ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 50

[EPA–HQ–OAR–2014–0128; FRL–5788–05–OAR]

RIN 2060–AS35

Review of the Secondary National Ambient Air Quality Standards for Oxides of Nitrogen, Oxides of Sulfur, and Particulate Matter

AGENCY: Environmental Protection Agency (EPA).

ACTION: Final rule.

SUMMARY: Based on the Environmental Protection Agency's (EPA's) review of the air quality criteria for ecological effects and secondary national ambient air quality standards (NAAQS) for oxides of nitrogen (N oxides), oxides of sulfur (SO_X), and particulate matter (PM), the EPA is revising the existing secondary sulfur dioxide (SO_2) standard to an annual average, averaged over three consecutive years, with a level of 10 parts per billion (ppb). Additionally, the Agency is retaining the existing secondary standards for N oxides and PM, without revision. The EPA is also finalizing revisions to the data handling requirements for the secondary SO_2 NAAQS.

DATES: This final rule is effective on January 27, 2025.

ADDRESSES: The EPA has established a docket for this action under Docket ID No. EPA–HQ–OAR–2014–0128. All documents in the docket are listed on the *https://www.regulations.gov* website. Although listed in the index, some information is not publicly available, *e.g.,* CBI or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, is not placed on the internet and will be publicly available only in hard copy form. Publicly available docket materials are available electronically through *https://www.regulations.gov.*

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Executive Summary

This document presents the Administrator's final decisions in the current review of the secondary NAAQS for SO_X, N oxides, and PM. Specifically, this document summarizes the background and rationale for the Administrator's final decisions to revise the secondary SO_2 standard to an annual average, averaged over three consecutive years, with a level of 10 ppb, and to retain the existing standards for N oxides and PM. In conducting this review of the secondary SO_X, N oxides, and PM NAAQS, the EPA has carefully evaluated the currently available scientific literature on the ecological

effects of SO_X, N oxides, and PM [1] as described in the Integrated Science Assessment (ISA) and conducted quantitative air quality, deposition, and risk analyses. The Administrator's final decisions are based on his consideration of the characterization of the available scientific evidence in the ISA; quantitative and policy analyses presented in the Policy Assessment (PA), and related analyses; advice from the Clean Air Scientific Advisory Committee (CASAC); and public comments on the proposed decision.

Sections 108 and 109 of the Clean Air Act (CAA) require the EPA to periodically review the air quality criteria—the science upon which the standards are based—and the standards themselves. Under section 109(b)(2) of the Act, a secondary standard must ''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 protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air.'' As a result of the current review, the Administrator concluded that the current 3-hour secondary SO_2 standard is not requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of SO_X in ambient air, and that it should be revised to an annual average SO_2 standard, averaged over three years, with a level of 10 ppb to provide the requisite protection for the effects of SO_X, including those related to atmospheric deposition of sulfur (S) compounds in sensitive ecosystems. The Administrator also decided to retain the secondary nitrogen dioxide (NO_2) and PM standards, without revision. With regard to the secondary NO_2 standard, the Administrator finds that the evidence related to N oxides does not call into question the adequacy of protection provided by the existing standard. Additionally, the Administrator concludes that no change to the annual secondary $PM_{2.5}$ standard is warranted and that the existing $PM_{2.5}$ secondary standard should be retained without revision.

This document additionally includes revisions related to implementation of the proposed secondary SO_2 annual standard. Specifically, the EPA is enacting revisions to the data handling requirements in appendix T of part 50 to include specifications needed for the new annual average standard. This document also describes the SO_2 monitoring network and its adequacy for surveillance for the revised annual standard. Lastly, the document discusses implementation processes pertinent to implementation of the new standard.

I. Background

A. Legislative Requirements

Two sections of the 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 and then to issue air quality criteria for those pollutants. The Administrator is to list those pollutants ''emissions of which, in his judgment, cause or contribute to air pollution which may reasonably be anticipated to endanger public health or welfare''; ''the presence of which in the ambient air results from numerous or diverse mobile or stationary sources''; and for which he ''plans to issue air quality criteria . . . .'' (42 U.S.C. 7408(a)(1)). Air quality criteria are intended to ''accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of [a] pollutant in the ambient air . . . .'' 42 U.S.C. 7408(a)(2).

Section 109 of the Act (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 [42 U.S.C. 7409(a)]. Under section 109(b)(2), a secondary standard must ''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 protect the public welfare from any known or anticipated adverse effects associated with the presence of [the] pollutant in the ambient air.'' [2]

In setting primary and secondary standards that are ''requisite'' to protect public health and welfare, respectively, 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. See generally, *Whitman* v. *American Trucking Ass'ns,* 531 U.S. 457, 465–472, 475–76 (2001). Likewise, ''[a]ttainability and technological feasibility are not relevant considerations in the promulgation of national ambient air quality standards'' (*American Petroleum Institute* v. *Costle,* 665 F.2d 1176, 1185 [D.C. Cir. 1981]). However, courts have clarified that in deciding how to revise the NAAQS in the context of considering standard levels within the range of reasonable values supported by the air quality criteria and judgments of the Administrator, EPA may consider ''relative proximity to peak background . . . concentrations'' as a factor (*American Trucking Ass'ns,* v. *EPA,* 283 F.3d 355, 379 [D.C. Cir. 2002]).

Section 109(d)(1) of the Act requires periodic review and, if appropriate, revision of existing air quality criteria to reflect advances in scientific knowledge on the effects of the pollutant on public health and welfare. Under the same provision, the EPA is also to periodically review and, if appropriate, revise the NAAQS, based on the revised air quality criteria.[3]

Section 109(d)(2) addresses the appointment and advisory functions of an independent scientific review committee. Section 109(d)(2)(A) requires the Administrator to appoint this committee, which is to be composed of ''seven members including at least one member of the National Academy of Sciences, one physician, and one person representing State air pollution control agencies.'' Section 109(d)(2)(B) provides that the independent scientific review committee ''shall complete a review of the criteria . . . and the national primary and secondary ambient air quality standards . . . and shall recommend to the Administrator any new . . . standards and revisions of existing criteria and standards as may be appropriate. . . .'' Since the early 1980s, this independent review function has been performed by the CASAC of the EPA's Science Advisory Board.

Section 109(b)(2) specifies that ''[a]ny national secondary ambient air quality standard prescribed under subsection (a) 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 protect the public welfare from any known or anticipated adverse effects associated with the presence of such air pollutant in the ambient air.'' Consistent with this statutory direction, EPA has always understood the goal of the

[1] Welfare effects of PM considered in the review of the PM secondary standards completed in 2020, and reconsidered more recently, include effects on visibility and climate and materials damage (88 FR 5558, January 27, 2023).

[2] Under CAA section 302(h) (42 U.S.C. 7602(h)), effects on welfare include, but are not limited to, ''effects on soils, water, crops, vegetation, manmade 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.''

[3] This section of the Act requires the Administrator to complete these reviews and make any revisions that may be appropriate ''at five-year intervals.''

NAAQS is to identify a requisite level of air quality, and the means of achieving a specific level of air quality is to set a standard expressed as a concentration of a pollutant in the air, such as in terms of parts per million (ppm), ppb, or micrograms per cubic meter ($\mu g/m^3$). Thus, while deposition-related effects are included within the ''adverse effects associated with the presence of such air pollutant in the ambient air,'' EPA has never found a standard that quantifies atmospheric deposition onto surfaces to constitute a national secondary ambient air quality standard. Rather, EPA has established ambient air quality standards that specify air quality by quantifying pollution in the ambient air to address effects of such pollution, whether from ambient concentrations or deposition.

B. Related Control Programs

States are primarily responsible for ensuring attainment and maintenance of ambient air quality standards once the EPA has established them. Under CAA sections 110 and part D, subparts 1, 5, and 6 for nitrogen and sulfur oxides, and subparts 1, 4, and 6 for PM, and related provisions and regulations, States are to submit, for the EPA's approval, State implementation plans (SIPs) that provide for the attainment and maintenance of such standards through control programs directed to sources of the pollutants involved. The States, in conjunction with the EPA, also administer the prevention of significant deterioration of air quality program that covers these pollutants. See 42 U.S.C. 7470–7479. In addition, Federal programs provide for or result in nationwide reductions in emissions of N oxides, SO_X, PM and other air pollutants under title II of the Act, 42 U.S.C. 7521–7574, which involves controls for motor vehicles, nonroad engines and equipment, and under the new source performance standards in section 111 of the Act, 42 U.S.C. 7411.

C. History of the Secondary Standards for N Oxides, SO_X and PM

Secondary NAAQS were first established for N oxides, SO_X and PM in 1971 (36 FR 8186, April 30, 1971). Since that time, the EPA has periodically reviewed the air quality criteria and secondary standards for these pollutants, with the most recent reviews that considered the evidence for ecological effects of these pollutants being completed in 2012 and 2013 (77 FR 20218, April 3, 2012; 78 FR 3086, January 15, 2013). The subsections below summarize key proceedings from the initial standard setting in 1971 to the last reviews in 2012–2013.[4]

1. N Oxides

The EPA first promulgated NAAQS for N oxides in April 1971 after reviewing the relevant science on the public health and welfare effects in the 1971 Air Quality Criteria for Nitrogen Oxides (air quality criteria document or AQCD).[5] With regard to welfare effects, the 1971 AQCD described effects of NO_2 on vegetation and corrosion of electrical components linked to particulate nitrate (U.S. EPA, 1971). The primary and secondary standards were both set at 0.053 ppm NO_2 as an annual average (36 FR 8186, April 30, 1971). In 1982, the EPA published an updated AQCD (U.S. EPA, 1982a). Based on the 1982 AQCD, the EPA proposed to retain the existing standards in February 1984 (49 FR 6866, February 23, 1984). After considering public comments, the EPA published the final decision to retain these standards in June 1985 (50 FR 25532, June 19, 1985).

The EPA began a second review of the primary and secondary standards for oxides of nitrogen in 1987 (52 FR 27580, July 22, 1987). In November 1991, the EPA released an updated draft AQCD for CASAC and public review and comment (56 FR 59285, November 25, 1991). The CASAC reviewed the draft document at a meeting held on July 1, 1993, and concluded in a closure letter to the Administrator that the document provided ''an adequate basis'' for EPA's decision-making in the review (Wolff, 1993). The final AQCD was released later in 1993 (U.S. EPA, 1993). Based on the 1993 AQCD, the EPA's Office of Air Quality Planning and Standards (OAQPS) prepared a Staff Paper,[6] drafts of which were reviewed by the CASAC (Wolff, 1995; U.S. EPA, 1995a). In October 1995, the EPA proposed not to revise the secondary NO_2 NAAQS (60 FR 52874; October 11, 1995). After consideration of the comments received on the proposal, the Administrator finalized the decision not to revise the NO_2 NAAQS (61 FR 52852; October 8, 1996). The subsequent (and most recent) review of the N oxides secondary standard was a joint review with the secondary standard for SO_X, which was completed in 2012 (see subsection 4 below).

2. SO_X

The EPA first promulgated secondary NAAQS for SO_X in April 1971 based on the scientific evidence evaluated in the 1969 AQCD (U.S. DHEW, 1969a [1969 AQCD]; 36 FR 8186, April 30, 1971). These standards, which were established on the basis of evidence of adverse effects on vegetation, included an annual arithmetic mean standard, set at 0.02 ppm SO_2,[7] and a 3-hour average standard set at 0.5 ppm SO_2, not to be exceeded more than once per year. In 1973, based on information indicating there to be insufficient data to support the finding of a study in the 1969 AQCD concerning vegetation injury associated with SO_2 exposure over the growing season, rather than from short-term peak concentrations, the EPA proposed to revoke the annual mean secondary standard (38 FR 11355, May 7, 1973). Based on consideration of public comments and external scientific review, the EPA released a revised chapter of the AQCD and published its final decision to revoke the annual mean secondary standard (U.S. EPA, 1973; 38 FR 25678, September 14, 1973). At that time, the EPA additionally noted that injury to vegetation was the only type of SO_2 welfare effect for which the evidence base supported a quantitative relationship, stating that although data were not available at that time to establish a quantitative relationship between SO_2 concentrations and other public welfare effects, including effects on materials, visibility, soils, and water, the SO_2 primary standards and the 3-hour secondary standard may to some extent mitigate such effects. The EPA also stated it was not clear that any such effects, if occurring below the current standards, were adverse to the public welfare (38 FR 25679, September 14, 1973).

In 1979, the EPA announced initiation of a concurrent review of the air quality criteria for SO_X and PM and plans for development of a combined AQCD for these pollutants (44 FR 56730, October

[4] Since the late 1970s, each review of the air quality criteria and standards has generally involved the development of an Air Quality Criteria Document or ISA and a Staff Paper or staff Policy Assessment, which is often accompanied by or includes a quantitative exposure or risk assessment, prior to the regulatory decision-making phase.

[5] In reviews initiated prior to 2007, the AQCD provided the scientific foundation (*i.e.,* the air quality criteria) for the NAAQS. Since that time, the ISA has replaced the AQCD.

[6] Prior to reviews initiated in 2007, the Staff Paper summarized and integrated key studies and the scientific evidence, and from the 1990s onward, it also assessed potential exposures and associated risk. The Staff Paper also presented the EPA staff's considerations and conclusions regarding the adequacy of existing NAAQS and, when appropriate, the potential alternative standards that could be supported by the evidence and information. More recent reviews present this information in the Policy Assessment.

[7] Established with the annual standard as a guide to be used in assessing implementation plans to achieve the annual standard was a maximum 24-hour average concentration not to be exceeded more than once per year (36 FR 8187, April 30, 1971).

2, 1979). The EPA subsequently released three drafts of a combined AQCD for CASAC review and public comment. In these reviews, and in guidance provided at the August 20–22, 1980, public meeting of the CASAC on the first draft AQCD, the CASAC concluded that acidic deposition was a topic of extreme scientific complexity because of the difficulty in establishing firm quantitative relationships among emissions of relevant pollutants, formation of acidic wet and dry deposition products, and effects on terrestrial and aquatic ecosystems (53 FR 14935, April 26, 1988). The CASAC also noted that a fundamental problem of addressing acid deposition in a criteria document is that acid deposition is produced by several different criteria pollutants: SO_X, N oxides, and the fine particulate fraction of suspended particles (U.S. EPA, 1982b, pp. 125–126). The CASAC also felt that any document on this subject should address both wet and dry deposition, since dry deposition was believed to account for a substantial portion of the total acid deposition problem (53 FR 14936, April 26, 1988; Lippman, 1987). For these reasons, CASAC recommended that, in addition to including a summary discussion of acid deposition in the final AQCD, a separate, comprehensive document on acid deposition be prepared prior to any consideration of using the NAAQS as a regulatory mechanism for the control of acid deposition.

Following CASAC closure on the AQCD for SO_X in December 1981, the EPA released a final AQCD (U.S. EPA, 1982b), and the EPA's OAQPS prepared a Staff Paper that was released in November 1982 (U.S. EPA, 1982c). 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, subsequently preparing the following documents to address acid deposition: *The Acidic Deposition Phenomenon and Its Effects: Critical Assessment Review Papers, Volumes I and II* (U.S. EPA, 1984a, b) and *The Acidic Deposition Phenomenon and Its Effects: Critical Assessment Document* (U.S. EPA, 1985) (53 FR 14935–36, April 26, 1988). Although these documents were not considered criteria documents and had not undergone CASAC review, they represented the most comprehensive summary of scientific information relevant to acid deposition completed by the EPA at that point.

In April 1988, the EPA proposed not to revise the existing secondary standards for SO_X (53 FR 14926, April 26, 1988). The proposed decision reflected the Administrator's conclusions that: (1) based upon the then-current scientific understanding of the acid deposition problem, it would be premature and unwise to prescribe any regulatory control program at that time; and (2) when the fundamental scientific uncertainties had been decreased through ongoing research efforts, the EPA would draft and support an appropriate set of control measures (53 FR 14926, April 26, 1988). This review of the secondary standard for SO_X was concluded in 1993, subsequent to the CAA Amendments of 1990 (see section I.C.3.) with the decision not to revise the secondary standard. The EPA concluded that revisions to the standard to address acidic deposition and related SO_X welfare effects were not appropriate at that time (58 FR 21351, April 21, 1993). In describing the decision, the EPA recognized the significant reductions in SO_2 emissions, ambient air SO_2 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 controlling 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).

3. Related Actions Addressing Acid Deposition

In 1980, Congress created the National Acid Precipitation Assessment Program. During the 10-year course of this program, the program issued a series of reports, including a final report 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_2 by 10 million tons and N oxides 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 S and N 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 pertaining to ecosystem effects of criteria pollutants, such as acid deposition. For example, a new section 108(g) was inserted, stating that ''[t]he 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 welfare in CAA section 302(h) was expanded to indicate that welfare effects include those listed therein, ''whether caused by transformation, conversion, or combination with other air pollutants.'' Additionally, in response to legislative initiatives such as the 1990 Amendments, the EPA and other Federal agencies continued research on the causes and effects of acidic deposition and related welfare effects of SO_2 and implemented an enhanced monitoring program to track progress (58 FR 21357, April 21, 1993).

4. Most Recent Review of the Secondary Standards for N Oxides and SO_X

In December 2005, the EPA initiated a joint review [8] of the air quality criteria

[8] Although the EPA has historically reviewed separately the secondary standards for oxides of nitrogen and oxides of sulfur, the EPA conducted a joint review of these standards in recognition of the chemical interactions in the atmosphere and

Continued

and secondary NAAQS for oxides of nitrogen and sulfur (70 FR 73236, December 9, 2005). The review focused on the evaluation of the protection provided by the standards 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 standards were developed to protect against, and (2) effects associated with the deposition of N oxides and SO_X to sensitive aquatic and terrestrial ecosystems (77 FR 20218, April 3, 2012).

The Integrated Review Plan (IRP) for the review was released in December 2007, after review of a draft IRP by the public and CASAC (72 FR 57570, October 10, 2007; Russell, 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 (72 FR 72719, December 21, 2007; 73 FR 10243, February 26, 2008; Russell and Henderson, 2008; 73 FR 46908, August 12, 2008; 73 FR 53242, September 15, 2008; Russell and Samet, 2008a). The EPA released a final ISA (referred to as 2008 ISA below) in December 2008 (73 FR 75716, December 12, 2008; U.S. EPA, 2008a). Based on the scientific information in the ISA, the EPA planned and developed a quantitative Risk and Exposure Assessment (REA),[9] two drafts of which were made available for public comment and reviewed by the CASAC (73 FR 10243, February 26, 2008; 73 FR 50965, August 29, 2008; Russell and Samet, 2008b; 73 FR 53242, September 15, 2008; 74 FR 28698, June 17, 2009; Russell and Samet, 2009). The final REA was released in September 2009 (U.S. EPA, 2009a; 74 FR 48543; September 23, 2009).

