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How to Measure the Effects of Acid Deposition:

A Framework for Ecological Assessments

Acknowledgements

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Acronyms

AIRMoN	Atmospheric Integrated Research Monitoring Network
CASTNet	Clean Air Status and Trends Network
ELS	Eastern Lake Survey
EMAP	Ecological Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
FHM	Forest Health Monitoring Program
GIS	Geographic Information Systems maps
IMPROVE	Interagency Monitoring of Protected Visual Environments
ISEM	Intensive Site Ecosystem Monitoring
LTER	Long Term Ecological Research Program
LRM	Long Term Monitoring Project
MAGIC	Model of Acidification of Groundwater in Catchments
MAHA	Mid-Atlantic Highlands Assessment
N, NO_x, NO_3	Nitrogen, Nitrogen Oxides, Nitrate
NADP/NTN	National Atmospheric Deposition Program/National Trends Network
NAMS	National Air Monitoring Stations
NAPAP	National Acid Precipitation Assessment Program
NAWQA	National Water Quality Assessment Program
NH_4	Ammonium
NOAA	National Oceanic and Atmospheric Administration
NSS	National Stream Survey
NSWS	National Surface Water Survey
PAMS	Photochemical Assessment Monitoring Stations
$PM_{2.5}$ PM_{10}	Particulate Matter (2.5 microns in size or less, 10 microns in size or less)
RADM	Regional Acid Deposition Model
S, SO_2, SO_4	Sulfur, Sulfur Dioxide, Sulfate
SENIOR	Southeastern Network for Intensive Oxidant Research
SCION	Southeastern Consortium Intermediate Oxidant Network
SLAMS	State and Local Air Monitoring Stations
SON	Spatial Ozone Network
SOS	Southern Oxidant Study
TIME	Temporally Integrated Monitoring of Ecosystems project
USDA	U.S. Department of Agriculture
VOC	Volatile Organic Compounds
WLS	Western Lakes Survey

Section I. Overview

In an effort to reduce the adverse effects of acid deposition on human health and the environment, Congress established the Acid Deposition Control Program, which was passed in 1990 as Title IV of the Clean Air Act Amendments (hereafter “Title IV”). Title IV requires reductions in annual emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), the precursors of acid rain, from electric utilities.

EPA hopes to facilitate the use of localized monitoring where available in conjunction with national networks and promote ecological assessment initiatives at the state and tribal nation levels in order to better understand which regions of the country show signs of improvement and if any are continuing to degrade. This combination of local, regional and national ecosystem assessments will improve the decision-making and evaluation process regarding current air pollution control strategies.

Phase I of the Acid Rain Program achieved substantial emission reductions, resulting in significant environmental and health benefits. As even greater emission reductions occur under Phase II of the Acid Rain Program (2000 forward), the ability to describe the ecological response to these reductions becomes increasingly important. This type of assessment is key to determining whether current control levels provide adequate protection to human health and the environment, and whether further pollution control steps may be necessary. Given the trans-boundary nature of air pollution, mitigating the problem on a regional or national scale will usually prove much more effective than controlling emissions in a single state. One of the key roles states and tribal nations can fill is long-term monitoring of acid deposition or water quality and biological parameters. States and tribal nations have a lot to gain from measuring whether there have been improvements in the health of their ecological resources since implementation of Title IV (1995).

For purposes of this handbook, an ecological assessment is defined as:

> a process in which a clear understanding of baseline conditions and ensuing changes to ecosystems are monitored and documented over time with the goal of establishing long-term environmental trends.

An ecological assessment can be “integrated” and capture the full range of processes and responses from emissions to atmospheric transport to deposition to ecological and human health impacts. Most assessments, however, examine just a piece of that larger picture. Integrated assessments are useful to synthesize existing knowledge, but smaller, more focused assessments are extremely important and valuable as well. For many states and tribes these smaller assessments are more practical and will make up the large majority of the analyses conducted.

This Handbook describes a process and provides general guidelines that states and tribal nations can follow in beginning to assess ecological benefits resulting from the emission reductions achieved under Title IV. Information on basic assessment approaches, relevant national monitoring programs, as well as the availability of modeling data are discussed in the remainder of this handbook. EPA assumes that local monitoring data availability is known foremost by individual states and tribal nations, so that information is not included here. The goal of EPA’s Clean Air Markets Division (formerly the Acid Rain Division) in developing this Handbook is to encourage ecological assessment initiatives at the state and tribal nation level, especially by those that are not currently monitoring ecosystem effects or performing ecological assessment studies. Title IV is a national program resulting in significant emission reductions nationwide, so the Acid Rain Program focuses primarily on national and regional monitoring programs to discern national trends.

EPA recognizes that the level and extent of environmental protection measures are directly dictated by the availability of resources. The resource base of states and tribes can vary greatly from those who have few methods to pay for assessments to those who are confident assessments are a valuable investment for the future. All states do receive grants, called section 105 funds, that may be used for Acid Rain assessments. EPA can assist states in designing assessment projects and provide other technical assistance as needed. Tribes also have access to EPA funds that can be used for assessments.

While the information in this handbook focuses on the needs of states and tribal nations it will also be of use to university researchers, other federal scientists, foreign researchers and other related organizations, although they are not explicitly addressed.

Tribal Nations Have Unique Situations

Although one handbook will not address all needs of states and tribes alike, this handbook attempts to provide information that may be helpful to both groups. EPA recognizes that tribes have treaty and trust relationships with the U.S. government as well as relationships with states. Tribes and states often have different values and motivations for conducting ecological assessments and may have unclear boundaries of management responsibility.

A tribe may have many reasons for asserting environmental decision-making authority over its reservation. The environmental values and ideals that a tribe holds may differ from those addressed by state agencies but tribes are nevertheless often affected by decisions made by states. The process by which a tribe makes environmental decisions may also differ from the public participation process conducted by state agencies. The reservation is the home of the tribe, with historic, cultural, and religious significance which may not be understood or appreciated by non-tribal agencies. This often makes the protection of the environmental quality of the reservation a high priority to tribal members.

Many tribes have not been systematically monitoring and documenting key ecological parameters over the past few decades to assess change. This should not keep these tribes from beginning the assessment process now. In addition, tribes have their own unique ways of establishing historical or baseline ecological information based on their culture of oral history. Often it provides a greater level of detail in assessing long-term change than documented monitoring alone. Although it does pose challenges to comparing the historically-derived information to actual field measurements collected in the present day, traditional ecological knowledge should be considered a starting point in providing valuable information different from what current scientific knowledge can provide. This knowledge, used in conjunction with scientific methods is invaluable to the understanding of ecological resources on tribal lands.

Using Section 105 Funds for Assessment Purposes

States receive block grants from EPA in order to do work on air issues. These funds are called “section 105 funds” after the section of the Clean Air Act that authorizes them. They can be used for a wide variety of purposes, one of which is assessing the impacts of emissions reduction programs. EPA encourages states with an interest in conducting assessments to use section 105 funds for that purpose. Some potential uses include:

- setting up atmospheric deposition or ecological monitoring site(s)
- conducting simple trends analyses on existing data sets that have not yet been “mined”
- integrated analyses of some combination of emissions, atmospheric transport, deposition, and ecological effects
- communicating existing assessment data or data being collected under another program to the public and/or policymakers
- other assessment projects relating to acid deposition

EPA Regional and Headquarters staff can provide technical assistance to states designing and evaluating these assessments if requested.

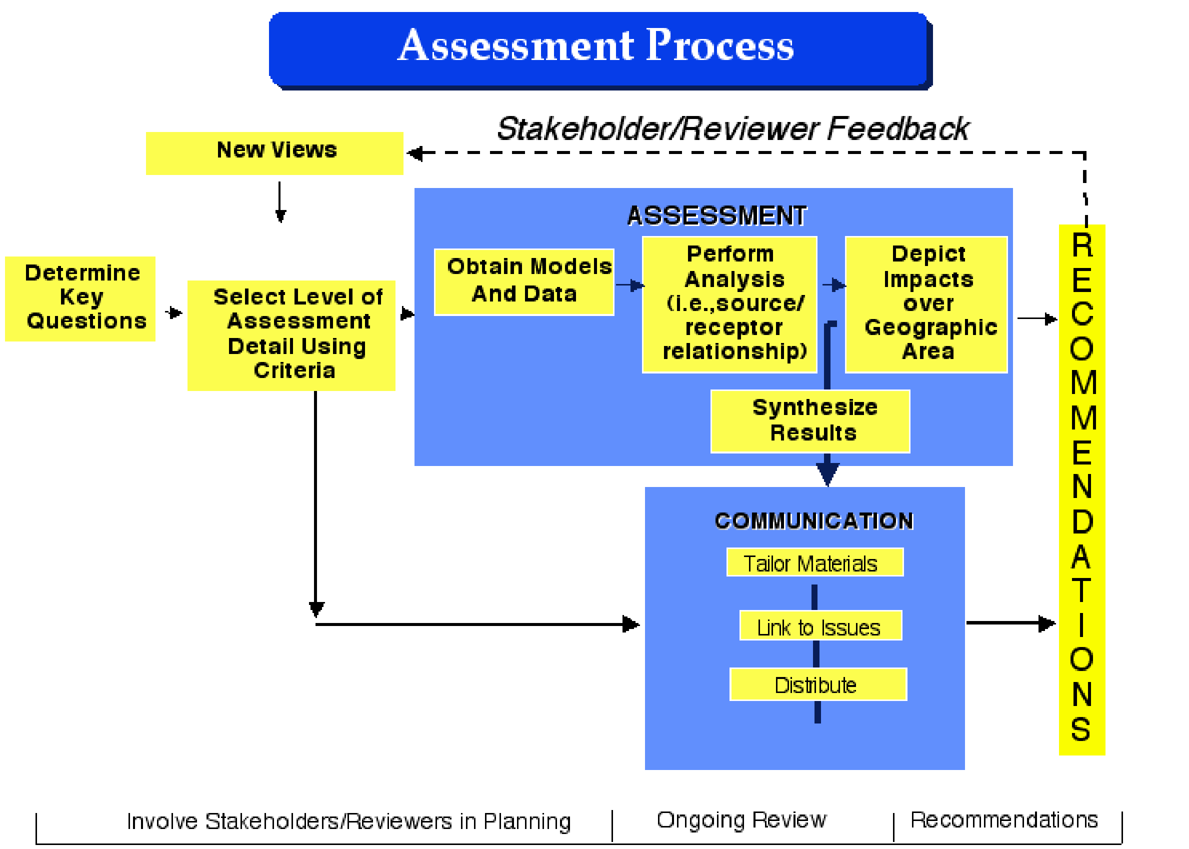
Section II. Assessment Process

The primary purpose of lowering emissions is to reduce the adverse effects to human health and the environment. Resource managers need to determine if the environment is reaping the intended benefits, over what timeframe, and what additional actions might need to be taken. In other words, assessments are the basis for any course-corrections or improvements made during the now-popular adaptive management process. In general, environmental assessments can help determine how successful current and past policies are in protecting natural resources and how much further the policies may need to go. An assessment uses science to answer policy-relevant questions such as, “Are our forests healthier since we reduced emissions?” or “Do we have fewer acidic lakes and streams than 10 years ago?” Assessments can also be useful in identifying gaps in knowledge, identifying a research strategy, prioritizing needs, and allocating resources needed to achieve environmental goals (Bernabo, 1993).

Value of Assessments

Assessments assist in this effort by providing the vehicle for organizing and focusing information on environmental policies. They are the link between the best data

Figure 1. Ecological Assessment Process with Feedback Loops.



and knowledge available (both monitoring and scientific experiments on mechanisms) and any actions taken such as analyzing, interpreting, and using the information to make decisions. For the purposes of this Handbook, an assessment is considered an iterative process of analyzing and synthesizing various pieces of information in order to evaluate and communicate their significance for decisionmaking. This includes decision-making as it relates to a resource manager's development of a research strategy, or decision-making as it relates to a policy-maker's evaluation of an emission reduction policy.

When conducting an assessment, structured frameworks, methodologies, and guidelines are usually followed. Figure 1 shows a pictorial representation of the assessment process. In an ideal world, these individual assessments are repeated over time to continually evaluate changes and improve understanding of why the changes are occurring. Therefore, the assessment process (the act of repeating individual assessments) is considered an iterative one of refining our understanding of environmental change as science and societal values evolve. An individual assessment hopefully will not be a complete replication of a previous assessment but an evolution based on greater understanding. The iterative process is an important function because the credibility of assessments for policy applications requires a process of open review with wide participation to avoid the perception or reality of policy biases. However, in cases where an iterative assessment process is impossible, a single assessment for a given geographic area or ecosystem still provides a wealth of information.

Ecological assessments as a process are imperfect. It should not be expected that the process is easy, or even well formulated. It requires some willingness to experiment as the process is undertaken. Experts acknowledge that it is not known how all the various natural communities or species within ecosystems will respond to pollution reductions. However, acknowledging the uncertainty does not prevent decisions from being made on a daily basis regarding managing resources. Therefore the pertinent question becomes: "how do I manage those resources most effectively in the face of uncertainty?" Assessments provide a solid framework from which to answer this question.

This Handbook identifies a set of ground rules that can be helpful in establishing boundaries and providing structure to the process. It also provides guidance on performing the five basic steps to conducting an ecological assessment. Each of these steps will be discussed in more detail in the following sections:

Section IV: Identify the key policy-relevant questions to be addressed (e.g., Is recovery occurring in those lakes and streams known to have been impacted by acid deposition? Are fish populations healthier?).

Section V: Collect and synthesize environmental monitoring data and information relevant to the policy questions (e.g., surface water chemistry data, tree health data).

Section VI: Identify available and appropriate analytical tools for collective data analysis (e.g., models, statistical analyses).

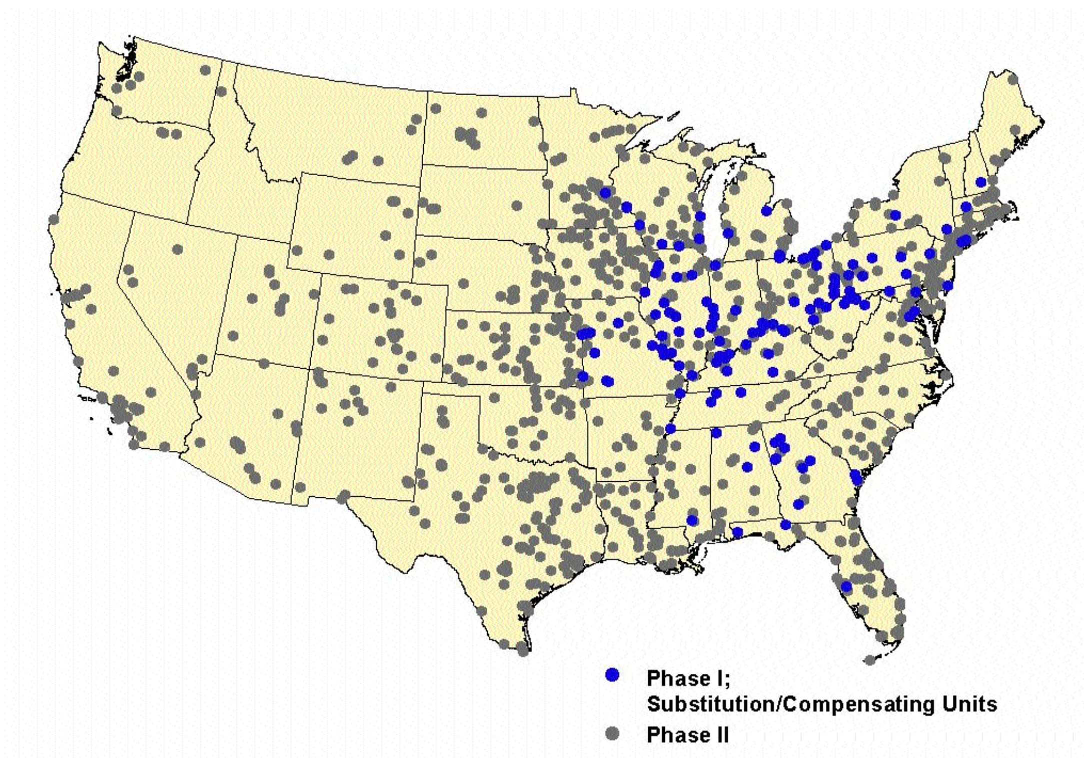
Section VII: Integrate and assess the environmental monitoring data and information in a format that addresses the policy questions.

Section VIII: Communicate the results to the policy, scientific, environmental, and industrial communities as well as to the general public.

Assessing the Acid Rain Program

EPA's Acid Rain Program, established under Title IV (Acid Deposition Control) of the 1990 Clean Air Act Amendments, calls for major reductions of sulfur dioxide and nitrogen oxides, the pollutants that cause acid rain. The program uses market-based incentives to achieve a nationwide limit on SO_2 emissions more cost effectively than traditional regulatory methods. The Acid Rain Program requires a two-phased tightening of restrictions on fossil fuel-fired power plants, resulting in a permanent cap on SO_2 of 8.95 million tons nationwide, half the amount emitted in 1980. Phase I began in 1995, affecting roughly 440 of the larger, higher emitting electric utility units in the eastern United States. NO_x emission reductions are also phased, with Phase I beginning in 1996. Rather than setting an absolute limit on emissions, Title IV controls how much NO_x is emitted for each unit of fuel consumed (lb/mm Btu). (Total NO_x emissions are not capped). The limits on emission rates per unit of fuel consumed will maintain annual NOx emissions 2 million tons below what emissions would have been without the Acid Rain Program (beginning in 2000). Phase II for both SO_2 and NO_x began in 2000 and requires reductions in both pollutants from more than 2000 units across the country. Figure 2 displays the geographical distribution of those sources affected by Title IV.

Figure 2: Electric Generating Units Affected By Phases 1 and 2 of Title IV.



Phase I of Title IV has led to greater than expected reductions in emissions. National emissions of SO_2 and NO_x are shown in Figures 3 and 4. The even more substantial reductions that will occur during Phase II make the ability to describe the ecological response increasingly important in determining whether current control levels provide adequate environmental protection.

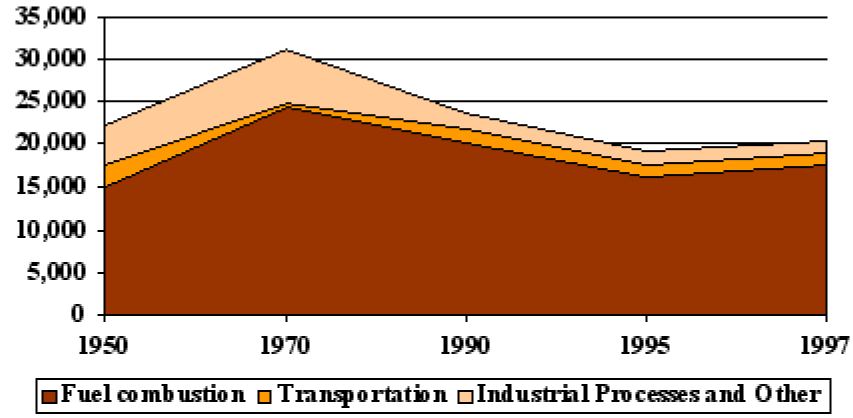
A reduction in sulfur and nitrogen oxides emitted into the atmosphere will result in a reduction of pollutant concentrations in the air and a reduction of acidic deposition to the Earth's surface. Even so, it is important to have realistic expectations. Atmospheric transport and deposition is a complex process and there is almost never a 1:1 or linear relationship between the tons of emissions reduced and tons of deposition avoided. Seasonal variability can mask ecosystem changes due to reductions in deposition. Only after several years of monitoring data will it be possible to separate the seasonal variability from an overall change.

