National Program and project plans for future years.

3. **Developing an Inventory of All Federal and State-Sponsored Acid Deposition Research.** The initial tabulation was completed this spring and the inventory will be maintained and updated for use by the Task Force and all interested parties. This inventory includes information on all ongoing projects with the performer(s), duration, funding, study area, research goals, methodologies, and expected outputs. The private sector has conducted a similar inventory of its activities; together with the Task Force's effort, this should provide a complete catalog of all acid deposition research and monitoring activities in the United States.

Research Progress and Outlook

MAJOR RESEARCH QUESTIONS

The National Program includes research, monitoring, and assessment activities to develop answers to major research questions. In addition to identifying and reducing scientific uncertainties, the National Program is organizing the scientific information to address policy questions. The Task Force is establishing a systematic framework for evaluating the costs and benefits of alternative policy options for controlling man-made sources of acidity or mitigating adverse effects.

Some of the overall research questions the National Program is specifically addressing are given here with some indication of the type of work underway to answer the questions.

1. **Does acid deposition significantly affect aquatic resources, crops, soils, forests, materials, or human health?** Except for poorly buffered lakes, evidence on other actual impacts is inconclusive. The National Program included intensive laboratory and field studies to develop a more definitive understanding of the potential for damage to sensitive resources.

2. **Where are the sensitive resources? How much damage has occurred, or how long will it take for damage to occur?** Concern about acid deposition centers around its potential and known effects. The National Program is developing inventories of the aquatic, terrestrial, and cultural resources at risk and is surveying the resources that have already been affected by acid deposition.

3. **What is the relative contribution of wet versus dry deposition acids?** Dry deposition may constitute up to 50 percent or more of acidifying substances, but reliable methods for its routine collection and measurement do not yet exist. Vigorous efforts are underway in the National Program to develop appropriate techniques for adequately monitoring dry deposition on a routine basis. In the meantime, interim methods for collecting dry deposition will be used to provide the best currently attainable data.

4. **What is the relative importance of local versus distant pollution sources in controlling the acidity of deposition at a given location?** Neither models nor measurements currently address this question with a reasonable degree of confidence. The National Program includes a broad atmospheric sciences effort with models, experiments, and measurements in the field and laboratory designed to improve our understanding of source/receptor relationships as rapidly as possible. Information on the characteristics and magnitude of local and regional sources of man-made emissions is being refineded as well.

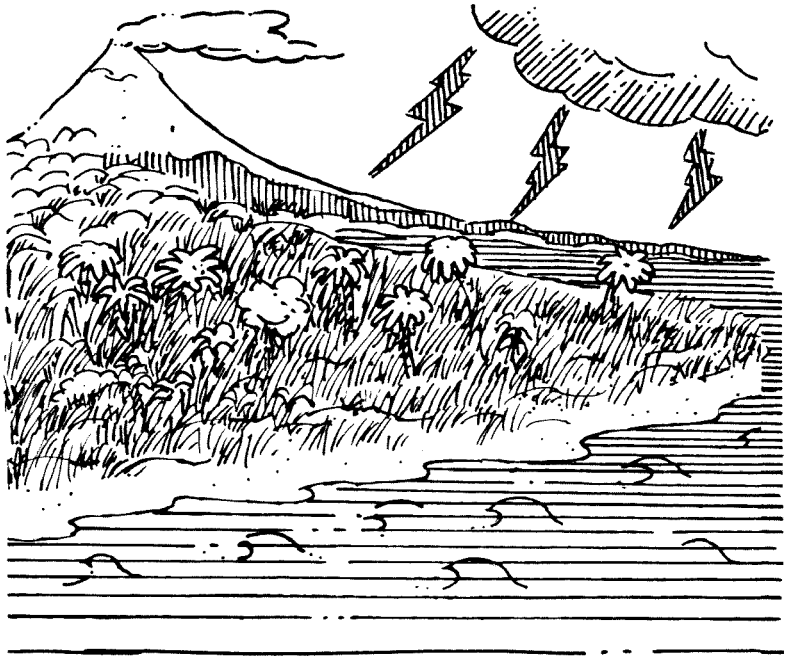
5. **What is the relative contribution of man-made versus natural sources of acid-forming material?** Significant natural sources exist, but their role is uncertain. The amount of natural acid precursors arising from sources such as oceans and marshes is being determined by the National Program to assess their contribution to acidity over North America. The magnitude, distribution, and character of man-made emissions are also being inventoried to more accurately identify their contribution to acid deposition.

6. **What is the temporal and spatial distribution of acid deposition?** Monitoring efforts before 1977 were fragmented and generally inadequate for determining trends. A National Trends Network with standardization and quality control has been established to answer these questions. Using a variety of information sources, research is also underway to improve monitoring techniques and to decipher any past trends.

7. **What changes in deposition would result from a given change in sulfur dioxide, nitrogen oxides, organics, and/or primary sulfate emissions?** Scientists cannot precisely calculate the amount of emission reductions that would be required to reduce acid deposition below a particular level within a given area. We need to know more about atmospheric processes to accurately quantify source/receptor relationships. The National Program's assessment activities integrate information on sources and atmospheric processes to address this question.

A. Natural Sources

BACKGROUND*



The sources of acid precipitation precursors are both natural and man-made. Natural sources will continue to contribute to precipitation chemistry despite any foreseeable abatement procedures that might control man-made sources. Emission control strategies and alternative energy options, therefore, require an accurate assessment of the relative importance of the two types of sources.

To make that assessment, the National Program's natural sources research focuses on answering two key questions:

- What natural emissions can influence precipitation chemistry?
- What are their strengths locally, regionally, nationally, and globally?

This research seeks answers to these questions in the context of current knowledge of natural emissions, which is summarized as follows.

The present understanding recognizes both biogenic and nonbiogenic natural sources. Some estimates place biogenic sources—vegetation and microbial activities in upland terrestrial sites, tidal/intertidal areas, and nutrient-rich oceanic regions—at 80 percent of the total natural source strength. The nonbiogenic sources include geothermal activities, natural combustion, lightning, and airborne soil and water aerosols. Sulfur- and nitrogen-containing gases are currently suspected to be the principal emissions from natural sources that influence precipitation chemistry, but natural alkaline materials such as ammonia and wind-generated aerosols and other acidifying components such as chlorine compounds could also play significant roles.

Various researchers have estimated numerous global budgets for sulfur compounds and have put natural emissions from 35 to 85 percent of the total global sulfur budget. On regional scales, the few existing estimates place natural sulfur emissions at a much smaller fraction, only a few percent in one study of the northeastern United States. However, these estimates are derived largely from a few measurement series. Furthermore, it is not clear whether differences among the data arise from natural variation within the environment or from problems with the instruments and techniques used in measuring natural sulfur emissions.

A recently completed assessment of nitrogen oxide emissions found that industrial and agricultural emissions together are approximately twice natural emissions on a global scale, while in North America fossil fuel combustion was found to produce 3 to 13 times more nitrogen oxide than natural sources. Systematic studies are required to accurately determine natural nitrogen oxide emissions with higher accuracy and geographical resolution than is currently available.

RESEARCH GOALS AND ACTIVITIES

To resolve these uncertainties, the National Program's research on natural sources has set the following specific objectives for FY 1982 to FY 1985:

1. Establish the reliabilities of the current state-of-the-art sulfur flux-measurement instruments and techniques.
2. Identify via field measurements, modeling, and laboratory studies the major potential sources of natural sulfur emissions that could contribute to precipitation chemistry.
3. Determine the strength of acid-forming natural sulfur emissions from land and ocean sources by using existing data and supplementary studies.
4. Develop accurate techniques for identifying and quantifying natural nitrogen emissions that could contribute to precipitation chemistry.
5. Estimate the strengths of acid-forming nitrogen emissions using survey measurements.
6. Provide an initial assessment, measurement technique development, and survey measurements of the natural alkaline emissions that can contribute to precipitation chemistry.

Reaching these goals will lead to a significant accomplishment by the National Program: an experimental data base that adequately characterizes the source strengths of the natural sulfur, nitrogen, chlorine, and alkaline emissions that influence precipitation chemistry on regional and national spatial scales.

* These background sections are based on scientific information available from a variety of sources, including research sponsored by Federal and State agencies; environmental, private sector, and international organizations; and other countries.

These findings, together with analogous ones from man-made sources research, will feed into the atmospheric transport/transformation, source/receptor models used to study atmospheric processes. The models will then be able to assess the impact of natural emissions relative to man-made emissions.

PROGRAM ACCOMPLISHMENTS—FY 1982

The research projects on natural sources began in FY 1982. Because of delays in budget allocations, funds became available midway through the fiscal year; hence, the results summarized here represent only the start of the program.

- **Instrument Development.** The initial research thrust in FY 1982 was to develop and test analytical techniques for sulfur- and nitrogen-containing species. One of the major problems in reliably measuring low sulfur concentrations, water vapor in the sample, has been satisfactorily solved by developing a membrane that selectively removes water without altering most other concentrations. A sensitive technique for measuring concentrations expected for natural nitrogen emissions has also been developed. Both of these instrumentation advances should greatly improve the quality of future field measurements required by the National Program's research in natural sources and atmospheric processes.
- **Modeling.** Studies are beginning to partition the likely sources of natural nitrogen compounds. Using measurements obtained in remote oceanic areas, photochemical models have shown that most of the nitrogen produced over the oceans arises from lightning, with about a 10 percent contribution from the stratosphere. In FY 1983, these studies will be extended to other areas to improve estimates of the contribution of lightning over continents.
- **Field Measurements.** Preliminary oceanic field measurements have found reduced sulfur compounds in biologically productive seawater in the Gulf of Mexico and the North Pacific Ocean. Crude estimates of release rates of these compounds to the atmosphere from the ocean suggest they could be a significant source of atmospheric sulfur. These data will guide the FY 1983 oceanic measurements described here.

FUTURE ACTIVITIES

A major element in the natural sources research program is determining the confidence levels of various techniques used to estimate sulfur gas emissions from natural sources. The information gained not only will permit a better assessment of the existing data base, but will help plan how to improve it: both efforts will take place during FY 1983 and FY 1984.

Also in FY 1983, the Natural Sources Task Group will comprehensively review the existing land-based sulfur emission data base, emphasizing the acid precipitation problem. This inventory, categorized by soil types, will yield a "first-look" at the magnitude of the natural sulfur source budget, and it will be used to identify existing needs. Field measurements will occur in the following year as needed, drawing on the previous instrument development.

Parallel to these studies, a detailed field and laboratory investigation will examine the characteristics of specific major sulfur emitters. These latter data will provide by the middle of FY 1984 a much needed prognostic understanding of sulfur sources and their importance to the acid deposition problem.

Research cruises from FY 1983 to FY 1985 will further explore oceanic emissions of sulfur. Emphasis will be placed on quantifying the factors that influence the rate of fixation of inorganic sulfur by marine organisms, their release of reduced sulfur compounds and the vertical distribution of these compounds within the upper oceanic layer, and the transport of reduced sulfur compounds across the sea/atmosphere interface. Additionally, the correlation between the areal distribution of reduced sulfur compounds in productive seawaters with biological parameters that are amenable to remote sensing will be determined.

Laboratory kinetic studies will investigate the paths by which natural emissions are converted to acids. These rates and mechanisms are necessary in atmospheric models that will assess the acidification of precipitation by natural emissions. Initial estimates of sulfur compounds will begin in FY 1984 and continue through FY 1985.

In FY 1983 distributions and deposition fluxes of nitrate, sulfate, and ammonium will be modeled over remote oceanic stations, where the understanding of natural processes can best be tested. It is anticipated that these studies will point out previously unsuspected sources, if they exist. An initial assessment of the global budget of atmospheric nitrate precursors will be made in FY 1985.

The study of natural alkaline materials will be completed in FY 1983. This research will gather existing data on airborne alkaline materials; assess amounts and identities by region, seasonal variation, influence of meteorological conditions, and solubilities; and thereby estimate their potential neutralizing effect on precipitation.

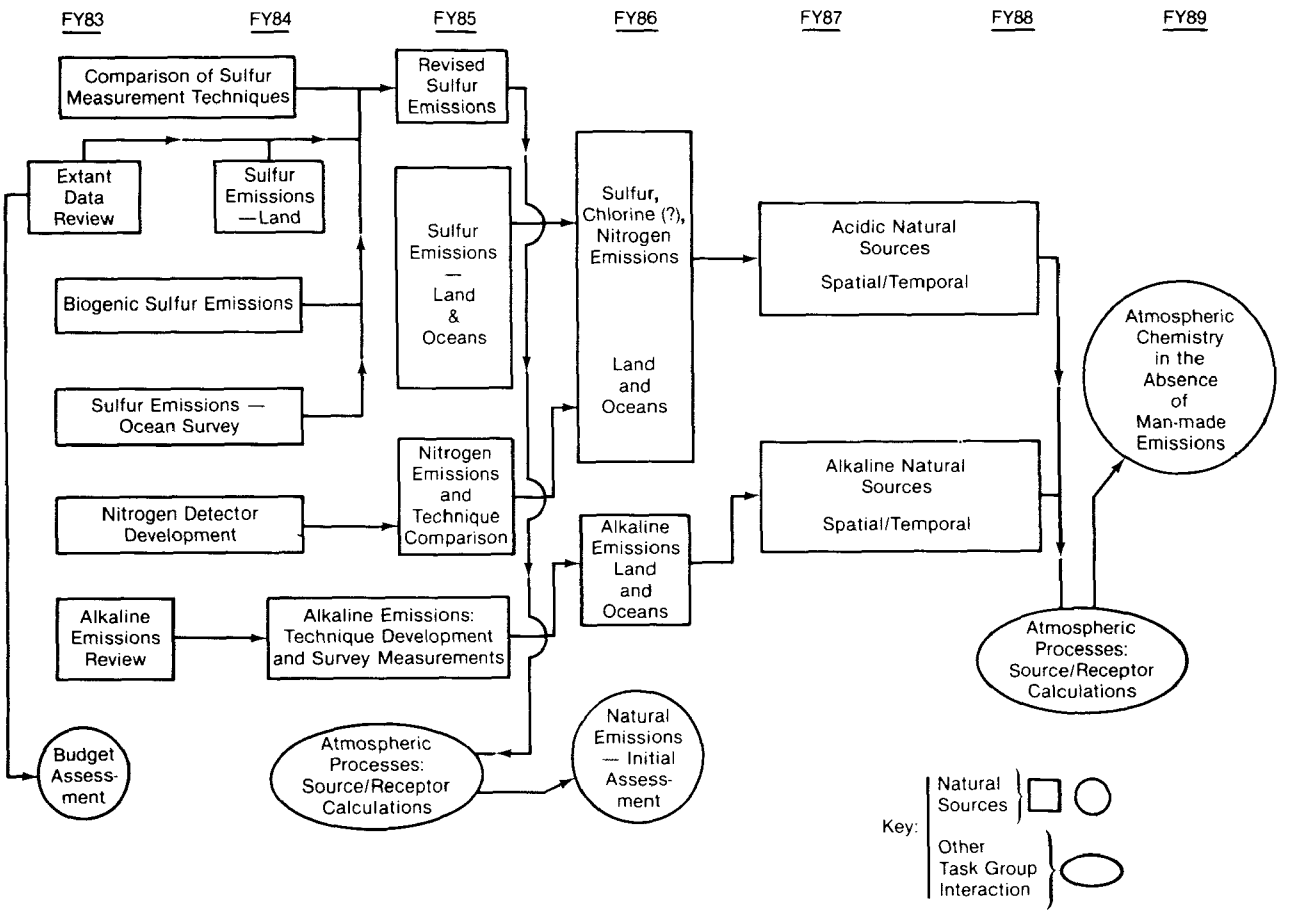
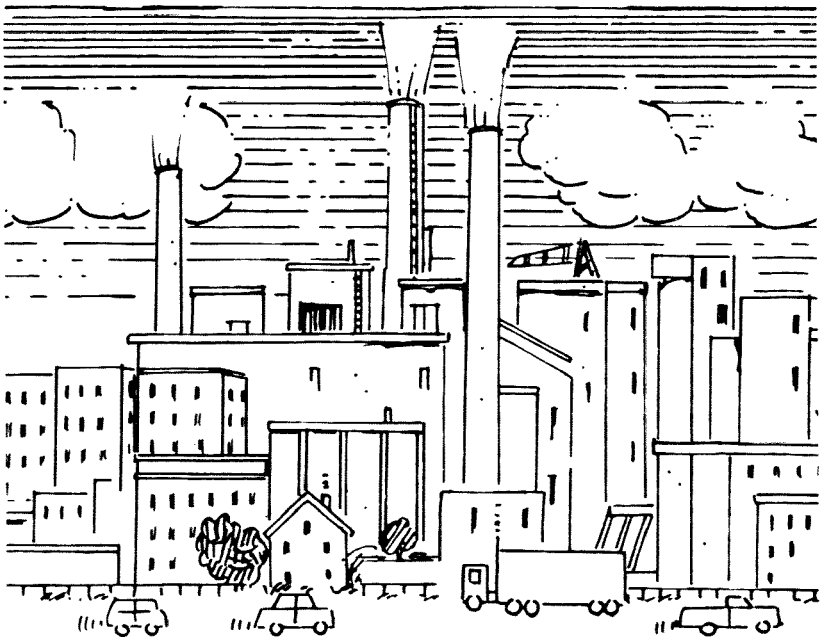


Figure A-1.—Proposed program implementation strategy, Natural Sources.

B. Man-Made Sources

BACKGROUND



Research on acid deposition has identified several substances believed to be precursors to the formation of acid compounds in the atmosphere. As more knowledge of the acid formation process is gained, the list may change.

A current list of pollutants likely to be important includes sulfur dioxide, oxides of nitrogen, volatile organic compounds, primary sulfates, ammonia, hydrochloric and hydrofluoric acids, and alkaline dusts. Of these, sulfur dioxide and oxides of nitrogen have long been recognized as important; studies of the potential influences of other pollutants, including trace metals, are continuing.

Experimental work is developing emissions factors; its purpose is to increase the accuracy of existing factors and to develop new factors for pollutants recently identified as potential precursors of acid deposition. Typically these factors are expressed as pounds of pollutant emitted for a unit produced or unit of fuel consumed. The quality of any emissions inventory depends on the accuracy of these factors. Work to develop new emissions factors is focusing on nitrogen oxides, primary sulfates, hydrocarbons, hydrochloric acid, and trace metals such as vanadium and manganese. Emissions factors for sulfur oxides are being refined.

Total emissions of sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) for the United States and Canada in 1980 were calculated as part of the work done for the U.S./Canadian Memorandum of Intent. These calculations are (in million tonnes per year):

	United States	(%)	Canada	(%)	Total
SO_2	24.1	(55.5)	4.8	(72.7)	28.9
NO_x	19.3	(44.5)	1.8	(27.3)	21.1
		(100.0)		(100.0)	

Canadian emissions of nitrogen oxides make up a smaller percentage of that country's total emissions than do domestic NO_x emissions in the U.S. total. A large portion of the Canadian sulfur dioxide emissions is generated by primary metal smelting, which contributes relatively few nitrogen oxides.

Over the past 60 years U.S. sulfur dioxide emissions have fluctuated between about 16 and 28 million tonnes per year, primarily following the rate of coal use in the country. The low point in total emissions was during the 1930's, the high point during World War II—closely followed by the early 1970's, before the 1970 Clean Air Act had an impact. The bulk of these emissions in the United States occurs east of the Mississippi River.

In contrast, nitrogen oxide emissions have increased more evenly over the years in response to increasing fuel use. The shift in coal use from domestic and industrial grade combustion to utility pulverized coal combustion has also increased average emissions because of higher combustion temperatures.

Future projections of sulfur dioxide and nitrogen oxide emissions depend on assumptions about future economic activity and regulatory changes. With no changes in regulation, the U.S./Canadian Work Group projects a 7.8 percent increase in sulfur dioxide emissions (a 5 percent drop in Canada offsetting a 10 percent increase in the United States). The Work Group expects nitrogen oxide emissions to increase a total of about 25 percent. Different retirement rates of older industrial facilities in the United States and replacement by new facilities subject to the existing emissions limitations for new sources could make these preliminary estimates highly uncertain.

RESEARCH GOALS AND ACTIVITIES

The fundamental purpose of the National Program's man-made sources research is to provide the other Task Groups with information on man-made pollutants needed for the overall assessment program. This research involves developing estimates of past, present, and future emissions of pollutants from man-made sources and then devising quantitative methods to estimate the effects and costs of possible government regulation of these emissions. The overall purpose of this research effort can be summarized in the following objectives:

1. Provide, with adequate geographic, temporal, and economic sector resolution, an accurate and complete inventory of emissions from man-made sources believed to be important in acid deposition processes.

2. Provide models that (a) predict how these emissions may be altered by such factors as economic growth, fuel supply, emissions regulations, and control techniques; and (b) calculate the cost of alternative control strategies.

A series of projects is being conducted to attain these research objectives. In 1985 an interim version of the emissions data required to achieve these objectives will be completed, and in 1986, an interim group of models. The Man-made Sources Task Group plans to submit final versions of the emissions data base and the required models in 1988.

PROGRAM ACCOMPLISHMENTS—FY 1982

One major accomplishment in FY 1982 was to adopt an organizational structure to compile and analyze research results. In addition, continuing technical projects have provided valuable information on meeting National Program objectives and on conducting future projects. Major accomplishments are summarized.

- **Preliminary General Specification for the Man-made Emissions Inventory Data Base.** Current work is delineating the pollutants to be included in the inventory's data base, specifying the geographic resolution, the time frame (annual, weekly, daily), and the sources of pollutants for which emissions data will be provided. This will set a uniform standard for emissions data to be used by the National Program in examining atmospheric processes related to acid deposition. All man-made sources research projects will be evaluated in terms of their ability to supply necessary data, and, if needed, will be redirected to satisfy National Program needs.

- **Preliminary General Specification for the Man-made Sources Models.** These models will provide a tool to help analysts develop and assess various regulatory strategies. The National Program requires specific data to be generated by man-made sources models, given general descriptions of various projected emissions levels. The models will help determine potential decreases in emissions from a set of policy options and their costs. The Man-made Sources Task Group will review the specifications for the models, then transmit them to the scientific community for review and comment. The final specification will be used to evaluate existing and planned projects and make appropriate adjustments.

- **Initial Plan for Acid Deposition Inventory.** This document proposes a plan for creating a data base for the emissions inventory, which will provide a single source of emissions data within the National Program. The inventory is designed to meet the information needs of National Program researchers and other interested persons in the scientific community who are explaining and modeling atmospheric processes related to acid deposition and developing and evaluating pollution reduction techniques.

- **Acid Precipitation Precursor Study.** The completed Acid Precipitation Precursor Study presented findings on the general relationship between fossil fuel use and the location and degree of acid precipitation. This study points out the potential importance of petroleum combustion in addition to coal combustion in forming acid deposition. The National Program will use this document to help plan its emissions inventory activities, including the potential expansion of the emissions examined and the definition of required resolution. As a result of this study, the National Program will also examine emissions from transportation activities more closely.