Drawing on the information in the REA and ISA, the EPA OAQPS prepared a PA, two drafts of which were made available for public comment and review by the CASAC (75 FR 10479, March 8, 2010; 75 FR 11877, March 12, 2010; Russell and Samet, 2010b; 75 FR 57463, September 21, 2010; 75 FR 65480, October 25, 2010; Russell and Samet, 2010a). The final PA was released in January 2011 (U.S. EPA, 2011). For the purpose of protection against the direct effects on vegetation of exposure to gaseous oxides of nitrogen and sulfur, the final PA concluded that consideration should be given to retaining the current standards. With respect to the effects associated with the deposition of oxides of nitrogen and oxides of sulfur to sensitive aquatic and terrestrial ecosystems, the 2011 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, the 2011 PA concluded that consideration should be given to a new multipollutant standard intended to address deposition-related effects (details provided in section II.A.1.b. below). Based on consideration of the final PA, the CASAC provided additional advice and recommendations on the multipollutant, deposition-based standard described in the 2011 PA (76 FR 4109, January 24, 2011; 76 FR 16768, March 25, 2011; Russell and Samet, 2011).

On August 1, 2011, the EPA published a proposed decision to retain the existing annual average NO_2 and 3-hour average SO_2 secondary standards, recognizing the protection they provided from direct effects on vegetation (76 FR 46084, August 1, 2011). Further, after considering the multipollutant approach to establishing secondary standards that was described in the 2011 PA, the Administrator proposed not to set such a new multipollutant secondary standard in light of a number of uncertainties. Alternatively, the Administrator proposed to revise the secondary standards by adopting secondary NO_2 and SO_2 standards identical to the 1-hour primary NO_2 and SO_2 standards, both of which were set in 2010, noting that these new primary standards, while not set based on consideration of atmospheric deposition,[10] were likely to reduce oxides of nitrogen and sulfur emissions and associated nitrogen and sulfur deposition in sensitive ecosystems (76 FR 46084, August 1, 2011). After consideration of public comments, the EPA decided to retain the existing standards (without revision) to address the direct effects on vegetation of exposure to gaseous oxides of nitrogen and sulfur. At that time, the EPA also described its decision that it was not appropriate to set new secondary standards at that time to address deposition-related effects associated with oxides of nitrogen and sulfur (77 FR 20218, April 3, 2012).

The EPA's 2012 decision was challenged by the Center for Biological Diversity and other environmental groups, who argued that the EPA, having decided that the existing standards were not adequate to protect against adverse public welfare effects such as damage to sensitive ecosystems, was required to identify the requisite level of protection for the public welfare and to issue NAAQS to achieve and maintain that level of protection. The District of Columbia Circuit (D.C. Circuit) disagreed, finding that the EPA acted appropriately in not setting a secondary standard given 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 . . . '.'' [11] 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.[12]

5. PM

The EPA first established a secondary standard for PM in 1971 (36 FR 8186, April 30, 1971), based on the original AQCD, which described the evidence as to effects of PM on visibility, materials, light absorption, and vegetation (U.S. DHEW, 1969b). To provide protection generally from visibility effects and materials damage, the secondary standard was set at 150 μg/m^3, as a 24-hour average, from total suspended particles (TSP), not to be exceeded more than once per year (36 FR 8187; April 30, 1971).[13]

In October 1979, the EPA announced the first review of the air quality criteria and NAAQS for PM (44 FR 56730, October 2, 1979). A combined AQCD for PM and SO_X was released in 1982, after CASAC and public review of drafts (U.S. EPA, 1982b). Soon after, the OAQPS released a Staff Paper (U.S. EPA, 1982d), two drafts of which had received public and CASAC review (Friedlander, 1982). In 1984, the EPA proposed replacing the secondary standard with an annual TSP standard with a level within the range of 70–90 μg/m^3, as an expected annual arithmetic

associated contributions to acid deposition and related environmental effects. The joint review was also responsive to a National Research Council recommendation that the EPA consider pollutants in combination, as appropriate, in considering the NAAQS (NRC, 2004).

[9] The REAs for NAAQS reviews may be presented in appendices to the PA or in stand-alone documents (*e.g.,* U.S. EPA 2020b, 2020c, and PA for current review [U.S. EPA, 2024]).

[10] The 1-hour primary standards set in 2010 were a NO_2 standard of 100 ppb, as the 98th percentile of 1-hour daily maximum concentrations, averaged over three years, and a SO_2 standard of 75 ppb, as the 99th percentile of daily maximum 1-hour concentrations, averaged over three years (75 FR 6474, February 9, 2010; 75 FR 35520, June 22, 2010).

[11] *Center for Biological Diversity, et al.* v. *EPA,* 749 F.3d 1079, 1087 (2014).

[12] *Id.* at 1088.

[13] Additionally, a guide to be used in assessing implementation plans to achieve the 24-hour standard was set at 60 μg/m^3, as an annual geometric mean (36 FR 8187; April 30, 1971).

mean (49 FR 10408, March 20, 1984). After consideration of public comment and review by the CASAC and the public, the OAQPS released an Addendum to the Staff Paper in 1986 (Lippman, 1986; U.S. EPA, 1986). In 1987, the EPA completed the review by adopting two new primary PM NAAQS and setting the secondary standards identical to the primary standards in all respects, all with a new indicator for PM (particles with a nominal mass median diameter of 10 microns, PM_{10}). The new primary and secondary standards included (1) a 24-hour standard of 150 $\mu g/m^3$, in terms of one expected exceedance per year, on average over three years and (2) an annual secondary standard of 50 $\mu g/m^3$, as an annual arithmetic mean, averaged over three years (52 FR 24634, July 1, 1987).

In April 1994, the EPA initiated the second periodic review of the air quality criteria and NAAQS for PM. In developing the AQCD, the Agency made available three external review drafts for public and CASAC review; the final AQCD was released in 1996 (U.S. EPA, 1996). The OAQPS released a Staff Paper in November 1997, after CASAC and public review of two drafts (U.S. EPA, 1996; Wolff, 1996). The EPA proposed revisions to the PM standards in 1996 and promulgated final standards in 1997 (61 FR 65738; December 13, 1996; 62 FR 38652, July 18, 1997). With the 1997 decision, the EPA added new standards, using particles with a nominal mean aerodynamic diameter less than or equal to 2.5 µm ($PM_{2.5}$) as the indicator for fine particles. The new secondary $PM_{2.5}$ standards were set equal to the primary $PM_{2.5}$ standards, in all respects, as follows: (1) an annual standard with a level of 15.0 $\mu g/m^3$, based on the 3-year average of annual arithmetic mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors,[14] and (2) a 24-hour standard with a level of 65 $\mu g/m^3$, based on the 3-year average of the 98th percentile of 24-hour $PM_{2.5}$ concentrations at each monitor within an area. The EPA also retained the primary and secondary annual PM_{10} standards, without revision, and revised the form of the 24-hour primary and secondary PM_{10} standards to be based on the 99th percentile of 24-hour PM_{10} concentrations at each monitor in an area.

Following promulgation of the 1997 PM NAAQS, several parties filed petitions for review, raising a broad range of issues. In May 1999, the U.S. Court of Appeals for the D.C. Circuit upheld the EPA's decision to establish fine particle ($PM_{2.5}$) standards, (*American Trucking Ass'ns, Inc.* v. *EPA,* 175 F. 3d 1027, 1055–56 [D.C. Cir. 1999]). The D.C. Circuit also found ''ample support'' for the EPA's decision to regulate coarse particle (PM_{10}) pollution but vacated the 1997 PM_{10} standards, concluding that the EPA had not provided a reasonable explanation justifying use of PM_{10} as an indicator for coarse particles (*id.* at 1054–55). Pursuant to the D.C. Circuit's decision, the EPA removed the vacated the 1997 PM_{10} standards, leaving the pre-existing 1987 PM_{10} standards in place (65 FR 80776, December 22, 2000). The D.C. Circuit also upheld the EPA's determination not to establish more stringent secondary standards for fine particles to address effects on visibility (*id.* at 1027). The D.C. Circuit also addressed more general issues related to the NAAQS, including issues related to the consideration of costs in setting NAAQS and the EPA's approach to establishing the levels of NAAQS.

In October 1997, the EPA initiated the third periodic review of the air quality criteria and NAAQS for PM (62 FR 55201, October 23, 1997). The EPA released the final AQCD in October 2004, after the CASAC and public review of several drafts (U.S. EPA, 2004a, b). The OAQPS released a Staff Paper in December 2005 (U.S. EPA, 2005). Also in December 2005, the EPA proposed to revise the PM NAAQS and solicited public comment on a broad range of options (71 FR 2620, January 17, 2006). In September 2006, after consideration of public comment, the EPA revised the PM NAAQS, making revisions to the secondary standards identical to those for the primary standards, with the decision describing the protection provided specifically for visibility and non-visibility related welfare effects (71 FR 61144, 61203–61210, October 17, 2006). The EPA revised the level of the 24-hour $PM_{2.5}$ standards to 35 $\mu g/m^3$, retained the level of the annual $PM_{2.5}$ standards at 15.0 $\mu g/m^3$, and revised the form of the annual $PM_{2.5}$ standards by narrowing the constraints on the optional use of spatial averaging. For PM_{10}, the EPA revoked the annual standards and retained the 24-hour standards, both with a level of 150 $\mu g/m^3$.

Several parties filed petitions for review of the 2006 p.m. NAAQS decision, with one raising the issue of the secondary $PM_{2.5}$ standards being identical to the primary standards. On February 24, 2009, the D.C. Circuit issued its opinion in *American Farm Bureau Federation* v. *EPA,* 559 F. 3d 512 (D.C. Cir. 2009), remanding the standards to the EPA stating the Agency had failed to adequately explain how setting the secondary standards identical to the primary standards provided the required public welfare protection, including for visibility impairment (*Id.* at 528–32). The EPA responded to the court's remands as part of the subsequent PM NAAQS review.

In June 2007, the EPA initiated the fourth periodic review of the air quality criteria and the PM NAAQS (72 FR 35462, June 28, 2007). To inform planning for the review, the EPA held science/policy issue workshops later that year (72 FR 34003, June 20, 2007; 72 FR 34005, June 20, 2007). Plans for the review and for welfare assessments were developed in 2008 and 2009; the ISA was completed in 2009, an urban-focused visibility assessment was completed in 2010 and the PA was released in 2011 (U.S. EPA, 2008b; U.S. EPA, 2009b; U.S. EPA, 2009c; U.S. EPA, 2010; U.S. EPA, 2011). In June 2012, the EPA proposed revisions to the PM NAAQS and in December 2012 announced its final decisions to revise the primary and secondary $PM_{2.5}$ annual standards (77 FR 38890, June 29, 2012; 78 FR 3086, January 15, 2013). With regard to the secondary standards, the EPA retained the 24-hour $PM_{2.5}$ and PM_{10} standards, with a revision to the form of the 24-hour $PM_{2.5}$, to eliminate the option for spatial averaging (78 FR 3086, January 15, 2013). Petitioners challenged the EPA's final rule. On judicial review, the revised standards and monitoring requirements were upheld in all respects (*National Association of Manufacturers* v. *EPA,* 750 F.3d 921, [D.C. Cir. 2014]).

The subsequent review of the PM secondary standards, completed in 2020, and its subsequent reconsideration focused on consideration of protection provided from visibility effects, materials damage, and climate effects (85 FR 82684, December 18, 2020; 89 FR 16202, March 6, 2024). Those effects—visibility effects, materials damage and climate effects—are not addressed in this review. The evidence for ecological effects of PM is addressed in the review of the air quality criteria and standards described in the PA for this review.

[14] The 1997 annual $PM_{2.5}$ standard was compared with 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 last review (completed in 2012) 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 core-based statistical area (CBSA) (78 FR 3236, January 15, 2013).

D. Current Review

In August 2013, the EPA issued a call for information in the **Federal Register** for information related to the current review of the air quality criteria for SO_X and N oxides and announced a public workshop to discuss policy-relevant scientific information to inform the review (78 FR 53452, August 29, 2013). Based in part on the information received in response to the call for information, the EPA developed a draft IRP, which was made available for consultation with the CASAC and for public comment (80 FR 69220, November 9, 2015). Comments from the CASAC and the public on the draft IRP were considered in preparing the final IRP (Diez Roux and Fernandez, 2016; U.S. EPA, 2017). In developing the final IRP, the EPA expanded the review to also include review of the criteria and standards related to ecological effects of PM in recognition of atmospheric transformations and deposition involving the three pollutants (N oxides, SO_X and PM) and associated ecological effects (U.S. EPA, 2017). In so doing, the EPA clarified that other effects of PM, including materials damage, climate effects and visibility effects are beyond the scope of this review (IRP, p. 1–2 and section 2.1).

In March 2017, the EPA released the first external review draft of the *Integrated Science Assessment (ISA) for Oxides of Nitrogen, Oxides of Sulfur, and Particulate Matter Ecological Criteria* (82 FR 15702, March 30, 2017), which was then reviewed by the CASAC at public meetings in May and August 2017 (82 FR 15701, March 30, 2017; 82 FR 35200, July 28, 2017; Diez Roux and Fernandez, 2017). A second external review draft ISA was released in 2018 and reviewed by the CASAC at public meetings in September 2018 and April 2020 (83 FR 2018; July 9, 2018; 85 FR 16093, March 30, 2020; Cox, Kendall, and Fernandez, 2020a).[15] The EPA released the final ISA in October 2020 (85 FR 66327, October 19, 2020; U.S. EPA, 2020a).

In 2023, the draft PA, including the REA for aquatic acidification as an appendix,[16] was released for review by the CASAC and for public comment (88 FR 34852, May 31, 2023). The CASAC conducted its review at public meetings in June and September 2023 and conveyed its advice to the Administrator on the standards and comments on the draft PA in late September 2023 (88 FR 17572, March 23, 2023; 88 FR 45414, July 17, 2023; Sheppard, 2023). In January 2024, the EPA released the final PA (89 FR 2223, January 12, 2024; U.S. EPA, 2024). In April 2024, the EPA proposed to revise the secondary SO_2 standard and retain the secondary standards for N oxides and PM (89 FR 26620, April 15, 2024). During the subsequent public comment period, public comments were received both orally during a virtual public hearing on May 8, 2024 (89 FR 26114, April 15, 2024) and in writing to the docket (as discussed in section II.B.2. below).[17] Significant comments received are addressed in this preamble to this final action and in the accompanying Response to Comments document, which can be found in the docket for this review. The schedule for completion of this review has been governed by a consent decree that requires the EPA to sign for publication a notice of final rulemaking concerning review of the NAAQS for N oxides, SO_X and PM no later than December 10, 2024 (*Center for Biological Diversity* v. *Regan* [No. 4:22–cv–02285–HSG (N.D. Cal.)]).

Materials upon which the decision in this review is based, including the documents described above, are available to the public in the docket for this review.[18] The EPA is basing its decision in this review on studies and related information included in the air quality criteria, which have undergone CASAC and public review. The studies assessed in the ISA and PA, and the integration of the scientific evidence presented in them, have undergone extensive critical review by the EPA, the CASAC, and the public. The rigor of that review makes these studies, and their integrative assessment, the most reliable source of scientific information on which to base decisions on the NAAQS, decisions that all recognize to be of great import. Decisions on the NAAQS can have profound impacts on public health and welfare, and NAAQS decisions should be based on studies that have been rigorously assessed in an integrated manner not only by the EPA but also by the statutorily mandated independent scientific advisory committee, as well as the public review that accompanies this process.

Some commenters have referred to and discussed individual scientific studies on the welfare effects of SO_X, N oxides, and PM that were not included in the ISA (''new'' studies) and that have not gone through this comprehensive review process. In considering and responding to comments for which such ''new'' studies were cited in support, the EPA has provisionally considered the cited studies in the context of the findings of the ISA (Weaver, 2024). The EPA's provisional consideration of these studies did not and could not provide the kind of in-depth critical review described above, but rather was focused on determining whether they warranted reopening the review of the air quality criteria to enable the EPA, the CASAC and the public to consider them further as part of this review. This approach, and the decision to rely on studies and related information included in the air quality criteria, which have undergone CASAC and public review, is consistent with the EPA's practice in prior NAAQS reviews and its interpretation of the requirements of the CAA. Since the 1970 amendments, the EPA has taken the view that NAAQS decisions are to be based on scientific studies and related information that have been assessed as a part of the pertinent air quality criteria, and the EPA has consistently followed this approach. This longstanding interpretation was strengthened by new legislative requirements enacted in 1977, which added section 109(d)(2) of the Act concerning CASAC review of air quality criteria. See 71 FR 61144, 61148 (October 17, 2006, final decision on review of NAAQS for particulate matter) for a detailed discussion of this issue and the EPA's past practice.

As discussed in the EPA's 1993 decision not to revise the ozone (O_3) NAAQS, ''new'' studies may sometimes be of such significance that it is appropriate to delay a decision in a NAAQS review and to supplement the pertinent air quality criteria so the studies can be taken into account (58 FR at 13013–13014, March 9, 1993). In the present case, the EPA's consideration of ''new'' studies concludes that, taken in context, the ''new'' information and findings do not materially change any of the broad scientific conclusions made in the air quality criteria regarding the health and welfare effects of the subject pollutants in ambient air. For this reason, reopening the air quality criteria review is not warranted. Accordingly, the EPA is basing the final decisions in this review on the studies and related information included in the air quality

[15] A change in CASAC membership contributed to an extended time period between the two public meetings.

[16] The planning document for quantitative aquatic acidification exposure/risk analyses was also made available for public comment and consultation with the CASAC (83 FR 31755, July 9, 2018; Cox, Kendall, and Fernandez, 2020b; U.S. EPA, 2018; 83 FR 42497, August 22, 2018).

[17] The public hearing transcript and any written testimony provided are also in the docket.

[18] The docket for this review, Docket ID No. EPA–HQ–OAR–2014–0128, has incorporated the ISA docket (Docket ID No. EPA–HQ–ORD–2013–0620) by reference. Both are publicly accessible at *https://www.regulations.gov*.

criteria that have undergone rigorous review by the EPA, the CASAC, and the public. The EPA will consider these ''new'' studies for inclusion in the air quality criteria for the next review, which will provide the opportunity to fully assess these studies through a more rigorous review process involving the EPA, the CASAC, and the public.

II. Rationale for Decisions

This section presents the rationale for the Administrator's decisions in the review of the secondary NAAQS for the ecological effects of SO_X, N oxides and PM. This rationale is based on a thorough review of the full evidence base, including the scientific information available since the last reviews of the secondary standards for N oxides, SO_X and PM. This information on ecological effects associated with SO_X, N oxides and PM and pertaining to their presence in ambient air, which includes studies generally published between January 2008 and May 2017 (and considered in the ISA), is integrated with the information and conclusions from previous assessments and presented in the ISA (ISA, section IS.1.2).[19] The Administrator's rationale also takes into account: (1) the PA evaluation of the policy-relevant information in the ISA and presentation of quantitative analyses of air quality, exposure and aquatic acidification risks; (2) CASAC advice and recommendations, as reflected in discussions of drafts of the ISA and PA at public meetings and in the CASAC's letters to the Administrator; (3) public comments received during the development of these documents; and (4) public comments received on the proposed decisions.

