Integrated Review Plan for the Secondary National Ambient Air Quality Standards for Nitrogen Dioxide and Sulfur Dioxide

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Integrated Review Plan for the Secondary National Ambient Air Quality Standards for Nitrogen Dioxide and Sulfur Dioxide

U. S. Environmental Protection Agency
National Center for Environment Assessment
Office of Research and Development
and
Office of Air Quality Planning and Standards
Office of Air and Radiation
Research Triangle Park, North Carolina 27711

DISCLAIMER

This integrated review plan serves as a management tool for the U.S. Environmental Protection Agency's National Center for Environmental Assessment and the Office of Air Quality Planning and Standards. The approach described in this plan may be modified to reflect information developed during this review and to address advice and comments received from the Clean Air Scientific Advisory Committee and the public throughout this review. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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KEY TERMS

Acidification: The process of increasing the acidity of a system (lake, stream, forest soil). Atmospheric deposition of acidic or acidifying compounds can acidify lakes, streams and forest soils.

Air Quality Indicator: The substance or set of substances (e.g., $PM_{2.5}$, NO_2, SO_2) occurring in the ambient air for which a level is set for a NAAQS standard and monitoring occurs.

ANC (Acid Neutralizing Capacity): A key indicator of the ability of water to neutralize the acid or acidifying inputs it receives. This ability depends largely on associated biogeophysical characteristics.

Biologically Relevant Indicator: A measure that sufficiently characterizes the exposure-response relationship between a biological receptor and a pollutant stressor so as to be useful as a predictor of expected receptor response over a range of pollutant exposure levels.

Dry Deposition: The removal of gases and particles from the atmosphere to surfaces in the absence of precipitation (rain, snow) or occult deposition.

Ecosystem: A dynamic complex of interacting plants, animals, and microorganisms and the non-living environment.

Ecosystem Benefit: The value, expressed either qualitatively, quantitatively and/or in economic terms where possible, associated with changes in ecosystem services that result, either directly or indirectly in improved human health and/or welfare. Some examples of ecosystem benefits that derive from improved air quality include improvements in habitat for sport fish species, drinking water quality, visual quality of scenic views, and quality of recreational areas.

Ecosystem Services: Conditions and processes through which natural ecosystems, and the species that are part of them, currently help sustain and fulfill human life or have the potential to do so in the future. Examples include, clean air, clean water, food and fiber production, flood protection, water purification, pollination, and pest control. Improvements in these services may be valued as an ecosystem benefit.

Eutrophication: The process by which a body of water becomes enriched in dissolved nutrients that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen

Occult Deposition: The removal of gases and particles from the atmosphere to surfaces by fog or mist.

Welfare Effects: Effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being, whether caused by transformation, conversion, or combination with other air pollutants (CAA 302(h))

Wet Deposition: The removal of gases and particles from the atmosphere to surfaces by rain or other precipitation

Valuation: The economic or non-economic process of determining either the value of maintaining a given ecosystem type, state or condition, or the value of a change in, an ecosystem, its components, or the services it provides.

1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is conducting a review of the existing primary (health-based) and secondary (welfare-based) National Ambient Air Quality Standards (NAAQS) for nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). The reviews of the primary NAAQS for NO_2 and for SO_2 are addressed in separate plans released during the winter of 2006/2007. The purpose of this document is to communicate the integrated plan for the joint review of the secondary NAAQS for these pollutants.

In this document, the terms NO_2 and NO_x and SO_2 and SO_x are not interchangeable. The terms NO_x (oxides of nitrogen) and SO_x (sulfur oxides) refer to the listed Criteria Air Pollutants for which EPA has regulatory authority under Sections 108 and 109 of the Clean Air Act (CAA), and for which criteria must be developed and reviewed every 5 years. In this review, NOx refers to all oxides of nitrogen (conventionally referred to as NOy in the scientific community), not simply the sum of NO and NO_2 (conventionally referred to as NOx in the scientific community). The oxides of nitrogen compounds in the ambient air are nitric oxide (NO), nitrogen dioxide (NO_2), nitrous oxide (N_2O), nitrogen trioxide (NO_3), dinitrogen trioxide (N_2O_3), dinitrogen tetroxide (N_2O_4), dinitrogen pentoxide (N_2O_5); other ambient oxides of nitrogen include nitric acid (HNO_3), peroxyacetylnitrate (PAN), and other organic compounds such as nitrites, nitrates, nitrogen acids, and N-nitroso compounds (EPA, 1993). The terms NO_2 and SO_2 refer to the specific air quality indicators (pollutant species) specified by the current standards whose concentrations are monitored to determine whether the NAAQS is being met in a given location. The ecological importance of both oxidized and reduced forms of nitrogen has been widely recognized by the scientific community. The science assessment and the risk/exposure assessment will also evaluate total reactive nitrogen (which includes both oxidized and reduced forms), and its impacts on public welfare. Additionally, we will attempt to evaluate, and quantify where possible, the separate contributions of ambient versus other sources of total reactive nitrogen in various ecosystems nationwide, as well as the contributions of NOx to ambient reactive nitrogen relative to other contributors to ambient reactive nitrogen.

Section 1.1 below includes additional explanation on the use of these terms within the context of the various phases of the new NAAQS review process. This review will evaluate new information published in the peer-reviewed literature since the completion of the last NO_2 (1995) and SO_2 (1996) reviews, including assessments of the adequacy of the current secondary NAAQS, and consider the possible need for a new single indicator or suite of indicators, as well as changed or retained level(s) and/or averaging times for the standards, which may include nitrogen and sulfur compounds other than NO_2 and SO_2.

This review plan is organized into six chapters. Chapter 1 presents background information on the recently-revised NAAQS review process; on the nature of the NOx/SOx problem; on the legislative requirements for the review of the NAAQS; and on the regulatory history of past reviews of the NAAQS for NO_2 and SO_2. Chapter 2 presents the proposed review schedule. Chapter 3 presents a set of key policy-relevant questions that will serve to focus the NAAQS review process on the critical scientific and policy issues. Chapters 4 through 6 discuss the science, risk/exposure, and policy assessment portions of the review.

We consulted with the Clean Air Scientific Advisory Committee (CASAC, panel members are listed in Appendix A), an independent scientific advisory committee established under the Clean Air Act, on an earlier draft of this document. As this review proceeds, the plan described here may be modified to reflect information received during the review process and to address advice and comments received from the CASAC and from the public throughout this review.

1.1 LEGISLATIVE REQUIREMENTS

Two sections of the Clean Air Act (CAA) govern the establishment and revision of the NAAQS. Section 108 (42 U.S.C. 7408) directs the Administrator to identify and list "air pollutants" that "in his judgment, may reasonably be anticipated to endanger public health and welfare" and their "presence . . . in the ambient air results from numerous or diverse mobile or stationary sources" and to issue air quality criteria for those that are listed. Air quality criteria are intended to "accurately reflect the latest scientific knowledge useful in indicating the kind and extent of identifiable effects on public health or welfare which may be expected from the presence of [a] pollutant in ambient air . . . ."

Section 109 (42 U.S.C. 7409) directs the Administrator to propose and promulgate "primary" and "secondary" NAAQS for pollutants listed under section 108. A secondary standard, as defined in Section 109(b)(2), must "specify a level of air quality the attainment and maintenance of which, in the judgment of the Administrator, based on such criteria, is required to protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air."[1]

In setting standards that are "requisite" to protect public health and welfare, as provided in section 109(b), EPA's task is to establish standards that are neither more nor less stringent than necessary for these purposes. In so doing, EPA may not consider the costs of implementing the standards. *Whitman v. American Trucking Associations*, 531 U.S. 457, 465-472, 475-76 (2001).

Section 109(d)(1) requires that "not later than December 31, 1980, and at 5-year intervals thereafter, the Administrator shall complete a thorough review of the criteria published under section 108 and the national ambient air quality standards . . . and shall make such revisions in such criteria and standards and promulgate such new standards as may be appropriate . . . ." Section 109(d)(2) requires that an independent scientific review committee "shall complete a review of the criteria . . . and the national primary and secondary ambient air quality standards . . . and shall recommend to the Administrator any new . . . standards and revisions of existing criteria and standards as may be appropriate . . . ." Since the early 1980's, this independent review function has been performed by the Clean Air Scientific Advisory Committee (CASAC) of EPA's Science Advisory Board.

1.2 REGULATORY HISTORY OF THE SECONDARY NAAQS FOR NO_2 AND SO_2

1.2.1 NO_2 NAAQS

In 1971, the first air quality criteria document for NOx was issued by the National Air Pollution Control Association (NAPCA), one of EPA's predecessor agencies. After reviewing the relevant science on the public health and welfare effects associated with oxides of nitrogen, EPA promulgated identical primary and secondary NAAQS for NO_2 on April 30, 1971. Under section 109 of the Act, these standards were set at 0.053 parts per million (ppm) as an annual average (36 FR 8186). In 1982, EPA published *Air Quality Criteria for Oxides of Nitrogen* (EPA, 1982), which updated the scientific criteria upon which the initial standards were based.

[1] Welfare effects as defined in section 302(h) [42 U.S.C. 7602(h)] include, but are not limited to, "effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

On February 23, 1984, EPA proposed to retain these standards (49 FR 6866). After taking into account public comments, EPA published the final decision to retain these standards on June 19, 1985 (50 FR 25532).

In November 1991, EPA released an updated draft Air Quality Criteria Document (AQCD) for CASAC and public review and comment (56 FR 59285). The draft AQCD provided a comprehensive assessment of the available scientific and technical information on heath and welfare effects associated with NO_2 and other NO_x compounds. The CASAC reviewed the document at a meeting held on July 1, 1993 and concluded in a closure letter to the Administrator that the document "provides a scientifically balanced and defensible summary of current knowledge of the effects of this pollutant and provides an adequate basis for EPA to make a decision as to the appropriate NAAQS for NO_2" (Wolff, 1993).

The EPA also prepared a draft Staff Paper that summarized and integrated the key studies and scientific evidence contained in the revised AQCD and identified the critical elements to be considered in the review of the NO_2 NAAQS. The Staff Paper received external review at a December 12, 1994 CASAC meeting. The CASAC comments and recommendations were reviewed by EPA staff and incorporated into the final draft of the Staff Paper, as appropriate. The CASAC reviewed the final draft of the Staff Paper in June, 1995 and responded by written closure letter (Wolff, 1995). In September, 1995, EPA finalized the Staff Paper, "Review of the National Ambient Air Quality Standards for Nitrogen Dioxide: Assessment of Scientific and Technical Information," (EPA, 1995).

On October 2, 1995, the Administrator announced her proposed decision not to revise either the primary or secondary NAAQS for NO_2 based on the information available to her in this review (60 FR 52874; October 11, 1995). After careful evaluation of the comments received on the October 1995 proposal, the Administrator made a final determination that revisions to neither the primary nor the secondary NAAQS for NO_2 were appropriate at that time (61 FR 52852, October 8, 1996). The level for both the existing primary and secondary NAAQS for NO_2 remains 0.053 ppm (equivalent to 100 micrograms per cubic meter of air [ug/m^3]) in annual arithmetic average, calculated as the arithmetic mean of the 1-hour NO_2 concentrations.

1.2.2 SO_2 NAAQS

Based on the 1970 sulfur oxides criteria document (DHEW, 1970), EPA promulgated primary and secondary NAAQS for SO_2, under section 109 of the Act on April 30, 1971 (36 FR

8186). The secondary standards included a standard at 0.02 ppm in an annual arithmetic mean and a 3-hr average of 0.5 ppm, not to be exceeded more than once per year. These secondary standards were established solely on the basis of vegetation effects evidence. In 1973, revisions made to Chapter 5 "Effects of Sulfur Oxide in the Atmosphere on Vegetation" of Air Quality Criteria for Sulfur Oxides (EPA 1973), indicated that it could not properly be concluded that the vegetation injury reported resulted from the average SO_2 exposure over the growing season, rather than the short-term peak concentrations. EPA, therefore, proposed (38 FR 11355) and then finalized a revocation of the annual mean secondary standard (38 FR 25678). At that time, EPA was aware that sulfur oxides have other public welfare effects, including effects on materials, visibility, soils and water. However, the available data were considered insufficient to establish a quantitative relationship between specific sulfur dioxide concentrations and effects needed for standard setting (38 FR 25679).

In 1979, EPA announced that it was revising the AQCD for sulfur oxides concurrently with that for particulate matter and would produce a combined particulate matter (PM) and sulfur oxides criteria document. Following its review of a draft revised criteria document in August, 1980, the CASAC concluded that acid deposition was a topic of extreme scientific complexity because of the difficulty in establishing firm quantitative relationships among: (1) emissions of relevant pollutants (e.g., SO_2 and oxides of nitrogen), (2) formation of acidic wet and dry deposition products, and (3) effects on terrestrial and aquatic ecosystems. CASAC also noted that acid deposition involves, at a minimum, several different criteria pollutants - oxides of sulfur, oxides of nitrogen, and the fine particulate fraction of suspended particles. The Committee felt that any document on this subject should address both wet and dry deposition, since dry deposition was believed to account for at least one half of the total acid deposition problem.

