EPA

Office of Acid Deposition,
Environmental Monitoring, and Quality Assurance

ACID DEPOSITION RESEARCH PROGRAM

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Atmospheric Sciences

Policy Questions

- What are emissions in designated base years for policy development and implementation purposes?
- How much does it cost to control these emissions?
- What are the current patterns of acid deposition?
- What is the quantitative relationship between the distribution, rate, and form of emission and the distribution, rate, and form of deposition?

The objective of the Atmospheric Sciences Research Program is to develop a scientific understanding of the cause/effect relationship between sources of emissions and acid deposition in sensitive receptor areas. Understanding the distribution, rate, and form of emissions is a critical first step to developing an understanding of cause/effect relationships between emission sources and receptors of acid deposition.

What are emissions in designated base years for policy development and implementation purposes?

The first policy-related question is: What are emissions in designated base years for policy development and implementation purposes?

Emissions that contribute to acid deposition include a number of trace gases, of which oxides of sulfur and nitrogen are the most important. Sulfur dioxide (SO_2), nitrogen oxide and nitrogen dioxide (considered together as NO_x) oxidize in the atmosphere after they are emitted to form sulfuric acid and nitric acid, respectively, or acidic salts. Volatile organic compounds (VOCs) can enhance the production of oxidants as can NO_x. These oxidants hasten the atmospheric transformation of SO_2 and NO_x into their respective acids. Ammonia and alkaline dust emissions are also of interest for determining the acidity of atmospheric deposition. The fraction of emissions for each of these chemical species for which man-made sources are responsible varies from very high for SO_2 (more than 95% in the eastern United States) to relatively low (about half) for ammonia and alkaline dust.

About two-thirds of the SO_2 in the eastern United States is emitted by coal-fired electric utility plants. Most of the remainder of SO_2 emissions in the East come from industrial combustion of fossil fuels in boilers and process heaters. The SO_2 emissions in the West come principally from primary metal smelters, predominantly copper. The highest concentration of SO_2 emissions is in the Ohio River basin which has a high concentration of high-sulfur coal-fired power plants.

Principal sources of NO_x are highway vehicles, power plants and industrial combustion. Although these sources are more concentrated in the Midwest and Northeast, they are also concentrated in large metropolitan areas throughout the United States and Canada.

Historically, emissions of SO_2 have risen irregularly since the beginning of the century, reaching a maximum in the early 1970s. They have fallen by about one-fourth since then. The NO_x emissions have risen more steadily and sharply, beginning in the early 1940s, and have only declined by about 5% since reaching a maximum in the late 1970s. It has been estimated that emissions of VOCs increased by about 50% between 1940 and 1970, and have gradually declined since then to about the same levels found in the mid-1950s.

It is important to note that there are regional differences in emissions and that different emission trends exist in each region. For example: emissions have decreased in the Northeast primarily as a result of the implementation of emission controls; growth in industry and population in the Southeast during the 1970s has resulted in increases in emissions in that region; and labor strikes, emission controls, and changes in Western smelter operations have resulted in emissions fluctuations in the West.

In 1986, a final 1980 emissions data base and inventory and a preliminary 1985 point source emission file is expected to be completed. A preliminary 1985 emissions inventory is expected to be completed in 1987. In 1988, a final 1985 emissions data base and a final 1985 emissions inventory are expected to be completed.

How much does it cost to control these emissions?

Emissions change as changes occur in demand for power and products, sources of fuels utilized, proposed emission control strategies and emission control technology. This leads to the next policy-related question: How much does it cost to control these emissions?

Emission projection and cost-of-control models are currently under development. These models are capable of projecting emission trends over the next several decades for alternative sets of future conditions and control requirements. The models are also capable of indicating the cost of additional control requirements.

In 1986, an initial version of the Advanced Utility Simulation Model (AUSM) is expected to be delivered. Testing of initial versions of AUSM, the Volatile Organic Compounds Model (VOCM), the PROcess Modeling Projection Technique (PROMPT), and the Industrial Combustion Emissions (ICE) emission models are expected to be completed in 1987. In 1988, testing and assessment of refined emissions models is expected to be completed.

What are the current patterns of acid deposition?

The previous policy questions addressed the distribution, rate, and form of emissions. It is also necessary to discern the distribution, rate, and form of acid deposition. The wet and dry components of deposition and trends of deposition need to be determined. This leads to the next policy-related question: What are the current patterns of acid deposition?