Assessments must continue long after emissions reductions take place because of the time lag before ecological responses are seen. Even after reductions occur, ecosystems may take many years or even require human intervention (such as restocking fish) before recovering to a condition comparable those known historically. Decades of leaching valuable minerals from soils, the removal of sensitive fish species, or changes in ecosystem structure cannot be reversed quickly and it can take decades or longer to rebuild mineral stores, reintroduce missing links in aquatic ecosystems, and reach other necessary milestones to recovery.

A preliminary interpretation of regional monitoring data from EPA (CASTNet) and NOAA (AIRMoN) indicates that Title IV emission reductions are having a positive effect on reducing air concentration levels of SO_2 (NAPAP, 1998). An analysis of wet deposition monitoring data (NADP) demonstrates that Phase I emission reductions resulted in a decrease in the acidity of precipitation and sulfate deposition in the Midwestern and northeastern U.S. (see Figures 5 and 6). The spatial and temporal trends of these reductions are important components in assessing the ecosystem effects.

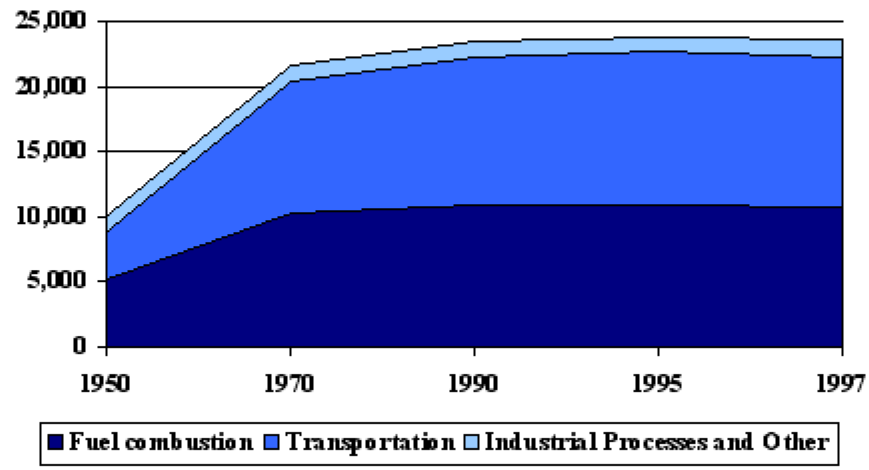
A full range of ecosystem responses are expected over time, based on various characteristics of the ecosystem. Ecosystems are complex and are constantly responding to multiple inputs and stressors, such as other pollutants, climate, and land-use patterns. These inputs and stressors cause chemical changes within ecosystems, which can exhibit long lag times before manifesting a response. This lag time between pollutant loadings and ecosystem response underscores the need for continuous long-term monitoring, which helps in our understanding of what changes are occurring and when they are occurring. Figure 7 displays the timeframe of environmental responses to these reduced emissions, which can range from hours in the case of changes in air concentrations of SO_2 and decades to centuries in the case of forest health and soil nutrient reserves.

Figure 3. National Emissions of Sulfur Dioxide (in thousand tons).



Source: National Air Pollutant Emissions Trends Update, 1970-1997. U.S. Environmental Protection Agency, Research Triangle Park, NC.

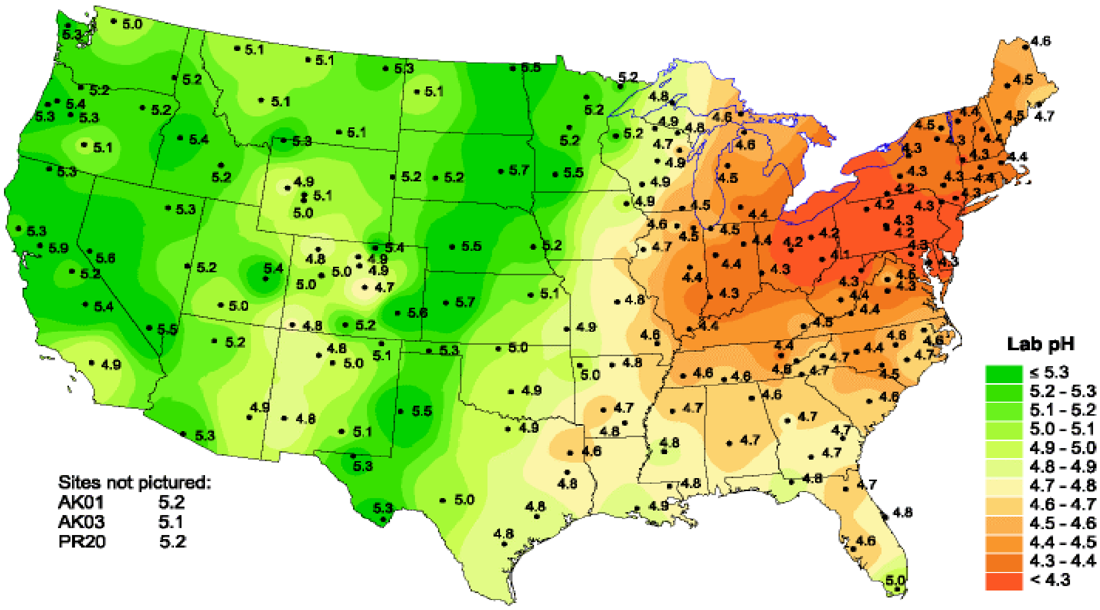
Figure 4. National Emissions of Nitrogen Oxide (in thousand tons).

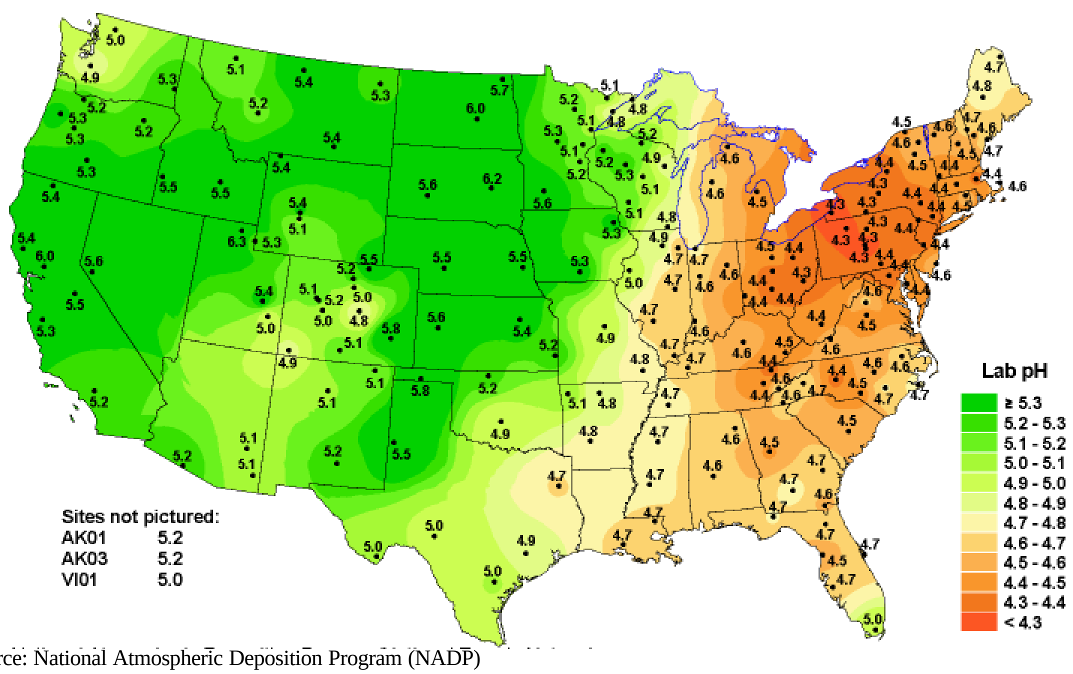


Source: National Air Pollutant Emissions Trends Update, 1970-1997. U.S. Environmental Protection Agency, Research Triangle Park, NC.

It is also important to remember that within this assessment process some relationships are better understood than others. For example, emissions, air concentrations, and deposition data are fairly well understood in comparison to the ecosystem, and especially to the biological cell/tissue/population effects. There are some good case studies of causal mechanisms, but the great majority of ecological sensitivities and effects or responses are not well understood. The process is to then infer that the ecosystem or specific biological organisms will be under less stress from the reduced pollutants and health will improve. It might be helpful to think of the efforts to determine causal relationships as a series of hypotheses that are being tested and then constantly revised.

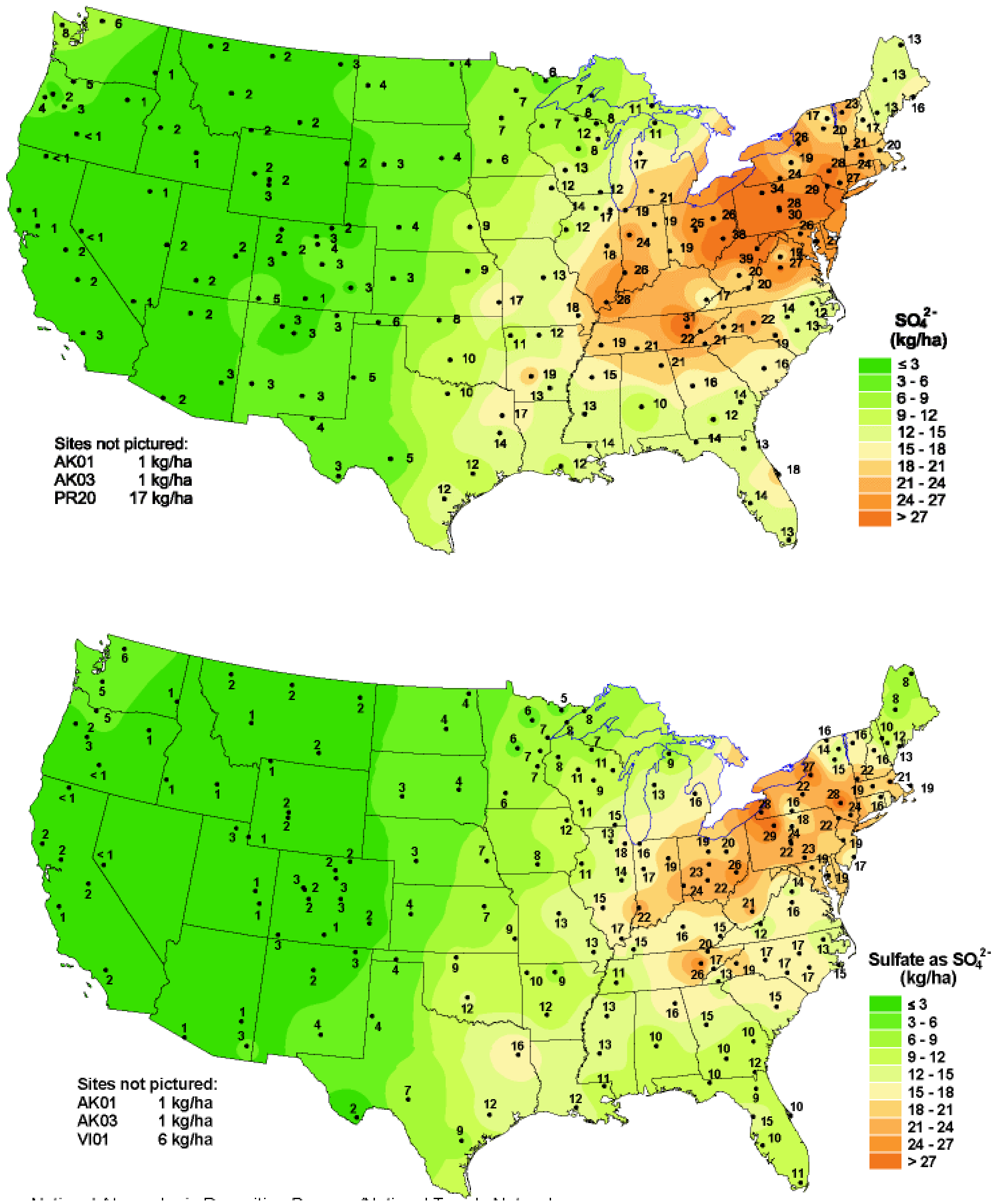
Figure 5. Average pH of Precipitation at Monitoring Sites in 1994 (pre-Phase I of Title IV) and 2000 (post-Phase I).





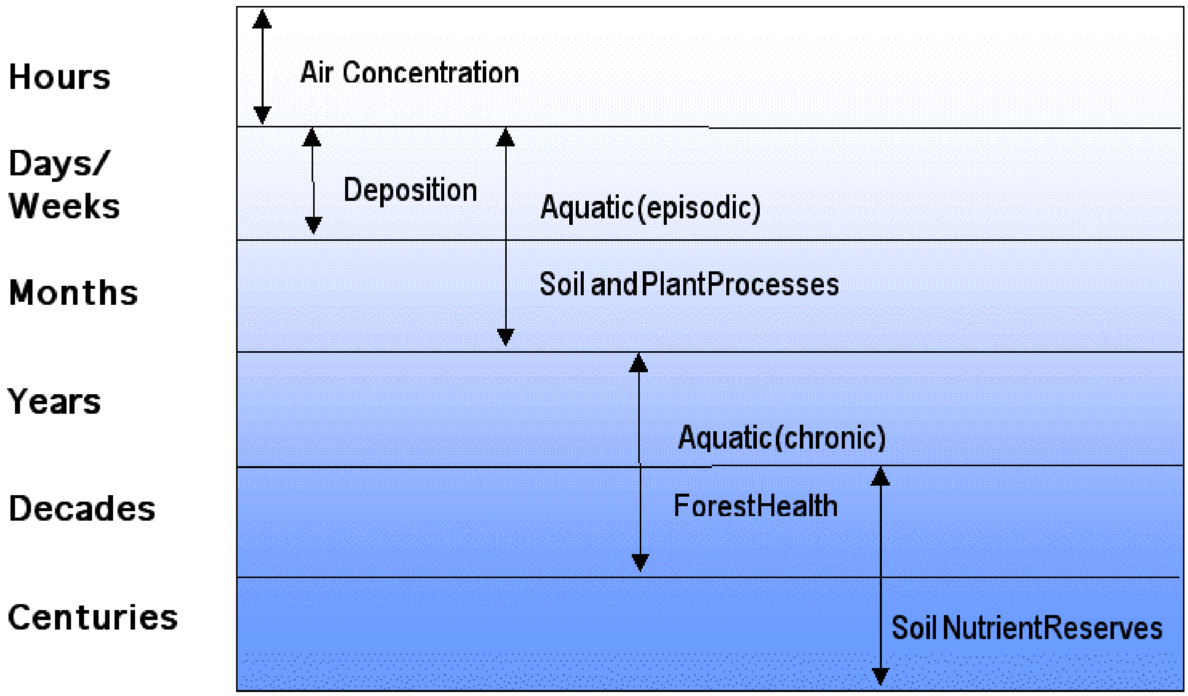
Source: National Atmospheric Deposition Program (NADP)

Figure 6. Sulfate Deposition at Monitoring Sites in 1994 (pre-Phase I of Title IV) and 2000 (post-Phase I).



Source: National Atmospheric Deposition Program (NADP)

Figure 7. Various Response Times to Changes in Emissions.



Note: The time it takes for various environmental impact areas (soils, aquatic, and forest ecosystems) to respond to changes in emissions varies tremendously. Episodic aquatic ecosystems may be affected in days/weeks, whereas forest health and soil nutrient reserves may take decades to centuries.

Section III. Scope of Assessment

This section outlines the scope of an assessment. The different characteristics of assessments are discussed in terms of the level of complexity that can be considered. At one end is what is referred to as a "Core Assessment," or the simplest analysis that can be done to provide meaningful information for the questions being posed by the state or tribal nation. The other extreme is referred to as an "Ultimate Assessment." An Ultimate Assessment attempts to take into account all of the relevant interrelated issues associated with the questions being posed and in order to provide a detailed quantitative analysis of the relationships among issues, causes, and effects. In this section, we provide guidelines for determining the level of data detail and model sophistication that might be appropriate for the Core, the Ultimate and, as is likely to be the more typical case, an assessment that falls somewhere in between.

What Distinguishes Core and Ultimate Assessments?

The scope of an assessment is characterized in terms of the issues of concern and the key questions asked along with the level of detail of the analysis (e.g., data and models) used to address the issues. This Handbook concentrates on ecological assessments related to acid deposition. However, the same framework can be used to design assessments to answer all sorts of environmental questions. For acid deposition, the questions center around the effectiveness of emission reduction strategies in improving ecosystem environments. Considering the relationships of ecological effects to other impacts and multiple driving factors (such as meteorology or climate change in addition to emission reductions) broadens the scope of the assessment.

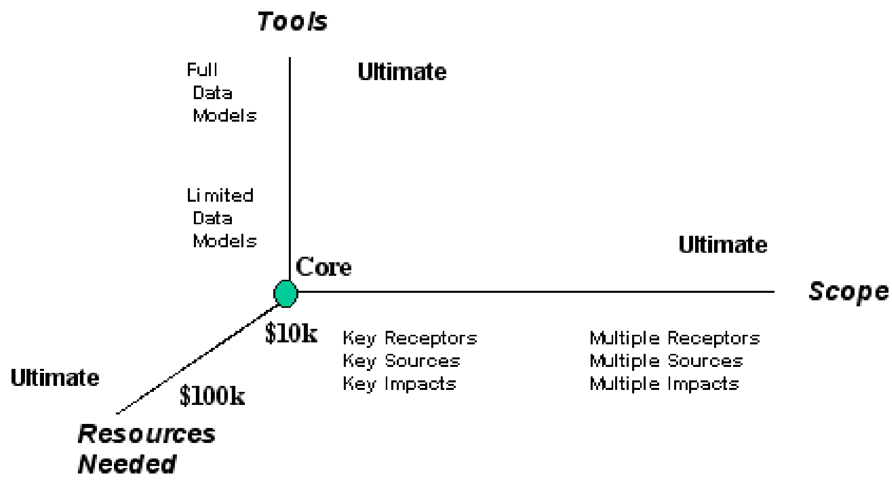
A Core Assessment considers changes in key sources as well as key ecological receptor areas. The emphasis is on using existing analyses and data, and non-key but related factors and issues are not explicitly addressed. Data and modeling analysis requirements are well focused and minimal.