Before presenting the rationale for the Administrator's final decisions and their foundations, section II.A.1. provides an introduction that also summarizes the basis for the existing standards (section II.A.1.a.), provides background on the prior review of deposition-related effects of N oxides and SO_X (section II.A.1.b.), and summarizes the general approach in this review (section II.A.1.c.). Section II.A.2. provides an overview of the air quality information and analyses relating S and N deposition to concentrations of SO_X, N oxides and PM. Section II.A.3. provides an overview of the currently available ecological effects evidence as summarized in the ISA, focusing on consideration of key policy-relevant aspects, and section II.A.4. provides an overview of the exposure and risk information for this review, drawing on the quantitative analyses of aquatic acidification risk, presented in the PA. Section II.B.1. provides a summary of the Administrator's proposed decisions (section II.B.1.c.), which drew on both evidence-based and exposure/risk-based considerations from the PA (section II.B.1.a.) and advice from the CASAC (section II.B.1.b.). Section II.B.2. discusses comments received on the proposed decision, and section II.B.3. presents the Administrator's conclusions and associated rationale. The final decisions are summarized in section II.C.

A. Introduction

The Agency's approach in its review of secondary standards is consistent with the requirements of the provisions of the CAA related to the review of NAAQS and with how the EPA and the courts have historically interpreted the CAA. These provisions require the Administrator to establish secondary standards that, in the Administrator's judgment, are requisite (*i.e.,* neither more nor less stringent than necessary) to protect the public welfare from known or anticipated adverse effects associated with the presence of the pollutant in the ambient air. In so doing, the Administrator considers advice from the CASAC and public comment. This approach is based on a recognition that the available welfare effects evidence generally reflects a range of effects that include ambient air-related exposure circumstances for which scientists generally agree that effects are likely to occur as well as lower levels at which the likelihood and magnitude of response become increasingly uncertain. The CAA does not require that standards be set at a zero-risk level, but rather at a level that reduces risk sufficiently to protect the public welfare from known or anticipated adverse effects.

The Agency's decisions on the adequacy of the current secondary standards and, as appropriate, on any potential alternative standards considered in a review, are largely public welfare policy judgments made by the Administrator based on the Administrator's informed assessment of what constitutes requisite protection against adverse effects to the public welfare. A public welfare policy decision draws upon scientific information and analyses about welfare effects, exposures and risks, as well as judgments about the appropriate response to the range of uncertainties that are inherent in the scientific evidence and analyses. The ultimate determination as to what level of damage to ecosystems and the services provided by those ecosystems is adverse to public welfare is not wholly a scientific question, although it may be informed by scientific studies linking ecosystem damage to losses in ecosystem services and information on the value of those losses of ecosystem services. In reaching decisions on secondary standards, the Administrator seeks to establish standards that are neither more nor less stringent than necessary for this purpose. In evaluating the public welfare protection afforded by the standards, the four basic elements of the NAAQS (indicator, averaging time, level, and form) are considered collectively.[20]

Generally, conclusions reached by the Administrator in secondary NAAQS reviews on the amount of public welfare protection from the presence of the pollutant(s) in ambient air that is appropriate to be afforded by a secondary standard take into account a number of considerations. Among these considerations are the nature and degree of effects of the pollutant, including the Administrator's judgments on what constitutes an adverse effect to the public welfare, as well as the strengths and limitations of the available and relevant information, with its associated uncertainties. Across reviews, it is generally recognized that such judgments should neither overstate nor understate the strengths and limitations of the evidence and information nor the

[19] In addition to the review's opening ''Call for Information'' (78 FR 53452, August 29, 2013), multiple search methodologies were applied to identify relevant scientific findings that have emerged since the 2008 ISA. Search techniques for the current ISA identified and evaluated studies and reports that have undergone scientific peer review and were published or accepted for publication between January 2008 (providing some overlap with the cutoff date for the 2008 ISA) and May 2017. Studies published after the literature cutoff date for this ISA were also considered in the ISA if they were submitted in response to the Call for Information or identified in subsequent phases of ISA development, particularly to the extent that they provide new information that affects key scientific conclusions. References that are cited in the ISA, the references that were considered for inclusion but not cited, and electronic links to bibliographic information and abstracts can be found at: *https://hero.epa.gov/hero/index.cfm/project/page/project_id/2965* (ISA, section IS.1.2).

[20] The indicator defines the chemical species or mixture to be measured in the ambient air for the purpose of determining whether an area attains the standard. The averaging time defines the period over which air quality measurements are to be averaged or otherwise analyzed. The form of a standard defines the air quality statistic that is to be compared to the level of the standard in determining whether an area attains the standard. For example, the form of the annual NAAQS for fine particulate matter ($PM_{2.5}$) is the average of annual mean concentrations for three consecutive years, while the form of the 3-hour secondary NAAQS for SO_2 is the second highest 3-hour average in a year. The level of the standard defines the air quality concentration used for that purpose.

appropriate inferences to be drawn as to risks to public welfare, and that the choice of the appropriate level of protection is a public welfare policy judgment entrusted to the Administrator under the CAA taking into account both the available evidence and associated uncertainties (80 FR 65404–05, October 26, 2015). Thus, the Administrator's final decisions in such reviews draw upon the scientific information and analyses about welfare effects, environmental exposures and risks, and associated public welfare significance, as well as judgments about how to consider the range and magnitude of uncertainties that are inherent in the scientific evidence and quantitative analyses.

1. Background

Ecological effects of N oxides, SO_X and PM include those related to direct contact of the airborne pollutants with plants and those related to atmospheric deposition of N- and S-containing compounds into sensitive ecosystems. As summarized in section II.A.1.a. below, it is the former category of effects (from direct contact) that were considered in establishing the existing standards, with those effects as the basis for the secondary standards for N oxides and SO_X. In the last review of those standards, deposition-related effects were also considered. However, as summarized in section II.A.1.b. below, the extent of the uncertainties associated with the complex methodology investigated for defining a deposition-based standard in that review were found to be so significant that the Administrator concluded that the limitations and uncertainties in the available information were too great to support establishment of a new standard using this methodology that could be concluded to provide the requisite protection for such effects under the Act (77 FR 20218, April 3, 2012). As described in the proposal for the current action, and generally summarized in section II.A.1.c. below, in the current review we have taken a different approach to considering standards that might be expected to provide the appropriate level of protection from deposition-related effects.

a. Basis for Existing Secondary Standards

The existing 3-hour secondary SO_2 standard, with its level of 0.5 ppm, and the annual secondary NO_2 standard, with its level of 0.053 ppm were established in 1971 (36 FR 8186, April 30, 1971). The basis for both the existing SO_2 and NO_2 secondary standards is to provide protection to the public welfare related to direct effects on vegetation (U.S. DHEW, 1969a; U.S. EPA, 1971). There are three secondary PM standards—established in 1997 (annual $PM_{2.5}$ standard) and 2006 (24-hour $PM_{2.5}$ and PM_{10} standards)—variously based on consideration of materials damage, visibility impacts, climate effects and ecological effects.[21]

The welfare effects evidence for SO_X in previous reviews indicates a relationship between short- and long-term SO_2 exposures and foliar damage to cultivated plants, as well as reductions in productivity, species richness, and diversity (U.S. DHEW, 1969a; U.S. EPA, 1982c; U.S. EPA, 2008a). At the time the standard was set, concentrations of SO_2 in the ambient air were also associated with other welfare effects, including effects on materials and visibility related to sulfate, a particulate transformation product of SO_2 (U.S. DHEW, 1969a). However, the available data were not sufficient to establish a quantitative relationship between specific SO_2 concentrations and such effects (38 FR 25679, September 14, 1973). Accordingly, direct effects of SO_X in ambient air on vegetation are the basis for the existing secondary standard for SO_X.

The welfare effects evidence for N oxides in previous reviews includes foliar injury, leaf drop, and reduced yield of some crops (U.S. EPA, 1971; U.S. EPA, 1982c; U.S. EPA, 1993; U.S. EPA, 2008a). Since it was established in 1971, the secondary standard for N oxides has been reviewed three times, in 1985, 1996, and 2012 (50 FR 25532, June 19, 1985; 61 FR 52852; October 8, 1996; 77 FR 20218, April 3, 2012). Although those reviews identified additional effects related to N deposition, they all have concluded that the existing NO_2 secondary standard provided adequate protection related to the effects of direct contact of airborne N oxides with vegetation on which the standard is based.

In the last review of the secondary PM standards with regard to protection from ecological effects, completed in 2013, the EPA retained the 24-hour $PM_{2.5}$ standard, with its level of 35 μg/m^3, and the 24-hour PM_{10} standard, with its level of 150 μg/m^3 (78 FR 3228, January 15, 2013). With regard to the annual $PM_{2.5}$ standard, the EPA retained the averaging time and level, set at 15 μg/m^3, while revising the form to remove the option for spatial averaging consistent with this change to the primary annual $PM_{2.5}$ standard (78 FR 3225, January 15, 2013). The effects considered in that review of the secondary PM standards include effects on visibility, materials damage, and climate effects, as well as ecological effects; the EPA concluded that those standards provided protection for ecological effects (*e.g.,* 78 FR 3225–3226, 3228, January 15, 2013). In reaching this conclusion, it was noted that the PA for the review explicitly excluded discussion of the effects associated with deposited PM components of N oxides and SO_X and their transformation products, which were being addressed in the joint review of the secondary NO_2 and SO_2 NAAQS (78 FR 3202, January 15, 2013). The ecological effects of PM considered in the 2013 review included direct effects on plant foliage as well as effects of the ecosystem loading of PM constituents such as metals or organic compounds (2009 ISA, section 2.5.3). For all of these effects, the 2013 decision recognized an absence of information that would support any different standards and concluded the existing standards, with the revision to the form of the annual $PM_{2.5}$ standard, provided the requisite protection (78 FR 3086, January 15, 2013).

b. Prior Review of Deposition-Related Effects

In the 2012 review of the NO_2 and SO_2 secondary standards, the EPA recognized that a significant increase in understanding of the effects of N oxides and SO_X had occurred since the preceding secondary standards reviews for those pollutants (77 FR 20236, April 3, 2012). Considering the extensive evidence available in the 2012 review, the Agency concluded that the most significant risks of adverse effects of N oxides and SO_X to the public welfare were those related to deposition of N and S compounds in both terrestrial and aquatic ecosystems (77 FR 20236, April 3, 2012). Accordingly, in addition to evaluating the protection provided by the secondary standards for N oxides and SO_X from effects associated with the airborne pollutants, the 2012 review also included extensive analyses of the welfare effects associated with atmospheric deposition of N and S compounds in sensitive aquatic and terrestrial ecosystems, described in the 2009 REA and 2011 PA (77 FR 20218, April 3, 2012).

The 2009 REA assessed atmospheric deposition of N and S compounds and the risks it posed of two categories of ecosystem effects: acidification and nutrient enrichment in both terrestrial

[21] As noted in section I.D. above, the 2020 review of the PM secondary NAAQS and its reconsideration focused on visibility effects, materials damage and climate effects, while the ecological effects of PM are being addressed in this combined review (89 FR 16205, March 6, 2024).

and aquatic ecosystems (U.S. EPA, 2009a). In so doing, however, the 2009 REA and 2011 PA recognized that the different types of effects varied in the strength of the evidence and of the information characterizing quantitative linkages between pollutants in ambient air and ecosystem responses, and in associated potential public welfare implications. The support in the evidence for quantitative assessment of aquatic acidification-related effects was strongest and the least uncertain.

With regard to nutrient enrichment-related effects, despite the extensive evidence of deleterious effects of excessive ecosystem loading of nitrogen, the identification of options to provide protection from deposition-related effects was limited by several factors. These included the influence in terrestrial ecosystems of other air pollutants such as O_3, and limiting factors such as moisture and other nutrients, and their potential to confound the characterization of the effects of changes in any one stressor, such as N deposition, in those systems (2011 PA, section 6.3.2). Forest management practices were also recognized to have the ability to significantly affect nitrogen cycling within a given forest ecosystem (2008 ISA section 3.3.2.1 and Annex C, section C.6.3). In aquatic systems, appreciable contributions of non-atmospheric sources to nutrient loading in most large waterbodies, and limitations in data and tools, contributed uncertainties to characterizations of incremental adverse impacts of atmospheric N deposition (2011 PA, section 6.3.2). With regard to terrestrial acidification effects, data limitations contributed uncertainty to identification of appropriate indicator reference levels, and the potential for other stressors to confound relationships between deposition and terrestrial acidification effects was recognized with regard to empirical case studies described in the 2008 ISA.

Based on the strong support in the evidence for the relationship between atmospheric deposition of acidifying N and S compounds and loss of acid neutralizing capacity (ANC) in sensitive ecosystems, with associated aquatic acidification effects, the REA analyses for this endpoint (aquatic acidification) received greatest emphasis in the review relative to other deposition-related effects. This emphasis on aquatic acidification-related effects of N oxides and SO_X also reflected the advice from the CASAC. Accordingly, the 2011 PA focused on aquatic acidification effects in identifying policy options for providing public welfare protection from deposition-related effects of N oxides and SO_X, concluding that the available information and assessments were only sufficient at that time to support development of a standard to address aquatic acidification. Consistent with this, the PA concluded it was appropriate to consider a secondary standard in the form of an aquatic acidification index (AAI) and identified a range of AAI values (which correspond to ANC levels) for consideration in establishing such a standard (2011 PA, section 7.6.2). Conceptually, the AAI is an index that uses the results of ecosystem and air quality modeling to estimate waterbody ANC. The standard level for an AAI-based standard was conceptually envisioned to be a national minimum target ANC for waterbodies in the ecoregions of the U.S. for which data were considered adequate for these purposes (2011 PA, section 7.6.2).

While the NAAQS have historically been set in terms of an ambient air concentration, an AAI-based standard was envisioned to have a single value established for the AAI, but the concentrations of SO_X and N oxides would be specific to each ecoregion, taking into account variation in several factors that influence waterbody ANC, and consequently could vary across the U.S. The factors, specific to each ecoregion (''F factors''), which it was envisioned would be established as part of the standard, include surface water runoff rates and ''transference ratios.'' The latter is the term assigned to factors applied to deposition values (estimated to achieve the minimum specified ANC) to back-calculate or estimate the highest ambient air concentrations of SO_X and N oxides that would meet the AAI-based standard level (2011 PA, Chapter 7).[22] The ecoregion-specific values for these factors would be specified based on then-available data and simulations of the Community Multiscale Air Quality (CMAQ) model and codified as part of such a standard. As part of the standard, these factors would be reviewed in the context of each periodic review of the NAAQS.

After consideration of the PA conclusions, the Administrator concluded that while the conceptual basis for the AAI was supported by the available scientific information, there were limitations in the available relevant data and uncertainties associated with specifying the elements of the AAI, specifically those based on modeled factors, that posed obstacles to establishing such a standard under the CAA. It was recognized that the general structure of an AAI-based standard addressed the potential for contributions to acid deposition from both N oxides and SO_X and quantitatively described linkages between ambient air concentrations, deposition, and aquatic acidification, considering variations in factors affecting these linkages across the country. However, the Administrator judged that the limitations and uncertainties in the available information were too great to support establishment of a new standard that could be concluded to provide the requisite protection for such effects under the Act (77 FR 20218, April 3, 2012). These uncertainties generally related to the quantification of the various elements of the standard (the ''F factors'') and their representativeness at an ecoregion scale. These uncertainties and the complexities in this approach were recognized to be unique to the 2012 review of the NAAQS for N and S oxides and were concluded to preclude the characterization and degree of protectiveness that would be afforded by an AAI-based standard, within the ranges of levels and forms identified in the PA, and the representativeness of F factors in the AAI equation described in the 2011 PA (77 FR 20261, April 3, 2012). As the EPA said:

> ''[T]he Administrator recognizes that characterization of the uncertainties in the AAI equation as a whole represents a unique challenge in this review primarily as a result of the complexity in the structure of an AAI based standard. In this case, the very nature of some of the uncertainties is fundamentally different than uncertainties that have been relevant in other NAAQS reviews. She notes, for example, some of the uncertainties uniquely associated with the quantification of various elements of the AAI result from limitations in the extent to which ecological and atmospheric models, which have not been used to define other NAAQS, have been evaluated. Another important type of uncertainty relates to limitations in the extent to which the representativeness of various factors can be determined at an ecoregion scale, which has not been a consideration in other NAAQS.'' [77 FR 20261, April 3, 2012]

The Administrator concluded that while the existing secondary standards were not adequate to provide protection against potentially adverse deposition-

[22] These were among the ecoregion-specific factors that comprised the parameters F1 through F4 in the AAI equation (2011 PA, p. 7–37). The parameter F2 represented the ecoregion-specific estimate of acidifying deposition associated with reduced forms of nitrogen, NH_X (2011 PA, p. 7–28 and ES–8 to ES–9). The 2011 PA suggested that this factor could be specified based on a 2005 CMAQ model simulation over 12-km grid cells or might involve the use of monitoring data for NH_X applied in dry deposition modeling. It was recognized that appreciable spatial variability, as well as overall uncertainty, were associated with this factor.

related effects associated with N oxides and SO_X, it was not appropriate under section 109 of the CAA (given the uncertainties summarized immediately above) to set any new or additional standards at that time to address effects associated with deposition of N and S compounds on sensitive aquatic and terrestrial ecosystems (77 FR 20262–20263, April 3, 2012). This decision was upheld upon judicial review.

c. General Approach for This Review

As is the case for all NAAQS reviews, this secondary standards review uses the Agency's assessment of the current scientific evidence and associated quantitative analyses as a foundation to inform the Administrator's judgments regarding secondary standards for SO_X, N oxides and PM that are requisite to protect the public welfare from known or anticipated adverse effects associated with that pollutant's presence in the ambient air. The approach for this review of the secondary SO_X, N oxides, and PM standards builds on the last reviews of those pollutants, including the substantial assessments and evaluations performed over the course of those reviews, and considering the more recent scientific information and air quality data now available to inform understanding of the key policy-relevant issues in the current review. The EPA's assessments are primarily documented in the ISA and PA, both of which received CASAC review and public comment, as summarized in section I.D. above.

This review of the secondary standards for SO_X, N oxides, and PM assesses the protection provided by the standards from two categories of effects: direct contact effects of the airborne pollutants and also the effects of the associated S- and N-containing compounds (in gaseous and particulate form) deposited in ecosystems. In so doing, the review draws on the currently available evidence as assessed in the ISA (and prior assessments) and quantitative exposure, risk, and air quality information in the PA, including the REA for aquatic acidification.