Estimates from existing linear models suggest that 25% of total sulfur emissions in North America comes down as wet deposition; that is, in precipitation as rain or snow. A roughly equivalent amount (30%) comes down as dry deposition; that is, deposition in the form of particulates that fall out of the atmosphere or gasses that are adsorb-

ed by surfaces. The remainder (45%) blows out over the Atlantic to be deposited elsewhere. These estimates do not address either the non-linearities or the regional differences that occur. What is important to note from these estimates is that dry deposition can be of the same importance as wet. Therefore, it is important to measure both wet and dry deposition.

Wet deposition alone is now being monitored at 150 stations in the National Trends Network (NTN) which reached full-scale operation in 1982. The samples are collected on a weekly basis. The precipitation samples are sent for analysis to a central laboratory located at the Illinois State Water Survey Laboratory in Champaign-Urbana, Illinois where they are analyzed for: hydrogen ion (H^+), ammonium ion (NH_4^+), calcium ion (Ca^{2+}), magnesium ion (Mg^{2+}), sodium ion (Na^+), potassium ion (K^+), sulfate ion (SO_4^{2-}), nitrate ion (NO_3^-), chloride ion (Cl^-), pH and conductivity.

Based upon very limited measurements as reported in the National Academy of Sciences (NAS) Report, "Acid Deposition Long-Term Trends":

- Sulfate and nitrate in the eastern half of the United States and southeastern Canada are in general a factor of five greater than those in remote areas of the earth. This suggests that sulfate and nitrate levels in this area have increased by this amount since sometime before the 1950s.
- Precipitation is currently more acidic in parts of the eastern United States than it was in the 1950s, or mid-1960s.
- Precipitation sulfate concentrations and possibly acidity have increased in the southeastern United States since the mid-1950s.
- For Hubbard Brook in New England, since 1964: hydrogen ion shows no trend; sulfate has decreased 2% per year; sodium, chloride, calcium, magnesium, and potassium have shown strong decreases with time; and nitrate appears to have increased until about 1970-1971 and subsequently leveled off.

Dry deposition requires much more complex monitors than wet deposition. Because methods of direct measurement are very complicated, dry deposition generally must be inferred or calculated from measurements of ambient concentrations and other variables (i.e., meteorological conditions, surface type and condition, time of day, etc.).

Installation of the first 30 dry deposition sites is to be initiated late in 1986. The first 30 monitors will be sited in the Northeast where sensitive receptor areas are located and significant acid deposition concentrations are expected. These sites will also provide data necessary for model evaluation. An additional 15 dry deposition monitoring sites are to be installed in 1987, with five sites in the Southeast and ten in the western United States. The dry deposition measurements are planned to include: SO_2, NO_2, O_3, HNO_3, particulate SO_4^{2-}, and particulate NO_3^-. By the end of 1988, one year of data from the first 30 dry deposition sites and five years of data from 150 NTN wet deposition sites are expected to be available.

What is the quantitative relationship between the distribution, rate, and form of emission and the distribution, rate, and form of deposition?

The programs and policy-related questions associated with the distribution, rate, and form of emission, and the distribution, rate and form of acid deposition have been previously addressed. It is also necessary to understand the atmospheric processes that provide the link between sources of emissions and the deposition of acidic substances in sensitive receptor areas. Understanding of the atmospheric chemical and physical processes is required to be able to quantitatively describe source/receptor relationships. This leads to the next policy question: What is the quantitative relationship between the distribution, rate, and form of emission and the distribution, rate, and form of deposition?

The greatest density of SO_2 emission is along the Ohio River valley with 50% of the total United States emissions coming from eight states (Ohio, Indiana, Pennsylvania, Illinois, Missouri, Kentucky, West Virginia, and Tennessee). The NAS has concluded that, "...in eastern North America a causal relationship exists between anthropogenic sources of emissions of SO_2 and the presence of sulfate aerosol, reduced visibility and wet deposition of sulfate.

The wet deposition of SO_4^{2-} conforms with the distribution of SO_2 emissions and climatic air mass transport. This correspondence provides a qualitative understanding that the high density of SO_2 emissions in the Ohio River valley is the source of sulfate measured in precipitation samples in the northeastern United States.

