



# **Integrated Review Plan for the Secondary National Ambient Air Quality Standards for Ecological Effects of Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter**

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# **Integrated Review Plan for the Secondary National Ambient Air Quality Standards for Ecological Effects of Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter**

## **U. S. Environmental Protection Agency**

National Center for Environmental Assessment  
Office of Research and Development  
and  
Office of Air Quality Planning and Standards  
Office of Air and Radiation

Research Triangle Park, North Carolina

## **DISCLAIMER**

This Integrated Review Plan serves as a public information document and as a management tool for the U.S. Environmental Protection Agency's National Center for Environmental Assessment and Office of Air Quality Planning and Standards in conducting the review of the secondary national ambient air quality standards for ecological effects of oxides of nitrogen, oxides of sulfur and particulate matter. The approach described in this plan may be modified to reflect information developed during this review, and in consideration of advice and comments received from the Clean Air Scientific Advisory Committee and the public during the course of the review. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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## LIST OF ACRONYMS AND ABBREVIATIONS

AAI	Aquatic Acidification Index
ADR	Adirondack Mountains of New York
Al <sup>3+</sup>	aluminum
ANC	Acid Neutralizing Capacity
AQCD	Air Quality Criteria Document
ASSETS EI	Assessment of Estuarine Trophic Status eutrophication index
Bc/Al	Base cation to aluminum ratio, also Bc:Al
Bcw	base cation weathering
C	carbon
Ca <sup>2+</sup>	calcium
CAA	Clean Air Act
CASAC	Clean Air Scientific Advisory Committee
CASTNet	Clean Air Status and Trends Network
CLAD	Critical Loads of Atmospheric Deposition
CMAQ	Community Multiscale Air Quality model
CSS	coastal sage scrub
CTM	chemical transport model
CWA	Clean Water Act
DOI	U.S. Department of Interior
EMAP	Environmental Monitoring and Assessment Program
EPA	U.S. Environmental Protection Agency
FASOM	Forest and Agricultural Sector Optimization Model
FEG-CS	final ecosystem goods and services
FEM	Federal Equivalent Method
GHG	greenhouse gas
GIS	Geographic Information Systems
H <sup>+</sup>	hydrogen ion
H <sub>2</sub> SO <sub>4</sub>	sulfuric acid
ha	hectare
HERO	Health and Environmental Research Online
Hg	mercury
HNO <sub>3</sub>	nitric acid
HONO	nitrous acid
HREA	Health Risk and Exposure Assessment
IAN	Integration and Application Network
IMPROVE	Interagency Monitoring of Protected Visual Environments
IRP	Integrated Review Plan
ISA	Integrated Science Assessment
K <sup>+</sup>	potassium
kg/ha/yr	kilograms per hectare per year
LTM	Long-Term Monitoring
MAGIC	Model of Acidification of Groundwater in Catchments
MCF	mixed conifer forest
MeHg	methylmercury

Mg <sup>2+</sup>	magnesium
N	nitrogen
N <sub>2</sub>	gaseous nitrogen
N <sub>2</sub> O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NADP	National Atmospheric Deposition Program
NAPAP	National Acid Precipitation Assessment Program
NARS	National Aquatic Resource Surveys
NCCA	National Coastal Condition Assessment
NCCOS	National Centers for Coastal Ocean Science
NCCR	National Coastal Condition Report
NCEA	National Center for Environmental Assessment
NCLD	National Critical Loads Database
NEEA	National Estuarine Eutrophication Assessment
NESCS	National Ecosystem Services Classification System
NH <sub>3</sub>	ammonia gas
NH <sub>4</sub> <sup>+</sup>	ammonium ion
NH <sub>4</sub> NO <sub>3</sub>	ammonium nitrate
NH <sub>4</sub> HSO <sub>4</sub>	ammonium bisulfate
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	ammonium sulfate
NH <sub>x</sub>	category label for NH <sub>3</sub> plus NH <sub>4</sub> <sup>+</sup>
NLA	National Lake Assessment
NO	nitric oxide
NO <sub>2</sub>	nitrogen dioxide
NO <sub>3</sub> <sup>-</sup>	reduced nitrate
NOAA	National Oceanic and Atmospheric Administration
NO <sub>x</sub>	nitrogen oxides
NO <sub>y</sub>	total oxidized nitrogen
NRC	National Research Council
NRSA	National River and Stream Assessment
NTN	National Trends Network
NTR	organic nitrate
NWCA	National Wetland Condition Assessment
OAQPS	Office of Air Quality Planning and Standards
OAR	Office of Air and Radiation
ORD	Office of Research and Development
PA	Policy Assessment
PAN	peroxyacyl nitrates
pH	relative acidity
PM	particulate matter
PM <sub>2.5</sub>	In general terms, particulate matter with an aerodynamic diameter less than or equal to a nominal 2.5 μm; a measurement of fine particles
PM <sub>10</sub>	In general terms, particulate matter with an aerodynamic diameter less than or equal to a nominal 10 μm
POP	persistent organic pollutant
ppb	parts per billion

ppm	parts per million
QA	quality assurance
QMP	quality management plan
REA	Risk and Exposure Assessment
RIA	Regulatory Impact Analysis
S	sulfur
SO <sub>2</sub>	sulfur dioxide
SO <sub>3</sub>	sulfur trioxide
SO <sub>4</sub>	sulfate
SO <sub>4</sub> <sup>2-</sup>	sulfate ion
SOPM	secondary organic particulate matter
SO <sub>x</sub>	sulfur oxides
SPARROW	SPATIally Referenced Regressions on Watershed Attributes
SRB	Sulfate-Reducing Bacteria
TIME	Temporally Integrated Monitoring of Ecosystems
TSP	total suspended particles
µeq/L	microequivalents per liter
µg/m <sup>3</sup>	micrograms per cubic meter
VOC	volatile organic compound
WHO	World Health Organization
WREA	Welfare Risk and Exposure Assessment
WSA	Wadeable Streams Assessment
WTP	willingness to pay

## KEY TERMS

- Acidification:** The process of increasing the acidity of a system (e.g., 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<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub>) occurring in the ambient air for which the National Ambient Air Quality Standards set a standard level and monitoring occurs.
- Alpine:** The biogeographic zone made up of slopes above the tree line, characterized by the presence of rosette-forming herbaceous plants and low, shrubby, slow-growing woody plants.
- 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, such as underlying geology, base cation concentrations, and weathering rates.
- Arid Region:** A land region of low rainfall, where “low” is widely accepted to be less than 250 mm precipitation per year.
- Base Cation Saturation:** The degree to which soil cation exchange sites are occupied with base cations (e.g., Ca<sup>2+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>) as opposed to Al<sup>3+</sup> and H<sup>+</sup>. Base cation saturation is a measure of soil acidification, with lower values being more acidic. There is a threshold whereby soils with base saturations less than 20% (especially between 10%–20%) are extremely sensitive to change.
- Biodiversity:** The variability among living organisms in a given ecosystem
- Critical Load:** A quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge (Nilsson and Grennfelt 1988, UNECE 2004).  
Informal Definition: The threshold of deposition below which specified harmful ecological effects do not occur (Porter et al. 2005).
- Denitrification:** The anaerobic reduction of oxidized nitrogen (e.g., nitrate or nitrite) to gaseous nitrogen (e.g., N<sub>2</sub>O or N<sub>2</sub>) by denitrifying bacteria.
- Dry Deposition:** The removal of gases and particles from the atmosphere to surfaces in the absence of precipitation (e.g., rain, snow) or occult deposition (e.g., fog).
- Ecological Risk:** The likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors (U.S. EPA, 1992).
- Ecological Risk Assessment:** A process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors (U.S. EPA, 1992).
- Ecoregion:** Areas where ecosystems (and the type, quality, and quantity of environmental resources) are generally similar. In this document, ecoregions are defined using the Omernik system (Omernik 1987).
- Ecosystem:** The interactive system formed from all living organisms and their abiotic (i.e., physical and chemical) environment within a given area. Ecosystems cover a

hierarchy of spatial scales and can comprise the entire globe, biomes at the continental scale, or small, well-circumscribed systems such as a small pond.

**Ecosystem Benefit:** The value, expressed 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. Examples of ecosystem benefits that derive from improved air quality include improvements in habitats for sport fish species, the quality of drinking water and recreational areas, and visibility.

**Ecosystem Function:** The processes and interactions that operate within an ecosystem.

**Ecosystem Services:** The benefits individuals and organizations obtain from ecosystems. These benefits may be qualitative or quantitative.

**Eutrophication:** The process by which nitrogen additions stimulate the growth of autotrophic biota, usually resulting in the depletion of dissolved oxygen.

**Nitrogen Enrichment:** The process by which a terrestrial system becomes enhanced by nutrient additions to a degree that stimulates the growth of plant or other terrestrial biota, usually resulting in an increase in productivity.

**Nitrogen Saturation:** The point at which nitrogen inputs from atmospheric deposition and other sources exceed the biological requirements of the ecosystem; a level beyond nitrogen enrichment.

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

**Semi-arid Regions:** Regions of moderately low rainfall, which are not highly productive and are usually classified as rangelands. “Moderately low” is widely accepted as between 100- and 250-mm precipitation per year.

**Sensitivity:** The degree to which a system is affected, either adversely or beneficially, by oxides of nitrogen and/or oxides of sulfur pollution (e.g., acidification, nutrient enrichment). The effect may be direct (e.g., a change in growth in response to a change in the mean, range, or variability of nitrogen deposition) or indirect (e.g., changes in growth due to the direct effect of nitrogen consequently altering competitive dynamics between species and decreased biodiversity).

**Species Richness:** The number of species within a given area or ecosystem.

**Total Reactive Nitrogen:** This includes all biologically, chemically, and radiatively active nitrogen compounds in the atmosphere and biosphere, such as  $\text{NH}_3$ ,  $\text{NH}_4^+$ ,  $\text{NO}$ ,  $\text{NO}_2$ ,  $\text{HNO}_3$ ,  $\text{N}_2\text{O}$ ,  $\text{NO}_3^-$ , and organic compounds (e.g., urea, amines, nucleic acids).

**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.

**Variable Factors:** Influences which by themselves or in combination with other factors may alter the effects on public welfare of an air pollutant (section 108 (a)(2))

- (a) Atmospheric Factors: Atmospheric conditions that may influence transformation, conversion, transport, and deposition, and thereby, the effects of an air pollutant on public welfare, such as precipitation, relative humidity, oxidation state, and co-pollutants present in the atmosphere.

(b) Ecological Factors: Ecological conditions that may influence the effects of an air pollutant on public welfare once it is introduced into an ecosystem, such as soil base saturation, soil thickness, runoff rate, land use conditions, bedrock geology, and weathering rates.

**Vulnerability:** The degree to which a system is susceptible to, and unable to cope with, the adverse effects of oxides of nitrogen and oxides of sulfur air pollution.

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

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

# 1 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is currently reviewing the air quality criteria and associated secondary National Ambient Air Quality Standards (NAAQS) for oxides of nitrogen, oxides of sulfur, and particulate matter (PM). In any such review, the purpose of the Integrated Review Plan (IRP) document is to communicate the current plan for the review, the process for conducting the review and key policy-relevant scientific and technical issues that will guide the review. In the context of the secondary standards for oxides of nitrogen, oxides of sulfur and PM, the scope for this IRP pertains to the protection of the public welfare from adverse effects related to ecological effects.<sup>1</sup>

Oxides of nitrogen and oxides of sulfur occur in the atmosphere with a variety of other gases and particles, undergoing complex chemical and physical interactions and forming transformation products, which in the gas phase contribute to direct phytotoxic injury to ecosystems and through atmospheric deposition contribute to other ecosystem welfare effects. In characterizing such effects related to atmospheric deposition of oxides of nitrogen and oxides of sulfur and their transformation products, this review also recognizes the contribution of PM through deposition to eutrophication-related effects, acidification-related effects, and other such welfare effects, as well to the direct and other indirect effects on vegetation, soils, and biota. In recognition of linkages between these pollutants (oxides of nitrogen, oxides of sulfur and PM) with respect to deposition and atmospheric chemistry, as well as from an ecological effects perspective, the reviews for these criteria pollutants are being conducted together for this secondary NAAQS review.<sup>2</sup> Addressing the pollutants together enables us to take a comprehensive look at the nature and interactions of the pollutants, which is important for

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<sup>1</sup>The existing secondary standards for oxides of nitrogen and sulfur were set based on consideration of direct effects on vegetation associated with exposure to gaseous oxides of nitrogen and sulfur. The last review of those standards focused particularly on consideration of the evidence of these pollutants contribution through atmospheric deposition to ecosystem effects such as eutrophication, acidification, and sulfur enrichment. The scope of the review described in this plan includes consideration of both such ecological effects of nitrogen and sulfur oxides as well as of PM.

<sup>2</sup> Although the EPA generally considers criteria and standards for each of the six criteria pollutants individually, EPA has considered joint reviews of the air quality criteria. For example, in 1982, EPA considered PM and oxides of sulfur together in the criteria document. In addition, in 2005 EPA similarly initiated a joint review of the air quality criteria for nitrogen and sulfur oxides and the secondary NAAQS for nitrogen dioxide (NO<sub>2</sub>) and sulfur dioxide (SO<sub>2</sub>). In so doing, the EPA noted that nitrogen and sulfur oxides and their associated transformation products are linked from an atmospheric chemistry perspective, as well as from an environmental effects perspective. The joint review was also responsive to the National Research Council (NRC) recommendation for the EPA to consider multiple pollutants, as appropriate, in forming the scientific basis for the NAAQS (NRC, 2004).

ensuring that all scientific information relevant to deposition-related ecological effects is thoroughly evaluated.

Thus, this IRP addresses the review of the secondary (welfare-based) NAAQS for oxides of nitrogen, oxides of sulfur and PM, focusing on the contribution of these pollutants to ecological effects and particularly the contribution of these pollutants through atmospheric deposition to ecosystem effects. Additional welfare effects associated with PM, such as visibility impairment, climate effects and materials damage, and the health effects of PM (including particulate transformation products of oxides of nitrogen and oxides of sulfur) will be considered as part of the review of the NAAQS for PM (U.S. EPA, 2009a). The health effects of oxides of nitrogen and oxides of sulfur are being considered in separate assessments as part of the reviews of the primary (health-based) NAAQS for oxides of nitrogen (U.S. EPA, 2014a) and oxides of sulfur (U.S. EPA, 2014b).

In this document, the term, oxides of nitrogen, refers to all forms of oxidized nitrogen (N) compounds, including NO, NO<sub>2</sub>, and all other oxidized N-containing compounds formed from NO and NO<sub>2</sub>.<sup>3</sup> The term, oxides of sulfur, includes sulfur dioxide (SO<sub>2</sub>), sulfur trioxide (SO<sub>3</sub>), and other less commonly occurring oxides. Particulate matter (PM) is the generic term for a broad class of chemically and physically diverse substances that exist as discrete liquid and/or solid particles over a wide range of sizes. Particles may be emitted directly from anthropogenic and natural sources, or formed in the atmosphere by transformations of gaseous emissions such as sulfur dioxide (SO<sub>2</sub>), nitrogen oxide (NO<sub>x</sub>), ammonia (NH<sub>3</sub>) and volatile organic compounds (VOC).<sup>4</sup> The chemical and physical properties of PM vary greatly with time, region, meteorology, and source category.

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<sup>3</sup> This follows usages in the Clean Air Act Section 108(c): “Such criteria [for oxides of nitrogen] shall include a discussion of nitric and nitrous acids, nitrites, nitrates, nitrosamines, and other carcinogenic and potentially carcinogenic derivatives of oxides of nitrogen.” By contrast, within air pollution research and control communities, the terms “oxides of nitrogen” and “nitrogen oxides” are restricted to refer only to the sum of NO and NO<sub>2</sub>, and this sum is commonly abbreviated NO<sub>x</sub>. The category label used by this community for the sum of all forms of oxidized nitrogen compounds including those listed in Section 108(c) is total oxidized nitrogen (NO<sub>y</sub>). Where used in this document (e.g., chapter 3), definitions used for such abbreviations are provided there.

<sup>4</sup> Examples of secondary particle formation include: (1) the conversion of SO<sub>2</sub> to sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) vapor that nucleates new particles or condenses on existing particles and further reacts with NH<sub>3</sub> to form various inorganic salts (e.g., ammonium sulfate, (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, or ammonium bisulfate, NH<sub>4</sub>HSO<sub>4</sub>); (2) the conversion of NO<sub>2</sub> to nitric acid (HNO<sub>3</sub>) vapor that condenses onto existing particles and reacts further with ammonia to form ammonium nitrate (NH<sub>4</sub>NO<sub>3</sub>); and (3) reactions involving gaseous VOC yielding organic compounds with low vapor pressures that nucleate or condense on existing particles to form secondary organic particulate matter (U.S. EPA, 2004, section 3.3).

The review will focus on the basic elements of the secondary NAAQS; the indicator,<sup>5</sup> averaging time,<sup>6</sup> form,<sup>7</sup> and level.<sup>8</sup> These elements, which serve to define each ambient air quality standard, must be considered collectively in evaluating the welfare protection afforded by the standards.<sup>9</sup> The current secondary NAAQS for oxides of nitrogen and oxides of sulfur are intended to protect against direct damage to vegetation by exposure to gas-phase oxides of nitrogen and oxides of sulfur. The current secondary standards for PM are intended to address PM-related welfare effects, including visibility impairment, ecological effects, effects on materials, and climate impacts.<sup>10</sup>

The Clean Air Scientific Advisory Committee (CASAC), an independent scientific advisory committee established under the Clean Air Act (CAA), reviewed a draft of the IRP at public teleconference meetings held on December 1, 2015 and February 29, 2016. The CASAC provided its advice on the draft IRP to the Administrator in a letter dated April 1, 2016 (Diez Roux and Fernandez, 2016).<sup>11</sup> This final IRP reflects the EPA staff's consideration of the CASAC's advice and of comments received from members of the public. As this review progresses, the plan described in this IRP may be modified to reflect information received during

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<sup>5</sup> The "indicator" of a standard defines the chemical species or mixture that is measured in determining whether an area attains the standard.

<sup>6</sup> The "averaging time" defines the time period over which ambient measurements are averaged (e.g., 1-hour, 8-hour, 24-hour, annual).

<sup>7</sup> The "form" of a standard defines the air quality statistic that is compared to the level of the standard in determining whether an area attains the standard.

<sup>8</sup> The "level" defines the allowable concentration of the criteria pollutant in the ambient air.

<sup>9</sup> Across the NAAQS reviews, EPA has used a variety of exposure metrics to evaluate the protection afforded by the standards and those metric have often differed in a variety of ways from the ambient air concentration metrics of those standards. We note that while exposure metrics are used to assess the likely occurrence and/or frequency and extent of effects under different air quality conditions, the air quality standards are intended to control air quality to the extent requisite to protect from the occurrence of public health or welfare effects judged to be adverse.

<sup>10</sup> The secondary standard for oxides of nitrogen is an annual average not to exceed 0.053 parts per million (ppm) NO<sub>2</sub>. The secondary standard for oxides of sulfur is a 3-hour average of 0.5 ppm SO<sub>2</sub>, not to be exceeded more than once per year. The secondary annual PM<sub>2.5</sub> standard is set at a level of 15 ug/m<sup>3</sup>, with an annual arithmetic mean averaged over three years, and secondary 24-hour PM<sub>2.5</sub> standard is set at a level of 35 ug/m<sup>3</sup>, as the 98<sup>th</sup> percentile of the 24-hour average, averaged over 3 years. The secondary annual PM<sub>10</sub> standard is an annual arithmetic mean, averaged over three years with a level of 50 ug/m<sup>3</sup>, and the secondary 24-hour PM<sub>10</sub> standard is a 24-hour average of 150 ug/m<sup>3</sup>, not to be exceeded more than once per year on average over a three year period.

<sup>11</sup> See <https://yosemite.epa.gov/sab/sabpeople.nsf/012670d45b5cac588525706a00421ce4/23f29bf38fe9e8ef85257dcc0063b3b1!OpenDocument> for a list of the members of the CASAC Secondary NAAQS Review Panel for Oxides of Nitrogen and Sulfur.

the review process, to address additional advice received from the CASAC, and/or to address comments received from the public.

This review plan is organized into six chapters. Chapter 1 presents background information on the NAAQS review process, the legislative requirements for the review of the NAAQS, past reviews of the NAAQS for NO<sub>2</sub>, SO<sub>2</sub> and PM, and the proposed review schedule. Chapter 2 presents information on the nature of the ecological effects and a set of policy-relevant questions that will serve to focus the NAAQS review process on the critical scientific and policy issues. Chapters 3 through 5 discuss the science, exposure/risk, and policy assessment portions of the review. Chapter 6 contains cited references. As the assessments proceed, various aspects of the process described in this plan described may be modified to reflect information received during the review process.

## **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 certain “air pollutants” that, in his or her judgment, “cause or contribute to air pollution which may reasonably be anticipated to endanger public health and welfare” and whose “presence . . . in the ambient air results from numerous or diverse mobile or stationary sources” and to issue air quality criteria for air pollutants that are listed (42 U.S.C. § 7408(a) & (b)). 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 . . . .” (42 U.S.C. § 7408(b)).

Section 109 (42 U.S.C. § 7409) directs the Administrator to propose and promulgate “primary” and “secondary” NAAQS for pollutants for which air quality criteria are issued under section 108. Section 109(b) (1) defines a primary standard as one “the attainment and maintenance of which in the judgment of the Administrator, based on such criteria and allowing an adequate margin of safety, are requisite to protect the public health”.<sup>12</sup> A secondary standard, as defined in section 109(b)(2), “shall specify a level of air quality the attainment and maintenance of which in the judgment of the Administrator, based on such criteria, is requisite to

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<sup>12</sup> The legislative history of section 109 indicates that a primary standard is to be set at “the maximum permissible ambient air level . . . which will protect the health of any [sensitive] group of the population,” and that for this purpose “reference should be made to a representative sample of persons comprising the sensitive group rather than to a single person in such a group” [S. Rep. No. 91-1196, 91st Cong., 2d Sess. 10 (1970)].

protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air”<sup>13</sup> (42 U.S.C. § 7409(b)(2)).

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 . . . .” (42 U.S.C. § 7409(d)(1)). Sections 109(d)(2)(A) and 109(d)(2)(B) require 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 . . . .” 42 U.S.C. § 7409(d)(2). Since the early 1980s, this independent review function has been performed by the CASAC.

Section 109(d)(2)(C) further states that “[s]uch committee shall also (i) advise the Administrator of areas in which additional knowledge is required to appraise the adequacy and basis of existing, new, or revised national ambient air quality standards, (ii) describe the research efforts necessary to provide the required information, (iii) advise the Administrator on the relative contribution to air pollution concentrations of natural as well as anthropogenic activity, and (iv) advise the Administrator of any adverse public health, welfare, social, economic, or energy effects which may result from various strategies for attainment and maintenance of such national ambient air quality standards.” The CAA does not specify the timing for advice under section 109(d)(2)(C), and this requirement is not tied to the five-year review cycle established for the air quality criteria and the NAAQS.

The requirement that primary standards provide an adequate margin of safety was intended to address uncertainties associated with inconclusive scientific and technical information available at the time of standard setting. It was also intended to provide a reasonable degree of protection against hazards that research has not yet identified.<sup>14</sup> Both kinds of uncertainties are components of the risk associated with pollution at levels below those at which human health effects can be said to occur with reasonable scientific certainty. Thus, in selecting

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<sup>13</sup> Welfare effects as defined in CAA 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.”

<sup>14</sup> See *Lead Industries Association v. EPA*, 647 F.2d 1130, 1154 (D.C. Cir. 1980); *American Petroleum Institute v. Costle*, 665 F.2d 1176, 1186 (D.C. Cir. 1981); *American Farm Bureau Federation v. EPA*, 559 F. 3d 512, 533 (D.C. Cir. 2009); and *Association of Battery Recyclers v. EPA*, 604 F. 3d 613, 617-18 (D.C. Cir. 2010).

primary standards that provide an adequate margin of safety, the Administrator is seeking not only to prevent pollution levels that have been demonstrated to be harmful but also to prevent lower pollutant levels that may pose an unacceptable risk of harm, even if the risk is not precisely identified as to nature or degree. In addressing the requirement for an adequate margin of safety, the EPA considers such factors as the nature and severity of the health effects involved, the size of the sensitive group(s), and the kind and degree of uncertainties. The selection of any particular approach to providing an adequate margin of safety is a policy choice left specifically to the Administrator's judgment.<sup>15</sup> The CAA does not require the Administrator to establish a primary NAAQS at a zero-risk level or at background concentration levels, but rather at a level that reduces risk sufficiently so as to protect public health with an adequate margin of safety.<sup>16</sup>

In establishing 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, the Administrator seeks to establish standards that are neither more nor less stringent than necessary for this purpose. It is recognized that this final decision will be largely a public welfare policy judgment and will draw upon scientific evidence and analyses about effects on public welfare, as well as judgments about how to deal with the range of uncertainties that are inherent in the relevant information. The CAA 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 setting standards that are "requisite" to protect public health and welfare, as provided in section 109(b), the EPA's task is to establish standards that are neither more nor less stringent than necessary. In so doing, the EPA may not consider the costs of implementing the standards.<sup>17</sup> Likewise, "[a]ttainability and technological feasibility are not relevant considerations in the promulgation of national ambient air quality standards<sup>18</sup>." Although, as noted above, section 109(d)(2)(C)(iv) provides that the CASAC shall advise the Administrator of any adverse social, economic, or energy effects which may result from strategies for attainment and maintenance of the NAAQS, for EPA to consider advice on the costs of attaining and maintaining the NAAQS as part of the review of the NAAQS would be grounds for judicial vacatur of EPA's final decision.