For these reasons, the CASAC recommended that a separate, comprehensive document on acid deposition be prepared prior to any consideration of using the NAAQS as a regulatory mechanism for the control of acid deposition. CASAC also suggested that a discussion of acid deposition be included in the AQCDs for both nitrogen oxides and PM and SOx. In response to these recommendations, EPA subsequently prepared the following documents: The Acidic Deposition Phenomenon and Its Effects: Critical Assessment Review Papers, Volumes I and II (EPA, 1984), and The Acidic Deposition Phenomenon and Its Effects: Critical Assessment Document (EPA, 1985) (53 FR 14935 -14936). These documents, though they were not considered criteria documents and did not undergo CASAC review, represented the most comprehensive summary of relevant scientific information completed by the EPA at that point.

Following CASAC closure on the criteria document for SO_2 in December 1981, EPA OAQPS published a Staff Paper in November, 1982. The issue of acid deposition was not, however, assessed directly in this Staff Paper because EPA followed the guidance given by CASAC.

On April 26, 1988 (53 FR 14926), EPA proposed not to revise the existing primary and secondary standards. This proposal regarding the secondary SO_2 NAAQS was due to the Administrators conclusions that (1) based upon the then-current scientific understanding of the acid deposition problem, it would be premature and unwise to prescribe any regulatory control program at that time, and (2) when the fundamental scientific uncertainties had been reduced through ongoing research efforts, EPA would draft and support an appropriate set of control measures.

In spite of the complexities and significant remaining uncertainties associated with the acid deposition problem, it soon became clear that a program to address acid deposition was needed. On November 15, 1990, Amendments to the CAA were passed by Congress and signed into law by the President. In Title IV of these Amendments, Congress included a statement of findings that had led them to take this action, including that: (1) the presence of acid compounds and their precursors in the atmosphere and in deposition from the atmosphere represents a threat to natural resources, ecosystems, materials, visibility, and public health; (2) the problem of acid deposition is of national and international significance; and (3) current and future generations of Americans will be adversely affected by delaying measures to remedy the problem. The goal of Title IV was to reduce emissions of SO_2 by 10 million tons and NOx emissions by 2 million tons from 1980 emission levels in order to achieve reductions over broad geographic regions/areas.

Congress, however, clearly envisioned that further action might be necessary in the long term and reserved judgment on the form it could take, as evidenced by the inclusion of section 404 of the 1990 Amendments (Clean Air Act Amendments of 1990, Pub. L. 101-549, § 404). This section required EPA to conduct a study on the feasibility and effectiveness of an acid deposition standard or standards to protect “sensitive and critically sensitive aquatic and terrestrial resources” and at the conclusion of the study, submit a report to Congress. Five years later EPA submitted to Congress its report titled Acid Deposition Standard Feasibility Study: Report to Congress (EPA, 1995) in fulfillment of this requirement. The Acid Deposition

Standard Feasibility Study Report to Congress concluded that establishing acid deposition standards for sulfur and nitrogen deposition may at some point in the future be technically feasible although appropriate deposition loads for these acidifying chemicals could not defined with reasonable certainty at that time.

The 1990 Amendments also added new language to sections of the CAA pertaining to the scope or application of the secondary NAAQS designed to protect the public welfare. Section 108 (g) specified that "the Administrator may assess the risks to ecosystems from exposure to Criteria Air Pollutants (as identified by the Administrator in the Administrator's sole discretion)." The definition of public welfare in section 302 (h) was expanded to state that the welfare effects identified should be protected from adverse effects associated with criteria air pollutants "…whether caused by transformation, conversion, or combination with other air pollutants."

In 1999, seven Northeastern States cited this amended language in section 302(h) in a petition to EPA to use its authority under the NAAQS program to promulgate secondary NAAQS for the criteria pollutants associated with the formation of acid rain. The petition stated that this language "clearly references the transformation of pollutants resulting in the inevitable formation of sulfate and nitrate aerosols and/or their ultimate environmental impacts as wet and dry deposition, clearly signaling Congressional intent that the welfare damage occasioned by sulfur and nitrogen oxides be addressed through the secondary standard provisions of Section 109 of the Act. The petition further stated that "recent federal studies, including the NAPAP Biennial Report to Congress: An Integrated Assessment, document the continued-and increasing-damage being inflicted by acid deposition to the lakes and forests of New York, New England and other parts of our nation, demonstrating that the Title IV program had proven insufficient." The petition also listed other adverse welfare effects associated with the transformation of these criteria pollutants, including visibility impairment, eutrophication of coastal estuaries, global warming, tropospheric ozone and stratospheric ozone depletion.

In a related matter, the Office of the Secretary of the U.S. Department of Interior (DOI) requested in 2000 that the EPA initiate a rulemaking proceeding to enhance the air quality in national parks and wilderness areas in order to protect resources and values that are being adversely affected by air pollution. Included among the effects of concern identified in the request were acidification of streams, surface waters and/or soils, eutrophication of coastal waters, visibility impairment, and foliar injury from ozone.

In a Federal Register notice in 2001, EPA announced receipt of these items and requested comment on the issues raised by these requests. EPA stated that it would consider any relevant comments and information submitted, along with the information provided by the petitioners and DOI, before making any decision concerning a response to these requests for rulemaking.

In this review, EPA will again revisit the appropriateness and feasibility of setting a secondary NAAQS to address the welfare effects resulting from the deposition of these criteria pollutants and their transformation products. This plan describes potential elements of that review.

1.3 OVERVIEW OF THE NAAQS REVIEW PROCESS

U.S. EPA has recently decided to make a number of changes to the process for reviewing the NAAQS (described at www.http://epa.gov/ttn/naaqs/). The revised NAAQS review process contains four major components: an integrated review plan, a science assessment, a risk/exposure assessment, and a policy assessment/rulemaking. In addition to these procedural modifications, for this secondary NAAQS review we have decided to examine two of the six criteria pollutants, oxides of nitrogen and sulfur oxides, together, rather than individually, as has been done in the past. This decision derives from the fact that NOx, SOx, and their associated transformation products are linked from an atmospheric chemistry perspective, as well as from an environmental effects perspective (most notably in the case of secondary aerosol formation and acidification in ecosystems). These interactions have been recognized historically by both CASAC and EPA; the science related to these interactions continues to evolve and grow, emphasizing the importance of considering them together.

The first phase of the revised NAAQS review process is the development of the integrated review plan. This document represents the current plan and specifies the schedule of the review, the process for conducting the review, and the key policy-relevant science issues that will guide the review. This plan will be submitted for review and comment to CASAC, other non-EPA scientists, and the public. The final integrated review plan will take into account comments from these entities.

The second phase of the process is the development of the science assessment, which consists of the Integrated Science Assessment (ISA) for NOx and SOx and supporting details in its annexes. The U.S. EPA's National Center for Environmental Assessment (NCEA) along with contractor support is currently developing the annexes to the ISA. These annexes will contain a comprehensive description and evaluation/assessment of the full breadth of the recent scientific literature pertaining to known and anticipated effects on public welfare associated with the presence of the NOx and SOx criteria pollutant(s) in the ambient air, emphasizing the information that has become available since the last review in order to reflect the current state of knowledge. NCEA will then critically evaluate, integrate, and synthesize the most policy-relevant science from the annexes into an ISA. The ISA is intended to provide information useful in forming judgments about air quality indicator(s), form(s), averaging time(s) and level(s) for the secondary NAAQS. Hence, the ISA and its associated annexes function in the new NAAQS review in part as the Air Quality Criteria Document (AQCD) did in previous reviews. The schedule includes production of a first and second draft ISA, both of which will undergo CASAC and public review prior to completion of the final ISA. Section 4 provides a more detailed description of the planned scope, organization and assessment approach for the annexes and ISA, as well as EPA's rationale for conducting a joint review of these criteria pollutants.

In the third phase of the revised review process, the risk/exposure assessment, OAQPS plans to draw upon the ISA to develop quantitative and qualitative estimates of the risks of adverse welfare effects occurring as a result of current ambient levels of nitrogen oxides and sulfur oxides, levels that meet the current standards for NO_2 and SO_2, or levels that meet possible alternative standards. Section 5 of this Plan contains more detail about possible approaches EPA could take in conducting the risk/exposure Assessment. Once the draft ISA is complete, EPA will release a Scope and Methods Plan/document for CASAC and public review that describes the actual scope of the analyses to be performed and the tools/methods that will be employed. Once the risk/exposure assessment is complete, a report will be developed that focuses on key results, observations, and uncertainties and may include results from specific analyses designed to inform the review. This risk/exposure assessment report will also undergo review by CASAC and the public.

The fourth component of the revised process will be a policy assessment/rulemaking. Under the revised NAAQS process, a policy assessment reflecting Agency views will be published in the Federal Register as an advance notice of proposed rulemaking (ANPR). The ANPR will be accompanied by supporting documents, such as air quality analyses and technical support documents, as appropriate. The ANPR takes the place of the Staff Paper prepared for previous NAAQS reviews. Issuance of a proposed and final rule will then complete the rulemaking process.

1.4 SCIENCE PRIMER: NO_X/SO_X EFFECTS ON ECOSYSTEMS

The following section is intended to provide a brief summary of the generally-accepted effects of NOx and SOx pollution on ecosystems. The information presented here is drawn from the last NOx (1995) and SOx (1996) NAAQS reviews as well as from more recent peer-reviewed scientific literature. Nitrogen and sulfur interactions in the environment are highly complex. Both are essential, and sometimes limiting, nutrients needed for growth and productivity. Excesses of nitrogen or sulfur can lead to acidification, nutrient enrichment, and eutrophication. Nitrogen effects occur along a continuum, from growth-enhancing fertilization to growth-depressing conditions associated with varying levels of nitrogen inputs. The excess nitrogen deposition described here results when available nitrogen cannot be assimilated by the existing vegetation or immobilized by the soil buffering capacity.

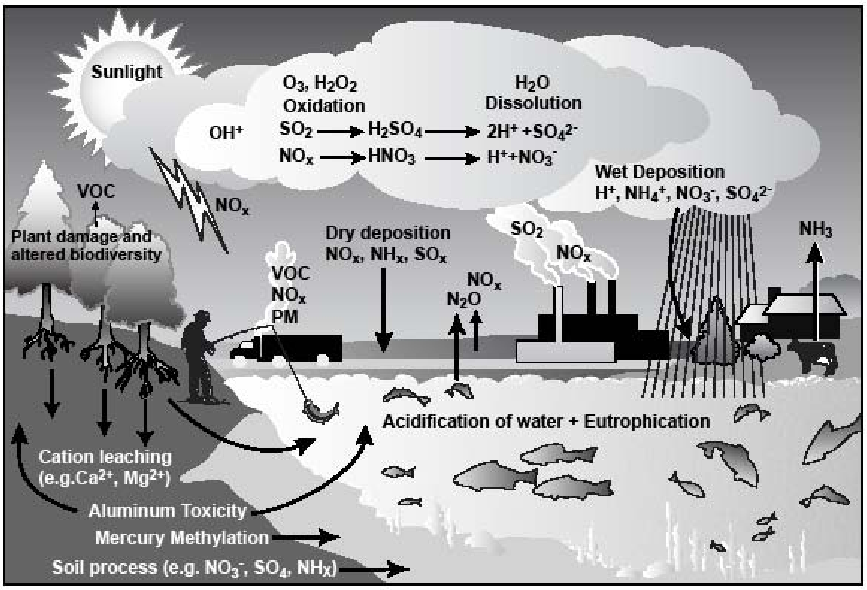
Emissions of NOx and SOx compounds into the air react through a complex series of gas-phase and heterogeneous reactions to produce additional intermediate compounds and final products. These reactions with NOx and SOx often occur and under the same meteorological influences as those acting on formation of ozone (O_3) and secondary aerosols. These nitrogen- and sulfur-containing compounds are removed from the air by deposition – wet (rain, snow), cloud and fog, and dry (gases and particles) -- onto surfaces. Prevailing winds can transport these compounds hundreds of miles and across state and national borders.

Deposition of other chemical species derived from NOx and SOx emissions to the environment can initiate changes in ecosystem biogeochemistry, structure, and function. Since both NOx and SOx emissions can react in the atmosphere to form strong acids, one of the possible environmental endpoints is acidification. Acidification results in a cascade of effects that alter biogeochemical cycles and harm terrestrial and aquatic ecosystems. These effects include slower growth, the injury or death of forest vegetation, and localized extinction of fish and other aquatic species. Acid deposition can also cause accelerated erosion of exposed materials and structures, such as buildings and statues.

In addition to acidification, NOx acts with other sources of reactive nitrogen, including ammonia-based nitrogen, to increase the total amount of nitrogen available to the organisms in terrestrial and aquatic ecosystems. Depending on the ecosystem and the endpoints that are of concern, this extra nitrogen can be considered to have both positive and negative effects. For example, low-level chronic nitrogen deposition can act as a fertilizer and increase productivity in terrestrial forests, but this extra nitrogen may change the species composition of the understory plants and lichens. At high levels of nitrogen deposition there may be negative effects on forest productivity. In general, ecosystems adapted to low nitrogen availability are most vulnerable to the effects of nitrogen deposition. Excess nitrogen to vulnerable ecosystems can cause “Nitrogen pollution,” resulting in a suite of terrestrial and aquatic ecological problems including biodiversity losses, community shifts, eutrophication, and harmful algal blooms. Lastly, SOx interacts with mercury (Hg) in ecosystems to increase the production of methylmercury, a powerful toxin that bioaccumulates, often to the point of causing toxic doses to top members of food chains (e.g., river otters and panthers).