Although we have a qualitative understanding of this source/receptor link, we do not have an adequate quantitative understanding. We do not know that reducing emissions will result in a proportionate reduction in acid deposition. Thus, we have a need for numerical source/receptor models as assessment tools to address large potential changes in emissions, and numerous different proposed emissions control scenarios. Regional models are needed to provide national/state levels of resolution. Mesoscale models are needed to address local versus distant source/receptor relationships (e.g., assessment of material damage in eastern cities and other urban areas, conducting Prevention of Significant Deterioration (PSD) permitting analyses for Western sources or other assessments in areas of complex terrain, and evaluating aquatic and terrestrial ecological effects and determining the relative importance of local versus distant sources of emissions).

Existing models (such as the models that were used to estimate the relative amounts of wet and dry deposition resulting from North American SO_2 emissions) do not have the capacity to address non-linear processes or represent the state-of-the-science understanding of the atmospheric chemistry and physics cause/effect source/receptor relationships. In order to handle proposed control strategies involving large changes in emissions, it is extremely important to have a model that works for the right reasons, i.e., properly simulates the atmospheric chemistry and physics. Thus, such models need to be able to simulate non-linear atmospheric processes including: multi-layers transport, chemical

transformation, dry deposition, precipitation scavenging processes, and the interactions between these component processes.

The conversion of SO_2 to SO_4^{2-} is limited by available oxidants. If oxidants are limited, not all SO_2 can be converted to SO_4^{2-}; therefore, a reduction in SO_2 would not result in a proportionate reduction in SO_4^{2-}. The question becomes: When are oxidants limited with respect to SO_2 emissions?

Linearity is expected over continental and annual time scales; however, non-linearity is expected over small spatial and temporal scales. A key question is: What are the smallest spatial and temporal scales over which processes are linear? In order to address these needs, regional and mesoscale acid deposition models are currently being developed with frameworks to accommodate non-linear processes and state-of-the-science understanding of atmospheric processes. These models are expected to be tested and evaluated by a planned model evaluation field program.

In 1987, a regional model for calculating sulfur deposition is expected to be completed. A regional model for deposition of all acid substances and one year of surface monitoring for evaluation of atmospheric models are expected to be available by the end of 1988.

Outputs

- 1986
  - Final 1980 emissions data base and inventory completed
  - Preliminary 1985 point source emission file completed
  - Initial version of Advanced Utility Simulation Model delivered
- 1987
  - Preliminary 1985 emissions inventory completed
  - Testing of initial versions of emission models completed
  - Regional model for sulfur deposition delivered
- 1988
  - Final 1985 emissions data base completed
  - Final 1985 emissions inventory completed
  - Refined versions of emission models completed
  - Testing and model assessment of refined emission models completed
  - One year of data from first 30 dry deposition sites delivered
  - Five years of data from 150 National Trends Network wet deposition sites delivered
  - Advanced version of regional model for acidic deposition delivered
  - Completion of first year of surface monitoring for evaluation of atmospheric models

Aquatic Effects

Policy Questions

- How extensive is the current damage?
- What are the anticipated rate and extent of damage in the future?
- What rates of deposition will provide various levels of protection for sensitive surface waters?

Suspected acidification in the lakes in the northeastern regions of the United States was crucial in initiating EPA's focus on acidic deposition. The recent NAS report on long-term trends found considerable evidence to show that acidic deposition has been influential in changing the nature of lakes in the Northeast. A major question, left unanswered in that report and in a 1984 report on lake acidification, is whether many more lakes and streams will become acidic in the next few years, or whether any damage now visible is all we will see for a few decades, because short-term ecological resistance to acidic inputs has been overcome, leaving longer-term (30 to 100 years) resistances in place.

Acid deposition raises the hydrogen ion concentration, which by definition results in lower pH. As pH decreases, effects on aquatic ecosystems increase, so that below pH five, sport fish populations do not generally exist. The pH of rain in the Northeast is now in the low fours, but the pH of lake water is usually higher than rainfall pH; for example, the median pH of lakes in the Adirondack Mountains is 6.8.

Alkalinity, or more properly, acid neutralizing capacity (ANC), is related to pH; it is the ability of the system to buffer acidic inputs. An ANC less than zero means the water has no ability to neutralize acids. Lakes with ANC less than zero and pH less than five are classified as acidic.

Early in our research experience, the United States/Canada Memorandum of Intent concluded that long-term and short-term acidification of some low alkalinity waters had occurred in Canada and the United States in areas receiving acidic deposition. Although the relative importance of various acidification mechanisms has not been demonstrated, we now know that many factors in a lake's surrounding watershed contribute to its overall sensitivity.

How extensive is the current damage?