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<sup>15</sup> See *Lead Industries Association v. EPA*, 647 F.2d at 1161-62; *Mississippi v. EPA*, 723 F. 3d at 265.

<sup>16</sup> See *Lead Industries v. EPA*, 647 F.2d at 1156 n.51, *Mississippi v. EPA*, 723 F. 3d 246, 255, 262-63 (D.C. Cir. 2013).

<sup>17</sup> See generally *Whitman v. American Trucking Associations*, 531 U.S. 457, 465-472, 475-76 (2001)

<sup>18</sup> *American Petroleum Institute v. Costle*, 665 F. 2d at 1185

## 1.2 OVERVIEW OF THE NAAQS REVIEW PROCESS

The current process for reviewing the NAAQS includes four major phases: (1) planning, (2) science assessment, (3) risk/exposure assessment, and (4) policy assessment and rulemaking. Figure 1-1 provides an overview of this process, and each phase is described in more detail below.<sup>19</sup>

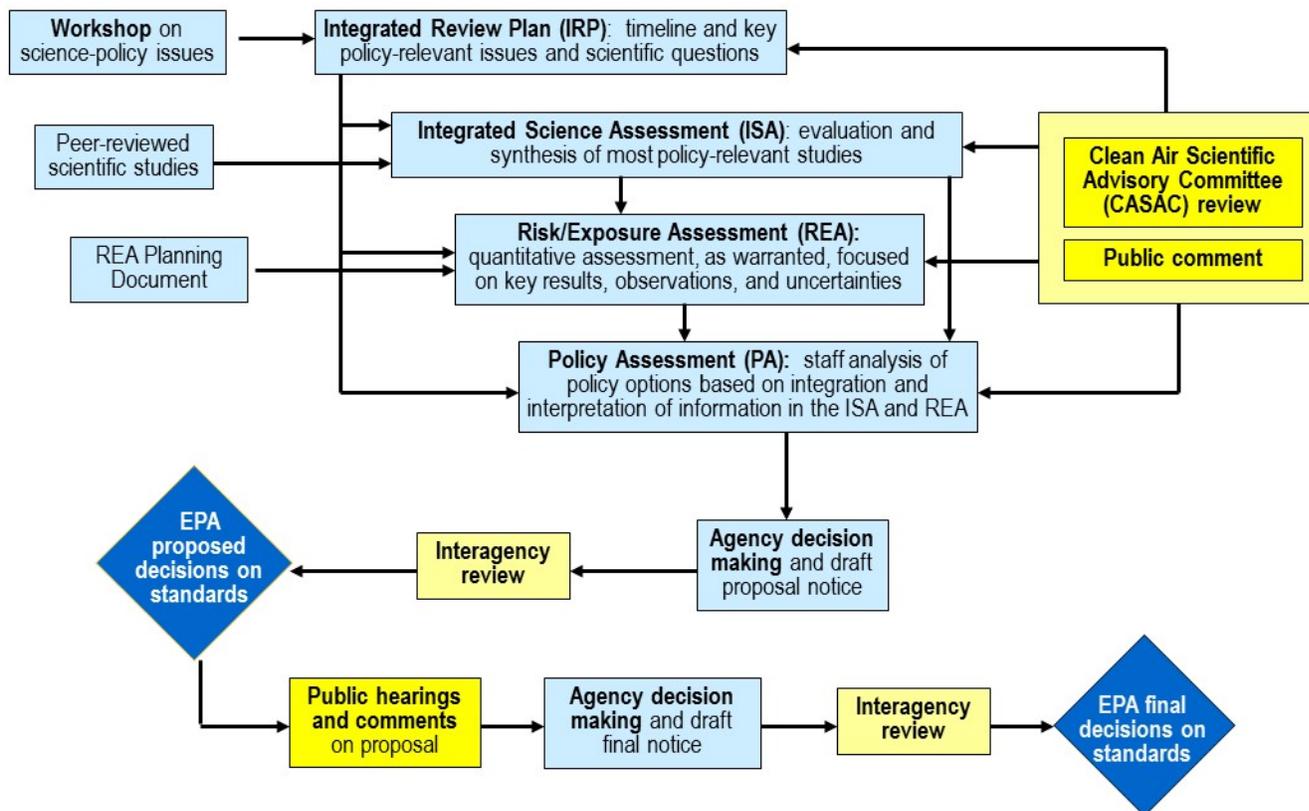


Figure 1-1. Overview of the EPA's process for reviewing NAAQS.

<sup>19</sup> The EPA maintains a website on which key documents developed for NAAQS reviews are made available (<http://www.epa.gov/ttn/naqs/>). The EPA's NAAQS review process has evolved over time. Information on the current process is available at: <http://www.epa.gov/ttn/naqs/review.html>.

**Table 1-1. Overview of documents developed in NAAQS reviews.**

Document	Purpose	CASAC Review
Integrated Review Plan (IRP)	Presents the anticipated schedule and process for the review, and the key policy-relevant science issues. Not intended to provide detailed scientific or technical information, plans for quantitative assessments, or conclusions on existing or alternative standard(s).	Consideration of the CASAC advice and public comments on the draft IRP is reflected in the final IRP.
Integrated Science Assessment (ISA)	Comprehensive review, synthesis and evaluation of the most policy-relevant science, including key science judgments. Does not present quantitative assessments or conclusions on existing or alternative standard(s).	Consideration of the CASAC advice and public comments on draft(s) of the ISA is reflected in the final ISA.
Risk and Exposure Assessment (REA) Planning Document(s)	Drawing upon the information in the ISA, presents the planned approaches and scopes of the quantitative risk and exposure analyses that are warranted. Does not present conclusions on existing or alternative standard(s).	Consideration of the CASAC advice and public comments on the REA Planning document is reflected in the REA(s).
Health and Welfare REAs (HREA, WREA)	Drawing upon the information in the ISA, presents quantitative assessments of risks and exposures, as warranted, under various air quality scenarios, including just meeting the existing and potential alternative standard(s). Does not present conclusions on existing or alternative standard(s).	Consideration of the CASAC advice and public comments on drafts of the REA(s) is reflected in the final REA(s).
Policy Assessment (PA)	Drawing upon the information in the ISA and REA(s), provides a transparent staff analysis of the scientific basis for policy options for consideration; facilitates the CASAC advice to the Agency and recommendations to the Administrator on the adequacy of the existing standards and, as warranted, on the revisions that may be appropriate to consider.	Consideration of the CASAC advice and public comments on draft(s) of the PA is reflected in the final PA.
Proposed Rule	Communicates the Administrator's proposed decision(s); informed by the ISA, REA(s), PA and the advice of the CASAC Public comment period, including public hearings as warranted.	
Final Rule	Communicates the Administrator's final decision(s); informed by the ISA, REA(s), PA, advice of the CASAC, and public comments on the proposed rule.	

The planning phase of the NAAQS review process begins with a public workshop intended to provide the EPA an opportunity to receive input and advice on the key science and policy issues around which the review will be structured. Workshop participants are asked to highlight significant new and emerging research related to these key science and policy issues, and to make recommendations to Agency staff regarding the design and scope of the review. Drawing from workshop discussions, a draft IRP is prepared jointly by the EPA's National Center for Environmental Assessment (NCEA), within the Office of Research and Development (ORD), and the EPA's Office of Air Quality Planning and Standards (OAQPS), within the Office of Air and Radiation (OAR). The IRP presents the plan for the review, including the anticipated schedule, the key policy-relevant science issues that will guide the review, and the approach to developing the assessment documents that will inform the review. A draft of the IRP is made available for the CASAC review and for public comment, and the final IRP reflects the EPA staff's consideration of the CASAC advice and public comments.

Following the IRP, the EPA's NCEA develops the Integrated Science Assessment (ISA). The ISA provides a concise review, synthesis, and evaluation of the most policy-relevant science, including key science judgments that are important to the design and scope of exposure and risk assessments, as well as other aspects of the NAAQS review. The ISA (and any supplementary materials that may be developed) provides a comprehensive assessment of the current scientific literature pertaining to known and anticipated effects on public health and/or welfare associated with the presence of the pollutant in the ambient air, emphasizing information that has become available since the last air quality criteria review in order to reflect the current state of knowledge. As such, the ISA forms the scientific foundation for each NAAQS review and is intended to provide information useful in forming judgments about air quality indicator(s), averaging time(s), form(s), and level(s) for the NAAQS. The schedule typically includes production of a first and, if needed, second draft ISA, both of which undergo the CASAC and public review. The final ISA reflects staff's consideration of the CASAC advice and of the public input provided on drafts of the ISA. Chapter 3 below provides a more detailed description of the planned scope, organization, and assessment approach for the ISA in the current review.

In the risk/exposure assessment phase, OAQPS staff considers information and conclusions presented in the ISA, with regard to support provided for the development of quantitative assessments of the risks and/or exposures for health and/or welfare effects. As an initial step, staff prepares a planning document (the Risk and Exposure Assessment or REA Planning Document) that considers the extent to which newly available scientific evidence and tools/methodologies warrant the conduct of quantitative risk and exposure assessments. As discussed in Chapter 4 below, the REA Planning Document focuses on the degree to which

important uncertainties in the last review may be addressed by new information available in this review. Specifically, the document considers the extent to which newly available data, methods, and tools might be expected to appreciably affect the assessment results or address important gaps in our understanding of the exposures and risks associated with nitrogen oxides, sulfur oxides, and PM. To the extent warranted, the REA Planning Document will also outline a general plan, including scope and methods, for conducting quantitative assessments. The REA Planning Document is typically prepared in conjunction with the first or second draft ISA and are reviewed by the CASAC at a public meeting and made available for public comment.

When developed, the REA provides concise presentations of exposure and/or risk assessments, including presentations of methods, key results, and uncertainties. One or more drafts of the REA undergo the CASAC review at public meetings and are made available for public comment. Staff considers the CASAC advice and public input received in preparing the final REA. Chapter 4 below provides more detailed descriptions of the approaches in this review for considering the potential support for an REA.

The review process ends with the policy assessment and rulemaking phase. The Policy Assessment (PA) is prepared prior to issuance of proposed and final rules, presenting staff's considerations and conclusions regarding the adequacy of the current standards and, if warranted, the range of revised standards that could be supported by the available scientific evidence and exposure/risk information. The PA integrates and interprets the information from the ISA and REA(s) to frame policy options for consideration by the Administrator. Such an evaluation of policy options is intended to help bridge the gap between the Agency's scientific assessments, presented in the ISA and REA (when available), and the judgments required of the EPA Administrator in determining whether it is appropriate to retain or revise the NAAQS. The PA is also intended to facilitate the CASAC's advice to the Agency and recommendations to the Administrator on the adequacy of the existing standards and on revisions that may be appropriate to consider. In evaluating the adequacy of the current standards and, as appropriate, a range of potential alternative standards, the PA considers the available scientific evidence and, as available, quantitative risk and exposure analyses together with related limitations and uncertainties. The PA focuses on the evidence and information that is most pertinent to evaluating the basic elements of NAAQS: indicator, averaging time, form, and level. The schedule typically includes production of a first and, if needed, second draft PA, both of which undergo the CASAC review at public meetings. Staff considers the CASAC advice and public input received in preparing the final PA.

Following issuance of the final PA, the EPA develops and publishes a notice of proposed rulemaking that communicates the Administrator's proposed decisions on the NAAQS. These

proposed decisions are based on the Administrator's consideration of the scientific evidence assessed in the ISA; quantitative exposure and risk information presented and assessed in the REAs, as available; staff's considerations and conclusions based on the evidence and information, as presented in the PA; the CASAC advice received during the development of the ISA, REA, and PA; and public input received on drafts of those assessment documents. Prior to publication in the *Federal Register*, a draft proposal notice undergoes interagency review involving other federal agencies.<sup>20</sup> Materials upon which proposed decisions are based, including the documents described above, are made available to the public in the regulatory docket for review.<sup>21</sup>

A public comment period, during which one or more public hearings are generally held, follows publication of the notice of proposed rulemaking. Taking into account comments received on the proposed rule,<sup>22</sup> the Agency develops a final rule, a draft version of which undergoes interagency review prior to publication in the *Federal Register*. Chapter 5 of this IRP discusses the development of the PA and the rulemaking steps for this review.

### **1.3 HISTORY OF THE REVIEWS FOR THE SECONDARY NAAQS OF ECOLOGICAL EFFECTS OF OXIDES OF NITROGEN, OXIDES OF SULFUR, AND PM**

Establishment of the initial secondary standards for oxides of nitrogen, oxides of sulfur and PM in 1971 recognized the direct effects of these pollutants on vegetation. In subsequent reviews, deposition-related effects on ecosystems, including nutrient loading, and acidification were recognized. A broad range of such direct and indirect ecological effects have been considered in the most recent reviews of these pollutants, which are summarized below.

#### **1.3.1 Oxides of Nitrogen**

In 1971, after reviewing the relevant science on the public health and welfare effects associated with oxides of nitrogen, including information on effects on vegetation, the EPA

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<sup>20</sup> Where implementation of the proposed decision would have an annual effect on the economy of \$100 million or more, (e.g., by necessitating the implementation of emissions controls) the EPA also develops and releases a draft regulatory impact analysis (RIA) concurrent with the notice of proposed rulemaking. This activity is conducted under Executive Order 12866. The RIA is conducted independently of the rulemaking process and, by law, is not considered in decisions regarding the NAAQS.

<sup>21</sup> All documents in the docket are listed in the [www.regulations.gov](http://www.regulations.gov) index. Publicly available docket materials are available either electronically at [www.regulations.gov](http://www.regulations.gov) or in hard copy at the Air and Radiation Docket and Information Center. The docket ID number for this review of the secondary oxides of nitrogen, oxides of sulfur and PM NAAQS is EPA-HQ-OAR-2014-0128.

<sup>22</sup> When issuing the final rulemaking, the Agency responds to all significant comments on the proposed rule.

promulgated identical primary and secondary standards at a level of 0.053 parts per million (ppm) NO<sub>2</sub>, as an annual arithmetic mean (36 FR 8186, April 30, 1971; U.S. EPA, 1971). In 1982, the EPA reviewed the air quality criteria and published *Air Quality Criteria for Oxides of Nitrogen* (U.S. EPA, 1982). In addition to the evidence of direct effects on vegetation, the 1982 criteria review for welfare effects considered evidence of visibility effects and acid precipitation. Based on this information, the EPA proposed to retain the existing secondary standard (49 FR 6866, February 23, 1984). After taking into account public comments and based on the conclusion that the existing annual standard provided adequate protection against welfare effects and there was no need for a different secondary standard, the EPA decided to retain the existing standard (50 FR 25532, June 19, 1985).

In November 1991, the EPA initiated another review and released an updated draft air quality criteria document (AQCD) for review and comment by the CASAC and the public (56 FR 59285, November 1991). The final AQCD was released later in 1993 (U.S. EPA, 1993), and staff of the OAQPS prepared a draft Staff Paper that summarized and integrated the key studies and scientific evidence from the AQCD and identified the critical elements to be considered in the review of the NO<sub>2</sub> NAAQS. After review by the CASAC and receipt of public comment, the EPA finalized the Staff Paper (U.S. EPA, 1995a). Based on the available information in this review, which associated NO<sub>2</sub> and other nitrogen compounds with a wide range of effects including the acidification and eutrophication of aquatic systems, potential changes in the composition and competition of some species of vegetation in wetland and terrestrial systems, and visibility impairment, the EPA proposed to retain the existing secondary standard without revision (60 FR 52874, October 11, 1995). After consideration of public comments, the Administrator concluded that revisions to neither the primary or the secondary standard were appropriate at that time (61 FR 52852, October 8, 1996). At the same time, the Administrator recognized the importance of reducing atmospheric nitrogen loads into major waterbodies, including the Chesapeake Bay, highlighting a number of then-new activities aimed at lessening the effects of atmospheric deposition of NO<sub>x</sub> (61 FR 52855, October 8, 1997).

The most recent review of the secondary standards for oxides of nitrogen, in which the evidence on direct ecological effects and ecosystem deposition-related effects, such as eutrophication and acidification, was performed jointly with a review of the secondary standards for oxides of sulfur beginning in 2005 (described in section 1.3.4 below).

### **1.3.2 Oxides of Sulfur**

Based on the 1970 sulfur oxides criteria document (DHEW, 1970), the EPA promulgated the initial primary and secondary NAAQS for SO<sub>2</sub> (36 FR 8186, April 30, 1971). The secondary

standards were set (different from the primary standards) at  $60 \mu\text{g}/\text{m}^3$  (0.02 ppm), as an annual arithmetic mean, and  $1,300 \mu\text{g}/\text{m}^3$  (0.5 ppm), as a maximum 3-hour concentration, not to be exceeded more than once per year. These standards were established based particularly on consideration of vegetation effects evidence described in the 1970 criteria document. Based on additional data available in 1973, revisions were made to Chapter 5 “Effects of Sulfur Oxide in the Atmosphere on Vegetation” of the Air Quality Criteria for Sulfur Oxides (U.S. EPA, 1973), which led the EPA to propose (38 FR 11355, May 7, 1973) and then finalize a revocation of the annual mean secondary standard (38 FR 25678, September 14, 1973). At that time, the EPA additionally considered welfare effects related to effects on materials, visibility, soils and acidification of rain. However, the EPA concluded that either protection from such effects was afforded by the primary standard or that sufficient data were not then available to develop criteria for standards based on these effects (38 FR 25680, September 14, 1973). The EPA additionally noted ongoing research and invited comment on such effects including acid rain and adverse ecosystem changes.

In 1980 and 1981, the EPA released three drafts of a combined AQCD for oxides of sulfur and PM for the CASAC review and public comment. In its reviews, the CASAC concluded that acidic deposition was a topic of extreme scientific complexity, noting that a fundamental problem of addressing acid deposition in a criteria document is that acidic deposition is produced by several pollutants, including oxides of sulfur, oxides of nitrogen, and the fine particulate fraction of suspended particles (U.S. EPA, 1982, pp. 125-126). Following the CASAC closure on the criteria document in December 1981, the EPA released a final AQCD (U.S. EPA, 1982), and the OAQPS prepared a staff paper that was released in November, 1982 (U.S. EPA, 1982). The issue of acidic deposition was not, however, assessed directly in the OAQPS staff paper because the EPA followed the guidance given by the CASAC.

In response to the CASAC recommendations for a separate comprehensive discussion of acidic deposition, the EPA subsequently prepared the following documents: The Acidic Deposition Phenomenon and Its Effects: Critical Assessment Review Papers, Volumes I and II (U.S. EPA, 1984), and The Acidic Deposition Phenomenon and Its Effects: Critical Assessment Document (U.S. EPA, 1985). Although these documents were not considered criteria documents and had not undergone the CASAC review, they represented the most comprehensive summary of relevant scientific information completed by the EPA at that point.

On April 26, 1988, the EPA proposed not to revise the existing primary and secondary standards. This proposal regarding the secondary  $\text{SO}_2$  NAAQS was due to the Administrator’s conclusions that (1) based upon the then-current scientific understanding of the acidic 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, the EPA would draft and support an appropriate set of control measures (53 FR 14926, April 26, 1988). In 1993, following the Clean Air Act Amendments of 1990 (see section 1.3.3 below), the EPA decided not to revise the secondary standard, concluding that revisions to the standard to address acidic deposition and related SO<sub>2</sub> welfare effects was not appropriate at that time (58 FR 21351, April 21, 1993). At this time, the EPA recognized the significant reductions in SO<sub>2</sub> emissions, ambient SO<sub>2</sub> concentrations and ultimately deposition expected to result from implementation of the title IV program, which was expected to significantly decrease the acidification of water bodies and damage to forest ecosystems and to permit much of the existing damage to be reversed with time (58 FR 21357, April 21, 1993). While recognizing that further action might be needed to address acidic deposition in the longer term, the EPA judged it prudent to await the results of the studies and research programs then underway, including those assessing the comparative merits of secondary standards, acidic deposition standards and other approaches to control of acidic deposition and related effects, and then to determine whether additional control measures should be adopted or recommended to Congress (58 FR 21358, April 21, 1993).

### **1.3.3 Related Actions Addressing Acid Deposition**

In 1980, Congress created the National Acid Precipitation Assessment Program (NAPAP). During the 10-year course of this program, a series of reports were issued and a final report was issued in 1990 (NAPAP, 1991).

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 including the following: “1) the presence of acidic 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; ... 3) the problem of acid deposition is of national and international significance; ... 5) 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<sub>2</sub> by 10 million tons and NO<sub>x</sub> emissions by 2 million tons from 1980 emission levels in order to achieve reductions over broad geographic regions/areas. In envisioning that further action might be necessary in the long term, Congress included section 404 of the 1990 Amendments. This section requires the 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 the EPA submitted to Congress its report titled *Acid Deposition*

*Standard Feasibility Study: Report to Congress* (U.S. EPA, 1995b) in fulfillment of this requirement. The Report to Congress concluded that establishing acid deposition standards for sulfur and nitrogen deposition might at some point in the future be technically feasible although appropriate deposition loads for these acidifying chemicals could not be defined with reasonable certainty at that time.

The 1990 Amendments also added new language to sections of the CAA that pertain 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 response to such legislative initiatives, the EPA and other Federal agencies continued research on the causes and effects of acidic deposition and related welfare effects of SO<sub>2</sub> and implemented an enhanced monitoring program to track progress (58 FR 21357, April 21, 1993).

#### **1.3.4 Most Recent Review of the Oxides of Nitrogen and Oxides of Sulfur NAAQS**

In 2005, the EPA initiated a joint review of the air quality criteria for oxides of nitrogen and sulfur and the secondary NAAQS for NO<sub>2</sub> and SO<sub>2</sub>.<sup>23</sup> The review focused on the evaluation of the protection provided by the secondary standards for oxides of nitrogen and oxides of sulfur for two general types of effects (1) direct effects on vegetation of exposure to gaseous oxides of nitrogen and sulfur, which are the type of effects that the existing NO<sub>2</sub> and SO<sub>2</sub> secondary standards were developed to protect against, and (2) effects associated with the deposition of oxides of nitrogen and sulfur to sensitive aquatic and terrestrial ecosystems (77 FR 20218, April 3, 2012).

The review was initiated in December 2005, with a call for information (70 FR 73236, December 9, 2005) for the development of a revised ISA.<sup>24</sup> A draft IRP was released in October

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<sup>23</sup> Although the EPA has historically adopted separate secondary standards for oxides of nitrogen and oxides of sulfur, the EPA conducted a joint review of these standards because oxides of nitrogen and sulfur and their associated transformation products are linked from an atmospheric chemistry perspective, as well as from an environmental effects perspective. The joint review was also responsive to the National Research Council (NRC) recommendation for the EPA to consider multiple pollutants, as appropriate, in forming the scientific basis for the NAAQS (NRC, 2004).

<sup>24</sup> The review was conducted under a schedule specified by consent decree entered into by the EPA with the Center for Biological Diversity and four other plaintiffs. The schedule, which was revised on October 22, 2009 provided that the EPA sign notices of proposed and final rulemaking concerning its review of the oxides of nitrogen and oxides of sulfur NAAQS no later than July 12, 2011 and March 20, 2012, respectively.

2007, reviewed by the CASAC and the final IRP was released in December 2007 (U.S. EPA, 2007). The first and second drafts of the ISA were released in December 2007 and August 2008 respectively for the CASAC and public review. The final ISA (U.S. EPA, 2008a) was released in December 2008 (73 FR 75716, December 12, 2008).

Based on the scientific information in the ISA, the EPA developed a REA to further assess the national impact of the effects documented in the ISA. The Draft Scope and Methods Plan for Risk/ Exposure Assessment outlining the scope and design of the future REA was released in March 2008 (U.S. EPA, 2008b). First and second drafts of the REA were released (August 2008 and June 2009) for the CASAC review and public comment. The final REA (U.S. EPA, 2009) was released in September 2009.

Drawing on the information in the final REA and ISA, a first and second draft PA were released in March 2010 and September 2010, respectively. The final PA was released in January 2011 (U.S. EPA, 2011a). With respect to the direct effects on vegetation of exposure to gaseous oxides of nitrogen and sulfur, which are the effects the existing NO<sub>2</sub> and SO<sub>2</sub> secondary standards serve to protect against, the PA concluded that consideration should be given to retaining the current standards for that purpose.

With respect to the effects associated with the deposition of oxides of nitrogen and oxides of sulfur to sensitive aquatic and terrestrial ecosystems, the PA focused on the acidifying effects of nitrogen and sulfur deposition on sensitive aquatic ecosystems. Based on the information in the ISA, the assessments in the REA, and the CASAC advice (Russell and Samet, 2010a,b), the PA concluded that currently available scientific evidence and assessments called into question the adequacy of protection provided by the existing NO<sub>2</sub> and SO<sub>2</sub> secondary standards against deposition-related effects on sensitive aquatic and terrestrial ecosystems, including acidification and nutrient enrichment. Further, the PA concluded that consideration be given to a new multipollutant standard intended to address deposition-related effects. More specifically, the final PA described a potential standard based on the Aquatic Acidification Index (AAI) equation, an equation which characterizes relationships between oxides of nitrogen and oxides of sulfur, the related deposition of nitrogen and sulfur, and the associated aquatic acidification effects.<sup>25</sup> The PA also recognized, as did the CASAC, that the characterization of such complex and variable linkages between air quality, deposition and ecological effect as described in the AAI required consideration of information and analyses that have limitations and uncertainties.