- **Studies Characterizing the Sources of Acid Precipitation.** Studies begun in the latter part of FY 1982 and continuing through FY 1984 include (1) investigation of boron as a tracer of aerosol from the combustion of fossil fuels; (2) sulfur isotope analysis; (3) receptor modeling, precision, accuracy, and data requirements; and (4) source characterization for receptor model source apportionment of acid rain precursor species. Because these studies have begun recently, they have not yet produced results for publication. Eventually, they will lead to improved characterization of sources of acid deposition precursors.

All these accomplishments reflect the emphasis in the latter half of 1982 to better define the products to be provided by the Man-made Sources Task Group to other research groups, and to formulate effective and economic plans for meeting these needs. This effort will provide more accurate and timely results with a minimum of expenditure.

- **Advanced Utility Simulation Model (AUSM).** When completed, this model will allow the National Program to evaluate the costs and changes in emissions that would result from a wide range of control strategies for utilities. In FY 1982 a prototype, single-State version of the AUSM was developed and successfully operated for several States. A data base was developed that will allow operating the model for each State. The AUSM can be used with other models to compare costs and emission changes for strategies involving different combinations of sectors, pollutants, and regions. This modeling effort used in conjunction with the other emissions models will show how emission patterns might be altered by a number of control scenarios and the cost of each scenario. These emission pattern data coupled with transformation/transport models and acid deposition/damage models will help determine the cost/benefit relationship for the control scenarios that might be considered.

- **Industrial Combustion Emissions Model.** Work was begun on this model, which, when completed, will be able to evaluate the costs and emissions reduction potential of alternative regulatory strategies for industrial combustion sources. The model will focus initially on the industrial boiler sector.

FUTURE ACTIVITIES

The National Program's Man-made Sources Task Group's major goal in FY 1983-84 is to review and modify specifications for the Man-made Emissions Data Base and Model Set. After completing this in early FY 1983, the group will review its own projects against the specifications to ensure they satisfy National Program needs.

Besides working to establish the Man-made Emissions Data Base, the group will continue work on the utility and industrial emissions models during FY 1983-84. Under the National Program, man-made sources research will develop a comprehensive emissions inventory for a 1980 base year. This inventory will separate information on

sulfur dioxide, nitrogen oxides, sulfates, and volatile organic compounds on a seasonal basis for the United States and southeastern Canada, covering both point and area sources. Research will develop emissions factors for ammonia, chlorides, fluorides, and alkaline dusts.

Planning will continue for compiling an improved emissions inventory for a 1984 base year. Finally, the group will develop an historical inventory of sulfur dioxide and nitrogen oxides.

Advanced Utility Simulation Model. In FY 1983-84 a fully documented State level version of the AUSM and associated data bases will be transferred to government computer systems and tested. In addition, work will begin on developing the remaining components required to operate the model for either national or regional analyses.

Industrial Combustion Emissions Model. The effort to develop the Industrial Combustion Emissions Model will intensify, with delivery scheduled for early in FY 1984. FY 1983 activities will focus on modifying the fuel choice decision module. Process heaters may be added to the model's capabilities. The Technical Advisory Committee will continue to guide the project's activities and evaluate its products.

Industrial Process Emissions Model. The Environmental Protection Agency will begin to develop an Industrial Processes Emissions Model in FY 1983, accelerating these activities through FY 1984. Initial emphasis will be on identifying the most significant pollutants and the industries emitting them, along with determining the best mechanism to model emissions from industrial processes. The model will be able to evaluate the cost and effectiveness of alternative control strategies imposed on industrial processes. This model will be compatible with the Industrial Combustion Emissions Model, thereby aiding analyses of the entire industrial sector.

The refinement process for these models will be undertaken in FY 1985 and continue through FY 1988.

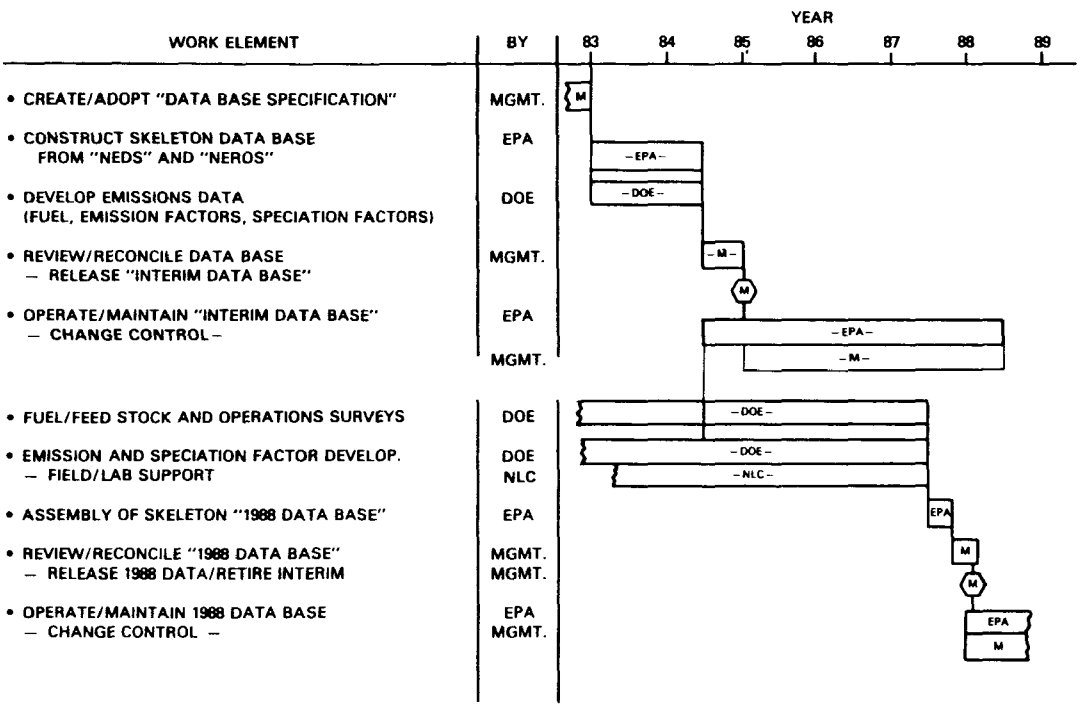


Figure B-1.—Proposed schedule—emissions data base, Man- made Sources.

WORK ELEMENT	BY
• CREATE/ADOPT "MODEL SET SPECIFICATION"	MGMT.
• CONSTRUCT HISTORICAL EMISSIONS MODEL	EPA
• CONSTRUCT FUEL/COST SUPPLY SUB MODEL (USING EIA DATA BASE)	EPA
• CONSTRUCT ASSESSMENT SCENARIO SUB MODEL	EPA
• CONSTRUCT CONTROL COST SUB MODEL	EPA
• CONSTRUCT UTILITY SIMULATION MODEL	EPA
• CONSTRUCT INDUSTRIAL COMBUSTION MODEL	EPA
• REVIEW/RECONCILE "INTERIM MODEL SET"	MGMT.
— RELEASE "INTERIM MODEL SET"	MGMT.
• OPERATE/MAINTAIN "INTERIM MODEL SET"	EPA
— CHANGE CONTROL —	MGMT.
• CONSTRUCT "INDUSTRIAL PROCESSES MODEL"	EPA
• CONSTRUCT "TRANSPORTATION MODEL"	EPA
• CONSTRUCT "RESIDENTIAL/COMM. MODEL"	EPA
• PREPARE "AS BUILT" DESCRIPTIONS OF MODEL SET/ASSUMPTIONS	EPA
• REVIEW/RECONCILE "MODEL SET"	MGMT.
— RELEASE "MODEL SET"	MGMT.
• OPERATE/MAINTAIN "MODEL SET"	EPA
— CHANGE CONTROL —	MGMT.

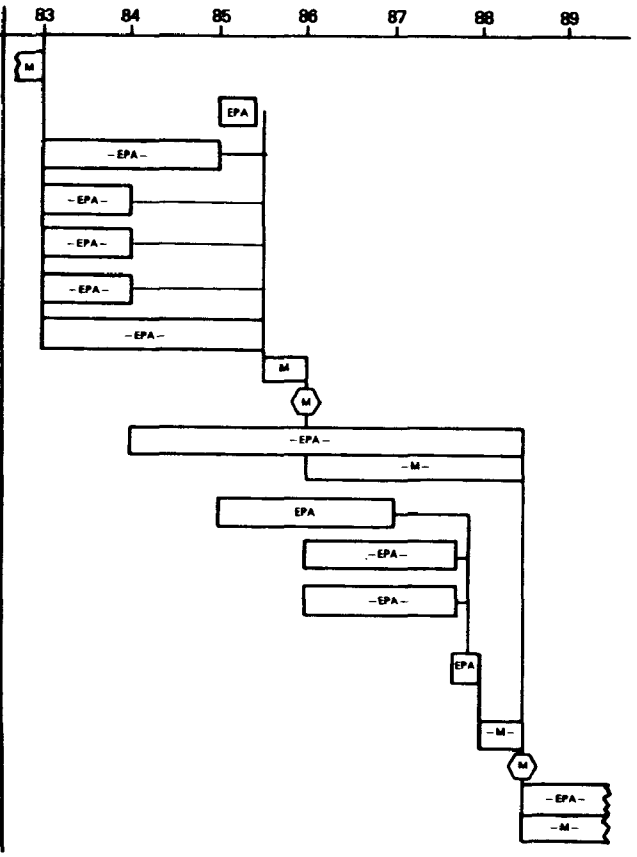
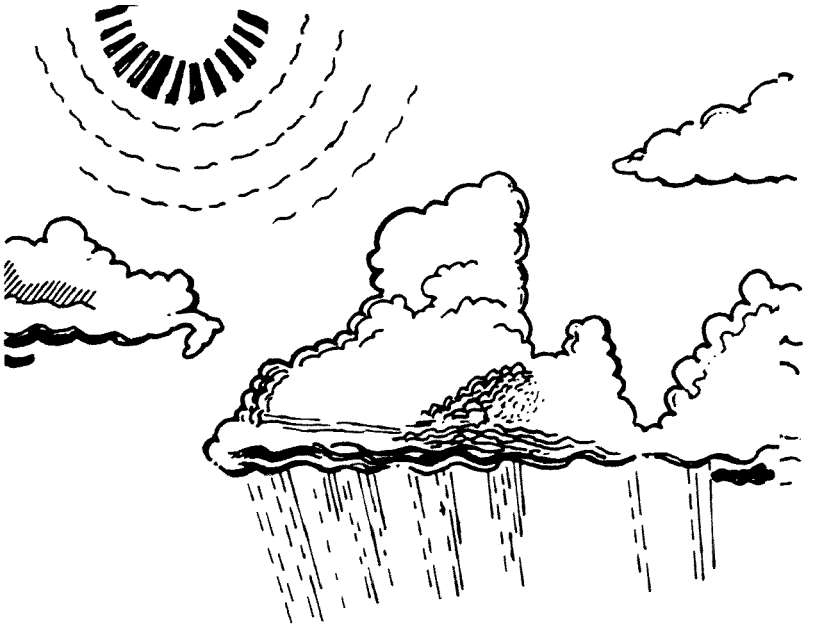


Figure B-2.—Proposed schedule—model set data base, Man-made Sources.

C. *Atmospheric Processes*

BACKGROUND



One of the basic observations about acid rain is the approximate coincidence of the region of highest precipitation acidity with the areas of greatest sulfur dioxide and nitrogen oxides emissions. Further, we know that these two pollutants are the primary precursors to acid materials, and are transformed in the atmosphere, at least partially, to sulfuric and nitric acid. To date, however, no one has been able to reliably assess the contribution of a specific source or set of areal sources to the acidity of deposition in a given distant region. To establish this source/receptor relationship, which is needed to evaluate the effectiveness of different proposed control strategies, the relationship between emissions and deposition must be reliably quantified.

Research on atmospheric processes is subdivided into three major categories:

Transport. The speed and direction of the winds at the level of ejection are the major influences on the movement of the pollutants. How far they are moved depends upon whether the given pollutants are gases or particles, at what level they enter the atmosphere, and how they are transported vertically during their lifetime. For example, gases emitted at or transported to levels well above the earth's surface will travel farther than large particles ejected at the surface. Such factors are important in understanding local versus long-range transport.

Transformation. While the material is being moved by the air currents, chemical changes can take place. For example, smog may form in the presence of sunlight, or sulfur dioxide may be incorporated in a cloud droplet, forming sulfuric acid. These complex interactions, especially those in clouds, are not yet well understood and probably hold an important key to explaining acid deposition patterns.

Deposition. After the pollutant material is transported and possibly chemically transformed, it is finally deposited either by contacting a surface directly (dry deposition) or by being incorporated into precipitation and brought down to the earth's surface in rain or snow (wet deposition). The relative importance of wet and dry deposition is one of the major questions still unanswered.

Because transport, transformation, and deposition form such a complex system, scientists have tried to sort out their relative importance by using mathematical models. At present, the models cannot account for every step but have been designed to cover the gross features of the atmospheric processes. The major emphasis to date has been on transport studies, with very rough approximations of the transformation and deposition processes.

Plans are being made to incorporate more realistic conditions into future, more sophisticated models. A major goal of the National Program's atmospheric processes research is to develop reliable models that can be used in a predictive and interpretive mode to explain source/receptor relationships.

Because the development of reliable models is complex, alternative approaches to determining source/receptor relationships are being developed. One way would be to conduct a series of field experiments in which inert tracers or isotopically tagged man-made pollutants released into the atmosphere are measured and then tracked while they are transported and diluted, transformed physically and chemically, and eventually deposited on the earth's surface. Such studies provide empirical information on the processing of these pollutants between sources and receptors.

RESEARCH GOALS AND ACTIVITIES

The National Program's research on atmospheric processes is designed to provide an understanding of the atmospheric link between the emission of pollutants and acid deposition. Understanding this link requires research that addresses the following key questions:

1. What are the important chemical species and processes governing the formation of acidic substances in the atmosphere and how do they operate?
2. What are the most important meteorological processes governing the transport of acidic substances and their precursors?
3. How do the processes of wet and dry removal operate and how does their relative importance change as distance from the source increases?

4. How can the processes of transport, transformation, and removal be modeled so that we can understand current and predict future deposition patterns?

The answers to question 1 will tell us which atmospheric pollutants will have to be controlled to reduce acid deposition. The answers to questions 2 and 3 will indicate which source regions are most likely to affect a given receptor region. However, the models developed in response to question 4 will be the primary policy development tools. These models will provide quantitative estimates of the effects that changes in existing pollution sources will have on existing patterns of acid deposition. In other words, the models will tell us what the pollution sources have affected, what changes (if any) must be made, and in what quantities.

To answer these questions, the atmospheric processes research focuses on the following specific objectives:

- Improve understanding of the vertical and horizontal transport of acidic substances and their precursors.
- Improve understanding of the major chemical transformations that produce acidic substances in the atmosphere.
- Improve understanding of precipitation scavenging processes in the atmosphere.
- Improve treatment of dry deposition in numerical models of source/receptor relationships.
- Improve and develop predictive and interpretive models that explain source/receptor relationships in the atmosphere.
- Perform field studies that are necessary to provide a data base for developing and testing source/receptor models. Such studies will also provide an independent way of evaluating the source/receptor relationship on an empirical basis.

PROGRAM ACCOMPLISHMENTS—FY 1982

Transport

- **Air trajectories were calculated from the receptor of acid deposition backwards in time for numerous sites in the United States.** This technique allows a chemical climatology to be established for various areas in the United States. Initial results have been published, and the work continues on a routine basis. The importance of connecting the deposition chemistry with the transport meteorology is one of the necessary activities in understanding patterns of acid deposition and their impact on sensitive ecological areas.
- **Data from the sites in the Global Background Research Program are being used to evaluate the long-range transport on a hemispheric scale.** Results show that acidity of sites in remote areas is higher than would be expected if carbon dioxide were the only factor influencing pH at "clean air" sites. Weak and strong acids found in the samples show that the total acidity may be related to a mixture of natural and man-made sources. These results will be used in subsequent model calculations.
- **Initial observations confirm the importance of clouds in the transformation process of precipitation chemistry.** Research results support the hypothesis that fair weather cumulus clouds play a major role in transforming sulfur dioxide to sulfate during the late spring, summer, and early fall. Aircraft measurements of air pollutants above and below fair weather cumulus clouds indicated that these clouds transported pollution out of the sub-cloud boundary layer and into the air above. Moreover, the air pollutants processed through the clouds underwent significant chemical transformation.
- **A large cooperative program was started to study the eastern North American chemical budget.** Since August 1982 numerous private and government organizations including NOAA, NASA, General Motors, and others have cooperated in a study that consists of intensive measurements of aerosols both on the ground and by aircraft, precipitation collection and analysis, and meteorological flow studies. The results of this project will help define one portion of the sulfur and nitrogen budget of eastern North America, that is, what percentage of these substances are transported off the East Coast.
- **Planning and initial testing of field equipment began for Cross Appalachian Tracer Experiment (CAPTEX).** This long-range tracer experiment, which will begin in 1983, consists of releasing an inert tracer under specific meteorological conditions and measuring the transport of the tracer over hundreds of miles. The results of such experiments will be used to help verify meteorological models.

Transformation

- **Preliminary results were obtained from a study of the influence of man-made materials on the cloud-forming process.** Measurements made of clouds and aerosols in polluted and nonpolluted air in the Northeast identified man-made aerosols hundreds of kilometers downwind from the source. This study is a part of the effort to understand the chemistry and scavenging processes in the atmosphere, and will provide necessary input for model development.
- **Preliminary results were obtained from a laboratory study investigating the kinetics and photochemistry of nitrate radicals.** A laboratory experimental apparatus has been designed and assembled to study the chemistry of the nitrate radical. This radical is an important member of the nitrogen oxide family and is involved in both gas-phase and heterogeneous reactions leading to nitric acid formation. This experiment will provide critical data needed to model the chemistry of nitrogen oxides, particularly in urban environments, and will provide direct input to the more sophisticated models planned for FY 1985. In a separate experiment, kinetic data have been obtained on the self reaction of hydroperoxyl radicals. This reaction is very important because it produces hydrogen peroxide, thought to be the major oxidizer of sulfur dioxide to sulfuric acid.
- **The atmospheric transformation of nitric oxide, nitrogen dioxide, and nitric acid in the clean marine atmosphere is being investigated to increase our understanding of the chemistry that produces nitric acid.** The atmospheric photochemistry of the oxides of

nitrogen has been modeled for clean marine air. The oxidation of nitrogen dioxide to nitric acid by the hydroxyl radical in the gas phase is probably a major mechanism in converting nonacidic oxides of nitrogen to nitric acid in rural environments. The research results will be useful in evaluating the oxidation rate of nitrogen oxides in the relatively unpolluted regions of the atmosphere.

Deposition

• **Reanalysis of the past precipitation chemistry data suggests the recent trend toward increased precipitation acidity in the midwestern United States is more a consequence of less alkaline dust in the precipitation than greater concentrations of acidifying agents.** The complexity of interpreting past precipitation chemistry data to establish trends of acid deposition has been a topic of controversy mainly because of the unknown quality of the data. Recent information from federally-funded research emphasized the necessity for total chemistry interpretation, not just focusing on the isolated acidic components. A rational interpretation of the chemistry network data of the mid 1950's suggested that drought-induced increases in alkaline crustal dust decreased precipitation acidity.

• **The first comprehensive descriptive maps of the distribution of major chemical species over North America have been produced.** The maps, prepared from the MAP3S, NADP, and CANSAP data bases, display seasonal concentrations and depositions of calcium, ammonium, nitrate, sulfate, and hydrogen ion. In general, the maps show relatively high concentrations of acidic species over the upper northeastern States and lower Canadian Provinces, but the greatest acid deposition is wholly confined to the United States over eastern Ohio, western Pennsylvania, and northern West Virginia.

• **Research on deposition of trace elements in forests indicates that atmospheric deposition dominates the landscape cycle of lead and has a measurable influence on the cycles of cadmium and zinc, but a minimal influence on the manganese cycle in a deciduous forest in the eastern United States.** Rain event deposition rates are orders of magnitude greater than the intervening dry deposition rates; however, dry deposition supplies 20 to 90 percent of the total annual input to the forest. This research directly links atmospheric deposition, both wet and dry, and the effects research on terrestrial ecosystems. The National Program recognizes that the study and sampling of atmospheric deposition of metals should not be overlooked, and that dry deposition must be included in future network sampling strategies.

Models

• **A new wet scavenging model has been used to analyze precipitation data from the recently completed Oxidation and Scavenging Characteristics of April Rains study (OSCAR).** The model includes an improved treatment of the physical process of scavenging and an improved, nonlinear chemistry module that accounts for aqueous phase reactions of sulfur and nitrogen compounds. In an application to one of the OSCAR storms, the model was able to explain the chemical composition of a sequence of precipitation samples. The model strongly indicates that scavenging rates for that particular storm were governed by the concentrations of oxidants such as hydrogen peroxide and ozone and not by the ambient concentrations of sulfur and nitrogen oxides. Understanding the physical and chemical processes governing wet deposition is important in developing improved source/receptor models and determining the emissions that may have to be controlled in any action to mitigate acid deposition. The results from the OSCAR model will be integrated into the overall atmospheric processes modeling effort.

• **The Advanced Statistical Trajectory Regional Air Pollution Model (ASTRAP) was used along with seven other linear source/receptor models to analyze wet deposition measurements in the eastern United States and Canada for the year 1978.** A procedure was developed for using deposition monitoring data to evaluate source/receptor models; however, the actual evaluation showed that there was an insufficient data base for determining whether or not existing source/receptor models are capable of explaining current deposition patterns. Since 1978, the monitoring effort has expanded, especially in the Northeast. From 1980 to the present, an excellent data base exists that the models can be tested against.

FUTURE ACTIVITIES

Research under the National Program will continue to improve our understanding of atmospheric processes; particular emphasis will be on improving the ability to determine source/receptor relationships so that the consequences of changes in emission can be reliably predicted.

Highlights of the expected accomplishments for FY 1983 to 1985 include:

A comprehensive plan for developing an advanced nonlinear source/receptor model will be produced and implemented. Further advancement in modeling through such nonlinear models will be critical in planning regulatory options.

Work will begin on a detailed experimental and management plan for conducting a major field experiment to provide data for developing and evaluating source/receptor models. The planning for field activities will begin in FY 1983 with possible implementation in FY 1985.

The Cross Appalachian Tracer Experiment will be conducted, providing the first sizeable data set for evaluating long-range trajectory models. To do this, inert tracers will be released in the Midwest and in Canada, and their concentrations measured over 800 miles away on the East Coast. How well the models' predictions compare to the actual measurements will help put limits on the usefulness of the models. The first major CAPTEX will be in September to November, 1983. Based on the results of that experiment, CAPTEX II will be planned for FY 1985.