In an Ultimate Assessment, multiple consequences of emission changes throughout the region surrounding the receptor sites of concern are taken into account. Related issues and influences such as changes in ozone, particulate matter and haze are also explicitly considered. Social, economic, and political influences may also be included in the analysis. Data and modeling analysis requirements are more complex since more sources, processes, and environmental impacts are explicitly taken into account.

The differences between the Core and the Ultimate Assessment scope, tools, and resource requirements are summarized in Figure 8. The Core is limited to quantitative analysis of one or two key or representative impacts associated with one or two receptor areas (e.g., a lake or terrestrial ecosystem) associated with a small well-defined set of sources (e.g., nearby major stationary source). The data used in the analysis are available and well characterized. Similarly, models used are easy to access and apply. Analyzed and fully developed reference tables and/or graphics indicating source and receptor region relationships derived from the Regional Acid Deposition Model, can also be used to help in the assessment at the Core level. In general, a basic Core Assessment could be initiated as a screening or scoping study with costs in the range of ten to fifteen thousand dollars whereas the more complex assessments require resources up to a hundred thousand dollars or beyond. Often a scoping or Core Assessment can provide the information needed to help the decision maker decide on next steps, which might include a more extensive assessment.

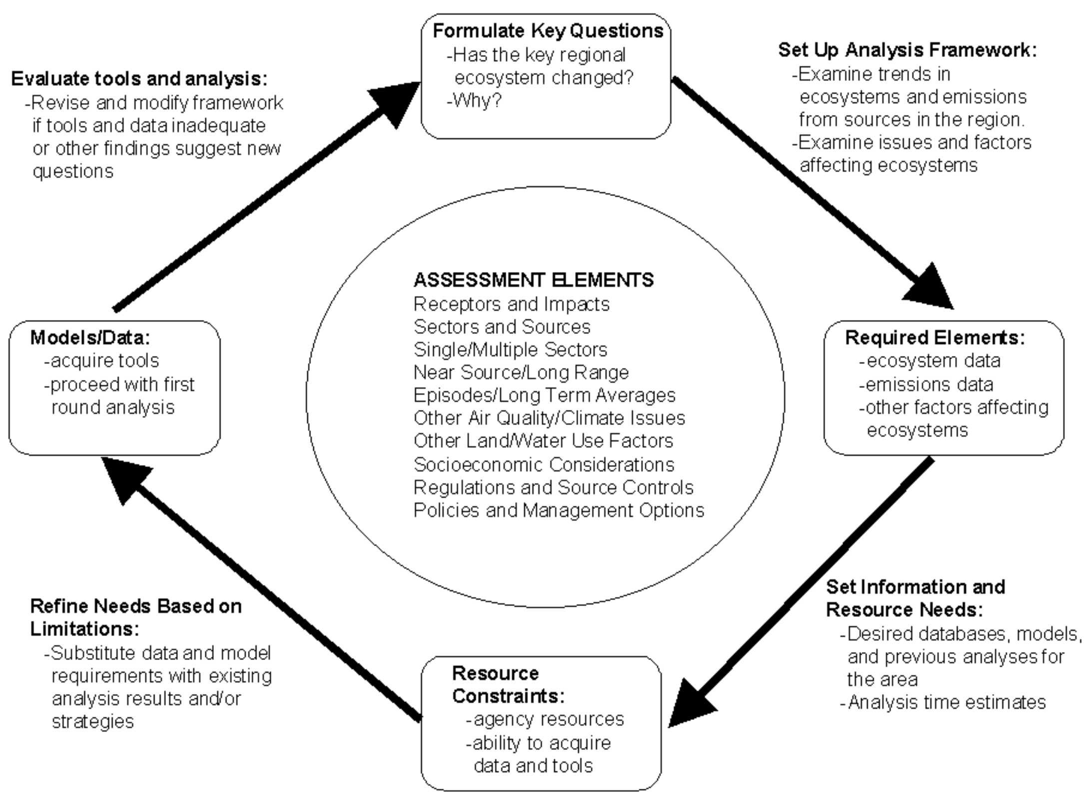
Each step of the Assessment Strategy outlined in Figure 9 implies a range of possible questions, analyses, models, data and resource requirements. Core questions about key impacts and major sources (e.g., has the key regional ecosystem changed as a result of emission changes?) differ from questions that consider a broader range of factors (e.g., other economic and social factors as well as emission trends) in ultimately determining answers to the "why" question. The complexity of the question determine the elements to be considered. Basic ecosystem and emissions data are needed for Core

Figure 8. Comparison of Core and Ultimate Assessments.



A Core assessment is limited in the number of receptors, sources and impacts as well as analytic tools used and resource requirements. As you move from a Core assessment toward an Ultimate assessment all of these requirements increase.

Figure 9. Assessment Strategy



Assessments while additional information is needed to answer broader questions.

It should be kept in mind that resource constraints will become more significant as the assessment becomes more complex. A state or tribe may have relatively easy access to information required for the Core Assessment, but may have complex questions that require something close to an Ultimate Analysis to answer. However, for more complex analyses approaching the Ultimate, the resource requirements (time, expertise and cost) become higher. After evaluating the questions, framework and resource requirements, the assessment can be scaled up or down to meet the needs of the tribal nation or state within the available resources.

Key criteria for determining the scope of an assessment

- **key questions**
- **data quality/quantity**
- **model availability**
- **local analysis expertise**
- **computer constraints**
- **time limitations**
- **funding considerations**

What are Key Criteria for Determining the Scope?

The scope of the assessment is determined, to a large extent, by the specific policy questions being addressed (these questions will be discussed in detail in the following section). The range of receptors, impacts, sources and other factors to be considered in establishing causes and effects sets the bounds for the level of analysis required. In-depth questions dealing with multiple relationships and scales can be posed. However, if the data and/or modeling support is not readily available or cannot be obtained within budget, then less rigorous approaches must be taken, which rely on previous analyses or data not explicitly related to the question being posed.

Several criteria then determine the needed and/or feasible level of detail for the assessment. The level of detail that can actually be addressed depends on the data and model availability and quality; staff, computer and other resource requirements and availability; assessment deadlines or other time constraints; and basic funding considerations.

Section IV. Key Questions

Those conducting assessments, such as resource managers, should seek the input of relevant stakeholders such as scientists, policymakers, industries, environmental groups, and community groups in formulating the assessment questions. Involving stakeholders at the outset will help to ensure that an ecological assessment is both relevant and credible. Such inclusion will also increase an assessment's chance of being perceived as a useful and successful exercise upon its completion. The stakeholder process is also important because it brings to the table the societal values, preferences, and priorities, as well as scientific knowledge and agency priorities. It is also important to keep in mind that societal values can be very different for different groups. For example, the value that a tribal society places on natural resources and their stewardship can vary greatly from that of a non-tribal society, just as such values can drastically vary from one geographic location to another. Assessments involving more than one community should make sure as many voices as possible have a chance to participate in the process.

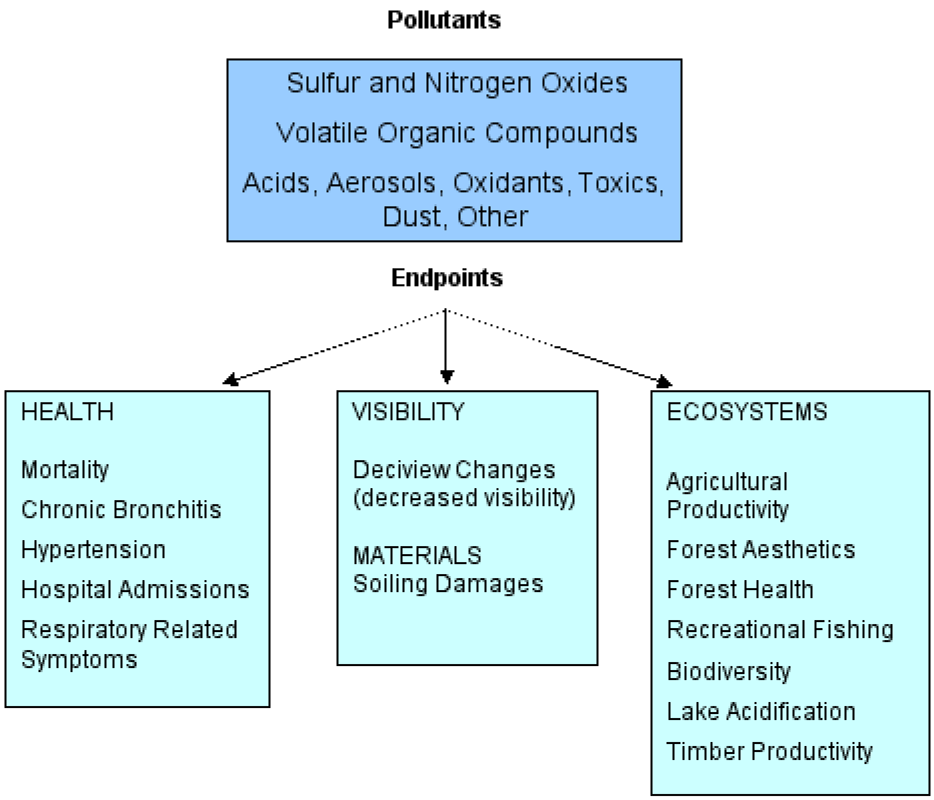
Below is a sample list of the types of policy-relevant questions likely to be identified for the purpose of assessing ecological change from Title IV emission reductions. It might be helpful to categorize the questions as either "feasible" or "not feasible at the present time" based on the scope of the assessment you narrowed in on in Section III.

- Have sensitive ecosystems in this state or tribal nation been identified?
- What are the current physical, chemical, or biological characteristics or states of these ecosystems?
- Have baseline measurements been established?
- How have these characteristics changed over time and what are the trends in these changes?
- How are emissions spatially distributed in relation to sensitive ecosystems and/or existing ecological problems?
- Does this state or tribal nation have (or have access to) adequate monitoring and spatial coverage to detect changes in deposition and ecosystem effects?
- What are the dose-response relationships of atmospheric deposition (specifically sulfur, nitrogen, and base cations) on aquatic and terrestrial resources?
- What evidence do we have of ecosystem changes due to increases in atmospheric deposition?
- What evidence do we have documenting ecosystem recovery due to reductions in atmospheric deposition or reductions in sulfur concentrations?
- Are there baseline ecological (biological) data available in order to measure a change in a certain sensitive ecosystem?
- What are the best parameters to measure ecosystem level changes (e.g., water chemistry changes, population changes, etc.)?
- Are there uncertainties that affect the understanding of the links and cause/effect relationships between emission decreases, deposition changes, and ecological effects (e.g., responses influenced by other factors such as climate change, ozone, land-use changes and the carbon cycle)?
- What are the environmental/human health endpoints?

These questions can be further expressed in terms of particular impacts or endpoints. Some key endpoint examples are summarized in Figure 10. Endpoints for human health effects have been extensively studied and are directly related to criteria pollutant standards. Endpoints associated with ecosystem and other welfare parameters such as visibility and materials damage also have been studied in detail. Assessments of ecological impacts are critical to our ability to improve the state-of-the-science and incorporate ecological effects into future policies.

Once the relevant questions are developed, it can then be determined how useful current research or monitoring data will be in providing answers, and what methods of research and assessment should be applied. In developing the key questions to assess the impacts of acid deposition for a particular area, it is important to keep in mind that Title IV of the Clean Air Act took effect in 1995. This date represents that point at which decreases in emission rates can be referenced and compared to earlier and/or later periods. Some reduction in emissions may even have occurred prior to 1995 as util-

Figure 10. Examples of Endpoints Associated with Pollutant Impacts



ity companies adjusted emission levels in anticipation of pending regulations.

The key questions are likely to differ from one state or tribal nation to another and are apt to change over time as new concerns arise and/or as new perceptions emerge from ongoing research into the effects of acid deposition on ecosystems. It is likely, therefore, that the data required to address decision needs will vary with location and over time. It is also likely that, as our understanding of the ecological effects of sulfate and nitrate deposition improves, different data and tools may be needed than what were needed in 1990 or 1995. Where information is not available from nearby monitoring sites designed to measure deposition and other effects of changes in pollutant emissions (e.g., ambient air and surface water quality), data from other monitoring programs and/or model results will need to be used. Data from unrelated programs should be used with the guidance of experts who understand the assumptions and other technical issues that may impact the strength of the assessment.

Section V. Identifying and Using Available Data Sources

In order to answer your policy-relevant questions, you need scientific data and information. This section outlines the data on acid deposition and its ecological effects that are available for use by states and tribal nations from national networks.

National air quality and deposition monitoring networks are used to answer questions about trends on national and regional scales. Using national monitoring emissions and deposition data will provide overall trends, however, there are no comparable national monitoring networks for surface water/soil chemistry or ecological data designed to provide a national picture of ecological effects. To get an idea of what is happening with the local ecology it will most likely be necessary to look at intensive monitoring projects on specific ecosystems or research projects conducted by universities, state or federal scientists, etc. A vast amount of high-quality science was conducted in the 1980s and early 1990s by the scientific community for the purpose of attaining the state of science and technology on the issue of acidic deposition. This science was sponsored by the U.S. National Acid Precipitation Assessment Program (NAPAP) and fed into a NAPAP Integrated Assessment Report (NAPAP 1991). Much of the benchmark science that is summarized in those reports, along with the methods employed, should prove to be a good foundation for most types of ecological assessments conducted today.

Descriptions of many ongoing national air monitoring networks and ecological monitoring networks are listed in Table 1 with some additional detail in the paragraphs that follow the table. This list is not comprehensive. Again, national coverage is the focus of those networks cited in Table 1. States, universities, and other groups have databases that could be accessed and of direct relevance since many of them will focus on smaller spatial scales or specific ecosystems. It is strongly recommended that such databases be explored in addition to the national datasets. For example, if you were conducting an assessment within the state of Minnesota you would contact the MN Department of Natural Resources for ecological and water databases, the MN Pollution Control Agency for emissions and water databases, and the University of MN for ecological and water databases.

EPA has combined many of its databases into the Envirofacts Warehouse, which can be accessed at http://www.epa.gov/enviro/index_java.html. Data sets are also available from monitoring networks that are no

NEW!! C-MAP NOW AVAILABLE!!

C-MAP is the Clean Air Mapping and Analysis Program, a website designed and maintained by EPA Clean Air Markets Division. This Web site is designed to take advantage of new geographic mapping techniques to assess the environmental benefits of sulfur dioxide and nitrogen oxide emission reduction programs, such as the Acid Rain Program. Using a Geographic Information System (GIS), C-MAP allows users to view a series of national and regional maps in the "Map Gallery" section, and then download the data used to generate the maps in the "GIS Data Download" section. The maps display information showing how changes in emissions result in changes in air quality indicators, acid deposition, and sensitive ecosystems. The GIS database provides an extensive inventory of national/regional level emissions, environmental effects, and demographic data available for download, including air quality, surface water quality, acid deposition, forest health, and sensitive ecosystem data. Many of the datasets described in this Handbook can be accessed or linked to from C-MAP.
See: http://www.epa.gov/airmarkets/cmap/

Table 1. Air, Deposition, and Ecological Network Descriptions and Pollutants Monitored

MONITORING NETWORKS						
Network and Operating Organization	**Key Substances Monitored**	**Objectives**	**Spatial Coverage**	**Temporal Coverage**	**QA/QC# Levels**	**Web Ref.**
Air and Deposition Networks						
Atmospheric Integrated Research Monitoring Network (AIRMoN[1])* —NOAA	Precipitation chemistry and dry deposition. SO_2, NO_x, O_3, CO, VOC	Regional deposition	Eastern US network with nine sites (MAP3S), 12 sites (CORE)	Wet: 1992 Dry: 1985	Complete	1
Clean Air Status and Trends Network (CASTNet[2])—EPA	Precipitation chemistry and dry deposition, SO_2, NO_x, O_3, and HNO_3.	Regional deposition	National network with 70 sites	1988	Complete	2
Interagency Monitoring of Protected Visual Environments (IMPROVE[3])—USNPS	$PM_{2.5}$ (speciated), PM_{10}	Regional aerosols and visibility	National park network with 40 sites	1988	Complete	3
National Air Monitoring Stations (NAMS[4])—states, local agencies	PM_{10}, SO_2, CO, O_3, NO_2, Pb	Urban air quality	National network with 1019 sites	1979	Complete	4
National Trends Network (NTN)/ National Atmospheric Deposition Program (NAD[5])—EPA	Precipitation chemistry	Regional deposition	US (47 states) Puerto Rico network with 199 sites	1978	Complete	5
Photochemical Assessment and Monitoring Stations (PAM[6])—states, local	O_3, NO, HC_s carbonyls	Urban O_3	Major metropolitan area network with 22 sites	1994	Complete	6
State and Local Air Monitoring Stations (SLAM[7])—states, local agencies	PM_{10}, SO_2, CO, O_3, NO_2, Pb, TSP, (trace metals and meteorology - some sites)	Urban air quality	National network with 4059^+ sites (SLAMS sites and others)	1979	Complete	7
Southern Oxidant Study (SO[8])**—EPA, universities, states, EPRI, National Labs, Private companies	O_3 (SON); O_3, NO, CO, SO_2, HNO_3, NO_y, VOC (SCION); O_3, NO_x, NO_y, VOC, PAN, Carbonyls, NO_2 (SENIOR)	Urban and rural O_3	Southeastern US network with 46 sites (SON), 3-15 sites (SCION), 2-5 sites (SENIOR)	1988	Complete	8

Ecological Networks	**Sample Parameters Monitored**	**Objectives**	**Spatial Coverage**	**Temporal Coverage**	**QA/QC# Levels**	**Web Ref.**
Forest Health Monitoring (FHM[9])— USDA Forest Service and others	Plant species diversity, leaf area index, tree regeneration, lichen communities, foliar chemistry, tree mortality, air pollution, bioindicator plants, soils	Forest ecosystem health and sustainability	National network with about 4,000 sites on systematic grid; part of larger EMAP network of 12,600 plots	1990	Complete	9
Environmental Monitoring and Assessment Program (EMAP[10])—EPA	Water: discharge, sediment load, aquatic biota, trace metals, habitat Marine / Coastal: salinity/fresh-water flux, chlorophyll / zoo-plankton, submerged/coastal habitats Soils: texture, chemistry, toxicity, mineralogy Animals: species / range/ population	Assessments of ecological condition and forecasts of the future risks to the sustainability of US natural resources	National network of 12,600 sites on systematic grid	1988	Complete	10
Long Term Monitoring (LTM[11])—EPA	Acidity, sulfate and nitrate concentration	Track changes in surface water chemistry	81 sites in the Northeast and upper Midwest -lakes in ME, VT, Adirondacks of NY, MI, WI, MN; streams in Catskill Mtns. NY	1982	Complete	11
Long-Term Ecological Research (LTER[12])—NSF	Climate: meteorology, wet and dry deposition Water: discharge, sediment load, organic contaminants Marine /Coastal: salinity/freshwater flux, submerged/coastal habitats Soils: texture, chemistry, mineralogy, faunal biomass Vegetation: growth rate/above-ground biomass, Animals: food source & quality, recruitment Miscellaneous: fire	Support research on long-term ecological phenomena such as production, population patterns, dynamics of organic matter, nutrient flux	18 intensive research sites in US and Puerto Rico	1980	Panel review of proposals and journal publications	12
National Water-Quality Assessment Program (NAWQA[13])— USGS	Water: discharge, sediment load, organic contaminants, aquatic biota, inorganic chemistry, sediment chemistry, trace metals, habitat Marine / Coastal: salinity/fresh -water flux, nutrients/ contam.	Identify common environmental characteristics associated with the occurrence of key water-quality constituents and to explain their differences	Nation-wide 60 river basins and aquifers; these together account for 60 to 70 % of US water use and population served by public water supplies	1986 pilot 1991 full program	Complete	13

* AIRMoN combines MAP3S and CORE/satellite to generate a new monitoring activity to which on-line modeling and analysis can be easily appended. AIRMoN is designed to build upon existing observing networks.
~ CASTNet combines EPA's dry deposition network previously known as the National Dry Deposition Network (NDDN) and 26 National Park Service dry deposition monitoring sites.
** SOS is a 3-tiered network: Southern Regional Oxidant Network (SERON), Spatial Ozone Network (SON), Southeastern Consortium Intermediate Oxidant Network (SCION), Southeastern Network for Intensive Oxidant Research (SENIOR).