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<sup>25</sup> In the AAI equation, aquatic acidification effects were considered in terms of the acid neutralizing capacity (ANC) of the aquatic system, a metric chosen for its association with water quality properties and with principle adverse effects of aquatic acidification (2011 PA, section 7.2.1).

On August 1, 2011, the EPA published a proposed decision to retain the existing annual average NO<sub>2</sub> and 3-hour average SO<sub>2</sub> standards, recognizing the protection they provided from direct effects on vegetation (76 FR 46084, August 1, 2011). In the proposal, the Administrator further concluded that the existing NO<sub>2</sub> and SO<sub>2</sub> secondary standards were not adequate to protect against the adverse impacts of acidification of both aquatic and terrestrial ecosystems or nutrient enrichment of terrestrial ecosystems. She then considered the new multipollutant AAI-based approach that was described in the PA for a standard to address deposition-related effects associated with oxides of nitrogen and oxides of sulfur. While the Administrator recognized that there was a strong scientific basis for development of the AAI-based standard, she also recognized that there were current limitations in relevant data and uncertainties associated with specifying the elements of the AAI based on modeled factors that were relevant to the question of whether she could reach a reasoned decision as to an appropriate AAI-based standard under section 109. In particular, the Administrator noted these limitations and uncertainties result in a considerable degree of uncertainty as to how well the quantified elements of the AAI standard would predict the actual relationship between varying ambient concentrations of oxides of nitrogen and sulfur and ANC levels across the distribution of water bodies within the various ecoregions in the U.S. As a result, the Administrator proposed to conclude that there would be considerable uncertainty as to the actual degree of protection that would be afforded by such a standard. (76 FR 46084, August 1, 2011).

The Administrator proposed not to set such a new multipollutant secondary standard. In addition, she proposed to revise the secondary standards by adding secondary standards identical to the NO<sub>2</sub> and SO<sub>2</sub> primary 1-hour standards set in 2010, noting that these new standards<sup>26</sup> would result in reductions in oxides of nitrogen and sulfur that would directionally benefit the environment by reducing nitrogen and sulfur deposition to sensitive ecosystems (76 FR 46084, August 1, 2011).

After consideration of public comments, the Administrator's final decision retained the existing standards to address the direct effects on vegetation of exposure to gaseous oxides of nitrogen and sulfur and did not set additional standards at that time to address effects associated with deposition of oxides of nitrogen and sulfur on sensitive aquatic and terrestrial ecosystems (77 FR 20218, April 3, 2012). The Administrator concluded that while the current secondary standards were not adequate to provide protection against potentially adverse deposition-related effects associated with oxides of nitrogen and sulfur, it was not appropriate under Section 109 to

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<sup>26</sup> The 2010 primary 1-hour standards include the NO<sub>2</sub> standard set at a level of 100 parts per billion (ppb) and the SO<sub>2</sub> standard set at a level of 75 ppb.

set any new secondary standards for such effects at that time. In addition, the preamble discussed the creation of a pilot field program to collect and analyze data in order to better understand the degree of protectiveness that an AAI-based standard would likely afford.

The Administrator also determined that setting new secondary standards identical to the existing 1-hour NO<sub>2</sub> and SO<sub>2</sub> primary standards would be neither necessary nor appropriate as, in her judgment, such standards could not reasonably be judged to provide requisite protection of public welfare. In addition, the Administrator decided that it was appropriate to retain the existing NO<sub>2</sub> and SO<sub>2</sub> secondary standards to address direct effects of gaseous NO<sub>2</sub> and SO<sub>2</sub> on vegetation. Thus, taken together, the Administrator decided to retain and not revise the current NO<sub>2</sub> and SO<sub>2</sub> secondary standards: a NO<sub>2</sub> standard set at a level of 0.053 ppm, as an annual arithmetic average, and a SO<sub>2</sub> standard set at a level of 0.5 ppm, as a 3-hour average, not to be exceeded more than once per year (77 FR 20281, April 3, 2012).

The EPA's final decision was challenged by the Center for Biological Diversity and other environmental groups. The petitioners argued that having decided that the existing standards were not adequate to protect against adverse public welfare effects such as damage to sensitive ecosystems; the Administrator was required to identify the requisite level of protection for the public welfare and to issue a NAAQS to achieve and maintain that level of protection. The D.C. Circuit disagreed, finding that the EPA acted appropriately in not setting a secondary standard given the EPA's conclusions that "the available information was insufficient to permit a reasoned judgment about whether any proposed standard would be 'requisite to protect the public welfare . . .'." <sup>27</sup> In reaching this decision, the court noted that the EPA had "explained in great detail" the profound uncertainties associated with setting a secondary NAAQS to protect against aquatic acidification. <sup>28</sup>

### **1.3.5 PM NAAQS**

The EPA first established NAAQS for PM in 1971 (36 FR 8186, April 30, 1971), based on the original Air Quality Criteria Document (AQCD) (DHEW, 1969). The AQCD assessed the evidence for a variety of PM-associated welfare effects, including effects on vegetation, as well as visibility impairment and materials damage (e.g., soiling, corrosion). Based on the air quality criteria, the secondary standards were set (different from the primary standards) at 150 µg/m<sup>3</sup>,

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<sup>27</sup> Center for Biological Diversity, et al. v. EPA, 749 F.3d 1079, 1087 (2014).

<sup>28</sup> Id. at 1088.

24-hour average, not to be exceeded more than once per year, and  $60 \mu\text{g}/\text{m}^3$ , annual geometric mean, as a guide to be used in assessing implementation plans to achieve the 24-hour standard.<sup>29</sup>

The EPA began the first periodic review of the air quality criteria and NAAQS for PM in 1979 and completed it in 1987 (44 FR 56730, October 2, 1979; 52 FR 24634, July 1, 1987). In the 1987 decision, the EPA changed the indicator for the primary standards from TSP to  $\text{PM}_{10}$ , in order to focus on the subset of inhalable particles small enough to penetrate to the thoracic region of the respiratory tract.<sup>30</sup> The primary 24-hour standard was set at  $150 \mu\text{g}/\text{m}^3$ , with a form of one expected exceedance per year, on average over three years, and the primary annual standard was set at  $50 \mu\text{g}/\text{m}^3$ , with a form of annual arithmetic mean, averaged over three years. The secondary standards were revised to be identical to the revised primary standards. With regard to protection of vegetation, the Administrator concluded that a separate secondary particle standard was not needed. The EPA additionally announced activities aimed at addressing acidic deposition, as well as visibility which was recognized as a related regional air quality problem.

The second periodic review of the air quality criteria and NAAQS for PM was completed in 1997 (62 FR 38652, July 18, 1997). Consideration of welfare effects focused predominantly on visibility effects, as well as materials damage and soiling effects associated with deposition. In the 1997 decision, the EPA determined that the fine and coarse fractions of  $\text{PM}_{10}$  should be considered separately, and the EPA added new primary and secondary standards using  $\text{PM}_{2.5}$  as the indicator for fine particles.<sup>31</sup> These new standards were as follows: (1) an annual standard with a level of  $15.0 \mu\text{g}/\text{m}^3$ , based on the 3-year average of annual arithmetic mean  $\text{PM}_{2.5}$  concentrations from single or multiple community-oriented monitors;<sup>32</sup> and (2) a 24-hour standard with a level of  $65 \mu\text{g}/\text{m}^3$ , based on the 3-year average of the 98<sup>th</sup> percentile of 24-hour  $\text{PM}_{2.5}$  concentrations at each monitor within an area. The EPA additionally retained the annual  $\text{PM}_{10}$  standard and revised the form of the 24-hour  $\text{PM}_{10}$  standard to be based on the 99<sup>th</sup> percentile of 24-hour  $\text{PM}_{10}$  concentrations at each monitor in an area. The EPA revised the

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<sup>29</sup> A more complete and detailed history of the PM NAAQS, including establishment of federal reference methods (FRM) and federal equivalent methods (FEM), is described in the 2016 PM IRP (U.S. EPA 2016b).

<sup>30</sup>  $\text{PM}_{10}$  refers to particles with a nominal mean aerodynamic diameter less than or equal to 10  $\mu\text{m}$ .

<sup>31</sup>  $\text{PM}_{2.5}$  refers to particles with a nominal mean aerodynamic diameter less than or equal to 2.5  $\mu\text{m}$ .

<sup>32</sup> The level of the 1997 annual  $\text{PM}_{2.5}$  standard was to be compared to measurements made at the community-oriented monitoring site recording the highest concentration or, if specific constraints were met, measurements from multiple community-oriented monitoring sites could be averaged (i.e., “spatial averaging”). In the 2012 PM review, the EPA replaced the term “community-oriented” monitor with the term “area-wide” monitor. *Area-wide* monitors are those sited at the neighborhood scale or larger, as well as those monitors sited at micro-or middle scales that are representative of many such locations in the same CBSA (78 FR 3236, January 15, 2013).

secondary standards by setting them equal in all respects to the primary standards based primarily on considerations related to materials damage and soiling effects.<sup>33</sup>

The third periodic review of the air quality criteria and NAAQS for PM was completed in 2006, with revisions to the primary and secondary standards (62 FR 55201, October 23, 1997; 71 FR 2620, January 17, 2006; (71 FR 61144, October 17, 2006). With regard to the primary and secondary standards for fine particles, the EPA revised the level of the 24-hour PM<sub>2.5</sub> standards to 35 µg/m<sup>3</sup>, retained the level of the annual PM<sub>2.5</sub> standards at 15.0 µg/m<sup>3</sup>, and revised the form of the annual PM<sub>2.5</sub> standards by narrowing the constraints on the optional use of spatial averaging. With regard to the primary and secondary standards for PM<sub>10</sub>, the EPA retained the 24-hour standards, with levels at 150 µg/m<sup>3</sup>, and revoked the annual standards. In addition, a new reference method was added for the measurement of PM<sub>10-2.5</sub> in the ambient air, in order to provide a basis for approving federal equivalent methods (FEMs) and to promote the gathering of scientific data to support future reviews of the PM NAAQS.

Several parties filed petitions for review following promulgation of the revised PM NAAQS in 2006. These petitions addressed several issues, including setting the secondary PM<sub>2.5</sub> standards identical to the primary standards. On February 24, 2009, the U.S. Court of Appeals for the District of Columbia Circuit issued its opinion in the case *American Farm Bureau Federation v. EPA*, 559 F. 3d 512 (D.C. Cir. 2009). With regard to the secondary PM<sub>2.5</sub> standards, the court remanded the standards to EPA because the Agency failed to adequately explain why setting the secondary PM standards identical to the primary standards provided the required protection for public welfare, including protection from visibility impairment.<sup>34</sup> The EPA responded to the court's remands as part of the next review of the PM NAAQS, which was initiated in 2007.

In June 2007, the EPA initiated the fourth periodic review of the air quality criteria and the PM NAAQS by issuing a call for information in the *Federal Register* (72 FR 35462, June 28, 2007). Based on the NAAQS review process, as revised in 2008 and again in 2009,<sup>35</sup> the EPA held science/policy issue workshops on the primary and secondary PM NAAQS (72 FR 34003,

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<sup>33</sup> Following promulgation of the 1997 PM NAAQS, petitions for review were filed by a large number of parties, addressing a broad range of issues, as described in detail in section 1.3 of the 2016 PM IRP (U.S. EPA 2016b). These issues included the consideration of cost in setting NAAQS. As described in section 1.1 above, the court reaffirmed prior rulings holding that in setting NAAQS the EPA is “not permitted to consider the cost of implementing those standards.” *Id.* at 1040-41.

<sup>34</sup> *American Farm Bureau Federation*, 559 F. 2d at 528-32.

<sup>35</sup> The history of the NAAQS review process, including revisions to the process, is discussed at <http://www3.epa.gov/ttn/naaqs/review2.html>.

June 20, 2007; 72 FR 34005, June 20, 2007), and prepared and released the planning and assessment documents that comprise the review process (i.e., IRP (U.S. EPA, 2008c), ISA (U.S. EPA, 2009a)), REA planning documents for health and welfare (U.S. EPA, 2009b,c), a quantitative health risk assessment (U.S. EPA, 2010a) and an urban-focused visibility assessment (U.S. EPA, 2010b), and PA (U.S. EPA, 2011b). In June 2012, the EPA announced its proposed decision to revise the NAAQS for PM (77 FR 38890, June 29, 2012).

In December 2012, the EPA announced its final decisions to revise the primary NAAQS for PM to provide increased protection of public health (78 FR 3086, January 15, 2013). With regard to primary standards for PM<sub>2.5</sub>, the EPA revised the level of the annual PM<sub>2.5</sub> standard to 12.0 µg/m<sup>3</sup> and retained the 24-hour PM<sub>2.5</sub> standard with its level of 35 µg/m<sup>3</sup> and the 24-hour primary PM<sub>10</sub> standard. With regard to the secondary PM standards, the EPA generally retained the 24-hour and annual PM<sub>2.5</sub> standards and the 24-hour PM<sub>10</sub> standard to address visibility and non-visibility welfare effects. On judicial review, the revised standards were upheld in all respects.<sup>36</sup>

#### **1.4 SCOPE OF THE CURRENT REVIEW**

With regard to scope, this review is focused on reviewing the air quality criteria and associated secondary NAAQS for oxides of nitrogen, oxides of sulfur, and PM, and the protection of the public welfare from adverse effects related to ecological effects. These ecological effects include eutrophication, acidification, and sulfur enrichment associated with the deposition of oxides of nitrogen, oxides of sulfur, and PM, as well as the direct and other indirect effects of oxides of nitrogen, oxides of sulfur, and PM on vegetation, soils, and biota.

In characterizing such effects related to atmospheric deposition of oxides of nitrogen and oxides of sulfur and their transformation products, this review also recognizes the contribution of PM through deposition to eutrophication-related effects, acidification-related effects, and other such welfare effects, as well to the direct and other indirect effects on vegetation, soils, and biota. In recognition of linkages between these pollutants (oxides of nitrogen, oxides of sulfur and PM) with respect to deposition and atmospheric chemistry, as well as from an environmental effects perspective, the reviews for these criteria pollutants are being conducted together for this secondary NAAQS review. Addressing the pollutants together enables us to take a comprehensive look at the nature and interactions of the pollutants, which is important for ensuring that all scientific information relevant to ecological effects is thoroughly evaluated. In this way, this approach is consistent with the previous review of the secondary NO<sub>2</sub> and SO<sub>2</sub>

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<sup>36</sup> NAM v EPA, 750 F.3d 921 (D.C. Cir. 2014).

NAAQS, in which the EPA conducted a joint review focused on the protection provided against the effects of deposition of oxides of nitrogen and oxides of sulfur to sensitive aquatic and terrestrial ecosystems. The approach in the last review recognized that oxides of nitrogen and oxides of sulfur, and their associated transformation products, are linked from the perspectives of both atmospheric chemistry and ecological effects, providing “a strong basis for considering these pollutants together” (77 FR 20222, April 3, 2012). This approach also addresses the CASAC’s comments on the draft IRP for this review, as well as the CASAC’s comments on the draft IRP for the PM NAAQS review. In particular, the CASAC expressed concern that PM-deposition-related effects were not adequately covered in the PM review; and they also encouraged the EPA to include all reduced nitrogen compounds, including ammonia and ammonium, to properly evaluate ecological impacts from nitrogen deposition in the secondary standards review for oxides of nitrogen and oxides of sulfur (Diez Roux and Fernandez, 2016; Diez Roux, 2016).

Based on the available scientific information, EPA will consider the extent to which the current NO<sub>2</sub>, SO<sub>2</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> secondary (welfare) standards are requisite to protect the public welfare, within the meaning of section 109(b) of the CAA (section 1.1, above), and with regard to the effects that are the focus of this review. To the extent the available information calls into question the adequacy of the protection afforded by one or more of these existing secondary standards, the EPA will consider potential alternatives that could be supported by the available scientific evidence and, as available, exposure-/risk-based information, in terms of the basic elements of the NAAQS (indicator, averaging time, form, level).

## 1.5 ANTICIPATED REVIEW SCHEDULE

In August 2013, the EPA's NCEA in Research Triangle Park, NC announced the official initiation of the current joint periodic review of air quality criteria for oxides of nitrogen and oxides of sulfur. The Agency began by announcing in the *Federal Register* (78 FR 53452, August 29, 2013) the formal commencement of the review and a call for information. The projected schedule for the four phases of the review is shown in Table 1-2.

**Table 1-2. Anticipated schedule for the review.**

Stage of Review	Major Milestone	Actual or Target Date
Planning	Literature Search	Ongoing
	<i>Federal Register</i> Call for Information	August 2013
	Workshop on Science/Policy Issues	March 4-6, 2014
	Release Draft IRP for CASAC/public review	November 2015
	CASAC Review Meeting for Draft IRP	December 1, 2015
	Release Final IRP	January 2017
Science Assessment	Release First Draft ISA for CASAC/public review	Winter 2017
	CASAC Review Meeting for First Draft ISA	Spring 2017
	Release Second Draft ISA for CASAC/public review	Spring 2018
	CASAC Review Meeting for Second Draft ISA	Summer 2018
	Release Final ISA	Spring 2019
Risk/Exposure Assessments	Release REA Planning Document(s) for CASAC/public review	Fall 2017
	CASAC Review Meeting for REA Planning Document(s)	Winter 2017/2018
	Release First Draft REA(s) for CASAC/Public Review	Fall 2018
	CASAC Review Meeting for First Draft REA(s)	Winter 2018/2019
	Release Second Draft REA(s) for CASAC/Public Review	Fall 2019
	CASAC Review Meeting for Second Draft REA(s)	Winter 2019/2020
	Release Final REA(s)	Fall 2020
Policy Assessment/ Rulemaking	Release First Draft PA for CASAC/public review	Fall 2018
	CASAC Review Meeting on First Draft PA	Winter 2018/2019
	Release Second Draft PA	Fall 2019
	CASAC Review/Public Comment on Second Draft PA	Winter 2019/2020
	Release Final PA	Fall 2020
	Proposed Rulemaking	2021
	Final Rulemaking	2022

## 2 KEY POLICY-RELEVANT ISSUES

In each NAAQS review, an initial step is to address the following overarching question:

- **Does the currently available scientific evidence and exposure/risk-based information support or call into question the adequacy of the protection afforded by the current standard(s)?**

As appropriate, reviews also address a second overarching question:

- **What alternative standards, if any, are supported by the currently available scientific evidence and exposure/risk-based information and are appropriate for consideration?**

To inform our evaluation of these overarching questions in the current review, we have identified a number of more specific policy-relevant questions for consideration (see below). These policy-relevant questions will focus on key issues reflecting aspects of the welfare effects evidence, air quality information, and information from quantitative exposure and risk assessments that can inform the Administrator's decisions in the current review. Questions will build upon the conclusions from the last review on the evidence and information, including conclusions on the uncertainties and limitations in that evidence and information.

As discussed in Chapter 1, the scope for this review pertains to the protection of the public welfare from adverse effects related to ecological effects. These ecological effects include eutrophication, acidification, and sulfur enrichment associated with the deposition of oxides of nitrogen, oxides of sulfur, and PM, as well as the direct and other indirect effects of oxides of nitrogen, oxides of sulfur, and PM on vegetation, soils, and biota. In characterizing such effects related to atmospheric deposition, this review also recognizes the linkages between the criteria pollutants (oxides of nitrogen, oxides of sulfur and PM) with respect to deposition and atmospheric chemistry, as well as their combined contributions to ecological effects.

Thus, this IRP addresses the review of the secondary (welfare-based) NAAQS for oxides of nitrogen, oxides of sulfur and PM, focusing on the contribution of these pollutants to ecological effects and particularly the contribution of these pollutants through atmospheric deposition to ecosystem effects. Additional welfare effects associated with PM, such as visibility impairment, climate effects and materials damage, and the health effects of PM (including particulate transformation products of oxides of nitrogen and oxides of sulfur) are considered as part of the review of the NAAQS for PM (U.S. EPA, 2009a). The health effects of oxides of nitrogen and oxides of sulfur are considered in separate assessments as part of the review of the primary (health-based) NAAQS for oxides of nitrogen (U.S. EPA, 2014a) and oxides of sulfur (U.S. EPA, 2014b).

The review will focus on the basic elements of the secondary NAAQS; the indicator, averaging time, form, and level. These elements, which serve to define each ambient air quality standard, must be considered collectively in evaluating the welfare protection afforded by the standards. The current secondary NAAQS for oxides of nitrogen and oxides of sulfur are intended to protect against direct damage to vegetation by exposure to gas-phase oxides of nitrogen and oxides of sulfur. The current secondary standards for PM are intended to address PM-related welfare effects, including visibility impairment, ecological effects, effects on materials, and climate impacts. More specifically, with respect to ecological effects, in the context of PM, the Administrator considered direct effects on metabolic processes of plants; contribution to total metal loading resulting in alteration of soil biogeochemistry and microbiology, plant and animal growth and reproduction; and contribution to total organics loading resulting in bioaccumulation and biomagnification across trophic levels.

Sections 2.1 and 2.2 below describe the important considerations and conclusions from the last reviews with regard to the adequacy of the secondary standards for oxides of nitrogen and oxides of sulfur and PM, as well as important uncertainties and limitations in the evidence and information in those reviews. In so doing, section 2.1 focuses on direct ecological effects and section 2.2 focuses on deposition-related ecosystem effects. Section 2.3 discusses the general approach in the current review of the secondary standards for the ecological effects of oxides of nitrogen, oxides of sulfur and PM and outlines the key policy-relevant issues. These issues are presented as a series of policy-relevant questions that will frame our approach and be addressed in detail in the science assessment, risk assessment, and policy assessment sections of the review.

## **2.1 DIRECT ECOLOGICAL EFFECTS**

In addition to effects exerted through deposition and loading to aquatic and terrestrial ecosystems (as discussed in section 2.2 below), the last reviews of the NAAQS for oxides of nitrogen, oxides of sulfur and PM considered the available evidence for direct ecological effects, with a particular focus on direct effects to vegetation (2008 Oxides of Nitrogen and Oxides of Sulfur ISA, section 3.4; 2009 PM ISA, section 9.4.3). The last review of the oxides of nitrogen and oxides of sulfur secondary standards considered the direct effects of gaseous oxides of nitrogen and oxides of sulfur on vegetation and the Administrator retained the existing standards in recognition of the protection they afforded against such effects (77 FR 20241 April 3, 2012). The last review of the PM secondary standards also considered the direct effects of PM to ecological receptors (e.g., direct effects of PM deposition on vegetation surfaces) and the Administrator's decision to retain the existing secondary standards in that review also addressed such effects (78 FR 3225-3226, January 15, 2013). Findings from the past reviews of the three

pollutants will be considered in the current review in light of the currently available information, including that newly available in this review.

Based on the evidence for direct effects of oxides of nitrogen and oxides of sulfur available in the last review of the secondary NAAQS for oxides of nitrogen and oxides of sulfur, the 2008 ISA concluded there to be sufficient evidence to infer causal relationships between exposure to gaseous oxides of nitrogen and oxides of sulfur and injury to vegetation, including decreasing photosynthesis and induction of visible foliar injury (2008 ISA, section 3.4.2.4). As summarized in the 2011 PA, acute and chronic exposures to gaseous pollutants, SO<sub>2</sub>, NO<sub>2</sub>, nitric oxide, nitric acid and peroxyacetyl nitrate are associated with negative impacts to vegetation, such as effects on growth, reduced photosynthesis, decreased yield, and foliar injury (2011 PA, section 3.3; 2008 ISA, section 3.4.2.4). Phytotoxic effects of gas phase oxides of nitrogen and sulfur were recognized to depend on the exposure concentration and duration, and on species sensitivity (2011 PA, section 3.3.3). The evidence for such effects available in the last review was predominantly at levels well above ambient concentrations observed in the U.S. and did not suggest such effects were occurring below the levels of the current secondary standards (2008 ISA section 3.4.2.4; 77 FR 20234, April 3, 2012).

In the last PM NAAQS, the 2011 PM ISA found there to be a likely causal relationship between deposition of PM and a variety of effects on individual organisms (2011 PM ISA, section 9.4.7). Such effects include those related to direct effects on metabolic processes of plant foliage (2011 PM ISA, section 9.4.7). The PM ISA additionally observed that “[i]nvestigations of the direct effects of PM deposition on foliage have suggested little or no effects on foliar process, unless deposition levels were higher than is typically found in the ambient environment” and that “[e]xposure to a given concentration of PM may, depending on the mix of deposited particles, lead to a variety of phytotoxic responses” (2011 PM ISA, p. 9-192 to 9-193). Uncertainties associated with our consideration of direct ecological effects of PM that were recognized in the last review relate to both the presence of multiple ecological stressors that can confound attempts to link specific responses to PM deposition, as well as to the multitude of factors that influence PM deposition thus affecting our ability to predict the amount of PM deposited to sensitive receptors from measured concentrations of PM in ambient air (2011 PM PA, section 5.3.4). Concurring with the advice from the CASAC, the Administrator concluded it to be important to maintain an appropriate degree of control of both fine and coarse particles to address non-visibility welfare effects, including ecological effects (those addressed here, as well as those addressed in section 2.2 below), and in the absence of information that would support any different standards, the Administrator concluded that it was appropriate to retain the existing

suite of secondary standards to protect against such effects (78 FR 3225-3226, January 15, 2013).