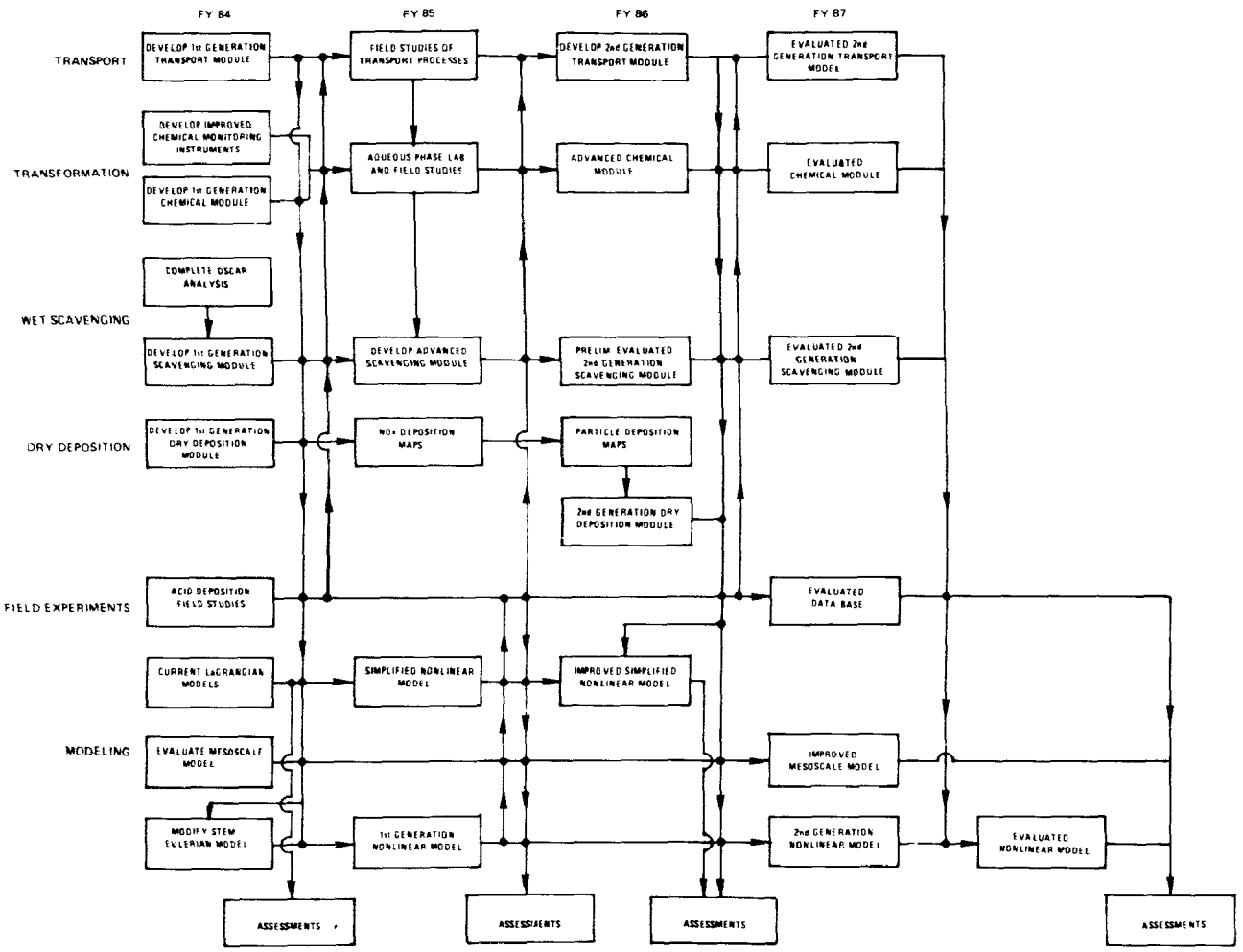
In FY 1983 research to investigate the source/receptor relationships of long-term precipitation chemistry data bases at Hubbard Brook and from the MAP3S network will be completed. These studies will demonstrate the feasibility and limitations of the trajectory analysis ap-

proach defining source/receptor relationships, and will be used to evaluate the more complex models.

The North American sulfur and nitrogen study will, by the end of FY 1983, produce preliminary results on amounts of materials transported out to sea. These initial estimates of the sulfur and nitrogen transport will be used in the National Program's work on assessments and policy analysis.

The atmospheric trajectory models will be used in various parts of the world for precipitation chemistry evaluation. By the end of FY 1984, the Southern Hemisphere data will be added so that trajectory calculations can be made there also. This will allow scientists to evaluate the global transport of acid-forming materials.

The key reactions that control the atmospheric production and loss of hydrogen oxides and ozone will be identified and measured. Thus, the gas phase oxidation of sulfur dioxide and oxides of nitrogen can be quantitatively estimated. A review of the current acid deposition models and the draft plan for developing a Eulerian acid deposition model will be completed to determine how information on the critical reactions can be incorporated in these models. This study will be finished in FY 1983. The recommendations will be used to direct and focus this modeling effort in FY 1984 and 1985.

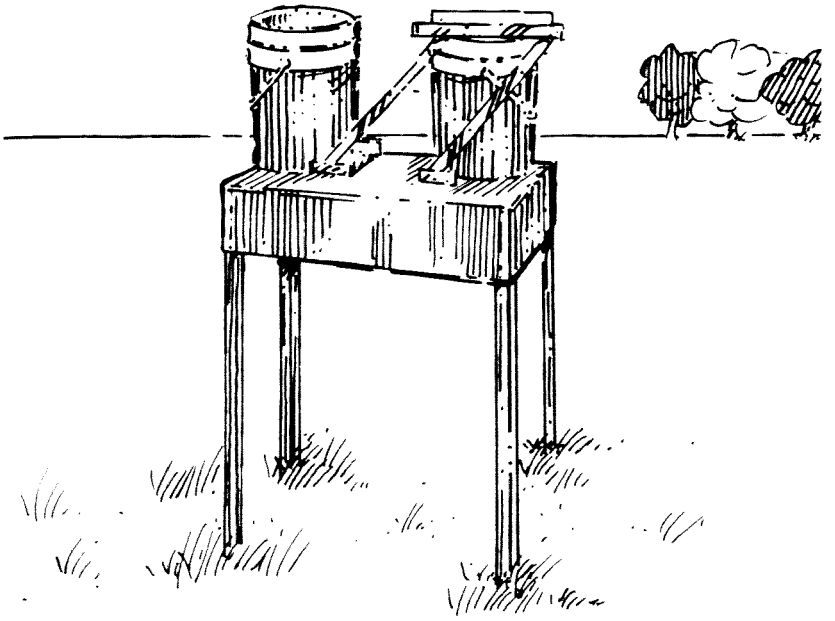


TASK GROUP C: PROGRAM LINKAGE

Figure C-1. – Proposed program implementation strategy, Deposition Monitoring.

D. Deposition Monitoring

BACKGROUND



Precipitation chemistry in the United States has been measured on an erratic basis since the early 1920's. These early data were gathered mostly for agricultural research. Since the early 1970's careful attention has turned to the design and operation of collectors and networks, and to procedures that will improve the data quality.

Monitoring of dry deposition is in its infancy. Although collectors trap wet and dry materials separately, little credence is given to the dry portion because gases are not collected and the collecting surface (a plastic bucket) does not replicate the natural surfaces of vegetation, soils, and waters. Thus, present estimates of dry deposition are based on limited research results under specialized, short-term conditions.

The two major networks for wet deposition in North America are the National Atmospheric Deposition Program (NADP) in the United States and the Canadian Network for Sampling Precipitation (CANSAP) in Canada:

	Start date	No. of sites	Frequency of sampling	Type of collector
NADP	1978	108	weekly (wet) and bi-monthly (dry)	wet & dry
CANSAP	1977	59	daily, monthly composite	wet only

The distribution of annual average pH of wet deposition on North America in 1982 is shown in Figure D-1. Isopleths have not been drawn for the western part of the continent because abrupt changes in topography in mountainous areas require the development of modified procedures for their construction. The regions of lowest pH (4,2) in eastern North America roughly coincide with the regions of highest man-made emissions of acid precursors (primarily sulfur dioxide) in the midwestern and northeastern United States and near the Sudbury smelters in Canada. The continuing pattern of lowest pH values in the northeastern United States and Canada suggests that the impacts of acid-forming emissions are felt most strongly within the regions where those emissions are produced. This does not suggest that longer-range transport is unimportant, however.

Variations of 30 to 50 percent in pH values sometimes occur among sites within a given State. This may indicate effects of local sources, insufficient quality control, or both. These variations underscore the importance of long-term data sets in describing geographical trends. Also, most NADP/National Trends Network sites are in rural precipitation in the United States. Because of the presence of many local emission sources, many studies have found precipitation in urban areas to be more concentrated in acid-forming constituents, as a general rule, than precipitation collected in rural areas.

Network data also show that concentrations of many pollutants tend to be high when precipitation volume is low. Thus, fogs and mists are more acidic than heavy rains. This may be important in assessing damage to pH-sensititve receptors.

Values of pH substantially less that 5.6 have been reported in some remote areas of the world where annual average pH values have been found to be as low as pH 4.9. Such measurements have demonstrated that a pH of 5.6, often considered "normal" for wet deposition in the absense of man-made, acid-forming gases, cannot be considered a benchmark for identifying regions affected by man-made emissions.

In North America,historical trends in precipitation chemistry have been difficult to quantify because of differences in past collection methods and sampling sites, the brevity of the records available, and the relatively modest changes in precursor emissions in recent years. The limited data available from past studies suggest that calcium concentrations may have decreased, nitrate concentrations probably increased, and sulfate concentrations apparently changed little in the past 25 years. Data from the mid-1950's show substantially higher alkalinity than contemporary data, perhaps because of a drought in the Midwest at the time. Recent studies reported in the literature also indicate that pre-1960 alkalinity values may have been overestimated by the analytical methods in common use that the time.

There are no widely accepted methods for monitoring dry deposition on a routine nationwide basis. The limited data available suggest that wet and dry deposition account for roughly equal amounts of acid deposits nationwide, with more dry deposition in arid climates, and less in humid areas. Near emission sources, dry deposition is believed to be a more important contributor of acid-forming substances than wet deposition because of rapid

settling of larger particles. Much additional research is needed on dry deposition measuring methods; a great deal of this work is now being done by agencies in the Deposition Monitoring Task Group.

The monitoring networks begun since 1977 have developed a fairly complete initial picture of wet deposition chemistry on a regional and national scale. But, sizeable areas of the western United States are not yet adequately covered, and the length of record is not yet sufficient to determine long-term trends. As additional sites are added to the National Trends Network and the record of each site becomes longer, a more complete, consistent, and long-term data base will become available. At present, subregional scale wet deposition patterns are less well delineated, especially near sources and in urban areas. Local variations in acidity are generally not well-defined. Variations in the chemical composition of wet deposition around local sources require intense study and monitoring to delineate. Studies of this sort are being conducted in a few urban centers, with more planned in future years.

Recent temporal trends in the chemistry of wet and dry deposition are difficult to quantify reliably, with the possible exception of the nitrate content of wet deposition, which shows increases roughly paralleling the increase in man-made emissions of nitrogen oxides. The difficulty in discerning recent trends is due to the shortness of the data record at most stations.

RESEARCH GOALS AND ACTIVITIES

Planning and coordinating atmospheric-deposition monitoring under the National Program is the responsibility of the Task Group on Deposition Monitoring. The goals of the National Program's deposition monitoring activities are:

1. Determine the spatial and temporal variations in the composition of atmospheric deposition within the United States through a National Trends Network.
2. Develop methods for the reliable measurement of dry deposition.
3. Continue and increase research on methods for deposition monitoring.
4. Support a Global Trends Network (GTN) through operating monitoring sites at remote locations throughout the world.

Each of these objectives was emphasized in FY 1982.

PROGRAM ACCOMPLISHMENTS—FY 1982

• **National Trends Network.** The design of the NTN was completed. Recommendations for locations of 150 sites in 48 States (Figure D-2), were based on "Ecoregions of the United States" established by the U.S. Forest Service with consideration given to concentration gradients and sensitive areas. Approximately 90 existing NADP monitoring sites will be incorporated into the NTN. A site review team began visiting each existing and proposed NADP/NTN site and will issue approval or recommend changes for all sites by the end of FY 1983. The NADP/NTN is supported by a combination of Federal, State, and private funds and will continue to be coordinated as part of the National Acid Precipitation Assessment Program. Data from NADP/NTN will be used by other Task Groups as background for their studies and, in particular, by the Assessments and Policy Analysis Task Group for their assessments.

Figure D-1.—Precipitation-weighted annual average pH of wet deposition—1981. (Based on data from the monitoring network of the National Atmospheric Deposition Program and from the Canadian Network for Sampling Precipitation.

Sufficient data are now available from the NADP network and the Canadian Network for Sampling Precipitation to permit an analysis of the spatial and short-term temporal trends in wet chemical deposition in North America. A 1982 NADP report evaluating pH data from these two networks through 1980 shows little apparent change in the distribution of acidity in the United States over the last 7 or 8 years, although there are few data from the early period. Data from NADP confirm that assessing future trends requires long-term monitoring to overcome year-to-year variations.

• **Global Trends Network.** Within the GTN (Fig. D-3), precipitation samples are collected in remote areas of the world and returned to the United States for analysis. Techniques developed in the GTN will be used in the operations of the NTN, while research-related data from the GTN will provide information on background levels of precipitation acidity for input into model calculations and for evaluating the overall acid rain problem. The GTN was established in part to measure precipitation chemistry in areas far from man-made sources; such measurements have shown an average rain acidity pH of about 5.0 at remote sites in Hawaii and Amsterdam Island in the Indian Ocean. It is anticipated that continued sampling from this program will show trends of global acidity and help describe the chemical climatology of different regions of the earth.

• **Quality Assurance.** The quality assurance program audits laboratory performance by regular submission of blind samples. Field measurement quality is

checked by semiannual submission of performance samples for analysis by over 100 site operators. Additionally, an experiment conducted in cooperation with North Carolina State University is measuring the effects of rain sampling frequency and within-site variability on the precision of sampling atmospheric deposition data. The results of this experiment are expected to contribute to the assessment of the validity of using NTN data in describing regional patterns of acid precipitation.

At six border locations (three in Canada and three in the United States), U.S. and Canadian scientists collect precipitation samples according to both countries' protocols. The data from each collector at each site are compared to detect differences arising from collection techniques. This information will be extremely important when trying to evaluate possible cross-border differences in chemical composition and validity of combining NADP/NTN and CANSAP data for trend analysis or other purposes.

• **Dry Deposition Methods.** In June 1982, an intercomparison field study of dry deposition monitoring and measurement methods was conducted for the National Program by the Illinois State Water Survey. Thirteen laboratories from the United States and Canada compared four micrometeorological methods, three types of surrogate surfaces, concentration monitoring, leaf washing, and material effects measurement. The analyzed data will be reported at a symposium in the spring of 1983.

Current plans call for measuring ambient air concentrations of relevant substances at monitoring stations nationwide. During FY 1982, a pilot effort was begun to compute dry deposition fluxes from air concentration and deposition velocities. Instrument shelters were installed at three locations representative of the surface types of the northeastern United States, especially forests and croplands. These sites will provide opportunities for applying detailed research techniques for direct flux measurement and for evaluating the deposition velocity calibration to be used at "concentration monitoring" sites for a future dry deposition network.

• **Data Base Management and Data Analysis.** The acid rain data base has grown during the year to over 100,000 observations in the United States and Canada. The networks currently entering data into the data base include NADP/NTN, CANSAP, MAP3S, and EPA's Region IV Network. EPA has developed an Interagency Agreement with Pacific Northwest Laboratories to design a more versatile Acid Deposition Data System to meet varying information demands.

Data analysis in FY 1982 included a prototype summary report on national acid deposition data trends and

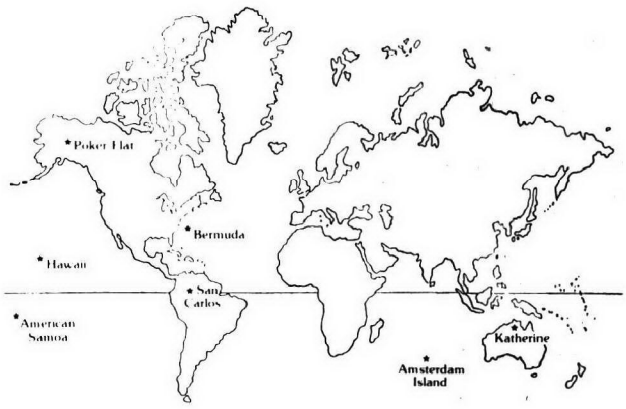


Figure D-3.—Location of Global Trends Network (GTN) stations.

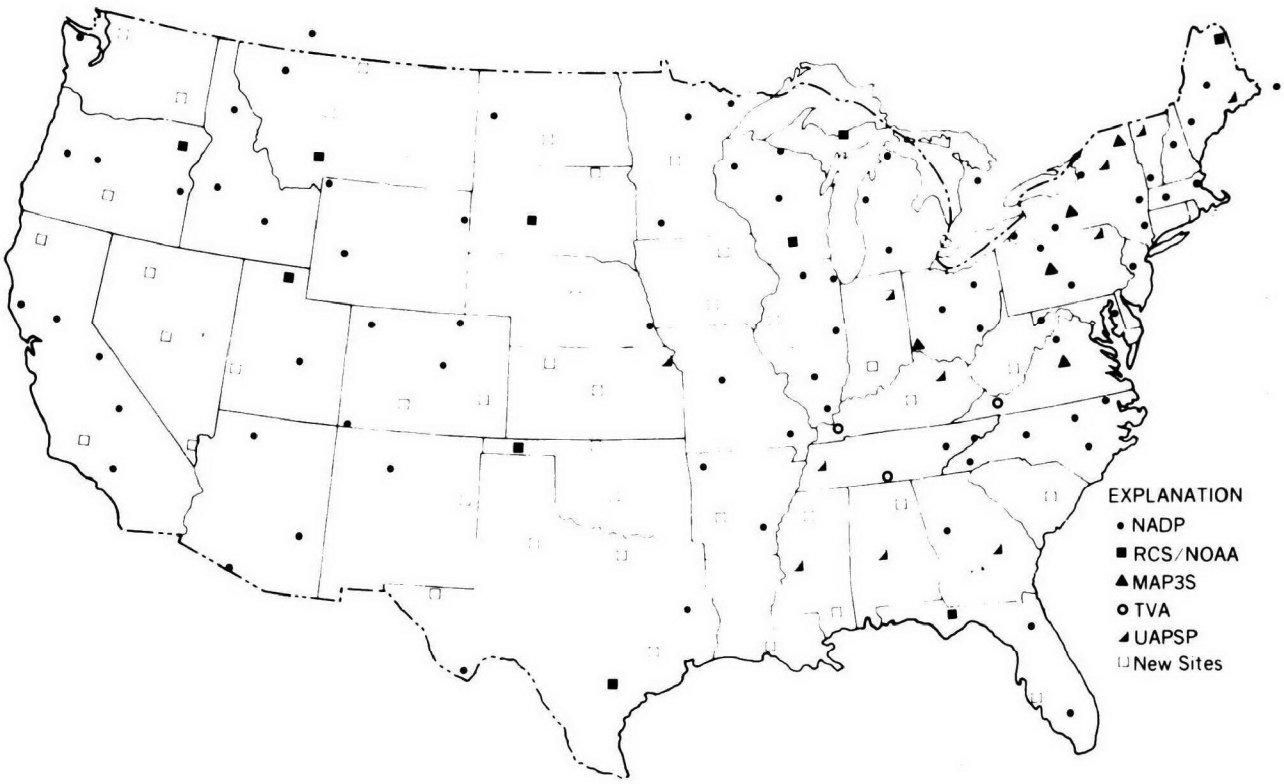


Figure D-2.—Locations of proposed National Trends Network (NTN) stations.

an investigation of new methods for spatial analysis. The report examined new ways of presenting and simplifying the large amounts of data developed in a monitoring network, a technique for analyzing the confidence limits of the spatial distribution of given concentrations, and objective improvements in network design.

- **TVA Regional Trend Monitoring Network**. During FY 1982 TVA continued to operate three regional air quality trend monitoring stations. In addition to collecting biweekly wet- and eight weekly-dry deposition samples, these stations also monitor background concentrations of suspended particulates, suspended sulfate, sulfur dioxide, nitrogen dioxide, ozone, and gaseous flouride. Rigorous quality assurance/quality control procedures were implemented at the TVA central analytical laboratory for deposition analysis. A technical report "Atmospheric Deposition in the Tennessee Valley: 1979-1980" was published and presented at the 75th Annual Meeting of the Air Pollution Control Association. Plans call for upgrading one or more of these sites for inclusion in the NTN.
- **New Research Sites Established.** Three research sites will conduct special measurements and test newly-developed equipment and methods for monitoring wet and dry deposition. These sites will also serve as the standards for their regions. They are located at Pennsylvania State University, the Walker Branch Watershed in Oak Ridge, Tenn., and Niwot Ridge in a biopreserve in the Rocky Mountains in Colorado.

FUTURE ACTIVITIES

In FY 1983 the Task Group will concentrate on implementing most of the sites of the NADP/NTN, developing methods for monitoring dry deposition, and further improving methods for monitoring wet deposition. Quality assurance programs will be used to oversee the data collection and analysis to assure data comparability among the several operational and research networks.

National Trends Network. Coordination and operation of the NTN will continue , including establishing 20 to 40 new sites in cooperation with several Federal, State, and private sector agencies. Site visitation and evaluation of all existing and proposed NTN sites will be completed and the agencies named to operate those sites started in FY 1983 and FY 1984. The Task Group will produce a special study of the Global Trends Network data using both recent and historical data.

Development of Dry Deposition Monitoring Methods. Intercomparison field studies will be run, one each at three core research sites in Oak Ridge, Tenn., Argonne, Ill., and State College, Pa. *Development of Flux Monitoring Methods:* The performance of a variety of micrometeorological methods will be tested and compared with alternative techniques such as surface accumulation. *Development of Concentration Monitoring Methods:* The temporal distribution functions for concentration and velocity of deposition will be determined so that optimum sampling and analysis procedures may be specified for network operation. The sites at State College, Pa., and Oak Ridge, Tenn., are located near calibrated watersheds and will provide comparisons between "concentration monitoring" and mass budget measurement estimates of dry deposition fluxes.

Development of Automated Instruments. A program is beginning to develop automated instruments to determine the chemical composition precipitation at the time of the precipitation event. First priority will be developing an improved pH instrument; the goal is to have a prototype available for limited field testing by the end of FY 1983.

Plans through FY 1989. The timetable for implementing various elements of the Deposition Monitoring Task Group's program is illustrated in Figure D-4.