1.	AIRMoN	http://www.arl.noaa.gov/research/programs/airmon.html
2.	CASTNet	http://www.epa.gov/castnet
3.	IMPROVE	http://www.aqd.nps.gov/ard/impr/
4.	NAMS	http://www.epa.gov/cludygxb/programs/namslam.html
5.	NADP/NTN	http://nadp.sws.uiuc.edu/nadpoverview.asp
6.	PAMS	http://www.epa.gov/oar/oaqps/pams/
7.	SLAMS	http://www.epa.gov/cludygxb/programs/namslam.html
8.	SOS	http://www2.ncsu.edu/ncsu/CIL/southern_oxidants/index.html
9.	FHM	http://willow.ncfes.umn.edu:80/fhm_fact/evalmon.htm
10.	EMAP	http://www.epa.gov/emap/
11.	LTM	contact John Stoddard 541-754-4441, US EPA Corvallis, OR
12.	LTER	http://lternet.edu/
13.	NAWQA	http://water.usgs.gov/nawqa/nawqa_home.htm

longer active (not included in Table 1). This information can be helpful in assessing trends but locating these data sets may require a bit of investigation. Considerations for using databases to address ecological assessment questions and general approaches to assuring the quality of data, which is not part of a national network, also are provided.

Emissions Databases

EPA is the primary source of emissions data for all of the United States, at both national and state levels. These data are available at http://www.epa.gov/ttn/chief. Complete documentation of emissions inventory development for the U.S. can be found in the EPA *National Air Quality and Emissions Trends Report, 1998* (http://www.epa.gov/oar/aqtrnd98/). That report is a good starting point for obtaining total emissions data for assessments. Emissions are summarized by pollutant, category, and state. Emissions associated with a particular source will need to be accessed from local state agencies. Development of inventories can be done specially for a regional assessment by supplementing the EPA inventories with updated and source specific information and by implementing a variety of emissions models. However, this is a resource intensive process. At the very least, any inventory used for an assessment, particularly a local assessment, should be spot-checked to see if it appears reasonable.

Under Title IV each regulated unit (e.g. boiler at a power generating facility) is required to account for every ton of emissions. In order to ensure compliance each unit was required to install a continuous emission monitoring system (CEM) to record various parameters on an hourly basis such as heat input and total mass emissions. The data are electronically transferred to EPA's Emissions Tracking System (ETS) each quarter and compared against the number of allowances held by each unit at the end of each year. (Allowances are allocated by EPA each year and each allowance allows the holder to emit one ton of SO_2. Allowances can be bought and sold or banked for future use.) Emissions data from non-affected sources are estimated using models and representative emission measurements. Emissions data from sources in the Acid Rain Program can be accessed on the web at http://www.epa.gov/airmarkets/emissions/.

The Emissions & Generation Resource Integrated Database (E-GRID) is a comprehensive source of data on the environmental characteristics of all electric power generated in the United States. An integration of 18 different federal data sources, E-GRID2000 provides information on air pollutant emissions and resource mix for 4600 individual power plants, more than 2000 generating companies, states, and regions of the power grid. The data are expressed in terms that allow direct comparison of the environmental attributes of electricity generation at any level. The latest version, E-GRID2000, includes data from 1996 through 1998. The new 1998 data have been reconfigured to reflect the industry's current structure, including company mergers, power plant divestiture to non-utility companies, and grid reconfigurations through December 31, 2000. E-GRID is accessible through a user-friendly data browser or by viewing Microsoft Excel spreadsheets, both downloadable from the EPA Clean Air Markets web site at (http://www.epa.gov/airmarkets/egrid/index).

The EPA Office of Enforcement and Compliance operates the American Indian Lands Environmental Support Project (AILESP). AILESP integrates and assesses recent multi-media point-source releases, the potential impacts of contaminants, and recent compliance and enforcement histories for facilities located on and within five kilometers of Tribal areas. This project uniquely assimilates and synthesizes disparate data sources to create a better understanding of the nature and extent of permitted point sources on and near Tribal areas. AILESP can be found on EPA's website at http://es.epa.gov/oeca/ailesp/index.html. Emissions at the tribal level can be deduced from the emissions inventories by examining the emissions for states and counties that overlap tribal lands. Emissions for specific sources or source categories in a particular area may be available from local, state or tribal agencies. Information also is readily available for counties.

National Air and Deposition Monitoring Networks

The two pollutants controlled under Title IV are sulfur dioxide (SO_2) and nitrogen oxides (NO_x) because of their recognized contributions to adverse health and ecosystem effects. There are many national networks that monitor SO_2 and NO_x as part of their design and are therefore an available source of air quality data (see Table 1). Detailed descriptions of national monitoring and analysis of these and other key pollutants (e.g., those for which standards have been set) at the metropolitan level are also available in the EPA *National Air Quality and Emissions Trends Report 1998* mentioned earlier. In addition, both maps and time series are available for one or more sites on a large selection of (wet) deposition parameters at the National Atmospheric Deposition Program: http://nadp.sws.uiuc.edu/.

Ambient monitoring for SO_2 and NO_x has been done at urban monitoring stations as well as some rural stations for up to 25 years. The IMPROVE visibility network has almost 10 years of aerosol speciation data (e.g., sulfates, nitrates, organic and elemental carbon, and ammonium) for $PM_{2.5}$ and PM_{10} (particles 2.5 microns or less in size and 10 microns or less in size). Precipitation chemistry in some networks goes back almost two decades. All monitoring data generally are available to the public upon request to the network manager responsible, but may require persistence in obtaining the specific information you need.

NADP/NTN: The National Atmospheric Deposition Program (NADP) was established in 1978 to provide information on geographical patterns and temporal trends in U.S. precipitation chemistry. A major objective of the program is to characterize geographical patterns and temporal trends in acid deposition of the United States through development and maintenance of a deposition monitoring network called the National Trends Network (NTN). Long-term monitoring stations are sponsored by cooperating agencies and organizations that volunteer personnel, equipment, analytical costs, and other resources and agree to follow the Network's standard established procedures. The network currently consists of over 200 monitoring sites across the nation with 5 of those stations located on tribal lands (ME, SC, MI, MN, NY). NADP/NTN criteria and protocols ensure uniformity in siting, sampling methods, analytical techniques, data handling, and overall network operation.

CASTNet/ AIRMoN: The EPA Clean Air Status and Trends Network (CASTNet) and the National Oceanic and Atmospheric Administration (NOAA) Atmospheric Integrated Research and Monitoring Network (AIRMoN) both provide information on site-specific deposition that can be interpolated in some instances to a regional scale. Dry deposition measurements in these networks are a product of ambient air concentrations and modeled deposition velocities. CASTNet measures ambient O_3, SO_2, HNO_3, particulate nitrate, and sulfate and ammonium species. CASTNet is a primary source for data to estimate dry acidic deposition and to provide data on rural ozone levels. Used in conjunction with other national monitoring networks, CASTNet determines the effectiveness of national emission control programs. CASTNet data has been collected since 1987 and is available on the web at http://www.epa.gov/castnet.

AIRMoN brings together wet and dry deposition components to reveal the causes of observed trends. The AIRMoN-wet program relies on common field equipment, a single analytical laboratory, and centralized quality assurance. Daily samples are collected, and samples are analyzed for nitrate, sulfate, and ammonium. The AIRMoN-dry program relies on a two-tiered approach that infers dry deposition from air quality, meteorology, and surface observations and directly applies eddy flux and/or gradient techniques. These methods yield average dry deposition rates to areas, typically many hundred meters in radius, surrounding observation points. Observation sites are located within areas that are both spatially homogeneous and representative of the larger region. Sites selected for wet deposition measurement may not be representative sites for dry deposition measurement.

SLAMS/NAMS: State or Local Air Monitoring Stations (SLAMS) and National Air Monitoring Stations (NAMS) are federally mandated air quality monitoring networks. They are designed to measure criteria pollutants (characterizing maximum concentrations, population exposure, source impacts, attainment and non-attainment areas. The NAMS network, a subnetwork of SLAMS, is designed to track air quality in urban, multi-source-impacted areas with high population density. These surface air quality measurements will generally be impacted by local and regional sources. The current generation of O_3, NO/NO_x, SO_2 and CO instrumentation used in these networks can deliver virtually continuous data.

PAMS: Photochemical Assessment Monitoring Stations (PAMS) is a small and newer network designed to improve understanding of ozone (O_3). PAMS is intended to provide information for control strategy development and evaluation, emissions tracking, trend analysis, and exposure. It measures O_3, speciated VOC, and NO_x. Speciated VOC and carbonyl compounds currently being measured have minimum sampling times of one hour and three hours respectively. The methods used to measure speciated hydrocarbons and carbonyls in PAMS are still evolving, and quality assurance procedures and standards are still being developed. For example, the NO_2 channel of the NO_x analyzers (like all present generation commercial chemiluminescent NO_x analyzers) suffers from interference by more oxidized forms of NO_x such as HNO_3 and PAN.

SOS: Like PAMS, the Southern Oxidant Study (SOS) provides information primarily on O_3 and its precursors. However, unlike the routine monitoring of the PAMS, SLAMS, and NAMS networks, SOS provides detailed information on interaction between regional and urban O_3 pollution in the southern United States. SOS has included simultaneous and interacting regional- and urban-scale air quality field experiments embedded in a three-tiered network of sub-networks having different levels of spatial and temporal resolution and instrumental and technological sophistication. The network includes:

- Spatial Ozone Network (SON) for continuously monitoring surface O_3 concentrations at some sites
- Southeastern Consortium Intermediate Oxidant Network (SCION) for monitoring O_3, NO, NO_y, HNO_3, CO, SO_2 and speciated hydrocarbon concentrations at a smaller number of sites
- Southeastern Network for Intensive Oxidant Research (SENIOR), which uses state-of-the-science instrumentation to characterize detailed chemistry and chemical processes at a variable number of rural sites in the region during intensive measurement campaigns.

Ecological Monitoring

The response of ecosystems to changes in emissions is still the most elusive piece of the assessment puzzle. Ecosystems rarely show linear changes to management decisions, and as was mentioned earlier, the lags in ecological responses resulting from emission reductions is primarily on the order of decades to centuries (see Figure 7). National ecological monitoring networks are limited, although state-level or regional networks exist in many parts of the country.

Therefore, one of the key roles states and tribal nations can fill is long-term monitoring of water quality and biological parameters. These data are critical in the actual documentation of recovery. Monitoring ecological changes requires a commitment to consistent, long-term monitoring to receive the full benefits of the network. Decision-makers often have difficulty supporting efforts with payoffs 20 years in the future, but without good long-term monitoring data it is impossible to document ecosystem recovery and to verify models. For ecological networks that have been established, it is often a recurring battle to simply maintain the existing network. During budget cuts networks are vulnerable targets often resulting in the loss of monitoring stations, the funds to analyze what data is collected, or other functions of the network. Such changes often compromise the integrity of the entire network. This may explain some of the variability encountered in ecological data sets.

A partial list of parameters which could be measured to document changes due to reductions in deposition include: water chemistry changes; phytoplankton/zooplankton population changes or species presence/absence changes; fish species changes; fish survival in formerly fishless waters; coastal eutrophication; red spruce recovery; decreases in the severity of acidic episodes; decreases in the mercury levels in fish; changes in diatom species found in the surface sediments of lakes. The National Research Council has recently published a book titled *Ecological Indicators for the Nation* (http://books.nap.edu/books/0309068452/html/index.html). The book identifies national level indicators needed for decision making and also shows how the recommended methods can be useful at regional and local scales.

Below is a brief description of those networks referenced in Table 1 including a more complete list of the parameters measured.

Forest Health Monitoring (FHM): Founded in 1990, the multi-agency FHM serves as both the scientific foundation and the administrative framework for collecting, managing, assessing, and reporting forest health information. The goals of the program are to monitor, assess, and report on the long-term status, changes, and trends in forest ecosystem health and sustainability in the U.S. The USDA Forest Service in cooperation manages FHM with other program partners. All measurements are taken annually (June 15-Sept. 15) on a systematic grid of about 4,000 forested ground plots across the nation. A quarter of the plots are measured each year on a four-year cycle.

In addition to the ground plot measurements, detection surveys are conducted. These include aerial and ground-based survey data on forest insects, diseases, and other forest stressors collected by FHM participants, and data from other programs on factors such as climate, weather, air pollution, management practices, and forest growth.

A special aspect of FHM is a network of intensive site ecosystem monitoring sites (ISEM). These are on biologically representative sites such as the Long Term Ecosystem Research (LTER) sites, and are designed to (i) correlate stressors with forest condition, (ii) improve monitoring and evaluation techniques, (iii) identify causal agents, and (iv) improve the estimation of future forest condition.

The FHM measures the following parameters:

- plant species diversity
- bioindicator plants
- lichen communities
- tree mortality
- lichen chemistry
- wildlife habitat
- tree damage
- root condition
- dendrochemistry
- branch evaluation
- leaf area index
- tree regeneration
- vegetation structure
- air pollution
- tree growth
- foliar chemistry
- scenic beauty
- tree crown condition
- dendrochronology
- soils

Long-Term Monitoring Project (LTM): As part of the EPA's ongoing Long-Term Monitoring project, changes in surface water chemistry have been monitored since the early 1980's. Sampling occurs at 45 lakes in the Northeast and Upper Midwest and at 12 streams mainly in the Mid-Atlantic region (lakes in Maine and Vermont; Adirondack and Catskill regions of New York; Michigan, Wisconsin, and Minnesota [MI, WI, MN monitored until 1995]; Virginia streams in the Mid Appalachians; and streams in the Catskill Mountains, New York). Among the factors being monitored are acidity, sulfate concentration and nitrate concentration. Note that LTM data is not available via the internet but can be obtained upon request to EPA (see Table 1).

The Temporally Integrated Monitoring of Ecosystems (TIME) project is a related EPA program to measure water quality in acid-sensitive environments. Sampling occurs at 60 lakes in the Northeast and 60 streams in Mid-Atlantic region. It formed part of the Mid-Atlantic Highlands Assessment (MAHA) to provide a suite of environmental assessment tools.(http://www.epa.gov/emfjulte/html/remap/three/index.html).

Environmental Monitoring and Assessment Program (EMAP): EMAP is an EPA research program designed to develop the tools necessary to monitor and assess the status and trends of the nation's ecological resources. EMAP's goal is to develop the scientific understanding necessary to translate environmental monitoring data from multiple spatial and temporal scales into assessments of ecological condition and forecasts of the future risks. EMAP will develop and demonstrate indicators to monitor the condition of ecological resources, and investigate multi-tier designs that address the acquisition and analysis of multi-scale data including aggregation across tiers and natural resources. Measurements are taken annually at 12,600 sites in the eastern portion of the United States, which include areas of Maryland, Virginia, West Virginia, North Carolina and Pennsylvania. EPA recently announced the initiation of the Western Environmental Monitoring and Assessment Program that began in the summer of 1999 and will run for five years.

EMAP measures the following parameters:

Water:

- discharge
- aquatic biota
- sediment chemistry
- habitat
- sediment load
- inorganic chemistry
- trace metals

Marine/coastal:

- salinity/freshwater flux
- zooplankton
- nutrients/contaminants
- submerged/coastal habitats
- chlorophyll
- animals
- sediment

Soils:

- texture
- toxicity
- structure
- strength
- erodability
- chemistry
- mineralogy
- climate
- faunal biomass

Animals

- species/range/population

Miscellaneous

- landscape pattern

Vegetation

- growth rate
- above-ground biomass
- disease intensity
- recruitment
- species/cover/range
- nutrient availability

Long-Term Ecological Research (LTER): The National Science Foundation established the LTER program in 1980 to support research on long-term ecological phenomena in the United States. The Network now consists of 21 sites representing diverse ecosystems and research emphases. A network office coordinates communication, network publications, and planning activities. The LTER involves more than 1,100 scientists and students investigating ecological processes operating at long time scales (e.g., decades) and over broad spatial scales. The LTER Network is committed to long-term ecological research on the following core areas:

- Pattern and control of primary production
- Spatial and temporal distribution of populations selected to represent trophic structures
- Pattern and control of organic matter accumulation and decomposition in surface layers and sediments
- Patterns of inorganic inputs and movements of nutrients through soils, groundwater and surface waters

LTER measurement increments vary from hourly to annually, based on indicator of interest. Some of the indicators included are listed below:

Climate:
- meteorology
- snow

Precipitation/deposition:
- wet deposition
- dry deposition

Water:
- discharge
- organic contaminants
- inorganic chemistry
- trace metals
- sediment load
- aquatic biota
- sediment chemistry
- habitat

Marine/coastal:
- salinity/freshwater flux
- zooplankton
- nutrients/contaminants
- submerged/coastal habitats
- chlorophyll
- animals
- sediment

Soils:
- texture
- mineralogy
- structure
- chemistry
- climate
- faunal biomass

Vegetation:
- growth rate
- above-ground biomass
- nutrient availability
- recruitment
- species/cover/range

Animals:
- food source/quality
- species/range/population
- recruitment

Miscellaneous:
- fire

National Water-Quality Assessment Program (NAWQA): NAWQA, which is managed by USGS, provides information on water resources in 60 river basins and aquifers which together account for 60 to 70 percent of the nation's water use and population served by public water supplies. The NAWQA goal is to identify the common environmental characteristics associated with the occurrence of key water-quality constituents and to explain their differences. To make the program cost effective and manageable, intensive assessment activities in each of the study units are conducted on a rotational basis, with one-third of the study units being studied intensively at any given time. For each study unit, 3- to 5-year periods of intensive data collection and analysis are alternated with 5- to 6-year periods of less intensive study and monitoring. Coinciding with the study-unit investigations are national synthesis assessments. Generally, two to four national synthesis topics are studied at a given time. Two issues of national priority—the occurrence of nutrients and pesticides in rivers and ground water—were selected as the first issues, followed by the occurrence and distribution of volatile organic compounds (VOCs). Collectively, NAWQA measures:

Water:
- discharge
- organic contaminants
- inorganic chemistry
- trace metals
- sediment load
- aquatic biota
- sediment chemistry
- habitat

Marine/coastal:
- salinity/freshwater flux
- nutrients/contaminants

National Surface Water Survey (NSWS): The National Surface Water Survey (NSWS) sampled the chemistry of 2,311 lakes and 433 streams nation-wide between 1984 and 1986. The objective was to characterize and classify these aquatic systems in terms of their acidic sensitivity, chemistry, biological and bathymetric features. The Survey was divided into the National Lake Survey and the National Stream Survey. Closely related studies included the Long-Term Monitoring Project (1982-present) and the Episodic Response Project (1988-1990). These data are particularly useful as a baseline to compare with more recent data to assess whether any significant changes have taken place since the implementation of the Acid Rain Program.