With regard to direct contact effects, we draw on the currently available evidence as assessed in the ISA, including the determinations regarding the causal nature of relationships between the airborne pollutants and ecological effects, which focus most prominently on vegetation, and quantitative exposure and air quality information. Based on this information, we consider the policy implications, most specifically whether the evidence supports the retention or revision of the current NO_2 and SO_2 secondary standards. With regard to the effects of PM, we take a similar approach, based on the evidence presented in the current ISA and conclusions from the review of the PM NAAQS concluded in 2013 (in which ecological effects were last considered) to assess the effectiveness of the current PM standard to protect against these types of impacts.

With regard to deposition-related effects, we consider the evidence for the array of effects identified in the ISA (and summarized in section II.A.3. below), including both terrestrial and aquatic effects; and the limitations in the evidence and associated uncertainties as well as the public welfare implications of such effects. The overall approach takes into account the nature of the welfare effects and the exposure conditions associated with effects in identifying S and N deposition levels appropriate to consider in the context of public welfare protection. To identify and evaluate metrics relevant to air quality standards (and their elements), we have assessed relationships developed from air quality measurements near pollutant sources and deposition estimates nearby and in downwind ecoregions. In so doing, the available quantitative information both on deposition and effects, and on ambient air concentrations and deposition, has been assessed with regard to the existence of linkages between SO_X, N oxides, and PM in ambient air and deposition-related effects. These assessments, summarized briefly in the sections below (and in detail in the PA), inform judgments on the likelihood of occurrence of deposition-related effects under air quality that meets the existing standards for these pollutants or potential alternatives.

In considering the information on atmospheric deposition and ecological effects, we recognize that the impacts from the dramatically higher deposition rates of the past century can affect how ecosystems and biota respond to more recent, lower deposition rates, complicating interpretation of impacts related to more recent, lower deposition levels. This complexity is illustrated by findings of studies that compared soil chemistry across intervals of 15 to 30 years (1984–2001 and 1967–1997). These studies reported that although atmospheric deposition in the Northeast declined across those intervals, soil acidity increased (ISA, Appendix4, section 4.6.1). As noted in the ISA, ''[i]n areas where N and S deposition has decreased, chemical recovery must first create physical and chemical conditions favorable for growth, survival, and reproduction'' (ISA, Appendix 4, section 4.6.1). Thus, the extent to which S and N compounds (once deposited) are retained in soil matrices (with potential effects on soil chemistry) influences the dynamics of the response of the various environmental pathways to changes in air quality, including changes in emissions, ambient air concentrations and associated deposition.

The two-pronged approach applied in the PA for deposition-related effects includes the consideration of deposition levels that may be associated with ecological effects of potential concern and consideration of relationships between ambient air concentrations and levels of deposition. In considering the ecological effects evidence, the focus is on effects for which the evidence is most robust with regard to established quantitative relationships between deposition and ecosystem effects. Such quantitative information for terrestrial ecosystems is derived primarily from analysis of the evidence presented in the ISA. For aquatic ecosystems, the primary focus has been given to effects related to aquatic acidification, for which we have conducted quantitative risk and exposure analyses based on available modeling applications that relate acid deposition and acid buffering capability in U.S. waterbodies, as summarized in section II.A.4. below (PA, section 5.1 and Appendix 5A). Regarding the second prong of the approach, we employed several different types of analyses to inform an understanding of relationships between ambient air concentrations near pollutant sources in terms of metrics relevant to air quality standards (and their elements) and ecosystem deposition estimates (as described in section II.A.2. below). Interpretation of findings from these analyses, in combination with the identified deposition levels of interest, and related policy judgments regarding limitations and associated uncertainties of the underlying information, informed the Administrator's proposed conclusions on the extent to which existing standards, or potential alternative standards, might be expected to provide protection from these levels and inform the Administrator's final decisions in this review, as discussed in section II.B.3. below.

In summary, the approach to evaluating the standards with regard to protection from ecological effects related to ecosystem deposition of N and S compounds in this review involves multiple components: (1) review of the scientific evidence to identify the ecological effects associated with the three pollutants, those related

both to direct pollutant contact and to ecosystem deposition; (2) assessment of the evidence and characterization of the REA results to identify deposition levels related to categories of ecosystem effects; and (3) analysis of relationships between ambient air concentrations of the pollutants and deposition of N and S compounds to understand aspects of these relationships that can inform judgments on ambient air standards that protect against air concentrations associated with direct effects and against deposition associated with deposition-related effects that are judged adverse to the public welfare. As discussed in the PA and the proposal, however, relating ambient air concentrations of N oxides and PM to deposition of N compounds is particularly complex because N deposition also results from an additional air pollutant that is not controlled by NAAQS for N oxides and PM. Thus, separate from the evaluation of secondary standards for SO_X, the evaluation for N oxides and PM also considers current information (*e.g.,* spatial and temporal trends) related to the additional air pollutant, ammonia (NH_3), that contributes to N deposition and also related to PM components that do not contribute to N deposition. Evaluation of all of this information, together, is considered by the Administrator in reaching his decision, as summarized in section II.B.3. below.

2. Overview of Air Quality and Deposition

The three criteria pollutants that are the focus of this review (SO_X, N oxides, and PM) include both gases and particles. Both their physical state and chemical properties, as well as other factors, influence their deposition as N- or S-containing compounds. The complex pathway from pollutant and precursor emissions (section II.A.2.a.) to ambient air concentrations (section II.A.2.b.) and to eventual deposition (section II.A.2.c.) varies by pollutant and is influenced by a series of atmospheric processes and chemical transformations that occur at multiple spatial and temporal scales (ISA, Appendix 2; PA, Chapters 2 and 6).

A complication in the consideration of the influence of these criteria pollutants on N deposition and associated ecological effects is posed by the contribution of other, non-criteria, pollutants in ambient air, specifically NH_3. Although emissions of N oxides have appreciably declined, NH_3 emissions have risen. Together, these co-occurring trends have reduced the influence of N oxides on total N deposition (PA, sections 6.2.1, 6.4.2 and 7.2.3.3). Geographic variability and temporal changes in the percentage of PM composed of N- (and S-) containing compounds, are other factors affecting decisions in this review.

a. Sources, Emissions and Atmospheric Processes Affecting SO_X, N Oxides and PM

Sulfur dioxide is generally present at higher concentrations in the ambient air than the other gaseous and highly reactive SO_X (ISA, Appendix 2, section 2.1) and, as a result, SO_2 is the indicator for the existing NAAQS for SO_X. The main anthropogenic source of SO_2 emissions is fossil fuel combustion (PA, section 2.2.2). Based on the 2020 National Emissions Inventory (NEI), the top three emission sources of SO_2 in the U.S. are coal-fired electricity generating units (48% of total), industrial processes (27%), and other stationary source fuel combustion (9%).

Once emitted to the atmosphere, SO_2 can either remain as SO_2 in the gas phase and be transported and/or be dry deposited, or it can be oxidized to form sulfate particles (SO_4^{2-}), with modeling studies suggesting that oxidation accounts for more than half of SO_2 removal nationally (PA, section 2.1.1). The rate of SO_2 oxidation accelerates with greater availability of oxidants, which are generally depleted near source stacks. Consequently, oxidization to SO_4^{2-} generally occurs in cleaner air downwind of SO_X sources (2008 ISA, section 2.6.3.1). As SO_4^{2-} particles are generally within the fine particle size range, they are a component of $PM_{2.5}$ and have an atmospheric lifetime ranging from 2 to 10 days (PA, section 2.1.1). The areas of highest SO_2 and SO_4^{2-} deposition are generally near or downwind of SO_X emissions sources, with most S deposition occurring in the eastern U.S. (PA, section 2.5.3). Geographic variation in precipitation also influences the spatial distribution of S wet deposition. In sum, both SO_2, and the SO_4^{2-} particles converted from SO_2, contribute to S deposition, and do so over different time and geographic scales, with dry deposition of SO_2 typically occurring near the source, and wet deposition of sulfate particles distributing more regionally.

The term N oxides refers to all forms of oxidized nitrogen compounds, including NO, NO_2, nitric acid (HNO_3), and particulate nitrate (NO_3^-). Most N oxides enter the atmosphere as either NO or NO_2, which are collectively referred to as NO_X (PA, section 2.1.2). Anthropogenic sources account for the majority of NO_X emissions in the U.S., per 2020 NEI estimates, with highway vehicles (26% of total), stationary fuel combustion including electric generating units (25%), and non-road mobile sources (19%) identified as the largest contributors to total emissions (PA, section 2.2.1). Once emitted into the atmosphere, NO_X can deposit to the surface or be chemically converted to other gaseous N oxides, including HNO_3, as well as to particulate NO_3^-, which may occur in either the fine or coarse particle size range, such that not all particulate NO_3^- is a component of $PM_{2.5}$. In general, gas phase N oxides tend to have shorter atmospheric lifetimes, either dry depositing (*e.g.,* as HNO_3) or quickly converting to particulate NO_3^-, which has a similar atmospheric lifetime as particulate SO_4^{2-} and is generally removed by precipitation in wet deposition.

In addition to N oxides, there is another category of nitrogen pollutants, referred to as reduced nitrogen, which also contributes to nitrogen deposition. The most common form of reduced N emitted into the air is NH_3 gas (PA, sections 2.1.3 and 2.2.3), which is not a criteria pollutant. The main sources of NH_3 emissions include livestock waste (49% of total in 2020 NEI), fertilizer application (33%) and aggregate fires (11%). Ammonia tends to dry deposit near sources, with a fraction of what is emitted being converted to particle form, as ammonium (NH_4^+), which can be transported away from sources and is most efficiently removed by precipitation (PA, section 2.1.3).

Particulate matter is both emitted to the atmosphere and formed in the atmosphere from precursor chemical gases, such as N Oxides, SO_X and NH_3. Accordingly, $PM_{2.5}$ contributing to S and N deposition generally results from chemicals formed in the atmosphere after being emitted (*e.g.,* particulate SO_4^{2-}, particulate NO_3^-, NH_4^+). The majority of $PM_{2.5}$ mass in recent periods (*e.g.,* 2019–2021) is composed of materials that do not contribute to S and N deposition (PA, section 2.4.3 and 6.4.2). For example, at $PM_{2.5}$ monitoring sites across the U.S., SO_4^{2-} generally comprises no more than about a third of $PM_{2.5}$ mass (in eastern sites), with much lower percentages at monitoring sites in much of the West and South (PA Figure 2–30 and section 2.4.3). Similarly, nitrogen-containing species are also a minority of $PM_{2.5}$ mass, representing less than about 30% and down to about 5% or lower in some areas of South (PA, sections 2.4.3 and 6.4.2).

b. Recent Trends in Emissions, Concentrations, and Deposition

Emissions of SO_X, oxides of N, and PM have declined dramatically over the past two decades, continuing a longer-

term trend (PA, section 2.2). Total SO_2 emissions nationwide declined by 87% between 2002 and 2022, including reductions of 91% in emissions from electricity generating units and 96% in emissions from mobile sources. Total anthropogenic NO_X emissions also trended downward from 2002 to 2022 by 70% nationwide, driven in part by large reductions in emissions from highway vehicles (84%) and stationary fuel combustion (68%) (PA, section 2.2.1). In contrast with these declining 20-year trends in NO_X and SO_X emissions, the annual rate of NH_3 emissions increased by over 20 percent nationwide between 2002 and 2022 (PA, section 2.2.3). The two largest contributors are emissions from livestock waste and fertilizer application, which have increased by 11% and 44%, respectively. These trends in NO_X and NH_3 emissions have had ramifications for N deposition patterns across the U.S., as described further below.

The large reductions in SO_X and NO_X emissions have resulted in substantially lower ambient air concentrations in recent years relative to the past. This is true for both 3-hour and 1-hour average concentrations. With regard to 3-hour SO_2 concentrations, 2021 design values for the existing 3-hour standard at all State and Local Air Monitoring Stations (SLAMS) with valid design values (n= 333) [23] are less than the level of the existing secondary standard (500 ppb) [24] and more than 75 percent of the sites have design values below 20 ppb (PA, section 2.4.2). This reflects a downward trend since 2000, with the median design value declining from about 50 ppb to less than 10 ppb in 2021 (PA, Figure 2–27).

Similarly, design values for the primary SO_2 standard (annual 99th percentile of daily maximum 1-hour average concentrations, averaged over 3 years) have also declined. In the mid-1990s, the median value of all sites with valid 1-hour design values often exceeded 75 ppb (PA, Figure 2–26). Since then, the entire distribution of design values (including source-oriented sites) has continued to decline such that the median design value for the 1-hour primary standard across the network of sites is now between 5 and 10 ppb (PA, Figure 2–26). Annual average SO_2 concentrations have also declined over this period. Additionally, both peak and mean SO_2 concentrations are higher at source-oriented sites than monitoring locations that are not source-oriented.[25]

Regarding NO_2, design values for the secondary standard (annual averages) at all 399 sites with valid design values in 2021 are below the 53 ppb level of the existing standard,[26] and 98% of sites have design values below 20 ppb. In 2021, the maximum design value was 30 ppb,[27] and the median was 7 ppb, reflecting a downward trend since 2000 when the median annual design value was 15 ppb.

Likewise, the median of the annual average $PM_{2.5}$ concentrations also decreased substantially from 2000 to 2021, from 12.8 $\mu g/m^3$ to 8 $\mu g/m^3$. The median of the annual 98th percentile 24-hour $PM_{2.5}$ concentrations at the more than 1000 sites monitored also decreased, from 32 $\mu g/m^3$ in 2000 to 21 $\mu g/m^3$ in 2021. Although both the annual average and 98th percentile 24-hour $PM_{2.5}$ concentrations decreased steadily from the early 2000s until 2016, these values have fluctuated in recent years due to large-scale wildfire events (PA, section 2.4.3; U.S. EPA, 2023, Figures 23 and 24).

The changes in emissions and associated concentrations since 2000 have also contributed to appreciable changes in N and S deposition nationwide (PA, sections 2.5.3 and 6.2.1). For S compounds, the dramatic reduction in SO_X emissions (87% nationwide) resulted in concordant reductions in S deposition, 68% on average across U.S. (PA, section 6.2.1). This decline is observed across the contiguous U.S. (CONUS), with the largest reductions in regions downwind of large sources such as electricity generating units. For N deposition, the impact of the appreciable reduction in N oxides emissions has been offset by deposition arising from increasing emissions of reduced forms of nitrogen over the same timeframe.

c. Relationships Between Concentrations and Deposition

As the NAAQS are set in terms of pollutant concentrations, analyses in the PA evaluated relationships between criteria pollutant concentrations in ambient air and ecosystem deposition across the U.S. These relationships were evaluated over a range of conditions (*e.g.,* pollutant, region, time period), and with consideration of deposition both near sources and at distance (allowing for pollutant transport and associated transformation) using five different approaches (PA, Chapter 6 and Appendix 6A).

First, as part of a ''real-world experiment,'' the PA analyses leveraged the recent downward trends in NO_X and SO_X emissions and corresponding air quality concentrations as well as the trends in deposition to examine the correlation between observed decreases in emissions and concentration and observed changes in deposition over the past two decades (PA, section 6.2.1). The deposition estimates used in these analyses (termed TDep) [28] are based on a hybrid approach that involves a fusion of measured and modeled values, where measured values are given more weight at the monitoring locations and modeled data are used to fill in spatial gaps and provide information on chemical species that are not measured by routine monitoring networks (Schwede and Lear, 2014). For the second approach, we assessed how ambient air concentrations and associated deposition levels are related within the CMAQ [29] both across the U.S. and then at certain Class I areas [30] (PA, section

[23] A design value is a statistic that summarizes the air quality data for a given area in terms of the indicator, averaging time, and form of the standard. Design values can be compared to the level of the standard and are typically used to designate areas as meeting or not meeting the standard and assess progress towards meeting the NAAQS. Design values are computed and published annually by EPA (*https://www.epa.gov/air-trends/air-quality-designvalues*).

[24] The existing secondary standard for SO_2 is 0.5 ppm (500 ppb), as a 3-hour average, not to be exceeded more than once per year.

[25] In the 2019–2021 period, the maximum design value for the primary SO_2 standard was 376 ppb at a monitoring site near an industrial park in southeast Missouri. It is important to note that peak and mean SO_2 concentrations are higher at source-oriented sites than monitoring locations that are not source-oriented. Additionally, it is not uncommon for there to be high SO_2 values in areas with recurring volcanic eruptions, such as in Hawaii (PA, section 2.4.2).

[26] Sites in the contiguous U.S. have met the existing NO_2 secondary standard since around 1991 (PA, Figure 2–22).

[27] The maximum annual average NO_2 concentrations has been at, slightly above, or slightly below 30 ppb since about 2008, with the highest 3-year average value just above 30 ppb (PA, Figures 2–22 and 7–9).

[28] Other than the estimates associated with the CMAQ analysis (second approach referenced above), the deposition estimates used in these analyses are those provided by the National Atmospheric Deposition Program, TDep Science Committee. One of the outputs of this effort are annual datasets of total deposition estimates in the contiguous U.S. (CONUS), which are referred to as the TDep datasets (technical updates available from NADP, 2021; ISA, Appendix 2, section 2.6). TDep datasets do not currently exist for areas outside of the CONUS.

[29] The CMAQ is a state of the science photochemical air quality model that relies on scientific first principles to simulate the concentration of airborne gases and particles and the deposition of these pollutants back to Earth's surface under user-prescribed scenarios. See *https://www.epa.gov/cmaq* for more detail.

[30] 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 6,000 acres in size, provided the park or wilderness area was in existence on August 7, 1977. Other areas may also

6.2.2.1) where additional monitoring data are collected as part of the Clean Air Status and Trends Network (CASTNET) and the Interagency Monitoring of Protected Visual Environments (IMPROVE) networks. As a third approach, we analyzed the relationships across a limited number of monitoring locations (in Class I areas) where both air quality data (CASTNET and IMPROVE) and wet deposition of S and N was measured to evaluate the associations between concentrations and deposition at a local scale (PA, section 6.2.2.2 and 6.2.2.3). The fourth approach also considered the associations between the two terms, at the local scale, but did so using a broader set of ambient air concentration measurements (*i.e.,* all valid SO_2, NO_2, and $PM_{2.5}$ measurements at SLAMS across the U.S.) and the hybrid set of TDep estimates (PA, section 6.2.3).

Finally, in recognition of the fact that air quality at upwind locations can also influence downwind deposition, the fifth approach used a trajectory model (HYSPLIT—The Hybrid Single-Particle Lagrangian Integrated Trajectory model) to identify upwind areas where emissions might be expected to influence deposition at downwind ecoregions (PA, section 6.2.4 and Appendix 6A).[31] Once those potential zones of influence were established, we evaluated the relationships between air quality metrics for the three pollutants [32] at sites within those zones (sites of influence) and deposition estimates in the downwind ecoregion, as 3-year averages for five periods: 2001–2003, 2006–2008, 2010–2012, 2014–2016 and 2018–2020. The metrics, Ecoregion Air Quality Metrics (EAQMs), include a weighted-average (EAQM-weighted) and a maximum metric (EAQM-max). The EAQM-max is the maximum concentration among the upwind monitoring sites identified for each downwind ecoregion. For the EAQM-weighted, the value of each site linked to the downwind ecoregion was weighted by how often the forward HYSPLIT trajectory crossed into the ecoregion, *i.e.,* sites with more frequent trajectory intersections with the ecoregion were weighted higher (PA, section 6.2.4.1).