## **2.2 DEPOSITION-RELATED ECOLOGICAL EFFECTS**

The scientific information related to deposition-related ecosystem effects of oxides of nitrogen, oxides of sulfur, and PM was considered in the reviews of the secondary standards for those pollutants completed in 2012 and 2013 (77 FR 20218 April 3, 2012; 78 FR 3087, January 15, 2013). Consideration of such effects in the review of the secondary standards for PM (discussed further below) focused on effects not addressed in the Oxides of Nitrogen and Oxides of Sulfur review. Key aspects of both reviews are summarized in the subsections below.

### **2.2.1 2012 Review of the Secondary NAAQS for Oxides of Nitrogen and Oxides of Sulfur**

The 2012 review of the secondary NAAQS for oxides of nitrogen and oxides of sulfur was completed in 2012 (77 FR 20218, April 3, 2012). In that review, EPA considered the available scientific evidence on deposition-related and other (direct) effects of oxides of nitrogen and oxides of sulfur and as well as the results of quantitative analyses of deposition-related effects. As described in section 1.3 above, this was the first time that the Agency had considered deposition-related information for these pollutants in such a manner. EPA jointly assessed the scientific information, associated risks, and standards because oxides of nitrogen and oxides of sulfur in the ambient air, and their associated transformation products, such as deposited nitrogen and sulfur, are linked from an atmospheric chemistry perspective, as well as jointly contributing to ecological effects. Based on the evidence presented in the ISA with regard to acidification and nutrient enrichment effects, the findings of the REA, the synthesis of both the scientific evidence and REA results in the PA as to the adequacy of the current standards, the advice of the CASAC and public comments, the Administrator concluded that the existing secondary standards did not provide adequate protection from deposition-related effects on ecosystems. As described further below, the Administrator additionally found the limitations and uncertainties in the available information to be too great to support establishment of a new standard that could be concluded to provide the requisite protection for such effects (77 FR 20218, April 3, 2012).

Ecological effects related to deposition of oxides of nitrogen and oxides of sulfur were broadly categorized into those related to ecosystem acidification, ecosystem nutrient enrichment and various other effects (e.g., changes in mercury methylation in aquatic ecosystems related to sulfur deposition) (2008 ISA, chapter 4; 2011 PA, chapter 3). Nutrient enrichment (eutrophication) was recognized to occur in both aquatic and terrestrial ecosystems, with the types and prevalence of nutrient enrichment effects recognized to vary between ecosystem types (2011 PA, section 3.2). The 2011 PA also recognized that acidification also occurs in both

aquatic and terrestrial ecosystems (2011 PA, section 3.1). In the acidification process, geochemical components of terrestrial and freshwater aquatic ecosystems are altered in a way that leads to effects on biological organisms. Because oxides of nitrogen and sulfur deposited to terrestrial ecosystems often move through the soil and eventually leach into adjacent water bodies, deposition to terrestrial ecosystems can also be a cause of acidification in aquatic ecosystems (2011 PA, section 3.1).

The 2008 ISA found that acidifying deposition in aquatic ecosystems can cause the loss of acid-sensitive species, with more species lost with greater acidification, and that these effects are linked to changes in surface water chemistry, including sulfate and nitrate concentrations in surface waters, ANC,<sup>37</sup> inorganic aluminum concentrations, and surface water pH (2008 ISA, pp. 6-7). These changes can result in the loss of acid-sensitive biological species such as salmonids and this disruption of food web dynamics can cause changes to the diet, breeding distribution and reproduction of certain species of bird, such as goldeneye ducks and loons (2008 ISA, section 3.2.4; 2011 PA, section 3.1). The available information indicated that in the Adirondacks and Shenandoah areas, rates of acidifying deposition of oxides of nitrogen and sulfur are still well above pre-acidification (1860) conditions<sup>38</sup> (2011 PA, section 2.5.3). In addition, quantitative modeling estimated that in 2002 total sulfur and nitrogen deposition loadings to 44% of the Adirondack lakes evaluated and 85% of streams evaluated in the Shenandoah area exceeded the critical load for an ANC of 50  $\mu\text{eq/L}$ <sup>39</sup> (2009 REA, section 4.2.4.1), indicative of ANC levels with which negative effects on aquatic biota have been associated (2011 PA, Table 3-3; 2008 ISA, sections 3.2.4.4 and 3.2.4.5) resulting in losses in fitness in species such as the Blacknose Dace.

The 2008 ISA also found a causal relationship between acidifying deposition and changes in terrestrial biota, with studies of terrestrial systems exposed to elevated levels of acidifying deposition showing decreased growth and increased susceptibility to disease and injury in

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<sup>37</sup> Acid neutralizing capacity or ANC is the most widely used indicator of the sensitivity of an aquatic ecosystem to acid inputs and has been found in various studies to be the best single indicator of the potential for biological response and health of aquatic communities in acid sensitive systems (2011 PA, section 3.1.3).

<sup>38</sup> The year 1860 was used in the last review as a pre-industrial comparison period (2011 PA, p. 7-17).

<sup>39</sup> As noted in the final NO<sub>x</sub>/SO<sub>x</sub> PA, the evidence indicates that at annual average ANC levels between 100 and 50  $\mu\text{eq/L}$ , the fitness of sensitive species (e.g., brook trout, zooplankton) begins to decline. The term fitness generally refers to measures of population response in terms of ability to withstand stress (fecundity, survival, etc.). When annual average ANC is <50  $\mu\text{eq/L}$ , negative effects on aquatic biota are observed, including large reductions in diversity of fish species, and declines in health of fish populations, affecting reproductive ability and fitness. Annual average ANC levels below 0  $\mu\text{eq/L}$  are generally associated with complete loss of fish species and other biota that are sensitive to acidification (2011 PA, p. ES-3 and Table 3-3).

sensitive tree species, such as red spruce and sugar maple (2008 ISA, section 4.2.1.2). The 2009 REA evaluated a small number of sensitive areas as case studies. The sugar maple case study area (Kane Experimental Forest, Pennsylvania) evaluated steady state conditions associated with total nitrogen and sulfur deposition and found that 2002 deposition levels yielded estimates of a base cation to aluminum (Bc/Al) ratio below 1.2,<sup>40</sup> indicating the potential for a greater than 20 percent reduction in growth. In the red spruce case study area (Hubbard Brook Experimental Forest, New Hampshire), 2002 deposition levels were associated with a Bc/Al ratio slightly above 1.2, indicating slightly less potential for significant reductions in growth. When the methodology was extended to a 27-state region, the calculated Bc/Al ratio fell below 1.2 in 12% of the sugar maple plots and 5% of the red spruce plots; however, results from individual states ranged from 0 to 67% of the plots for sugar maple and 0 to 100% of the plots for red spruce that fell below the Bc/Al ratio of 1.2 (2011 PA, p. ES-4).

With regard to nutrient enrichment, the 2008 ISA recognized that the numerous ecosystem types that occur across the U.S. have a broad range of sensitivity to nitrogen deposition. While organisms in their natural environment are commonly adapted to a specific regime of nutrient availability, a change in the availability of one important nutrient, such as nitrogen, may result in an imbalance in the ecosystem, with effects on ecosystem processes, structure and function. In certain nitrogen-limited ecosystems, including some ecosystems managed for commercial production, nitrogen deposition can result in beneficial increases in productivity. Nutrient enrichment effects from deposition of oxides of nitrogen are difficult to disentangle from the overall effects of nitrogen enrichment. Other sources of nitrogen input may also contribute large amounts of nitrogen. For example, the inputs of reduced nitrogen from deposition and nitrogen inputs from non-atmospheric sources such as runoff into estuaries may contribute significant amounts of nitrogen to sensitive ecosystems (2008 ISA, section 3.3).

The 2011 PA noted that available ecological indicators for nutrient enrichment in estuaries were not sufficiently sensitive to changes in inputs from atmospheric sources of nitrogen oxides to be useful in assessing the adequacy of the current NO<sub>2</sub> secondary standard. However, the 2008 ISA concluded that nitrogen deposition can alter species composition and

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<sup>40</sup> A commonly used indicator of terrestrial acidification is the base cation to aluminum ratio, Bc/Al. A meta-analysis of red spruce studies indicated a 20 percent reduction in growth (compared to controls) at a Bc/Al ratio of 1.2 (considered “intermediate level of protection” in the REA) (2009 REA, pp. Appendix 5-43 to 5-45). The same study indicated a 20 percent reduction in sugar maple growth (compared to controls) at a Bc/Al ratio of 0.6 (considered “low level of protection” in REA) (2009 REA, pp. Appendix 5-43 to 5-45). While not defining whether a 20 percent reduction in growth can be considered significant, existing economic studies suggest that avoiding significant declines in the health of spruce and sugar maple forests may be worth billions of dollars to residents of the Eastern U.S. (2011 PA, p. ES-4).

cause eutrophication in wetlands, estuarine and freshwater ecosystems, and the 2011 PA considered the extent to which information available for some freshwater systems might inform consideration of the adequacy of the NO<sub>2</sub> secondary standard. The PA analyses of waterbodies noted that, in the Rocky Mountains, for example, deposition loads of 1.5 to 2 kg/ha/yr, (which are within the range associated with ambient nitrogen oxide levels meeting the current standard) have been estimated to cause changes in species composition in diatom communities (2011 PA, section 3.2.3; 2008 ISA, section 3.3.5).

With regard to terrestrial nutrient enrichment, the 2011 PA noted that most terrestrial ecosystems in the U.S. were nitrogen-limited, and therefore sensitive to perturbation caused by nitrogen additions. Analyses in the REA indicated total nitrogen deposition levels for 2002 to be of a magnitude that may be associated with changes in species composition (2011 PA, section 3.2.3; 2009 REA, section 5.3.1).

Based on consideration of this information in the ISA, the assessments in the REA, and in agreement with the CASAC advice (Russell and Samet, 2010a, b), the PA concluded that consideration should be given to a new approach for a multipollutant standard intended to address deposition-related effects. More specifically, the PA focused on developing an approach for such a standard targeting ecological effects associated with acidifying deposition of oxides of nitrogen and sulfur in aquatic ecosystems. The PA recognized that the body of scientific evidence linking the deposition of ambient oxides of nitrogen and sulfur to acidification in sensitive aquatic ecosystems was well developed and that, further, it supported the conclusion that both oxides of nitrogen and oxides of sulfur are major contributors to aquatic acidification and that acidification of aquatic ecosystems is best characterized and understood in terms of the combined rather than individual effects of oxides of nitrogen and sulfur (2011 PA, chapter 7).

The PA approach was based on an AAI equation, with some aspects of it described using the terms traditionally used in defining NAAQS (indicator, form, averaging time and level). In this AAI equation, the aquatic acidification effects were considered in terms of the ANC of the aquatic system, given that the ANC was concluded to provide the most stable metric that was both highly associated with the water quality properties and was directly responsible for the principal adverse effects associated with aquatic acidification: fish mortality and reduced aquatic species diversity. Calculation of the AAI, as proposed in the PA, relied upon ecosystem and air quality modeling to estimate the ecosystem's natural ability to buffer acidic deposition from ambient nitrogen and sulfur deposition. The equation relies on ambient air concentrations of reactive oxidized nitrogen (NO<sub>y</sub>) as the indicator for oxides of nitrogen, and SO<sub>x</sub>, which is the sum of SO<sub>2</sub> and particulate sulfate (SO<sub>4</sub>), as the indicator for oxides of sulfur, in addition to the relevant ecological and atmospheric factors that modify the relationships between the ambient air

indicators and ANC. In general, the AAI was meant to reflect the difference between the natural acid neutralizing capability of a region and acidifying deposition inputs from NO<sub>y</sub> and SO<sub>x</sub> in the ambient air.

The AAI, as described in the PA, was constructed from steady state ecosystem modeling, and included atmospheric transference ratios and deposition of reduced forms of nitrogen (ammonia gas and ammonium ion, expressed as NH<sub>x</sub>). These non-oxidized forms of nitrogen were included since ecosystems respond to total nitrogen deposition, whether from oxidized or reduced forms. More specifically, the AAI equation was defined in terms of four ecological and atmospheric factors and the ambient air indicators NO<sub>y</sub> and SO<sub>x</sub>:

$$\text{AAI} = F1 - F2 - F3[\text{NO}_y] - F4[\text{SO}_x]$$

where F1<sup>41</sup> represents the ecosystems natural ability to provide acid neutralizing capacity and to neutralize nitrogen deposition through plant uptake and other processes; F2<sup>42</sup> represents acidifying deposition associated with reduced forms of nitrogen, NH<sub>x</sub>; and F3<sup>43</sup> and F4<sup>44</sup> are the transference ratios that convert concentrations on NO<sub>y</sub> and SO<sub>x</sub> to related deposition of nitrogen and sulfur (2011 PA, section 7.7).

Recognizing the spatial variability across the U.S. of the factors in the AAI equation, the PA suggested that AAI values were meant to be calculated specifically for each ecologically relevant region. In applying the equation, the PA concluded that consideration should be given to averaging calculated annual AAI values over 3 to 5 years to provide reasonable stability in the resulting index value due to the relatively high degree of inter annual variability expected in such an index that is so strongly influenced by the amount and pattern of precipitation that occurs within a region from year to year. In describing the AAI-based approach for an oxides of nitrogen and oxides of sulfur secondary standard, the PA conveyed that in establishing the standard, EPA would specify a level for the AAI and the equation could be solved for oxides of nitrogen and oxides of sulfur concentrations for each specified region. With regard to a level for the AAI, the PA concluded consideration should be given to a level within the range of 20 to 75

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<sup>41</sup> F1 is defined as:  $\text{ANC}_{\text{lim}} + \text{CL}_r / \text{Q}_r$ , with  $\text{ANC}_{\text{lim}}$  representing a target ANC level. With regard to  $\text{CL}_r$ , the PA developed distributions of of calculated critical loads for a specific ecoregion; in setting an AAI-based standard, a percentile would need to be specified to reference the value of  $\text{CL}_r$  to be used in the AAI equation (2011 PA, p. 7-37). The PA described the percentile as an aspect of the form for the standard (2011 PA, section 7.7).

<sup>42</sup> F2 is defined as:  $\text{NH}_x / \text{Q}_r$ , where  $\text{NH}_x$  is the deposition divided by  $\text{Q}_r$  (2011 PA, p. 7-37).

<sup>43</sup> F3 is defined as:  $\text{TNO}_y / \text{Q}_r$ , where  $\text{TNO}_y$  is the transference ratio that converts deposition of NO<sub>y</sub> to ambient air concentrations of NO<sub>y</sub> (2011 PA, p. 7-37).

<sup>44</sup> F4 is defined as:  $\text{TSO}_x / \text{Q}_r$ , where  $\text{TSO}_x$  is the transference ratio that converts deposition of SO<sub>x</sub> to ambient air concentrations of SO<sub>x</sub> (2011 PA, p. 7-37).

µeq/L noting that a target ANC value of 20 µeq/L would be a reasonable lower end of this range, so as to protect against chronic acidification-related adverse impacts on fish populations which have been characterized as severe at ANC values below this level. Further, a target ANC value of 75 µeq/L would be a reasonable upper end of this range in recognition that the potential for additional protection at higher ANC values is substantially more uncertain in light of evidence that acidification-related effects are far less sensitive to increases in ANC above this value (2011 PA, section 7.7). After consideration of the approach presented in the PA, advice from the CASAC, and public comment, the Administrator concluded that the limitations and uncertainties in the available information was too great to support establishment of a new AAI-based standard that could be concluded to provide the requisite protection (77 FR 20218, April 3, 2012). While the Administrator recognized that there was a strong scientific basis for development of the AAI-based standard<sup>45</sup>, she also recognized that there were current limitations in relevant data and uncertainties associated with specifying the elements of the AAI based on modeled factors that were relevant to the question of whether it is appropriate under Section 109 to set a specific AAI-based standard (77 FR 20255, April 3, 2012).<sup>46</sup> In particular, the EPA noted these limitations and uncertainties result in a considerable degree of uncertainty as to how well the quantified elements of the AAI standard would predict the actual relationship between varying ambient concentrations of oxides of nitrogen and sulfur and ANC levels across the distribution of water bodies within the various ecoregions in the U.S (77 FR 20255, April 3, 2012). These uncertainties were critical for determining the actual degree of protection that would be afforded by such a standard and thus called into question whether an AAI-based standard meets the requirements of Section 109 (77 FR 20255, April 3, 2012). Based on these considerations the Administrator judged that the current limitations and uncertainties were of such nature and degree as to have prevented her from reaching a reasoned decision such that she was adequately confident as to what level and form (in terms of a selected percentile) of such a standard would provide any particular intended degree of protection of public welfare that the Administrator determined satisfied the requirements to set an appropriate standard under Section 109 of the CAA (77 FR 20255, April 3, 2012).

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<sup>45</sup> The Administrator recognized that while an AAI-based standard was innovative and unique, the structure of the proposed standard was well-grounded in the science underlying the relationships between ambient concentrations of oxides of nitrogen and sulfur and the aquatic acidification related to deposition of nitrogen and sulfur associated with such ambient concentrations (77 FR 20251, April 3, 2012).

<sup>46</sup> The Administrator recognized that for purposes of Section 109(b) and (d) of the CAA, such a standard must in her judgment be requisite to protect public welfare, such that it would be neither more nor less stringent than necessary for that purpose (77 FR 20251, April 3, 2012).

The Administrator additionally considered the option of setting new secondary standards identical to the current 1-hour NO<sub>2</sub> and SO<sub>2</sub> primary standards as an approach to achieve increased protection of the public welfare from deposition-related effects on ecosystems. She recognized, however, that the available information did not support a demonstrable linkage between 1-hour average concentrations of these pollutants in ambient air and the impact of longer-term deposition-related acidification associated with oxides of nitrogen and sulfur on aquatic ecosystems that are in part or whole sensitive to acidification. As a result, the Administrator concluded there was no basis for a reasoned judgment as to what levels of 1-hour NO<sub>2</sub> and SO<sub>2</sub> standards would be requisite to protect public welfare (77 FR 20259, April 3, 2012).

The Agency recognized several important uncertainties and data limitations both related to characterizing the relationships between N and S deposition and ecological effects generally and those specifically relating to the development of the AAI. While these uncertainties and limitations did not call into question the causality statements linking N and S deposition to adverse ecological effects, they did introduce significant uncertainty in applying the AAI on a national scale, particularly for areas of the country for which less data was available (77 FR 20259, April 3, 2012). These gaps in field measurement data limited our understanding of risk to areas of the country without robust datasets. These data limitations included gaps in soil weathering data as well as limited water quality data for determining sensitivity.

There were also limitations and uncertainties in air quality data both in the ability to evaluate modeled data as well as the ability to characterize components of ambient air and deposition important to the AAI. For example, uncertainties in modeled dry deposition estimates were increased due to the lack of observed dry deposition data for relevant chemical species. Inherent complexities in source characterization and ambient concentration patterns significantly increased the degree of uncertainty in NH<sub>x</sub> deposition (77 FR 20259, April 3, 2012). These limitations increased the uncertainties involved in translating atmospheric concentrations to deposition which was necessary for calculating the AAI.

Additionally, the 2011 PA noted that the information and assessments available at the time were not sufficient to support the development of a national standard specifically to address other acidification and eutrophication effects. It also concluded that a standard targeting specifically aquatic acidification would not likely address other deposition-related ecological effects, including effects related to terrestrial acidification and nutrient enrichment effects in sensitive terrestrial and aquatic ecosystems. Specific areas of uncertainty for these other categories of effects were identified in the REA and include:

- *Terrestrial acidification*: Quantitative modeling assumptions made for base cation weathering (Bcw) and forest soil ANC input parameters, which are poorly measured in non-glaciated soils and based largely on default values.
- *Aquatic eutrophication*: The significant role of multiple non-atmospheric nitrogen inputs in coastal areas, extrapolation of estuarine data to larger regional areas, and similar data limitations in freshwater systems.
- *Terrestrial eutrophication*: Uncertainties in deposition monitoring instrumentation and measurement protocols, as well as limited available of data in remote areas.
- *Mercury methylation*: Quantitative aspects of the relationship between sulfur deposition and mercury methylation, including in the roles of spatial and biogeochemical factors.

Overall, uncertainties in the previous review generally related to limited information on: (1) the extent of sensitivity of the ecoregion to the effect, including response to long-term exposure to elevated deposition levels; (2) the relationship between the observed ecological effect and effects on ecosystem services; and (3) the ability to characterize adverse effects across ecosystems and across multiple media. These are discussed in more detail in Chapter 4.

As part of the final rulemaking, the Administrator proposed that the EPA undertake a field pilot program to enhance the Agency's understanding of the degree of protectiveness that would be afforded by a new standard based on the AAI (77 FR 20259, April 3, 2012). For this field pilot program, the EPA proposed to establish monitors in three to five eco-regions that would be used to collect ambient measurements of NO<sub>y</sub>, SO<sub>x</sub>, and ammonia, as well as nitrate, sulfate, and ammonium in precipitation over a period of five years. While the program was not completely funded as anticipated, due in large part to budget sequestration in 2013, the EPA did purchase and deploy monitors in northern New York, Vermont, Colorado, Wyoming, and North Carolina. The field pilot program was intended to provide additional information that would be useful for an AAI-based standard. Although it is unclear whether the current review will focus on the AAI metric to the same degree as was done in the last review,<sup>47</sup> the monitors are providing data that are helpful in characterizing gaseous concentrations and deposition of oxides of nitrogen and sulfur and which will be used to inform this review.

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<sup>47</sup> There was an informational workshop that was held for the new review in March 2014 to solicit the input of experts regarding the state of the new science. In this workshop, participants discussed the fact that a substantial amount of new research had become available since the last review and participants expressed views that the scientific information available for this review was likely to support an expanded review that goes beyond the last review's focus on aquatic acidification to address in greater depth other effects, such as terrestrial eutrophication. Given that the pilot field program was intended to provide additional information that would be useful for an AAI-based standard, it is unclear whether the data from the pilot program will be as useful for the current review as previously anticipated.

### 2.2.2 2012 Review of Secondary NAAQS for PM

Ecosystem deposition-related ecological effects of PM considered in the 2012 PM review (which excluded effects of deposited oxides of nitrogen and sulfur)<sup>48</sup> included contribution to total metal loading resulting in alteration of soil biogeochemistry and microbiology, plant and animal growth and reproduction; and contribution to total organics loading resulting in bioaccumulation and biomagnification across trophic levels (2009 PM ISA, section 9.4). Based on the evidence available in that review, the ISA determined that the evidence was sufficient to conclude that “a causal relationship is likely to exist between deposition of PM and a variety of effects on individual organisms and ecosystems” (2009 PM ISA, p. 2-30, sections 2.5.3 and 9.4.7). As observed in the 2009 PM ISA, “[t]he deposition of PM onto vegetation and soil, depending on its chemical composition, can produce responses within an ecosystem” and [t]he ecosystem response to pollutant deposition is a direct function of the level of sensitivity of the ecosystem and its ability to ameliorate resulting change” (2009 PM ISA, p. 9-193). The ISA also noted the potential for PM pollutants deposited to the soil to “alter ecological processes of energy flow and nutrient cycling, inhibit nutrient uptake, change ecosystem structure, and affect ecosystem biodiversity,” recognizing that [c]hanges in the soil environment can be important in determining plant and ultimately ecosystem response to PM inputs (2009 PM ISA, p. 9-193). In considering limitations in the available evidence, the ISA also noted that it was generally difficult to characterize the nature and magnitude of effects and to quantify relationships between ambient concentrations of PM and ecosystem responses due to significant data gaps and uncertainties, as well as to the considerable variability that existed in the components of PM and their various ecological effects (2009 PM ISA, p. 9-193). Similarly, the PA recognized uncertainty associated with the multitude of factors that influence PM deposition (2011 PM PA, section 5.3.4). Concurring with the advice from the CASAC, the Administrator concluded it to be important to maintain an appropriate degree of control of both fine and coarse particles to address non-visibility welfare effects, including ecological effects (those addressed here, as well as those addressed in section 2.1 above), and in the absence of information that would support any different standards, the Administrator concluded that it was appropriate to retain the existing suite of secondary standards to protect against such effects.

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<sup>48</sup> Effects associated with deposited PM components of oxides of nitrogen and oxides of sulfur and their transformation products were addressed in the 2012 review of the secondary NAAQS for oxides of nitrogen and oxides of sulfur (78 FR 3202, January 15, 2013), while the 2009 PM ISA consideration of ecological effects emphasized the effects of deposition of PM constituents other than oxides of nitrogen and oxides of sulfur, primarily metals and carbonaceous compounds (2009 PM ISA, p. 2-27).

## 2.3 GENERAL APPROACH FOR THE CURRENT REVIEW

The approach for this review builds on the substantial body of information developed in the last review, taking into account the more recent scientific information and air quality data now available to inform our understanding of the key policy-relevant issues. The approach described below is most fundamentally based on using the EPA's assessment of the current scientific evidence and associated quantitative analyses to inform the Administrator's judgments regarding secondary standards that are requisite to protect the public welfare from any known or anticipated adverse effects. This approach will involve interpreting scientific and technical information in the context of a series of key policy-relevant questions drawing on both evidence- and exposure/risk-based considerations.