National Lake Survey. The Eastern Lake Survey - Phase I (ELS-I), conducted in the fall of 1984, was the first part of a long-term effort by the U.S. Environmental Protection Agency National Surface Water Survey. It was designed to quantify the acid-base status of surface waters in the United States in areas expected to exhibit low buffering capacity at a single point in time. The effort was in support of the National Acid Precipitation Assessment Program. The survey involved a three-month field effort in which 1,612 probability sample lakes and 186 special interest lakes in the Northeast, Southeast, and Upper Midwest regions of the United States were sampled.

The Eastern Lake Survey - Phase II (ELS-II), conducted in the spring, summer and fall of 1986, focused on the northeastern United States. ELS-II involved the re-sampling of a subset of lakes in the northeastern United States sampled in ELS-I to determine chemical variability and biological status. Furthermore, within-index period variability was examined in the fall of 1986 to provide insight concerning the ability to detect chemical changes over time, and the precision of the estimates of the number of acidic lakes from Phase I.

The Western Lake Survey-Phase I (WLS-I), conducted in the fall of 1985, involved 719 lakes in the western states (CA, OR, WA, Rocky Mountain states).

The parameters measured in Phase I included: aluminum, alkalinity, acid neutralizing capacity, calcium, dissolved inorganic carbon, dissolved organic carbon, chloride, color, specific conductance, iron, potassium, magnesium, manganese, ammonium, sodium, sulfate, nitrate, pH, total phosphorus, silica, turbidity, water chemistry. The parameters measured in Phase II included: selected re-survey of chemistry survey of Phase I, lake bathymetry, spring, summer, and fall seasonal chemistry, summer chlorophyll, and summer zooplankton species / abundance.

National Stream Survey. The National Stream Survey (NSS-I) primary goals were (1) to determine the percentage, extent (number, length, and drainage area), location, and chemical characteristics of streams in the United States that are presently acidic, or that have low acid neutralizing capacity (ANC) and thus might become acidic in the future, and (2) to identify streams representative of important classes in each region that might be selected for more intensive study or long-term monitoring. The parameters measured included: aluminum, alkalinity, acid neutralizing capacity, calcium, carbonate, color, specific conductance, dissolved inorganic carbon, dissolved organic carbon, bicarbonate, potassium, magnesium, ammonium, sodium, nitrate, total nitrogen, pH, total phosphorus, silica, total suspended solids, and turbidity. NSS datasets can be accessed through the following website: http://www.epa.gov/emfjulte/html/otherdata/napap/nss/index.html

General Steps for Conducting Data Quality Assurance (QA)

Quality assuring data is necessary in order to provide some level of confidence that the data are representing what is actually occurring in the environment. Use of data that has not been formally quality-assured may be necessary when quality-assured data is not adequate or when non-quality-assured data sets useful to the assessment are available. Data that has not been quality-assured should be indicated as such when used and treated cautiously.

Several quality checks can be applied to increase confidence in the data.

- Check with data managers for documentation and informal evaluation of the data base
- Examine the data base for prominent anomalies (e.g. missing data, negatives, spikes)
- Seek explanation for anomalies from data managers
- Fill data gaps or omit periods without reliable information
- Obtain additional formal or informal expert evaluation of the data patterns
- Derive a rough estimate of data uncertainty (e.g. range of error/accuracy/reliability) for the data set

Application of all of these steps would constitute a thorough evaluation of the data set.

The extent to which a data base can be evaluated depends on the assessment needs and the resources available. For scoping assessments, a detailed evaluation of the data as noted above may not be needed. Bringing in additional expert evaluation and development of well-defined uncertainty bounds is less critical. Similarly if resources are very limited, the last two steps may not be feasible. At a minimum, it is important to scan the data for prominent anomalies and omit them to avoid obvious errors in the analysis.

Section VI. Identifying Appropriate Analytical Tools

Relationships between emission changes, pollutant concentrations in the atmosphere, deposition of pollutants and the impact on ecological and other resources can be quantified and predicted through the use of computer models and associated databases. Models range from those that describe links between one receptor area and one source to others that describe the complex regional scale relationships, considering the influence of all major sources and projecting a wide variety of receptor impacts throughout the region. Some models address changes over short time periods such as episodes, others focus on longer time periods, and some attempt to do both. Usually, models focus on one part of the overall assessment. Emission models develop emissions data for input into air quality models. The output of the air quality models are then translated into impacts using a variety of models characterizing human health and ecological welfare and other effects. Selection of the best model framework or best set of models depends on the question being asked. Resources and availability of the models also are factors.

It is important to keep in mind the limitations of modeling. Models are valuable tools that can be used to predict future scenarios or to better understand changing parameters, but they cannot replace actual field measurements that monitor the current status of the environment. Models must be verified and tested against observational data to ensure that they accurately reflect what is measured in the "real world" (this will be discussed in more detail later in this section). This becomes complicated when working with complex models that rely upon outputs from other models. Combining models also multiplies the uncertainty of the final results and can make them less reliable.

A range of models for drawing links between emissions, air concentrations, deposition and impacts are summarized in Table 2. Input data requirements, model outputs, capabilities and limitations, and references for the models are included. This set is not inclusive; rather, it provides models representative of the full range of outputs from emissions to effects.

Air Quality

As described in the previous section, air quality data is available from various national networks. Similarly, deposition data is available from large-scale networks. Trend analysis—examining emission changes and air quality and deposition changes over a period of time—provides a way of exploring how impacts are affected by changes in emissions. When observations are not adequate, either because of the locations of monitors or when the samples were collected, modeling can provide data for the trend analysis. Air quality models are most useful for examining future conditions. A number of models have been evaluated by EPA and are available on the EPA web site. These models range in applications from individual emissions sources to multiple sources and to larger regional scale analysis.

The most comprehensive, extensively evaluated and applied acid deposition model is the Regional Acid Deposition Model (RADM). The model was developed during the 1980s and is used in the NAPAP assessments. RADM continues to be one of the primary modeling systems used to characterize and address acid deposition and related air quality issues in the Eastern US. RADM is also used to predict or project the effectiveness of proposed pollutant reduction legislation on acid deposition and visibility.

One of the applications of RADM has been to develop what are called "principle airsheds." Principle airsheds are conceptual boundaries that separate areas containing sources that deposit efficiently to a particular receptor region from those that do not. Airsheds are different from watersheds, which have actual physical boundaries. Any given source is in a single watershed, but a single source can be in many airsheds depending on how many receptor regions it significantly influences. In addition, sources that are not in a particular receptor region's airshed can still contribute small amounts of deposition to that receptor. Airsheds can be developed for waterbodies, such as the Chesapeake Bay or Albemarle Sound, or for terrestrial ecosystems such as the Adirondack region of New York or Shenandoah National Park. These airsheds do not represent the only

Table 2. Representative Models and Required Data Sources

Model/Data	Key Advantages	Key Limitations	Applicability	Ref.	Input for Ecological Models/Analysis
Emissions (Needed for Trend Analysis Using Data and/or Air Quality Models)					
EPA Trends Data	Comprehensive (all of US)	Averages over time and space	Regional analysis	1	Can be used in direct correlation studies but best used as input into air quality analysis which then relates to ecological analysis of trends and impacts
	Multiple years	Averages over categories	Background for local analysis		
	Extensive QA	Key pollutants only	Long term trends		
County Level Data	More resolution	Accessibility	Detailed subregional analysis	2	
Local Analysis	Source specific	Accessibility	Individual point source studies	2	
Intensive Studies	Details on pollutants	Limited in time and space	Used in complex air quality models		
	In-situ emission measurements	Accessibility	Default for missing emissions	2	
Emissions Modeling	Projections automated	Difficult to use	Comprehensive assessments	3	
	National, 3D gridded coverage		Used in complex air quality models		
Meteorology (Necessary Input for Air Quality Modeling and for some Data Based Trend Analysis)					
STAR data	Multiple years of data available	Limited to monitoring locations	Individual sources/areas	4	Necessary for air quality analysis in support of ecological analysis
Mesoscale modeling	Regional, 3D gridded coverage	Requires experienced user	Regional to national scales	3	
Air Quality (Range of Models--All Can Provide Input for Ecology Models)					Analysis and/or existing modeling data is used.
Models3	Comprehensive chemistry/coverage	Not readily available yet	Regional to national scales	3	Annual possible Regional patterns
	Extensive testing	Requires experienced user	Short term analysis mainly		
ICST	Readily available from web	Highly simplified chemistry	Single source analysis	4	Annual Single source
	Provides annual averages	Only local meteorology	Can examine annual average changes		
RADM	Comprehensive chemistry/coverage	Requires experienced user	Acid Deposition	5	Annual available Regional patterns
	Extensive QA	Set up for eastern US only	Best to use RADM data, not model		
Other EPA models	Variable complexity	Reduced chemistry and meteorology	Variable	6	Variable
Impacts					
Ecological (Requires observations or modeling of pollutant concentrations and deposition, preferably over long time periods)					
Terrestrial Models					
PnET	Robust generic model, includes climate and soils, specific to any forest type and area display, easily adapted to other areas.	Does not model S, N, or ozone except in separate specialized versions	Highly adaptable to include acidic effects in a range of ecosystems	7, 8, 12, 13, 14	

Table 2 Cont.

Model Data	Key Advantages	Key Limitations	Applicability	REF	Input for Ecological Models/Analysis
PnET-CN	Simulates N dynamics, robust simulation of N mineralization, N leaching and N soil saturation	Limited to N, calibrated to Northeast U.S.	Can simulate transient response to biomass removals. Adaptable to other areas and forest types	7	
PnET-O_3	Focuses on ozone effects on forests	Uncertainties remain on O_3 effects on water use efficiency and its effects on growth	Limited to hardwoods	13	
Aquatic Models					
MAGIC	Extensively tested and calibrated in diverse regions of N. America, and Europe, improved recent versions	Does not model N	Widely used, adaptable to variety of lake conditions and experimental uses	9,11	
MAGIC-WAND	Models major N fluxes; being tested and approved	Not as detailed as MERLIN or PnET-CN	Being widely applied/tested	11	
Integrated Assessment Models	Several integrated assessment models were reviewed by NAPAP (1998) that may be relevant to states and tribal nations: These include TAF, RAISON, RAINS, RESGEN, ENEM, DEP, and IMPACT				

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source areas for emissions that impact these receptor regions; rather they represent the area from which emissions are frequently and easily transported to the receptor region.Airsheds are useful conceptual and communications tools but they must be used carefully with a clear understanding of their underlying assumptions.

A selection of RADM results from a recent assessment is provided in the Appendix. The results illustrate how acid deposition, aerosol concentrations and visibility are expected to change as a result of reductions in emissions. The results also provide information that can be used in individual state and tribal assessments of the impacts of proposed legislation on human health and the well-being of ecosystems in their particular regions. The RADM results are described in more detail in the Appendix. Additional information on RADM-derived regional acid deposition impacts for the Eastern US is located at http://www.sph.unc.edu/ies/airpoll.htm.

For those doing assessments west of the Mississippi River, there are two models that can be used: Models-3/CMAQ and REMSAD. Until recently, air quality models typically addressed only single pollutant issues. Models-3/CMAQ (Community Multiscale Air Quality) was developed by EPA's National Exposure Research Laboratory to address the broad scope of the 1990 Amendments and the complex interaction among pollutants. CMAQ is still undergoing evaluation but is expected to be available shortly.

The Models-3 framework provides tools to prepare emissions and meteorological inputs, define emissions control strategies, project future emissions inventories, execute meteorological models, delineate a geographic domain, select alternative atmospheric chemical reaction mechanisms, set vertical and horizontal grid resolutions, and manage a series of air quality model runs. CMAQ is applied through the Models-3 system. CMAQ contains state-of-the-science simulations of atmospheric transport processes, atmospheric chemistry, aerosol dynamics and chemistry, cloud chemistry and dynamics, and deposition processes. A key aspect of the Model-3/CMAQ system's structure is its flexibility to incorporate scientific and modeling advances, to test alternative modeling approaches, and to link with human and ecosystem exposure models. Models-3 is available at http://www.epa.gov/asmdnerl/models/.

REMSAD was developed by ICF Consulting for the US EPA. It is based on an Eulerian (grid) approach and may be applied at scales ranging from a single metropolitan region to a continent containing multiple urban areas. It was designed to be capable of simulating the complex long-range transport and deposition of atmospheric pollutants to aquatic environments, and to assess the relative impacts of alternative control strategies. Although initially developed to study the transport and removal of airborne toxics, the interdependence of the processes which also control the formation and removal of particles was recognized, and therefore the model was designed for both toxics and particulate matter applications. REMSAD is non-proprietary and can be run on a desktop computer. More information about REMSAD is at http://www.epa.gov/ttn/scram/ under "alternative models."

Ecological Impacts

The endpoints of assessments—stream pH, visibility, human health, etc.—are often known as "receptors." Relating changes in emissions to resulting changes in key receptors can be challenging, given the complexity of the environment and the slow pace of changes in ecological systems. Whereas comparisons of emissions and air quality should be made using data from consistent time periods/years; ecological impact models translate concentration and deposition changes into future estimates of ecological changes. Since many ecological changes occur over many years, information from air quality models has to be adapted for use in these longer-term time frames. Make sure that the model you choose to use can provide the correct outputs (e.g. does it provide the streamwater chemistry parameters you need?) and that it can be applied to the correct spatial scale. Many ecological models are designed for small areas, and changes or additional runs may be necessary to extrapolate to the area in question.

MAGIC is one of the models developed to estimate acidification of lakes and streams in response to sulfur deposition is MAGIC (Model of Acidification of Groundwater in Catchments). It was the principal model used by NAPAP to estimate future damage to lakes and streams in the eastern United States. MAGIC is a lumped-parameter model of intermediate complexity, developed to predict the long-term effects of acidic deposition on surface water chemistry. The model simulates soil solution chemistry and surface water chemistry to predict the monthly and annual average concentrations of the major ions in waterbodies. At the heart of MAGIC is the size of the pool of exchangeable base cations in the soil. As the fluxes to and from the pool change over time due to changes in atmospheric deposition, the chemical equilibria between soil and soil solution shift to give changes in surface water chemistry. Although there are some uncertainties with regard to the model, particularly concerning watershed nitrogen dynamics, MAGIC provides a generally accurate, well-tested, and widely accepted tool for modeling the response of surface water chemistry to sulfur deposition.

PnET-BGC is an integrated model that simulates the concentrations and transport of major elements, including nitrogen, in forest vegetation, soil, and water. The model was formulated by linking two submodels to allow for the simultaneous simulation of major element cycles in forest and interconnected aquatic ecosystems. These submodels include 1) PnET, a simple generalized model of monthly carbon, water, and nitrogen balances which provides estimates of net primary productivity, nitrogen uptake, and water balances (Aber et al 1997; Aber and Driscoll 1997); and 2) BGC, a new submodel which expands PnET to include vegetation and organic matter interactions of other elements (including calcium, magnesium, potassium, sodium, silica, sulfur, phosphorous, aluminum, and chloride), abiotic soil processes, solution speciation, and surface water process. PnET-BGC uses measured and estimated data on meteorology and atmospheric deposition. The model is run for several hundred model years prior to the advent of anthropogenic deposition to allow the forest, soil, and water to come to steady-state conditions. The model simulates estimates of changes in atmospheric deposition from 1850 to the present day. Future scenarios of changes in atmospheric deposition are simulated using projections provided from simulations with the Regional Acid Deposition Model (RADM) based on model runs of air emission control scenarios.

General Steps for Conducting Model Quality Assurance

Many standard models have been documented and evaluated for use in various applications. Models that have not been thoroughly tested but are considered appropriate for the assessment can be evaluated using a hierarchy of methods. The most familiar approach is direct comparison with observational data. This approach, however, is often not adequate for evaluating models because the necessary observational data may not be available or may not be strict enough for testing the model for a specific application. Often the observational data itself may already be earmarked for use with the model in doing the assessment.

Several steps can be applied to gain further confidence in the model:

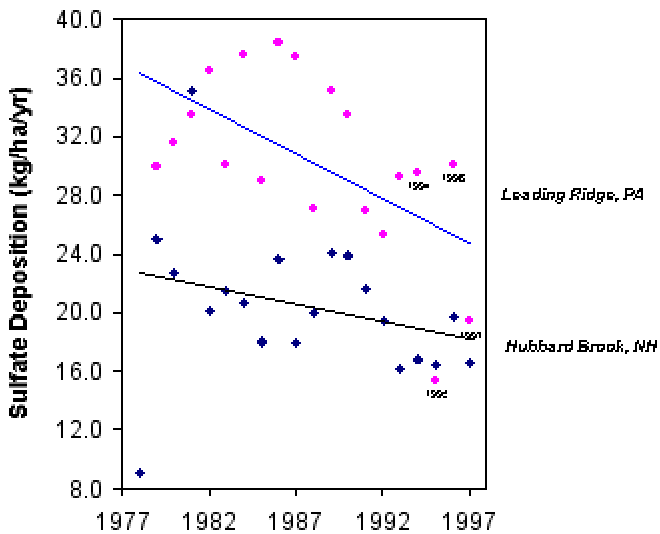
- Compare model results with observational data if the observational data is available.
- Examine the extent to which models and observations produce the same associations among key variables.
- Check how appropriately the model responds to changes in key input parameters such as emissions.
- Examine documentation to see how the model is behaving in simulating key variables compared to simulations of other model studies.
- Check scientific and technical reviews if available to see how well the model integrates current scientific knowledge for the current application purposes.
- Seek expert reviews of the models.

All of these steps performed together would constitute a thorough review of the model. In cases where this level of evaluation is not needed, as in a scoping study or where resources are not available for an in-depth evaluation, then a limited evaluation should be done. At a minimum, the model should be executed for a variety of conditions to check how robust it is under a range of parameter values, such as emissions, that are relevant to the assessment questions.