A summary illustration of NOx and SOx effects on the environment is presented in Figure 1.1.

Figure 1.1 Nitrogen and Sulfur cycling and interactions in the environment.



1.4.1 Acidification Effects on Freshwater and Terrestrial Ecosystems from Sulfur and Nitrogen Deposition

The process of acidification affects both freshwater aquatic and terrestrial ecosystems. Acid deposition causes acidification of sensitive surface waters. The effects of acid deposition on aquatic systems depend largely upon the ability of the ecosystem to neutralize the additional acid. As acidity increases, aluminum leached from soils and sediments, flows into lakes and streams and can be toxic to both terrestrial and aquatic biota. The lower pH concentrations and higher aluminum levels resulting from acidification make it difficult for some fish and other aquatic organisms to survive, grow, and reproduce.

Research on effects of acid deposition on forest ecosystems has come to focus increasingly on the biogeochemical processes that affect uptake, retention, and cycling of nutrients within these ecosystems. Decreases in available base cations from soils are at least partly attributable to acid deposition. Base cation depletion is a cause for concern because of the role these ions play in acid neutralization and, because calcium, magnesium and potassium are essential nutrients for plant growth and physiology. Changes in the relative proportions of these nutrients, especially in comparison with aluminum concentrations, have been associated with declining forest health.

1.4.2 Excess Nitrogen in Terrestrial and Estuarine Ecosystems

In addition to acidification effects, NOx contributes to total nitrogen loading of ecosystems. In terrestrial systems, too much nitrogen can affect species diversity by favoring plant species with high nitrogen requirements over other species which may have evolved specialized capabilities to thrive under more nitrogen-limited conditions. Elevated soil nitrogen tends to cause changes in the ability of invasive species to colonize, biodiversity, and community structure. Animals that depend on specific plants for habitat and food may also be threatened by changes in vegetation resulting from increased nitrogen inputs.

Atmospheric deposition of nitrogen is a significant source of total nitrogen to many estuaries in the United States. The amount of nitrogen entering estuaries that is ultimately attributable to atmospheric deposition is not well-defined. On an annual basis, atmospheric nitrogen deposition may contribute significantly to the total nitrogen load, depending on the size and location of the watershed. In addition, episodic nitrogen inputs, which may be ecologically important, may play a more important role than indicated by the annual average concentrations. Estuaries in the U.S. that suffer from nitrogen enrichment often experience a condition known as eutrophication. Symptoms of eutrophication include changes in the dominant species of phytoplankton, low levels of oxygen in the water column, fish and shellfish kills, outbreaks of toxic alga, and other population changes which can cascade throughout the food web. In addition, increased phytoplankton growth in the water column and on surfaces can attenuate light causing declines in submerged aquatic vegetation, which serves as an important habitat for many estuarine fish and shellfish species.

1.4.3 Reduced Nitrogen

Although this review must initially address NOx, it appears evident that total reactive nitrogen (i.e., both oxidized and reduced forms of nitrogen) is important from an ecosystem effects perspective. As such, the interactions between reduced forms of nitrogen (namely ammonia, NH_3, and ammonium, NH_4^+) and NOx and SOx in the atmosphere and associated deposition processes will be considered. Ammonia is an additional source of nitrogen to the environment that contributes to the problems caused by excess nitrogen deposition — nutrient enrichment and eutrophication. Ammonia can also contribute to increasing soil acidity via nitrification, the microbially-mediated transformation of ammonium to nitrate. The atmospheric lifetime of gas-phase ammonia is on the order of a day; however, in the presence of sulfuric or nitric acids, ammonia can form aerosols, predominantly ammonium sulfate and ammonium nitrate, with lifetimes on the order of 7-10 days. This longer lifetime increases the potential for long-range transport of nitrogen and sulfur, and contributes to fine particulate matter pollution and regional haze. Ammonium sulfates and nitrates also participate in climate modification effects, directly through radiative cooling by light scattering and indirectly through modifications of cloud cover and precipitation by acting as cloud condensation nuclei. A detailed discuss of these processes is included in the PM review.

2. REVIEW SCHEDULE

EPA's National Center for Environmental Assessment in Research Triangle Park, NC (NCEA-RTP) announced the official initiation of the current periodic review of air quality criteria for NOx on December 9, 2005 and for SOx on May 15, 2006. For each of these reviews, the Agency began by announcing in the Federal Register (70 FR 73236 and 71 FR 28023) the formal commencement of the review and a call for information. With these reviews underway, a workshop addressing the separate, joint review of just the secondary standards for these two pollutants was announced in the Federal Register on June 20, 2007 (72 FR 11960). The proposed schedule for this joint review process is shown in Table 2-1; underlined dates indicate the court-ordered schedule.

Table 2-1. Proposed Schedule for Joint NOx and SOx Secondary Standard Review [1]

Stage of Review	Major Milestone	Target Dates
Planning	Literature Search	Ongoing
	Federal Register Call for Information	December 2005
	Prepare Draft NO_2/SO_2 NAAQS Work Plan	December 2005-August 2007
	Workshop on science/policy issues	July 2007
	CASAC consultation	October 2007
	Prepare final integrated NO_2/SO_2 NAAQS Work Plan	December 2007
Integrated Science Assessment (ISA)	Prepare first draft of ISA	December 2007
	CASAC/public review first draft ISA	April 2008
	Prepare second draft of ISA	July/August 2008
	CASAC/public review second draft ISA	October 2008
	Prepare final ISA	<u>December 12, 2008</u>
Risk/Exposure Assessment (R/EA)	REA methodology released to CASAC and the public	January 2008
	CASAC/public consultation on REA methodology	April 2008
	First draft REA released to CASAC and the public	August 2008
	CASAC/public review of the first draft of the REA	October 2008
	Second draft of REA released to CASAC and the public	March 2009
	CASAC/public review of second draft of REA	May 2009
	Final REA released	July 2009
Policy Assessment/ Rulemaking	Publish ANPR	August 2009
	CASAC review/public comment on ANPR	October 2009
	Proposed rulemaking	<u>February 12, 2010</u>
	Final rulemaking	<u>October 19, 2010</u>

[1] Schedule may be modified from time to time, as necessary, to reflect actual project requirements and progress.

3. KEY POLICY-RELEVANT ISSUES

In this review of the ecosystem-related effects on public welfare related to NOx and SOx, a series of policy-relevant questions will frame our approach and will be addressed in detail in the science assessment, risk/exposure assessment, and policy assessment sections of the review. For this first time in the NAAQS review process, the secondary standards for NOx and SOx will be reviewed together due to the pollutants' combined effects on atmospheric chemistry, deposition processes, and ecosystem-related public welfare effects. As a result, the issue of appropriate indicators becomes central to the review of the standards. This review will evaluate what appropriate indicators are for NOx and SOx, if these indicators should be combined into one standard, if separate standards should be issued, or if a suite of standards should be issued. In evaluating environmental responses to these pollutants, the variability present in ecosystems across the nation should also be considered. Issues of ecosystem susceptibility should be addressed, as should the issue of whether individual effects or combined effects are more important to a given ecosystem (i.e., is it NOx or SOx alone or the combination that is important).

As noted in the introduction, both EPA and CASAC have acknowledged the importance of NOx, SOx, and their associated transformation products with respect to acidification effects on ecosystems. This review will focus on the ecosystem-related welfare effects that result from the deposition of these pollutants and their transformation products, rather than on the effects of aerosol NOx and SOx that remain in the atmosphere. The issues associated with NOx and SOx particles; including visibility impairment and climate associated with ambient concentrations of particulates and aerosols are being addressed in the secondary PM NAAQS review, which is also currently underway.

The review of the adequacy of the current standard for each effects category involves addressing questions such as:

- To what extent does the available information demonstrate or suggest that NOx/SOx-related effects are occurring at current ambient conditions or at levels that would meet the current standards?
- To what extent does the available information inform judgments as to whether any observed or anticipated effects are adverse to public welfare?
- To what extent are the current secondary standards likely to be effective in achieving protection against any identified adverse effects?

To the extent that the evidence suggests that revision of the current secondary NO_2/SO_2 NAAQS is appropriate, ranges of standards will be identified (including different or alternate indicators, terms of exposure indices, averaging times, levels, and forms) that reflect a range of alternative policy judgments as to the degree of protection that is requisite to protect public welfare from known or anticipated adverse effects. To account for variability in ecosystem responses across the nation, ecosystem characteristics may be an important consideration in evaluating the form(s) of the standard(s). The form(s) of the standard(s) may be based on a complex formula that incorporates ecosystem characteristics, atmospheric transformations, climatic conditions, environmental effects and other interactions. In so doing, the following questions should be addressed:

- Does the available information provide support for considering different NOx/SOx chemical indicators or exposure indices?
- Does the available information provide support for considering some joint standard(s) or are separate standards appropriate?
- What range of levels and forms of alternative standards are supported by the information, and what are the uncertainties and limitations in that information?
- To what extent do specific levels and forms of alternative standards reduce adverse impacts attributable to NOx/SOx, and what are the uncertainties in the estimated reductions?

In order to be able to answer these questions, we believe that the relevant scientific issues that need to be addressed in the science, risk/exposure, and policy assessment portions of this review include:

- identifying important chemical species in the atmosphere
- identifying the atmospheric pathways that govern chemical transformation, transport, and deposition of NOx and SOx to the environment
- identifying the attributes of ecosystem receptors that govern their susceptibility to effects from deposition of nitrogen and sulfur compounds
- identifying the relevant time scales of ecosystem impacts and matching those time scales to relevant time scales for ambient indicators
- describing the relationships between ambient indicators and biologically relevant indices of effects, including ecosystem services associated with the indicator (but not excluding other non-economic evaluations)
- evaluating alternative measures to assess the adversity of effects on ecosystem services, including, for example, economic valuation

- evaluating if current levels may have a long-term impact due to cumulative loadings, and if this is relevant to a NAAQS review
- evaluating environmental impacts and sensitivities to varying meteorological scenarios and climate conditions

4. SCIENCE ASSESSMENT

4.1 SCOPE AND ORGANIZATION

The scope of the joint NO_X and SO_X ISA is limited to welfare topics that do not duplicate those addressed by the particulate matter (PM) science assessment. The welfare effects of visibility impairment and climate interactions associated with particulate NO_X and SO_X will be addressed within the secondary PM NAAQS review, as these processes occur via NO_X and SO_X residing in the particulate or aerosol phase and interact with other chemical components of PM. The issue of NOx as a tropospheric precursor to ozone is discussed in detail in the photochemical oxidant NAAQS review (EPA 2006 and 2007). The effects of acidification and nitrogen-nutrient deposition on ecosystems are the main focus of this assessment; however, other welfare effects are discussed.

The science assessment will be organized into the integrated science assessment (ISA) and its supporting annexes. The ISA will critically evaluate and integrate the scientific information on the exposure and environmental effects associated with atmospheric deposition of NO_x and SO_x to provide a policy-relevant review as discussed in Chapter 3[2]. The annexes, which evaluate and summarize relevant studies, will provide a detailed basis for developing the ISA. The annexes will evaluate over a thousand published papers. Key findings will be summarized and integrated by discipline, pollutant impact or assessment endpoint pertinent to decisions on possible revision of the NO_2 and SO_2 secondary NAAQSs. Although emphasis will be placed on the presentation of environmental effects data, other scientific data will also be presented and evaluated in order to provide a better understanding of the nature, sources, distribution, measurement, transformations, and concentrations of NO_x and SO_x in ambient air and in various environmental compartments

The focus of the ISA and its annexes will be literature published since the previous reviews of air quality criteria for NO_x and SO_x. Key findings and conclusions from the previous Air Quality Criteria Documents (AQCDs) will be briefly summarized at the beginning of the ISA. The results of recent studies will be integrated with previous findings. Important older studies will be more specifically discussed if they are open to reinterpretation in light of newer

[2] Note that evidence related to human health effects of NO_x and SO_x will be considered in two separate science assessment documents that will prepared as part of the review of the primary NAAQS.

data. Generally, only information that has undergone scientific peer review and that has been published (or accepted for publication) in the open literature will be considered. However, exceptions may be made depending on the importance of the subject information and its relevance to the review of the NO_2 and SO_2 secondary NAAQS, as determined in consultation with CASAC.

Emphasis will be placed on studies conducted at or near NO_x and SO_x concentrations found in ambient air. Other studies may be included if they contain unique data, such as the documentation of a previously unreported effect or of a mechanism for an observed effect; or if they were studies that included both higher and lower concentrations designed to determine exposure-response relationships.

4.2 ASSESSMENT APPROACH

The NCEA-RTP is responsible for preparing the ISA and its annexes for NOx and SOx. Expert authors include EPA staff with extensive knowledge in their respective fields and extramural scientists contracted to the EPA.