Figure 2-1 summarizes the general approach, including consideration of the policy-relevant questions, which will frame the current review. The ISA, REA, if warranted, and PA developed in this review will provide the basis for addressing the key policy-relevant questions (below) and will inform the Administrator's judgments as to the adequacy of the current secondary NO<sub>2</sub>, SO<sub>2</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> standards, as well as his/her decisions as to whether to retain or revise these standards.

This approach is consistent with the requirements of the NAAQS provisions of the CAA and with how the EPA and the courts have historically interpreted the CAA. As described in section 1.1 above, secondary NAAQS "specify a level of air quality the attainment and maintenance of which, in the judgment of the Administrator, [based on the current scientific information], is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air." Effects on welfare 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 effect on economic values and on personal comfort and well-being, whether caused by transformation, conversion, or combination with other air pollutants" (CAA, Section 302(h)). Secondary standards are not meant to protect against all known or anticipated effects related to the subject criteria pollutant(s), but rather those that are judged to be adverse to the public welfare, and a bright-line determination of adversity is not required in judging what is requisite (78 FR 8312, January 15, 2013; see also 73 FR 16496, March 27, 2008).

The CAA provides no specific definition of public welfare or of adversity to public welfare. Thus, the level of protection from known or anticipated adverse effects to public welfare that is requisite for the secondary standard is a public welfare policy judgment to be made by the Administrator. The general approach in this review recognizes that the Administrator's judgment

will be informed by conclusions drawn with regard to adversity of effects to public welfare in decisions on secondary standards in past reviews (e.g., 2015 review of the secondary standard for ozone, 80 FR 65291, October 26, 2015). In past NAAQS reviews, the EPA has recognized that an evaluation of adversity to public welfare might appropriately consider the likelihood, type, magnitude, and spatial scale of the effect as well as the potential for recovery and any uncertainties relating to these considerations. Additionally, the degree to which effects are considered adverse may depend on the organizational scale of the effect (e.g., species to ecosystem level) as well as the intended use for or service (and value) of the affected receptor, ecosystem and resources, and the significance of that to the public welfare.<sup>49</sup>

Because oxides of nitrogen, oxides of sulfur and PM are deposited from the ambient air into ecosystems where they have the potential to affect organisms, populations and ecosystems, considerations in this review will include potential impacts on the public welfare from alterations in structure and function of ecosystems. Considerations will also include potential impacts in areas with special federal protections, and lands set aside by states, tribes and public interest groups to provide similar benefits to the public welfare, consistent with past NAAQS decisions (e.g. 80 FR 65292, October, 26, 2015). Such areas include Class I areas<sup>50</sup> which are federally mandated to preserve certain air quality related values.

A consideration particular to this review relates to the temporal and spatial scales, and associated variability, of some ecological effects. For example, effects of oxides of nitrogen, oxides of sulfur and PM on aquatic and terrestrial ecosystems are diverse and occur over time as a result of atmospheric reactions, transport and deposition.<sup>51</sup> The evaluation of environmental responses to these pollutants, thus, will consider the variability of environmental characteristics of ecosystems across the nation, including those related to ecosystem susceptibility and to the relative importance of individual effects (such as acidification or nutrient enrichment).

In addition, the approach and policy-relevant questions described here recognize the likelihood of multiple exposure metrics being used to relate the broad and diverse set of

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<sup>49</sup> For example, analyses may assess ecosystem service impacts in terms of impacts on ecosystems that may be important to the public welfare. Ecosystem services have been defined as “the benefits that people obtain from ecosystems” (U.S. EPA, 2013, Preamble, p. 1xxii; UNEP, 2003). Conceptually, changes in ecosystem services may be used to aid in considering the significance of particular effects on the public welfare.

<sup>50</sup> Areas designated as Class I include all international parks, national wilderness areas which exceed 5,000 acres in size, national memorial parks which exceed 5,000 acres in size, and national parks which exceed six thousand acres in size, provided the park or wilderness area was in existence on August 7, 1977. Other areas may also be Class I if designated as Class I consistent with the Act.

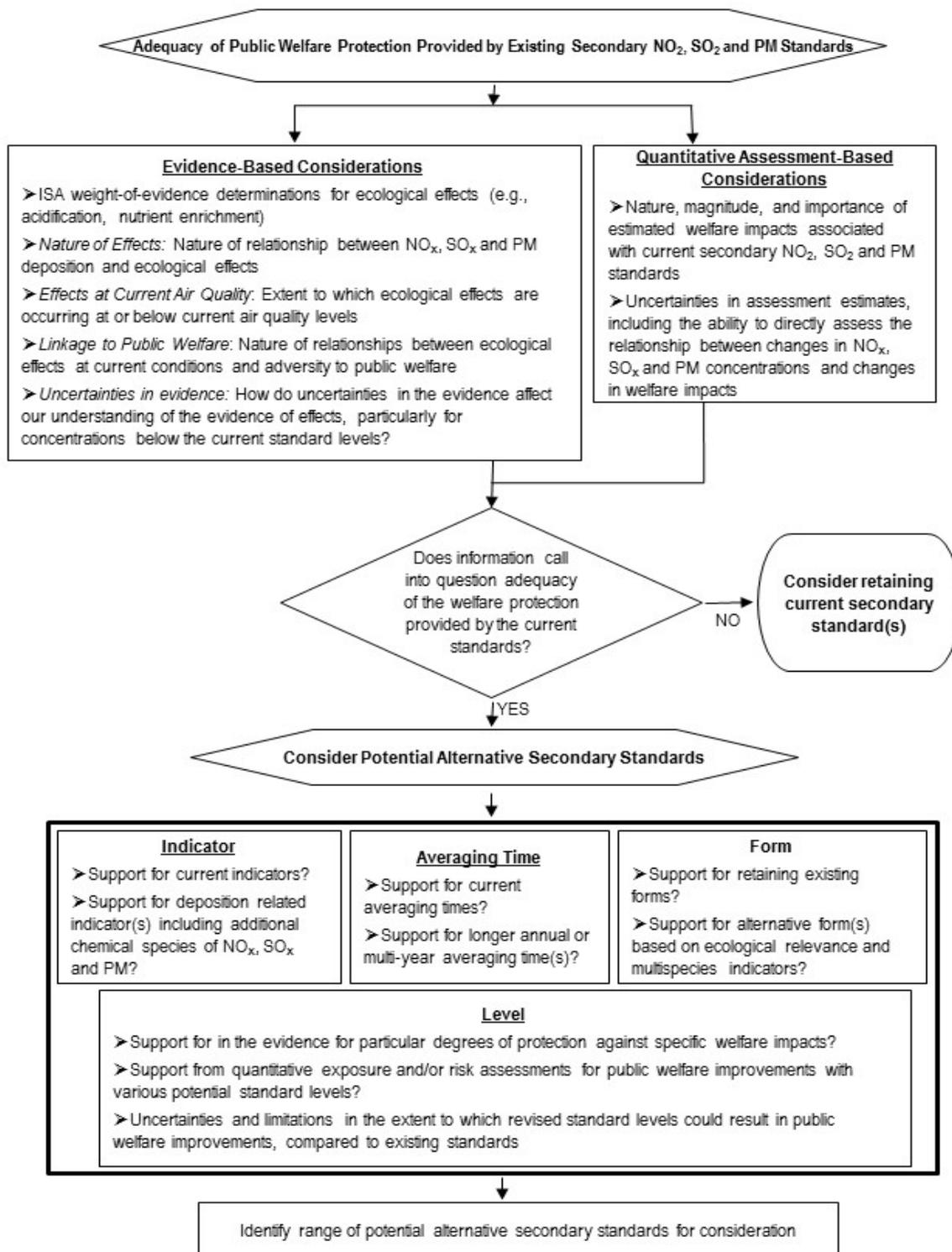
<sup>51</sup> Similar fate, transport, and depositional processes apply to both acidification and fertilization effects, which include both eutrophication in aquatic systems and nutrient enrichment in terrestrial systems.

endpoints pertinent in this review and their associated ecosystem impacts to ambient air concentrations of oxides of nitrogen, oxides of sulfur and PM. Use of such analyses is consistent with such use in other NAAQS reviews where EPA has evaluated the protection afforded by standards using a variety of exposure metrics that often differ in a variety of ways from the ambient air concentration metrics of the standards, themselves.<sup>52</sup> In considering such analyses, we recognize the use of exposure metrics to assess the likely occurrence and/or frequency and extent of effects under different air quality conditions and that such use informs judgements by the Administrator on air quality standards that control air quality to the extent requisite to protect against public welfare effects judged to be adverse and that are neither more nor less stringent than necessary for this purpose.

We note that the final decision on the adequacy of the current standards and, as appropriate, revision of these standards, is largely a public welfare policy judgment to be made by the Administrator. The Administrator's final decision will draw upon scientific information and analyses about ecosystem effects, exposure and risks, as well as judgments about how to consider the range and magnitude of uncertainties that are inherent in the scientific evidence and analyses. In addressing the key questions in this review, we will, as in the previous review and other NAAQS reviews, consider the implications of placing more or less weight or emphasis on different aspects of the scientific evidence and exposure and/or risk-based information to inform the Administrator's public welfare policy judgments. Evidence-based considerations include those related to the ecosystem effects evidence assessed and characterized in the ISA. Exposure and/or risk-based considerations draw from the results of the quantitative analyses.

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<sup>52</sup> For example, in the 2012 PM review, the EPA assessed the extent to which the existing 24-hour secondary standard for PM<sub>2.5</sub>, expressed as a 24-hour concentration (of PM<sub>2.5</sub> mass per cubic meter of air) not to be exceeded more than once per year on average over three years, could provide the desired protection from effects on visibility in terms of the 90th percentile, 24-hour average PM<sub>2.5</sub> light extinction, averaged over three years, based on speciated PM<sub>2.5</sub> mass concentrations and relative humidity data (79 FR 3086, January 15, 2013). In the screening-level risk analyses in the 2008 review of the secondary standard for lead, concentrations in soil, surface water and sediment were evaluated to assess the potential for welfare effects related to lead deposition from air, while the standard is expressed in terms of the lead concentration in particles suspended in air (73 FR 67009, November 12, 2008). For other examples, see the preamble for the 2015 ozone review decision (80 FR 65399, October 26, 2015). Further, depending on the evidence base, some NAAQS reviews have also considered whether a standard with an averaging time of one duration may provide protection against effects elicited by exposures of appreciably shorter or longer durations (80 FR 65399, October 26, 2015).



**Figure 2-1. Overview of general approach for review of secondary oxides of nitrogen, oxides of sulfur, and PM standards.**

The initial overarching question in this review is as follows:

- **Does the currently available scientific evidence and exposure-/risk-based information support or call into question the adequacy of the public welfare protection for ecological effects afforded by the current secondary NO<sub>2</sub>, SO<sub>2</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> standards?**

In the context of this overarching question, we will consider a series of more specific policy-relevant questions related to the available scientific evidence and information from quantitative assessments. Such questions relate to identification of the ecological effects most pertinent to current ambient concentrations of these criteria pollutants and the associated uncertainties, the impacts of such effects on ecosystems, and identification of at-risk ecosystems and receptors. We will also consider questions regarding the extent to which the current information provides approaches and metrics for quantitatively assessing the key effects and protection provided by the current standards. Such questions include the following.

- To what extent has new scientific evidence improved our understanding of the nature and magnitude of ecological and ecosystem effects<sup>53</sup> of oxides of nitrogen, oxides of sulfur and PM, including our understanding of the variability associated with such effects for various ecosystem types, climatic conditions, and interactions with other environmental factors and pollutants?
- What new information is available that changes or enhances our understanding of aquatic acidification effects and/or quantification of these effects? What new information is available in this review that changes or enhances our understanding of other ecological effects on aquatic and terrestrial ecosystems, particularly those related to terrestrial nutrient enrichment and quantification of such effects?
- To what extent are there new studies available on the relationship between levels of atmospheric deposition of nitrogen, sulfur and PM and associated effects of concern, including studies that address how these effects vary by ecosystem type and are affected by other environmental factors? Is there new information available to inform our understanding of how reductions in atmospheric levels of oxides of nitrogen, oxides of sulfur and PM, and associated deposition, relates to changes in aquatic and terrestrial ecosystems and ecological functions?
- To what extent have important uncertainties identified in the last review been reduced and/or have new uncertainties emerged?
- To what extent have uncertainties in data and modeling been reduced from the previous reviews? What types of ecological effects can be quantitatively related to oxides of nitrogen, oxides of sulfur, and PM in ambient air and associated deposition?

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<sup>53</sup> These ecological effects include eutrophication (nutrient enrichment), acidification, and sulfur enrichment associated with the deposition of oxides of nitrogen, oxides of sulfur, and PM, as well as the direct and indirect effects of PM on vegetation, soils, and biota.

- By what metrics are oxides of nitrogen, oxides of sulfur, and PM in ambient air best quantified for purposes of characterizing relationships of exposure with ecological impacts, including eutrophication (nutrient enrichment), acidification, sulfur enrichment and changes in ecological function, and associated effects on the public welfare? What are the uncertainties in relationships using such metrics?
- What information is available to inform our understanding of the relationship between ambient concentrations of oxides of nitrogen, oxides of sulfur and PM and such exposure metrics?
- Under air quality conditions meeting the current standards, what is the estimated magnitude of the exposures, in terms of appropriate metrics, in ecosystems across the U.S. and what does this indicate regarding the potential for associated ecological effects of public welfare importance? Might the estimates of such effects be of sufficient magnitude, severity, extent and/or frequency such that they might reasonably be judged to be adverse to public welfare?

If the available evidence and information from quantitative analyses indicates that revision of the current standards might be appropriate, we will also evaluate how the standards might be revised by considering the following overarching question:

- **What alternative standards, if any, are supported by the currently available scientific evidence and quantitative information and are appropriate for consideration?**

More specifically, we will evaluate how the scientific information and assessments may inform decisions regarding the basic elements of the standards (indicator, averaging time, form, level). We recognize that these elements are considered collectively in evaluating the public welfare protection afforded by the current or any potential alternative standards. In this regard, specific policy-relevant questions to be addressed include the following:

- To what extent does the available information provide support for a revised national standard targeting protection from ecological effects of oxides of nitrogen, oxides of sulfur, and PM that are adverse to the public welfare?
- To what extent does the current information indicate that revision to one or more element(s) of the existing standards might be expected to provide increased public welfare protection from ecological effects of public welfare importance?
  - To what extent does the current information support consideration of a standard with a different *indicator*, such as one reflecting multiple components of PM and oxides of nitrogen and sulfur, than the existing standards?
  - Based on quantitative assessments using the exposure metrics best associated with effects of public welfare importance, to what extent might a revised standard with such an indicator be expected to provide increased protection from ecological effects of these three criteria pollutants?

- To what extent does the current information indicate that such a standard might be expected to more effectively or more efficiently control air quality and exposures, in terms of appropriate metric(s), than the existing standards (and associated indicators)?
  - Similarly, to what extent does the welfare effects evidence and/or quantitative analyses provide support for considering any different *averaging times, forms, and/or levels*? What are the associated uncertainties?
- To what extent does the currently available scientific information, including analyses based on the exposure metrics best associated with ecological effects of public welfare importance, support evaluation of the protection that might be afforded by potential alternative standards from adverse effects to the public welfare? What are the important uncertainties and limitations in the available evidence and assessments related to such analyses? Do such analyses indicate potential alternative standards that are appropriate to consider?
- What does the current information indicate with regard to the potential for other less well understood ecological effects under conditions expected to be associated with the current and potential alternative standards?

## **3 DEVELOPMENT OF THE INTEGRATED SCIENCE ASSESSMENT**

The ISA comprises the science assessment phase of the Secondary National Ambient Air Quality Standards (NAAQS) for Ecological Effects of Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter review. As described in Chapter 1, this assessment focuses on updating the air quality criteria associated with ecological evidence to inform the review of the oxides of nitrogen, oxides of sulfur, and particulate matter (PM) secondary NAAQS.

### **3.1 SCOPE**

The ISA will critically evaluate and integrate the scientific information on the ecological effects associated with oxides of nitrogen, oxides of sulfur and PM, and their deposition, individually and in combination. Discipline areas included will be atmospheric science, biogeochemistry, plant and animal physiology, ecotoxicology, population ecology, community ecology and ecosystem services. The purpose is to synthesize the current state of knowledge on the most relevant issues pertinent to the review of the secondary NAAQS, to identify changes in the scientific evidence base since the previous review, and to describe remaining or newly identified uncertainties. The ISA discussions will be designed to focus on the key policy-relevant questions described in Section 3.4.

The ISA will evaluate the literature published since the 2008 Oxides of Nitrogen and Sulfur—Ecological Criteria ISA (hereafter referred to as the 2008 Oxides of Nitrogen and Oxides of Sulfur ISA) and incorporate this newer evidence with evidence considered in the last review. Conclusions from the 2008 Oxides of Nitrogen and Oxides of Sulfur ISA will be briefly summarized within ISA chapters, and the results of recent studies will be synthesized with previous findings.

### **3.2 ORGANIZATION**

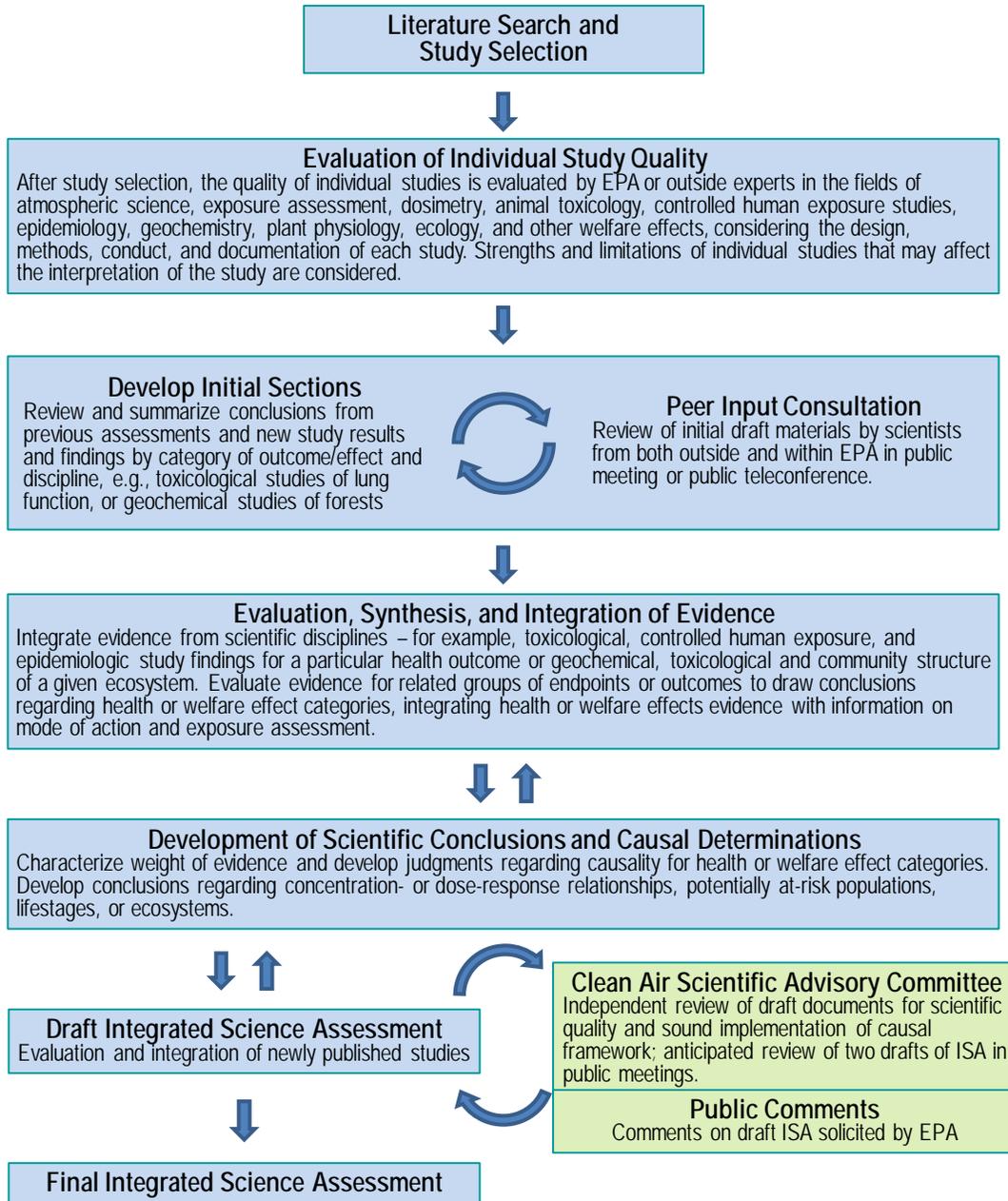
The organization of the ISA will begin with a discussion of the legislative history of prior NAAQS review documents associated with oxides of nitrogen, oxides of sulfur, and particulate matter, as well as procedures for the assessment of scientific information. An integrated synthesis chapter will summarize the key information for each topic area, the causal determinations for relationships between the criteria pollutants and ecological effects, information describing the extent to which ecological effects can be attributable specifically to the criteria pollutants, and other uncertainties related to the interpretation of scientific information. The integrated synthesis chapter also will present a discussion of policy-relevant

issues such as the deposition-response relationships, and the ecological significance of effects. Subsequent chapters are organized by subject area and contain the detailed evaluation of results of recent studies integrated with previous findings (see section 3.4 for specific issues to be addressed). Sections for each major ecological effect category conclude with a causal determination about the relationship with the criteria pollutants, or an associated chemical indicator. The ISA will conclude with a chapter that examines ecological effects data to draw conclusions about potential at-risk ecosystems and regions. The ISA may be supplemented with additional materials if required to support information contained within the ISA. These supplementary materials may include more detailed and comprehensive coverage of relevant publications and may accompany the ISA or be available in electronic form as output from the Health and Environmental Research Online (HERO) database developed by the EPA (<http://hero.epa.gov/>). Supplementary information available in the HERO database will be presented as electronic links in the ISA.

### **3.3 ASSESSMENT APPROACH**

The National Center for Environmental Assessment (NCEA) is responsible for preparing the ISA. In each NAAQS review, development of the ISA begins with a “Call for Information” published in the Federal Register. This notice announces EPA’s initiation of activities in the preparation of the ISA for the specific NAAQS review and invites the public to assist through the submission of research studies in the identified subject areas. This and subsequent key components of the process currently followed for the development of an ISA (i.e., the development process) are presented in Figure 3-1 and are described in greater detail in the Preamble to the ISA (U.S. EPA, 2015).

## Integrated Science Assessment Development Process



**Figure 3-1. General process for development of Integrated Science Assessments (ISAs).**

(Modified from the Preamble to the ISA for Oxides of Nitrogen-Human Health Criteria, U.S. EPA, 2015)

Important aspects of the development of the ISA are described in the sections below, including the approach for searching the literature, identifying relevant publications, evaluating individual study quality, synthesizing and integrating the evidence, and developing scientific conclusions and causality determinations. These responsibilities are undertaken by subject-matter experts, who author ISA chapters. These experts include EPA staff with extensive knowledge in their respective fields and extramural scientists solicited by EPA for their expertise in specific fields. This section of the IRP also presents specific policy-relevant questions developed from input received at the “Workshop to Discuss Policy-Relevant Science to Inform EPA’s Review of the Secondary NAAQS for Oxides of Nitrogen and Sulfur” that was held March 4-6, 2014. These questions are intended to guide the development of the ISA. The process for scientific and public review of drafts of the ISA is described in Section 3.4.

### **3.3.1 Literature Search and Selection of Relevant Studies**

The NCEA uses a structured approach to identify relevant studies for consideration and inclusion in the ISA. As previously mentioned a Federal Register Notice is published to announce the initiation of a review and to request information, including relevant literature, from the public. The EPA maintains an ongoing, multi-tiered literature search process that includes extensive manual and computer-aided citation mining of databases on specific topics in a variety of disciplines. The search strategies are designed a priori and iteratively modified to optimize identification of pertinent publications. In addition, papers are identified for inclusion in several other ways: specialized searches on specific topics; relational searches that identify recent publications that have cited references from previous assessments; identification of relevant literature by external scientific experts; recommendations from the public and the CASAC during the call for information and external review process; and review of citations in previous assessments. The studies identified will include research published or accepted for publication from January 2008, which slightly precedes the publication end date for studies reviewed in the 2008 ISA for Oxides of Nitrogen and Sulfur-Ecological Criteria.

References identified through this multipronged search strategy are reviewed for relevance. Some publications are excluded based on screening of the title. Publications considered for inclusion in the ISA after reading the title are listed in the HERO database (<http://hero.epa.gov>). Studies and reports that have undergone scientific peer review and have been published or accepted for publication are considered for inclusion in the ISA.

From the group of considered references, references are selected for inclusion in the ISA based on review of the abstract and full text. The references cited in the ISA include a hyperlink to the HERO database. The selection process is based on the extent to which the study is

potentially informative, pertinent, and policy-relevant. These studies include those that provide a basis for or describe the relationship between the criteria pollutant and effects, in particular, those studies that offer innovation in method or design and studies that reduce uncertainty on critical issues. Uncertainty can be addressed, for example, by analyses of potential confounding or effect modification by co-pollutants or other factors, analyses of concentration-response or dose-response relationships, or analyses related to time between deposition and response. Evidence from previous studies (prior to January 2008) will be included to integrate with results from recent studies, and in some cases, characterize the key policy-relevant information in a particular subject area. Analyses conducted by the EPA using publicly available data, for example, air quality and emissions data, are also considered for inclusion in the ISA. The combination of approaches described above is intended to produce the comprehensive collection of pertinent studies needed to address the key scientific issues that form the basis of the ISA.