Section VII. Integrating Information to Assess Response

Assessing the effectiveness of the Acid Rain Program requires the ability to relate changes in emissions to changes in deposition and to changes in sensitive receptors. An assessment can focus on any one of these steps, or it can be integrated and look at all of them. The end-goal of the technical analysis is to evaluate how well current emission control efforts work in reducing human and environmental impacts and to facilitate and assess the potential need for further actions. These assessments will almost certainly receive public scrutiny, and must be able to withstand the normal processes of evaluating financial and other costs associated with proposed management actions. In addition, it will be important to establish the level of certainty that can be placed on the finding. This section illustrates possible methods of analyzing spatial and temporal patterns and then relating these patterns and changes to ecological impacts using statistical and other assessment techniques.

Figure 11. Sulfate Deposition at Two NADP Sites from 1978 to 1997.



Source: NADP website (http://nadp.sws.uiuc.edu/)

Analyzing Spatial and Temporal Patterns. Changes in spatial patterns, often illustrated using GIS (Geographic Information System) maps and time series trends, expressed in graphical formats, provide a useful indicator of the effects and of the effectiveness of the Title IV. Ideally, pre-regulatory concentrations, emissions and deposition data will be obtained and used for comparison and quantification of the magnitude of changes. At the national scale there was a large decrease in sulfur dioxide emissions during the 1970's and early 1980's, with additional decreases in the 1990s. About a 30% reduction occurred in the eastern U.S. between 1980 and 1995. This is due in part to the fact that utility companies had already started to reduce their emissions of sulfur dioxide. If the site is located in the eastern U.S., data may show a dramatic decrease in SO_2 emissions in 1995, which is consistent with the first year of compliance under Title IV.

Trend analysis should be done over several years; year-to-year trends are often "noise" and not reliable in the long-term. However, a comparison of national deposition maps from 1994 versus 1995 displays the expected drop in overall SO_2 concentration and sulfate deposition expected from the large reductions in sulfur dioxide emissions that took place in 1995.

This relationship is even more apparent when comparing the longer-term trend in deposition between 1980 and 2000. The 1994-1995 drop in total annual sulfate deposition in response to Title IV regulations stands out in Figure 11 above. Monitoring data from Leading Ridge, PA showed an especially marked drop in 1995. In addition to temporal variability, there is spatial variability in the response as well. The response of deposition to emissions followed a somewhat different pattern at Hubbard Brook, NH, but a sharp reduction after Title IV took effect is still apparent.

Bivariate Relationships. Bivariate plots are often used to examine the relationship between emissions (e.g., SO_2 emissions on the x-axis) and the concentrations and/or total deposition of the acid derivative sulfate (SO_4^{-2}) in precipitation (on the y-axis). In the example above, Driscoll et al. (1998a) found a linear relationship accounting for half of the variation (where $r^2 = 0.48$ to 0.62) at the Hubbard Brook Watershed in New Hampshire. This implies that cutting emissions will, with a 48-62% certainty, result in a proportional decrease in rain and stream concentrations of sulfate.

To further illustrate these analysis techniques, dNADP sulfur and precipitation data was downloaded from the NADP website (http://nadp.sws.uiuc.edu/). The data was plotted using maps, time series, and bivariate graphs to facilitate the analysis.

There is a known positive relation between the annual total precipitation and the total deposition. At the PA and NH locations cited above, however, the relationship for the 1978 to 1997 period is not a particularly strong one, or at least highly variable as you can see (Figure 12).

The precipitation/SO_4 deposition relationship has several implications: (i) the significantly higher precipitation at the PA station in 1996 (32% increase, or a total of 152.4 mm ppt) compared to 1995 (115.8 mm ppt) can explain much of the increased total annual SO_4 deposition in 1996 relative to the year earlier; (ii) the total annual SO_4 deposition dropped in 1997 compared to 1996 and was similar to that of 1995; this was consistent with the total precipitation in 1997 (107.2 mm ppt) being similar to that in 1995; and (iii) the total annual precipitation in 1994 (106.0 mm ppt) was similar to that of 1995, discounting the likelihood that the 1994 –1995 drop in SO_4 deposition was due to a difference in rainfall between those years.

Integrated Analysis. Another common analysis technique involves plotting the emissions over a one to three-decade interval simultaneously with ambient air concentrations, total deposition rates, and typically, a response such as change in water chemistry or soil cation base capacity. Likens et al (1996), Driscoll et al (1993, 1995, 1998a), Lawrence et al (1995), and Shortle et al. (1997) provide examples of this approach.

In Figure 13, annual average levels of the ambient air SO_2 concentration (Allegheny County, PA), the SO_4 deposition rate (Leading Ridge, PA), and the streamwater SO_4 concentration (Young Woman's Creek at Renovo, PA) are plotted simultaneously over the 1977 to 1997 interval.

This integrated analysis example shows a direct

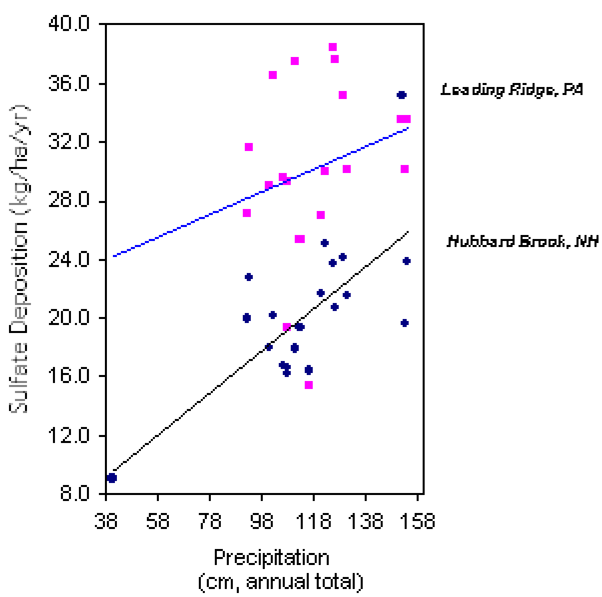
Essential Steps for Integrating Data

Define the key questions and the needs of the manager/decision maker. The key questions identified in Section IV form the focus of the analysis of the scientific data and related information. The assessment is designed to support the evaluation and decision-making processes.

Acquire and analyze necessary emissions, concentration, and deposition data. This is the vital first step in analyzing the impact of changes in emissions in response to Title IV. Establishing these relationships is important since there is generally good supporting evidence (NAPAP, 1990) that reductions in emissions are reflected "downstream" (e.g., decreased air concentrations and deposition rates of acidic compounds).

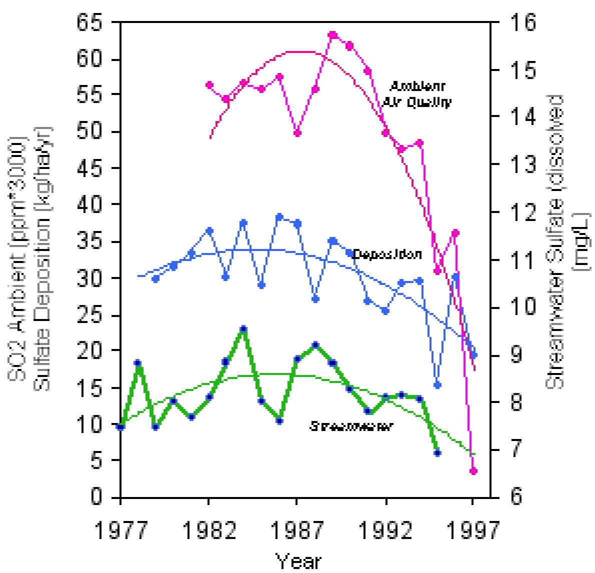
Acquire and analyze ecosystem data. Acquisition and analysis of ecosystem data is the next, and perhaps more challenging, step. Data on explicit ecosystem indicators are limited and linking impacts to deposition requires integration of information on different temporal scales possibly covering large source areas.

Figure 12. Relationship Between Sulfur Deposition and Precipitation at Two NADP Sites Over the 1978-1997 Interval.



Source: NADP website (http://nadp.sws.uiuc.edu/)

Figure 13. A Comparison of Ambient Air Quality, Deposition, and Streamwater Data from 1977-1997 at Selected Sites in Pennsylvania.



Sources:

Ambient air SO_2: http://www.epa.gov/aqspubl1/annual_summary.html

Deposition Rate SO_4:

http://nadp.sws.uiuc.edu/nadpdata/siteinfo.asp?id=PA42&net=NADP

Streamwater SO_4 Concentration:

http://wwwrvares.er.usgs.gov/wqn96cd/wqn/wq/formats/wq.fmt

comparison between changes that occurred along the sequence of emission to air quality to deposition to stream response. It also illustrated the relative ease of access to websites with acid rain data, and of the limitations and difficulties likely to be encountered.

Limitations of Using Web Databases

Some of the limitations and difficulty in using the Web databases, such as those used in these analyses, are as follows:

Changing analysis methods. In the case of some parameters, the laboratory methods changed over the two-decade interval so that values were not strictly comparable, and strict continuity was lost. Contact with the database manager proved valuable / necessary where choices had to be made and/or where questions arose as to the significance of sampling or laboratory methods changes.

Monitoring locations. The location of sample sites and/or summary area (as in the case of the county average used for ambient air quality) were not spatially consistent, e.g., data were not necessarily available for any one geographical location of interest.

Years for which data is available. The selected starting and ending dates limited the number of sites for which the analysis could be done; not all stations selected started in our year of choice (1997). The data on streamwater values for 1996 and 1997 were not on the Web and were accessed by calling the USGS database manager.

Annual averages. The number of samples and/or the months of observations to represent an annual average varied in all cases, suggesting that a robust analysis would require considerable commitment of time and access to appropriate statistical expertise.

Locating the correct database. A considerable fraction of the time (e.g., half to two-thirds) to complete the analysis and construct the graphs was spent in locating and accessing the appropriate databases. Although a large potential choice exists, the number of suitable databases ***were*** narrowed to a smaller number in practice.

Confidence intervals. Statistical confidence (e.g., sd, se, range) of each sample point was not explicit / immediately available, but could probably be obtained by accessing the original sample data.

These and other analytical challenges have been discussed for this kind of integration by Clow et al (1999: ftp://bqsnt.cr.usgs.gov/manilles/Clowfact3.pdf). Their results are encouraging since they were able to observe clear responses to emissions reductions when long time series were used and where the data had been rigorously screened and appropriately transformed to achieve methods consistency.

Even with the very rudimentary analysis in the "test" illustration of Figure 13, some consistency in the deposition and streamwater response to decreasing ambient SO_2 levels can be discerned. The sharp changes in 1995 in response to Title IV regulations are unambiguous in all cases. Note that the vertical scales differ between the three parameters and can influence the apparent degree of change. To achieve simplicity of scale, the ambient air quality was multiplied by 3,000. This has the effect that the marked air quality response may be somewhat exaggerated relative to the deposition and streamwater trends. Microsoft Excel (and other graphics routines) enable the user considerable flexibility in scaling final presentations. Trend lines can be added; those shown are second order polynomials. Correlations and other statistics are easily achieved. The correlations between air quality and deposition, for example, was r =0.65; between air quality and streamwater response, r = 0.51. Although the correlation between deposition and streamwater was significant (also r = 0.51), the soils in the watershed are likely to strongly influence the degree of response depending on the extent to which sulfur oxides are retained in soil and vegetation.

Section VIII. Communicating Results

Effective communication with key people and organizations is a critical element in the success of ecological assessments. A communication strategy is necessary to make sure the important information gets to diverse audiences and to integrate varied approaches and formats for effective communication. A highly effective method for designing a communication strategy is based on two steps: (1) assessing communication needs and potential responses, and (2) developing detailed guidelines for implementing the most effective responses.

The needs assessment and guidelines for responses are based on the answers to four questions:

- WHO do the assessment managers need to communicate with?
- WHY do the assessment managers need to communicate with them?
- WHAT information must be communicated?
- HOW can it be communicated most effectively?

The answers to the "who, why, and what" questions are developed through discussions with scientists, managers, policy makers and other key people. Those answers provide a starting point for developing the "how" answers. These questions and answers provide an analytical matrix for defining the assessment managers' communication goals and the most effective ways to accomplish them.

The "WHO" answers enable the assessment managers to target the most relevant audiences instead of dissipating their resources in communication efforts that are too broad or diffuse. In most situations where state and tribal agencies are assessing ecological responses to emission reductions achieved under the Acid Rain Control Program, the most important audiences will be policy makers, such as members of state legislatures, Congress, and the general public. However, it is important not to overlook other key groups such as environmental advocacy organizations and industry trade groups.

The "WHY" answers must provide precise definitions of the various and sometimes diverse goals of the dissemination effort in order to determine what information must be communicated. For example, one goal may be to increase the general public's awareness of the broad problems involved in an environmental policy issue, while another may be to inform legislators about assessment results related to a bill that is being considered.

The "WHAT" answers must propose various types and levels of information that are needed to achieve the goals that have been defined. For example, broad explanations of ecological problems and general policy options may be presented to the general public, while detailed scientific conclusions related to specific provisions of a particular bill may be more useful to legislators.

The "HOW" answers will provide detailed guidelines for implementing the communication strategy. Once the "WHO", "WHY" and "WHAT" have been defined, the services of an experienced communication professional can be very valuable in selecting the most effective communication media and methods to reach precisely targeted audiences with carefully selected information. For example, the best ways to communicate with the citizens of a densely populated eastern state may be quite different from those that will most effectively reach the members of a tribe scattered across a western tribal nation.

A well-designed strategy will define the assessment managers' communication needs and provide a prioritized list of specific responses to those needs. It also will specify the professional skills and experience needed to implement the responses effectively. It will provide managers and those who have been assigned day-to-day responsibility for communication with the necessary information and resources to organize, oversee, and carry out communication activities knowledgeably and effectively.

Section IX. Examples of State-level Ecological Assessments

Minnesota

The Minnesota Department of Natural Resources (DNR) has developed tools (e.g., Geographic Information Systems, Ecological Classification Systems, environmental indicators, and biological surveys) that describe and predict how resources interact within ecosystems, and how they respond to human uses. The DNR is applying these tools over large geographic areas over long time frames. One program that has emerged from this is the Minnesota Environmental Indicators Initiative (EII). This project will create the framework for an integrated, statewide network for selecting and monitoring environmental indicators. The EII will provide the first statewide network for (1) understanding and forecasting ecosystem health status and trends, (2) assessing the ability of ecological systems to provide resource benefits, (3) anticipating emerging environmental problems, and (4) monitoring progress in maintaining and restoring ecosystems.

(http://www.dnr.state.mn.us/eii/)

Vermont

The Vermont Forest Ecosystem Monitoring (VForEM) is a network of cooperators from government, academic and private sectors who gather and pool information on Vermont's forest ecosystem. Using a multi-disciplinary approach to understanding forest ecosystems, over 40 cooperators from various disciplines work together at two sites, Mount Mansfield and the Lye Brook Wilderness Area, to integrate research and monitoring programs. This includes the integration of data from multiple data sets maintained in the VForEM Data Library, and results in a holistic view of ecosystems. VForEM projects fall into six general categories:

- Terrestrial Flora
- Terrestrial Fauna
- Surface Water
- Atmosphere
- Geology and Soils
- Human Impact

(http://www.uvm.edu/~snrdept/VMC/index.html)

Maryland

In 1987, the Maryland Department of Natural Resources designed the Maryland Biological Stream Survey (MBSS) to provide information on the ecological consequences of acid deposition and other human-related impacts. MBSS is a long-term monitoring program designed to describe the current status of aquatic biota, physical habitat and water quality in first, second, and third order non-tidal streams. MBSS data will also be used to identify probable causes of ecological degradation, investigate relationships between human activities and ecological response, and identify areas in need of protection or restoration. Approximately 1,000 sites were sampled between 1995 and 1997. Monitoring parameters include the following:

- pH
- Sulfate
- Nitrate
- Conductivity
- Temperature
- Dissolved Oxygen
- Dissolved Organic Carbon
- Acid Neutralizing Capacity

(http://www.dnr.state.md.us/streams/acid/index.html)

Maine

Maine's Department of Environmental Protection is in the last stages of an assessment done in collaboration with the Northeast States for Coordinated Air Use Management (NESCAUM) and EPA's Clean Aire Markets Division. The assessment used the RADM model to correlate sulfate and nitrate deposition in New England with upwind emissions. Due to the variability in data of one or a few deposition monitoring sites, this assessment chose a regional analysis of sulfate and nitrate deposition of the New England area. Total precipitation and total deposition data sets were combined and normalized to a mean of 1 (Shannon, 1999). Analyses indicate a correlation between emissions and a drop in sulfate deposition, but there was no change in nitrate deposition. Further analysis indicates a positive correlation between the decrease in sulfate deposition in New England and a change in lake chemistry in Maine.

(http://www.state.me.us/dep)

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Appendix A. Frequently-Raised Issues and Questions

This section discusses some of the questions that are frequently raised when conducting assessments of acid deposition. It is useful to be aware of these issue from the beginning, so as to take them into account when designing and conducting the assessment as well as communicating the results.

Emissions, Concentration, and Deposition Analysis Considerations

The following notable issues, complications, and data limitations and other constraints have implications on how the data can be interpreted.

Only a portion of acid deposition precursors are currently being controlled. Although the largest emitting power plants were controlled under Phase I in 1995, a larger number of utilities did not come into compliance until 2000 when Phase II began and controls on Phase I sources were tightened further. However, other chemical species such as NO_x are not as aggressively controlled under Title IV and still others such as ammonium (NH_4) not at all. The result is that only a portion of total acidity is being reduced by Title IV, therefore, any analysis is unlikely to document a complete ecosystem response.

Methods of measurement of S and N deposition are variable, and some nitrogen deposition data is thought to be underestimated. The difficulty in accurately measuring and modeling deposition, particularly of nitrogen compounds, remains a large obstacle to accurately quantifying actual acidity impacts. Wet deposition sites are located away from local emissions sources (e.g., major highways, chemical factories, cattle, hog and chicken farms, and fertilizer applications) in order to be as regionally representative as possible.

Evaluations of nitric acid based on ozone behavior as a surrogate indicate that dry deposition measurements of nitrogen may underestimate actual rates by as much as 30% during the summer, depending on the site. In addition, nitrogen deposition measurements do not include ammonia and organic nitrogen, which may further underestimate total nitrogen deposition loads. In addition, NADP measures NH_4 somewhat inaccurately; values may be underestimated by as much as 15%.

Both of these inaccuracies tend to underestimate nitrogen depositon, so current nitrogen deposition estimates can be considered conservative. Since any underestimations apply universally across the entire data record, they should not affect the trends in deposition but could affect analyses of environmental response (NAPAP, 1990).

Dry deposition is very condition and site specific, and models do not currently exist that can accurately quantify the variations. Therefore, some modelers make the assumption that total deposition is twice that of wet deposition. If wet deposition of S or N is 20 kg/ha/yr, for example, the total deposition is estimated to be 40 kg/ha/yr. By deduction, the dry deposition component is assumed to be 20 kg/ha/yr. Studies show, however, that numerous factors influence the dry deposition rate and a uniform assumption is unwarranted. For example over the extent of the Chesapeake Bay, it is typically assumed that dry deposition is uniform, but the reality is that it is dependent on precipitation, wind, temperature, and water currents; these all vary greatly from north to south over the length of the Bay.