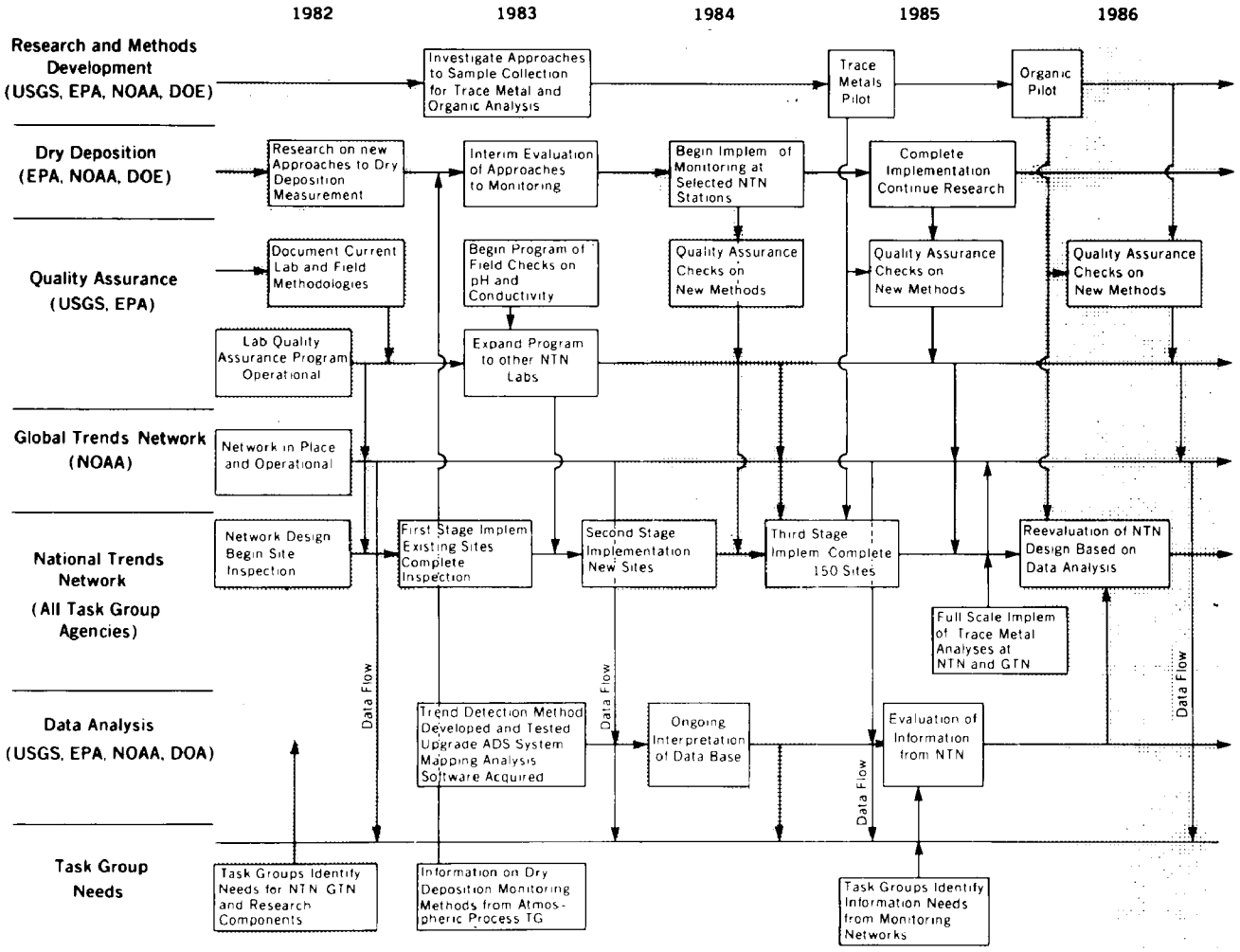
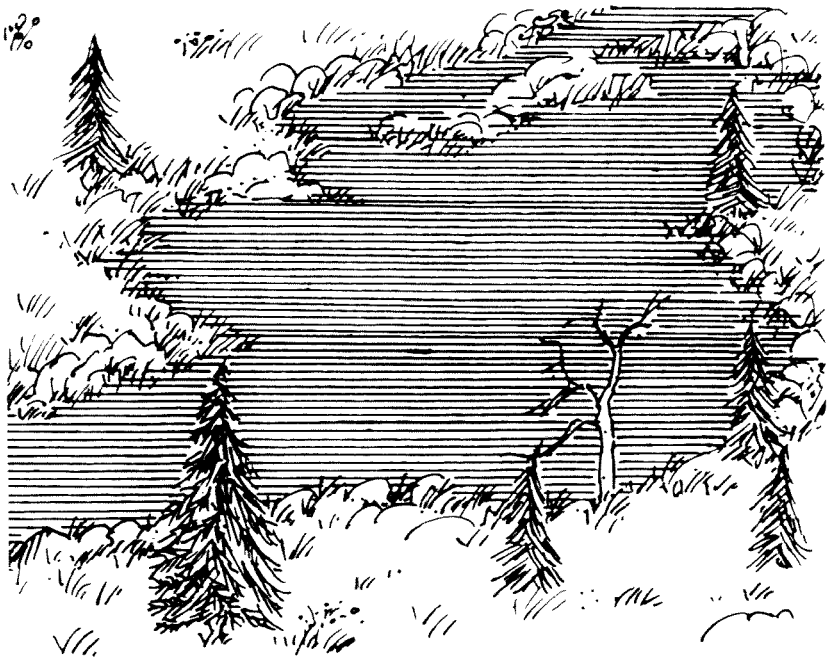


Figure D-4—Proposed program implementation strategy, Deposition Monitoring

E. *Aquatic Effects*

BACKGROUND



The Aquatic Effects Task Group works to meet specific objectives that will provide information needed to assess the effects of acid deposition on aquatic ecosystems. A general summary of current scientific knowledge follows.

Acid deposition has been reported in the literature as causing both long- and short-term episodic depressions in pH, and loss in alkalinity in some lakes and streams in the United States and Canada. The total number of lakes and streams in eastern North America thought to have been acidified by acid deposition is a very small percentage of the total aquatic resource. Elevated concentrations of toxic elements such as aluminum, and biological effects, including losses in fish populations, have been reported to accompany some of these pH depressions. However, in most of the reported cases, clear relationships were not established between acid deposition and observed effects.

Current scientific knowledge does not make it possible to derive quantitative loading effects relationships for aquatic ecosystems. However, based on results of empirical studies, interpretation of long-term water quality data, and studies of sediment cores, it can be concluded that acid deposition has caused long- and short-term acidification of some low alkalinity surface waters. The purpose of the extensive research efforts in the United States and Canada is to develop such quantitative relationships as soon as possible.

Extent of acidification and sensitivity of lakes, streams, groundwaters, and wetlands of the United States. Sensitivity of surface waters to acidification is usually assessed on the basis of alkalinity. Alkalinity measures the extent to which water is buffered against chemical changes caused when acidic substances enter it. However, only a few historical records on surface water chemistry exist that can be used to assess past trends in acidification. The records available for areas exposed to acid deposition show increases in sulfate and corresponding decreases in pH for some lakes and streams. In most cases the historical data bases were not sufficiently complete to determine if a cause and effect relationship existed.

The Adirondack Mountains, located in a zone receiving highly acid deposition, comprise one of the most sensitive lake districts in the eastern United States. Fifty-two percent of 214 high elevation lakes sampled in 1975 had pH values less than 5.0. A study of 95 small, low alkalinity lakes in New England for which historical data were available showed that 64 percent had experienced significant pH decreases. Two other studies have indicated pH decreases in some lakes surveyed in Maine. On the other hand, preliminary studies suggest certain lakes in Wisconsin have shown a decrease in acidity over time.

Factors that control the susceptibility of natural waters to acidification. A complex set of factors governs the response of a body of water to acid. Geology determines the geochemical materials (thus the geochemical reactions) that acid precipitation encounters as it passes through the watershed. The hydrodynamics of the watershed determines the duration of contact of precipitation with the reaction materials. Together, these two factors govern potential chemical reactions, their extent, and their degree of occurrence. The addition of minerals other than those that produce alkalinity is critical to the aquatic ecosystem. Aluminum, in particular, appears to be mobilized by acidification of the terrestrial ecosystem and then leached into the aquatic ecosystem where it can affect fish and possibly other animals and plants.

The processes controlling sensitivity and tolerance of waters to acid loading are not yet sufficiently understood to predict the short- and long-term effects of various deposition rates on aquatic ecosystems. To generate this needed information, the Aquatic Effects Task Group is developing quantitative models that relate atmospheric influences (such as sulfate or hydrogen ion concentration of precipitation) and watershed-derived factors (such as alkalinity or sulfate concentration in lakes) to each other. Detailed mechanistic models are exploring relevant physical and chemical processes in a watershed to describe or predict changes. The Integrated Lake-Watershed Acidification Study (ILWAS) sponsored by the Electric Power Research Institute is an example. These models were developed from specific data sets, and their more general predictive value, as well as that of models yet to be developed, remains to be determined by this research objective.

Biological processes, biological populations, and aquatic communities affected by surface water acidification. Nine rivers in Nova Scotia have lost their Atlantic salmon populations while fish have survived in other rivers in the same area that have higher pH and greater alkalinity. In the Adirondack Mountains of New York, comparison of data from the 1930's with recent surveys shows that at least 180 former brook trout ponds are acidic and no longer support brook trout, although a direct association with acid deposition has not been established. The relative contribution of natural and man-made sources and changes in land use to acidification of these lakes and rivers, however, is not known.

Many species of amphibians breed in temporary pools formed by the mixture of spring rains and snowmelt. Many such pools are subject to low pH conditions. Embryonic deformities and mortalities in the yellow-spotted salamander have been observed in New York State where the acidity of meltwater pools was 1.5 pH units lower than that of nearby permanent ponds. Population densities of the bullfrog and woodfrog were less in acidic streams and ponds in Ontario versus ponds with higher pH values. These data are very limited in scope and therefore, the extent of the problem is not known.

With few exceptions, the mechanisms of effects of acidification on fish, amphibians, and other aquatic organisms are not understood. Biological changes can occur as pH drops below 6.0 and can become increasingly severe as pH declines further. Many water bodies have natural pH levels below 6.0. Aluminum and possibly other toxic elements become available in acidic waters and contribute to biological changes. These effects are currently known only qualitatively, except for the relationship between aluminum and some fish species.

Potential for acidification of surface waters, groundwaters, and wetlands to affect human health. Studies conducted in Sweden found long-term chemical changes in groundwaters from water-bearing rock formations in sandy soils near cities. Few data are available concerning changes over time in groundwater quality in the United States, although in a few cases waters from acidic wells and municipal reservoirs are associated with elevated concentrations of toxic metals leached from domestic water supply pipes. But the linkage to acid deposition, if any, remains unclear. A survey of water systems and groundwaters in the Northeast is underway, but the results are not yet available. Little is known concerning possible health implications of wetland acidification.

Mitigative (liming) techniques for restoring or protecting acidified aquatic resources of the United States. Liming is one mitigative option for temporarily protecting and possibly rehabilitating affected aquatic systems. Used in this context, liming is a generic term that indicates adding any "basic" material to surface waters, sediments, or soils to neutralize them or increase alkalinity. Liming is not considered a permanent solution to surface water acidification, but symptomatically treats the problem. Preliminary research on liming operations (primarily in Scandinavia) has indicated that some short-term protection and/or renovation of affected surface waters is possible. However, these studies are not complete and important questions remain on the long-term biological consequences of liming, its costs, application, materials and their chemical reactions, impact of episodic events, and the problems of resource management (e.g., restocking programs).

In field tests in North America and Sweden powdered limestone appears to be the most economical and effective reagent. However, it has disadvantages, such as precipitation of aluminum on lake bottoms with possible resolubilization during highly acidic episodes (such as spring snowmelt). Liming of streams has also been attempted, but with generally unsatisfactory results. Permanent limestone structures are ineffective because of biological fouling, and lime slurries are quickly dissipated, requiring continuous and expensive maintenance. The benefits and costs of liming and other actions for mitigating acidification and associated biological conditions in the United States are under study.

RESEARCH GOALS AND ACTIVITIES

The end point of the National Program's aquatic effects research is to quantify the effects of acid deposition on surface and groundwaters and wetlands of the United States, to describe how these effects can be corrected at the site of the problem, and to determine the ecological consequences of the remedial methods.

Research will also provide information needed to evaluate the current effects of acidification on freshwater chemistry; the likely sites of future water quality changes if acid deposition rates remain the same, increase, or decrease; and the extent and importance of changes in the ecosystem's plant and animal life associated with changes in the chemistry of lakes, streams, and wetlands.

The aquatic effects research focuses on five major objectives:

1. Quantify the extent of "sensitive" or "acidified" lakes, streams, groundwaters, and wetlands of the United States.
2. Identify and quantify the factors that control tolerance, sensitivity, and susceptibility of surface and groundwaters to acid deposition and determine how these factors can be used to predict future aquatic acidification under different loading rates.
3. Determine the relationships between surface water acidification and biological processes, biological populations, and aquatic communities and how these relationships can be used to predict future ecological effects.
4. Determine the potential for acidification of surface waters, groundwaters, and wetlands to affect human health.
5. Develop mitigative (liming) techniques for restoring or protecting acidified lakes, streams, and groundwaters of the United States.

Throughout FY 1982 the Aquatic Effects Task Group reviewed all current and planned aquatic effects research projects to (1) evaluate the relative overall priority of the research; (2) clearly define specific project objectives and determine their relevance to the research and assessment objectives of the National Program; (3) identify research deliverables in specific terms, and ascertain exactly how and when those deliverables will be available; and (4) assure that all researchers use compatible laboratory and

field methodologies, or that deviations from a standard methodology are made for valid reasons.

The Aquatic Effects Task Group held a partial research peer review in February 1982. A Federal effects research review a year later (in February 1983) (1) allowed the National Program's research to be reviewed in a comprehensive manner rather than as a series of discrete agency projects; (2) assessed the quality of the science; (3) provided a forum for interaction by field level scientists; and (4) evaluated the progress of the various research approaches. Throughout 1983 the Aquatic Effects Task Group will continue to critically evaluate all research to be sure that each project contributes to the identified objectives, milestones, and deliverables.

PROGRAM ACCOMPLISHMENTS—FY 1982

• **Accelerated assessment of the extent of the problem of acidification of lakes, streams, and groundwaters of the United States.** This multiagency effort comprises an assessment program to bring relevant existing water quality data together on a national basis for use in assessing the extent of sensitivity to acidification. In FY 1982 this effort was accelerated to provide results in 1983 and 1984. Specific objectives are:

1. Identify and map the extent and degree of sensitivity to acidification of lakes and streams in the United States.
2. Determine trends in the acidification of surface waters.
3. Provide a verified, quality assured data base for available methodology to predict surface water acidification based on given deposition rates. The data base will also help correlate geographic patterns of surface water sensitivity and acidification with spatial patterns of climatic, geologic, physiographic, edaphic, and land use factors.

In FY 1982 various individual projects of the National Program included a national inventory of existing water quality data applicable to assessment of sensitivity and acidification of surface and groundwaters, supplementary field surveys in the southern Appalachians, data stored in the Acidification Chemistry Information Database (ACID), and a national map indicating general patterns of surface water alkalinity (see Fig. E-1 insert on back cover).

• **The Aquatic Effects Task Group began a study to identify, quantify, and predict the factors that control the susceptibility of natural waters to acidification.** This study will mold numerous research projects into a nationwide source that will lead to a predictive modeling capability. The Task Group has begun a thorough review of the various models for predicting acidification. One or more of these approaches (or others to be developed) will be used by the National Program to predict future acidification of surface waters based on different acid loading rates for an FY 1985 assessment.

• **A major report has identified the needs of aquatic effects research.** This report reviews acid deposition phenomena in aquatic systems, develops a framework for pulling together existing information, and then evaluates and refines a preliminary model to estimate effects of acid deposition on aquatic resources.

• **A preliminary survey of New England surface and groundwater supplies was completed.** Preliminary results showed that, in general, the water supplies in the New York Adirondack region and in the New England States are quite corrosive. The most notable exception to this was the water supplies of Connecticut, which appear to be less corrosive than those in the other States. With laboratory analysis nearly completed, it appears that the maximum contaminant level for lead is seldom exceeded. Elevated concentrations have occasionally been observed, especially in standing waters. This study is being conducted to ascertain whether acid deposition might affect municipal water supplies.

• **The Aquatic Effects Task Group began a long-term program to monitor the chemistry and plant and animal life of surface waters in key sections of the Nation.** By quantifying current effects of a range of acid loading rates, the long-term surface water monitoring program is providing information needed to formulate recommendations for acceptable loading rates of acid materials from the atmosphere.

Aquatic Effects Task Group agencies cooperated in developing a standardized sampling/analysis protocol for chemical survey and monitoring of surface waters. This protocol will be completed in early FY 1983.

Sites for long-term monitoring of lakes and streams have been identified. Close coordination and cooperation among the agencies will result in an effective, compatible network. Annual reports from each site will be combined into an overall annual summary report, which will be submitted to the Task Force.

• **A number of new biological effects studies started in FY 1982.** Three different approaches (field, laboratory, and population modeling) are being used to identify and quantify the effects of lake and stream acidification on aquatic life. Studies emphasize identifying the operating stress mechanism (a toxicant and its mode of effect) and its effects on species of economic and recreational use, particularly fish and waterfowl.

Critical research issues to resolve before assessments can be made are (a) the distribution of species in sensitive waters in relation to current or future acidification; (b) biological effects of surge versus continuous acid loading; (c) individual and population effects of various levels of pH, aluminum, and heavy metals on fish and other aquatic life; and (d) sensitivity of key aquatic species, particularly fish, at various life stages to sublethal effects of low pH. The most intense work will center on areas across the Nation currently receiving acid deposition whose surface waters are highly sensitive to acidification (Northeast, upper Midwest, Appalachian Mountains, sections of the Rocky Mountains, the Cascades, and Sierra Nevada Mountains).

• **An evaluation of mitigation strategies for restoring or protecting lakes, streams, and watersheds has progressed.** An in-depth report by the Aquatic Effects Task Group summarizes up-to-date available information on liming; lists State, Federal, and private sector contacts on liming projects; and digests liming projects in the northeastern and midwestern States. Current research projects and research in Scandinavia, Canada, and the United States are included.

The Task Force organized and conducted a week-long international workshop on liming. The Aquatic Effects

Task Group developed a research strategy and set priorities for field and laboratory projects addressing liming materials and application techniques and the biological and chemical changes associated with liming.

- Laboratory and field tests are assaying the biological and chemical consequences of liming and other mitigative treatments of acidified and sensitive lake and stream systems. This project concerns the development and testing of management procedures and strategies by which lakes and streams can be at least temporarily protected from the harmful effects of acid deposition, acidification, and associated metal/ion toxicity. These tests, involving both laboratory and field investigations, include surface waters where fish populations have either been reduced by acidification or are under stress because of acidification. Another laboratory and field project was begun on placing limestone gravel in spring upwellings as a possible mitigation measure in acidic brook trout lakes.

FUTURE ACTIVITIES

Major FY 1983 to 1985 priorities of the National Program's aquatic effects research are to (1) make substantial progress in assessing the extent of the problem and place a comprehensive long-term surface water monitoring program on line; (2) develop a better understanding of the geochemical linkage between terrestrial and aquatic systems; (3) begin biological effects studies that will result in regional predictions of future acidification; (4) complete drinking water surveys of the eastern United States; and (5) begin field tests to evaluate liming options.

More specifically, highlights of expected FY 1983 accomplishments include:

Regional maps of sensitive waters of the United States. Preliminary maps developed in FY 1982 are not of sufficient detail or accuracy to allow for national assessments. Detailed regional maps developed in FY 1983 and 1984 will provide much greater detail and be based on more data.

Preliminary report on quantification of the extent and scope of surface waters at risk in the United States. Although national and regional maps are critical to the assessment of surface waters at risk, a quantitative and statistical analysis of all relevant data from the national survey (alkalinity, pH, sulfate, and others) will provide an inventory of acidified waters and simultaneous analysis of watershed data, water chemistry, and atmospheric deposition data.

Preliminary report on analysis of causative factors for alkalinity, pH decreases, and pH increases. Appropriate data from the national survey will help analyze historical trends in water chemistry and whether they can be related to atmospheric deposition.

Report on historical trends in surface water acidification from lake sediment coring studies. An alternative approach to the detection and analysis of historical trends in lake water chemistry is through the study of lake sediment cores. Core samples yield independent records of past chemistry and biology in the lake. These findings can then be compared with trends deduced from historical analyses of water chemistry.

Complete upper Midwest synoptic surveys of water quality and related plant and animal life. Studies made over the past 4 years constitute an excellent data base for comparison with future conditions in that part of the United States most densely populated with lakes.

Interim report on stream and reservoir survey of the southern Appalachians. Low alkalinity, sensitive surface waters in the southern Appalachians consist of streams and reservoirs; natural lakes are essentially nonexistent. Both short-term surveys and long-term monitoring will ascertain the distribution and numbers of these sensitive waters and their response to acidifying forces.

Final report of sensitivity to acid deposition of aquatic resources in the Rocky Mountain National Park. This will assess the extent of the problem in a pristine region and the consequences of environmental degradation.

Report on trends at active lake and stream monitoring stations. A multiagency effort is establishing long-term study sites on strategically located lakes and streams across the United States. Regular sampling of lakes, streams, and precipitation will provide needed information on the response of sensitive surface waters in different regions to atmospheric loading.

Report on methodology and data base needed to predict biological (particularly fish) resources at risk. This methodology will provide for an assessment of the effects of increased acidification on fishery resources both regionally and nationally.

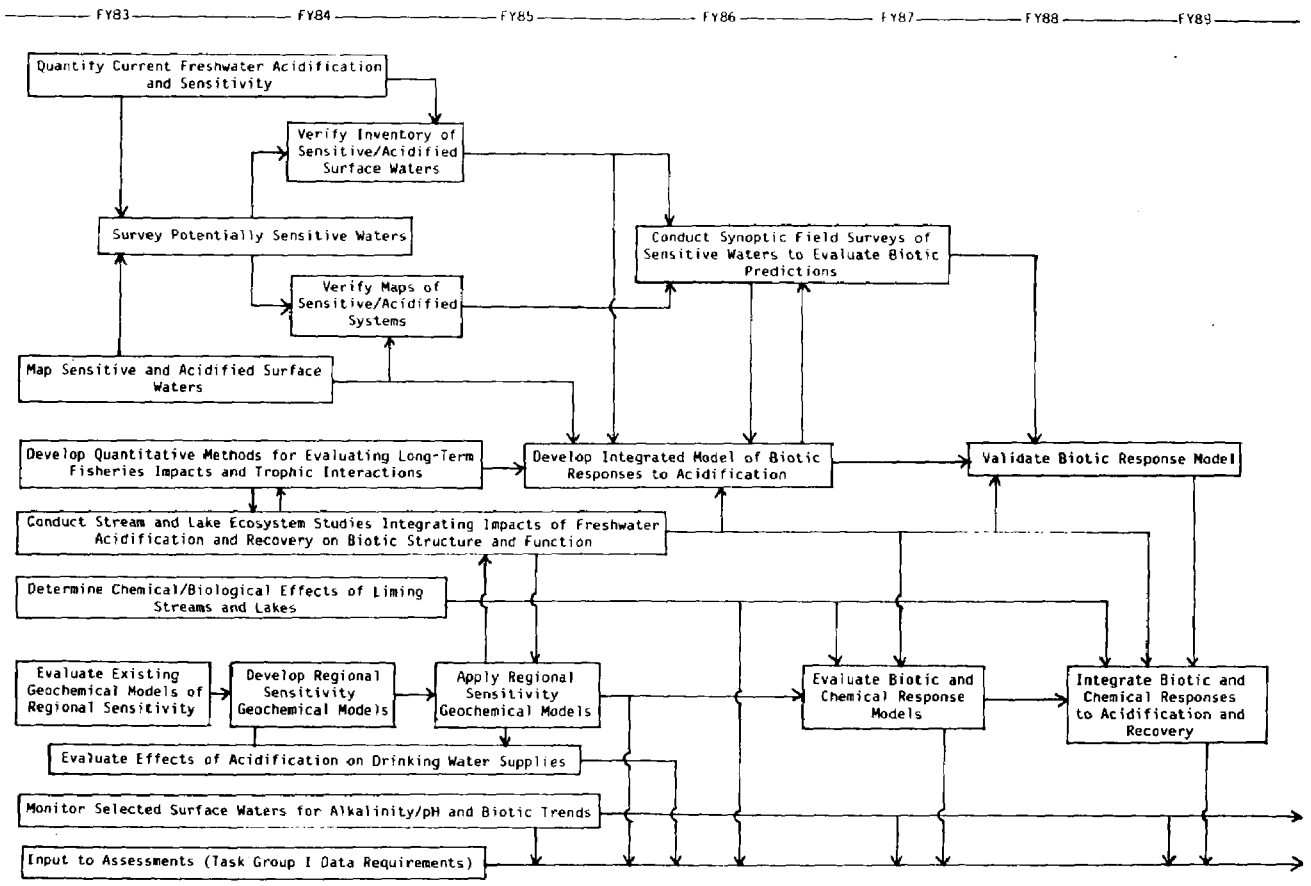
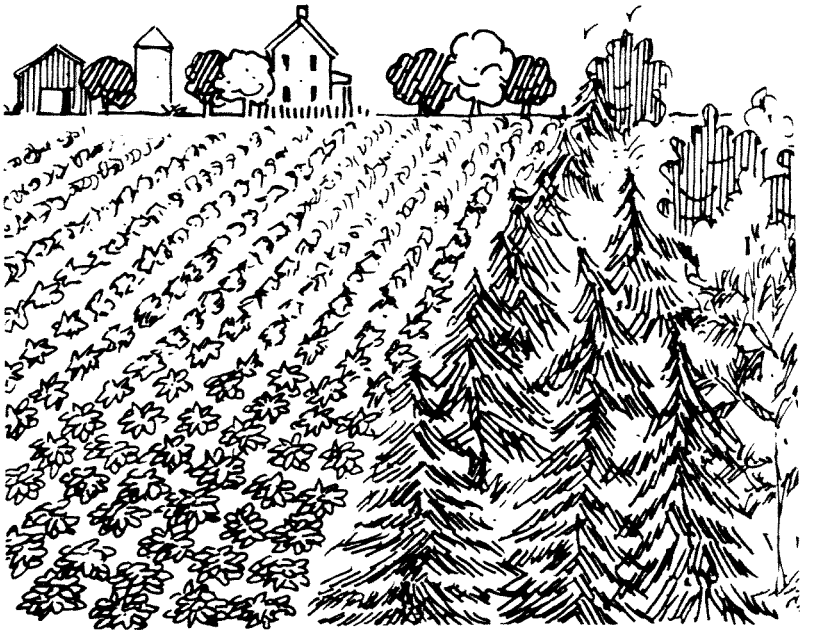


Figure E-2.—Proposed program implementation strategy, Aquatic Effects.