4.2.1 Literature Search

The NCEA-RTP uses a systematic approach to identify relevant studies for consideration. A Federal Register Notice (FRN) was published on December 9, 2005 for NOx and on May 15, 2006 for SOx to announce the initiation of this review and request information from the public. An initial publication base has been established by searching various databases using as key words the terms nitrogen oxides (NO_x), nitrogen dioxide (NO_2), nitric acid (HNO_3), peroxyacytyl nitrate (PAN), ammonia (NH_3), total reactive nitrogen, atmospheric deposition of nitrogen and sulfur, terrestrial ecosystems, aquatic ecosystems, wetlands, etc. This search strategy will periodically be reexamined and modified to enhance identification of pertinent published papers. Additional papers are identified for inclusion in the publication base in several ways. First, EPA staff reviews pre-publication tables of contents for journals in which relevant papers are published. Second, expert chapter authors are charged with independently identifying relevant literature. Finally, additional publications are identified by both the public and CASAC during the external review process. The studies identified will include research published or accepted for publication by a date determined to be as inclusive as possible given the relevant target dates in the NAAQS review schedule. Some additional studies, published after that date, may also be included if they provide new information that impacts one or more key scientific issues. The combination of these approaches should produce a comprehensive collection of pertinent studies needed to form the basis of the ISA.

4.2.2 Criteria for Study Selection

Emphasis shall be placed on studies that evaluate effects at realistic ambient levels and studies that consider NO_X and SO_X as components of a complex mixture of air pollutants. Studies conducted in any country that contribute significantly to the knowledge base shall be included in the assessment, but emphasis may be placed on findings from studies conducted in the United States and Canada where differences in emissions and the air pollutant mixture are important. In assessing the relative scientific quality of studies reviewed here and to assist in interpreting their findings, the following considerations will be taken into account: (1) to what extent are the aerometric data/exposure metrics of adequate quality and sufficiently representative to serve as credible exposure indicators; (2) were the study populations well defined and adequately selected so as to allow for meaningful comparisons between study groups; (3) were the ecological assessment endpoints reliable and policy relevant; (4) were the statistical analyses used appropriate and properly performed and interpreted; (5) were likely important covariates (e.g., potential confounders or effect modifiers) adequately controlled or taken into account in the study design and statistical analyses; and (6) were the reported findings internally consistent, biologically plausible, and coherent in terms of consistency with other known facts.

These guidelines provide benchmarks for evaluating various studies and for focusing on the highest quality studies in assessing the body of environmental effects evidence. Detailed critical analysis of all NO_X and SO_X environmental effects studies, especially in relation to the above considerations, is beyond the scope of the ISA and its Annexes. Of most relevance for evaluation of studies is whether they provide useful qualitative or quantitative information on exposure effect or exposure response relationships for environmental effects associated with current ambient air concentrations of NO_X and SO_X or deposition levels likely to be encountered in the United States.

4.2.3 Content and Organization of the ISA

The content of the ISA will be organized and developed to address the overarching policy-relevant questions listed in Chapter 3.

The scientific information in the ISA will be drawn from a series of more comprehensive ISA annexes. The annexes will be focused on accomplishing two goals. The first goal will be to identify scientific research that is relevant to informing key policy issues. The second goal will be to produce a base of evidence containing all of the publications relevant to the review of the NOx and SOx secondary standards. Sections of the ISA annexes will include the following, not necessarily in this order:

(1) Atmospheric chemistry of NO_x and SO_x; emissions, transport, and transformations in the atmosphere

(2) Deposition processes of atmospherically derived NO_x and SO_x, ambient concentrations and the relationship between ambient concentrations and deposition

(3) Environmental response networks, monitoring networks and models;

(4) Acidification effects of NO_x and SO_x on terrestrial and aquatic ecosystems

(5) Non-acidification effects of NO_x on terrestrial and aquatic ecosystems;

(6) Non-acidification effects of SO_x on terrestrial and aquatic ecosystems;

(7) Impacts of NOx/SOx on ecosystems modified by climate change factors

(8) Assessing the available information for potentially determining critical loads to ecosystems

(9) Effects of NO_x and SO_x deposition on acid-driven erosion of man-made materials and structures; and

(10) Valuation of NOx and SOx effects on the environment.

The ISA will convey the reasoning used to select which scientific studies are most policy-relevant. Detailed discussions of studies considered for the ISA, but not deemed most relevant, will be limited to the annexes. The ISA will integrate scientific information from the 10 subject areas identified by the annexes into main topic areas. At this point we anticipate these sections to be Atmospheric Concentration and Deposition, and Ecosystems. However upon further evaluation of the literature Materials and Structures Damage may be a third area of the ISA.

1. ***Atmospheric Concentration and Deposition***: The ISA will evaluate what we know about the factors that influence deposition, the uncertainties associated with extrapolation from

ambient air concentrations to ecosystem exposures to NOx and SOx, and spatial patterns of NOx and SOx deposition. Specific questions include, but are not limited to:

a. How are uncertainties described when extrapolating between stationary monitoring instruments and ecosystem exposure?

b. What is the spatial distribution of NOx and SOx on a national scale? What are the most effective means of using our observations and predictive models to address spatial, temporal and compositional distribution of nitrogen and sulfur? What additional information (observations, process formulations) would enhance our ability to quantify current exposures and track changes over time?

c. How does reduced nitrogen (NHx) alter the atmospheric chemistry, transport and deposition of NOx or SOx?

2. Integration of ***ecological*** evidence: The integration section will begin with an overview of three ecologic concepts that are important to clarify at the onset of the discussion: scale, function and structure (organism to region) and ecosystem services. The integration of ecologic evidence will be organized according to impacts. These impacts are acidification (combined effects of NOx and SOx), nitrogen nutrient effects (NOx) and sulfur nutrient effects (SOx). With regard to nitrogen nutrient effects, it is important to note that ecosystems are typically sensitive to total reactive nitrogen (Nr) input. Therefore NOx is evaluated as a component of total nitrogen input from various anthropogenic sources. The following questions will be addressed for each ecological impact:

a. Is the biogeochemistry of ecosystems impacted and what are the chemical indicators of impact?

b. How are organisms impacted? Which biological species are most sensitive? How is sensitivity defined?

c. What ecosystems are most sensitive to NOx and SOx pollution?

d. How does NOx and SOx pollution impact ecosystem services?

e. What new information is available on the levels of deposition that can cause harm in ecosystems?

f. What are the most appropriate spatial and temporal scales to evaluate impacts on ecosystems?

g. What is the relationship between ecological vulnerability and NOx and SOx pollution variations in current meteorology or gradients in climate?

h. Are there time lags to ecosystem “recovery”? What are the physical, chemical and ecological characteristics of “recovery”?

4.3 Public and Scientific Review

4.3.1 Informal Peer Consultation Workshop of the ISA Annexes

A combined peer review/policy kickoff workshop was held in Chapel Hill, NC on July 17-19, 2007. This peer consultation workshop provided a forum for the authors of the ISA and its annexes to receive comments from their scientific peers on the first draft of their findings. Peer reviewers were given a copy of the chapter they were assigned prior to the workshop and were asked to conduct an informal review by providing written comments on its scientific content. Each peer consultant was also asked to participate in the workshop. Reviewers provided critical comments on the adequacy of the coverage of the literature, the presentation of the evidence in both text and figures or tables, the appropriateness of the conclusions from the evidence and any new issues or literature that should be considered. At this workshop, expert reviewers were also asked to participate in a discussion of the integrative aspects of the evidence, to assist the EPA in subsequent preparation of the ISA.

4.3.2 Public Review of External Review Drafts

Since the conclusion of the workshop review process, the authors, contributing reviewers, and NCEA-RTP Project Team have met to resolve how to address comments received and will revise the draft annexes and complete preparation of the First External Review Draft (ERD) NO_x and SO_x ISA. After clearance by the U.S. EPA, the draft document will be released for public comment as announced in a Federal Register Notice. The ERD will be made available for review during a specified time period, usually of 60 to 90 days; written comments are solicited during this time. A similar procedure will be followed for public and CASAC review of a Second External Review Draft that EPA expects to be necessary before completion of the Final NO_x and SO_x ISA.

4.3.3 Review by Clean Air Scientific Advisory Committee

At the time the First External Review Draft is released to the public, that draft document will also be sent to the Clean Air Scientific Advisory Committee (CASAC) of EPA's Science

Advisory Board (SAB). CASAC members and consultants (see Appendix A) will review the draft document and discuss their comments in a public meeting announced in the Federal Register. At the meeting, the NCEA-RTP Project Team plans to present an overview of the main features of the document, a summary of key issues raised by public comments received on the document, and the charge to the committee, as well as being prepared to discuss proposed revisions, if indicated. Based on CASAC's past practice, EPA expects that key CASAC advice and recommendations for revision of the document will be summarized by the CASAC Chair in a letter to the EPA Administrator. EPA will take into account any such recommendations, as well as CASAC and public comments at the meeting and any written comments received, in revising the draft NO_x and SO_x ISA. As noted earlier, EPA expects that it will be necessary to prepare a Second External Review Draft for further CASAC review and public comment. After appropriate revision, the final document will be made available on an EPA website and subsequently printed, with its public availability being announced in the Federal Register.

5. RISK/EXPOSURE ASSESSMENT

The risk/exposure assessment for the NOx and SOx secondary NAAQS review will build upon the scientific information presented in the Integrated Science Assessment. As discussed earlier in this document, the risk/exposure assessment will not focus on other welfare effects that might be associated with secondary pollutants associated with NOx and SOx. Depending on the results of the science assessment, air quality indicators for these criteria pollutants that differ from the current indicators may be considered in the risk/exposure assessment.

The risk/exposure assessment will evaluate potential alternative indices, in an attempt to quantify the relationship between ambient concentrations of NOx and SOx and potential welfare effects. To create these indices, we will evaluate exposures and impacts in various ecosystems with differing responses related to nitrogen and sulfur inputs. One possible approach, recommended by both CASAC and the NRC (2004) is considering the use of critical loads when evaluating secondary standards. Further, the risk/exposure assessment will use a variety of methods to assess the potential adversity of impacts including the effects of the pollutants on ecosystem goods and services, the degree to which ecosystem functions are impaired, long-term trends in specific ecosystems (where available), and both economic and non-economic valuation of ecosystem services. Our ability to address these issues will enable us to determine the extent to which the current standards provide requisite protection from any known or anticipated adverse effects associated with ambient levels of NOx and SOx. Given that it is the Administrator's final decision as to whether an effect is significantly adverse to warrant revising and/or replacing the current standards, or if the body of scientific evidence and assessment tools provide an adequate basis for supporting revised standards, the risk/exposure assessment will be designed to provide quantitative results which will best inform that decision.

To evaluate the nature and magnitude of ecosystem responses associated with adverse effects, the risk/exposure assessment will examine various ways to quantify the relationship between air quality indicators, deposition of biologically-accessible forms of nitrogen and sulfur, biologically-relevant indices relating deposition, exposure and effects on sensitive receptors and related impacts to ecosystem service(s). The risk/exposure assessment will evaluate the overall load to the system for nitrogen and sulfur as well as the variability in ecosystem responses to these pollutants and determining the exposure metric(s) that incorporates the temporal considerations (i.e. biologically-relevant timeframes), pathways, and biologically-relevant indices in order to maintain the functioning of these ecosystems. In addition, the risk/exposure assessment will attempt to address how sensitive ecosystems and their services affected by nitrogen and sulfur deposition may respond to variations in climatic elements such as temperature and rainfall.

The scope of the risk/exposure assessment will depend in part on the answers to the following questions:

- What are the appropriate geographic scale(s) and/or time frame(s) for the risk assessment? Information that will be considered in addressing this question includes: national-scale mapping, case studies of sensitive ecosystems, identification of representative ecosystem types, air pollution gradient studies, a weight-of-evidence approach incorporating both qualitative and quantitative information on risk, and, perhaps, some combination of the above.

- How can regional variation of effects be taken into account? How should the risk/exposure assessment address acidification and nutrient enrichment effects in different areas and ecosystem types (e.g., mesic, arid, mountain forests, alpine, and sub-alpine) at varying ambient concentrations of nitrogen and sulfur compounds? Can differences in regional sensitivity to deposition be completely characterized by underlying physical or biological attributes?

- To what degree are assumptions supported by the available science regarding linkages between pollutants in ambient air, deposition, and measurable ecosystem effects? What are the most useful metrics of both ambient pollution and the resulting effect?

- To what degree should the risk/exposure assessment take the potential for recovery into account in selecting data for qualitative and quantitative assessments?

- How can uncertainties be minimized and appropriately characterized?

5.1 ASSESSMENT APPROACH

There are a variety of ways to address the risk/exposure assessment for the review of the secondary NAAQS for NOx and SOx. One of the purposes of this document is to solicit ideas and evaluate the most appropriate way to approach this review. In order to assess risks to public welfare due to ambient nitrogen and sulfur deposition, the relationships (and associated uncertainties) between ambient concentrations, deposition, environmental effects, environmental receptors, and ecosystem services and ecosystem valuation should be established. Some of our preliminary ideas for the risk/exposure assessment are outlined below. A detailed description of the tools mentioned here and others that are currently available are described in detail in Appendix B.

Understanding the atmospheric chemistry and deposition of nitrogen and sulfur is central to this review. Most likely, we will use the Community Multi-Scale Air Quality (CMAQ) model (and derivative models such as the response-surface model) described in Appendix B to estimate ambient concentrations and deposition areas. Any assessment of atmospheric chemistry and deposition is highly-dependent on the variability associated with baseline inputs. Consideration will be given to analyzing five consecutive years of CMAQ outputs (2001-2005) delivered as part of EPA's Interagency Agreement with CDC to improve understanding of baseline deposition and the relationships between nitrogen and sulfur concentration and deposition in terms of magnitude and spatial relationships.