Experimental work on throughfall deposition (including gaseous, aerosol, particulate fractions of dry deposition) under a tree canopy shows that a significant amount of sulfur is deposited in the forest stand (e.g., a dramatic increase in sulfur relative to samples obtained above the canopy). There are also large differences in deposition rates between conifer and hardwood forest types. Both wet and dry deposition increase as the elevation increases.

There is a significant unknown source of sulfur at most sites in the Northeast U.S. Driscoll et al. have found a discrepancy in the S budget at most intensively sampled locations in the Northeast U.S. The quantities of output of sulfur in streamwater are larger than the measured inputs of sulfur in precipitation, suggesting a significant unknown S source. Three possible sources of the “unknown sulfur” were hypothesized: sulfur stored on S-absorbing sites in soils and sediments at the time of high S deposition are being "bled out" or leached; underestimates of dry S deposition; and mineralization of S from naturally occurring minerals. Investigations to date indicate that the first hypothesis is not supported by data. The error in dry deposition would have to be on the order of 2-3 fold. While possible, this appears to be unlikely. Mineralization of sulfur from naturally occurring minerals was tested using isotopes and papers to be the likely source. The preponderance of 150 sites sampled by EPA in 1990 show this phenomenon. Among 50 sites examined in the Adirondacks all (except for a few with large wetlands) show a sulfur surplus.

Climate is a major factor influencing deposition rates and can explain a significant part of the observed pattern over the last three years. Climate, notably the year-to-year changes in temperature and precipitation, is a significant factor affecting deposition rates. Title IV changes alone do not explain all of the variation in measured deposition and concentration. In Ohio, the total precipitation in 1995, 1996, and 1997 has been higher than the 15-year average and this can explain the higher than expected S and N deposition rates observed. Not only is concentration affected; total S and N deposition is a function of the amount of rainfall. The total precipitation has been going up at many eastern U.S. stations. Moreover, the high precipitation levels typical of high elevation mountain sites has meant that there has been little change so far in the total S deposition in response to Title IV. The higher temperatures at many stations in the eastern U.S. is also a factor since temperature influences the oxidation rate of SO_2 in the atmosphere. As was noted earlier SO_2 concentrations have come down by about 20%.

The time-scale and integration interval of the analysis is very important. Currently, recovery in response to Title IV, as measured by increased acid neutralizing capacity, is not being observed in most lakes and streams (Driscoll et al. 1998a, 1998b). The exception is New England lakes where signs of recovery are being observed. Soils and sediments have been sinks of S and N over several decades and it will be some time before the S and N leach out. The process of replacing the lost Ca, Mg, and cation base capacity is a geological process on the scale of decades and centuries. There is a need to recognize that different ecosystems and different processes may respond to deposition changes on various time scales, some more easily measured than others. In addition, sublethal, but persistent (chronic) effects of acidity stresses are now recognized to be as important as the direct, lethal, short-term or acute effects.

A long integration interval (e.g., one year) needs to be used when samples of N are being averaged from different monitoring networks. The problem is that although laboratory procedures are identical, the field monitoring procedures for N are not, so that values differ and cannot be averaged across multiple stations. While S is not affected in this way, nitrate levels cannot be simply averaged without correction factors. A long integration time helps somewhat to modulate any bias of different sampling procedures.

The spatial scale is very important; responses may not be uniform. There is not a uniform response or uniform recovery associated with Title IV or other programs. Some parts of New England., for example, are exhibiting signs of recovery, yet other parts of the eastern U.S. show no signs of recovery or even continue to degrade.

NADP was established to show region to region differences in the acidity of wet deposition. State or tribal nation scales will require much more detail than the NADP data are designed to provide. The appropriate unit of ecological analysis is the watershed, again on a much smaller scale than called for by the NADP sampling design. A model developed at Pennsylvania State University estimates the deposition on a 100 meter scale by including the National Weather Service and other meteorological data from the National Oceanic and Atmospheric Administration, high resolution topography data, vegetation cover, etc. The result is a highly detailed map that shows the considerable variation in deposition rates from one location to another. If a relatively small area is being studied, national monitoring data such as NADP may have limited utility.

Sensitivity of the ecosystem versus resolution of the data is important. The degree of sensitivity of ecosystem parameters and processes makes a difference in the scale of precision required in the deposition data.

Ecosystem Analysis Issues

The following notable issues, complications, and data limitations and other constraints have implications on how the data can be interpreted.

Typical Ecosystem Indicators. Some ecosystem components or processes are being monitored that are directly sensitive to acidic deposition. The following parameters, among others, are being monitored as indicators of acidic deposition effects: lichen communities, air quality bioindicators, soil base cations, acid neutralizing capacity, soil aluminum/calcium ratio, streamwater or lake chemistry (pH, sum of base cations, Ca, Mg, SO_4, NO_3), benthic macro-invertebrates, and fish populations.

Another source of data on indicators is a wide spectrum of biological data collected outside the acid rain monitoring network but of potential interest and utility in addressing certain policy questions, such as data collected as part of the Long Term Ecological Research Program (see Table 1).

Statistical Analyses. The kinds of statistical analyses and tests applied to the data will depend on the nature and complexity of the air quality–response links being explored. Bivariate graphs and time series frequently appear in the assessment literature. Shortle and Bondietti (1992) and Likens et al (1996) are examples of recent studies that examined the relationship between acid deposition rates and flux of base cations in soil, and in streamwater, respectively. Multivariate analyses (e.g., factor analysis, multiple regression) are less commonly reported in the literature, but present an effective option when examining several environmental parameters simultaneously.

There are some problems and outstanding questions about the methods and the databases that may have significant impacts on the interpretation of results. Among those noted in discussions with scientists are:

- the potential impacts of repeated re-sampling
- the importance of the timing of (re-)measurements
- high spatial variation and need for comparison across spatial gradients
- the difficulty in establishing true controls (e.g., before or after acid rain impacts; or acid rain versus non-acid rain regimes for comparison of identical sites)
- the need to define recovery
- the presence of unknown manmade or natural sources of sulfur and nitrogen

Ecological Models. Models offer an opportunity to examine some kinds of deposition responses that are difficult to measure or observe in the field such as long response times, subtle or transient effects, and spatial and temporal patterns that are difficult to monitor and map with sufficient resolution. They also offer the opportunity for experimentation by internal modeling exercises using constructs in the place of real world data. Some models already developed and available for analyzing acid rain effects are enumerated in Section VI. It will be important to determine what models are available and which may be of use in your assessment.

Most models need specific kinds of input data, and generate specific kinds of output (e.g., ecosystem responses) based on a set of assumptions about how the external influences affect key processes within the ecosystem. Assuming a model exists that can address the policy questions, it will be important to obtain documentation of the model, and articles describing its application to specific problems or issues.

The following key issues should also be kept in mind when conducting an ecological assessment.

Ecological changes may be due to many factors, and attributing the cause to decreasing atmospheric deposition will require good scientific monitoring data. There is a growing awareness that other factors may be playing a role in ecosystem effects. Organic pollutants such as trizene and atrazene, widely used in agriculture, are suspected by some scientists to be a factor in amphibian declines in the Northeast, for example. The skin of frogs is highly absorbent of these chemicals.

A suite of indicators is necessary to capture the full effects of changing acidic deposition on ecosystems. There is definitely a move away from single-factor evaluations (e.g., stream water chemical quality) toward indicators based on a multiplicity of interactions. Several experts from different disciplines may be involved. Managers need a broad integration of many component responses in order to make robust decisions. It is true that the broader analysis is perhaps less "rigorous" and precise scientifically than a narrowly taken approach on one or more parameters. However, a broad analysis can often describe the full range of ecosystem responses more accurately and lead to better-informed management decisions.

How many and what indicators should be used? There is no precise answer to this question. It varies depending on the data and resources available, and generally all desired indicators cannot be included. In discussions developing this Handbook, one scientist indicated "I am not suggesting hundreds but a selection of 6-12. The problem is that if you put a team of reviewers in a room, there would be a range of different perceptions on what the 6-12 indicators should be, and no consensus." Ecological assessments are still an evolving process.

In developing a comprehensive assessment, would the aquatic system be a good place to start? The development of an effective protocol to do an assessment is a huge and extremely difficult problem to tackle. A few key mechanisms can be identified; however, this is not the whole picture. There is the most information available on the aquatic side, so that is usually a good place to start. There is a sense that aquatic scientists are getting close to agreeing on a set of indicator species.

It is true that the data and the models for quantifying links between deposition and stream chemistry, and especially those between stream chemistry and the biological responses (invertebrates, fish) are good. These links are much better resolved than the terrestrial soil chemistry-tree responses.

Given that it is possible to develop a good assessment procedure and model for the aquatic ecosystem, the rhetorical question is how much confidence do you, the manager, and the end-users need in the assessment?

Despite the fact that these questions remain, managers cannot wait for perfect assessment designs or complete scientific consensus before taking action.

Appendix B. Sample Integrated Assessment

The modeling results presented here include analysis of total annual deposition, total annual mean aerosol concentrations and visibility for emission scenarios related to new and existing legislation. The Regional Acid Deposition Model (RADM) was used to model sulfur and nitrogen deposition and the Regional Particulate Model (RPM) was used to model particulates in order to calculate visibility. The results illustrate possible acid deposition and visibility changes in the future throughout the Eastern US. Results are presented on the standard 80 by 80-kilometer RADM grid.

Inspection of these maps provides a way to estimate potential changes in impacts related to deposition, aerosol concentrations and visibility within the individual grids. For example, a change in sulfate deposition within a grid can be translated into anticipated ecosystem responses in the grid some time in the future.

Background

This analysis was requested when legislation was proposed during the 106th Congress called Senate Bill S. 172. This legislation focuses on utility emissions because they account for about two-thirds of the total SO_2 emissions and one-third of the NO_x emissions in the United States. In addition, available control options and the costs associated with particular control scenarios are well understood (U.S. EPA 1998).

Emission inventories were developed for each scenario. EPA analyzed impacts of the full S. 172 bill and its components on acid deposition and visibility in the Eastern U.S. in 2010. Results of the major deposition, aerosol concentrations and visibility parameters for the East are presented here.

Scenarios. The following three scenarios were chosen for air quality and deposition modeling:

- **1990 Base.** The base case reflects emission conditions as they were in 1990. The emissions profile was derived from the EPA section 812 prospective study, *The Benefits and Costs of the Clean Air Act, 1990-2010* which examines the costs and benefits for air quality legislation for the next 10 years. More detail on how this inventory was developed is available in the study itself.

- **2010 Base (S-172) or Existing Clean Air Act (Title IV) Only**. The 2010 Base assumes full implementation of Title IV controls, and no additional controls from other emissions reduction programs affecting electric utility units.

- **2010 Full (S-172) or Existing Clean Air Act (Title IV) Plus Additional SO_2 and NO_X.** This scenario assumes the same conditions as in the 2010 Base plus addition controls on SO_x and NO_x as outlined in S172.

Results

The results are presented in graphical format and are grouped into acid deposition and visibility analyses.

The acid deposition analysis includes:

- Deposition: Sulfate and nitrate deposition for the three scenarios.
- Percent Change in Deposition: Percent changes in the base 1990 year and the two 2010 scenarios for sulfate and nitrate total deposition.

The visibility analysis includes:

- Aerosol Concentrations: Total aerosol concentration expressed by sum of sulfate, nitrate and ammonium aerosols for the three scenario years.
- Percent Change in Concentrations: Percent changes in total aerosol concentration for the three scenarios.
- Percent Change in Visibility: Percent changes in visibility calculated from the aerosol concentrations for the three scenarios.

Analysis of the information is provided. Guidance on how to interpret the information and use it in an assessment also is noted.

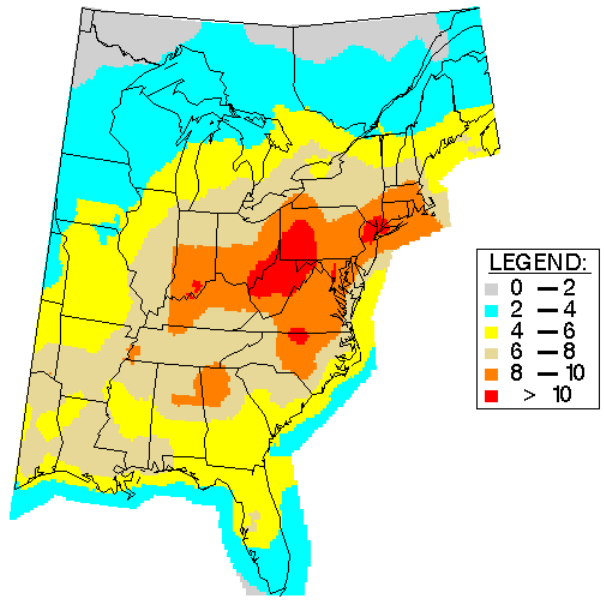
This air quality and deposition modeling was done using RADM, the aerosol and visibility modeling also included a component called RPM. When this is the case, the headers include the term RPM.

Acid Deposition Analysis

The first six maps represent the annual total deposition (wet and dry) for the three scenarios for nitrogen and for sulfur. The three graphs on this page depict nitrogen deposition in 1990, in 2010 with Title IV only, and in 2010 with Title IV and S-172. Deposition is expressed in kilograms nitrogen per hectare per year.

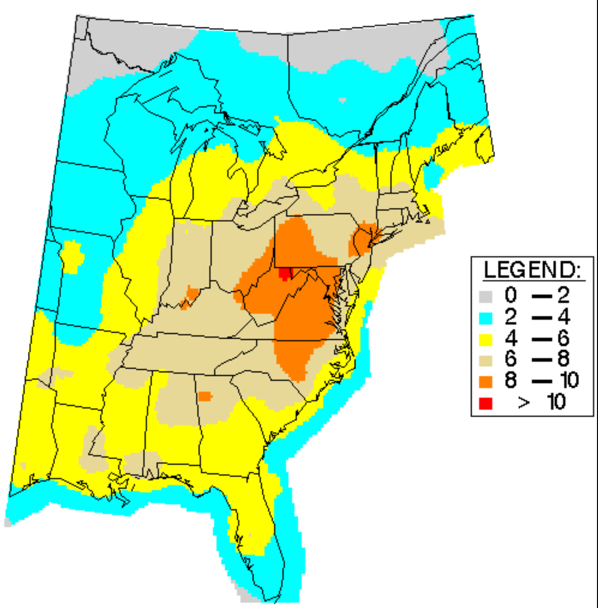
The highest nitrogen deposition levels are in the Ohio River Valley and areas to the east. Nitrogen deposition would decrease from over 10 kg-N/ha/yr in the Ohio River Valley in 1990 to 6-8 kg-N/ha/yr in 2010 if S-172 were implemented.

Annual Oxidized Nitrogen (NOx) Deposition in 1990 (kg-N/ha/yr)



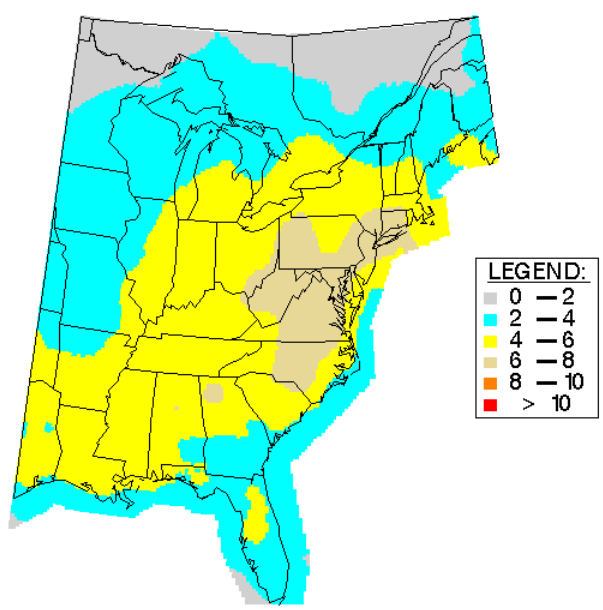
Source: Regional Acid Deposition Model (RADM)

Annual Oxidized Nitrogen (NOx) Deposition in 2010 with Implementation of Title IV only (kg-N/ha/yr)



Source: Regional Acid Deposition Model (RADM)

Annual Oxidized Nitrogen (NOx) Deposition in 2010 with Implementation of Title IV and S-172 (kg-N/ha/yr)

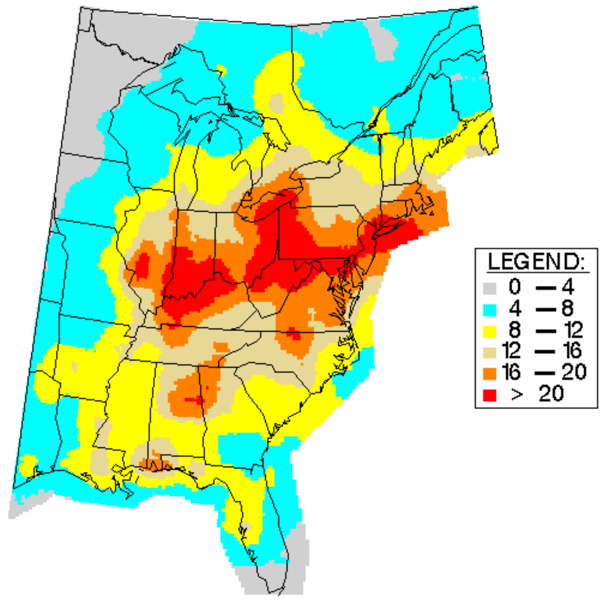


Source: Regional Acid Deposition Model (RADM)

The following three maps show sulfur deposition in 1990, in 2010 with Title IV only, and in 2010 with S-172. Deposition is expressed in kilograms sulfur per hectare per year.

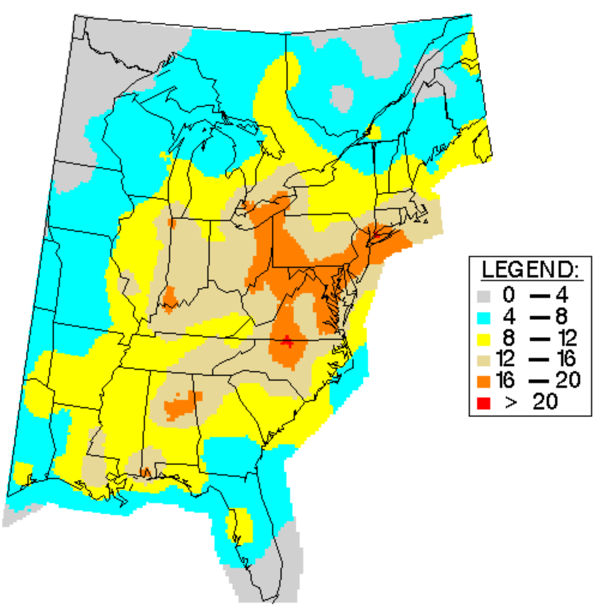
As illustrated, sulfate deposition is generally highest in the Ohio river valley and to the east of this area. The sulfate deposition load would decrease in those mid-west areas of highest deposition from more than 20 kg-S/ha/yr in 1990 to 12-16 kg-S/ha/yr in 2010 if S-172 were implemented. Title IV provides an intermediate level of reduction in deposition.