### **3.3.2 Evaluation of Individual Study Relevance and Quality**

After selecting studies for inclusion, individual study quality is evaluated by considering the design, methods, conduct, and documentation of each study, but not the study results. This uniform approach aims to consider the strengths, limitations, and possible roles of chance, confounding, and other biases that may affect the interpretation of the results from individual studies. In assessing the scientific quality of studies, the following parameters are considered:

- How clearly were the study design, study groups, methods, data, and results presented to allow for study evaluation?
- To what extent are the air quality data and deposition metrics of adequate quality to serve as credible exposure indicators?
- Were the study populations or model organisms adequately selected, and are they sufficiently well-defined to allow for meaningful comparisons between study or exposure groups?
- Are the statistical analyses appropriate, properly performed, and properly interpreted?
- Are likely covariates (i.e., potential confounding factors, modifying factors) adequately controlled for or taken into account in the study design or statistical analyses?
- Are the ecological endpoint measurements meaningful, valid, and reliable?

Additional considerations specific to particular scientific disciplines are discussed below.

#### Atmospheric Science

Atmospheric science studies focus on sources, chemical transformations of emissions, transport of emitted pollutants and their reaction products, techniques for measuring concentrations and deposition of nitrogen, which includes oxidized and reduced forms of N, and

sulfur oxides using quality-assured field, experimental, and/or modeling techniques. The most informative measurement-based studies will include detailed descriptive statistics and include a clear and comprehensive description of measurement techniques and quality control procedures used. The most informative modeling-based studies will incorporate appropriate chemistry, transport, dispersion, and/or deposition modeling techniques with a clear and comprehensive description of model science, evaluation procedures, and metrics. Additional information on PM, which does not contribute to N and S deposition, will be summarized from the 2009 PM ISA.

### Ecological Effects Assessment

For ecological effects assessment, both laboratory and field studies (including field experiments and observational studies) can provide useful data for causality determination. Because conditions can be controlled in laboratory studies, responses may be less variable and smaller differences may be easier to detect. However, the control conditions may limit the range of responses (e.g., animals may not be able to seek alternative food sources) or incompletely reflect pollutant bioavailability, so they may not reflect responses that would occur in the natural environment. In addition, larger-scale processes are difficult to reproduce in the laboratory. Field observational studies measure biological changes in uncontrolled situations, and describe an association between a disturbance and an ecological effect. Field data can provide important information for assessments of multiple stressors or where site-specific factors significantly influence exposure. They are also often useful for analyses of larger geographic scales and higher levels of biological organization. However, because conditions are not controlled, variability is expected to be higher and differences harder to detect. Field surveys are most useful for linking stressors with effects when stressor and effect levels are measured concurrently. The presence of confounding factors can make it difficult to attribute observed effects to specific stressors.

Some studies are considered “intermediate” and are categorized as being between laboratory and field studies. Some use environmental media collected from the field to examine the responses in the laboratory. Others are experiments that are performed in the natural environment while controlling for some, but not all, of the environmental conditions (i.e., mesocosm studies). This type of study in manipulated natural environments can be considered a hybrid between a field experiment and laboratory study since some aspects are performed under controlled conditions but others are not. They make it possible to observe community and/or ecosystem dynamics, and provide strong evidence for causality when combined with findings of studies that have been made under more controlled conditions.

### **3.3.3 Integration of Evidence and Determination of Causality**

The EPA uses a structured and transparent process to evaluate scientific information and determine the causality of relationships between air pollution and ecological effects (U.S. EPA, 2015). Evidence from across scientific disciplines for related ecological effects is evaluated, synthesized, and integrated to develop conclusions and causality determinations. This includes consideration of strengths and weaknesses in the overall collection of studies across disciplines. Confidence in the body of evidence is based on evaluation of study design and quality. The relative importance of different types of evidence to the conclusions varies by pollutant or assessment, as does the availability of different types of evidence for causality determination. Scientists will also evaluate uncertainty in the scientific evidence.

The ISA will evaluate the evidence for causal relationships between observed ecological outcomes and oxides of nitrogen, oxides of sulfur and PM exposures using a five level hierarchy that classifies the weight of evidence for causation. Determination of causality involves the evaluation and integration of evidence across disciplines for major outcome categories (e.g., aquatic acidification) or groups of related endpoints. Key considerations in drawing conclusions about causality include consistency of findings for an endpoint across studies, biological plausibility, and coherence of the evidence across disciplines and across related endpoints. In discussing the causal determination, the EPA characterizes the evidence on which the judgment is based, including strength of evidence for individual endpoints within the outcome category or group of related endpoints. The EPA evaluates evidence relevant to understand the quantitative relationships between pollutant exposures and ecological effects. This includes evaluating the concentration-response or deposition-response relationships and, to the extent possible, drawing conclusions on the levels at which effects are observed.

### **3.3.4 Quality Management**

The NCEA-RTP participates in the Agency-wide Quality Management System, which requires the development of a Quality Management Plan (QMP). Information on Quality Assurance may be found at [www.epa.gov/QUALITY/qmps.html](http://www.epa.gov/QUALITY/qmps.html).

Implementation of the ORD-wide and NCEA QMP ensures that all data generated or used by NCEA scientists “have a degree of confidence in the quality of the data; and, are of the type and quality appropriate for their intended use” and that all information disseminated by NCEA adheres to a high standard for quality including objectivity, utility, and integrity. Quality assurance (QA) measures detailed in the QMP are being employed for the current oxides of nitrogen, oxides of sulfur, and PM review, including the development of the ISA. The NCEA QA staff is responsible for the review and approval of quality-related documentation. NCEA

scientists are responsible for the evaluation (and documentation) of all inputs to the ISA, including primary (new) analysis and secondary (existing) data and analysis, to ensure their quality is appropriate for their intended purpose. NCEA adheres to the use of Data Quality Objectives, which clarify project objectives, define the appropriate type of data used in the project, and specify tolerable levels of confidence in the data and tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to identify the most appropriate inputs to the science assessment. The approaches utilized to search the literature and criteria for study selection and evaluation were detailed in the two preceding subsections. Generally, NCEA scientists rely on scientific information found in peer-reviewed journal articles, books, and government reports. Where information is integrated, re-analyzed, modeled, or reduced from multiple sources to create new figures, tables, or summation, the data generated are considered to be new and are documented and subjected to rigorous quality assurance and quality control measures to ensure their accuracy, validity, and reproducibility.

### **3.4 SPECIFIC ISSUES TO BE ADDRESSED IN THE ISA**

Policy-relevant questions that frame the entire review of the secondary oxides of nitrogen, oxides of sulfur and PM NAAQS also guide the development of the ISA. These policy-relevant questions are related to two overarching issues. The first issue is documenting new effects and determining whether new evidence reinforces or calls into question the evidence presented and evaluated in the last NAAQS review with respect to factors such as the concentrations of oxides of nitrogen, oxides of sulfur, and PM exposure associated with ecological effects and plausibility of ecological effects caused by oxides of nitrogen, oxides of sulfur and PM exposure. The second issue is whether uncertainties from the last review have been reduced and/or whether new uncertainties have emerged. Specific questions that will be addressed in the ISA are listed subsequently by topic area. In the ISA, these topic areas will be discussed in separate chapters or sections. The beginning of the ISA will include an integrative synthesis chapter that summarizes the key information for each topic area and the causal determinations. The integrative synthesis chapter also presents a discussion of policy-relevant issues such as the appropriate exposure metrics; ecologically relevant exposure times; concentration/deposition-response relationships including thresholds for effects and their ecological significance; and ecosystem services.

## Atmospheric Sciences

The ISA will present and evaluate data related to concentrations of oxides of nitrogen, oxides of sulfur and PM in ambient air; including sources and chemical reactions that determine the formation, degradation, and deposition of nitrogen and sulfur. Components of PM that do not contribute to N and S deposition were reviewed in the 2009 PM ISA and that information will be cited, however new information will not be reviewed in this ISA. The 2008 Oxides of Nitrogen and Oxides of Sulfur ISA concluded that ambient annual NO<sub>2</sub> and SO<sub>2</sub> concentrations have decreased significantly as reported in the routine national networks, owing to controls enacted since the 1970s, and that deposition is spatially heterogeneous across the U.S. with mean S deposition in the U.S. greatest east of the Mississippi River and the highest mean N deposition totals in the Ohio River valley. The current review will update and expand on these trends by reporting results from a number of recent publications on spatial and temporal concentration patterns based on national monitoring network data. It will also describe new advances in monitoring and modeling methods that reduce uncertainty in concentration estimates and improve understanding of NO<sub>y</sub> and SO<sub>x</sub> speciation. In addition, it will summarize advances in our understanding of transport, transformation and deposition processes. Specific policy-relevant questions related to air quality and atmospheric chemistry that will be addressed include the following:

- What new information is available on spatial and temporal trends in ambient NO<sub>y</sub>, SO<sub>x</sub> and PM concentration, particularly in vulnerable areas?
- What new information is available on NO<sub>y</sub>, SO<sub>x</sub> and PM sources, transport, transformation, and deposition processes that impact exposure?
- What new information is available on speciation of NO<sub>y</sub>, SO<sub>x</sub> and PM components and their impact on deposition?
- What new measurement and modeling methods have been developed that improve our understanding and predictive capabilities?

## Gas-phase Phytotoxic Effects

In the 2008 Oxides of Nitrogen and Oxides of Sulfur ISA, the evidence was sufficient to infer a causal relationship between exposure to SO<sub>2</sub>, NO, NO<sub>2</sub>, PAN, and HNO<sub>3</sub> and injury to vegetation. It was found that acute and chronic exposures to SO<sub>2</sub> have phytotoxic effects on vegetation which include foliar injury, decreased photosynthesis, and decreased growth. Acute exposures to NO<sub>2</sub>, NO, PAN, and HNO<sub>3</sub> was found to cause plant foliar injury and decreased growth. However, the majority of studies had been performed at concentrations of these gas-phase species above current ambient conditions observed in the U.S. Consequently, there was

little evidence that current concentrations of gas-phase S or N oxides are high enough to cause phytotoxic effects. One exception was that some studies indicate that current HNO<sub>3</sub> concentrations may be contributing to the decline in lichen species in the Los Angeles basin.

- What new information is available to characterize the effects of SO<sub>2</sub>, NO, NO<sub>2</sub>, PAN, and HNO<sub>3</sub> on vegetation?
- What are the current concentration of these NO<sub>y</sub> and SO<sub>x</sub> gases and are they high enough to cause effects on vegetation?
- What new information is available on lichen decline related to exposure to NO<sub>y</sub>, NH<sub>x</sub> and SO<sub>x</sub> gases?

### Terrestrial Nitrogen Enrichment

In the 2008 Oxides of Nitrogen and Oxides of Sulfur ISA the evidence was sufficient to infer a causal relationship between N deposition and the alteration of biogeochemical cycling of N and C in terrestrial ecosystems. It was found that N deposition alters the biogenic sources and sinks of two greenhouse gases (GHGs), CH<sub>4</sub> and N<sub>2</sub>O, in terrestrial ecosystems, resulting in increased emissions to the atmosphere. Also it was found that N deposition alters the biogeochemical cycling of C. A limited number of studies suggested that N deposition may increase C-sequestration in some forests, but has no apparent effect on C-sequestration in non-forest ecosystems.

A causal relationship was also inferred between N deposition and the alteration of species richness, species composition and biodiversity in terrestrial ecosystems. It was found that, in terrestrial ecosystems, N deposition can accelerate plant growth and change C allocation patterns (e.g., shoot:root ratio), which can increase susceptibility to severe fires, drought, and wind damage. The alteration of primary productivity can also alter competitive interactions among plant species. The increase in growth is greater for some species than others, leading to possible shifts in population dynamics, species composition, community structure, and in few instances, ecosystem type. There were numerous sensitive terrestrial biota and ecosystems identified that were affected by N deposition including acidophytic lichens, grasslands in Minnesota and pine ecosystems in the Rocky Mountains.

In the current review, specific policy-relevant questions related to N enrichment of terrestrial ecosystems will be addressed:

- What new information is available to characterize nitrogen critical loads for U.S. ecosystems?
- What new evidence and models exists to characterize the effects of nitrogen addition on biodiversity and invasive species? What new evidence exists to improve characterization the link between nitrogen addition changes in biodiversity to alteration of fire regimes,

faunal communities, etc.? What new information exists to characterize adverse effects in Class I areas?

- What new information is available to characterize the effects of N addition on ecosystem carbon cycling, carbon budgets and other greenhouse gas fluxes?
- What new information exists to characterize terrestrial N deposition links to ecosystem services?
- What new information is available to characterize the causal relationship between N deposition and the effects described above?
- How have terrestrial ecosystems have responded to increases or decreases in atmospheric nitrogen deposition?

### Terrestrial Acidification

In the 2008 Oxides of Nitrogen and Oxides of Sulfur ISA, the strongest evidence for a causal relationship came from studies of terrestrial systems exposed to elevated levels of acidifying deposition that showed reduced plant health, reduced plant vigor, and loss of terrestrial biodiversity. In multiple studies, consistent and coherent evidence showed that acidifying deposition can affect terrestrial ecosystems by causing direct effects on plant foliage and indirect effects associated with changes in soil chemistry. Biological effects of acidification on terrestrial ecosystems were generally attributable to aluminum toxicity, decreased ability of plant roots to take up nutrient cations and elevated leaching of  $\text{Ca}^{2+}$  from conifer needles. There are several indicators of stress to terrestrial vegetation, including percent dieback of canopy trees, dead tree basal area (as a percent), crown vigor index, and fine twig dieback. Forests of the Adirondack Mountains of New York (ADR), Green Mountains of Vermont, White Mountains of New Hampshire, the Allegheny Plateau of Pennsylvania, and high-elevation forest ecosystems in the southern Appalachians are the regions which are most sensitive to terrestrial acidification effects from acidifying deposition. There are widespread measurements of ongoing depletion of exchangeable base cations in forest soils in the northeastern U.S. despite recent decreases in acidifying deposition.

In the current review specific policy-relevant questions related to acidification in terrestrial ecosystems that will be addressed include the following:

- What new information is available on plant species or other biotic endpoints vulnerable to terrestrial acidification? What new information is available to characterize dose response relationships between deposition and these endpoints?
- What new information or models are available to characterize terrestrial acidification? Specifically, what new information is available to characterize critical loads?

- What new information is available to scale up site-specific data to address regional sensitivity to terrestrial acidification?
- What new evidence exists to characterize ecosystem services related to terrestrial acidification?
- What new information is available to characterize recovery where emissions have decreased?

### Aquatic Eutrophication

In the 2008 Oxides of Nitrogen and Oxides of Sulfur ISA the evidence was sufficient to infer a causal relationship between N deposition and biogeochemical cycling of N and C in freshwater aquatic and coastal marine systems. A causal relationship was also inferred between N deposition at current levels and species richness, species composition, and biodiversity in freshwater aquatic and coastal marine systems. N deposition was found to alter species assemblages and cause eutrophication of aquatic systems to the extent that N is the growth-limiting nutrient. Species assemblages may also be changed when N is added to the freshwater ecosystem. In estuarine systems, N from atmospheric and non-atmospheric sources contributes to increased phytoplankton and algal productivity leading to eutrophication. Estuary eutrophication is an ecological problem indicated by water quality deterioration, resulting in numerous adverse effects including hypoxic zones, species mortality and harmful algal blooms. The contribution of atmospheric deposition to total N loads varies in these systems.

In the current review specific policy-relevant questions related to eutrophication in aquatic systems that will be addressed include the following:

- Are there new endpoints available for assessing effects of eutrophication, especially on ecological populations (i.e., size and structure) or biodiversity (e.g., species richness, abundance, and composition) in freshwater and coastal systems? What new information is available on the changes in ecosystem services resulting from N addition to aquatic ecosystems?
- What new empirical data or modeling results are available that would enhance our understanding of the biogeochemistry of eutrophication in freshwater and/or coastal systems?
- What resources or evidence are available from other monitoring agencies which may aid in the assessment of eutrophication in aquatic systems? What new information exists to characterize adverse effects of eutrophication in protected areas (e.g., Class I areas, National Parks, Wilderness Areas)?
- What new information is available to characterize the causal relationship between N deposition and the effects described above?

### Aquatic Acidification

In the 2008 Oxides of Nitrogen and Oxides of Sulfur ISA there was sufficient evidence to infer a causal relationship between the exposure to oxides of nitrogen and oxides of sulfur, aquatic acidification and the loss of acid-sensitive species. In general, more species are lost with greater acidification. These effects are linked to changes in surface water chemistry, including concentrations of  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ , inorganic Al and  $\text{Ca}^{2+}$ , surface water pH, sum of base cations, ANC and base cation surplus. Decreases in ANC and pH and increases in inorganic Al concentration contribute to declines in zooplankton, macroinvertebrates and fish species richness. These effects on species richness may also affect ecosystem services, such as biodiversity and cultural services such as fishing and tourism.

In the current review specific policy-relevant questions related to acidifying deposition to aquatic systems that will be addressed include the following:

- What new information is available on biotic endpoints that may be vulnerable to aquatic acidification?
- What new information is available to characterize the relationship between ANC and biotic endpoints?
- What new information is available on the changes in ecosystem services resulting from N addition to aquatic ecosystems?
- What new evidence exists to characterize the relationship between ANC and pH? How do we reliably relate ANC in the field to pH thresholds of biotic toxicity developed in the lab?
- What new information is available to characterize the best models of aquatic acidification? What are the data requirements? Are those models appropriate for a regional scale?
- What new data exists to better characterize the current condition of water bodies and critical loads nationwide?
- What new information is available to characterize recovery where emissions have decreased?
- What new evidence exists to characterize ecosystem services related to aquatic acidification?

### Wetland Nitrogen Enrichment

In the 2008 Oxides of Nitrogen and Oxides of Sulfur ISA the evidence was sufficient to infer a causal relationship between N deposition and the alteration of biogeochemical N and C cycling in freshwater and coastal wetland systems. There was strong evidence on N deposition increasing  $\text{N}_2\text{O}$  emissions and  $\text{CH}_4$  emissions. Additional responses to N deposition in wetlands

were  $\text{NO}_3^-$  leaching, increased N mineralization, and higher denitrification rates, although the extent of these responses depended on season, climate, hydrology, vegetation type, and geography. Impacts of N deposition upon C cycling included increased plant productivity coupled with increased decomposition rates in bogs, and increased plant productivity in intertidal wetlands.

The evidence was also sufficient to infer a causal relationship between N deposition and the alteration of species richness, composition, and biodiversity in wetland ecosystems. The ISA identified rare North American plant species adapted to the low-N environment historically common in freshwater wetlands and thus vulnerable to N deposition, including three federally endangered species in the genus *Isoetes*, the endangered insectivorous green pitcher *Sarracenia oreophila*, the state-listed endangered insectivore *Drosera rotundifolia*, and 15 state-listed endangered *Sphagnum* species.

In the current review, specific policy-relevant questions related to N enrichment of wetland ecosystems will be addressed:

- What new evidence exists to characterize relative ambient air nitrogen loading contributions to wetland ecosystems that also receive N in surface water from other anthropogenic sources?
- What new empirical data or modeling results are available that would enhance our understanding of the biogeochemistry of nitrogen enrichment in wetlands?
- What are appropriate ecological endpoints in wetlands affected by nitrogen deposition?
- What new information is available on the changes in ecosystem services resulting from N addition to wetland ecosystems?
- Should restored or built wetlands be included and is evidence of effects of N deposition on these systems available?
- What new evidence exists to quantify the effect of N deposition upon rare wetland species?
- What new information is available to characterize the effects of N addition on wetland carbon cycling, carbon budgets and other greenhouse gas fluxes?
- What new evidence, models, or analyses exist that address how wetland ecosystem services are impacted by N deposition?
- What new information is available to characterize the causal relationship between nitrogen deposition and the effects described above?

### Sulfur-Driven Mercury Methylation

In the 2008 Oxides of Nitrogen and Oxides of Sulfur ISA evidence was sufficient to infer a causal relationship between S deposition at current levels and increased Hg methylation in

aquatic environments. Mercury is highly neurotoxic and once methylated principally by S-reducing bacteria, it can be taken up by microorganisms, zooplankton and macroinvertebrates, and concentrated in higher trophic levels, including fish eaten by humans. In 2006, 3,080 fish consumption advisories were issued because of methylmercury (MeHg), and as of July 2007, 23 states had issued statewide advisories. The production of meaningful amounts of MeHg requires the presence of  $\text{SO}_4^{2-}$  and Hg, and where Hg is present, increased availability of  $\text{SO}_4^{2-}$  results in increased production of MeHg. The amount of MeHg produced varies with oxygen content, temperature, pH, and supply of labile organic C. Watersheds with conditions known to be conducive to Hg methylation can be found in the northeastern U.S. and southeastern Canada, but significant biotic Hg accumulation has been widely observed in other regions that have not been studied as extensively, and where a different set of conditions may exist. In the current review specific policy-relevant questions related to sulfur-driven mercury methylation that will be addressed include the following:

- What new evidence exists to characterize the geographic extent of mercury methylation induced by sulfur deposition? Is there new evidence to characterize the effects of abiotic factors (e.g., pH) on the dose response between sulfur deposition and mercury methylation?
- What new evidence exists of the identity and distribution of organisms that methylate mercury? What new evidence exists of the trophic interactions by which methylated mercury moves through the food chain?

#### Ecological effects of other PM components

The ISA will include recent information on how PM-associated components other than those related to N and S deposition affect ecosystems. These other components include metals and persistent organic pollutants (POPs), such as pesticides, semi-volatile organic compounds, polyaromatic hydrocarbons, and flame retardants among others. In addition, studies based on PM measured as size fraction only are included.

#### Climate Modification

The ISA will include recent information on how climatic factors (e.g. temperature and precipitation) modify N and S deposition, as well as ecological response to deposition. Since the NAAQS are periodically reviewed at five year intervals, it is beyond the scope to consider future climate predictions, which are typically at the decadal or longer scales, to potentially modify either deposition or ecological effects.

### **3.5 SCIENTIFIC AND PUBLIC REVIEW**

Drafts of the ISA will be made available for review by the CASAC Secondary NAAQS Review Panel for Oxides of Nitrogen and Sulfur (CASAC) and the public as indicated in Figure 3-1 above; availability of draft documents will be announced in the Federal Register. The CASAC panel will review the draft ISA documents and discuss their comments in public meetings that will be announced in the Federal Register. The EPA will take into account comments, advice, and recommendations received from the CASAC and from the public in revising the ISA. The EPA will establish a public docket for the development of the ISA. After appropriate revision based on comments received from the CASAC and the public, the final document will be made available on an EPA website and in hard copy. A notice announcing the availability of the final ISA will be published in the Federal Register.

## 4 RISK AND EXPOSURE ASSESSMENT

Within the context of NAAQS reviews, a quantitative risk and exposure assessment (REA) is designed to estimate exposure and risks to public welfare<sup>54</sup> associated with the existing secondary standards and with potential alternative secondary standard(s), if any are appropriate to consider. This assessment can inform conclusions on the adequacy of the public welfare protection provided by these standards. The purpose of this chapter is to highlight key findings from the quantitative risk and exposure assessments conducted in the last reviews of the secondary NAAQS for oxides of nitrogen and oxides of sulfur and the secondary NAAQS for PM and to identify key issues to be addressed in planning for any additional quantitative assessments that might be warranted for the current review. The scope of any REA would be informed by the scientific evidence in the upcoming Integrated Science Assessment (ISA) for this review; existing and historical air quality patterns and trends; the availability of improved data, methods, tools, and models that could be used to evaluate ecological effects at various spatial and temporal scales and to identify sensitive ecosystems; the extent to which these data, methods, tools, and models may better characterize important uncertainties or provide additional insights beyond those provided by previous assessments; and available resources. Additionally, the scope would include a consideration of any potential qualitative and quantitative ecosystem goods and services that relate to ecological effects that might be included in any REA.

In the upcoming REA Planning Document, the EPA will evaluate newly available information within the context of the quantitative analyses in the last reviews of the oxides of nitrogen and oxides of sulfur secondary NAAQS and PM secondary NAAQS to determine 1) the extent to which important limitations and uncertainties may be better characterized by information newly available for the current review; and 2) the extent to which this new information may affect the results of the quantitative analyses from the last review in important ways or may suggest additional quantitative analyses that can improve our understanding of the welfare exposure and risks associated with the ecological effects of oxides of nitrogen, oxides of sulfur and PM. The REA Planning Document will also describe the scope and methods for any new or updated quantitative assessments warranted for this review and will take into account information presented in the first draft ISA. The CASAC advice and public comments on the

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<sup>54</sup> Welfare effects as defined in CAA 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.”

draft ISA will be considered in developing the REA Planning Document, which will also be subject to the CASAC review and will be made available for public comment. If warranted, one or more drafts of the REA would then be prepared and released for the CASAC review and public comment prior to completion of a final REA.