Initially we plan to conduct regression and related statistical analyses to generate statistical correlations between grid-level ambient concentrations of NOx and SO_2 and grid-level or appropriately spatially averaged (e.g., at the watershed level) deposition rates of sulfur and nitrogen. The regression analysis will use the results from the 2001-2005 CMAQ simulations conducted for the joint EPA/CDC project. The analysis will use linear and non-linear regression modeling, as well as spatial regression techniques, to develop reduced form equations. To the extent that data are available, the statistical modeling may also incorporate relevant meteorological and physical attributes, e.g. precipitation, relative humidity, wind speed and direction. These statistical relationships are not expected to provide predictive models. Rather, the goal is to develop appropriate estimates of the relationship between deposition metrics and ambient levels of NOx and SOx.

Another central issue in this review is determining which ecosystems are more or less sensitive to nitrogen and sulfur deposition. It may be useful to rank ecosystems (where data is available) based on a small subset of determinative underlying characteristics. These characteristics may include (but are not limited to): (1) potential nitrogen and sulfur retention rates, (2) potential nitrogen and sulfur uptake rates, which might include vegetative uptake, potential denitrification, and potential mobilization of nitrogen and sulfur, (3) potential residence time based on local hydrology (precipitation rates, conductivity) and geology (bedrock type, pervious surfaces, soil properties), and (4) total supply of nitrogen and sulfur including current and historical atmospheric deposition, and other non-atmospheric sources (such as fertilization, sewer leaks, point sources, etc.). Other ecosystem-specific characteristics, which may help assess sensitivities, include threatened and endangered species data where available, land-use type (including Class I, National Parks and Fish and Wildlife Refuges and National Wilderness areas), and baseline nitrogen and sulfur loading estimates. Where case-study or ecosystem-specific data are available, a subset of maps for the case-study region may be created. Complementary to these efforts, we may use statistical cluster analysis to group ecosystem units into similar sets. By clustering ecosystems together, we may reduce the number of locations that need to be modeled to adequately characterize the variability in ecosystem response to changes in nitrogen and sulfur deposition.

These types of analyses may aid in determining if case studies might be appropriate for looking at nitrogen and sulfur effects on various ecosystems and geographic regions as a means of extrapolating these impacts to the entire country. For those areas where data are available, watershed models (e.g., MAGIC, PnET-BGC, and DayCent-Chem) may be useful for evaluating the emission-deposition-ecosystem response linkage. (These models are described in more detail in Appendix B.) As the integrated science assessment and risk/exposure assessment progress, we anticipate identifying additional ways to evaluate biologically-relevant indicators and ecosystem valuation techniques that will ultimately help to direct and focus the final Risk Assessment.

5.2 TOOLS FOR RISK ASSESSMENT

In order to develop a risk analysis for a meaningful nationwide or ecosystem-specific metric, some of the available analytical tools for conducting a risk assessment are described/summarized in Appendix B. The more detailed model evaluation discussion included in the annexes and ISA will aid in selecting the appropriate modeling tools. With these tools, the risk/exposure assessment should be able to determine the appropriate endpoint(s)/indicator(s), geographic level/scale of protection, national or case-study modeling, and which ecosystem services are important.

5.3 KNOWLEDGE GAPS

As discussed above and in detail in Appendix B, the risk/exposure assessment will use simulation models of atmospheric emissions, transformation, fate, transport, and deposition to follow emissions from a source to a receptor, either aquatic or terrestrial. We plan to overlay available data sets related to deposition and adverse impacts with GIS-based approaches to aid in the evaluation of their spatial correlations. We also have published and evaluated regional or area-specific models that will aid in evaluating ecosystem effects in specific watersheds (i.e., for the Chesapeake Bay or the Adirondack mountains). Additionally, we are beginning to quantify ecosystem services and the benefits they provide. However, there are knowledge gaps in the linkages between these areas.

Some of the main questions the risk/exposure assessment will try to answer are, "If we can identify appropriate biologically relevant indices, can we establish a link between deposition of NOx and SOx and ecosystem response? Additionally, what ecosystem services are associated with changes in emissions?" Answering these questions raises other issues regarding the links between atmospheric deposition and an ecosystem response, and ecosystem services and emissions changes. Some of these questions are listed below.

Atmospheric Deposition, Fate, and Transport Modeling

- What are typical uncertainties for observed and regional model estimates of wet and dry NOx, NHx, and SOx deposition rates?
- Can deposition models be used to estimate deposition (wet, dry, cloud, fog) to a land-use specific surface, such as mountainous terrain, coniferous/deciduous forests, etc?
- If not, are there models that can take this output and estimate deposition to specific ecosystems?

Ecological Response Modeling

- Do we have sufficient data to develop dose-response functions linking changes in nitrogen and sulfur deposition to changes in ecosystem functions?
- Can we adequately characterize the uncertainties in these dose-response functions?
- Can ecosystem-specific models be used to represent similar ecosystems nationwide? What are the uncertainties associated with the transferability between a specific watershed model to multiple watersheds?

Ecosystem Services

- Can the current known ecological responses be translated into an ecosystem service or services?
- Can we value the changes in ecosystem services associated with changes in ecological indicators?
- Can a process-based model serve to link multiple ecosystem services in order to assess the 'true' impact of air quality on the 'bundles of services' provided by that ecosystem?
- How can we show that reducing emissions of NOx/SOx results in a specific ecosystem benefit?

Valuation

- What does the current valuation literature indicate about the values of change in ecosystems and the services they provide?
- Are there other methods for developing non-monetized value estimates?
- How do we link ecosystem responses and ecosystem services and how do we value the changes in those services?

5.3 PUBLIC AND SCIENTIFIC REVIEW

Drafts of the risk/exposure assessment will be reviewed by CASAC of EPA's Science Advisory Board (SAB). CASAC members and consultants (see Appendix A) will review the draft document and discuss their comments in a public meeting announced in the Federal Register. Based on CASAC's past practice, EPA expects that key CASAC advice and recommendations for revision of the document will be summarized by the CASAC Chair in a letter to the EPA Administrator. In revising the draft risk/exposure assessment for NO_x and SO_x, EPA will take into account any such recommendations. EPA will also consider comments received, from CASAC or from the public, at the meeting itself and any written comments received. EPA anticipates preparing a second draft of the risk/exposure assessment for CASAC review and public comment. After appropriate revision, the final document will be made available on an EPA website and subsequently printed, with its public availability being announced in the Federal Register.

6. POLICY ASSESSMENT

Based on the information in the ISA and the risk/exposure assessment, the Agency will develop an advance notice of proposed rulemaking (ANPR) that reflects EPA's views regarding the need to retain or revise the secondary NAAQS for NO_2 and SO_2. The ANPR will identify conceptual evidence-based and risk/exposure-based approaches for reaching public welfare policy judgments. It will discuss the implications of the science and risk/exposure assessments for the adequacy of the current standard, and it will present risk/exposure information associated with alternative standards. The ANPR will also describe a range of policy options for standard setting including a description of the underlying interpretations of the scientific evidence and risk/exposure information that might support such alternative standards and that could be considered by the Administrator in making NAAQS decisions.

The use of an ANPR will provide an opportunity for CASAC and the public to evaluate the policy options under consideration and to offer comments and recommendations to inform the development of a proposed rule. Taking into account CASAC advice and recommendations as well as public comment on the ANPR, the Agency will publish a proposed rule. This proposal will be followed by a public comment period. Taking into account comments received on the proposed rule, the Agency will then issue a final rule to complete the rulemaking process.

A final decision must draw upon scientific evidence and analyses about effects on public welfare and the nature and magnitude of ecosystem responses that are understood to have adverse effects, as well as judgments about how to deal with the range of uncertainties that are inherent in the scientific evidence and analyses. The Agency's approach to informing these judgments is based on the recognition that the available public welfare effects evidence generally reflects a continuum consisting of ambient levels at which scientists generally agree that public welfare effects are likely to occur, and that at lower ambient levels the likelihood and magnitude of the ecosystem responses become increasingly uncertain.

This evaluation should recognize that the effects of NOx/SOx compounds on aquatic and terrestrial ecosystems are diverse and occur over time as a result of deposition, include acidification and fertilization effects, are regionally specific, and occur through the atmospheric reactions, transport, and deposition of NOx/SOx compounds emitted from varied and ubiquitous sources. The links in the fate, transport, and deposition apply to both acidification and fertilization (which is understood to capture both eutrophication in aquatic systems and fertilization in terrestrial systems).

Other considerations in developing an indicator include using total reactive nitrogen as a biologically-relevant index for nutrient enrichment. Total reactive nitrogen deposited (and transported) should be viewed in context of baseline nitrogen availability. Ecosystem impacts may differ due to form of nitrogen deposited (e.g., oxidized vs reduced nitrogen), and the various forms of nitrogen deposited may be important in determining the form of the standard. Nitrogen deposition impacts also depend on soil characteristics, species composition and competition, and soil composition. In aquatic ecosystems, the range of biologically-relevant indices for nitrogen sensitivity may include dissolved oxygen concentrations, and the ratio of algae to diatoms. Acid neutralizing capacity (ANC) may be an appropriate biologically-relevant index for acidification depending on the time scale being considered. Acidification measured by sulfate and nitrate concentrations can change relatively rapidly (over several years), while ANC can take decades to change and reach a new equilibrium depending on releases of sulfate and other acidifying components due to current emissions/deposition or release of soil constituents including sulfate. The short-term effects from acid pulses may point to the need for a seasonal form of the standards. Nitrogen impacts through fertilization also have a seasonal component that may display a different pattern than that for acidification. The need for seasonal standards will be evaluated, noting that impacts may differ by the water type and land use in different areas. Ecosystem recovery time may also play an important role in determining the appropriate form and averaging time of standards.

The policy determination of what is an adverse impact may vary, depending on the method chosen to assess adversity. The NAAQS provisions in the Act require the Administrator to establish secondary standards that are requisite to protect public welfare from any known or anticipated adverse effects associated with the presence of the pollutant in the ambient air. In so doing, the Administrator seeks to establish standards that are neither more nor less stringent than necessary for this purpose. The provisions do not require that secondary standards be set to eliminate all welfare effects, but rather at a level that protects public welfare from those effects that are judged to be adverse. In the evaluation of ecosystem services and valuation as one potential measure of adversity, the assessment should consider the ecosystem benefits that are projected to occur as a result of reductions in the current standards.

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APPENDIX A: CASAC PANEL

U.S. Environmental Protection Agency
Science Advisory Board (SAB) Staff Office
Clean Air Scientific Advisory Committee (CASAC)
NO_X and SO_X Secondary NAAQS Review Panel

The Clean Air Scientific Advisory Committee (CASAC) was established under section 109(d)(2) of the Clean Air Act (CAA or Act) (42 U.S.C.7409) as an independent scientific advisory committee. CASAC provides advice, information and recommendations on the scientific and technical aspects of air quality criteria and national ambient air quality standards (NAAQS) under sections 108 and 109 of the Act. The CASAC is a Federal advisory committee chartered under the Federal Advisory Committee Act (FACA), as amended, 5 U.S.C., App. The Panel will comply with the provisions of FACA and all appropriate SAB Staff Office procedural policies.

Section 109(d)(1) of the CAA requires that the Agency periodically review and revise, as appropriate, the air quality criteria and the NAAQS for the six "criteria"' air pollutants, including NO_X and SO_X.

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Dr. Donna Kenski, Director, Lake Michigan Air Directors Consortium, Rosemont, IL

Dr. Naresh Kumar, Senior Program Manager, Environment Division, Electric Power Research Institute, Palo Alto, CA

Dr. Myron Mitchell, Distinguished Professor and Director, College of Environmental and Forestry, Council on Hydrologic Systems Science, State University of New York, Syracuse, NY

Mr. Richard L. Poirot, Environmental Analyst, Air Pollution Control Division, Department of Environmental Conservation, Vermont Agency of Natural Resources, Waterbury, VT

Mr. David J. Shaw, Director, Division of Air Resources, New York State Department of Environmental Conservation, Albany, NY

Dr. Kathleen Weathers, Senior Scientist, Institute of Ecosystem Studies, Millbrook, NY

APPENDIX B: ASSESSMENT TOOLS

B.1 MODELS

B.1.1 Community Multi-Scale Air Quality (CMAQ) Model

The CMAQ model is a three-dimensional grid-based Eulerian air quality model designed to estimate the formation and fate of ozone and other oxidants and their precursors; primary PM and secondary particulate matter precursors and atmospheric concentrations; toxics; and deposition of chemical species over scales ranging from continental to regional and urban to neighborhood (EPA, 1999; Byun and Schere, 2006; Dennis et al., 1996). The CMAQ model was peer-reviewed in 2003 for EPA as reported in "Peer Review of CMAQ Model" (Amar et al., 2004).

CMAQ is most often configured to output spatial fields of gridded concentrations and deposition on an hourly basis for the entire modeling domain. Pollutant concentrations are output for each vertical layer included the model simulation. Additional information on the horizontal and vertical configuration of the model is provided below. The current version of CMAQ (v4.6) is capable of one atmosphere modeling in which NOx, SOx, ozone, particulates, mercury, and selected toxic pollutants are included in a model simulation. A list of the key nitrogen and sulfur containing deposition species output by CMAQ is provided in Table B.1. This table also identifies the deposition species derived from CMAQ's nitrogen and sulfur deposition outputs.

The standard hourly CMAQ model predictions are post-processed to create gridded fields of daily average, monthly average, and annual average concentrations for layer 1, which is the layer nearest to the ground. The hourly deposition outputs are post-processed to produce gridded fields of daily, monthly, and annual total wet, dry and wet plus dry deposition.