The full set of quantitative results of the characterization of air quality and deposition relationships is discussed more thoroughly in Chapter 6 and Appendix 6A of the PA. The evaluation of measured air quality concentrations (SO_2, NO_2, and $PM_{2.5}$) and TDep estimates of deposition at all SLAMS (generally composed of sites that use either a Federal Reference Method [FRM] or a Federal Equivalence Method [FEM]) is a robust analysis (*i.e.,* large number of monitors distributed across the U.S.) and relevant given that compliance with the current standards (both primary and secondary) is judged using design value metrics based on measurements at the current SO_2, NO_2 and $PM_{2.5}$ monitors. As with any assessment, there are uncertainties and limitations, as discussed in the PA (PA, sections 6.3 and 6.4). For example, the SLAMS analyses are site-based comparisons that do not account for deposition associated with the transport of pollutants emitted some distance upwind. Similarly, the other analyses have their own limitations ranging from model uncertainty to limitations in geographical scope. In combination, these analyses supported the PA conclusion of a strong association between SO_2 and S deposition. The results and associated information for N oxides and PM, however, indicate more variable relationships, both between NO_2 concentrations and N deposition, and between $PM_{2.5}$ concentrations with either S or N deposition.

For SO_2, annual monitored SO_2 concentrations, at existing monitors within the SLAMS network, averaged over 3 years at the national scale were highly correlated with S deposition estimates in the TDep dataset at the local scale (correlation coefficient of 0.70),[33] especially in the earlier periods of the record and across the eastern U.S. (PA, section 6.2.3). This association is also seen in the relationships between SO_2 annual values at the identified upwind sites of influence and S deposition estimates from TDep in downwind ecoregions, especially in those locations where the annual average SO_2 concentrations are greater than 5 ppb (PA, section 6.2.4.2). Finally, we note that the observed declines in national levels of S deposition over the past two decades have occurred during a period in which emissions of SO_2 have also declined sharply (PA, sections 6.2.1 and 6.4.1).

Analyses in the PA also investigated relationships between S deposition and air quality metrics other than the current indicator species (SO_2) in a limited number of circumstances at relatively remote sites, generally distant from emissions sources. For example, an evaluation of the associations of total S TDep estimates with SO_4^{2-} concentrations and of wet S deposition with the sum of SO_2 + SO_4^{2-} at 27 sites in 27 Class I areas concluded that the correlations for S deposition with particulate SO_4^{2-} and total S (*i.e.,* SO_2 + SO_4^{2-}) were lower than what was exhibited for S deposition and SO_2 concentrations at the SLAMS (PA, section 6.2.2). The analyses also found poor correlation (correlation coefficient of 0.33) between total S deposition estimates (TDep) and $PM_{2.5}$ mass at IMPROVE sites in the 27 Class I areas (PA, sections 2.3.3 and 6.2.2.3). While this set of analyses is based on data at a relatively limited number of sites (*e.g.,* compared to the SLAMS network), the results do not indicate advantages to $PM_{2.5}$ mass, particulate SO_4^{2-}, or total S (SO_4^{2-} plus SO_2) over SO_2 (alone) as an indicator for a secondary NAAQS to address S deposition-related effects.

Both NO_2 and certain components of $PM_{2.5}$ (NO_3^- and NH_4^+) contribute to N deposition. As is the case for SO_2 and S deposition, there are multiple pathways for N deposition (dry and wet) and multiple scales of N deposition (local and regional). However, there are some additional complications to relating ambient air concentrations of NO_2 and $PM_{2.5}$ mass to N deposition. First, not all N deposition is caused by these pollutants (PA, Chapter 2 and section 6.1.1). Ammonia, which is not a criteria pollutant, also contributes to N deposition, especially through dry deposition at local scales. Second, only certain components of $PM_{2.5}$ mass contribute to N deposition (*i.e.,* NO_3^- and NH_4^+) and these comprise less than about 30% of $PM_{2.5}$ mass across the U.S., below 5% in some regions (PA, Figure 6–56). As a result of these two factors, the associations between NO_2 concentrations and N deposition, and between $PM_{2.5}$ concentrations and N deposition are less robust than what is observed for SO_2 and S deposition. The multi-faceted approach to evaluating these relationships confirmed this expectation. For example, there are

be Class I if designated as Class I consistent with the CAA.

[31] Upwind sites of influence were identified for all 84 ecoregions (level III categorization) in the contiguous U.S. Identification of monitoring sites linked to each downwind ecoregion was based on HYSPLIT modeling for a 120-hour period and focusing on monitoring site locations estimated to contribute at least 0.5% of hits to the downwind ecoregion in the trajectory modeling (PA, Appendix 6, section 6A.2).

[32] For SO_2, there were two sets of metrics: one based on an annual average and one based on the 2nd highest 3-hour maximum concentration in the year. Both the NO_2 and $PM_{2.5}$ metrics are annual averages. For relating to 3-year average deposition, all are averaged across three years.

[33] The correlation coefficients reported here, from the PA, are based on Spearman's rank correlation coefficient. These nonparametric coefficients are generally used with data that are not normally distributed to assess how well the relationship between two variables can be described via a monotonic function. The term ''r value'' is sometimes used as shorthand for this correlation coefficient. Higher values indicate that the two variables are highly associated with one another (can range from 1.0 to −1.0).

weaker associations of N deposition with NO_2 observations at SLAMS across the U.S. than what is observed in the similar S deposition and SO_2 analysis (PA, section 6.4.2). There is little correlation for N deposition with NO_2 concentrations, as evidenced by a Spearman's correlation coefficient of 0.38, compared to 0.70 for SO_2 and S deposition (PA, Table 6–6 and Table 6–4). Further, the trajectory-based analyses of the relationships between NO_2 annual values at the identified upwind sites of influence and N deposition estimates from TDep in downwind ecoregions indicate negative correlations (PA, Table 6–10). These negative correlations are observed for both the EAQM-weighed and EAQM-max values. This relative lack of association for NO_2 concentrations with N deposition was confirmed by national trends over the past 20 years, where sharp declines in NO_2 emissions and concentrations are linked in time with sharp declines in oxidized N deposition (PA, Table 6–2), but not with trends in total or reduced atmospheric N deposition. Since 2010, NO_2 concentrations have continued to drop while N deposition nationally has remained steady (PA, section 6.2.1). As for S deposition and S compound metrics, the PA also investigated relationships between N deposition and air quality metrics other than the current indicator species (NO_2) in the 27 Class I areas where collocated data were available. Recognizing that such information was not available in other, less remote areas of the U.S., including areas where contributing emissions are highest or at the regulatory SLAMS monitors, no clear advantages of these other parameters (*e.g.,* nitric acid, particulate NO_3^-, and NH_4^+) over NO_2 or $PM_{2.5}$ mass were indicated. Across all analyses, the evidence indicates NO_2 to be a weak indicator of total atmospheric N deposition, especially in areas where NH_3 is prevalent and where $PM_{2.5}$ mass is dominated by species other than NO_3^- or NH_4^+ (PA, section 6.4.2).

3. Overview of Welfare Effects Evidence

More than 3,000 welfare effects studies, including approximately 2,000 studies newly available since the last review, have been considered in the ISA.[34] [35] While expanding the evidence for some effect categories, the studies on acid deposition, an important category of effects in the last review, are largely consistent with the evidence that was previously available. The subsections below briefly summarize the nature of welfare effects of S oxides, N oxides and PM (section II.A.3.a.), the potential public welfare implications of these effects (section II.A.3.b.), and exposure concentrations and deposition-related metrics (section II.A.3.c.).

a. Nature of Effects

The welfare effects evidence base evaluated in the current review includes decades of extensive research on the ecological effects of N oxides, SO_X and PM. The sections below provide an overview of the nature of the direct effects of gas-phase exposure to oxides of nitrogen and sulfur (section II.A.3.a.(1)), acid deposition-related ecological effects (section II.A.3.a.(2)), N enrichment and associated effects (section II.A.3.a.(3)), and other effects (section II.A.3.a.(4)).

(1) Direct Effects of SO_X and N Oxides in Ambient Air

A well-established body of scientific evidence has shown that acute and chronic exposures to oxides of N and S, such as SO_2, NO_2, NO, HNO_3 and peroxyacetyl nitrate (PAN) in the air, are associated with negative effects on vegetation. The scientific evidence available for these effects in 1971 is the basis for the current secondary NAAQS for SO_X and N oxides.

The current scientific evidence continues to be sufficient to infer a causal relationship between gas-phase SO_2 and injury to vegetation (ISA, Appendix 3, section 3.6.1). High concentrations have been associated with damage to plant foliage (ISA, Appendix 3, section 3.2). In addition to foliar injury, which is usually a rapid response, and which can vary significantly among species and growth conditions (which affect stomatal conductance), SO_2 exposures have also been documented to reduce plant photosynthesis and growth. As exposures have declined in the U.S., some studies in the eastern U.S. have reported increased growth in some SO_2-sensitive tree species (*e.g.,* Thomas et al., 2013). Multiple factors, including reduced deposition, buffering and other environmental variables, may play a role in such species recovery. (ISA, Appendix 3, section 3.2, Schaberg et al., 2014). Some of this evidence seems to suggest a somewhat faster recovery than might be expected from deposition-related soil acidification alone, which may indicate a relatively greater role for changes in ambient air concentrations of SO_2, in combination with changes in other gases, than was previously understood (ISA, Appendix 3, section 3.2 and Appendix 5, section 5.2.1.3). For lichens, damage from SO_2 exposure has been observed to include reduction in metabolic functions that are vital for growth and survival (*e.g.,* decreases in photosynthesis and respiration), damage to cellular integrity (*e.g.,* leakage of electrolytes), and structural changes (ISA, Appendix 3, section 3.2).

The current scientific evidence also continues to be sufficient to infer a causal relationship between gas-phase NO, NO_2 and PAN and injury to vegetation (ISA, Appendix 3, section 3.6.2). The evidence base evaluated in the 1993 *Air Quality Criteria Document for Oxides of N* included evidence of phytotoxic effects of NO, NO_2, and PAN on plants through decreasing photosynthesis and induction of visible foliar injury (U.S. EPA, 1993 [1993 AQCD]). The 1993 AQCD additionally concluded that concentrations of NO, NO_2, and PAN in the atmosphere were rarely high enough to have phytotoxic effects on vegetation. Little new information is available since that time on these phytotoxic effects at concentrations currently observed in the U.S. (ISA, Appendix 3, section 3.3).

With regard to HNO_3, the evidence is sufficient to infer a causal relationship between exposure to HNO_3 and changes to vegetation (ISA, Appendix 3, section 3.6.3). The evidence suggests a role in observed declines in lichen species in the 1970s in the Los Angeles basin (ISA, Appendix 3, section 3.3). A 2008 resampling of areas shown to be impacted in the past by HNO_3 found community shifts, declines in the most pollutant-sensitive lichen species, and increases in abundance of nitrogen-tolerant lichen species compared to 1976–1977, indicating that these lichen communities have not recovered and had experienced additional changes (ISA, Appendix 3, section 3.4). The recently available evidence on this topic also included a study of six lichen species that reported changes in physiology and functioning including decreased chlorophyll content and chlorophyll fluorescence, decreased photosynthesis and respiration, and increased electrolyte leakage from HNO_3 exposures for 2–11 weeks (daily peak levels near 50 ppb) in controlled chambers. (ISA, Appendix 3, section 3.4).

(2) Acid Deposition-Related Ecological Effects

The connection between SO_X and N oxide emissions to ambient air,

[34] The ISA builds on evidence and conclusions from previous assessments, focusing on synthesizing and integrating the newly available evidence (ISA, section IS.1.1). Past assessments are cited when providing further details not repeated in newer assessments.

[35] The study count and citations are available on the project page for the ISA on the Health & Environmental Research Online (HERO) website (*https://heronet.epa.gov/heronet/index.cfm/project/page/project_id/2965*).

atmospheric deposition of S and/or N compounds, and the acidification of acid-sensitive soils and surface waters is well documented by many decades of evidence, particularly in the eastern U.S. (ISA, section IS.5; Appendix 8, section 8.1). Sulfur oxides and N oxides in ambient air undergo reactions to form acidic compounds that are removed from the atmosphere through deposition. Acidifying deposition can affect biogeochemical processes in soils, with ramifications for terrestrial biota and for the chemistry and biological functioning of associated surface waters (ISA, Appendix 7, section 7.1). These effects depend on the magnitude and rate of deposition, as well as multiple biogeochemical processes that occur in soils and waterbodies.

Soil acidification is influenced by the deposition of inorganic acids (HNO_3 and sulfuric acid [H_2SO_4]), NH_4^+, and by chemical and biological processes. When NO_3^-, or SO_42^- leach from soils to surface waters, an equivalent number of positive cations, or countercharge, are also transported. If the countercharge is provided by a base cation (*e.g.,* calcium, [Ca^{2+}], magnesium [Mg^{2+}], sodium [Na^+], or potassium [K^+]), rather than hydrogen ions (H^+), the leachate is neutralized, but the soil becomes more acidic from the hydrogen ions left behind, and the base saturation of the soil is reduced by the loss of the base cation. Depending on the relative rates of soil processes that contribute to the soil pools of H^+ and base cations, such as weathering, continued SO_4^{2-} or NO_3^- leaching can deplete the soil base cation pool, which contributes to increased acidity of the leaching soil water and by connection, the surface water. Accordingly, the ability of a watershed to neutralize acidic deposition is determined by a variety of biogeophysical factors including weathering rates, bedrock composition, vegetation and microbial processes, physical and chemical characteristics of soils, and hydrology (ISA Appendix 4, section 4.3).

Recently available evidence includes some studies describing early stages of recovery from soil acidification in some eastern forests. For example, studies at the Hubbard Brook Experimental Forest in New Hampshire reported indications of acidification recovery in soil solution measurements across the period from 1984 to 2011 (ISA, Appendix 4, section 4.6.1; Fuss et al., 2015). Another study of 27 sites in eastern Canada and the northeastern U.S. found reductions in wet deposition SO_4^{2-} were associated with increases in soil base saturation and decreases in exchangeable aluminum (ISA, Appendix 4, section 4.6.1; Lawrence et al., 2015). Recent modeling analyses indicate extended timeframes for recovery are likely, as well as delays or lags related to accumulated pools of S in forest soils (ISA, Appendix 4, section 4.6.1).

(a) Freshwater Ecosystems

As was the case in the last review, the body of evidence available in this review, including that newly available, is sufficient to infer a causal relationship between N and S deposition and the alteration of freshwater biogeochemistry (ISA, section IS.6.1). Additionally, based on the previously available evidence, the current body of evidence is also sufficient to conclude that a causal relationship exists between acidifying deposition and changes in biota, including physiological impairment and alteration of species richness, community composition, and biodiversity in freshwater ecosystems (ISA, section IS.6.3).

The effects of acid deposition on aquatic systems depend largely upon the ability of the system to neutralize additional acidic inputs from the environment, whether from the atmosphere or from surface inputs. There is a large amount of variability among freshwater systems in this regard, which reflects their underlying geology as well as their history of acidic inputs. Accordingly, different freshwater systems (*e.g.,* in different geographic regions) respond differently to similar amounts of acid deposition. The main factor in determining sensitivity is the underlying geology of an area and its ability to provide soil base cations through weathering to buffer acidic inputs (ISA, Appendix 8, section 8.5.1). As noted in the ISA, ''[g]eologic formations having low base cation supply, due mainly to low soil and bedrock weathering, generally underlie the watersheds of acid-sensitive lakes and streams'' (ISA, Appendix 8, p. 8–58).

Longstanding evidence has well characterized the changes in biogeochemical processes and water chemistry caused by N and S deposition and the ramifications for biological functioning of freshwater ecosystems (ISA, Appendix 8, section 8.1). The more recently available scientific research ''reflects incremental improvements in scientific knowledge of aquatic biological effects and indicators of acidification as compared with knowledge summarized in the 2008 ISA'' (ISA, Appendix 8, p. 8–80). Previously and newly available studies ''indicate that aquatic organisms in sensitive ecosystems have been affected by acidification at virtually all trophic levels and that these responses have been well characterized for several decades'' (ISA, Appendix 8, p. 8–80). For example, information reported in the previous 2008 ISA ''showed consistent and coherent evidence for effects on aquatic biota, especially algae, benthic invertebrates, and fish that are most clearly linked to chemical indicators of acidification'' (ISA, Appendix 8, p. 8–80). These indicators are surface water pH, base cation ratios, ANC, and inorganic aluminum concentration (ISA, Appendix 8, Table 8–9).

The effects of waterbody acidification on fish species are especially well documented, with many species (*e.g.,* brown and brook trout and Atlantic salmon) experiencing adverse effects from acidification and the earliest lifestages being most sensitive (ISA, Appendix 8, section 8.3). Many effects of acidic surface waters on fish, particularly effects on gill function or structure, relate to low pH or the combination of low pH and elevated dissolved aluminum (ISA, Appendix 7, section 7.1.2.5 and Appendix 8, sections 8.3.6.1 and 8.6.4). In general, biological effects in aquatic ecosystems are primarily attributable to low pH and high inorganic aluminum concentration (ISA, p. ES–14). Waterbody pH largely controls the bioavailability of aluminum, which is toxic to fish, and aluminum mobilization is largely confined to waters with a pH below about 5.5, which the ISA describes as corresponding to an ANC in the range of about 10 to 30 microequivalents per liter (μeq/L) in waters of the Northeast with low to moderate levels of dissolved organic carbon (ISA, Appendix 7, section 7.1.2.6 and Appendix 8, section 8.6.4).

The parameter ANC is an indicator of the buffering capacity of natural waters against acidification. Although ANC does not directly affect biota, it is an indicator of acidification that relates to pH and aluminum levels (ISA, p. ES–14) or to watershed characteristics like base cation weathering (BCw) rate (ISA, Appendix 8, sections 8.1 and 8.3.6.3). Accordingly, ANC is commonly used to describe the potential sensitivity of a freshwater system to acidification-related effects. It can be measured in water samples and is also often estimated for use in water quality modeling, as is done in the aquatic acidification risk assessment for this review (summarized in section II.A.4. below). Water quality models are generally better at estimating ANC than at estimating other indicators of acidification-related risk, such as pH.