Section 4.1 below describes the key analyses, findings and uncertainties and/or limitations from the last reviews of the secondary oxides of nitrogen and oxides of sulfur NAAQS and secondary PM NAAQS. Section 4.2 includes considerations for potential quantitative risk assessments for this review, and Section 4.3 describes the process for obtaining scientific and public review of the REA Planning Document and the REA itself, if warranted.

## **4.1 SUMMARY OF PREVIOUS RISK AND EXPOSURE ASSESSMENT**

### **4.1.1 Quantitative Assessments and Findings from the Prior Oxides of Nitrogen and Oxides of Sulfur Review**

The 2009 Oxides of Nitrogen and Oxides of Sulfur REA conducted for the previous review described the potential risk from deposition of oxides of nitrogen and sulfur to sensitive ecosystems. Specifically, it evaluated the relationships between atmospheric concentrations, deposition, biologically relevant exposures, targeted ecosystem effects, and, to the extent possible, associated ecosystem services. In order to link these effects, the previous REA examined various ways to quantify the relationships between air quality indicators, deposition of biologically available forms of nitrogen and sulfur, ecologically relevant indicators relating to deposition, exposure and effects on sensitive receptors, and related effects resulting in changes in ecosystem structure and services.

The previous REA assessed the ecological effects and ecosystem service effects associated with deposition of  $N_r$  and sulfur (S), focusing on four main targeted ecosystem effects on terrestrial and aquatic systems: (1) aquatic acidification; (2) terrestrial acidification; (3) aquatic nutrient enrichment, including eutrophication; and (4) terrestrial nutrient enrichment. In addition, the previous REA also qualitatively addressed the influence of sulfur oxide deposition on methylmercury production; nitrous oxide effects on climate; nitrogen effects on primary productivity and biogenic greenhouse gas fluxes; and phytotoxic effects on plants.

The EPA, in evaluating the available data and information related to environmental effects associated with oxides of nitrogen and oxides of sulfur determined that there was a major limitation in available data. Due to the lack of broad-scale data at the time of the previous REA, and since depositional effects are not evenly distributed across the United States, a case study approach was used for the quantitative assessments, building from the scientific information

presented in the ISA as well as the identification of ecosystems that are sensitive to nitrogen and/or sulfur deposition. The previous REA selected eight case study areas based on ecosystem characteristics, indicators, and ecosystem service information. More information about the quantitative analyses conducted for these case study areas is included in the sections below.

#### **4.1.1.1 Air Quality Relationships**

The air quality analyses in the previous REA described the then-recent emissions sources of nitrogen and sulfur, as well as atmospheric concentrations, estimates of deposition of total nitrogen, policy-relevant background, and non-atmospheric loadings of nitrogen and sulfur to ecosystems, both nationwide and in the case study areas. Spatial fields of deposition were created using wet deposition measurements from the National Atmospheric Deposition Program (NADP) National Trends Network and dry deposition predictions from the 2002 CMAQ model simulation. These analyses concluded that there was significant variation both spatially and seasonally across the country with the eastern US receiving much greater deposition of both nitrogen and sulfur than the west. The REA concluded that ambient oxides of nitrogen were a significant component of atmospheric nitrogen deposition, even in areas with relatively high rates of reduced nitrogen deposition and that atmospheric deposition of oxidized nitrogen contributed significantly to total nitrogen loadings in nitrogen sensitive ecosystems. In order to characterize various policy scenarios, it was necessary to link ambient air concentrations with deposition over distinct spatial scales that could be used to describe the variability in the sensitivity of ecosystems to a particular effect (e.g. acidification). For this purpose,  $\text{NO}_y$  and  $\text{SO}_x$  transference ratios were developed over each ecoregion as the ratio of total wet and dry deposition to ambient concentration. The transference ratios were based on the 2005 CMAQ simulations, using average values for each ecoregion and calculated as the annual deposition of  $\text{NO}_y$  or  $\text{SO}_x$  spatially averaged across the ecoregion and divided by the annual ambient air concentration of  $\text{NO}_y$  or  $\text{SO}_x$ , respectively, spatially averaged across the ecoregion. These calculated values were then used in the development of the AAI metric (described in section 2.1).

Significant uncertainties and limitations in the air quality analyses and models that were noted in the 2011 Oxides of Nitrogen and Oxides of Sulfur PA included the following:

- The lack of observed dry deposition data, which affected confidence in the AAI on an ecoregion scale, was due in part to the lack of efficient measurement technologies.
- Uncertainty in characterizing  $\text{NH}_x$  deposition was due to both the lack of field measurements and the inherent complexity of characterizing  $\text{NH}_x$  with respect to source emissions and dry deposition.

- The application of air quality (and other) models for purposes of specifying the factors in the AAI equation, on an ecoregion scale, was a new application that introduced uncertainties, especially in areas with limited observational data.

#### **4.1.1.2 Aquatic Acidification**

The previous REA used a steady state critical load model as well as the Model of Acidification of Groundwater in Catchments (MAGIC) model<sup>55</sup> to assess the role of aquatic acidification in two eastern United States case areas: northeastern New York's Adirondack area and the Shenandoah area in Virginia. Surface water trends in SO<sub>4</sub> and NO<sub>3</sub> concentrations and acid neutralizing capacity (ANC) levels were analyzed along with monitoring data from the EPA-administered Temporally Integrated Monitoring of Ecosystems (TIME)/Long-Term Monitoring (LTM) programs and the Environmental Monitoring and Assessment Program (EMAP) for the years 1990 to 2006. Past, present, and future water quality levels were estimated using both steady-state and dynamic biogeochemical models.

This case study estimated the percentage of lakes and streams that exceeded critical loads for alternative ANC levels in the Adirondack Mountains and Shenandoah National Park and the associated effects on ecosystem services such as recreational fishing. Despite some reductions in deposition since 1990, both the Adirondacks and Shenandoah still had higher deposition and acidity relative to modeled conditions for 1860; the EPA estimated that between 18 to 58 percent of modeled lakes in the Adirondacks and 52 to 93 percent of modeled streams in Shenandoah had nitrogen and sulfur deposition in 2002 exceeding ANC levels of 0 to 100, and modeling constant 2002 emissions yielded no improvement in water quality in the Adirondacks by 2050.

The EPA noted in the REA the degree of confidence in the analytic approaches. The REA stated that the available data used for the targeted effect of aquatic acidification were robust and considered high quality, and also noted that there was a high level of confidence about the use of these data and their value for extrapolating to a larger regional population of lakes. In addition, the REA expressed a fairly high confidence in the models, input parameters, and assessment of uncertainty used in the case study analysis for aquatic acidification. Lastly, the REA stated that there was high confidence associated with the ecological effect function developed for aquatic acidification.

We note that the information on aquatic acidification, and in particular the critical load values that were derived as part of the REA analysis approach for evaluating aquatic

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<sup>55</sup> 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.

acidification, helped to inform the development of the AAI in the PA. For more information about the AAI, refer to section 2.2.1.

#### **4.1.1.3 Terrestrial Acidification**

The role of terrestrial acidification was examined by using a simple mass balance model to calculate critical loads for Sugar Maple and Red Spruce forests in the eastern United States by using the base cation to aluminum (Bc/Al) ratio in acidified forest soils as an indicator to assess the impact of nitrogen and sulfur deposition on tree health. At the time of the last review these were the best studied species in North America with regard to impacts of acidification. The effects of deposition on tree growth and associated ecosystem services were evaluated using base cation to aluminum ratios of 0.6, 1.2, and 10 in the Kane Experimental Forest and the Hubbard Brook Experimental Forest, with effects on sugar maple and red spruce extrapolated to 17 states.

Case study results suggested that the health of at least a portion of the sugar maple and red spruce growing in the United States may have been compromised with acidifying total nitrogen and sulfur deposition in 2002, 3 to 75 percent of all sugar maple plots and 3 percent to 36 percent of all red spruce plots exceeded base cation to aluminum ratios of 0.6 to 10. We concluded that the pattern of case study results suggests that nitrogen and sulfur acidifying deposition in the sugar maple and red spruce forest areas studied were very close to, if not greater than, the critical loads for those areas and both ecosystems are likely to be sensitive to any future changes in the levels of deposition.

The EPA noted in the REA the degree of confidence in the analysis approaches. The REA stated that the available data used to quantify the effect of terrestrial acidification were robust and considered high quality, and the REA expressed a high level of confidence about the use of these data and their value for extrapolating to a larger regional population of forests. The REA also expressed a high level of confidence associated with the models, input parameters, and assessment of uncertainty used in the case study analysis for terrestrial acidification. Lastly, the REA noted that a fairly high confidence was associated with the ecological effect function developed for terrestrial acidification.

#### **4.1.1.4 Aquatic Nutrient Enrichment**

To evaluate the effects of nitrogen deposition on aquatic nutrient enrichment, the REA evaluated changes in the National Estuarine Eutrophication Assessment (NEEA)<sup>56</sup> index (comprised of measures of dissolved oxygen, secchi depth, chlorophyll a, submerged aquatic vegetation and other parameters) for the Potomac River Basin and the Neuse River Basin. The

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<sup>56</sup> <http://ian.umces.edu/nea/>

role of nitrogen deposition in two mainstem rivers feeding their respective estuaries was analyzed to determine if decreases in deposition could influence the risk of eutrophication as predicted using the Assessment of Estuarine Trophic Status eutrophication index (ASSETS EI) scoring system in tandem with SPATIally Referenced Regression on Watershed Attributes (SPARROW)<sup>57</sup> modeling. This modeling approach provides a transferrable, intermediate-level analysis of the linkages between atmospheric deposition and receiving waters, while providing results on which conclusions could be drawn.

The case study found that a decrease of 78 percent of atmospheric nitrogen deposition would be required to improve the eutrophication index category ASSETS EI Score for the Potomac from *Bad* to *Poor*, and that the Neuse River/Neuse River Estuary ASSETS EI score could not be improved from *Bad* to *Poor* with only decreases in the 2002 atmospheric deposition load to the watershed. Additional reductions would be required from other nitrogen sources within the watershed. The REA determined that the small effect of decreasing atmospheric deposition in the Neuse River watershed is because the other nitrogen sources within the watershed are more influential than atmospheric deposition to the total nitrogen loadings to the Neuse River Estuary as estimated with the SPARROW model. It was also noted in the REA that future application of the methods to case study areas where atmospheric deposition plays a larger role in the nitrogen loading to an estuary will likely provide more tangible results.

Furthermore, the REA noted that the available data used for the targeted effect of aquatic nitrogen enrichment are considered medium quality, with intermediate confidence about the use of these data and their value for extrapolating to a larger regional area. Additionally, the REA expressed that there was intermediate confidence associated with the models, input parameters, and assessment of uncertainty used in the case study analysis for excess aquatic nitrogen enrichment, and that there was a low level of confidence associated with the ecological effect function developed for excess aquatic nitrogen enrichment.

#### **4.1.1.5 Terrestrial Nutrient Enrichment**

To evaluate the effects of deposition on terrestrial nutrient enrichment, nitrogen deposition was compared to existing benchmarks for ecological effects in the coastal sage scrub (CSS) communities in southern California and the mixed conifer forest (MCF) communities in the San Bernardino and Sierra Nevada Mountains. No quantitative modelling was conducted for

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<sup>57</sup> SPARROW relates in-stream water quality measurements to characteristics of watersheds using a steady-state, nonlinear regression formulation that follows the rules of mass balance. The model empirically estimates the fate and transport of contaminants in river networks. It can track nutrient delivery locally to outlets of inland waterways and regionally to coastal waters.

this case study. Rather, geographic information systems (GIS) analysis supported a qualitative review of past field research to identify ecological benchmarks associated with CSS and mycorrhizal communities, as well as MCF's nutrient-sensitive acidophyte lichen communities, fine-root biomass in Ponderosa pine, and leached nitrate in receiving waters. These benchmarks, ranging from 3.1 to 17 kg N/ha/yr for CSS and MCF, were compared to 2002 CMAQ/NADP data to discern any associations between atmospheric deposition and changing communities. Evidence supported the finding that nitrogen alters CSS and MCF communities. 2002 CMAQ/NADP nitrogen deposition data showed that the 3.3 kg N/ha/yr benchmark had been exceeded in more than 93% of CSS areas (654,048 ha). Additionally, the 2002 CMAQ/NADP nitrogen deposition data exceeded the 3.1 kg N/ha/yr benchmark for lichen in MCF in more than 38% (1,099,133 ha) of MCF areas, and nitrate leaching was observed in surface waters.

The REA also used data from Rocky Mountain National Park to examine the sensitivity and effects of nutrient enrichment on aquatic and terrestrial ecosystems, and found that although a diverse array of U.S. ecosystems existed, exposure levels at which negative effects were observed appeared to be generally comparable to levels identified in other sensitive U.S. ecosystems (benchmarks range from 1.5 to 30.5 kg N/ha/yr).

Overall, the REA concluded that although the available data used for the targeted effect of terrestrial nitrogen enrichment were considered high quality, there was a limited ability to extrapolate these data to a larger regional area.

#### **4.1.1.6 Overarching Conclusions from the Quantitative Assessments**

Based on case study analyses, the previous REA concluded that known or anticipated adverse ecological effects were occurring under current conditions and that these adverse effects would continue into the future. The air quality analyses found that deposition of nitrogen and sulfur was higher in the East than the West, regional deposition corresponded with emissions and ambient concentrations, reduced nitrogen deposition exceeded oxidized nitrogen deposition in the vicinity of local ammonia sources, spatial variation in deposition existed within case study areas, and seasonal patterns of deposition varied in the case study areas.

#### **4.1.1.7 Limitations and/or Uncertainties in Quantitative Assessments in the Prior Oxides of Nitrogen and Oxides of Sulfur Review**

As mentioned previously, at the time of the prior review, the REA was limited to a case study approach, evaluating depositional effects through area-specific analyses. This approach limited our ability to evaluate effects on a broader-scale, and to evaluate shared effects across ecosystems. Overall, uncertainties in the previous review generally related to limited information on: (1) the extent of sensitivity of the ecoregion to the effect, including response to long-term

exposure to elevated deposition levels; (2) the relationship between the observed ecological effect and effects on ecosystem services; (3) the ability to characterize adverse effects across ecosystems and across multiple media. A summary of the uncertainties identified by the REA and PA in the prior review is included below.

- Aquatic acidification: While the 2012 review recognized that the body of scientific evidence linking the deposition of ambient oxides of nitrogen and sulfur to acidification in sensitive aquatic ecosystems was well developed, the 2011 Oxides of Nitrogen and Oxides of Sulfur PA noted that the information and assessments available at the time were not sufficient to support the development of a national standard specifically to address other acidification and eutrophication effects. It was also recognized that if a standard had been developed specifically to address aquatic acidification, it would not likely have provide targeted protection against other deposition-related ecological effects, including effects related to terrestrial acidification and nutrient enrichment effects in sensitive terrestrial and aquatic ecosystems.<sup>58</sup>
- Terrestrial acidification: Simple Mass Balance model assumptions made for base cation weathering (Bcw) and forest soil ANC input parameters that the previous review relied upon for critical load modeling were the main sources of uncertainty. These parameters were poorly measured in non-glaciated soils and required researchers to use default values. Uncertainty analyses in the literature supported this assessment and found Bcw contributed 49% to the total variability in the critical load estimates, and forest soil ANC contributed 46% to the total variability.
- Aquatic eutrophication: Analyses in the previous review indicated that reductions in atmospheric deposition alone could not solve coastal eutrophication problems due to multiple non-atmospheric nitrogen inputs. In addition, for estuarine systems, the data requirements were such that uncertainty was introduced by extrapolating these data to larger regional areas. For freshwater systems, there were similar data limitations which impacted the uncertainty in calibrating models and extrapolating model outputs to larger scales.
- Terrestrial eutrophication: There were several areas of significant uncertainty identified for this category of effect including both uncertainties in air quality metrics as well as the spatial extent of the available data. Specifically, characterizing oxides of nitrogen and sulfur deposition includes uncertainties in monitoring instrumentation and measurement protocols, as well as limitations in the spatial extent of existing monitoring networks, especially in remote areas. Also, spatial resolutions of the measured and modeled data used in this case study, as well as spatial and temporal variability associated with measurement and modeling introduced uncertainty in the representativeness of the modeled areas.

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<sup>58</sup> The 2011 Oxides of Nitrogen and Oxides of Sulfur PA also noted that it was likely that some additional protection from these other effects would result from reductions in atmospheric oxides of nitrogen and sulfur that would likely occur in response to an ecologically relevant aquatic acidification standard.

#### **4.1.2 Qualitative Assessments and Findings from the Prior Oxides of Nitrogen and Oxides of Sulfur Risk and Exposure Assessment**

The 2009 REA qualitatively evaluated depositional effects of sulfur on methyl mercury formation in aquatic ecosystems, direct effects of ambient nitrogen and sulfur on vegetation, and other effects including nitrous oxide, visibility and materials damage, and nitrogen deposition and correlation with greenhouse gas fluxes. Included below are summaries of the qualitative evaluations as well as any conclusions from the prior REAs.

##### **4.1.2.1 Sulfur deposition (as sulfate, $\text{SO}_4^{2-}$ ) and increased mercury methylation in wetlands and aquatic environments**

Information available at the time of the last review demonstrated that methylmercury (MeHg) production is mediated primarily by sulfate-reducing bacteria (SRB), and changes in  $\text{SO}_4^{2-}$  deposition result in changes in both Hg methylation and Hg concentration in fish. It was also shown that watersheds with conditions known to be conducive to Hg methylation could be found in the northeastern U.S. and southeastern Canada, though biotic Hg accumulation had been widely observed in other regions that had not been studied as extensively, and where a different set of conditions may exist. The qualitative assessment in the REA incorporated information from the ISA pertaining to mercury methylation effects on Little Rock Lake in Wisconsin. It noted that decreases in sulfate deposition were linked to observed decreases in methylmercury fish tissue concentrations in the lake.

The REA acknowledged that a number of factors influence or modify the relationship between sulfate and the methylation of Hg. It noted that establishing the quantitative relationship between  $\text{SO}_4^{2-}$  and MeHg in natural settings is difficult because of the presence of multiple interacting factors in aquatic and terrestrial environments, including wetlands, such as types of SRBs, sulfur species (including  $\text{SO}_4^{2-}$ ), mercury species, pH, organic acids and other factors, whose influence on methylation has not been quantified. The REA also noted that the rate of methylation varies spatially and with biogeochemical factors so that the correlation of sulfate deposition and methyl mercury could not be quantified for the purpose of interpolating the association across waterbodies or regions.

Overall, the REA noted that decreases in sulfate deposition will likely result in decreases in methyl mercury concentration but that spatial and biogeochemical variations nationally hindered the ability to establish large scale dose-response relationships.

##### **4.1.2.2 Direct Gaseous Effects on Vegetation**

In the 2009 REA, it was noted that oxides of nitrogen and oxides of sulfur gases have different degrees of phytotoxic effects on vegetation. A unique secondary NAAQS exists for  $\text{SO}_2$  to protect against acute foliar injury, but it was determined in 1993 that concentrations of  $\text{NO}$ ,

NO<sub>2</sub>, and PAN are rarely high enough to have phytotoxic effects on vegetation; therefore, no unique secondary standard exists.

At the time of the prior oxides of nitrogen and oxides of sulfur review, relatively little was known about the direct effects of HNO<sub>3</sub> vapor on vegetation, however, recent research on the decline of sensitive lichen species was highlighted in the ISA. HNO<sub>3</sub> also has a very high deposition velocity and may be an important source of nitrogen to plants. In the Transverse Range's MCF, HNO<sub>3</sub> has been estimated to provide 60% of all dry deposited nitrogen, and it has been suspected as the cause of a dramatic decline in lichen species (2009 REA, Section 6.4.3, pg 6-29). At high concentrations over the short-term, HNO<sub>3</sub> can damage vascular plants such as seedlings of ponderosa pine and California black oak (2009 REA, Section 6.4.3, pg 6-30). The REA noted that more research was needed to determine long-term exposure effects at lower concentrations.

#### 4.1.2.3 Other Effects

Other effects that were qualitatively evaluated in the 2009 REA for oxides of nitrogen and oxides of sulfur included:

- **Nitrogen deposition and its correlation with the rate of photosynthesis and net primary productivity and biogenic greenhouse gas fluxes.** The REA noted that the heterogeneity of ecosystems across the United States introduces variations into dose-response relationships
- **Nitrous oxide (N<sub>2</sub>O).** The REA recognized that as a potent GHG, it is most appropriate to analyze the role of N<sub>2</sub>O in the context of all of the GHGs rather than as part of the REA. Because such an analysis was outside the scope of this review, it was not included as a quantitative part of the REA.
- **Visibility and materials damage, such as corrosion, erosion, and soiling of paint and buildings.** It was noted that both effects were being addressed in the PM NAAQS review. Therefore, these effects were not quantitatively analyzed in the 2009 REA for oxides of nitrogen and oxides of sulfur.

#### 4.1.2.4 Ecosystem Services

In the previous REA, EPA qualitatively and quantitatively evaluated ecosystem services impacted by nitrogen and sulfur deposition and the extent to which we can quantify incremental impacts associated with such deposition. Due to limitations in broad national data on ecosystem impacts and valuation studies to rely on, the REA focused on using the case studies. For aquatic acidification, the REA evaluated the incremental change in ecosystem services related to recreational fishing and lake recreation in the Adirondacks using two methods. First, it estimated the change in value of fishing based on the change in fish abundance predicted by the change in

ANC from the MAGIC model. Second, the MAGIC modeling results were combined with economic values for recreational fishing in the Adirondacks which reflected a range of services associated with lake recreation such as quality of surrounding forest, bird abundance, and existence values.

The REA identified a range of ecosystem services related to terrestrial acidification including decreased habitat for threatened and endangered species, decreased forest productivity and aesthetics, increased soil erosion, reduced water retention and non-use value.

For quantitative analysis, the REA used preference studies for the southern Appalachians to capture willingness to pay (WTP) for forest improvements that specifically addressed non-use values. The REA also described USDA data on maple syrup production and conducted a pilot study using the Forest and Agriculture Sector Optimization Model (FASOM) to estimate changes in timber harvest for red spruce and sugar maple.

Ecosystem services related to aquatic eutrophication were assessed for the Chesapeake Bay and the Potomac and Neuse river basins in the REA. Using the results of the water quality modeling described above for the Potomac and Neuse river basins, coupled with reported economic values of impacts associated with improvements or declines, the REA estimated economic values associated with changes in nitrogen and sulfur. The REA also estimated increases in blue crab harvest, recreational fishing catch rates, boating, beach use, housing prices, and non-use values associated with potential nitrogen loading reductions.

The REA identified a range of ecosystem services related to terrestrial nutrient enrichment including recreational uses, decreased aesthetics, increased biomass of non-native grasses, increased fire risk, decreased water quality, decreased habitat suitability, and non-use values.

For quantitative analysis, the REA explored how changes in landscape due to increased nitrogen and sulfur would increase the risk of fires and what are the values associated with those increased risks. To assess the impact of fire risk, the REA used GIS to overlay nitrogen deposition with the locations of MCF and CSS, and CALFIRE data (State of California fire occurrence, prevention and fire-fighting expenditures) to describe the potential benefit of reducing nitrogen enrichment to these fire prone areas.

#### **4.1.3 Previous PM NAAQS Review**

As discussed in section 2.2.2, ecological effects of PM were considered in the 2012 PM NAAQS review and included direct ecological effects on metabolic processes of plants, as well as deposition-effects from contribution to total metal loading resulting in alteration of soil biogeochemistry and microbiology, plant and animal growth and reproduction; and contribution

to total organics loading resulting in bioaccumulation and biomagnification across trophic levels. Based on the determination in the 2009 PM ISA that a causal relationship is likely to exist between deposition of PM and a variety of effects on individual organisms and ecosystems (U.S. EPA, 2009a, p. 2-30; sections 2.5.3 and 9.4.7), the 2009 scope and methods plan for the PM NAAQS REA (U.S. EPA, 2009c) considered whether adequate evidence was available to conduct quantitative assessments for each of these categories of effects.