Table B.1. Key Predicted and Derived Nitrogen and Sulfur Deposition Species from CMAQ[1]

Predicted Deposition Species	***Derived Deposition Species***
Nitrogen Oxide (NO)	Oxidized Nitrogen
Nitrogen Dioxide (NO_2)	Reduced Nitrogen

Nitric Acid (HNO_3)	Total Nitrogen
Dinitrogen Pentoxide (N_2O_5)	Total Sulfur
Peroxyacetyl Nitrate (PAN)	
Ammonia (NH_3)	
Sulfur Dioxide (SO_2)	
Particulate Sulfate (SO_4)	
Particulate Nitrate (NO_3)	
Particulate Ammonium (NH_4)	

[1]Model predictions include both wet and dry deposition in units of kg/ha.

2002-Based Platform CMAQ Modeling

EPA/AQAD is developing an air quality modeling platform that includes meteorology and emissions[3] for 2002 along with projected emissions for 2009, 2014, 2020, and 2030. The future year projections reflect the combined effects of emissions growth and reductions associated with "national rules" up through the CAIR/CAMR/CAVR. CMAQ will be run for each of these five years for a 36 km nationwide domain and for separate 12 km modeling domains covering the eastern and western U.S. The area covered by each of these domains is shown in Figure B.1. The domain specifications are provided in Table B.2. All three modeling domains contain 14 vertical layers with a top at about 16,200 meters, or 100 mb. Note that the horizontal and vertical resolution selected for these simulations are not limited by the model. Rather, they were selected to balance (1) the desire to have annual nationwide simulations with fine scale resolution versus (2) the computational requirements of the simulations which increase with horizontal and vertical resolution[4].

The CMAQ meteorological input files were derived from simulations of the Pennsylvania State University / National Center for Atmospheric Research Mesoscale Model (Grell, Dudhia, and Stauffer, 1994). This model, commonly referred to as MM5, is a limited-area, nonhydrostatic, terrain-following system that solves for the full set of physical and thermodynamic equations which govern atmospheric motions. The outputs from MM5 were processed to create model-ready inputs for CMAQ using the Meteorology-Chemistry Interface

3 Emissions inputs for to CMAQ include anthropogenic and biogenic emissions from areas of the U.S., Canada, and Mexico that are within the modeling domain. Anthropogenic emissions for the U.S. were derived from the 2002 National Emissions Inventory.

Processor (MCIP) version 3.2: horizontal wind components (i.e., speed and direction), temperature, moisture, vertical diffusion rates, and rainfall rates for each grid cell in each vertical layer (EPA, 1999).

The lateral boundary and initial species concentrations for the CMAQ 36 km domain were obtained from a three-dimensional global atmospheric chemistry model, the GEOS-CHEM model (Yantosca, 2004). The global GEOS-CHEM model simulates atmospheric chemical and physical processes driven by assimilated meteorological observations from the NASA's Goddard Earth Observing System (GEOS). This model was run for 2002 with a grid resolution of 2 degree x 2.5 degree (latitude-longitude) and 20 vertical layers. The predictions were used to provide one-way dynamic boundary conditions at 3-hour intervals and the initial concentration field for the CMAQ simulations. The outputs from the 36 km domain are utilized to provide the initial and boundary condition concentrations for each of the two 12 km domains.

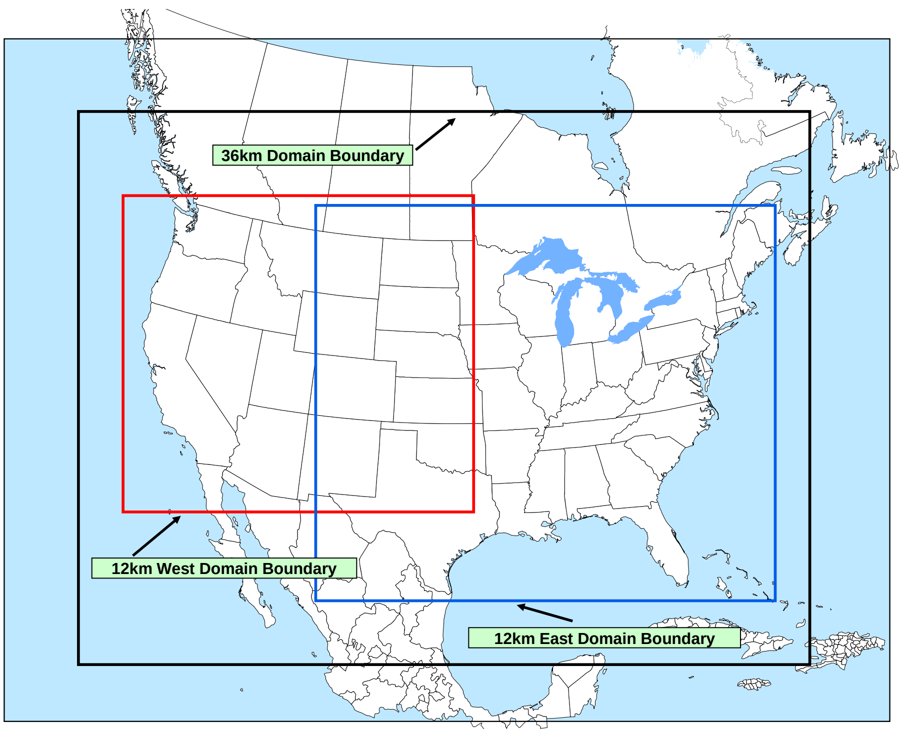


Figure B.1. Map of the CMAQ 36 km and 12 km Modeling Domains.

Table B.2. Geographic Specifications of Modeling Domains.

4 For various special studies, CMAQ has been run at 4 km and 1 km horizontal resolution for urban-scale domains and with a vertical resolution of over 30 layers.

36 km Domain (148 x 112 Grid Cells)			12 km Eastern Domain (279 x 240 Grid Cells)			12 km Western Domain (213 x 192 Grid Cells)		
	Lon	lat		lon	lat		lon	lat
SW	-121.77	18.17	SW	-106.79	24.99	SW	-121.65	28.29
NE	-58.54	52.41	NE	-65.32	47.63	NE	-94.94	51.91

B.1.2 Response Surface Models (RSM)

Air quality models can be a powerful regulatory tool for comparing the efficacy of various emissions control strategies, regulatory impacts and policy decisions. However, due to the often large computational costs and the complication of the required emission inputs and processing, using individual simulations from photochemical air quality models to meet policy deadlines can be inefficient. A promising tool for addressing this issue, Response Surface Modeling (RSM), has been developed by using advanced spatial statistical techniques to characterize the relationship between model outputs and input parameters in a highly economical manner. The RSM aggregates numerous pre-specified individual air quality modeling simulations into a multi-dimensional air quality "response surface." Simply, this metamodeling technique is a “model of the model” and can be shown to reproduce the results from an individual modeling simulation with little bias or error. The RSM provides a wide breadth of model outputs that can be used to rapidly assess air quality impacts of different control measures and assist in the development of multi-pollutant control strategies. Specifically, the RSM can be used in a variety of ways: (1) strategy design and assessment (e.g. comparison of urban vs. regional controls; comparison across sectors; comparison across pollutants); (2) optimization (develop optimal combinations of controls to attain standards at minimum cost); (3) model sensitivity (systematically evaluate the relative sensitivity of modeled air quality levels to changes in emissions inputs.

Response surface models have been successfully applied in the context of the ozone and particulate matter regulatory impact analyses. In those contexts, the RSMs were used to explore the sensitivity of ambient ozone and PM concentrations to changes in precursor emissions, for the purpose of designing strategies to reduce ambient concentrations. Documentation of these applications can be found in the regulatory impact analyses (U.S. EPA, 2006a, 2007).

Response surface models for nitrogen and sulfur deposition are in development and should be available to inform the Risk/Exposure Assessment. These models will allow us to explore the sensitivity of nitrogen and sulfur deposition for a number of different deposition species (reduced and oxidized nitrogen, wet and dry sulfur) to emissions of NOx, SO_2, and NH_3. The RSMs will also allow us to explore the chained relationships between emissions of NOx, SO_2, and NH_3 and ambient concentrations of NOx, NHx, and SOx, and the resulting changes in deposition. This will help to identify correlations or differences in the spatial patterns of the response of ambient concentrations versus the response of deposition.

B.1.3 Air Quest

AirQuest is a data management system. It stores air data in a single location and delivers it to various tools and applications. The data in AirQuest can be accessed via SAS, Excel, MS Access, Google Earth, ArcGIS, and a customized web-based interactive map.

AIRQuest was designed to serve as a single source for integrated, high quality, readily available air quality data, summaries, and statistics from regulatory monitoring networks. In addition, AIRQuest represents an opportunity to leverage data processing and storage resources, since a fully functional AIRQuest will remove the need for analysts to store large amounts of data on their desktops. In addition, by carefully defining and coming to agreement on business rules that define "the right way" to calculate air quality metrics, AIRQuest can ensure that every analyst has a consistent approach and consistent answers.

B.1.4 Total Risk Integrated Methodology (TRIM)

The TRIM design includes three individual modules which have been the subject of peer review and publication. Two of these modules are applicable to ecological risk assessments. The *Environmental Fate, Transport, and Ecological Exposure* module, TRIM.FaTE, accounts for movement of a chemical through a comprehensive system of discrete compartments (e.g., media and biota) that represent possible locations of the chemical in the physical and biological environments of the modeled ecosystem and provides an inventory, over time, of a chemical throughout the entire system.

TRIM.FaTE is a spatially explicit, compartmental mass balance model that describes the movement and transformation of pollutants over time, through a user-defined, bounded system that includes both biotic and abiotic compartments. Outputs include pollutant concentrations in multiple environmental media and biota, and also biota and pollutant intakes (e.g., mg/kg-day), all of which provide exposure estimates for ecological receptors (i.e., plants and animals).

Significant features of TRIM.FaTE include: (1) a fully coupled multimedia model; (2) user flexibility in defining scenarios, in terms of the links among compartments, and number and types of compartments, as appropriate for the application spatial and temporal scale; (3) transparent, user-accessible algorithm and input library that allows the user to review and modify how environmental transfer and transformation processes are modeled; (4) a full accounting of all of the pollutant as it moves among environmental compartments during simulation; (5) an embedded procedure to characterize uncertainty and variability; and (6) the capability to provide exposure estimates for ecological receptors.

In the *Risk Characterization* module, TRIM.Risk, estimates of human exposures or doses are characterized with regard to potential risk using the corresponding exposure- or dose-response relationships. The TRIM.Risk module is also designed to characterize ecological risks from multimedia exposures. The output from TRIM.Risk is intended to include documentation of the input data, assumptions in the analysis, and measures of uncertainty, as well as the results of risk calculations and exposure analysis.

The uncertainty and variability features (e.g., sensitivity & Monte Carlo analysis) augment TRIM's capability for performing iterative analyses. For example, the user may perform assessments varying from simple deterministic screening analyses using conservative default parameters to refined and complex risk assessments where the impacts of parameter uncertainty and variability are assessed for critical parameters.

B.1.5 Regional Vulnerability Assessment (ReVA)

The Regional Vulnerability Assessment (ReVA) program conducts research on innovative approaches to the evaluation and interpretation of large and complex datasets and models to assess the current conditions and likely outcomes of environmental decisions, including alternative futures. ReVA works with select client groups to develop research and demonstration pilots on how current data and appropriate models can be combined and interpreted across a geographic region to set management and ecosystem protection priorities and to proactively assess the outcomes of decisions that may impact multiple outcomes or involve tradeoffs in a transparent, defensible fashion.

To date, ReVA has completed the development of an environmental toolkit for EPA Region 3 and is actively engaged in developing tools for decision making that support urban and interstate issues (SEQL), regional multipollutant issues that affect human health and ecosystems (Region 4), and multistate partnerships that affect the health of international environmental resources (Region 5/ Great Lakes).

B.2 CASE STUDY MODELING

Integrated assessment case studies provide results for numerous environmental parameters, including emissions, atmospheric concentrations of pollutants, pollutant deposition to land and water surfaces, and changes in ecological parameters such as surface water chemistry, forest soil chemistry, or fish populations.   In some cases, it may also be possible to link changes in ecological parameters to changes in ecosystem services, and ultimately to the economic value of the changes in ecosystem services (which is one potential measure of adversity of effect). By comparing the environmental impacts of existing programs with alternative policy scenarios, integrated assessments of this type provide estimates of the incremental ecological effects of potential policy changes. The process for assessing the ecological outcomes of different potential standards frequently focuses on relationships between pollutant emissions, pollutant deposition (the means of exposure for many aquatic and terrestrial ecosystems) and ecosystem response. Currently, analytical tools exist to analyze the emission-deposition-ecosystem response linkage with particular focus on two ecological parameters – surface water chemistry and forest soil chemistry – in three case study areas:

- Northern New England lakes;
- Adirondack Mountain region lakes;
- Southern Blue Ridge region streams.