Acid neutralizing capacity is estimated as the molar sum of strong base cations minus the molar sum of strong acid anions, specifically including SO_4^{2-} and NO_3^- (*e.g.,* Driscoll et al., 1994). Thus, values below zero indicate a deficit in the ability to buffer acidic inputs, and increasing values above zero represent increasing buffering capability for acidic inputs (ISA, Appendix 7, section 7.1.2.6). In waters with high concentrations of naturally occurring organic acids, however, ANC may not be a good indicator of risk to biota as those acids can reduce bioavailability of aluminum, thus buffering the effects usually associated with low pH and high total aluminum concentrations (Waller et al., 2012; ISA, Appendix 8, section 8.3.6.4).

In addition to acidity of surface waters quantified over weeks or months, waterbodies can also experience spikes in acidity in response to episodic precipitation or rapid snowmelt events. In these events (hours-days), a surge or pulse of drainage water, containing acidic compounds, is routed through upper soil horizons rather than the deeper soil horizons that would usually provide buffering for acidic compounds (ISA, Appendix 7, section 7.1). While some streams and lakes may have chronic or base flow chemistry that provides suitable conditions for aquatic biota, they may experience occasional acidic episodes with the potential for deleterious consequences to sensitive biota (ISA, Appendix 8, section 8.5). For example, in some impacted northeastern waterbodies, ANC levels may dip below zero for hours to days or weeks in response to such events, while waterbodies labeled chronically acidic have ANC levels below zero throughout the year (ISA, Appendix 7, section 7.1.1.2; Driscoll et al., 2001). Headwater streams tend to be more sensitive to such episodes due to their smaller watersheds and, in the East, due to their underlying geology (ISA, Appendix 8, section 8.5.1).

National survey data available in the last review, and dating back to the early 1980s through 2004, indicated acidifying deposition had acidified surface waters in the southwestern Adirondacks, New England uplands, eastern portion of the upper Midwest, forested Mid-Atlantic highlands, and Mid-Atlantic coastal plain (2008 ISA, section 4.2.2.3; ISA, Appendix 8, section 8.5.1). For example, a 1984–1987 survey of waterbodies in the Adirondacks found 27% of streams to have ANC values below zero, with a minimum value of −134 μeq/L (Sullivan et al., 2006). Values of ANC below 20 μeq/L in Shenandoah stream sites have been reported as having a greater risk of episodic acidification and associated reduced populations of sensitive species, such as the native brook trout, compared to sites with higher ANC (Bulger et al., 1999; Bulger et al., 2000). A more recent study of two groups of Adirondack lakes for which water quality data were available from 1982 and 1992, respectively, reported significant increases in ANC in the large majority of those lakes, with the magnitude of the increases varying across the lakes (Driscoll et al., 2016; ISA, Appendix 7, section 7.1.3.1). As described in the ISA, ''[a]cidic waters were mostly restricted to northern New York, New England, the Appalachian Mountain chain, upper Midwest, and Florida'' (ISA, Appendix 8, p. 8–60). Despite the appreciable reductions in acidifying deposition that have occurred in the U.S. since the 1960s and 1970s, aquatic ecosystems across the U.S. are still experiencing effects from historical contributions of N and S (ISA, Appendix 8, section 8.6).

(b) Terrestrial Ecosystems

Longstanding evidence, supported and strengthened by evidence newly available in this review, describes the changes in soil biogeochemical processes caused by acidifying deposition of N and S to terrestrial systems that are linked to changes in terrestrial biota, with associated impacts on ecosystem characteristics (ISA, Appendix 5, section 5.1). Consistent with conclusions in the last review, the current body of evidence is sufficient to infer a causal relationship between acidifying deposition and alterations of biogeochemistry in terrestrial ecosystems. Additionally, and consistent with conclusions in the last review, the current body of evidence is sufficient to infer a causal relationship between acidifying N and S deposition and the alteration of the physiology and growth of terrestrial organisms and the productivity of terrestrial ecosystems. The current body of evidence is also sufficient to conclude that a causal relationship exists between acidifying N and S deposition and alterations of species richness, community composition, and biodiversity in terrestrial ecosystems (2008 ISA, sections 4.2.1.1 and 4.2.1.2; 2020 ISA, Appendix 4, section 4.1 and Appendix 5, sections 5.7.1 and 5.7.2).

Deposition of acidifying compounds to acid-sensitive soils can cause soil acidification, increased mobilization of aluminum from soil to drainage water, and depletion of the pool of exchangeable base cations in the soil (ISA, Appendix 5, section 5.2 and Appendix 4, sections 4.3.4 and 4.3.5). Physiological effects of acidification on terrestrial biota include slower growth and increased mortality among sensitive plant species, which are generally attributable to physiological impairment caused by aluminum toxicity (related to increased availability of inorganic aluminum in soil water) and a reduced ability of plant roots to take up base cations (ISA, Appendix 4, section 4.3 and Appendix 5, section 5.2).

The physiological effects of acidifying deposition on terrestrial biota can also result in changes in species composition whereby sensitive species, such as red spruce and sugar maple, are replaced by more tolerant species, or the sensitive species that were dominant in the community become a minority. For example, increasing soil cation availability (as in Ca^{2+} addition or gradient experiments) has been associated with greater growth and seedling colonization by sugar maple, while American beech is more prevalent on soils with lower levels of base cations where sugar maple is less often found (ISA, Appendix 5, section 5.2.1.3.1; Duchesne and Ouimet, 2009). Soil acid-base chemistry has also been found to be a predictor of understory species composition (ISA, Appendix 5, section 5.2.2.1), and limited evidence has indicated an influence of soil acid-base chemistry on diversity and composition of soil bacteria, fungi, and nematodes (ISA, Appendix 5, section 5.2.4.1). In addition to Ca^{2+} addition experiments, observational gradient studies have also evaluated relationships between soil chemistry indicators of acidification (*e.g.,* soil pH, base cation to aluminum (Bc:Al) ratio, base saturation, and aluminum) and ecosystem biological endpoints, including physiological and community responses of trees and other vegetation, lichens, soil biota, and fauna (ISA, Appendix 5, Tables 5–2 and 5–6). The 2020 ISA also reports on several large observational studies evaluating statistical associations between tree growth or survival, as assessed at monitoring sites across the U.S., and estimates of average deposition of S or N compounds at those sites over time periods on the order of 10 years (ISA, Appendix 5, section 5.5.2 and Appendix 6, section.6.2.3.1; Dietze and Moorcroft, 2011; Thomas et al., 2010; Horn et al., 2018). Negative associations were observed for survival and growth in several species or species groups with S deposition metrics; positive and negative associations were reported with N deposition (PA, sections 5.3.2.3 and 5.3.4 and Appendix 5B).

Although there has been no systematic national survey of U.S. terrestrial ecosystem soils, the forest ecosystems considered the most sensitive to terrestrial acidification from atmospheric deposition include forests of the Adirondack Mountains of New York, Green Mountains of Vermont, White Mountains of New Hampshire, the Allegheny Plateau of Pennsylvania, and mountain top and ridge forest ecosystems in the southern Appalachians (2008 ISA, Appendix 3, section 3.2.4.2; ISA, Appendix 5, section 5.3). Underlying geology is the principal factor governing the sensitivity of both terrestrial and aquatic ecosystems to acidification from S and N deposition. Geologic formations with low base cation supply (*e.g.,* sandstone, quartzite), due mainly to low weathering rates, generally underlie these acid sensitive watersheds. Other factors also contribute to the overall sensitivity of an area to acidifying nitrogen and sulfur deposition, including topography, soil chemistry, land use, and hydrology (ISA, Appendix 5, section 5.3). For example, ''[a]cid-sensitive ecosystems are mostly located in upland mountainous terrain in the eastern and western U.S. and are underlain by bedrock that is resistant to weathering, such as granite or quartzite sandstone'' (ISA, Appendix 7, p. 7–45). Further, as well documented in the evidence, biogeochemical sensitivity to deposition-driven acidification (and eutrophication [see following section]) is the ''result of historical loading, geologic/soil conditions (*e.g.,* mineral weathering and S adsorption), and nonanthropogenic sources of N and S loading to the system'' (ISA, Appendix 7, p. 7–45 and section 7.1.5).

(3) Nitrogen Enrichment and Associated Ecological Effects

Ecosystems in the U.S. vary in their sensitivity to N enrichment, with organisms in their natural environments commonly adapted to the nutrient availability in those environments. Historically, N has been the primary limiting nutrient for plants in many ecosystems. In such ecosystems, when the limiting nutrient, N, becomes more available, whether from atmospheric deposition, runoff, or episodic events, the subset of plant species able to most effectively use the higher nitrogen levels may out-compete other species, leading to a shift in the community composition that may be dominated by a smaller number of species, *i.e.,* a community with lower diversity (ISA, sections IS.6.1.1.2, IS.6.2.1.1 and IS.7.1.1, Appendix 6, section 6.2.4 and Appendix 7, section 7.2.6.6). Thus, change in the availability of nitrogen in nitrogen-limited systems can affect growth and productivity, with ramifications on relative abundance of different species of vegetation and potentially further and broader ramifications on ecosystem processes, structure, and function.

Both N oxides and reduced forms of nitrogen can contribute to N enrichment. In addition to atmospheric deposition, other sources of N compounds can play relatively greater or lesser roles in ecosystem N loading, depending on location. For example, many waterbodies receive appreciable amounts of N from agricultural runoff and municipal or industrial wastewater discharges. For many aquatic ecosystems, sources of N other than atmospheric deposition, including fertilizer and waste treatment, contribute more to ecosystem N than atmospheric deposition (ISA Appendix 7, sections 7.1 and 7.2). Additionally, the impacts of historic N deposition in both aquatic and terrestrial ecosystems pose complications to discerning the potential effects of more recent deposition rates.

(a) Aquatic and Wetland Ecosystems

Nitrogen additions to freshwater, estuarine and near-coastal ecosystems, including N from atmospheric deposition, can contribute to eutrophication, which typically begins with nutrient-stimulated rapid algal growth developing into an algal bloom that can, depending on various site-specific factors, be followed by anoxic conditions associated with the algal die-off (ISA, ES.5.2). Decomposition of the plant biomass from the subsequent algal die-off contributes to reduced waterbody oxygen, which in turn can affect higher-trophic-level species, *e.g.,* contributing to fish mortality (ISA, p. ES–18). The extensive body of evidence in this area is sufficient to infer causal relationships between N deposition and the alteration of biogeochemistry in freshwater, estuarine and near-coastal marine systems (ISA, Appendix 7, sections 7.1 and 7.2). Consistent with findings in the last review, the current body of evidence is also sufficient to infer a causal relationship between N deposition and changes in biota, including altered growth and productivity, species richness, community composition, and biodiversity due to N enrichment in freshwater ecosystems (ISA, Appendix 9, section 9.1). The body of evidence is sufficient to infer a causal relationship between N deposition and changes in biota, including altered growth, total primary production, total algal community biomass, species richness, community composition, and biodiversity due to N enrichment in estuarine environments (ISA, Appendix 10, section 10.1).

Evidence newly available in this review provides insights regarding N enrichment and its impacts in several types of aquatic systems, including freshwater streams and lakes, estuarine and near-coastal systems, and wetlands. With regard to freshwaters, for example, studies published since the 2008 ISA augment the evidence base for high-elevation waterbodies where the main N source is atmospheric deposition. Recent evidence continues to indicate that N limitation is common in oligotrophic waters in the western U.S., with shifts in nutrient limitation, from N limitation, to between N and phosphorus (P) limitation, or to P limitation, reported in some alpine lake studies (ISA, Appendix 9, section 9.1.1.3). Small inputs of N in such water bodies have been reported to increase nutrient availability or alter the balance of N and P, with the potential to stimulate growth of primary producers and contribute to changes in species richness, community composition, and diversity.

Another type of N loading effect in other types of freshwater lakes includes a role in the composition of freshwater algal blooms and their toxicity (ISA, Appendix 9, section 9.2.6.1). Information in this review, including studies in Lake Erie, indicates that growth of some harmful algal species, including those that produce microcystin, are favored by increased availability of N and its availability in dissolved inorganic form (ISA, Appendix 9, p. 9–28; Davis et al., 2015; Gobler et al., 2016).

The relative contribution of N deposition to total N loading varies among waterbodies. For example, atmospheric deposition is generally considered to be the main source of N inputs to most headwater stream, high-elevation lake, and low-order stream watersheds that are far from the influence of other N sources like agricultural runoff and wastewater effluent (ISA, section ES5.2). In other fresh waterbodies, however, agricultural practices and point source discharges have been estimated to be larger contributors to total N loading (ISA, Appendix 7, section 7.1.1.1). Since the 2008 ISA, several long-term monitoring studies in the Appalachian Mountains, the Adirondacks, and the Rocky Mountains have reported temporal patterns of declines in surface water NO_3^- concentration corresponding to declines in atmospheric N deposition (ISA, Appendix 9, section 9.1.1.2).

Declines in basin wide NO_3^- concentrations have also been reported for the nontidal Potomac River watershed and have been attributed to declines in atmospheric N deposition (ISA, Appendix 7, section 7.1.5.1).

Nutrient inputs to coastal and estuarine waters are important influences on the health of these waterbodies. Continued inputs of N, the most common limiting nutrient in estuarine and coastal systems, have resulted in N over-enrichment and subsequent alterations to the nutrient balance in these systems (ISA, Appendix 10, p. 10–6). For example, the rate of N delivery to coastal waters is strongly correlated to changes in primary production and phytoplankton biomass (ISA, Appendix 10, section 10.1.3). Algal blooms and associated die-offs can contribute to hypoxic conditions (most common during summer months), which can contribute to fish kills and associated reductions in marine populations (ISA, Appendix 10). Further, the prevalence and health of submerged aquatic vegetation (SAV), which is important habitat for many aquatic species, has been identified as a biological indicator for N enrichment in estuarine waters (ISA, Appendix 10, section 10.2.5). Previously available evidence indicated the role of N loading in SAV declines in multiple U.S. estuaries through increased production of macroalgae or other algae, which reduce sunlight penetration into shallow waters where SAV is found (ISA, Appendix 10, section 10.2.3). Newly available studies have reported findings of increased SAV populations in two tributaries of the Chesapeake Bay corresponding to reduction in total N loading from all sources since 1990 (ISA, Appendix 10, section 10.2.5). The newly available studies also identify other factors threatening SAV, including increasing temperature related to climate change (ISA, Appendix 10, section 10.2.5).

The degree to which N enrichment and associated ecosystem impacts are driven by atmospheric N deposition varies greatly and is largely unique to the specific ecosystem. Analyses based on data across two to three decades extending from the 1990s through about 2010 estimate that most of the analyzed estuaries receive 15–40% of their N inputs from atmospheric sources (ISA, section ES 5.2; ISA, Appendix 7, section 7.2.1), though for specific estuaries contributions can vary more widely. In areas along the West Coast, N sources may include coastal upwelling from oceanic waters, as well as transport from watersheds. Common N inputs to estuaries include those associated with freshwater inflows transporting N from agriculture, urban, and wastewater sources, in addition to atmospheric deposition across the watershed (ISA, section IS 2.2.2; ISA, Appendix 7, section 7.2.1).

There are estimates of atmospheric N loading to estuaries available from several recent modeling studies (ISA, Table 7–9). One analysis of estuaries along the Atlantic Coast and the Gulf of Mexico, which estimated that $62-81\%$ of N delivered to the eastern U.S coastal zone is anthropogenic in source, also reported that atmospheric N deposition to freshwater that is subsequently transported to estuaries represents $17-21\%$ of the total N loading into the coastal zone (McCrackin et al., 2013; Moore et al., 2011). In the Gulf of Mexico, 26% of the N transported to the Gulf in the Mississippi/Atchafalaya River basin was estimated to be contributed from atmospheric deposition (which may include volatilized losses from natural, urban, and agricultural sources) (Robertson and Saad, 2013). Another modeling analysis identified atmospheric deposition to watersheds as the dominant source of N to the estuaries of the Connecticut, Kennebec, and Penobscot rivers. For the entire Northeast and mid-Atlantic coastal region, however, it was the third largest source (20%), following agriculture (37%) and sewage and population-related sources (28%) (ISA, Appendix 7, section 7.2.1). Estimates for West Coast estuaries indicate much smaller contribution from atmospheric deposition. For example, analyses for Yaquina Bay, Oregon, estimated direct deposition to contribute only 0.03% of N inputs; estimated N input to the watershed from N-fixing red alder (*Alnus rubra*) trees was a much larger (8%) source (ISA, Appendix 7, section 7.2.1; Brown and Ozretich, 2009).

Evidence in coastal waters has recognized that nutrient enrichment may play a role in acidification of some coastal waters (ISA, Appendix 10, section 10.5). More specifically, nutrient-driven algal blooms may contribute to ocean acidification, possibly through increased decomposition, which lowers dissolved oxygen levels in the water column and contributes to lower pH. Such nutrient-enhanced acidification can also be exacerbated by warming (associated with increased microbial respiration) and changes in buffering capacity (alkalinity) of freshwater inputs (ISA, Appendix 10, section 10.5).

The impact of N additions on wetlands, and whether the wetlands may serve as a source, sink, or transformer of atmospherically deposited N varies with the type of wetland and other factors, such as physiography and local hydrology, as well as climate (ISA, section IS.8.1 and Appendix 11, section 11.1). Studies generally show N enrichment to decrease the ability of wetlands to retain and store N, which may diminish the wetland ecosystem service of improving water quality (ISA, section IS.8.1). Consistent with the evidence available in the last review, the current body of evidence is sufficient to infer a causal relationship between N deposition and the alteration of biogeochemical cycling in wetlands. Newly available evidence regarding N inputs and plant physiology expands the evidence base related to species diversity. The currently available evidence, including that newly available, is sufficient to infer a causal relationship between N deposition and the alteration of growth and productivity, species physiology, species richness, community composition, and biodiversity in wetlands (ISA, Appendix 11, section 11.10).

(b) Terrestrial Ecosystems

It is long established that N enrichment of terrestrial ecosystems increases plant productivity (ISA, Appendix 6, section 6.1). Building on this, the currently available evidence, including evidence that is longstanding, is sufficient to infer a causal relationship between N deposition and the alteration of the physiology and growth of terrestrial organisms and the productivity of terrestrial ecosystems (ISA, Appendix 5, section 5.2 and Appendix 6, section 6.2). Responsive ecosystems include those that are N limited and/or contain species that have evolved in nutrient-poor environments. In these ecosystems the N-enrichment changes in plant physiology and growth rates vary among species, with species that are adapted to low N supply being readily outcompeted by species that require more N. In this manner, the relative representation of different vegetation species may be altered, and some species may be eliminated altogether, such that community composition is changed and species diversity declines (ISA, Appendix 6, sections 6.3.2 and 6.3.8). The currently available evidence in this area is sufficient to infer a causal relationship between N deposition and the alteration of species richness, community composition, and biodiversity in terrestrial ecosystems (ISA, section IS.5.3 and Appendix 6, section 6.3).