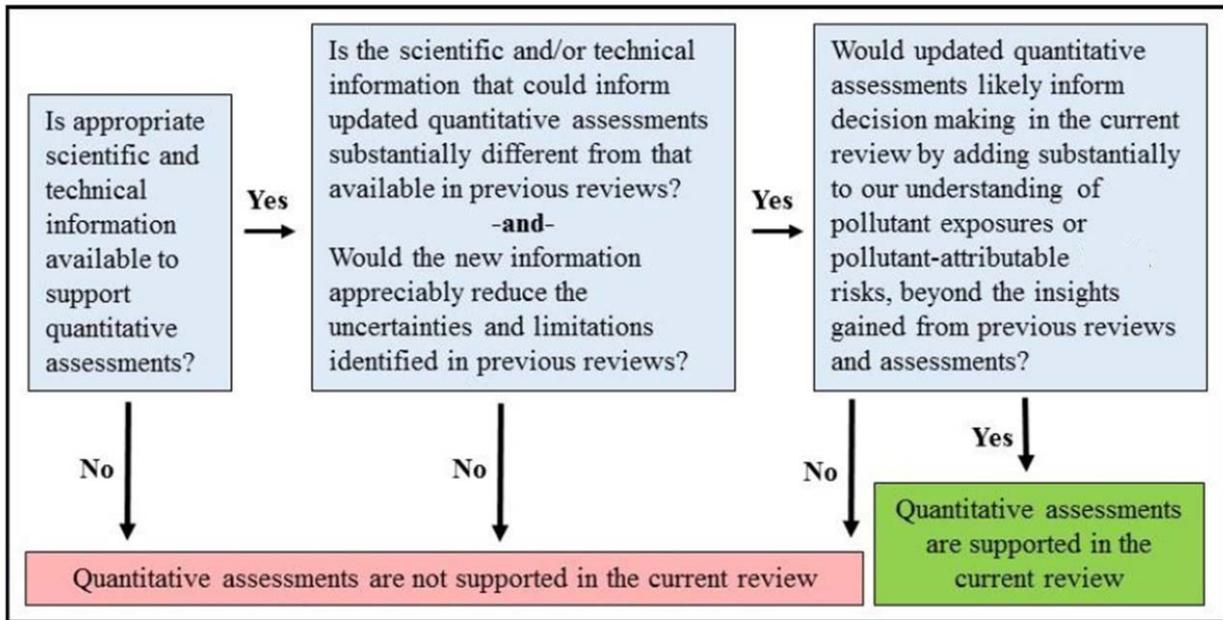
In general, the EPA determined that the available evidence did not support such quantitative assessments. More specifically, data to link PM toxicity to ecosystem function effects were available for only one tree species, and limited data on other species hindered additional analyses. Toxic effects of some PM components on plant leaves and soil were not well-characterized and it was difficult to isolate these endpoints from other environmental stressors. In addition, a lack of data on the site-specific composition of PM and soil-associated biota prevented quantitative analysis of population shifts from deposited PM, and a lack of data on bioavailability of PM components and uncertainties in cumulative exposure effects prevented quantitative analysis of PM metal toxicity to biota. There was also limited ambient data available measuring PM components, and data were unavailable regarding seasonal composition of near roadway PM and trophic transfer to animals that forage on roadsides. After a careful evaluation of the evidence, the EPA determined that data needed to conduct quantitative assessments for ecological welfare effects in the last review were not available.

## **4.2 CONSIDERATION OF POTENTIAL QUANTITATIVE RISK AND EXPOSURE ASSESSMENTS FOR THIS REVIEW**

The goals of a REA in the current review would be to provide information relevant to answering questions regarding the adequacy of the existing NO<sub>2</sub>, SO<sub>2</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> secondary standards and, if appropriate, the potential improvements in public welfare that could be achieved from meeting potential alternative standard(s). Any quantitative REA for the current review would build on the approaches used and lessons learned in the last review and would focus on whether newly available models, methods, tools, and data would substantially reduce the previously identified uncertainties or address major limitations that existed during the last review.

Potential support for conducting updated quantitative assessments in the current review will be considered in the REA Planning Document. Conclusions regarding such support will be based on our consideration of the available scientific evidence; the available technical information, tools, and methods; and judgments as to the likelihood that particular quantitative assessments will add substantially to our understanding of ecological exposures or environmental

risks, beyond the insights gained from the assessments conducted in the last review. Our anticipated approach to considering these factors, and for reaching conclusions on the support for particular quantitative assessments, is summarized in Figure 4-1, below.



**Figure 4-1. Planned approach to considering support for quantitative assessments.**

Key policy-relevant questions to inform the REA Planning Document are presented in greater detail in section 2.3. As we develop the REA Planning Document, we expect to further refine and expand the set of policy questions which will play a central role in defining both the purpose and scope of quantitative assessments. As warranted, these assessments will build on the approaches used and lessons learned in the 2012 review and would focus on improving the characterization of ecological exposures and associated environmental risks, including related uncertainties, in terms of newly available models, methods, tools, and data.

Although the REA Planning Document will provide more specific information, we provide some preliminary ideas regarding the anticipated scope of the current REA here. First, as discussed in Chapter 1, the REA will focus on ecological effects of oxides of nitrogen and oxides of sulfur oxides, as well as of PM. This will include consideration of effects of oxides of nitrogen and oxides of sulfur in the gas phase contributing to direct phytotoxic injury to vegetation, as well as direct effects of PM on metabolic processes of plants; and contribution of oxides of nitrogen, oxides of sulfur and PM through atmospheric deposition to other ecosystem welfare effects. The REA will not focus on other welfare effects, including visibility impairment, climate

effects and materials damage, that might be associated with oxides of nitrogen, oxides of sulfur and PM, and their transformation products, as these are addressed in the ongoing PM NAAQS review. As in the previous review, identifying sensitive ecosystems is likely to be an important component of a potential REA. Therefore, any potential REA analyses will likely include a combination of national and local-scale analyses reflecting various policy scenarios, and likely focus on areas in the contiguous U.S. due to the greater availability of data. The REA Planning Document will also include a consideration of any potential qualitative and quantitative data available regarding ecosystem goods and services that relate to ecological effects of concern.

The upcoming REA Planning Document will present the Agency's evaluation of the available scientific evidence as provided in the ISA and provide a detailed description of the scope and methods proposed for the REA, as warranted. The sections below provide some background on what factors the agency will consider in evaluating that potential support for conducting updated or new quantitative assessments in the current review.

#### **4.2.1 Air Quality Relationships**

As part of the REA Planning Document, we will need to consider how best to characterize both air quality concentrations and atmospheric deposition of oxides of nitrogen, oxides of sulfur and PM for various policy scenarios. As part of this, it will also be key to be able to relate ambient air quality concentrations to the deposition causing any assessed effects. This will be important in evaluating the protection provided by the current standards, as well as any potential alternative standards, against adverse ecological effects related to atmospheric concentrations and deposition of oxides of nitrogen, oxides of sulfur and PM.

Total atmospheric deposition is the sum of wet (i.e., precipitation), dry and occult (i.e., fog and clouds) deposition. In general, observations can only provide estimates of precipitation-based deposition. Given this, dry deposition, and therefore total deposition, must rely on methods that estimate deposition for an area. Therefore, to evaluate exposure to deposition, a combination of monitoring and modelling information would be informative. Available monitoring networks with sites located in sensitive ecoregions include the NADP networks (CASTNET, AMoN and NTN) and IMPROVE. In addition, chemical transport models (CTMs) can be used to estimate dry deposition based on their ability to integrate multiple physical and chemical processes relevant to dry deposition. These models account for the heat, mass transfer, and thermodynamic processes influenced by meteorology, land and water surface properties and atmospheric species of interest. CTMs also estimate wet deposition (precipitation-based), and can be applied to optimize the use of observed wet deposition with modeled dry and wet deposition to generate total deposition estimates.

In the last review, spatial fields of deposition were created using wet deposition measurements from the NADP National Trends Network and dry deposition predictions from the 2002 and 2005 CMAQ model simulation. In order to characterize various policy scenarios, transference ratios were based on 2005 CMAQ simulations to describe the variability in the sensitivity of ecosystems to a particular effect (e.g., aquatic acidification). Annual average transference ratios were calculated as the annual deposition of NO<sub>y</sub> or SO<sub>x</sub> spatially averaged across the ecoregion and divided by the annual ambient air concentration of NO<sub>y</sub> or SO<sub>x</sub>, respectively, spatially averaged across the ecoregion.

Since the prior review, deposition estimates have become available through the NADP's Total Deposition science committee, which has applied a "hybrid" approach that combines monitoring and modeling information. Deposition estimates based on this hybrid approach attempt to utilize the broad spatial and chemical composition coverage afforded by the CMAQ with the confidence instilled by using observations where available in order to provide estimates of deposition in areas without monitoring sites. In addition, new monitoring for ammonia gas through AMoN has become available since the last review that expands our available air quality and deposition measurements.

The REA Planning Document will consider how best to characterize both air quality concentrations and atmospheric deposition of oxides of nitrogen, oxides of sulfur and PM for various policy scenarios. In doing so, the REA Planning Document will evaluate any newly available air quality information and whether that information may substantially reduce the previously identified uncertainties or address major limitations that existed during the last review, as well as consider the approaches used and lessons learned in the last review. Policy scenarios may include a characterization of air quality and deposition for recent conditions, as well as for meeting current standards and/or potential alternative standards.

#### **4.2.1.1 Direct Ecological Effects**

As noted earlier, the EPA did not conduct quantitative assessments of direct ecological effects in the prior Oxides of Nitrogen and Sulfur and PM reviews. Direct ecological effects in this review include the effects of oxides of nitrogen and oxides of sulfur in the gas phase contributing to direct phytotoxic injury to vegetation, as well as direct effects of PM on metabolic processes of plants. In the REA Planning Document, we will consider whether sufficient data have become available in the ISA for the current review to conduct quantitative analyses on direct effects, in light of inherent uncertainties. Although we do not anticipate that sufficient information would become available to reduce these uncertainties, if it did, we would give consideration to whether conducting such quantitative analyses of ecological risks and associated ecosystem services would be practicable and would meaningfully inform this review.

If uncertainties and data gaps prevent the EPA from conducting a quantitative ecological risk assessment for this review, we anticipate that the upcoming PA would rely on information from the ISA regarding ecological effects from oxides of nitrogen, oxides of sulfur and PM.

#### **4.2.2 Deposition-Related Ecological Effects**

In addition to consideration of direct effects on ecological systems, this review will also address deposition-related effects. Oxides of nitrogen, oxides of sulfur and PM all contribute to nitrogen and sulfur deposition, which can cause substantial ecological effects. Nitrogen and sulfur compounds can affect ecosystems as a result of deposition and contribute to the biophysical and ecological processes, resulting in changes in biogeochemical processes, biological effects, and ecological effects. These effects may include acidification and eutrophication in either terrestrial or aquatic systems, as well as the mediation of the methylation of mercury in aquatic systems. In addition, PM can effect vegetation, soils and biota through contribution to total metal loading resulting in alteration of soil biogeochemistry and microbiology, plant and animal growth and reproduction, as well as through contribution to total organics loading resulting in bioaccumulation and biomagnification across trophic levels.

##### **4.2.2.1 Deposition-Related Effects from Nitrogen and Sulfur**

As mentioned earlier, in the prior secondary review of oxides of nitrogen and oxides of sulfur, several quantitative assessments were conducted in the REA to evaluate depositional effects from nitrogen and sulfur. These assessments, which relied on models or other data, were conducted at a local-scale through case studies, since the best available environmental and monitoring data for depositional effects were only at these scales. Because effects on ecosystems, and ecosystems themselves, are not distributed evenly, the inclusion of both national and local-scale assessments can provide a more complete evaluation of ecological risks.

For this review, we anticipate that new data, tools, and/or information will be available that may help to develop refined or new quantitative assessments and to include assessments at the national scale. For example, since that last review, new or refined national water quality assessments data, as well as critical loads data are now available for consideration. More information about the national assessment data and critical loads data is included in the sections below.

##### **4.2.2.1.1 National Water Quality Assessment Data**

As mentioned earlier, the prior secondary review of oxides of nitrogen and oxides of sulfur included a case study evaluating changes in the NEEA (comprised of measures of dissolved oxygen, secchi depth, chlorophyll a, submerged aquatic vegetation and other parameters) for the Potomac River Basin and the Neuse River Basin. The NEEA is a joint

initiative between the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Coastal Ocean Science (NCCOS) and the Integration and Application Network (IAN). The NEEA compiled data collected in the early 2000s by NOAA and used the ASSETS model (Bricker et al., 2003) to determine the eutrophic status and predict future conditions of U.S. estuaries and coastal water bodies.

The EPA has continued a series of surveys under the National Aquatic Resource Surveys (NARS) program which are designed to assess the status of and changes in quality of the nation's coastal waters, lakes and reservoirs, rivers and streams, and wetlands. The NARS assessments are statistical surveys designed to provide the public and decision makers with nationally consistent and representative information on the condition of the Nation's waters. These assessments include indicators that may be relevant to the current review.

The first NARS surveys were conducted in 2007 and the data were not available at the time of the last review. The NARS are made up of four following individual surveys that are implemented on a rotating basis:

- **National Coastal Condition Assessment (NCCA)** measures chlorophyll a, dissolved oxygen and nitrogen<sup>59</sup> at sampling sites at shorelines to nearshore boundary of the oceans and Great Lakes. The first NCCA survey was conducted in 2010 with results published in 2016. The NCCA was preceded by the National Coastal Condition report (NCCR), which consisted of 4 reports for the years 1990 to 1996, 1997 to 2000, 2001 to 2002, and 2003 to 2006.
- **National Lake Assessment (NLA)** is a statistical survey of the condition of our nation's lakes, ponds and reservoirs. Based on the sampling across the lower 48 states of over 1,000 lakes, a water body had to be either natural or man-made, greater than 2.47 acres (1 hectares, or ha),<sup>60</sup> at least 3.3 feet (1 meter) deep, and with a minimum quarter acre (0.1 hectare) of open water and minimum retention time of 1 week. The first NLA survey was conducted in 2007 (report published in 2009) and the second survey in 2012 (report published in 2016).
- **National Wetland Condition Assessment (NWCA)** is a statistical survey of all wetlands of the conterminous U.S. The survey encompasses both tidal and nontidal wetlands ranging from the expansive marshes of our coasts to the forested swamps, meadows, and waterfowl-rich prairie potholes of the interior plains. The first NWCA survey was conducted in 2011 with results published in 2016. A second survey was conducted in 2016.
- **National River and Stream Assessment (NRSA)** is a survey of 1.2 million miles of rivers and streams in the U.S., assesses the ecological condition of the full range of

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<sup>59</sup> Nitrogen was measured but not assessed in the Great Lakes.

<sup>60</sup> Previous sampling in 2007 assessed only lakes greater than 10 acres (1 hectare).

flowing waters in the conterminous U.S. (lower 48 states). The survey targeted the Great Rivers (such as the Mississippi and the Missouri), small perennial streams, and urban and non-urban rivers. Run-of-the-river ponds and pools are included, along with tidally influenced streams and rivers up to the leading edge of dilute sea water. The first NRSA survey was conducted in 2008 and 2009 with results published in 2016. The NRSA was preceded by the Wadeable Streams Assessment (WSA) which conducted one survey in 2004, with results published in 2007.

We will evaluate the extent to which these data from these national assessments can help inform decisions regarding potential quantitative approaches for the REA.

#### **4.2.2.1.2 Critical Loads**

At the time of the prior review, a combination of empirical critical loads data as well as model-derived critical loads were used for the quantitative analyses in the REA. Due to limited data on a broader scale, these analyses were conducted on a local scale. Since that time, new critical loads data have become available through published literature as well as data collected by the Critical Loads of Atmospheric Deposition Science Committee (CLAD), which was formally created by the NADP Executive Committee in 2010. The purpose of CLAD is to discuss current and emerging issues regarding the science and use of critical loads for effects of atmospheric deposition on ecosystems in the United States.<sup>61</sup> CLAD facilitates the exchange, use, and evolution of critical load science, technical information, and modeling and mapping methods within a broad multi-organization context.

A key component of CLAD is the development and maintenance of the “National Critical Loads Database (NCLD) of Sulfur and Nitrogen,” a compilation of empirical and calculated critical loads data and supporting information from many regional and national scale projects. The focus of this database is on critical loads of sulfur and nitrogen deposition and the effects on terrestrial and aquatic environments. The database is updated through periodic “calls for data” and corrections. It is anticipated that critical loads in the NCLD database, as well as critical loads data from publications cited in the ISA, will help inform decisions regarding the potential quantitative approaches for evaluating depositional effects of nitrogen and sulfur.

#### **4.2.3 Deposition-Related Effects from PM**

As mentioned earlier, the EPA did not conduct a quantitative assessment of deposition effects from PM in the prior review. For this review, the REA Planning Document will consider whether information would now be sufficient to conduct a quantitative ecological risk assessment associated with deposition of PM, primarily particulate organics and metals,

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<sup>61</sup> <http://nadp.sws.uiuc.edu/committees/clad/>

including whether information and data are now available to address the uncertainties identified in the last review of the PM NAAQS that prohibited a quantitative ecological risk assessment.

#### **4.2.4 Ecosystem Services**

The EPA routinely considers ecosystem services in reviews of the secondary NAAQS. Ecosystem services can be generally defined as the benefits that individuals and organizations obtain from ecosystems. The EPA has defined ecological goods and services as the “outputs of ecological functions or processes that directly or indirectly contribute to social welfare or have the potential to do so in the future. Some outputs may be bought and sold, but most are not marketed” (U.S. EPA, 2006). The use of ecosystem services metrics can help to quantify welfare effects and inform reviews of the standards. Services such as visibility, recreational hiking and hunting, commercial and recreational fishing, habitat for threatened and endangered species, and existence value have been considered, and in some cases, quantified and valued (80 FR 65292, October 26, 2015; 77 FR 20218, April 3, 2012; 78 FR 3086, January 15, 2013).

Through the REA for a particular NAAQS review, an evaluation of ecosystem services can be used as a tool for evaluating the potential impact that ecological effects can have on public welfare. Since the last review, a more refined system of categorizing ecosystem services has become available. This system is based on the concept of “final ecosystem goods and services” (FEGS-CS) as described in Landers and Nahlik (2013). The FEGS are “components of nature, directly enjoyed, consumed or used to yield human well-being.” Using the FEGS system allows the recognition that a specific ecological endpoint such as water quality can be either an intermediate or a final service. In addition, the EPA’s recently published National Ecosystem Services Classification System (NESCS) (U.S. EPA, 2014c) identifies FEGS as the “supply side” input into the “demand side” human economy. NESCS classification system is based on a conceptual framework that provides a way to systematically link ecological systems that produce ecosystem services and human systems that directly use these services (i.e., market production systems and households). We anticipate that this new information will help inform our consideration of ecosystem services in the current review.

#### **4.2.5 Characterization of Uncertainty**

An important issue associated with any REA is the characterization of variability and uncertainty. *Variability* refers to the heterogeneity in a variable of interest that is inherent and cannot be reduced through further research. In contrast, *uncertainty* refers to the lack of knowledge regarding both the actual values of model input variables (parameter uncertainty) and the physical systems or relationships (model uncertainty). In any risk assessment, uncertainty is ideally reduced by the maximum extent practical, through improved measurement of key

parameters and ongoing model refinement. However, significant uncertainty often remains, and emphasis is then placed on characterizing the nature of that uncertainty and its impact on risk estimates. The characterization of uncertainty can include both qualitative and quantitative analyses, the latter requiring more detailed information and often, the application of sophisticated analytical techniques. Sources of variability that are not fully reflected in the risk assessment can consequently introduce uncertainty into the analysis.

The REA Planning Document will discuss the consideration of using recent guidance from the World Health Organization (WHO, 2008), which presents a four-tiered approach for characterizing uncertainty ranging from screening level (Tier 0) to qualitative (Tier 1), deterministic (Tier 2) and probabilistic (Tier 3). With this four-tiered approach, the WHO framework provides a means for systematically linking the characterization of uncertainty to the sophistication of the underlying risk assessment, where the decision to proceed to the next tier is based on the outcome of the previous tier's assessment. Ultimately, the decision as to which tier of uncertainty characterization to include in a risk assessment will depend both on the overall sophistication of the risk assessment and the availability of information for characterizing the various sources of uncertainty. The REA planning document will describe in detail how we propose to implement the WHO framework, and what quantitative uncertainty analysis, where appropriate, we will pursue.

In designing a REA for the current review, our goal will be to reduce the impact of the sources of uncertainty identified in the 2009 Oxides of Nitrogen and Oxides of Sulfur REA and 2011 Oxides of Nitrogen and Oxides of Sulfur PA to the extent possible given available information. These uncertainties are described in detail in this Chapter and in Chapter 2. Additionally, we will consider the extent to which uncertainties in the quantitative approaches for evaluating effects can be minimized and/or the extent to which the new data and information suggest the need for new quantitative approaches. Should it be determined that a new or revised assessment approach is warranted for the current review, we will consider the extent to which these limitations are now minimized by new data and information that is available. Our goal will also be to address any newly identified sources of uncertainty and to incorporate the sources of variability into the analysis approach to ensure that the risk estimates are representative of the actual response of an ecosystem (including the distribution of that adverse response across the ecosystem).

### **4.3 SCIENTIFIC AND PUBLIC REVIEW**

The REA Planning Document will be distributed to the CASAC for review and provided to the public for review and comment. The document will be the subject of a review with the

CASAC at a public meeting or teleconference that will be announced in the *Federal Register*. The EPA does not produce a final REA Planning Document, but instead considers the CASAC recommendations and public comments in the design and when conducting the quantitative assessments either in a new REA or in updating or expanding the last assessment as part of the PA. In either case, staff would prepare at least one draft of the assessment for the CASAC review and public comment. The CASAC would review the document and discuss it at a public meeting that would be announced in the *Federal Register*. Based on past practice, the EPA expects that the CASAC would summarize key advice and recommendations for revision of the assessment in a letter to the EPA Administrator. In revising any draft REA, the EPA would take into account any such recommendations and also consider comments received from the public, both at the meeting itself and directly in writing. A final assessment would then be made available on an EPA website, with its public availability announced in the *Federal Register*.

## **5 POLICY ASSESSMENT AND RULEMAKING**

### **5.1 POLICY ASSESSMENT**

The PA provides a transparent staff evaluation and staff conclusions regarding policy considerations related to reaching judgments about the adequacy of the current standards and potential alternatives. The PA integrates and interprets the information from the ISA and, if available, REA to frame policy options for consideration by the Administrator. When final, the PA is intended to help “bridge the gap” between the Agency’s scientific assessments presented in the ISA and REA and the judgments required of the Administrator in determining whether it is appropriate to retain or revise the NAAQS.

The development of the PA is also intended to facilitate the CASAC’s advice to the Agency and recommendations to the Administrator on the adequacy of the existing standards or revisions that may be appropriate to consider, as provided for in the CAA. Staff conclusions in the PA are based on the information contained in the ISA and REA, as available, and any additional staff evaluations and assessments discussed in the PA. In so doing, the discussion in the PA is framed by consideration of a series of policy-relevant questions drawn from those outlined in section 2.3 above, including the fundamental questions associated with the adequacy of the current standards and, as appropriate, consideration of alternative standards in terms of the specific elements of the standards (i.e. indicator, averaging time, level, and form).

The PA for the current review will identify the range of policy options that the staff concludes could be supported by the available scientific evidence and the information from available quantitative assessments. In so doing, the PA will describe the interpretations of this evidence and information that could support various policy options, as appropriate, and that could be considered by the Administrator in making decisions on the secondary standards for oxides of nitrogen, oxides of sulfur and PM. This will include the identification of key uncertainties and limitations in the underlying scientific evidence and in the information available from quantitative assessments. The PA will also highlight areas for future welfare-related research, model development, and data collection.

In identifying a range of secondary standard options for the Administrator to consider, it is recognized that the final decision will be largely a public welfare policy judgment. A final decision must draw upon scientific information and analyses about welfare effects and risks, as well as judgments about how to deal with the range of uncertainties that are inherent in the scientific evidence and analyses. This approach is consistent with the requirements of the NAAQS provisions of the CAA and with how the EPA and the courts have historically

interpreted the CAA. These provisions 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. As discussed in section 1.1 above, 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.

Staff will prepare at least one draft of the PA document for the CASAC review and public comment. The draft PA document will be distributed to the CASAC for its consideration and made available to the public for review and comment, with notice of availability announced in the *Federal Register*. Review by the CASAC will be discussed at a public meeting that will be announced in the *Federal Register*. Based on past practice by CASAC, the EPA expects that the CASAC will summarize key advice and recommendations for revision of the document in a letter to the EPA Administrator. In revising the draft PA document, the EPA will take into account any such recommendations and also consider comments received from the CASAC and from the public, including those received at the meeting itself. A second draft will be produced if deemed necessary at that time. The final document will be made available on an EPA website, with its public availability announced in the *Federal Register*.

## **5.2 RULEMAKING**

Following issuance of the final PA and the EPA management consideration of staff analyses and conclusions presented therein, and taking into consideration the CASAC advice and recommendations, the Agency will develop a notice of proposed rulemaking. The proposed rulemaking notice conveys the Administrator's proposed conclusions regarding the adequacy of the current standards and any revision that may be appropriate. As specified by Executive Order, the EPA will submit a draft notice of proposed rulemaking to the Office of Management and Budget (OMB) for interagency review, to provide OMB and other federal agencies the opportunity for review and comment. After the completion of interagency review, the EPA will publish the notice of proposed rulemaking in the *Federal Register*. Monitoring rule changes associated with review of the secondary oxides of nitrogen, oxides of sulfur and PM standards will, as appropriate, be developed and proposed in conjunction with this NAAQS rulemaking.

At the time of publication of the notice of proposed rulemaking, all materials on which the proposal is based are made available in the public docket for the rulemaking.<sup>62</sup> Publication of the proposal notice is followed by a public comment period, generally lasting 60 to 90 days, during which the public is invited to submit comments on the proposal to the rulemaking docket. Taking into account comments received on the proposed rule, the Agency will then develop a notice of final rulemaking, which again undergoes OMB-coordinated interagency review prior to issuance by the EPA of the final rule. At the time of final rulemaking, the Agency responds to all significant comments on the proposed rule. Publication of the final rule in the *Federal Register* completes the rulemaking process.

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<sup>62</sup> The rulemaking docket for the current secondary Oxides of Nitrogen, Oxides of Sulfur, and PM NAAQS review is identified as EPA-HQ-OAR-2014-0128. Dockets are publicly accessible at [www.regulations.gov](http://www.regulations.gov). The EPA requests that comments from the public on the PA, REA and rulemaking documents be submitted to this docket. A separate docket for the ISA will be established and specified in the notice of availability of the first draft ISA. Public comments on drafts of the ISA may be submitted to that docket.

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