F. Terrestrial Effects

BACKGROUND



Only recently have efforts been made to establish the mechanisms by which atmospheric acid is transferred to aquatic ecosystems. If acid precipitation must pass through the terrestrial ecosystem prior to entering an aquatic ecosystem, it will usually be strongly influenced by the chemical nature of the vegetation, soil, and bedrock.

Aluminum movement from terrestrial systems has recently become a primary concern. Aquatic biologists have documented the effects of aluminum on fish and other aquatic organisms. It has been shown that aluminum does move into the aquatic system at a steady rate, increasing to high levels during spring snowmelt and heavy rainfall periods, and that the aluminum is coming from the terrestrial system, not the atmosphere. The availability of aluminum in the soil solution has direct implications for tree growth, and thus forest productivity. The tolerance of crops to soil-water aluminum is well known, but the toxicity data for forest trees and range plants are not available.

Terrestrial effects research encompasses soils, watersheds, forests and range plants, and crops. A number of uncertainties shroud the relationship of acid rain to the dynamics of these systems. Whether acid deposition is wet or dry, the interaction of ozone and sulfur dioxide and the life stage of the plant can modify plant response to acid deposition. That such factors vary by region adds to the uncertainty.

Other natural stress factors, such as insects and disease-causing agents, are capable of limiting forest and range productivity in the absence of acid deposition. Even if acid deposition should not prove to directly harm forest and range vegetation, it remains important to find out if it impairs the ecosystem's ability to rebound from common natural stresses—insects, disease, and drought among others—and stresses from man-made pollutants. Studies must consider how variations in precipitation chemistry may affect plant response.

While there is general agreement that unmanaged soils in forested and grassland areas in humid regions may be sensitive to acidification from acid precipitation, there is no indication to date that the soils have become acid because of it or that forest production is being affected.

Soil acidification by natural processes may be more significant than soil acidification by acid deposition. The rate and extent to which such acidification is occurring in nature, and the effects (if any) of acid rain on soil microbial processes are little understood.

The most consistent conclusion to be drawn from agricultural research at all scales and with all species has been "no effect" at current average ambient pH levels (pH 4.0-4.2). A few studies, including some with field corn and soybeans, have reported negative impacts of acid deposition, while still others showed a positive growth response. The economic importance of corn and soybeans and their location within the region most heavily exposed to acid rain and ozone warrants further studies to understand the nature of their response.

RESEARCH GOALS AND ACTIVITIES

The terrestrial effects research of the National Program includes work on the direct or indirect effects of acid deposition on three major components: forest trees and range plants, agricultural crops, and soils and watersheds. The objectives of the research are to address the following key questions:

1. What are the long-term effects of acid deposition on forest and rangeland productivity?
2. Can mathematical models be developed to estimate economic losses in major crop plants?
3. What are the relationships of acid deposition effects on soil chemistry to biological productivity?
4. What are the influences of soil weathering, leaching, and organic decomposition on ecosystem linkages among soil, water, and plant components?
5. Will acid deposition have a detrimental effect on forest and range ecology?
6. Are there threshold doses above which crop productivity will be adversely affected?
7. What are the ecosystem impacts of acid deposition, and can management options be developed to counteract them?

8. What are the physiological and biochemical processes by which plants may be changed by acid deposition?

To determine the effects of acid rain on forest productivity, their magnitude, and how they work, research is surveying trends in forest growth, determining through mechanistic studies, whether cause and effect relationships exist, and evaluating acid deposition's effect on the response of forest and range vegetation to other stress factors.

Agricultural research is focusing on major economic crops, such as corn and soybeans, and concentrating on those questions that can be most readily addressed within a 5-year time span. The emphasis is to generate realistic response functions that can be used in an assessment.

Effects on soil productivity are also being emphasized, as are mitigation measures with practical applications. Studies on soils and watershed processes are determining the changes that occur after acid deposition reaches the soil surface.

PROGRAM ACCOMPLISHMENTS—FY 1982

Forest Trees and Range Plants

Studies on forest and rangeland vegetation indicate that the effects of air pollution in general, and acid deposition in particular, are subtle and of long duration, and may alter the dynamics of plant community growth and succession. To provide the information for both economic and ecological assessments, studies emphasize the mechanisms that affect growth or mortality.

• **Tree ring sampling initiated.** Establishing regional tree growth rate changes is an essential assessment step. Changes in diameter growth can be easily converted to estimates of volume, which can subsequently be translated into economic terms. Testing is also underway to determine if trees are taking up unusually large quantities of metals; this is considered an indicator of anthropogenic activity. To assess growth rate changes over time, sampling has begun of tree ring cores in over 600 trees in 70 forest stands in 14 eastern States. Those States range from Maine to North Carolina, and extend west as far as Arkansas and Missouri.

• **Study of red spruce dieback started.** Because of both direct economic and aesthetic considerations, there is concern about red spruce dieback in the eastern United States, especially at high elevations. Dieback was generally preceded by an abrupt reduction in growth which began in 1960. At that time, a severe drought occurred in this area and may have been a triggering agent. Previous tree ring chronologies indicate fairly rapid recovery in the same systems from earlier droughts. Recovery from the current drought appears to be quite slow or nonexistent, possibly because of interactions with other stresses, both natural and anthropogenic.

• **Pine seedlings vary in their response to acid rain.** Some pine seedlings showed greatest growth response below pH 4.0, perhaps because of the nutrient effects of sulfur or nitrogen. Since southern pine forests are frequently fertilized, significant inputs of essential nutrients from atmospheric sources could substantially reduce fertilization costs.

• **Some loblolly pine seedlings show resistance to disease following acid rain exposure.** Fusiform rust is estimated to produce losses in yield in excess of $25 million per year in southeastern pine forests. Research suggests acid rain may increase rust resistance in pine. In response to simulated acid rain, some seedlings showed increased rust resistance traits, others decreases in fusiform rust galls.

Agricultural Crops

Several developments in methodology for studying acid rain effects on agricultural crops have been tested during FY 1982 that promise to improve evaluation. The ambient rainfall exclusion technique was perfected, a significant development. Researchers at six sites are developing such facilities for assessing crop loss. Field research with simulated rain, excluding ambient rainfall, is the state of the art in crop loss assessment relative to acid rain impacts. Significant progress in crop loss assessment is anticipated from the results of the 1983 growing season, as these key new experiments are performed.

CROP SENSITIVITY:

• **Potato study shows no apparent foliar injury from acid rain.** Potatoes are a major agricultural crop in the northeastern United States. In a field study, a commercially important potato cultivar was treated with simulated acid rain of various pH levels, similar to ambient rainfall at that site. No apparent foliar injury resulted from the treatment, even at levels as low as pH 2.7. Quality analysis of the 1982 tuber crop is in progress. This project will yield dose response data for both crop yield and crop quality. Both of these values are necessary for economic assessment of impacts to potatoes. In addition, information gained as a byproduct of the quality analyses will aid in understanding the mechanisms of effects.

• **No change observed in balance between clover and fescue.** Clover/fescue ratio is a good indicator of stress; both are important forage species that frequently are not as intensively managed as agricultural field crops. Therefore, it is important to see if soil management should be changed to maintain a clover-fescue forage system in the presence of acid rain. Data gathered through the first two harvests of this study showed no foliar necrosis or differences in yield or species composition that could be attributed to rain pH or soil management variables. However, in both species, the crop's nutritional quality appeared to decline at the lowest treatment (pH 3.5), indicating potential for long-range impacts on the nutrient and, therefore, market values of the crop.

DOSE-RESPONSE RELATIONSHIPS:

• **Soybean yields may or may not be adversely affected by acid deposition.** Studies indicate that yield reductions of sensitive cultivars were caused by decreases in number of pods at harvest, even without visible foliar injury. Some cultivars, however, are resistant. These results underline the need to develop damage functions for representative vegetation across a range of genetic and environmental variables.

• **A major field experiment established in the corn/soybean belt of Illinois** is dedicated to developing dose-response information on two varieties each of soybean and field corn using ambient rainfall exclusion and rainfall simulation techniques that permit study under undisturbed field conditions. This major experiment will significantly expand the data base on agricultural effects for the 1985 assessment.

• **Inhibition of corn yield.** A study of field corn using simulated acid rain between pH 5.6 and 3.0 showed inhibition of yield at pH 4.0 only, corroborating earlier reports with the same crop, and indicating that factors in addition to hydrogen ion are controlling the magnitude and direction of the effect. Mechanisms associated with the observed effect must be better understood before predictive assessments are possible with corn.

• **Concentration and ratios of ions.** Acid precipitation may stimulate plant growth and yield depending on the environmental conditions and the concentrations and ratios of ions in the simulant. Soybean yield varied depending on the sulfate to nitrate ratio in precipitation simulants; the response depended on pH. Since the sulfate to nitrate ratio in precipitation varies by region, this factor is an important consideration in regional assessments leading to the 1985 assessment.

• **Individual events.** The response of radishes and bushbeans to acid rain simulant was also significantly affected by the chemistry of individual events. Peak acidity events may be more important in affecting plant response than the total mean acidity during a growth season. Since current deposition monitoring does not measure peak acidity events, but rather, weekly average concentrations, research such as this may provide valuable feedback to research planning activities in the Deposition Monitoring Task Group.

Soils and Watersheds

Watersheds represent a linkage between terrestrial and aquatic systems critical to understanding changes in both forest and aquatic productivity and stability. Chronic disruption of nutrient cycling processes or the mobilization of nutrients and toxic elements in terrestrial and aquatic systems will probably cause long-term effects on both forest and aquatic productivity.

Current studies are aimed at: (1) evaluating characteristics that determine soil vulnerability in an attempt to establish criteria by which individual soil types might be categorized as to potential for either nutrient loss or toxic element mobility; (2) identifying the principal soil processes that can be altered by acid deposition, in order to understand the mechanisms controlling nutrient availability for plant growth; and (3) determining the role that vegetative cover plays in modifying acid deposition effects on both the terrestrial system and the transport of ions to aquatic systems.

SOIL VULNERABILITY:

Soils exhibit a broad range of potential for change in chemical and biological properties resulting from acid deposition. Possible effects include leaching of essential alkaline cations with subsequent decrease in soil fertility in addition to release of aluminum and heavy metals. Studies are underway to investigate a range of soils varying in their vulnerability to change.

• **Significant removal of nutrients observed in a southeastern soil.** Among the soils considered most vulnerable, a sandy soil from the southeastern United States was exposed in both field and laboratory to simulated rain as low as pH 3.0. At pH 3.7, significant amounts of calcium and potassium were removed from the top 76 cm of this sandy soil. Magnesium, calcium, ammonium, phosphorus, sulfate, and aluminum were all higher in the soil solution at the surface and decreased steadily with depth. Nitrate/nitrogen increased with soil depth. Ions in soil solution were more concentrated during dry periods or periods of low rainfall. All of these factors could have an effect on soil fertility and, therefore, productivity and the economic return on investment.

• **No significant changes noted at a New Jersey site.** Soil solution and stream pH at a forested site in New Jersey were not directly related to precipitation pH, apparently because of natural production of acids by the soil. Large quantities of potentially mobile aluminum were found in the upper mineral soil horizons and forest floor; however, the sampling period did not include enough acid precipitation events to permit evaluation of the relationship between soil solution, aluminum concentrations, and precipitation pH.

• **Aluminum leaching found to vary by soil type.** A study of three contrasting northeastern forest soils showed the soils vary in their susceptibility to leaching of aluminum to acid precipitation. Two factors were suggested as regulating aluminum mobility in these soils: the form and quantity of the aluminum and the presence of mechanisms that favor the retention of otherwise mobile anions.

SOIL CONDITIONS AND PLANT GROWTH:

• **Acid rain causes varied response in nutrient formation in some soils from northeastern watersheds.** In laboratory studies with soils from three northeastern watersheds, simulated acid rain inhibited nitrogen mineralization in some soils, had no effect in other soils, and stimulated nitrogen mineralization in still other soils. Among the soil processes important to regulating nutrient availability for plant growth are those involving the mineralization of nitrogen by microorganisms. The nutrient most often limiting plant growth and forest productivity in the Northeast is nitrogen, and nearly all that nitrogen is derived from the microbial mineralization of nitrogen. Because few soils were studied, it is not possible to predict the soils or regions in which the nitrogen-supplying capacity of soils (and hence the provision of the limiting nutrients for vegetation) will be inhibited, enhanced, or unaffected by acid rain. Additional information from other sites is needed to establish regional responses for assessment purposes.

• **Acid rain increases nutrient availability at a southeastern site.** Soil properties and environmental conditions may also play an important role in microbial processes, as indicated from the results of a southeastern United States study where acid precipitation increased the rate of both nitrification and mineralization. Denitrification occurred in the acid sandy soils with low organic mat-

ter content; however, the effect of acid precipitation on denitrification is not clear at this time. Acid precipitation of pH 3.7 did not have any significant impact on soil biomass, respiration and enzymatic activity; however, the soil type may be a very important influence.

• **Sulfur accumulates in forested southeastern watershed.** It was observed that sulfate accounts for about 60 percent of the anions present in North Carolina Appalachian precipitation. This study of mineral cycling processes in a forested southeastern watershed found accumulation of elemental sulfur, because of its adsorption and transformation into nonmobile forms. Both processes are very important in regulating soil and water chemistry and acidity by retarding anion mobility and, thereby, cation nutrient loss from terrestrial systems.

WATERSHED BUFFERING CAPACITY AND RESPONSE:

• **Precipitation pH was not altered in one New England watershed, though the source of acid precipitation precursors may have changed.** As part of a long-term study of nutrient cycling budgets relating to forest management, no significant shift in precipitation pH was found at Hubbard Brook watershed in New Hampshire. These same results, however, indicate a decrease in the ratio of sulfate to nitrate, suggesting an important shift in the source of acid precipitation precursors.

• **pH of precipitation altered by forest ecosystems.** Forest ecosystems can reduce the acidity of ambient rainfall. Rainfall at pH 3.5 to 4.5 on a hardwood forest in New Hampshire was buffered to pH 5.0 by the time it reached streamflow. A West Virginia watershed with low alkalinity received rainfall at pH 4.1; below the tree canopy, it had risen to pH 4.2; in groundwater at springs, it was pH 5.0; and at the outlet of the small watershed, pH 5.9. Aspen forests growing on slightly calcareous glacial till in Minnesota also effectively buffered the impact of pH precipitation events.

However, in another Minnesota tree stand, while the pH of precipitation passing through black spruce growing on peat land increased slightly, the wetland surface peat added significantly to hydrogen ion concentration and ultimately reduced pH to the 3.5–4.5 range. Red pine growing on shallow soil over granite bedrock added a slight amount of hydrogen ion to precipitation, but the soil subtracted about the same amount. In this case, incoming precipitation is fed with little change in pH directly to streams and lakes. The mixed or variable nature of these observed responses demonstrates that variables such as canopy species, soil, and bedrock clearly must be accounted for in estimating deposition inputs to aquatic ecosystems from terrestrial ecosystems.

• **Water quality data lacking in some southeastern States.** A nationwide assessment of existing water quality data indicates that there is insufficient information on water quality variations in small streams during storms in southern Appalachia.

• **Site-specific deposition data needed.** To extrapolate site-specific data to regional effects, it is necessary to know if environmental conditions where the data are gathered are representative of the region. The extrapolated information is used in dry deposition models to quantify acid additions to the terrestrial ecosystem. Two types of currently available deposition models were evaluated for their applicability to developing watershed mass balance estimates. Although both models are state of the art, both have proved to be either inaccurate for most mass balance applications, or have inadequate characterization of major measurement parameters. This study has identified the fact that the quality and level of resolution of the models tested will need to be improved to support the level of detail needed for proposed ecological and economic assessments.

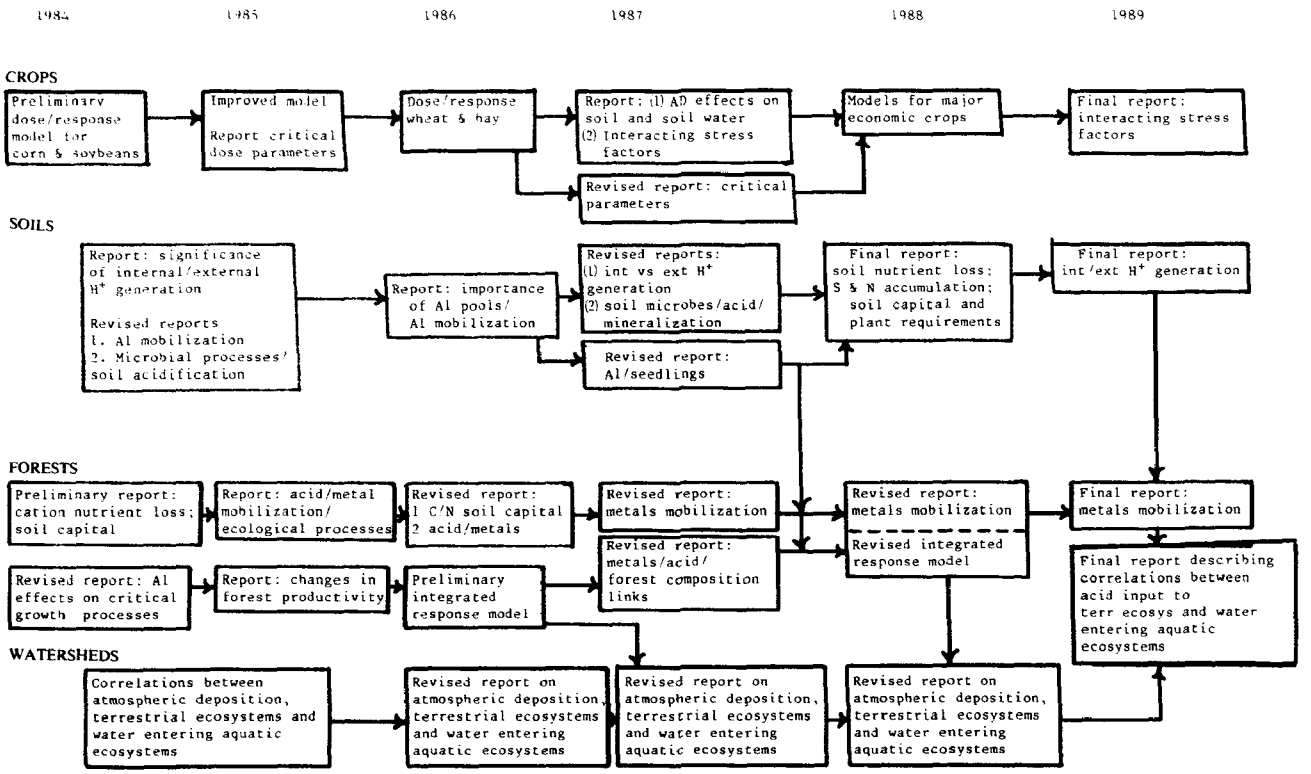
FUTURE ACTIVITIES

In the near future, research findings will accelerate as results of multiyear research activities are summarized. Among expected results between 1983 and 1985 are thresholds of damage to agricultural crops and dose-response relationships, specifically for corn and soybeans. This information will be used in developing models to estimate economic impact.

In forest ecosystems, tree ring studies will indicate the potential for determining growth changes related to acid deposition, as well as abnormal accumulation of metallic ions. There will be a preliminary report of soil nutrient budgets responsive to acid deposition. Changes of forest productivity correlated with acid deposition effects also will be summarized for major forest types. The role that various types and densities of vegetative cover play in modifying acid deposition effects on both the terrestrial system and the transport of ions to aquatic systems is being studied. Work beyond 1985 will concentrate on determining whether acid rain has predisposed trees to moisture stress.

Understanding the effects of acid deposition on the terrestrial ecosystem will be greatly improved by soil studies of aluminum and other metals, their mobility, and their uptake by both forest and agricultural crops, coupled with improved understanding of form and amount of acidic materials delivered to the forest floor. A report on the significance of hydrogen ion generated in soils will be prepared in 1985 as will reports on aluminum mobilization and on mineralization processes affected by soil acidification.