The assessment approach involves several steps and employs various analytical and modeling tools that, once integrated, provide a means to assess ecological impacts. The National Emissions Inventory is used to develop emissions inventories for area, mobile, and point sources other than electricity generating utilities (EGU). The Integrated Planning Model (IPM) is used to develop emissions inventories for EGUs. The inventories specify profiles of emissions by pollutant, place, time, and source type for each policy scenario. Atmospheric models (e.g., CMAQ) employ the emissions inventory inputs to project changes in atmospheric concentrations and deposition of pollutants to land and water surfaces. Ecological impacts, such as lake and stream water chemistry, or changes in forest soils, are assessed by using watershed models (e.g., MAGIC, PnET-BGC). These models employ atmospheric modeling output (deposition changes) to project changes in the surface water chemistry of lakes and streams, or changes in forest soil chemistry, in regions that are sensitive to atmospheric deposition of sulfur and nitrogen species. Ecological impacts of policy scenario implementation are then assessed using algorithms based on observed relationships between ecosystem chemical parameters (e.g., acid neutralizing capacity, soil base saturation) and biological indicators of ecosystem health (e.g., fish species richness).

Briefly, MAGIC is a lumped-parameter model of intermediate complexity, developed to predict the long-term effects of acidic deposition on surface water chemistry (Cosby et al. 1985a,b,c, 2001). The model simulates soil solution and surface water chemistry to predict average concentrations of the major ions. MAGIC calculates for each time step (in this case year) the concentrations of major ions under the assumption of simultaneous reactions involving sulphate adsorption, cation exchange, dissolution-precipitation-speciation of aluminium and dissolution-speciation of inorganic and organic carbon. MAGIC accounts for the mass balance of major ions in the soil by accounting for the fluxes from atmospheric inputs, chemical weathering, net uptake in biomass and loss to runoff.

At the heart of MAGIC is the size of the pool of exchangeable base cations in the soil. As the fluxes to and from this pool change over time owing to changes in atmospheric deposition, the chemical equilibria between soil and soil solution shift to give changes in surface water chemistry. The degree and rate of change of surface water acidity thus depend both on flux factors and the inherent characteristics of the affected soils. Data inputs required for calibration of MAGIC comprise lake and catchment characteristics, soil chemical and physical characteristics, input and output fluxes for water and major ions, and net uptake of base cations by vegetation.

PnET-BGC is a comprehensive forest-soil-water model developed by linking a monthly carbon, nitrogen, and water balance model PnET (Aber et al., 1997) with a soil model BGC to allow for comprehensive simulations of element cycling within forest and the interconnected aquatic ecosystems (Gbondo-Tugbawa et al., 2001). The model is able to simulate both abiotic processes and biotic processes. Especially the representation of biomass accumulation and the associated element cycling enable the evaluation of land disturbance and climatic events on soil and water chemistry (Gbondo-Tugbawa et al., 2001). The model uses relatively simple formulations and requires a moderate number of inputs to quantify the acid-base status of soil and surface waters under various levels of atmospheric deposition; therefore it can serve both as a research and a management tool. Its simplicity also makes it a good candidate for regional applications.

B.3 ECOSYSTEM SERVICES: IMPACT AND VALUATION

The final step of an integrated assessment of risks to the public welfare involves determining what level of ecosystem response translates into an effect that could reasonably be considered adverse to the public welfare. There are a number of ways to do this, including

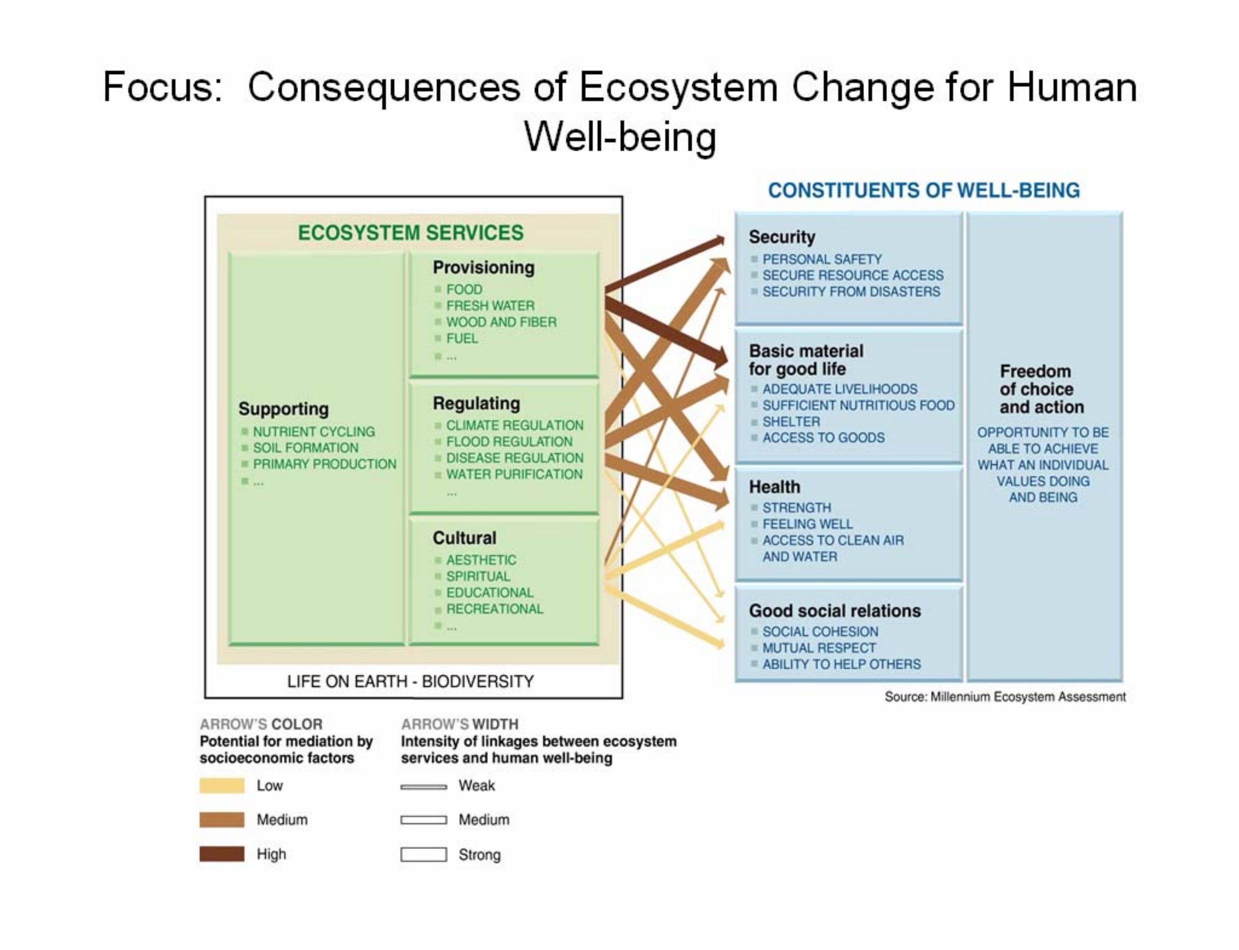
- direct measures of quantities that are of known value to the public, e.g. numbers of endangered species,
- direct economic valuation of ecosystem functions, including use and nonuse values (values that do not require an individual's direct use of an ecosystem – for example, the value of preserving an endangered species habitat, even though that individual will ever see that species in the wild),
- translation of ecosystem attributes into measures of ecosystem services which can then be valued using economic valuation methods, and
- direct non-economic valuation of ecosystem functions based on enumeration of preferences using non-monetized indices of preferences.

Similar to other elements of the Risk/Exposure Assessment, we are seeking input on the range of valuation methods that should be considered in helping to inform the discussion of adversity of ecosystem impacts.

B.3.1 Ecosystem services overview and why their consideration is needed

One way to assess adverse effects on welfare is through valuation of ecosystem services. The adverse effect would be the loss or reduction of those services through the effects of NOx and SOx on the underlying ecological processes and functions that constitute the service. The EPA defines ecosystem services as the outputs of healthy, intact ecosystems and the underlying ecosystem processes and functions that contribute to human well-being (USEPA 2006b). As articulated by the Millenium Ecosystem Assessment (2005) from the United Nations, these include provisioning services (e.g., clean water, food, wood, fiber, fuel), regulating services (e.g., water purification, climate regulation, etc.), supporting services (e.g. nutrient cycling, soil formation), and cultural services (e.g. recreation, spiritual) (Figure B.2). Regulating services are of key importance to the EPA because they directly impact air and water quality, and they have strong links to human heath and well-being. As such, valuation of ecosystem services may be one means of assessing whether an effect is adverse. Valuation provides a means for evaluating different services. The valuation may be monetized or non-monetized. Non-monetized measures of valuation include such things as quality of critical habitat, biodiversity, species composition, control/limiting invasive species and pest outbreaks. Determining the exposure response relationships of NOx and SOx on the ecosystem service and the underlying ecological process and function will provide a broader focus in determination of adverse impacts.

Figure B.2. Ecosystem services as defined by the Millennium Assessment and their linkage to human well being (From Millennium Assessment, 2005).

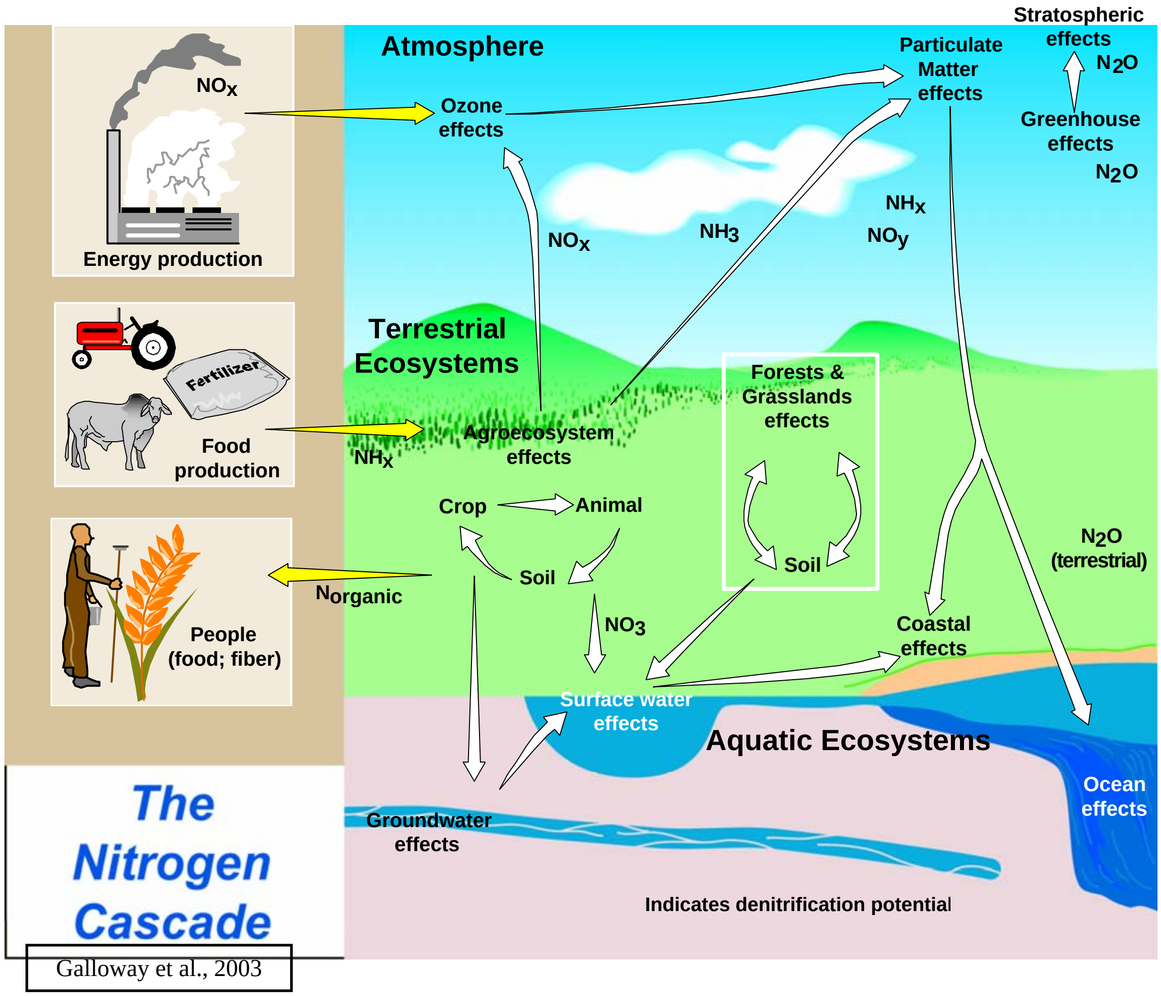


B.3.2 Ecosystem services relating to NOx/SOx secondary standard issues

Ecosystems provide services through a complex web of ecosystem processes that create and sustain the services. For example, if we are interested in how terrestrial and riparian ecosystems can help regulate nitrogen inputs to aquatic systems, we should consider all the nitrogen transformations and flow paths within these ecosystems (Figure B.3). Ecosystem processes can help mitigate adverse effects from environmental stressors, but processes can also be negatively affected by environmental stressors, decreasing the amount of ecosystem services they provide. For example, plant nutrient uptake and microbial denitrification and immobilization decrease the nutrient content in soil water, decreasing the potential for leaching into aquatic systems. Environmental stressors that decrease plant growth can increase nutrient flows to aquatic systems.