To measure the current extent of acidic surface waters, the National Surface Water Survey was initiated in 1983. Using a map of alkalinities of surface waters compiled from existing data as a general guide to areas of interest, a statistically sound plan was designed to yield a regionally representative picture of the current status of aquatic resources. The survey is divided into smaller projects: the Eastern Lake Survey, the Stream Survey, and the Western Lake Survey.

The Eastern Lake Survey, Phase I, sampled the Northeast, Southeast and Upper Midwest regions. Lakes with a surface area greater than four hectares were identified on topographical maps and statistically sampled to yield results that could be regionalized. A single sample taken near fall turnover serves as an index to the chemical status of each lake.

The results of the Eastern Lake Survey indicate that the largest estimated number of lakes with pH less than five are in the Adirondacks, Michigan's Upper Peninsula, and Florida. Other potentially sensitive areas contain few lakes with pH less than five. The largest estimated number of lakes with ANC less than zero are in the same regions. The overall estimated percentages of lakes in these regions with pH less than five are: Adirondacks, 10%; Michigan's Upper Peninsula, 9%; and Florida, 12%. These percentages are smaller when expressed on a lake area basis.

To give the current status of surface waters a useful perspective, EPA funded the NAS to assess historical acidity trends over time. They studied historical data on surface water chemistry, sediments, and fish populations. Trends analysis by NAS led to the conclusion that surface waters in the Northeast, and some in the upper Midwest, respond quickly to changes in acidic deposition, with statistically significant declines in surface water ANC and pH for some lakes over the past 50 years. Paleolimnologic study also showed increased surface water acidification between 1955 and 1970 for the Northeast. Analysis of fish populations showed that acidification has caused the decline of a number of fish communities in the Adirondacks.

Other studies done to address the extent question include: (1) the First Interim Assessment (a comprehensive assessment of the latest research), (2) a survey of precipitation-affected drinking water systems, and (3) the effect of storm events and snowmelt or "episodes" on aquatic chemistry.

Liming is being studied to determine whether it is an effective mitigation strategy for acidic lakes. Future study will help determine the long-term effectiveness and risks, as well as cost/benefit relationships. The Fish and Wildlife Service has the lead in this area of research.

What are the anticipated rate and extent of damage in the future?

At first, Scandinavians, North Americans, and others thought that acidification of sensitive waters would be detectable within one or two decades where rainfall pH was 4.6 or below. In 1981, the NAS concluded that of the options available, only control of emissions of sulfur and nitrogen oxides could significantly reduce the rate of degradation of aquatic ecosystems. They concluded that in some areas where rainfall pH approximates 4.1, reductions of 50% in deposited hydrogen ions might be necessary.

Now the NAS recognizes a new hypothesis and has identified two major mechanisms that control the rate of surface water acidification and lead to different watershed response rates even within the same region. These processes, which occur in the terrestrial portion of the watershed, are: (1) the ability to supply bases to neutralize acids, and (2) the ability of the watershed to retain sulfate,

which thereby limits the transport of hydrogen ions and potentially toxic aluminum to surface waters. When both processes are high, a capacity-protected system results. As these factors decrease, systems increasingly respond to acidic deposition. If at current deposition loadings, a system responds within a 100-year period, it is called a delayed-response system. When both processes are very low, a direct-response system results that is either acidic now or will become acidic within ten years.

To learn more about how surface waters respond to chronic acidic deposition, the Direct/Delayed Response Project (DDRP) was initiated in 1984. This project sampled a range of lake/watershed systems that should exhibit the above response time differences. One hundred and forty-five watersheds in the Northeast and 35 watersheds in the Southeast have been sampled, permitting regionalization of results for making population estimates.

Research in the DDRP includes collecting data to model watershed processes that affect water chemistry. These processes have been modeled to create a predictive tool for answering questions about future acidification and the acidification of other areas. The tools from this program will also enable the program to address the third policy area, target loadings for deposition.

What rates of deposition will provide various levels of protection for sensitive surface waters?

Deposition monitoring indicates loads are currently increasing in the Southeast and West and decreasing in the Northeast. The effect of changing rates of deposition is being studied by the Watershed Manipulation Project (WMP). The WMP will combine catchment, large plot, and laboratory experimentation to corroborate DDRP models and assumptions, and determine the relative importance of acidification processes. The data from the WMP will be used in combination with the models from the DDRP to address questions about target loadings for several regions.

The aquatic effects research program has maintained a trends-detection project since 1983 to assess trends in surface water acidification. Data from the long-term monitoring project will validate the research of the other projects.