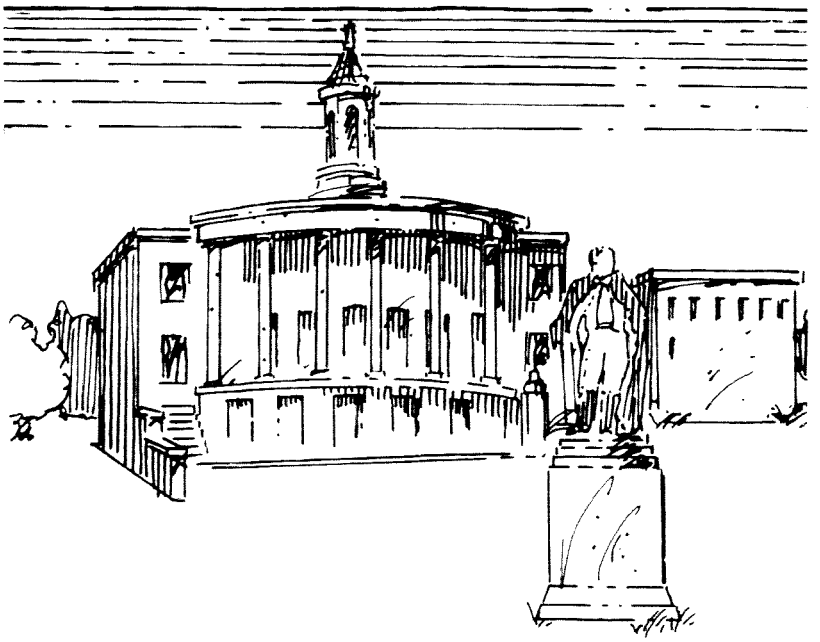
From 1986 to 1988 efforts will be accelerated to categorize soil types as to nutrient loss or toxic element mobility, as will studies to determine which soil processes controlling nutrient availability for plant growth will be altered by acidic fluxes. By 1988 these studies will begin to provide correlations that can be used to improve models. This will greatly aid the understanding of the influence of vegetative cover and soil behavior on water quality eventually reaching streams and lakes.



NOTE: There are no inventories of crops or forests scheduled by the Terrestrial Effects Task Group. The Department of Agriculture maintains an extensive crop reporting network and a forest survey. Both of these functions collect the data needed to support economic analysis of any detrimental or beneficial effects of acid deposition that are revealed by this or other research.

Figure F-1.—Proposed program implementation strategy, Terrestrial Effects.

G. *Effects on Materials*



BACKGROUND

Experience over the last century in both European and North American cities has shown that air pollutants accelerate the deterioration of materials. However, several factors complicate quantitative assessments of the impact of atmospheric pollutants, including acid precipitation, on conventional building materials. Building materials degrade to some extent with time, even in pristine environments, so it is important to differentiate between normal weathering and deterioration accelerated by air pollution.

Distinguishing between the relative amounts of damage caused by specific pollutants and their transformations in contact with various surfaces is even more elusive. The role played by acid precipitation is still a major unknown. This is especially true for the acid precipitation stemming from long-range transport of air pollutants.

The development of quantitative cause and effect relationships depends on the capability to correlate two independent data sets—materials deterioration and pollution monitoring.

Past attempts to estimate the materials damage costs related to pollutants are of questionable value, because:

1. The effects caused by various pollutants cannot yet be reliably separated from each other and from deterioration caused by natural agents such as moisture and temperature.
2. Estimates of the quantities of materials exposed to acidification are lacking.
3. The way society chooses among use, repair, and replacement of materials susceptible to air pollution damage is unclear.

Materials at risk are statuary and structures of cultural value as well as commonly used construction materials. These include man-made materials such as metals and alloys, paint, plastics, cement and concrete, masonry, roofing and siding materials, and natural materials such as marble, limestone, granite, calcareous sandstone, and other mineral substances. Inventories of the location and amounts of sensitive materials present in the geographic areas of concern do not exist. Such inventories must be completed if the economic effects of air pollution damage are to be assessed and comprehensive cost estimates developed.

Chemical corrosion processes deteriorate calcareous building materials and cause metals, particularly zinc and copper, to lose their protective oxide coverings. Over the years, a considerable amount of industrial research has evaluated the relative susceptibilities of materials and developed more resistant ones. However, little has been done to quantify the susceptibility as a function of pollutant concentrations or other exposure variables such as humidity, temperature, wind direction and velocity, precipitation quality and frequency, or the concentration of airborne salt particles.

Climatic and meteorological conditions are important unknowns with respect to materials damage, although some information is available. For example, it is known that high humidity increases the rate of attack of sulfur dioxide on zinc, and that local variations in temperature also can be expected to influence damage rates. Wind velocity and direction can affect the deposition velocity and also enhance surface abrasion by large airborne particles. An important role in materials damage also has been ascribed to special events such as dews, frosts, and fog in combination with dry acid deposition.

The principal air pollutants causing materials damage are sulfur dioxide, nitrogen oxides, ozone, and particulate matter. In addition to attacking surfaces directly, the first two are precursors of particulate sulfates and nitrates that can travel long distances and, as acid deposition, create effects many miles from the original emission sources. However, since pollutants are rarely encountered singly and are thought to act synergistically, they must be examined in combination and in different proportions corresponding to actual conditions. Information regarding the potentially important effects of ammonia and chlorine is also unavailable.

RESEARCH GOALS AND ACTIVITIES

Assessing damages to materials and cultural resources by acid deposition was a major new FY 1982 initiative of the National Acid Precipitation Assessment Program. The Task Force is planning and beginning several ac-

tivities to better understand and quantify the role of acid deposition in degrading various materials and cultural resources. The present state of the art of acid deposition materials damage modeling and related economic effects modeling is primitive and the required data bases are very poorly developed. The Materials Effects Task Group has designed a research strategy that will provide basic understanding of damage mechanisms from which effective protective measures for historic and cultural structures may be developed and from which more accurate economic estimates can be made.

The Materials Effects Task Group's research strategy addresses four key questions:

1. What portion of materials damage can be ascribed to acid deposition?
2. Which materials are susceptible to which specific air pollutants and to what degree?
3. What is the geographic distribution of susceptible materials?
4. What are the specific rates of damage or amounts of damage in economic terms?

PROGRAM ACCOMPLISHMENTS—FY 1982

In its first year, the Materials Effects Task Group concentrated on developing interagency coordination and cooperative study, and implementing new projects. Efforts during FY 1982 concentrated on (1) expanding field studies of materials deterioration; (2) intensifying efforts to look retrospectively at materials damage on marble tombstones, exposed bronze markers, and materials performance data from industry-sponsored research; (3) selecting and applying methods to measure air quality for the purposes of materials damage research; and (4) developing methods to inventory common construction materials as well as historic structures and monuments.

Research initiatives in FY 1982 included:

• **Establishing new field sites.** Two additional field sites were established at Washington, D.C., and Huntington Forest, N.Y. Unlike the first two sites at Chester, N.J., and Research Triangle Institute, N.C., these new locations did not have full environmental monitoring instrumentation and therefore various supplemental monitors had to be installed. Atmospheric corrosion testing, coordinated with simultaneous meteorological, acid deposition, and air quality measurements, is being conducted at these four field sites to quantitatively correlate specific pollutants present in acid deposition with materials damage. The corrosion responses of seven metals are being evaluated over exposure cycles ranging from 1 month to 3 years. The result will be dose-response functions for these metals.

A related problem now under investigation is the proper method of sheltering a set of samples from wet deposition. This work has produced a prototype movable cover activated by a rain sensor. This movable cover is now being evaluated for possible installation at Bureau of Mines sites. This will permit wet and dry deposition effects to be studied separately.

• **Calibrating static monitors for sulfur dioxide and nitrogen oxides.** These simple devices appear to promise a much cheaper method of characterizing air pollution levels at materials effects sites. However, the literature contains little concerning their performance under varying conditions of wind, humidity, temperature, and combined pollutants. Therefore, experiments have begun to study the response of these monitors, beginning with a 1-month field exposure during June 1982, as part of a major project on dry deposition conducted at Champaign-Urbana, Ill., for the National Program.

In this project, a variety of materials were exposed with the static monitors to compare their relative rates of sulfate and nitrate uptake. Extensive meteorological data were collected simultaneously. In addition, a flow chamber for calibrating the static monitors under controlled conditions was designed and built at Research Triangle Institute. Actual operation of the flow chamber will begin in early FY 1983. The availability of properly calibrated static monitors may ultimately permit operating materials exposure sites without elaborate air quality monitoring equipment.

• **Estimating damage functions from industry site data.** Much of the basic data are derived from commercial material test sites. The National Bureau of Standards (NBS) is collecting existing corrosion and material performance data. Methods are being developed to reconstruct past pollutant deposition levels for the regions and periods of commercially-sponsored materials exposure testing. Available material performance data have been identified and will be compiled in FY 1983, including historical pollutant levels and meteorological data. Correlation of these data sets will provide rough, interim estimates of material deterioration effects attributable to acid deposition until more definitive damage functions can be developed by field exposure corrosion testing.

• **Estimating bronze deterioration rates.** A project to estimate bronze deterioration rates resulting from exposure was begun in FY 1982. Bronze markers such as U.S. Geological Survey surveyors' benchmarks and National Historic Landmark plaques will be studied. In FY 1982, NBS tested and refined a mylar replica method to measure the rate of corrosion in the field. Bronze durability as a function of deposition levels will be estimated.

• **Estimating marble deterioration rates from tombstones.** Study of the differential rate of marble weathering, as measured on Veterans Administration tombstones, has produced a data base covering 3,500 individual stones. The data are now being analyzed and correlated against environmental factors, including air pollution levels. The final report is due in FY 1983. In addition, a report has been completed on maintenance practices in NPS cemeteries. The output of the tombstones study will be a set of correlations between marble deterioration rates and spatial and temporal variables, including retrospective estimates of pollution levels.

• **Pollution archaeology.** Success of the retrospective studies of materials damage requires estimates of past pollution levels. Since air pollution was not usually monitored prior to 1960, these levels must be inferred from other data sources. Two such efforts were begun in FY 1982. One approach involves calculating air pollution levels from historical records of fuel consumption. The estimates will use primarily local sources of data covering sources such as home heating, industries, and vehicles, including coal-fired locomotives. In addition, NBS began to develop a method to measure levels of at-

mospheric sulfur deposited on painted surfaces and trapped between repaintings. If measuring sulfur levels in lead paint layers proves feasible, a field study collecting paint samples from dated structures nationwide will be started in FY 1983 to verify sulfur deposition levels calculated from emissions inventories, and to refine regional scale estimates of deposition levels.

• **Prototype *in situ* deterioration monitoring.** Diagnosis of actual cases of materials deterioration is the practical application of results of field, lab, and retrospective research. As a prototype, deterioration of historic structures at Mesa Verde National Park, Colo., will be measured in parallel with environmental parameters. National Trends Network parameters will be supplemented by measures of gaseous concentrations, particulate composition, and temperature and moisture cycles. Field measurement techniques perfected at the prototype site will be available for general application nationwide.

• **Documenting protective treatments.** Baseline documentation of effective protective treatments for masonry monuments and buildings was undertaken for eight structures in FY 1982. Structures were chosen based on several criteria: masonry material, treatment material, and location of structure. Materials include marble with and without epoxy consolidants, sandstone with epoxy consolidants, cleaned brick, and terra cotta. Locations include New York, N.Y., Portland, Ore., Minneapolis, Minn., Chicago, Ill., San Francisco, Calif., New Orleans, La., and Boston, Mass. The results will be used to assess existing techniques for protecting such structures against environmental decay.

FUTURE ACTIVITIES

In FY 1983, work will continue toward producing interim damage functions for a 1985 assessment. Tombstone data, bronze marker data, and material performance data from industry will be correlated with reconstructed pollution histories. Several laboratories will begin to adapt advanced technology to increase the sensitivity of damage measurements; this will shorten the time frame for determining damage function. Work will be undertaken to characterize the mineralogy of major American stone sources and to predict their susceptibility to attack by acid deposition.

Chamber studies to investigate the role of moisture in acid deposition upon material surfaces and the effectiveness of protective treatments on statuary materials will begin in FY 1983. Additional materials—marbles, bronzes, and selected coating materials—will be added to the field exposure program.

Another initiative will develop data on the distribution of construction materials as related to population, history, availability of materials, and land use. This data will be incorporated into a land use classification that will produce an inventory of common construction materials.

The Materials Effects Task Group presently plans the following FY 1983 outputs:

Tombstone study results—a report of marble damage rates.

Bibliography of Effects of Acid Deposition on Corrosion and Deterioration of Materials, 1980-1983—a literature review covering existing knowledge of materials damage.

Description of field exposure sites and methods—a report setting forth for peer review the field exposure program.

Specifications for measuring damage to cultural resources—a document establishing the basis for investigating damage at cultural sites from acid deposition and other causes.

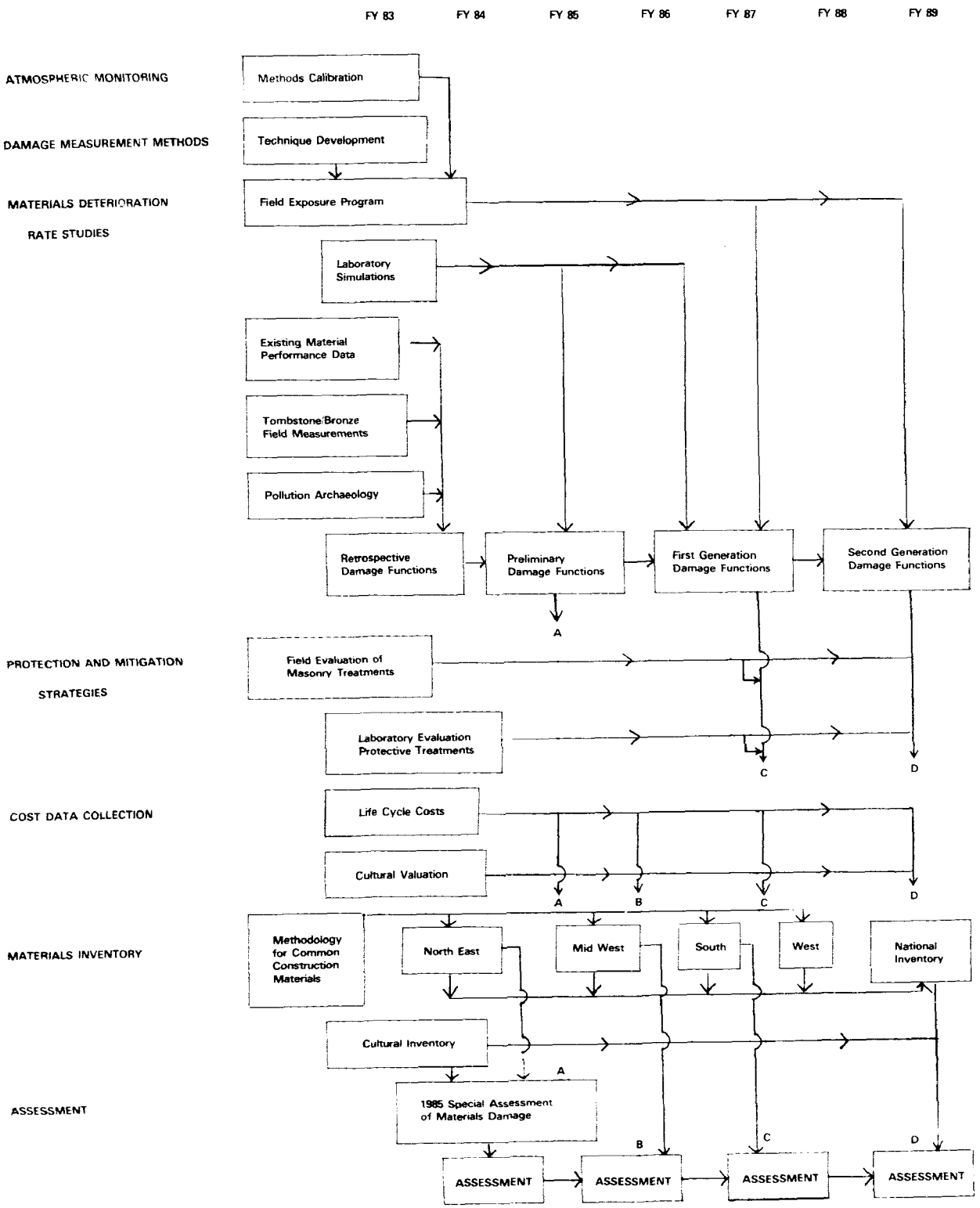
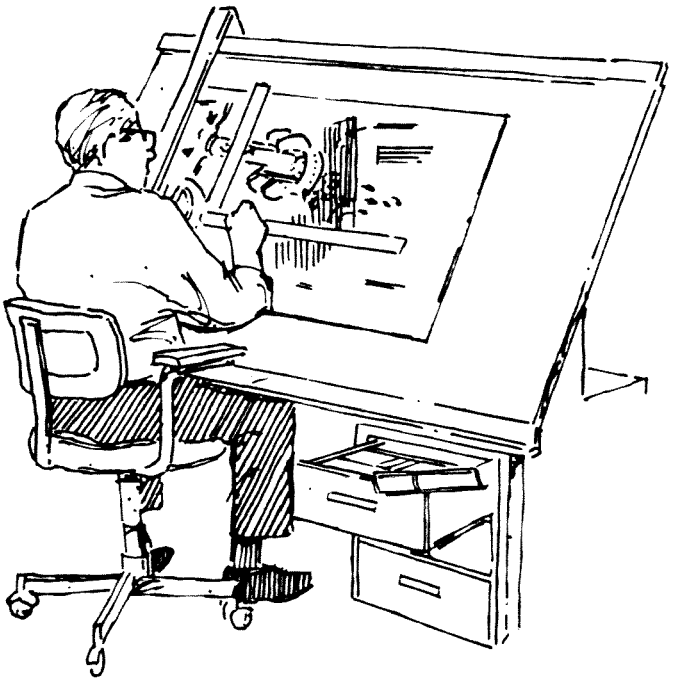


Figure G-1.—Proposed program implementation strategy, Effects on Materials and Cultural Resources.

H. Control Technologies

BACKGROUND



The relationship between man-made pollutants and acid deposition is not fully understood, but three pollutants have been linked to acid deposition. Sulfur oxides and nitrogen oxides have been analytically identified in acidic deposits with the ratio of each ranging from minor to major. Oxidants also have been highly correlated with the occurrence of acid precipitation and are probably involved in the atmospheric transformation of the gaseous oxides to acidic nitrates to sulfates that are deposited.

Emissions from fossil fuel power plants have been the focus of attention for possibly controlling the release of acid precursors because nationally this source produces a major share of the sulfur dioxide and a sizeable portion of the nitrogen oxides. However, other activities such as smelting, industrial combustion and processes, transportation, and space heating can all contribute significantly to the atmospheric loading of sulfur and nitrogen acid precursors and oxidants. The following discussion primarily addresses the utility source because our knowledge about the importance of other sources is less complete. All may contribute significantly (locally and/or regionally) to the formation of acid deposition, but their specific roles are still poorly understood.

Table H-1 summarizes the major man-made acid precipitation precursor pollutants, the major industrial sources, applicable controls, and explains their operation. For sulfur dioxide and nitrogen oxides, generally available controls are either expensive or inefficient. However, important technologies being developed, such as low nitrogen oxide burners and limestone injection multistage burners (LIMB), could someday provide more cost-effective control of acid precipitation precursors. For the directly emitted acidic compounds, very little information is available on the effectiveness of conventional control technology.

Table H-2 focuses on coal-fired power plants, major emitters of sulfur dioxide and nitrogen oxides pollutants. The table summarizes technologies that can be retrofitted to the sources of these man-made pollutants by performance, commercial status, costs, applicability, and important problems.

Flue gas desulfurization (FGD) technology is capable of highly efficient sulfur dioxide removal and has been commercially available for over 10 years. However, its capital costs are quite high; such systems would cost $60 to $90 million for a typical 300 MW coal-fired utility boiler. Also, widespread use of such systems would generate large quantities of wet solid waste product that must be disposed of in an environmentally acceptable manner.

Physical coal cleaning, although significantly less expensive than FGD, can decrease sulfur dioxide emissions only modestly since chemically-bound sulfur cannot be removed with current coal cleaning technology.

While switching to low sulfur fuel can achieve significant reductions, its capital costs can also be quite high—particularly when major boiler derating is needed to accommodate the lower fuel heat content of western low-sulfur subbituminous coals or particulate systems that require upgrading because of different coal effluent characteristics. Costs for this method also increase if locally mined coal can no longer be used.

Among the emerging control technologies, low nitrogen oxide burners may be particularly effective in controlling the oxides of nitrogen and may offer relatively inexpensive capital and operating costs, but achieve no sulfur dioxide control.

LIMB technology appears capable of moderate to high removals of both pollutants at less than 20 percent of FGD costs. LIMB technology is now in the prototype stage, but a demonstration may provide sufficient data by 1985 to permit industry to begin to evaluate its potential. Not enough information is now available to determine if target removal efficiencies can be met by LIMB without introducing boiler operating problems.

TASK GROUP ROLE

The Control Technology Task Group is tracking all relevant control hardware development efforts, and provides the appropriate agencies with guidance related to the National Program's objectives and requirements.

The interagency budget for the National Program does not include Federal funds for control technology hardware development because control technology activities are

conducted under preexisting programs at EPA, DOE, and TVA. The various reasons for controlling the primary man-made acid precursors, sulfur dioxide and oxides of nitrogen, make it difficult to directly assign the cost of such emission control hardware work to such different concerns as health, visibility, and acid rain. The National Program is actively coordinating with the relevant ongoing Federal control technology efforts to ensure that the concerns relative to acid deposition are addressed. A summary follows of the relevant Federal research and development activities in the existing control programs.

Technology	Agency	FY 82 ($ in millions)
SO_2 Control[1]	EPA	2.0
SO_2 Control	TVA	2.6
NO_x Control[2]	EPA	3.9
LIMB[3]/Low NO_x Burner	EPA	7.2
Simultaneous NO_x/SO_2	DOE	6.2
Total		21.9

[1]SO_2 = sulfur dioxide
[2]NO_x = oxides of nitrogen
[3]LIMB = limestone injection multistage burner

In addition to these Federal efforts, it is anticipated that the private sector will play a major role in bringing promising new technologies to the commercialization stage.