The web of ecosystem processes that influence the regulation of nitrogen transport to aquatic systems will also affect other ecosystem services such as carbon sequestration, so that management activities that alter these processes will affect a bundle of services, not just one. The impact of a land-use change will not have the same impact on all of the ecosystem services; while one ecosystem service may be improved by a land-use change, it may come at a cost of decreasing another ecosystem service. Food production is a classic example of tradeoffs between ecosystem services. Adding fertilizer to crops will increase food production but may decrease water quality as some fertilizer ends up in the waterways. Thus, when ecosystems services are quantified, it is imperative that the entire bundle of services is evaluated, and that the tradeoffs between ecosystem services be included in the quantification.

Figure B.3. The Nitrogen Cascade illustrates the complexity of pools and processes at the watershed scale that are interconnected with the addition of nitrogen to the system, and with the output of the system in terms of ecological services to benefit man. Adapted from, Galloway et al. 2003 (Ecological Research Program Strategic Directions, ORD, April 2007, Preliminary Draft)

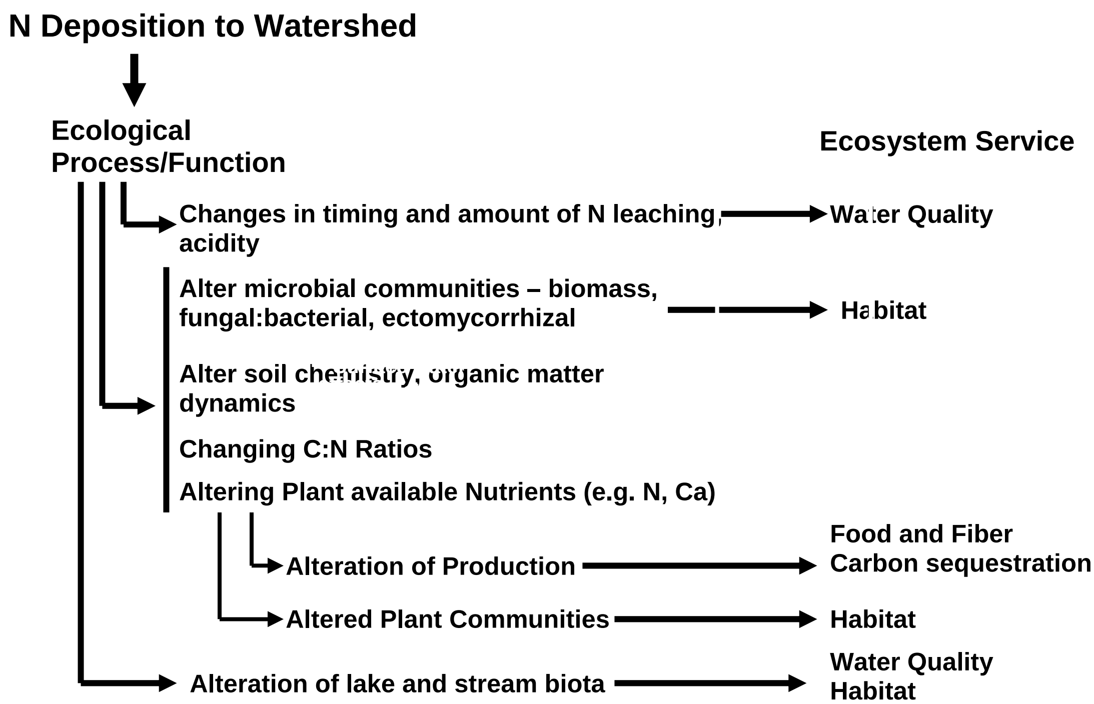


B.3.3 Valuation

While not the sole means of assessing adversity of effect, ecological improvements can benefit people indirectly by increasing the delivery of "ecosystem services," which are the end products of ecological functions important to humans (Dailey 1997, Balmford et al. 2002, NRC 2004, Banzhaf and Boyd 2005, Boyd and Banzhaf 2006). Such valuable ecological functions include the maintenance of stable climate conditions, the regulation of water availability and quality, and nutrient retention (Dailey 1997). Through their effect on ecosystem services, ecological improvements may lead to improved agricultural yields, recreational opportunities, human health or other types of benefits. For example, protecting wetlands and the natural flow regulation and water purification services they provide may lead to enhanced recreational fishing or swimming opportunities in connected water bodies, reduced flooding in downstream residential areas, or reduced incidences of illness from contaminated drinking water. Ecological improvements may also benefit people directly through aesthetic improvements or through increases in "nonuse" values (e.g., NRC 2004), which can arise from a variety of motivations including an intrinsic concern for the existence of species populations or ecosystems in a relatively undisturbed state or a desire to preserve healthy ecosystems for future generations.

Valuation is a tool for integrating information on the effects of NOx and SOx on the multiple ecosystem processes that form the basis for the ecosystem service. It provides a common currency to compare impacts. The National Research Council (2004) noted that the translation from ecosystem structure and function to ecosystem goods and services is described by an ecological production function (goods and services that can be produced from inputs of natural and human capital, labor, and other resources). Many ecological relationships can be quantified using existing data and models, at least for particular settings where data are quantified and models have been calibrated. A very simple example of some ecological processes or functions that would need to be quantified in order to determined the impact of nitrogen deposition on an ecological service is shown in Figure B.4.

Figure B.4. Ecological Relationships Potentially disrupted by nitrogen deposition and the Ecosystem Service potentially affected (prepared by Dr. Bob McKane, ORD)



A number of different approaches have been suggested for valuing ecosystem services:

1) Provisioning services commodity values. There are methods and data for obtaining monetary values for commodities under scenarios of change. These break down into 'natural resource values' for extracted goods (e.g. cut and sell the tree in the market) and 'environmental quality values' to leave the tree in the forest and obtain the benefits of it in its role in the ecosystem.

2) Other kinds of monetization. Economic methods that have been used to value ecological improvements include production or cost function approaches, travel cost models, hedonic property models, and stated preference surveys. Bioeconomic modeling, which involves combining models of species population or ecosystem dynamics with economic models of human behavior, is another approach that can potentially be used to value ecological improvements. Most bioeconomic models have been applied to fishery and forestry management problems, but in many cases these models could be adapted to estimate willingness

to pay for environmental improvements that may affect the growth rates or carrying capacities of the focal species.

3) When direct valuation is infeasible, benefits or value transfer methods may be employed. This method takes direct values for ecosystem services from a primary study for a particular location and transfers those values to a different location using either a point estimate or value transfer function. Direct transfer of point value estimates has the potential to lead to large uncertainties and in some cases biases in estimated values for ecosystem services, because of the high dependency of most ecosystem values on the specific characteristics of the location in which they were collected. Value transfer functions which allow the values to vary with ecosystem characteristics can provide for more accurate estimation, but still have large uncertainties.

4) Non-monetary values for individual and bundled services. These are developed from experimental field studies, literature and modeling activities. There are two types of non-monetary valuation methods, one based on direct physical or biological tradeoffs, and the other based on tradeoffs defined by human preferences for the ecosystem functions defined by different bundles of physical and biological attributes. Figure B.5 illustrates a conceptual approach for developing non-monetary values using physical and/or biological tradeoff functions. Ecological response functions (ERFs) and ecological tradeoff functions (ETFs) can be developed to quantify the response of a service to changes in NOx/SOx concentrations and the tradeoffs between different services given these ambient air quality drivers. ERFs and ETFs will have to be, for the most part, defined by data mining from existing published literature. In the future, however, these quantifying functions will be the focus of research to broaden the scope of the science assessment and risk/exposure assessment. Process-based models will be used to (1) synthesize/link the suite of ERFs and ETFs and (2) generate maps and summaries of ecosystem services and tradeoffs in response to current and future ambient air indicators for NOx and SOx. Ecological response functions are developed to show the response of a service to changes in an ecosystem driver and ecological tradeoff functions combining response functions to show the tradeoffs between different services given a driver. By describing the differing bundles of ecosystem services under varying levels of NOx and SOx and offering choices between those bundles, tradeoff or indifference curves can also be generated reflecting individual and population level preferences for different ecosystem functions. These tradeoffs can be presented to survey respondents using methods such as conjoint analysis, to provide measures of

preferences for different levels of ecosystem functions as expressed through ecosystem service levels. Figure B.6 shows an example of how ecosystem services information might be presented to a survey respondent in a conjoint analysis framework.

Figure B.5. Conceptual approach for quantifying Ecological Response Functions (ERF) and Ecological Tradeoff Functions (ETF) for ecosystem services in relation to different levels of NOx or SOx (forcing variables)

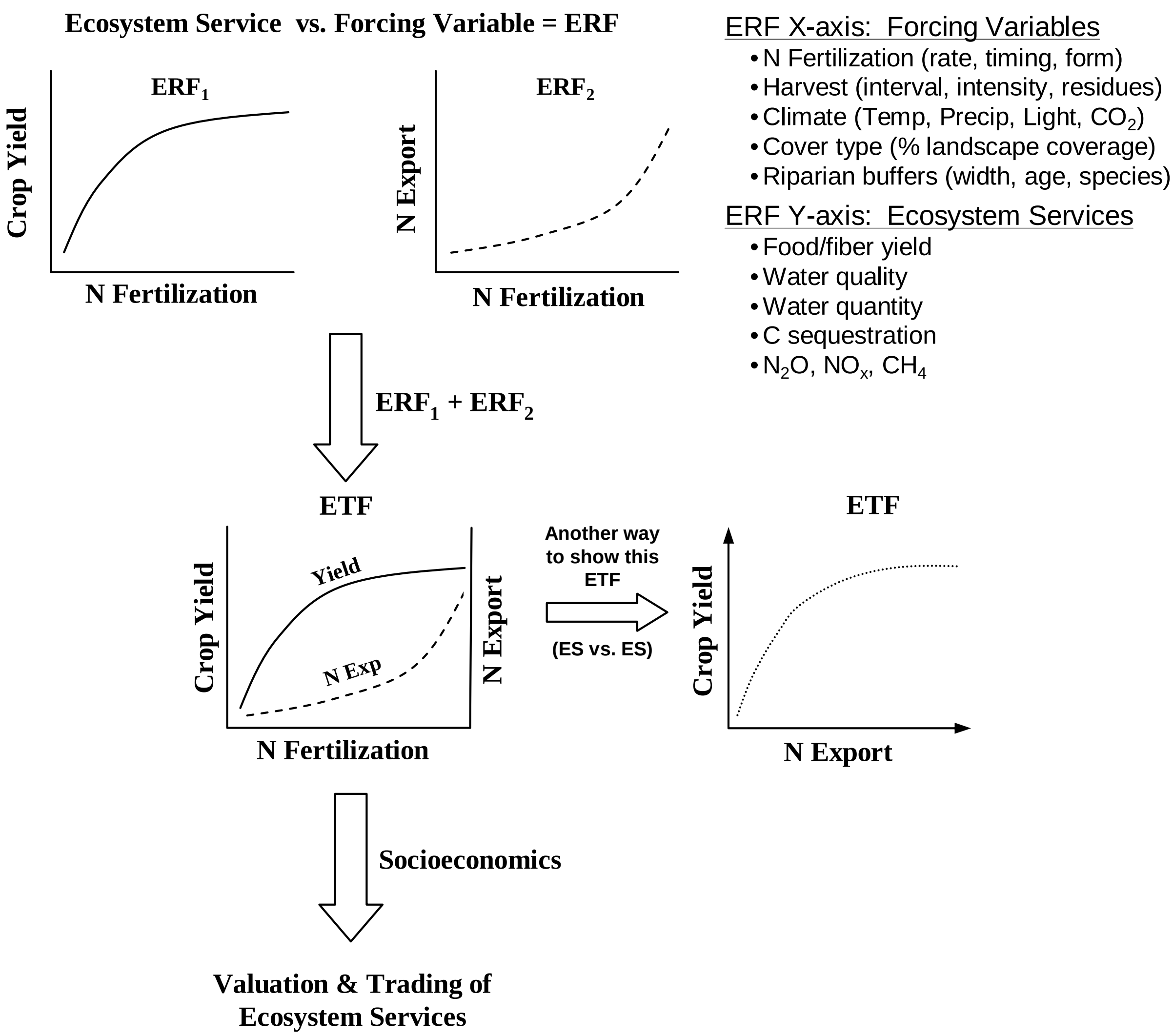


Figure B.6. Example Survey Design for Preference Based Ecosystem Tradeoffs

Example Conjoint Scenario Rating Form

Ecosystem Services Scenario Descriptions				
	Water Quality	Habitat	Food and Fiber Production	Carbon Sequestration
Scenario 1	Drinkable	Low diversity	High	High
Scenario 2	Drinkable	High diversity	Low	Low
Scenario 3	Swimmable	Medium diversity	Medium	Medium
Scenario 4	Boatable	Low diversity	High	Medium
Scenario 5	Swimmable	Low diversity	Low	Low

Scenario Rating
Please rate how desirable each scenario is overall by circling one of the numbers in each row of the following table:

	Highly Desirable	Quite Desirable	Desirable	Slightly Desirable	Neither Desirable nor Undesirable	Slightly Undesirable	Undesirable	Quite Undesirable	Highly Undesirable
Scenario 1	1	2	3	4	5	6	7	8	9
Scenario 2	1	2	3	4	5	6	7	8	9
Scenario 3	1	2	3	4	5	6	7	8	9
Scenario 4	1	2	3	4	5	6	7	8	9
Scenario 5	1	2	3	4	5	6	7	8	9

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