Previously available evidence described the role of N deposition in changing soil carbon and N pools and

fluxes, as well as altering plant and microbial growth and physiology in an array of terrestrial ecosystems (ISA, Appendix 6, section 6.2.1). Nitrogen availability is broadly limiting for productivity in many terrestrial ecosystems (ISA, Appendix 6, section 6.2.1). Accordingly, N additions contribute to increased productivity and can alter biodiversity. Eutrophication, one of the mechanisms by which increased productivity and changes in biodiversity associated with N addition to terrestrial ecosystems can occur, comprises multiple effects that include changes to the physiology of individual organisms, alteration of the relative growth and abundance of various species, transformation of relationships between species, and indirect effects on availability of essential resources other than N, such as light, water, and nutrients (ISA, Appendix 6, section 6.2.1).

The currently available evidence for the terrestrial ecosystem effects of N enrichment, including eutrophication, includes studies in a wide array of systems, including forests (tropical, temperate, and boreal), grasslands, arid and semi-arid scrublands, and tundra (PA, section 4.1; ISA, Appendix 6). The organisms affected include trees, herbs and shrubs, and lichen, as well as fungal, microbial, and arthropod communities. Lichen communities, which have important roles in hydrologic cycling, nutrient cycling, and as sources of food and habitat for other species, are also affected by atmospheric N (PA, section 4.1; ISA, Appendix 6). The recently available studies on the biological effects of added N in terrestrial ecosystems include investigations of plant and microbial physiology, long-term ecosystem-scale N addition experiments, regional and continental-scale monitoring studies, and syntheses.

The previously available evidence included N addition studies in the U.S. and N deposition gradient studies in Europe that reported associations of N deposition with reduced species richness and altered community composition for grassland plants, forest understory plants, and mycorrhizal fungi (soil fungi that have a symbiotic relationship with plant roots) (ISA, Appendix 6, section 6.3). Newly available evidence for forest communities in this review indicates that N deposition alters the physiology and growth of overstory trees, and that N deposition has the potential to change the community composition of forests (ISA, Appendix 6, section 6.6). Recent studies on forest trees include analyses of long-term forest inventory data collected from across the U.S. and Europe (ISA, Appendix 6, section 6.2.3.1). The recent evidence also includes findings of variation in forest understory and non-forest plant communities with atmospheric N deposition gradients in the U.S. and in Europe. For example, gradient studies in Europe have found higher N deposition to be associated with forest understory plant communities with more nutrient-demanding and shade-tolerant plant species (ISA, Appendix 6, section 6.3.3.2). A recent gradient study in the U.S. found associations between herb and shrub species richness and N deposition, that were related to soil pH (ISA, Appendix 6, section 6.3.3.2).

Recent evidence includes associations of variation in lichen community composition with N deposition gradients in the U.S. and Europe, (ISA, Appendix 6, section 6.3.7; Table 6–23). Differences in lichen community composition have been attributed to differences in atmospheric N pollution in forests of the West Coast, Rocky Mountains, and southeastern Alaska. Differences in epiphytic lichen growth or physiology have been observed along atmospheric N deposition gradients in the highly impacted area of southern California and in more remote locations such as Wyoming and southeastern Alaska (ISA, Appendix 6, section 6.3.7). Historical deposition may play a role in observational studies of N deposition effects, complicating the disentangling of responses that may be related to more recent N loading.

Newly available findings from N addition experiments expand on the understanding of mechanisms for plant and microbial community composition effects of increased N availability, indicating that competition for resources, such as water in arid and semi-arid environments, may exacerbate the effects of N addition on diversity (ISA, Appendix 6, section 6.2.6). The newly available studies in arid and semiarid ecosystems, particularly in southern California have reported changes in plant community composition, in the context of a long history of significant N deposition, with fewer observations of plant species loss or changes in plant diversity (ISA, Appendix 6, section 6.3.6).

Nitrogen limitation in grasslands and the dominance by fast-growing species that can shift in abundance rapidly (in contrast to forest trees) contribute to an increased sensitivity of grassland ecosystems to N inputs (ISA, Appendix 6, section 6.3.6). Studies in southern California coastal sage scrub communities, including studies of the long-term history of N deposition, which was appreciably greater in the past than recent rates, indicate impacts on community composition and species richness in these ecosystems (ISA, Appendix 6, sections 6.2.6 and 6.3.6). The ability of atmospheric N deposition to override the natural spatial heterogeneity in N availability in arid ecosystems, such as the Mojave Desert and California coastal sage scrub ecosystems in southern California, makes these ecosystems sensitive to N deposition (ISA, Appendix 6, section 6.3.8).

The current evidence includes relatively few studies of N enrichment recovery in terrestrial ecosystems. Among N addition studies assessing responses after cessation of additions, it has been observed that soil nitrate and ammonium concentrations recovered to levels observed in untreated controls within 1 to 3 years of the cessation of additions, but soil processes such as N mineralization and litter decomposition were slower to recover (ISA, Appendix 6, section 6.3.2; Stevens, 2016). A range of recovery times have been reported for mycorrhizal community composition and abundance from a few years in some systems to as long as 28 or 48 years in others (ISA, Appendix 6, section 6.3.2; Stevens, 2016; Emmett et al., 1998; Strengbom et al., 2001). An N addition study in the midwestern U.S. observed that plant physiological processes recovered in less than 2 years, although grassland communities were slower to recover and still differed from controls 20 years after the cessation of N additions (ISA, Appendix 6, section 6.3.2; Isbell et al., 2013).

(4) Other Deposition-Related Effects

Additional categories of effects for which the current evidence is sufficient to infer causal relationships with deposition of S or N compounds or PM include changes in mercury methylation processes in freshwater ecosystems, changes in aquatic biota due to sulfide phytotoxicity, and ecological effects from PM deposition other than N and S deposition (ISA, Table IS–1). The current evidence, including that newly available in this review, is sufficient to infer a causal relationship between S deposition and the alteration of mercury methylation in surface water, sediment, and soils in wetland and freshwater ecosystems (ISA, Table ES–1). The currently available evidence is also sufficient to infer a new causal relationship between S deposition and changes in biota due to sulfide phytotoxicity, including alteration of growth and productivity, species physiology, species richness, community composition, and

biodiversity in wetland and freshwater ecosystems (ISA, section IS.9).

With regard to PM deposition other than N and S deposition, the currently available evidence is sufficient to infer a likely causal relationship between deposition of PM and a variety of effects on individual organisms and ecosystems (ISA, Appendix 15, section 15.1). Particulate matter includes a heterogeneous mixture of particles differing in origin, size, and chemical composition. In addition to N and S and their transformation products, other PM components, such as trace metals and organic compounds, when deposited to ecosystems, may affect biota. Material deposited onto leaf surfaces can alter leaf processes, and PM components deposited to soils and waterbodies may be taken up into biota, with the potential for effects on biological and ecosystem processes. Studies involving ambient air PM, however, have generally involved conditions that would not be expected to meet the current secondary standards for PM. Further, although in some limited cases, effects have been attributed to particle size (*e.g.,* soiling of leaves by large coarse particles near industrial facilities or unpaved roads), ecological effects of PM have been largely attributed more to its chemical components, such as trace metals, which can be toxic in large amounts (ISA, Appendix 15, sections 15.2 and 15.3.1). The evidence largely comes from studies involving areas experiencing elevated concentrations of PM, such as near industrial areas or historically polluted cities (ISA, Appendix 15, section 15.4).

b. Public Welfare Implications

In evaluating the public welfare implications of the evidence regarding S and N related welfare effects, we must consider the type, severity, and geographic extent of the effects. In this section, we discuss such factors in light of judgments and conclusions regarding effects on the public welfare that have been made in NAAQS reviews.

As provided in section 109(b)(2) of the CAA, the secondary standard is to ''specify a level of air quality the attainment and maintenance of which in the judgment of the Administrator . . . is requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of such air pollutant in the ambient air.'' The secondary standard is not meant to protect against all known or anticipated welfare effects related to oxides of N and S, and particulate matter, 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 3212, January 15, 2013; 80 FR 65376, October 26, 2015; see also 73 FR 16496, March 27, 2008). 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 made by the Administrator. The Administrator's judgment regarding the available information and adequacy of protection provided by an existing standard is generally informed by considerations in prior reviews and associated conclusions.

The categories of effects identified in the CAA to be included among welfare effects are quite diverse, and among these categories there are many different types of effects that vary broadly with regard to specificity and level of resolution. For example, effects on vegetation and effects on animals are categories identified in CAA section 302(h), and the ISA recognizes effects of N and S deposition at the organism, population, community, and ecosystem level, as summarized in section II.A.3.a. above (ISA, sections IS.5 to IS.9). As noted in the last review of the secondary NAAQS for NO_X and SO_X, while the CAA section 302(h) lists a number of welfare effects, ''these effects do not define public welfare in and of themselves'' (77 FR 20232, April 3, 2012).

How important ecological impacts are to the public welfare depends on the type, severity and extent of the effects, as well as the societal use of the resource and the significance of the resource to the public welfare. Such factors can also be considered in the context of judgments and conclusions made in some prior reviews regarding public welfare effects. For example, in the context of secondary NAAQS decisions for O_3, judgments regarding public welfare significance have given particular attention to effects in areas with special federal protections (such as Class I areas), and lands set aside by states, Tribes, and public interest groups to provide similar benefits to the public welfare (73 FR 16496, March 27, 2008; 80 FR 65292, October 26, 2015).[36] In the 2015 O_3 NAAQS review, the EPA recognized the ''clear public interest in and value of maintaining these areas in a condition that does not impair their intended use and the fact that many of these lands contain O_3-sensitive species'' (73 FR 16496, March 27, 2008).

Judgments regarding effects on the public welfare can depend on the intended use, including conservation, or service (and value) of the affected vegetation, ecological receptors, ecosystems and resources and the significance of that use to the public welfare (73 FR 16496, March 27, 2008; 80 FR 65377, October 26, 2015). Uses or services provided by areas that have been afforded special protection can flow in part or entirely from the vegetation that grows there as well as other natural features and resources. Ecosystem services range from those directly related to the natural functioning of the ecosystem to ecosystem uses for human recreation or profit, such as through the production of lumber or fuel (Costanza et al., 2017; ISA, section IS.13). The spatial, temporal, and social dimensions of public welfare impacts are also influenced by the type of service affected. For example, a national park can provide direct recreational services to the thousands of visitors that come each year but also provide an indirect value to the millions who may not visit but receive satisfaction from knowing it exists and is preserved for the future (80 FR 65377, October 26, 2015).

In the last review of the secondary NAAQS for NO_X and SO_X, ecosystem services were discussed as a method of assessing the magnitude and significance to the public of resources affected by ambient air concentrations of oxides of nitrogen and sulfur and associated deposition in sensitive ecosystems (77 FR 20232, April 3, 2012). That review recognized that although there is no specific definition of adversity to public welfare, one paradigm might involve ascribing public welfare significance to disruptions in ecosystem structure and function. The concept of considering the extent to which a pollutant effect will contribute to such disruptions has been used broadly by the EPA in considering effects. An evaluation of adversity to public welfare might also consider the

[36] For example, the fundamental purpose of parks in the National Park System ''is to conserve the scenery, natural and historic objects, and wildlife in the System units and to provide for the enjoyment of the scenery, natural and historic objects, and wildlife in such manner and by such means as will leave them unimpaired for the enjoyment of future generations'' (54 U.S.C. 100101). Additionally, the Wilderness Act of 1964 defines designated ''wilderness areas'' in part as areas ''protected and managed so as to preserve [their] natural conditions'' and requires that these areas ''shall be administered for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness, and so as to provide for the protection of these areas, [and] the preservation of their wilderness character . . .'' (16 U.S.C. 1131 (a) and (c)). Other lands that benefit the public welfare include national forests which are managed for multiple uses including sustained yield management in accordance with land management plans (see 16 U.S.C. 1600(1)–(3); 16 U.S.C. 1601(d)(1)).

likelihood, type, magnitude, and spatial scale of the effect, as well as the potential for recovery and any uncertainties relating to these considerations (77 FR 20218, April 3, 2012).

The types of effects on aquatic and terrestrial ecosystems discussed in section II.A.3.1. above differ with regard to aspects important to judging their public welfare significance. For example, in the case of effects on timber harvest, such judgments may consider aspects such as the heavy management of silviculture in the U.S., while judgments for other categories of effects may generally relate to considerations regarding natural areas, including specifically those areas that are not managed for harvest. Effects on tree growth and survival have the potential to be significant to the public welfare through impacts in Class I and other areas given special protection in their natural/existing state, although they differ in how they might be significant.

In this context, it may be important to consider that S and N deposition-related effects, such as changes in growth and survival of plant and animal species, could, depending on severity, extent, and other factors, lead to effects on a larger scale including changes in overall productivity and altered community composition (ISA, section IS.2.2.1 and Appendices 5, 6, 8, 9, and 10). Further, effects on individual species could contribute to impacts on community composition through effects on growth and reproductive success of sensitive species in the community, with varying impacts to the system through many factors including changes to competitive interactions (ISA, section IS.5.2 and Appendix 6, section 6.3.2).

In acid-impacted surface waters, acidification primarily affects the diversity and abundance of fish and other aquatic life and the ecosystem services derived from these organisms. (2011 PA, section 4.4.5). In addition to other types of services, fresh surface waters support several cultural services, such as aesthetic, recreational, and educational services. The type of service that is likely to be most widely and significantly affected by aquatic acidification is recreational fishing. Multiple studies have documented the economic benefits of recreational fishing. Freshwater rivers and lakes of the northeastern United States, surface waters that have been most affected by acidification, are not a major source of commercially raised or caught fish; they are, however, a source of food for some recreational and subsistence fishers and for other consumers (2009 REA, section 4.2.1.3). It is not known if and how consumption patterns of these fishers may have been affected by the historical impacts of surface water acidification in the affected systems. Non-use services, which include existence (protection and preservation with no expectation of direct use) and bequest values, are arguably a significant source of benefits from reduced acidification (Banzhaf et al., 2006). Since the 2012 review, additional approaches and methods have been applied to estimate the potential effects of aquatic acidification on uses and services of affected aquatic ecosystems; with regard to economic impacts, however, ''for many regions and specific services, poorly characterized dose-response between deposition, ecological effect, and services are the greatest challenge in developing specific data on the economic benefits of emission reductions'' (ISA, Appendix 14, p. 14–23).

Nitrogen loading in aquatic ecosystems, particularly large estuarine and coastal water bodies, has and continues to pose risks to the services provided by those ecosystems, with clear implications to the public welfare (2011 PA, section 4.4.2; ISA, Appendix 14, section 14.3.2). For example, the large estuaries of the eastern U.S. are an important source of fish and shellfish production, capable of supporting large stocks of resident commercial species and serving as breeding grounds and interim habitat for several migratory species (2009 REA, section 5.2.1.3). These estuaries also provide an important and substantial variety of cultural ecosystem services, including water-based recreational and aesthetic services. Additionally, as noted for fresh waters above, these systems have non-use benefits to the public (2011 PA, section 4.4.5). Studies reviewed in the ISA have explored both enumeration of the number of ecosystem services that may be affected by N loading and the pathways by which this may occur, as well as approaches to valuation of such impacts. A finding of one such analysis was that ''better quantitative relationships need to be established between N and the effects on ecosystems at smaller scales, including a better understanding of how N shortages can affect certain populations'' (ISA, Appendix 14, sections 14.5 and 14.6). The relative contribution of atmospheric deposition to total N loading varies widely among estuaries, however, and has declined in some areas in recent years (ISA, Appendix 10, section 10.10.1).

A complication to considering the public welfare implications specific to N deposition in terrestrial systems is the potential for N to increase growth and yield of plants that, depending on the type of plant and its use by human populations (*e.g.,* food for livestock or human populations, trees for lumber), could be judged beneficial to the public. Such increased growth and yield may be judged and valued differently than changes in growth of other species. As noted in section II.A.3.a. above, enrichment in natural ecosystems can, by increasing growth of N limited plant species, change competitive advantages of species in a community, with associated impacts on the composition of the ecosystem's plant community. The public welfare implications of such effects may vary depending on their severity, prevalence, and magnitude. Impacts on some ecosystem characteristics (*e.g.,* forest or forest community composition) may be considered of greater public welfare significance when occurring in Class I or other protected areas, due to the value that the public places on such areas. In considering such services in past reviews for secondary standards for other pollutants (*e.g.,* O_3), the Agency has given particular attention to effects in natural ecosystems, indicating that a protective standard, based on consideration of effects in natural ecosystems in areas afforded special protection, would also ''provide a level of protection for other vegetation that is used by the public and potentially affected by O_3 including timber, produce grown for consumption and horticultural plants used for landscaping'' (80 FR 65403, October 26, 2015).

Although the welfare effects evidence base describes effects related to ecosystem deposition of N and S compounds, the available information does not yet provide a framework that can specifically tie various magnitudes or prevalences of changes in a biological or ecological indicator (*e.g.,* lichen abundance or community composition) [37] to broader effects on the public welfare. The ISA finds that while there is an improved understanding from information available in this review of the number of pathways by which N and S deposition may affect ecosystem services, most of these relationships remain to be quantified (ISA, Appendix 14, section 14.6).[38] This

[37] As recognized in section II.A.3.a.(3)(b) above, lichen communities have important roles in ecosystem function, such as in hydrologic cycling, nutrient cycling, and as sources of food and habitat for other species (ISA, Appendix 6).

[38] While ''there is evidence that N and S emissions/deposition have a range of effects on U.S. ecosystem services and their social value'' and

Continued

gap creates uncertainties when considering the public welfare implications of some biological or geochemical responses to ecosystem acidification or N enrichment and accordingly complicates judgments on the potential for public welfare significance. That notwithstanding, while shifts in species abundance or composition of various ecological communities may not be easily judged with regard to public welfare significance, at some level, such changes, especially if occurring broadly in specially protected areas, where the public can be expected to place high value, might reasonably be concluded to impact the public welfare. An additional complexity in the current review with regard to assessment of effects associated with existing deposition rates is that the current, much-improved air quality and associated reduced deposition is within the context of a longer history that included appreciably greater deposition in the middle of the last century, the environmental impacts of which may remain, affecting ecosystem responses.

In summary, several considerations are important to judgments on the public welfare significance of given welfare effects under different exposures. These include uncertainties and limitations that must be taken into account regarding the magnitude of key effects that might be concluded to be adverse to ecosystem health and associated services. Additionally, there are numerous locations vulnerable to public welfare impacts from S or N deposition-related effects on terrestrial and aquatic ecosystems and their associated services. Other important considerations include the exposure circumstances that may elicit effects and the potential for the significance of the effects to vary in specific situations due to differences in sensitivity of the exposed species, the severity and associated significance of the observed or predicted effect, the role that the species plays in the ecosystem, the intended use of the affected species and its associated ecosystem and services, the presence of other co-occurring predisposing or mitigating factors, and associated uncertainties and limitations.

c. Exposure Conditions and Deposition-Related Metrics

The ecological effects identified in section II.A.3.a. above vary widely in their extent and the resolution of the available information that describes the exposure circumstances under which they occur. The information for direct effects of SO_X, N oxides and PM in ambient air is somewhat more straightforward to consider as it is generally presented in terms of concentrations in air. For deposition-related effects, the information may be about S and N compounds in soil or water or may be for metrics intended to represent atmospheric deposition of those compounds. For the latter, as recognized in section II.A.1.c. above, we face the challenge of relating that information to patterns of ambient air concentrations.