By 1990, major strides will have been taken toward fully addressing the three main policy questions that provide the motivation for the aquatic effects research program.

Outputs

- 1986
  - First Interim Assessment
  - Eastern and Western Lake Survey reports (Phase I)
  - Results from Pilot Stream Survey
- 1987
  - Results from Stream Survey
  - Results from Cistern Survey
  - Direct/Delayed report for Northeast
- 1988
  - Direct/Delayed report on Southern Blue Ridge Province
  - Report on manipulation field trials
- 1989
  - Results from Episodic Response Project
  - Damage estimates for episodic events
  - Report on Watershed Manipulation Project
  - Report on watershed sulfur budgets and deposition monitoring comparisons
  - Long-term Monitoring Trends Assessment
  - Direct/Delayed report on Middle Atlantic region (pending)
- 1991
  - Direct/Delayed report on West (pending)
- 1992
  - Integration report for all Direct/Delayed Response Project results with Watershed Manipulation results

Materials Effects

Policy Questions

- What is the geographical extent of materials-at-risk?
- What are the quantitative relationships between the various forms of acidic deposition and the resulting damage rates to materials?
- What are the benefits of reducing the rate of acidic damage to materials?

Precursors to acidic deposition, especially SO_x, NO_x, and oxidants such as ozone, have long been known to be damaging to some classes of materials, with statuary and cathedrals being most noticeable. The relationship between materials degradation and acidic deposition itself is much less clear, and the question of how extensive the cultural, commercial, and personal resources that might be at risk specifically to acidic deposition is largely unknown. The policy questions that need to be addressed follow logically.

What is the geographical extent of materials-at-risk?

The research for the first policy question is directed toward developing inventories of residential and non-residential materials. These two classes were chosen because materials at risk characteristically follow these two divisions, e.g, residences are often made of wood, while high rises are more often glass or concrete. The residential inventory is developed from a statistical analysis of data collected from ground surveys, while the non-residential inventory can be compiled from aerial photography, analysis of existing records, and other data. Some data have been collected for the residential inventory of four cities in the Northeast. This data will be independently validated, and mathematical models will be developed to extrapolate the data to other cities. Work on the non-residential inventory is just beginning. By 1990, the two inventories will be completed and merged.

What are the quantitative relationships between the various forms of acidic deposition and the resulting damage rates to materials?

In addition to identifying the materials at risk, we must also know the incremental damage to each material due to acid deposition. Both laboratory and field studies are being conducted which will lead to the development of damage functions. A damage function shows the quantitative relationship between materials damage and acid deposition variables. In the laboratory, the materials specimens are exposed to a variety of air pollutants at known concentrations, providing individual damage mechanisms. Field exposure studies, conducted at five sites in the Northeast, aid in assessing the significance of the individual damage process is the context of all other environmental variables. Materials studied at these sites include metal alloys, carbonate stone, and painted wood and metal. The damage function for galvanized steel will be completed within the next year and the damage function for carbonate stone in the next two to three years.

What are the benefits of reducing the rate of acidic damage to materials?

Calculation of the economic benefits of reducing damage due to acidic deposition requires determination of the inventory of materials at risk and damage functions. However, to complete the calculation, other data are needed to define further material service lives, cost data and consumer response. Thus, surveys are planned that will answer these questions by 1990.

Outputs

- 1986
  - Residential materials inventory data base (Northeast)
- 1987
  - Residential materials inventory model
  - State-of-science report
  - Uncertainty analysis report
- 1988
  - Non-residential inventory data base (Northeast)
- 1989
  - Reinforced concrete damage survey report
  - Brick and mortar damage survey report
  - Consumer response report
- 1990
  - Complete materials inventory
  - Dose-response reports:
  - Galvanized steel
  - Weathering steel
  - Copper
  - Painted wood
  - Painted metal
  - Assessment of acid deposition on materials report

Forest Effects

Policy Questions

- Is there a significant problem of forest damage in the United States that might be attributed to acid deposition, alone or in combination with associated pollutants?
- If so, what is the causal relationship between acid deposition and associated pollutants and forest decline in the United States?
- If there is a causal relationship, what is the dose-response relationship between acid deposition and associated pollutants and forest damage in the United States?

Beginning in the early 1970s, extensive damage was reported for silver fir at high elevations in southern regions of the Federal Republic of Germany. This was followed by reports of similar damage to Norway spruce and European beech. In conifers, one of the most obvious and most extensive symptoms of damage was premature loss of older needle sets; another common symptom was chlorosis, or yellowing, of older needles.