TECHNOLOGY DEVELOPMENTS—FY 1982

During FY 1982, the sulfur dioxide and oxides of nitrogen control technology activities funded by EPA, DOE, and TVA made significant progress in developing improved methods for controlling these emissions. The Control Technologies Task Group has identified the following results as potentially relevant to addressing the acid deposition issue:

- **Successful initial tests of the Limestone Injection Multistage Burner (see Figures H-1 and H-2).** Encouraging initial results indicate the potential for LIMB as a low-cost retrofittable combination nitrogen oxides and sulfur dioxide control technology. The LIMB technique uses sorbent injection of limestone during combustion with low nitrogen oxides burners. This developing technology may be able to reduce these pollutants' emissions from utility boilers by over 50 percent. (EPA)

- **Development of burner systems that could reduce nitrogen oxides emissions by 75 percent.** Advanced burner systems for wall-fired and tangential-fired boilers have been tested that decrease nitrogen oxides emissions about 75 percent. Since coal-fired utility boilers generate 40 percent of the total nitrogen oxides from stationary sources, these new burner systems should have an important influence on future emissions from utility boilers. (EPA)

- **Improved sulfur dioxide wet scrubbing techniques.** Wet limestone and lime flue gas desulfurization process technologies have been improved by increasing sulfur dioxide removal efficiency and reagent utilization, upgrading reliability, and improving waste product disposal. Innovations include adipic acid, magnesium, and thiosulfate additives; forced oxidation; and scale prevention in scrubbers and mist eliminators. These techniques improve sulfur dioxide removal efficiency and process reliability to over 90 percent while reducing costs. (EPA, TVA and DOE)

- **Evaluation of dry scrubbing process.** The researchers evaluated the effectiveness of spray dryer flue gas desulfurization systems using lime, limestone, nahcolite, and trona, and investigated the relative merits of fabric filters and electrostatic precipitators for collecting fly ash and sorbent material. This technology provides a new and lower-cost option than wet scrubbing processes for controlling sulfur dioxide from certain utility boilers. (EPA and DOE)

- **Assembled coal data bases.** Data bases on the quantity, sulfur content, heating value, ash content, and desulfurization potential of U.S. coals were assembled. These permit evaluation of the amounts of coal from each State that can be used with different control technologies for compliance with differing sulfur dioxide emissions control regulations or strategies. (EPA and DOE)

- **Evaluated advanced simultaneous sulfur dioxide/nitrogen oxides flue gas treatment processes.** Progress was made in quantifying the cost and performance relationships, and identifying other promising emerging processes, such as electron beam irradiation, for further research. From this research may well evolve the next generation of air pollution control technology. (DOE and EPA)

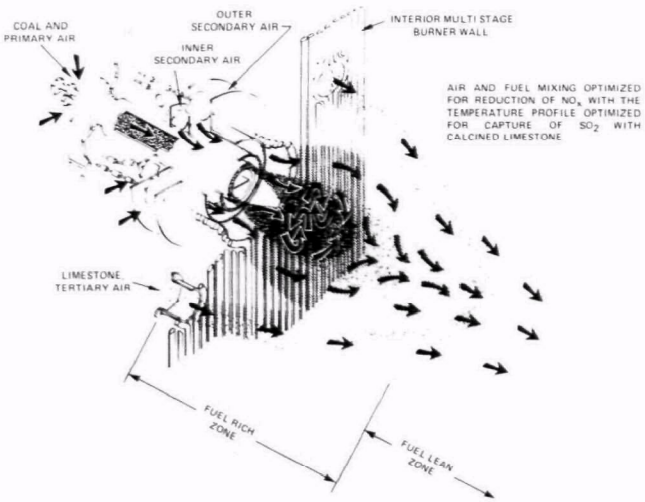


Figure H-1.—Limestone Injection Multistage Burner For Simultaneous NO_x and SO_x Control.

TABLE H-1 CONTROL OPTIONS FOR MAN-MADE ACID PRECIPITATION PRECURSORS

Major Acid Precipitation Pollutants	Major Sources	Applicable Control Approaches	Principles of Operation
Precursor Pollutants			
Sulfur Dioxide (SO_2)	– Electric Utilities: primarily high-S coal & oil power plants	– low sulfur fuel switching (commercial)	– Substitute naturally occurring low-S coal or oil.
		– physical coal cleaning (PCC) (commercial)	– Remove physically bound sulfur (pyrite) from coal via separation processes prior to combustion.
	– Industrial Fuel Combustion: primarily high-S coal & oil combustion	– flue gas desulfurization (FGD) (commercial)	– React acidic flue gas with alkaline liquids yielding either a throwaway or saleable sulfur compound product.
		– limestone injection multistage burners (LIMB) (developmental)	– Inject limestone in boiler through low-NO_x burners to react with sulfur gases to produce a throwaway product.
Nitrogen Oxides (NO_x)	– Electric Utilities; coal, oil, and gas fired	– low excess air (commercial)	– Minimize air used for combustion to reduce NO_x production from air N_2.
		– staged combustion (commercial)	– Add overfire air ports to allow fuel-rich early combustion conditions to reduce NO_x to elemental N_2 and O_2.
	– Industrial Fuel Combustion: coal, oil and gas boilers	– low NO_x burners (1st gen. commercial; 2nd gen. burners in demo phase)	– Replace old burners with specially designed burners to maximize fuel-rich early flame conditions for NO_x reduction.
		– flue gas cleaning (FGC) (commercial in Japan)	– Treat flue gas with NH_3 in selective catalysts to reduce NO_x to N_2 and O_2.
	– Stationary Engines: large diesels, gas turbines, and IC engines	– catalytic reduction (demo phase)	– Utilize combustion gas catalytic systems to reduce NO_x to N_2 and O_2 either with NH_3 (fuel-lean engines) or w/o NH_3 (fuel-rich engines).
		– combustion modification (demo phase)	– Modify engine to encourage staged combustion.
	– Mobile Sources: autos and trucks	– exhaust gas recirculation (commercial since 1972)	– Recirculate exhaust gas back to cylinders to lower temp. and lower oxidation of air N_2 and NO_x.
		– three-way catalyst (commercial since 1982)	– Special tailpipe catalytic system to reduce NO_x to N_2 and O_2.
Directly Emitted Acidic Pollutants			
Acid sulfates; predominantly sulfuric acid mist.	– Electric Utilities: coal- and oil-fired power plants	– Limited information suggests FGD and low-S fuel switching may provide some level of control for coal	– See SO_2 discussion above.
	– Non-Utility Fuel Combustion: coal and oil combustors	– Low excess air operation	– Lowering combustion air tends to decrease oxidation of SO_2 to SO_3 with subsequent sulfuric acid formation.
Hydrogen Chloride (HCl)	– Electric Utilities: high-Cl coal-fired power plants – Industrial Boilers: high-Cl coal	– flue gas desulfurization (FGD) – limestone injection multistage burners (LIMB)	– See SO_2 discussion above.

TABLE H-2 RETROFIT CONTROL TECHNOLOGIES FOR COAL-FIRED UTILITY BOILER

Process	SO_2 and NO_x Removal Efficiencies	Status	Estimated* Captial Costs ($/kW)	Applicability	Problems
Flue Gas Desulfurization (lime or limestone scrubbing)	90% SO_2 Reduction	Commercial	200 to 300	Most large utility boilers; costs could sharply increase over estimated values for difficult retrofits.	– High costs; especially for difficult retrofits. – Large quantities of wet waste to be disposed of.
Physical Coal Cleaning	20 to 30% SO_2 Reduction	Commercial	40 to 50	Centralized cleaning facilities can allow broad applicability	– Limited SO_2 removal; especially for difficult to clean coals. – Large quantities of pyrite solid residue for disposal.
Low-Sulfur Fuel Switching	60 to 80% SO_2 Reduction	Commercial	26 to 61	Most utility boilers	– Boiler derating sometimes required. – Potential displacement of locally mined coal.
Low-NO_x Burners (second generation)	60 to 70% Reduction	Early Commercialization	2 to 7	Most modern utility boilers	– NO_x removal only; no SO_2 removal.
Limestone Injection Multistage (Low No_x) Burners (LIMB)	50 to 60% SO_2 Reduction 50 to 60% NO_x Reduction	Developmental	27 to 37	Most utility boilers	– Technology will be commercial no earlier than 1985. – Questions must be resolved regarding performance and boiler reliability.

* Based on 300 MW, 3% sulfur coal, and Dec. 1982 dollars.

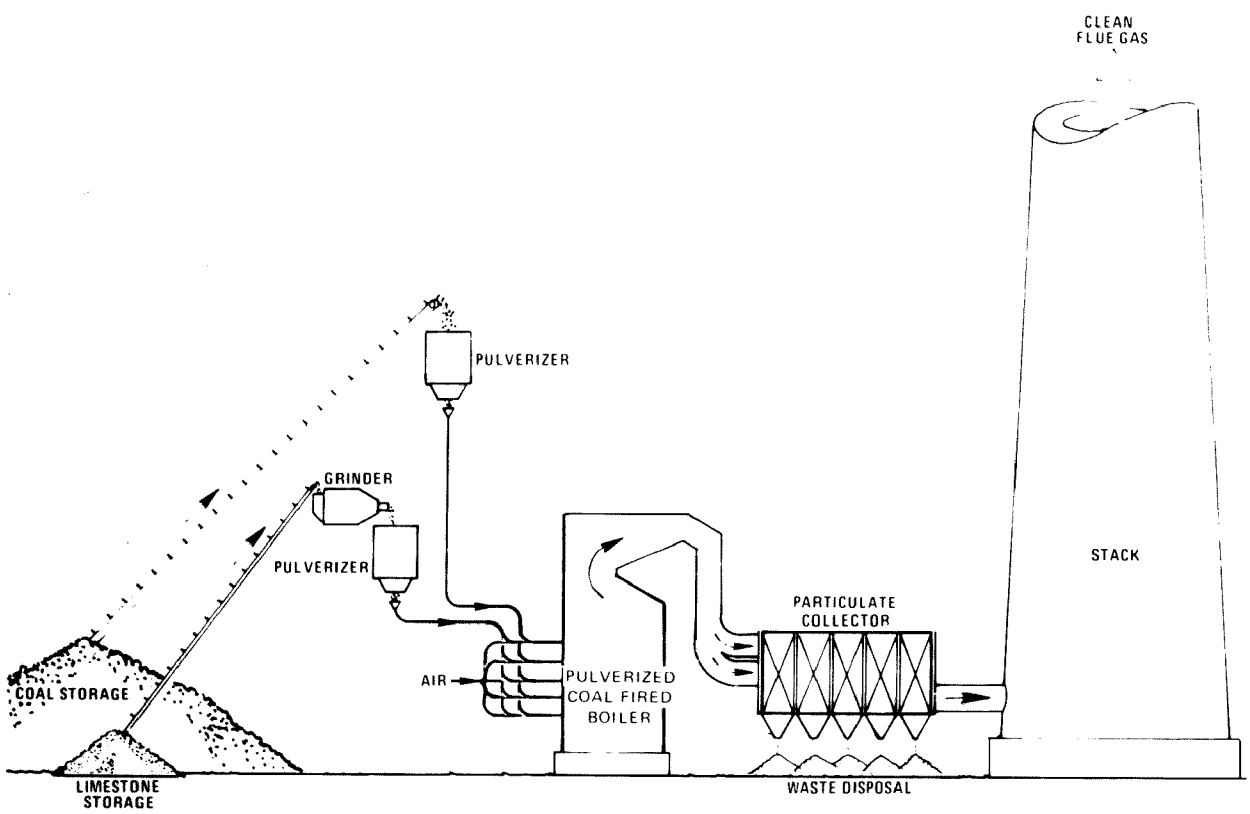
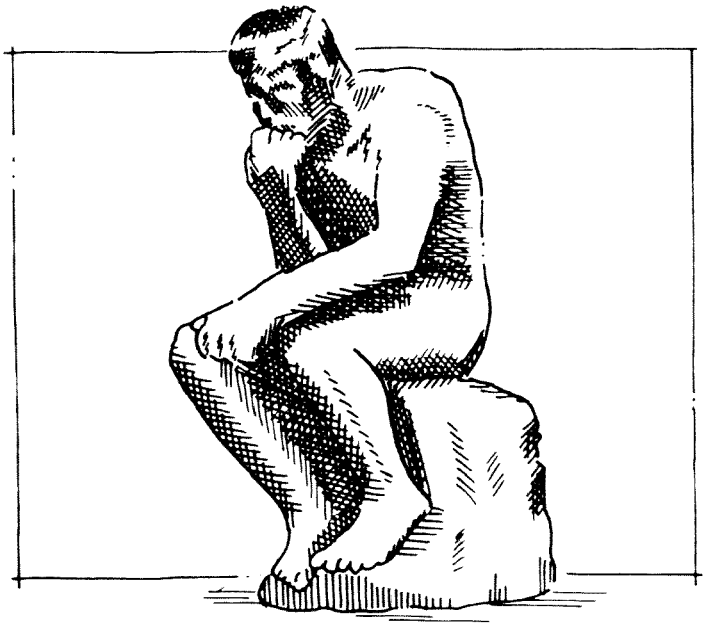


Figure H-2—Schematic of Integrated Limestone Injection Multistage Burner (LIMB) System.

I. *Assessments and Policy Analysis*

BACKGROUND



Work on assessments and policy analysis began when the National Acid Precipitation Assessment Program started in FY 1982. While the other technical and scientific components of the National Program date back to the rise in scientific interest in acid deposition, the assessment effort is directed toward specific goals and objectives that were defined in detail only when the Task Force began planning the National Program.

Assessments and policy analysis research must produce quantitative methods that organize and display scientific information in ways that allow comparison of alternative policies. A wealth of analytic methods is currently available: decision analysis, technology assessment, benefit-cost analysis, risk analysis, and so on, but seldom have they been comprehensively applied to regional air quality problems like acid deposition.

Two primary efforts to study the implications of air quality management decisions on a regional level have recently been published. One of these, the *Ohio River Basin Energy Study*, was sponsored by the EPA under the direction of the U.S. Senate. The other, *Costs and Benefits of Sulfur Oxide Control*, was prepared by the Organization for Economic Cooperation and Development (OECD) and treated the Western European situation.

Although both studies broke new ground in significantly advancing the methods available for performing such analysis, they also recognized substantial problems as yet unresolved in producing definitive results. Chief among these are ". . . the considerable uncertainties (partly due to lack of knowledge) that exist in assessment of the different components of the sulfur problem . . . the data base is by no means well established. And, the 'science' intended to improve this situation still requires a number of years to reach maturity."(OECD, p. 8)

More recently, the Congressional Office of Technology Assessment (OTA) has undertaken a comprehensive assessment of *The Regional Implications of Transported Air Pollutants*. The July 1982 Interim Draft of this report clearly recognizes the large uncertainties in current knowledge about the causes and consequences of acid deposition. The OTA report makes a useful contribution, attempting to summarize what is and is not known and to suggest approaches to decisionmaking under uncertainty. But the report also recognizes that the type of benefit-cost analysis that is an objective of the National Program is not currently feasible in the face of these uncertainties.

RESEARCH GOALS AND ACTIVITIES

The goal of the Assessments and Policy Analysis research program is to build upon earlier studies and draw from existing analysis methods to construct the means for comprehensive benefit-cost assessments. This capability will be unique in at least two ways. First, it will be designed to deal quantitatively with the range of uncertainty around various data and their use. This will allow continuous tracking of the research program while uncertainties decrease over time. In addition, developing methods to organize scientific results and apply them to policy questions early in the research program will ensure that the National Program can produce information that is relevant to making policy decisions.

The Task Force has defined the scope of the major assessment in FY 1985 to encompass four areas: (1) an assessment of current damages attributed to acid deposition; (2) an uncertainty analysis of key scientific areas, especially emissions and atmospheric processes; (3) the implications of uncertainty in these areas on policy alternatives; and (4) a description of the framework for the integrated assessment methodology, including the status of the development of its components, that will be the basis of the 1987 and 1989 integrated assessments.

The 1985 date for the current damage assessment is based on realistic projections of how soon critical scientific information will be available. Ongoing research programs within the National Program will delineate the existing uncertainties in the science and the impact these uncertainties have on policy alternatives.

More comprehensive assessments based on an integrated framework that combines emissions models, source/receptor relationships and dose-response functions will be possible in 1987 and 1989. At present, much of the basic information for these assessments is unavailable

but research projects within the National Program are vigorously pursuing this information.

Figure I-1 shows the information flow for the current damage assessment component of the FY 1985 assessment. The deposition information, inventories of sensitive resources, and dose-response information are produced by various technical components of the research program and combined to produce an estimate of the magnitude of physical damages. The assessments research program is working toward a detailed accounting of economic damages.

Figure I-2 illustrates the framework for improving information and models of atmospheric processes and similarly improving the way analyses of ecosystems and effects come together to compare costs and benefits of alternative policies. The key parts of this framework should be available in 1986 and integrated assessment results by 1987.

The Assessments and Policy Analysis program will prepare integrated assessments of the research results produced throughout the National Program. These assessments will involve interpreting the importance and quality of the research results, developing estimates of the benefits and associated costs of alternative control and mitigation measures, and formulating guidance for policymakers.

By applying benefit-cost assessments and special studies as needed, the National Program Assessment Group expects to answer the following key questions:

1. What is the physical, biological, and economic significance of current and expected adverse or beneficial effects from the deposition of acidic and acidifying materials in North America?
2. How are the composition and distribution of acid deposition in North America linked with emission patterns, and what significance do uncertainties have for control or mitigation strategies?
3. From what existing range of strategies for integrated emission control and receptor-oriented mitigation can policymakers choose?
4. Which strategies show the greatest promise of cost effectiveness or optimal cost-benefit, and what bounds of uncertainty should be placed around such conclusions?
5. What specific research would most effectively reduce the physical, biological, and economic uncertainties decisionmakers must face in choosing among strategy options for dealing with acidic deposition?

1985 CURRENT DAMAGE ASSESSMENT

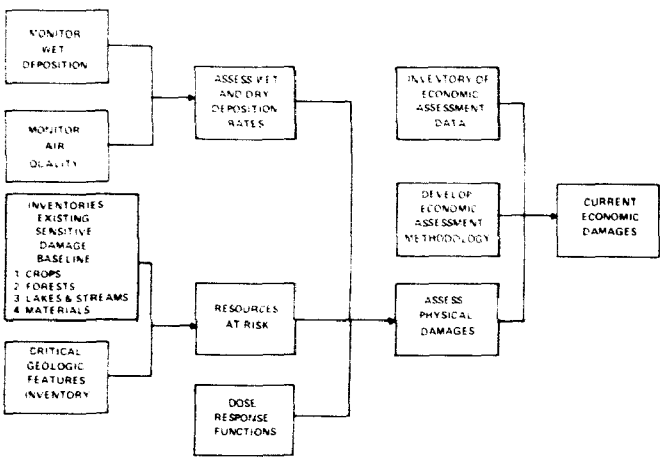


Figure I-1.—Inputs for current damage assessment.

PROGRAM ACCOMPLISHMENTS—FY 1982

- **Critical Assessment Document.** This document was requested by the Clean Air Science Advisory Committee. It differs from the future assessments planned for the National Program in that it is restricted to examining the current scientific literature in terms of its scientific quality and limitations. It does not attempt a comprehen-

INTEGRATED ASSESSMENT 1987 AND BEYOND

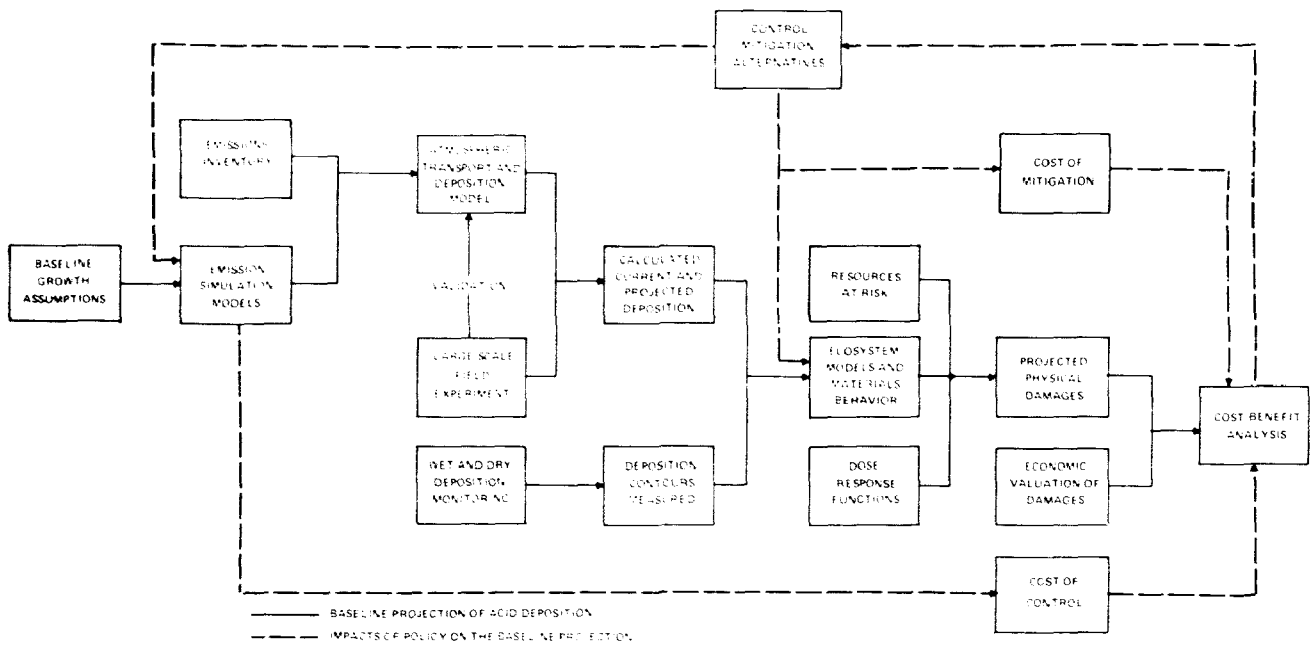


Figure I-2—Inputs for integrated assessments.

sive interpretation of the implications of this literature. A draft of more than 1,200 pages was prepared for public scientific review workshops in November 1982. This draft is now being revised by its 55 authors and editors and will be submitted in May 1983 for printing as a public review draft.

- **Integrated Control Strategies Modeling Project.** On the basis of this research, a detailed report on sulfur dioxide emissions from utilities for 1976 through 1980 has been prepared. The data base from which the report was produced is maintained on Federal Government computers. The U.S. utility industry emissions information contained in the U.S./Canada Memorandum of Intent Working Group 3B final report has been taken from this source. This project also analyzed projected emission rates to the year 2000. These reports provide definitive information for Government policymakers on the current and projected future emission rates of relevant pollutants.

- **Development and testing of methods for uncertainty estimation.** This project, begun in 1982, will provide (1) estimates of uncertainty in models and data elements, especially important where direct validation cannot be made; (2) estimates of the overall uncertainty arising from a combination of uncertainties about a series of processes; and (3) a basis for including uncertainty in the development of control or mitigation strategy. The first phase of this effort is underway; a report in 1983 will publish the results. This report will guide policymakers on the scientific limitations to predicting the effectiveness of proposed emission control programs.

- **Sulfur and nitrogen over the eastern North American airshed.** Substantial progress was made in developing a detailed atmospheric budget for all sources of sulfur and nitrogen compounds in eastern North America. This project will produce a final report during FY 1983. An effort to develop a comprehensive mass budget for sulfur and nitrogen fluxes, through integrated atmospheric, terrestrial, and aquatic ecosystems, will build upon this work. These emission inventories are also essential data for the atmospheric transport models used to quantify source/receptor relationships to study emission control options.

- **Aquatic effects of acid precipitation.** A model was developed to estimate the dose-response relationship (between surface water, pH, and number and species of fish) for aquatic ecosystems using probabilistic damage functions. Uncertainty in this analysis was handled by interviewing experts in the specific area of aquatic biology using a structured method to include their estimates of probability or uncertainty. The model will be used to estimate the economic damages expected from the acidification of surface waters.

- **Development of integrated assessment methodologies.** Policy analysis requires a consistent method for using the many relevant data bases, models, dose-response and economic relationships needed to predict the benefits and costs of any proposed emission control or mitigation. An Advanced Integrated Assessment Methodology is being developed to link these several analytical tools and relationships. Where appropriate, uncertainties will be handled within the methodology. The development of this methodology was begun in FY 1982 and will continue over the next several years as our scientific understanding of acid deposition matures.

FUTURE ACTIVITIES

FY 1983, with the exception of the projects already discussed, is the first year for the full program in Assessments and Policy Analysis research. Assessment research and development over the next 3 years will fall into three activity blocks, as outlined in Table 1. Emphasis will be placed on the first two blocks which are aimed at the long-term development of an integrated assessment methodology and at providing mid-course corrections to the overall national research program. Additionally, preparation of the 1985 assessment will require considerable effort over this time period.