Annual Total Sulfur (S) Deposition in 1990 (kg-S/ha/yr)



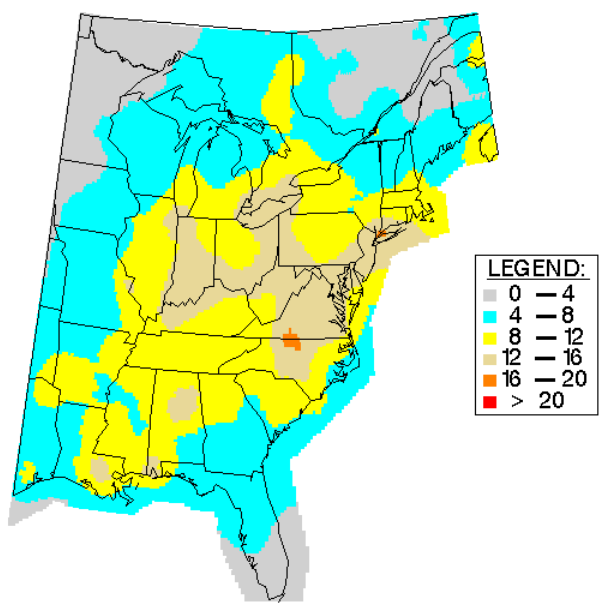
Source: Regional Acid Deposition Model (RADM)

Annual Total Sulfur (S) Deposition in 2010 with Implementation of Title IV only (kg-S/ha/yr) (base)



Source: Regional Acid Deposition Model (RADM)

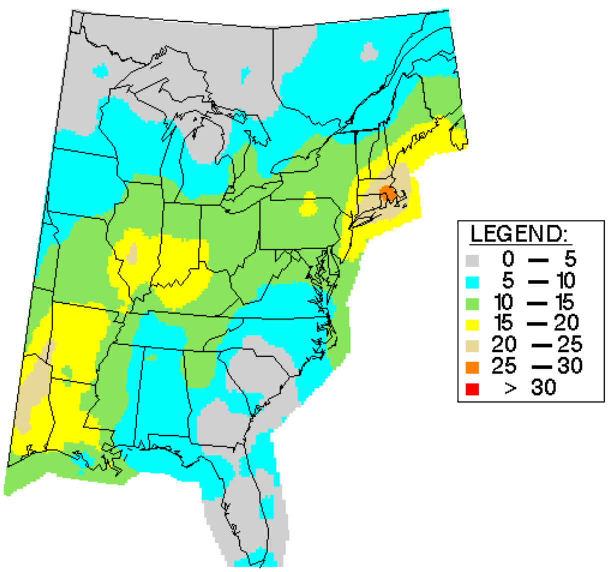
Annual Total Sulfur (S) Deposition in 2010 with Implementation of Title IV and S-172 (kg-S/ha/yr)



Source: Regional Acid Deposition Model (RADM)

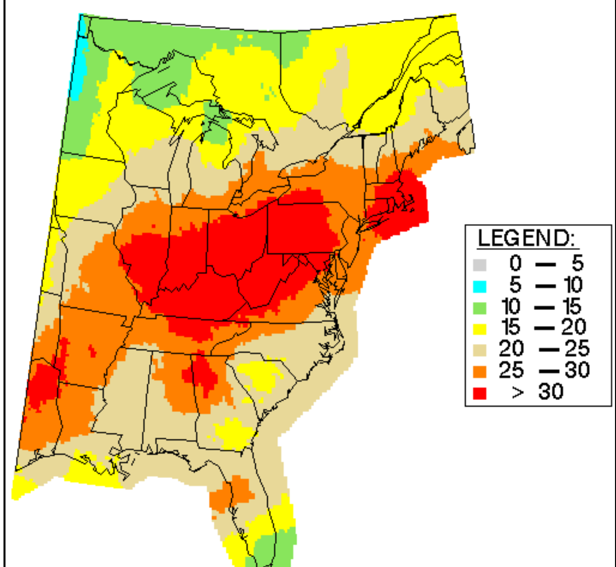
The following two sets of maps present the percent change in deposition. The first set on this page is for nitrogen deposition under 2010 conditions with Title IV only and for 2010 conditions with Title IV and S-172. Changes for both scenarios are in comparison to the 1990 Base conditions. As illustrated in the Title IV/S172 graphic, the areas of greatest improvement in nitrogen deposition levels are in the Ohio river valley area. There are also significant improvements in the south and in southern New England. Nitrate deposition shows a much greater level of improvement with implementation of the full S-172 emissions reductions than with only Title IV. Environmental impacts and/or benefits are expected to be highest in these areas of greatest reduction in deposition load.

Percent Reduction in Annual Oxidized Nitrogen (NOx) Deposition between 1990 Conditions and Implementation of Title IV only in 2010 (kg-N/ha/yr)



Source: Regional Acid Deposition Model (RADM)

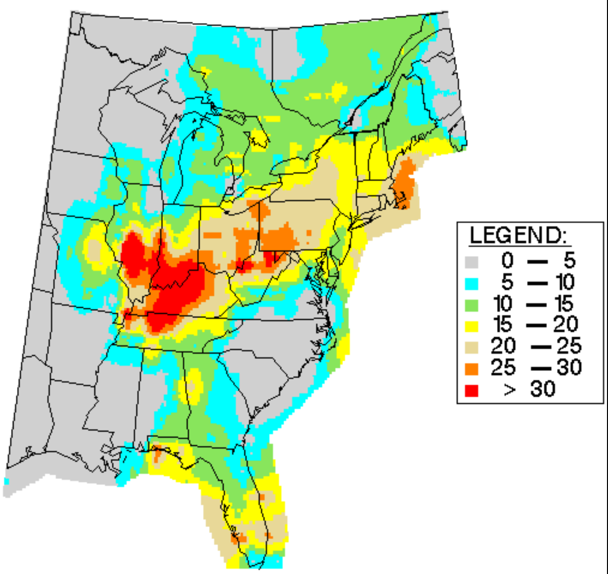
Percent Reduction in Annual Oxidized Nitrogen (NOx) Deposition between 1990 Conditions and Implementation of Title IV and S-172 in 2010 (kg-N/ha/yr)



Source: Regional Acid Deposition Model (RADM)

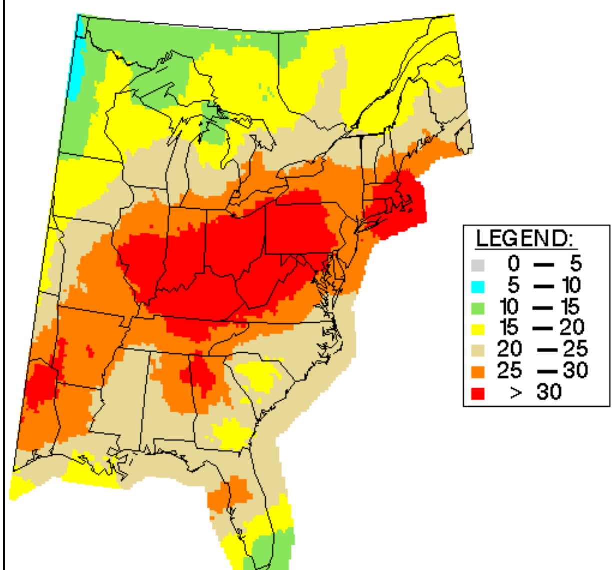
The two maps on this page present the percent change in sulfur deposition. The first is for 2010 conditions with Title IV only and the second is for 2010 conditions with Title IV and S-172. Changes for both scenarios are in comparison to the 1990 conditions. As illustrated in the Title IV/S172 graphic, the areas of greatest improvement in sulfur deposition levels are in the Ohio river valley area. There are also significant improvements in the south and in southern New England. Sulfate deposition shows a much greater level of improvement with implementation of the full S-172 emissions reductions than with only Title IV. Environmental impacts and/or benefits are expected to be highest in these areas of greatest reduction in deposition load.

Percent Reduction in Annual Total Sulfur Deposition Between 1990 Conditions and Implementation of Title IV only in 2010 (kg-S/ha/yr)



Source: Regional Acid Deposition Model (RADM)

Percent Reduction in Annual Total Sulfur Deposition Between 1990 Conditions and Implementation of Title IV and S-172 in 2010 (kg-S/ha/yr)

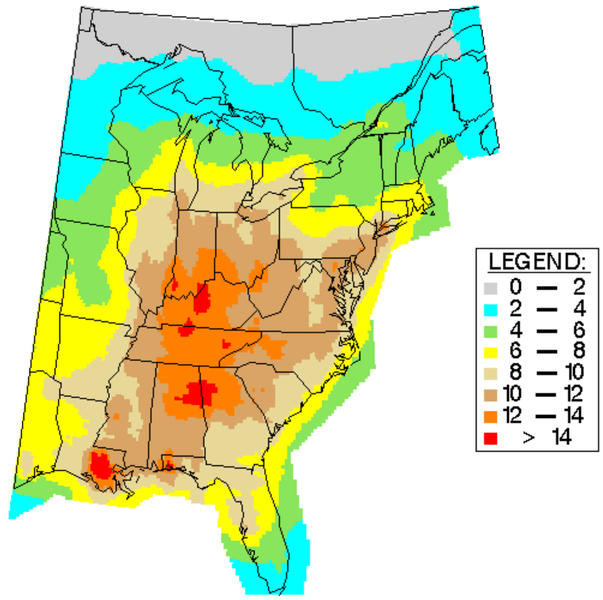


Source: Regional Acid Deposition Model (RADM)

Fine Particulate and Visibility Analyses

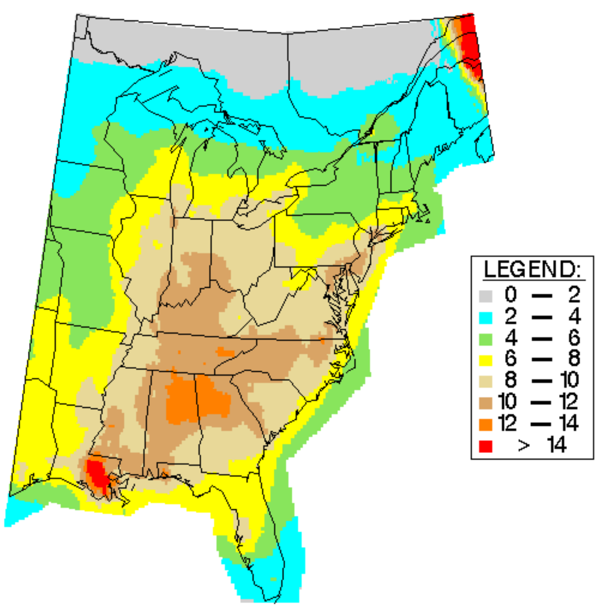
The first three maps present the annual mean total aerosol concentrations for 1990 and for the two 2010 scenarios. The concentrations are expressed as micrograms per cubic meter. The totals include contributions from sulfate, nitrate and ammonium aerosols. Contributions from other aerosols are assumed to be much lower than other components in the East and do not need to be included in the analyses. High concentrations occur mainly in the same regions as the high deposition levels.

Annual Mean Total Aerosol Concentrations (SO4, NO3, and NH4) in 1990 (ug/m3)



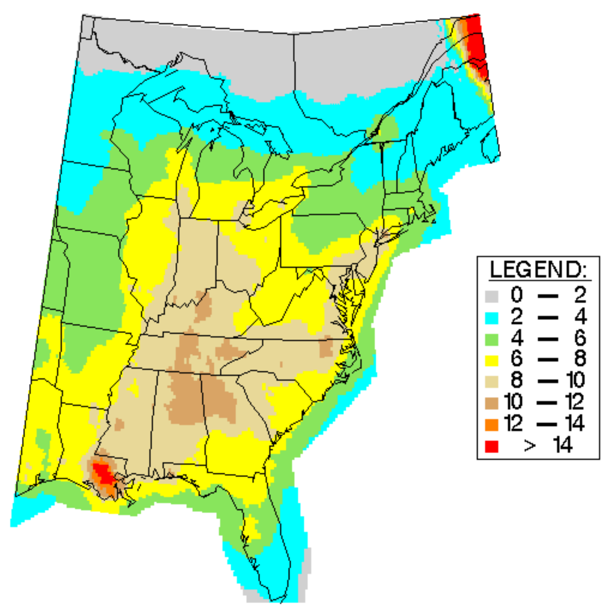
Source: Regional Acid Deposition Model (RADM) and RPM

Annual Mean Total Aerosol Concentrations (SO4, NO3, and NH4) with Implementation of Title IV only in 2010 (ug/m3)



Source: Regional Acid Deposition Model (RADM) and RPM

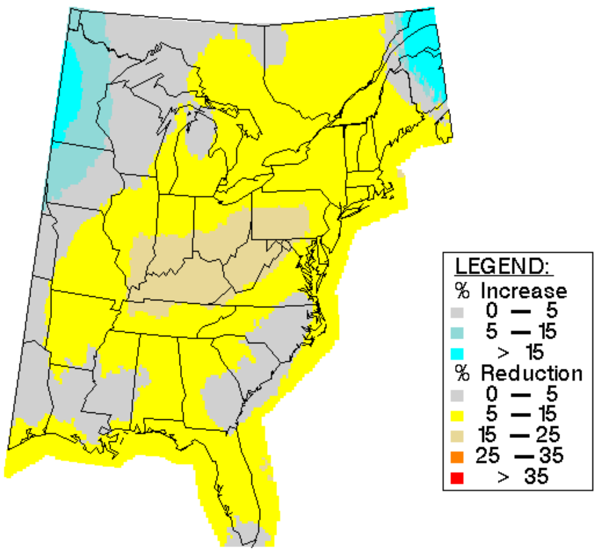
Annual Mean Total Aerosol Concentrations (SO4, NO3, and NH4) with Implementation of Title IV and S-172 in 2010 (ug/m3)



Source: Regional Acid Deposition Model (RADM) and RPM

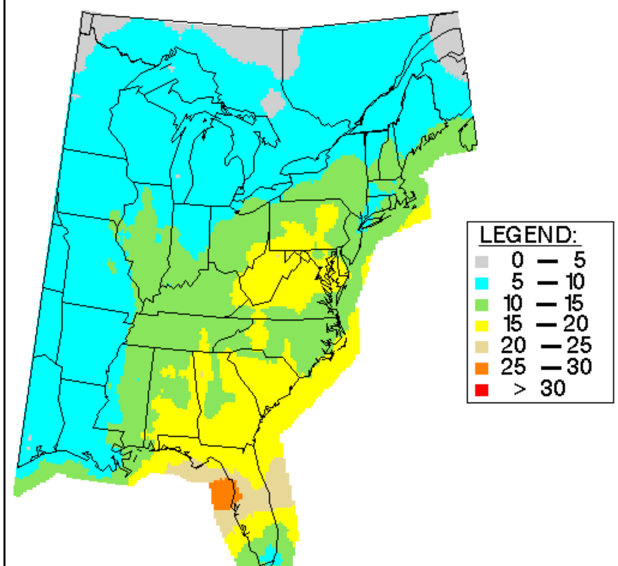
The next two maps show the percent reduction in total annual mean aerosol concentrations for both 2010 scenarios. Improvement is greatest mainly in the regions of the highest initial concentrations.

Percent Reduction in Aerosol Concentrations (SO4, NO3, and NH4) between 1990 Conditions and 2010 Conditions with Title IV (ug/m3)



Source: Regional Acid Deposition Model (RADM)

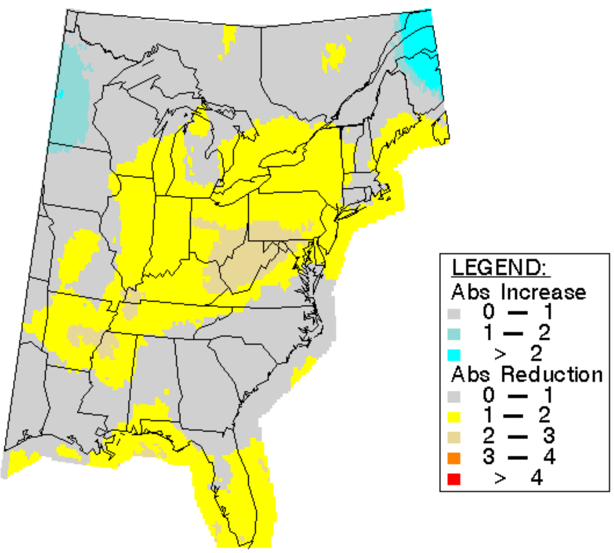
Percent Reduction in Aerosol Concentrations (SO4, NO3, and NH4) Between Implementation of Title IV only and Implementation of Title IV and S-172 in 2010 (ug/m3)



Source: Regional Acid Deposition Model (RADM) and RPM

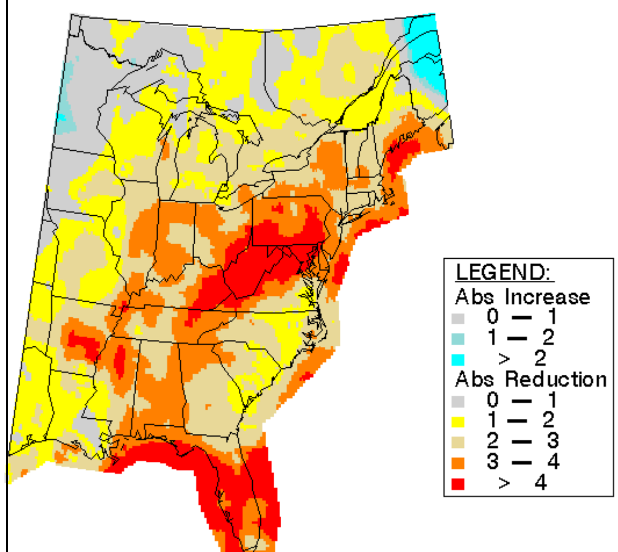
The last two maps present the visibility changes for the two 2010 cases. In both cases, the absolute change in visibility at the 90th percentile is presented. Deciview is a unit for visibility and is related to aerosol light extinction (light scattering and absorption of sunlight by the aerosols). Total light extinction is the sum of the concentrations of each visibility-reducing aerosol weighted by the light extinction efficiency of that aerosol. Sulfate and nitrate aerosols have similar light extinction efficiencies. The lower deciviews are related to better visibility and higher ones are associated with poorer visibility.

Annual Change in Visibility between 1990 Conditions and Implementation of Title IV only in 2010 (90th percentile change in deciviews)



Source: Regional Acid Deposition Model (RADM)

Annual Change in Visibility Between 1990 Conditions and Implementation of Title IV and S-172 in 2010 (90th percentile change in deciviews)



Source: Regional Acid Deposition Model (RADM), RPM