Similar symptoms have been observed at high elevations in the northeastern United States. Various changes in forest conditions have been observed in the United States since the early 1980s. Apparently increased mortality has been observed in high elevation stands of red spruce and balsam fir. Also, there is some indication that annual increment growth is reduced in these stands.

In both central Europe and the United States, the observed symptoms are non-specific; they could be caused by a number of different factors or combinations of factors. Acid deposition and air pollutants have been implicated as causal factors. A joint EPA-Forest Service research program, the Forest Response Program (FRP) has been established to study these factors.

Several different forest types exist throughout the United States and will be studied. The FRP has established four research cooperatives to study problems associated with these forest types:

- The Spruce/Fir Cooperative—to study northeastern and high elevation southeastern spruce and fir forests.
- The Southern Commercial Cooperative—to study commercially important species in the Southeast, such as loblolly, slash, and shortleaf pines.
- The Eastern Hardwoods Cooperative—to study various species of hardwood and Eastern white pine in the East.
- The Western Conifer Cooperative—to study important coniferous species in the West, such as Douglas fir and ponderosa pine.

In addition to these research cooperatives, three suppport groups will provide necessary information to the research cooperatives. These are:

- The National Vegetation Survey—to examine the extent and severity of damage.
- Deposition Monitoring—to provide air quality and deposition data.
- The Synthesis and Integration Team—to track activities of the cooperatives and assimilate the information for the generation of program-wide outputs.

Is there a significant problem of forest damage in the United States that might be attributed to acid deposition, alone or in combination with associated pollutants?

The first policy question to be addressed involves the extent and severity of forest damage. By the end of 1988, we can expect an evaluation of this problem that will come primarily from projects of the National Vegetation Survey and from exploratory research of the Eastern Hardwoods and Western Conifers cooperatives.

If so, what is the causal relationship between acid deposition and associated pollutants and forest decline in the United States?

The second policy question concerns the possible cause/effect relationship between acid deposition (and associated pollutants) and forest damage in the United States. In the Northeast, most damage is observed at high elevations, which are characterized by frequent exposure to clouds of low pH and high chemical loading. An important aspect of the Deposition Monitoring effort is the Mountain Cloud Forest Exposure Project, which will investigate this phenomenon at intensive study sites in the eastern United States.

A number of hypotheses have been proposed to explain observed damage. The main hypotheses include:

- Alteration of plant physiology leading to change in tree growth.
- Impact of gaseous air pollutants and leaching of nutrients from foliage.
- Over-fertilization with nitrogen through atmospheric deposition leading to increased winter injury through early break in dormancy or delayed cold hardening.
- Soil mediated mechanisms, including nutrient leaching and mobilization of toxic metal ions.
- The impact of natural factors such as drought, pests and pathogens.

Research in the cooperatives will test these hypotheses. The first-stage experiments involve studies in chambers in which experimental conditions can be closely regulated. This allows the study of very complex physiological processes under controlled conditions.

Studies will also be carried out in open-top chambers, which allow less control over experimental conditions, but can include larger plants under more natural environmental conditions. Field experiments will be carried out under natural conditions of deposition, climate and stand dynamics. All of these types of experiments will be used to test the postulated mechanisms of damage. These efforts will contribute information for an evaluation of the roles of sulfur and nitrogen compounds in forest damage. This evaluation can be expected in the early 1990s.

If there is a causal relationship, what is the dose-response relationship between acid deposition and associated pollutants and forest damage in the United States?

The final policy question involves quantification of tree responses and projection of responses under different deposition conditions. The primary responsibility for addressing this question lies with the Synthesis and Integration Team and involves development of a stand-level forest response model based on individual tree models. Data from the research cooperatives will be used to develop these models, which will ultimately allow predictions of health, growth and general forest condition. Results of this effort will lead to quantification of current responses of trees to sulfur and nitrogen compounds and to models which will allow decisions and predictions related to changes in deposition conditions. We expect these results in the early 1990s.

Outputs

- 1988
  - Evaluation of reported forest damage
- 1989
  - Preliminary evaluation of the roles of sulfur and nitrogen in forest damage
- 1990
  - Quantitative estimates of current forest response to sulfur and nitrogen
- 1991
  - Final evaluation of the roles of sulfur and nitrogen in forest damage
  - Projected role of atmospheric deposition in forests of the United States