The first block of activities focuses on developing a methodology for integrated assessments. These assessments combine available information on emissions sources, atmospheric transport, and deposition of acidic and acidifying materials; their transport after deposition through the relevant physical and biological receptor systems (both terrestrial and aquatic); and their effects upon these systems with estimates of how they change in response to changes in emissions or receptor-oriented mitigation measures. An integrated assessment also includes calculated costs of such control and mitigation measures. Performing an integrated assessment on a number of possible control and mitigation measures builds up a body of data for policy analysis.

Methods for conducting an integrated assessment of the acid deposition problem require extensive development. The first block is structured to break the development work into the several major components required to meet the first three key questions listed earlier. The last element within the block assembles these components into an Advanced Integrated Assessment Methodology (a well-defined protocol by which to conduct assessments).

The second block of activities provides detailed planning, oversight, coordination, and review to construct linkages for the Advanced Integrated Assessment Methodology. These include quality assurance for the assembled data bases and validation for the required process-simulation models. Additionally, this block of activities includes the actual assembly and integration of all the analysis tools required by the Advanced Methodology.

The third block of activities applies the Advanced Integrated Assessment Methodology to developing optimal strategies for emission control and mitigation. Additionally, other intermediate assessments and short-term policy analyses are included within this block, thus addressing the last two key questions.

A framework will be developed for integrating and coordinating research and deliverables between the Assessments and Policy Analysis Task Group and the other Task Groups, including a critical path analysis of the deliverables required from each, and will define the spatial and temporal resolution required for different data sets, relationships, or models. This analysis will identify key elements of the framework which, if delayed, would slow the overall assessment process. The integrating framework will generally resemble the information flow diagrams presented in Figures I-1 and I-2.

This research framework should not be misinterpreted to imply that the activities it outlines flow sequentially from the concept of a methodology to eventual application. In actual practice, this is a dynamic process with much iteration and many feedback loops. The Task Group must develop those feedbacks early in performing the work outlined in the second and third blocks in order to guide the development work in the first block.

Major reports expected in FY 1983 include the final Critical Assessment Document, a report on sulfur and nitrogen atmospheric budgets for eastern North America, a report on uncertainty analysis methodology evaluation, and a report on probabilistic dose-response damage functions for aquatic effects of acidification.

Table 1.—Tasks Group I Research Framework

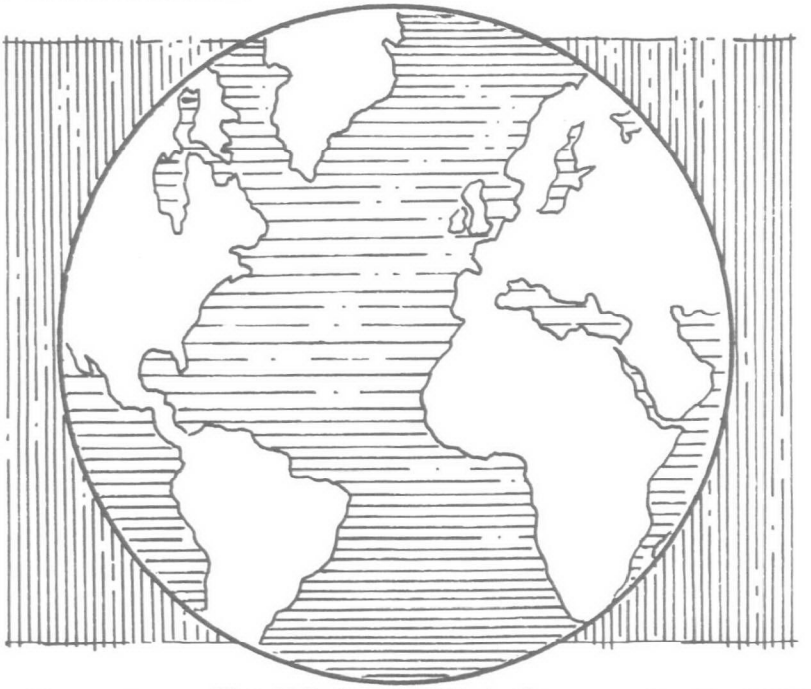
A. Integrated assessment methods development
1. Develop and apply economic benefits assessment methods;
2. Develop advanced effects assessment methodology;
3. Develop advanced methods for source/receptor assessment;
4. Develop integrated methods for constructing emission control and mitigation strategies; and
5. Develop advanced methods for integrated assessment.

B. Integrated assessment coordination and integration
1. Oversee assessment planning and coordination;
2. Coordinate data base development activities;
3. Coordinate model development and validation activities; and
4. Develop assessment model linkages.

C. Integrated assessment application and policy analysis
1. Perform and participate in special scientific/technical assessments;
2. Identify and analyze alternative emission control and mitigation measures;
3. Preliminary policy analysis/applied integrated assessment; and
4. Review status of assessments of major policy issues.

J. International Activities

BACKGROUND



The Acid Precipitation Act of 1980 requires the Interagency Task Force on Acid Precipitation to coordinate U.S. efforts with research performed in other countries. The Task Force established an International Activities Task Group, chaired by the Department of State, to encourage international cooperation on acid deposition research and monitoring.

Transboundary air pollution is of widespread international concern. The United States has actively participated in a number of international forums addressing long-range transport of air pollutants crossing international boundaries. In 1979, 34 governments, including the United States and Canada and the European Economic Community, signed the Long-Range Transboundary Air Pollution Convention under the auspices of the United Nations Economic Commission for Europe (UN/ECE).

In a separate, country-to-country agreement the United States and Canada signed a Memorandum of Intent (MOI) in 1980 to negotiate a transboundary air pollution agreement. To assist in the negotiations, joint technical Work Groups will compile all relevant data on the long-range transport of air pollution, with major emphasis on acid precipitation.

Although the MOI Work Groups and this Task Force are two different entities with distinct functions, many of the same scientists are involved in both efforts. The role of the bilateral Work Groups is to establish a mutually-agreed-upon technical basis for the U.S./Canadian negotiations on transboundary air pollution. The Task Force, on the other hand, is responsible for the long-term planning and implementation of the U.S. National Acid Precipitation Assessment Program.

RESEARCH GOALS AND ACTIVITIES

The International Activities Task Group's goals are to:

1. Encourage and facilitate productive interaction between the U.S. National Program and other nations conducting acid deposition research and monitoring activities.
2. Assist the Task Force and its Research Coordination Council in tracking international cooperative efforts.
3. Recommend to the Task Force ways to improve international cooperation and identify opportunities to work with other nations toward common research goals.
4. Inform the Task Force of activities, meetings, and developments in other nations.

The U.S.-Canada Work Groups under the 1980 Memorandum of Intent took precedence over the International Task Group's activities in 1982. The U.S.-Canada Work Groups have now essentially finished their primary tasks, and the documents are under review in both countries. Thus 1983 will see a more active role for the International Task Group, as it coordinates, tracks, and fosters cooperative research between the United States and other nations.

PROGRAM ACCOMPLISHMENTS—FY 1982

In April 1982, the Task Force and its Canadian counterpart, the Federal-Provincial Research and Monitoring Coordinating Committee met and agreed to pursue greater cooperation between the two nations' research efforts. The two research coordination groups declared that working-level contacts between scientists of both nations should be increased to develop proposals for specific cooperative research, and that such proposals would then be transmitted to the U.S. International Task Group and the Canadian RMCC Secretariat. The International Task Group and the RMCC Secretariat will serve as conduits for the two-way flow of proposals until a specific proposal is jointly approved by the Task Force and the Canadian RMCC. Following approval, cooperative research will be conducted directly by the appropriate bodies in the two countries.

FUTURE ACTIVITIES

The United States is considering several proposals for additional cooperative research with Canada. During early 1983, one or more should be ready to discuss with the Canadians as a possible joint project. It was agreed at

the Task Force/RMCC meeting in April 1982, to increase cooperative efforts on quality assurance, especially in precipitation monitoring, and these activities are being expanded.

After initially focusing on developing closer cooperation with Canada, the International Task Group will begin working to foster complementary research on acid deposition with other nations and international bodies. For example, the UN/ECE-sponsored Convention on Long-Range Transboundary Air Pollution will go into effect during 1983, and the International Task Group probably will be used to develop appropriate cooperative research projects and information exchange arrangements under that Convention.

NATIONAL ACID PRECIPITATION ASSESSMENT PROGRAM

ACTUAL EXPENDITURES
FY 1982
($ in thousands)

	EPA	DOA SE	DOA FS	NOAA	DOE	DOI PS	DOI GS	DOI FW	TVA	TOTAL
A. Natural Sources				600						$ 600
B. Man-made Sources	870				300					1170
C. Atmospheric Processes	3273			600	805	50			126	4854
D. Deposition Monitoring	797	253	127	700	497	75	585			3034
E. Aquatic Effects	1475		135		560	94	580	75	133	3052
F. Terrestrial Effects	1355	264	570		122	178	295		66	2850
G. Effects on Materials	250					178				428
H. Control Technologies	(10,400)*				(6200)*					(16,600)*
I. Assessments and Policy Analysis	1105				260					1365
Subtotals:		517	832			575	1460	75		
TOTALS:	$ 9125	1349		1900	2544		2110		325	$17,353

* Control Technologies figures not included in total. These funds for general development of SO_2 and NO_x control hardware are appropriated under other preexisting programs. The Control Technologies Task Group coordinates these efforts with the assessment and research activites of the National Program.

LIST OF TASK FORCE FY 1982 ACTIVITIES

Date	Activity	Purpose
11/25/81	RCC Meeting	Review draft material for inclusion in First Annual Report and receive guidance for final draft
12/18/81	RCC Meeting	Receive OMB FY 1983 budget passback and guidance
1/26/82	Research Coordination Council Meeting	Discuss and incorporate final changes to National Plan, review Task Group functions.
2/1/82	Task Force Meeting	Review and revise final National Acid Precipitation Assessment Plan.
2/23/82	RCC Meeting	Develop standard format for project descriptions in Operating Research Plan (ORP) and review draft strategic long-term framework, discuss purpose and format of Task Force's First Annual Review Meeting, discuss coordination with State and private sector efforts.
4/16/82	U.S./Canada Research Coordination Meeting	Meet with the Canadian Federal/Provincial Research and Monitoring Coordination Committee to seek ways to increase bilateral scientific cooperation and to discuss mechanisms for continued coordination of efforts.
4/20/82	RCC Meeting	Review and approve ORP outline, detailed planning of First Annual Review Meeting, announce mid-year FY 1982 budget report.
6/2/82	RCC Meeting	Review Task Groups' draft ORP's.
6/8/82	Task Force Meeting	Review OMB final comments on National Plan, discuss and revise long-term framework and ORP, approve agenda for First Annual Review Meeting, plan FY 1984 budget, examine proposed scope of work for inventory of Federal/State acid deposition projects.
7/13/82	RCC Meeting	Work on integration of Task Group and NLC inputs to ORP, review status of Critical Assessment Document, agree to distribution list for National Plan.
7/14/82	RCC Meeting	Define interrelationships of Task Groups' inputs and outputs, identify specific crosscutting issues to discuss at First Annual Review Meeting.
8/24/82	RCC Meeting	Receive preliminary FY 1984 budget guidance from OMB, review first complete draft of ORP, finalize planning for First Annual Review Meeting, discuss inventory of Federal/State research projects, report on data management needs study.
9/8/82	Task Force Meeting	Task Group leaders present initial FY 1984 budget proposals for review and guidance.
9/8-10/82	First Annual Review Meeting	Assess research progress, evaluate first draft of ORP, discuss proposed research directions and priorities, examine interrelationships among Task Groups.
9/21/82	RCC Meeting	Task Group leaders discuss status of FY 1984 budget, review FY 1984 budget submission to OMB.
9/21/82	Task Force Meeting	Review and approve final FY 1984 budget recommendations to OMB.

GLOSSARY

ACID	Acidification Chemistry Information Database
ASTRAP	Advanced Statistical Trajectory Regional Air Pollution Model
AUSM	Advanced Utility Simulation Model
CANSAP	Canadian Network for Sampling Precipitation
CAPTEX	Cross Appalachian Tracer Experiment
CEQ	Council on Environmental Quality
DOA	Department of Agriculture
DOC	Department of Commerce
DOE	Department of Energy
DOI	Department of Interior
DOS	Department of State
EPA	Environmental Protection Agency
FGD	Flue gas desulfurization
GTN	Global Trends Network
HHS	Health and Human Services
ILWAS	Integrated Lake-Watershed Acidification Study
LIMB	Limestone injection multistage burners
MAP3S	Multi-State Atmospheric Power Production Pollution Study
MOI	Memorandum of Intent
NADP	National Atmospheric Deposition Program
NAPAP	National Acid Precipitation Assessment Program
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NLC	National Laboratory Consortium
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NTN	National Trends Network
OECD	Organization for Economic Cooperation and Development
ORP	Operating Research Plan
OSCAR	Oxidation and Scavenging Characteristics of April Rains
OTA	Office of Technology Assessment (Congressional)
RCC	Research Coordination Council
RMCC	Canadian Federal/Provincial Research and Monitoring Coordinating Committee
TVA	Tennessee Valley Authority
UN/ECE	United Nations Economic Commission for Europe

Figure E-1—Total alkalinity of surface waters.

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U.S. Environmental Protection Agency
Library, Room 2404 PM-211-A
401 M Street, S.W.
Washington, DC 20460

EPA-600/D-82-333
Map and text

TOTAL ALKALINITY OF SURFACE WATERS -- A NATIONAL MAP

by

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Abstract. This map illustrates the regional patterns of mean annual alkalinity of surface water in the conterminous United States. As such, it affords a qualitative graphic overview to the sensitivity of surface waters to acidification. The map is based on data from approximately 2500 streams and lakes and apparent spatial correlations between these data and macro-watershed characteristics, especially land-use.

Key Words: surface water alkalinity, sensitivity to acidification, water quality.

Introduction

The accompanying map represents the first step in a comprehensive project to identify general patterns of surface water sensitivity to acidification. The map results from the growing demand for accurate identification of acid-sensitive aquatic areas of the conterminous United States and is part of a continuing program to (1) inventory and synthesize, state-by-state, the vast quantities of relevant water quality data; (2) conduct general field surveys to fill data gaps; (3) prepare detailed regional maps and update national maps; and finally (4) conduct extensive field surveys (including biological parameters) of critically sensitive areas.

The map was developed from mean annual total alkalinity values of approximately 2,500 streams and lakes and from the apparent relationships of these data with land use and other macro-watershed characteristics such as soil type and geology. Total alkalinity is used as an index of sensitivity because it expresses the acid neutralizing capacity of water bodies and thus their relative sensitivity or tolerance to acid inputs. The ranges of our six map units were chosen to illustrate patterns of relative sensitivity on a national scale. Although there is general agreement that total alkalinity expresses acid sensitivity of surface water, there is lack of agreement on exactly where the breaking points exist between sensitive, moderately sens-

itive, and insensitive waters. Hendrey et al. (1980) considered waters not sensitive to acidification when alkalinities exceeded 500 μeq/l and of high sensitivity when alkalinities were less than 200 μeq/l. The Ontario Ministry of the Environment (1981) proposed that alkalinities between 0 and 40 μeq/l indicate extreme sensitivity and those between 40 and 200 μeq/l moderate sensitivity. Zimmerman and Harvey (1978-1979) have suggested a triad of parameters to define acid sensitivity in surface waters: pH < 6.3-6.7, conductivity < 30-40 μmho/cm, and alkalinity < 300 μeq/l.

General patterns of average sensitivities of surface waters to acidification are depicted by this map, not worst-case or best-case conditions. Our intent is to show what one might expect to find in most surface waters most of the time. Subsequent larger-scale maps of the more sensitive areas will address worst-case conditions, ranges of conditions, and significant regional and (to the extent possible) local relationships between alkalinity and geology; soils; and climatic, physiographic, and human use factors. Confidence limits for areas of greatest sensitivity will also be provided. These maps will be compiled as detailed information is gathered and analyzed.

For the present, however, there is an urgent need to understand the relative sensitivity of surface waters in different parts of the country in order to (1) provide a national perspective on the extent of the problem, (2) provide logic and/or rationale for selecting geographic areas for more detailed studies, and (3) allow more accurate regional economic assessments of acid precipitation impacts on aquatic resources.

Map Development

The data used to compile this map were selected and mapped according to several categories. Stream sites were listed separately from lakes, natural lakes were distinguished from impoundments, and both stream sites and lakes were separated into two groups -- those associated with watersheds of less than 260 square kilometers (100 square miles) and those associated with watershed areas of between 260 and 2600 square kilometers (100 and 1,000 square miles). Except in areas that were very similar in land use, physiography, and soils (e.g., the Great Plains), data associated with watersheds larger than 2600 square kilometers (1,000 square miles) were excluded. As might be expected, we found that the patterns of alkalinity values in streams were quite similar to those of lakes in the same area. As the data were being gathered and plotted, and geographical patterns of high and low alkalinities developed, collection efforts tended to concentrate on these apparent areas of greatest sensitivity.

Most of the data were obtained from the U.S. Geological Survey via STORET, an EPA computer-based water quality data storage and retrieval system. The remainder came from varied sources, principally the National Eutrophication Survey (U.S. Environmental Protection Agency, 1974, 1978a, 1978b, 1978c), the Pennsylvania Cooperative Fishery Research Unit (Arnold, 1981), and the Tennessee Valley Authority (Meinert and Miller, 1981). Although various analytical procedures were used by the various agencies [U.S. Geological Survey and the Tennessee Valley Authority, single endpoint titration to pH 4.5; National Eutrophication Survey, colorometric end point (methyl orange);

and Pennsylvania Cooperative Fishery Research Unit, double endpoint titration], the alkalinity values obtained are reasonably equivalent and, we feel, comparable for our scale of spatial analysis.

Each data point was scrutinized to insure representativeness. To accomplish this, it was necessary to keep the watershed size consistent with the relative homogeneity of major watershed features such as physiography and land use. In areas of relative heterogeneity, most of the data were associated with small watersheds (less than 260 square kilometers). Representativeness of the data was imperative for detection of spatial patterns of alkalinity, possible correlations with patterns of other characteristics, and ultimately, extrapolation of the data. To include data from sites having large watersheds of widely differing characteristics (e.g., the Willamette River at Salem, Oregon, the watershed of which includes vast contrasts in soils, geology, climate, and land use), or data downstream from major industrial or municipal waste discharges, would mask these spatial patterns.

The data were plotted on a 1:3,168,000 scale base map of the United States. Each site was represented by a small circle color-coded to approximate value. The exact value of the site was noted beside the circle, together with a designation for lake or stream. The spatial patterns of alkalinity were then compared with maps showing characteristics that are believed to be driving or integrating factors affecting alkalinity; e.g., bedrock geology and soils, land use and vegetation. Driving factors, as used in this paper, refer to those that directly affect alkalinity (e.g., geology and soils). Integrating factors, on the other hand, are considered those that reflect combinations of driving factors; for example, land use and potential natural vegetation reflect regional combinations (or an integration) of driving factors such as soils, land surface form, climate, and geology. We believe that the importance of each of these driving factors, and the hierarchy of importance relative to the combinations of factors varies from one region to another. Clarifying these regionalities is a major goal of our overall synoptic analyses; they will be addressed in the text accompanying the subsequent larger scale maps.

It became apparent early in this study that land use generally correlated with alkalinity throughout much of the United States, and particularly in the West. In general, surface water alkalinity was low in areas of ungrazed forest and high where cropland predominated. In-between types of land use generally reflected alkalinity values that corresponded to the degree of agricultural use. However, the apparent relationship between land use and alkalinity varied considerably; in some areas, particularly in the Southeast, the relationship was poorly defined or nonexistent.

Except for some localized situations, we were not able to relate geographical patterns of surface water alkalinity with geological sensitivity as depicted by bedrock or soil types. Recent studies by Kaplan et al. (1981), McFee (1980), and Hendrey et al. (1980), based on county-by-county average values, have demonstrated such correlations. Since alkalinity, in large part, is a function of the nature of the rock and soil makeup of a drainage basin (Cole, 1975), it did not appear unreasonable to expect similar results in this mapping study. The lack of correlation is probably in large part a function of study scale. Had our focus not been on the nation, but rather on a small

region or state, possible surface water alkalinity/geology and/or soil type relationships may have been more perceptible. However, this lack of correlation may be due to one or more of several other factors. First, inconsistencies and inaccuracies in rock and soil type maps are common between, and even within, regions and between states. Second, the alkalinity in a lake or stream reflects the characteristics of both rocks and soils in the watershed. Even in small watersheds, large spatial variations in rock and soil types and depths can be found. Another confounding factor is that surface and subsurface watersheds frequently are difficult or impossible to define, particularly in areas of karst or continential glacial topography (Hughes and Omernik, 1981). Apparent surface watersheds of streams and lakes in such areas often differ greatly in area from the even more difficult to define ground watersheds.

Because of the general correlation of land use with alkalinity, the 1:3,168,000 scale base map with alkalinity values was overlayed onto a color enlargement of Anderson's Major Land Uses map (U.S. Geological Survey, 1970). When viewed on a light table, the general land use patterns and spatial relationships of surface water alkalinity to land use could be visualized. By studying these relationships and patterns, along with apparent local relationships with geologic and soil characteristics, interpretations were made and map units drawn to reflect these regional relationships.

Use of the Map

The development and usefulness of this map can best be illustrated by comparison with a more familiar graphic -- an isometric map of mean annual precipitation.[1] One should not use a precipitation map to predict the precipitation that will occur during a particular year at a given location. Rather, the map illustrates patterns of long term conditions. Few parts of the United States typically experience a truly "normal year" climatically. Generally, precipitation totals are somewhat higher or somewhat lower than the mean; occasionally, total deviation from the mean is extreme. Admittedly, precipitation maps may provide a more accurate indicator of their subject than the alkalinity map because of their more extensive data base (particularly from the temporal standpoint). However, precipitation maps are compiled using data from different geographical locations together with knowledge of apparent associations of these data with physiographic characteristics, water bodies, ocean currents, latitude, and other environmental factors. For example, precipitation patterns in mountainous areas, where data are scarce or lacking, are drawn to reflect the expected orographic effects of elevation and exposure to weather systems. Much the same kind of qualitative analysis was used to compile the alkalinity map. It is based on values from more than 2,500 stream sites and lakes throughout the United States, as well as knowledge of the apparent associations between the alkalinity data and other spatial phenomena, particularly land use.

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[1] McDowell and Omernik (1979) used this comparison to clarify the utility of a set of national maps of nutrient concentrations in streams from nonpoint sources (Omernik, 1977). The total alkalinity map was compiled in a similar fashion as the nutrient maps but with more than two and one-half times as many data points.

As with a precipitation map, caution should be exercised when using this alkalinity map. In many parts of the nation, nearly all of the surface waters have mean annual alkalinity values within the range illustrated in the map. In other areas -- particularly where there are complex variations in geology and soil type, and other factors affecting acid sensitivity -- there are wide spatial and temporal variances in alkalinity. For these types of areas, at this scale of mapping, we were only able to estimate the mean annual alkalinity of most surface waters; many may reflect higher or lower values.

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