With regard to the more complex consideration of deposition-related effects such as ecosystem acidification and N enrichment, there is also wide variation in the extent and level of detail of the evidence available to describe the ecosystem characteristics (*e.g.,* physical, chemical, and geological characteristics, as well as atmospheric deposition history) that influences the degree to which deposition of N and S associated with the oxides of S and N and PM in ambient air may be linked to ecological effects. One reason for this relates to the contribution of many decades of uncontrolled atmospheric deposition before the establishment of NAAQS for PM, oxides of S and oxides of N (in 1971), followed by the subsequent decades of continued deposition as standards were implemented and updated. The impacts of this deposition history remain in soils of many parts of the U.S. today (*e.g.,* in the Northeast and portions of the Appalachian Mountains in both hardwood and coniferous forests, as well as areas in and near the Los Angeles Basin), with recent signs of recovery in some areas (ISA, Appendix 4, section 4.6.1; 2008 ISA, section 3.2.1.1). This backdrop and associated site-specific characteristics are among the challenges faced in identifying deposition targets that might be expected to provide protection going forward from the range of effects for which we have evidence as a result of the deposition of the past.

Critical loads (CLs) are frequently used in studies that investigate associations between various chemical, biological, ecological and ecosystem characteristics and a variety of N or S deposition-related metrics. The term critical load, which refers to an amount (or a rate of addition) of a pollutant to an ecosystem that is estimated to be at (or just below) that which would result in an ecological effect of interest, has multiple interpretations and applications (ISA, p. IS–14). The dynamic nature of ecosystem pollutant processing and the broad array of factors that influence it adds complications to critical load identification and interpretation. Time is an important dimension, which is sometimes unstated (*e.g.,* in empirical or observational analyses) and is sometimes explicit (*e.g.,* in steady-state or dynamic modeling analyses) (ISA, section IS.2.2.4). Further, this variety in meanings stems in part from differing judgments and associated identifications regarding the ecological effect (both type and level of severity) on which the critical load focuses and judgment of its significance or meaning.

Studies, based on which CLs are often identified, vary widely with regard to the specific ecosystem characteristics being evaluated, as well as the benchmarks selected for judging them. The specific details of these various judgments influence the strengths and limitations, and associated uncertainty, of using critical load information from such studies for different applications. The summary that follows is intended to reach beyond individual critical loads developed over a variety of studies and ecosystems and consider the underlying study findings about key aspects of the environmental conditions and ecological characteristics studied. A more quantitative variation of this is the methodology developed for the aquatic acidification REA in this review, presented in the PA and summarized in section II.A.4. below. In those analyses, the concept of a critical load is employed with steady-state modeling that relates deposition to waterbody acid neutralizing capacity.

While recognizing the inherent connections between watersheds and waterbodies, such as lakes and streams, the organization of this section recognizes the more established state of the information, tools, and data for aquatic ecosystems for characterizing relationships between atmospheric deposition and acidification and/or nutrient enrichment effects under air quality associated with the current standards (PA, Chapter 5).[39] Further, we

''there are some economic studies that demonstrate such effects in broad terms,'' ''it remains methodologically difficult to derive economic costs and benefits associated with specific regulatory decisions/standards'' (ISA, Appendix 14, pp. 14–23 to 14–24).

[39] With regard to other deposition-related effects of S compounds, quantitative tools or approaches for relating S deposition to ecosystem impacts are not currently well developed. As summarized in section II.A.3.a.(4) above, these effects, in wetland and freshwater ecosystems, include the alteration of Hg methylation in surface water, sediment, and soils; and changes in biota due to sulfide phytotoxicity including alteration of growth and productivity, species physiology, species richness, community composition, and biodiversity. No studies are in the available evidence regarding the estimation of critical loads for SO_X deposition related to these non-acidifying effects of S deposition into these ecosystems (ISA, Appendix 12, section 12.6).

recognize the generally greater role of atmospheric deposition in waterbodies impacted by aquatic acidification compared to its role in eutrophication-related impacts of surface waters, particularly rivers and estuaries in and downstream of populated watersheds, to which direct discharges have also long contributed, as recognized in section II.A.3.a(3) above (ISA, Appendix 13, section 13.1.3.1; ISA, Appendix 7, section 7.1.1.1; 2008 ISA, section 3.2). Therefore, with regard to deposition-related effects, we focus first on the quantitative information for aquatic ecosystem effects in sections II.A.3.c.(1) below. Section II.A.3.c.(2) discusses the available evidence regarding relationships between deposition-related exposures and the occurrence and severity of effects on trees and understory communities in terrestrial ecosystems. Section II.A.3.c.(3) discusses the currently available information related to consideration of exposure concentrations associated with other welfare effects of nitrogen and sulfur oxides and PM in ambient air.

(1) Acidification and Nitrogen Enrichment in Aquatic Ecosystems

Prior to the peak in S deposition levels that occurred in the 1970s and early 1980s, when deposition likely exceeded 30 kg S/ha-yr in some areas (PA, Appendix B, Figure 5B–9), surface water SO_4^{2-} concentrations were increasing in response to the extremely high S deposition of the preceding years. Subsequently, and especially more recently, surface water SO_4^{2-} concentrations have generally decreased, particularly in the Northeast (Robinson et al., 2008; ISA, section 7.1.5.1.4). Some studies of long-term projections in some waterbodies (*e.g.,* in the Blue Ridge Mountains region in Virginia), however, continue to indicate little or slow reduction in acidic ions, even as emissions have declined. This is an example of the competing role of changes in S adsorption on soils and the release of historically deposited S from soils into surface water,[40] which some modeling has suggested will delay chemical recovery in those water bodies (ISA, Appendix 7, sections 7.1.2.2 and 7.1.5.1).

In the 2012 review of the oxides of N and S, quantitative analyses relating deposition in recent times (*e.g.,* since 2000) to ecosystem acidification, and particularly aquatic acidification, were generally considered to be less uncertain, and the ability of those analyses to inform NAAQS policy judgments more robust, than analyses related to deposition and ecosystem nutrient enrichment or eutrophication (2011 PA). While quantitative assessment approaches for aquatic eutrophication as a result of total N loading are also well established, and the evidence base regarding atmospheric deposition and nutrient enrichment has expanded since the 2012 review, the significance of non-air N loading to rivers, estuaries and coastal waters (as recognized in section II.A.3.a. above) continues to complicate the assessment of nutrient enrichment-related risks specifically related to atmospheric N deposition. Accordingly, the REA analyses developed in this review focus on aquatic acidification. The REA and its findings regarding deposition rates associated with different levels of aquatic acidification risk are summarized in section II.A.4. below. Thus, the paragraphs below focus on available quantitative information regarding atmospheric deposition and N enrichment in aquatic ecosystems.[41] The overview provided here draws on the summary in the PA of the evidence as characterized in the ISA with regard to deposition level estimates that studies have related to various degrees of different effects with associated differences in potential for or clarity in public welfare significance (PA, section 5.2).

The eutrophication of wetlands and other aquatic systems is primarily associated with nitrogen inputs, whether from deposition or other sources. Atmospheric deposition is the main source of new N inputs to some freshwater wetlands and fresh waterbodies, such as headwater streams and high-elevation lakes, while other N inputs, such as agricultural runoff and wastewater effluent, can be significant contributors to waterbodies in agricultural and populated areas (ISA, Appendix 9, section 9.1 and Appendix 11, section 11.3.1). Rates of total N deposition associated with eutrophication-related effects in aquatic systems ranges from a few kilograms per hectare per year (kg/ha-yr) for differences in diatom community composition in high elevation lakes to over 500 kg N/ha-yr for some effects in saltwater wetlands. While the evidence for these effects contributes to ISA causal determinations, it is often very location-specific and less informative for other uses, such as in quantitative assessments relating deposition to waterbody response across broad geographic areas.

In estuaries and coastal systems, the well-established relationships between N loading and algal blooms and associated water quality impacts have been the focus of numerous water quality modeling projects that have quantified eutrophication processes across a wide variety of U.S. ecosystems. These projects, which have generally involved quantification of N loading and association with various water quality indicators, have informed management decision-making in multiple estuaries, including Chesapeake Bay, Narraganset Bay, Tampa Bay, Neuse River Estuary and Waquoit Bay (ISA, Appendix 7, section 7.2). The indicators of nutrient enrichment employed include chlorophyll a, dissolved oxygen, and reduced abundance of submerged aquatic vegetation, among others (ISA, section IS.7.3 and Appendix 10, section 10.6).

The decision-making in these projects generally focuses on identification of total N loading targets for purposes of attaining water quality standards, informed by modeling work that includes apportionment of sources, which vary by system. We note that the assignment of targets to different source types (*e.g.,* groundwater, surface water runoff, and atmospheric deposition) in different waterbodies and watersheds varies for both practical and policy reasons. Further, during the multi-decade time period across which these activities have occurred, atmospheric deposition of N in coastal areas has declined. In general, however, atmospheric deposition targets for N for the large systems summarized above have been approximately 10 kg/ha-yr.

The establishment of target N loads to surface waterbodies is in many areas related to implementation of the total maximum daily load (TMDL) requirements of section 303(d) of the Clean Water Act.[42] Nutrient load allocation and reduction activities in some large estuaries predate

[40] Some modeling studies in some areas have indicated the potential for a lagged response even as emissions and deposition decline; this lag reflects a reduction in soil absorption of SO_4^{-2} and leaching of previously accumulated S from watersheds (ISA, Appendix 7, section 7.1.2.2).

[41] Separate quantitative analyses have not been performed in this review for N enrichment-related effects in these waterbodies in recognition of a number of factors, including modeling and assessment complexities, and site- or waterbody-specific data requirements, as well as, in some cases, issues of apportionment of atmospheric sources separate from other influential sources.

[42] Under the CWA, section 303(d), every two years, states and other jurisdictions are required to list impaired waterbodies not meeting water quality standards. For waterbodies on the list, a TMDL must be developed that identifies the maximum amount of pollutant a waterbody can receive and still meet water quality standards, *e.g.,* standards for dissolved oxygen and chlorophyll a (which are indicators of eutrophication).

development of CWA 303(d) TMDLs. The multiple Chesapeake Bay Agreements signed by the U.S. EPA, District of Columbia, and states of Virginia, Maryland, and Pennsylvania first established the voluntary government partnership that directs and manages bay cleanup efforts and subsequently included commitments for reduction of N and phosphorus loading to the bay. Efforts prior to 2000 focused largely on point-source discharges, with slower progress for nonpoint-source reductions via strategies such as adoption of better agricultural practices, reduction of atmospheric N deposition, enhancement of wetlands and other nutrient sinks, and control of urban sprawl (2008 ISA, section 3.3.8.3). Studies since 2000 estimate atmospheric deposition as a major N source in the overall N budget for the Chesapeake Bay [43] (ISA, section 7.2.1; Howarth, 2008; Boyer et al., 2002). The TMDL established for the Chesapeake Bay in 2010, under requirements of section 303(d) of the Clean Water Act, included a loading allocation for atmospheric deposition of N directly to tidal waters, which was projected to be achieved by 2020 based on air quality progress under existing CAA regulations and programs (U.S. EPA, 2010).[44]

Jurisdictions for other U.S. estuaries have also developed TMDLs to address nutrient loading causing eutrophication. For example, atmospheric deposition in 2000 was identified as the third largest source of N loading to Narragansett Bay via the watershed and directly to the Bay, at 20% of the total (ISA, Appendix 7, section 7.2.1). Similarly, atmospheric deposition was estimated to account for approximately a third of N input to several small- to medium-sized estuaries of southern New England, with the percentage varying widely for individual estuaries (ISA, Appendix 7, section 7.2.1; Latimer and Charpentier, 2010).[45] Another modeling study in the Waquoit Bay estuaries in Cape Cod, Massachusetts, using data since 1990, estimated atmospheric deposition to have decreased by about 41% while wastewater inputs increased 80%, with a net result that total loads were concluded to not have changed over that time period (ISA, Appendix 7, section 7.2.1). Another well-studied estuarine system is Tampa Bay, for which a 2013 study estimated atmospheric sources to account for more than 70% of total N loading based on 2002 data (ISA, Appendix 7, section 7.2.1). The TMDL for Tampa Bay allocates 11.8 kg/ha-yr N loading to atmospheric deposition (ISA, Appendix 16, section 16.4.2; Janicki Environmental, 2013). The Neuse River Estuary is another for which modeling work has investigated the role of N loading from multiple sources on nutrient enrichment [46] and associated water quality indicators, including chlorophyll a (ISA, Appendix 10, section 10.2).

Nitrogen loading to estuaries has also been considered specifically for impacts on submerged aquatic vegetation. For example, eelgrass coverage was estimated to be markedly reduced in shallow New England estuaries with N loading at or above 100 kg N/ha-yr (ISA, Appendix 10, section 10.2.5). Another study estimated loading rates above 50 kg/ha-yr as a threshold at which habitat extent may be impacted (ISA, Appendix 10, section 10.2.5; Latimer and Rego, 2010). Factors that influence the impact of N loading on submerged vegetation include flushing and drainage in estuaries (ISA, Appendix 10, section 10.6).

(2) Deposition-Related Effects in Terrestrial Ecosystems

The subsections below describe the available information for quantitative relationships between atmospheric deposition rates and acidification and N enrichment-related effects in terrestrial systems. In the 2012 review, analyses included a critical load-based quantitative modeling analysis focused on BC:Al ratios in soils for terrestrial acidification and a qualitative characterization of nutrient enrichment (2009 REA). The more qualitative approach taken for nutrient enrichment in the 2012 review involved describing deposition ranges identified from observational or modeling research as associated with potential effects/changes in species, communities, and ecosystems, with recognition of uncertainties associated with quantitative analysis of these depositional effects (2011 PA, section 3.2.3). In this review, rather than performing new quantitative analyses focused on terrestrial ecosystems, we draw on analyses in the 2009 REA and on more recent published studies recognized in the ISA that provide information pertaining to deposition levels associated with effects related to terrestrial acidification and N enrichment.

Several recent publications have added to the information available in the last review including analyses of large datasets from field assessments of tree growth and survival, as well as analyses of understory plant community richness, containing estimates of atmospheric N and/or S deposition (ISA, Appendix 6, section 6.5). The understory plant studies investigate the existence of associations of variations in plant community structure and other metrics including species richness, growth, and survival with variations in deposition during an overlapping time period, generally of a decade or two in duration. Soil acidification modeling and observational studies, as well as experimental addition studies, each with their various design features and associated strengths and limitations (as noted immediately below), inform consideration of N and S deposition levels of interest in the review.

In general, observational or gradient studies differ from the chemical mass balance modeling approach in a number of ways that are relevant to their consideration and use for our purposes in this review. One difference of note is the extent to which their findings address the ecosystem impacts of historical deposition. Observational studies describe variation in indicators in the current context, which may include stores of historically deposited chemicals. In these studies, such historical loading, and its associated impacts, can contribute to effects quantified by the study ecological metrics, yet the metric values are assessed in relation to estimates of more recent deposition. Mass balance modeling for steady-state conditions is commonly used for estimating critical loads for acidification risk but does not usually address the complication of historical deposition impacts that can play a significant role in timing of system recovery. In this type of modeling, timelines of the various processes are not addressed. While this provides a simple approach that may facilitate consideration unrelated to

[43] For example, a 2011 analysis estimated atmospheric deposition to the Chesapeake Bay watershed to account for approximately 25% of total N inputs to the estuary (ISA, Appendix 7, section 7.2.1).

[44] As recognized on the EPA web page describing this activity, the TMDL, formally established in December 2010 ''is designed to ensure that all pollution control measures needed to fully restore the Bay and its tidal rivers are in place by 2025.'' The website also indicates that ''EPA expects practices in place by 2017 to meet 60 percent of the necessary reductions,'' and for some areas to recover before others, but for it to take years after 2025 for the Bay and its tributaries to fully recover (*https://www.epa.gov/chesapeake-bay-tmdl/frequent-questions-about-chesapeake-bay-tmdl*).

[45] For example, across the 74 estuaries in the 3-state coastal region studied, N from atmospheric deposition to estuary watersheds was generally estimated to account for less than 25% of total N inputs, while estimates for a few small estuaries in CT were higher than 51% (but below 75%) (Latimer and Charpentier, 2010).

[46] One evaluation of progress in achieving mandated N reductions in the Neuse River Basin in NC found that flow-normalized N loading from NO_3^- decreased beginning in the 1992–1996 period (ISA Appendix 10, section 10.2; Lebo et al., 2012).

recovery timelines, it cannot address the potential for changes in influential factors that may occur over time with different or changed deposition patterns. Thus, while observational studies contribute to the evidence base on the potential for N/S deposition to contribute to ecosystem effects (and thus are important evidence in the ISA determinations regarding causality), their uncertainties (and underlying assumptions) differ from those of modeling analyses, and they may be somewhat less informative with regard to identification of specific N and S deposition levels that may elicit ecosystem impacts of interest. Both types of studies, as well as N addition experiments, which are not generally confounded by exposure changes beyond those assessed (yet may have other limitations), have been considered, with key findings summarized below.

(a) Deposition and Risks to Trees

The 2009 REA performed a steady-state modeling analysis to estimate the annual amounts of S and N acidifying deposition at or below which one of three BC:Al target values would be met in a 24-state area in which the acid-sensitive species, red spruce and sugar maple, occur. A range of acid deposition was estimated for each of the three target values. Recent estimates of total S and N deposition in regions of the U.S. appear to meet all but the most restrictive of these targets, for which the uncertainty is greatest (*e.g.,* ISA, Appendix 2, sections 2.6 and 2.7).[47]

Experimental addition studies of S, or S plus N have been performed in eastern locations, focusing on a small set of tree species, and generally involving S and N additions greater than 20 kg/ha-yr, in combination with appreciable background deposition at the time, and have generally not reported growth reductions (PA, Appendix 5B, Table 5B–1; ISA, Appendix 5, section 5.5.1). Uncertainties associated with these analyses include the extent to which the studies reflect steady-state conditions. Given the variability in the durations across these studies and the relatively short durations for some (*e.g.,* less than five years), it might be expected that steady-state conditions have not been reached, such that the S/N loading is within the buffering capacity of the soils. With regard to N addition alone, the available studies have reported mixed results for growth and survival (PA, Table 5B–1; Magill et al., 2004; McNulty et al., 2005; Pregitzer et al., 2008; Wallace et al., 2007). It is not clear the extent to which such findings may be influenced by species-specific sensitivities or soils and trees already impacted by historic deposition, or other environmental factors.

With regard to S deposition, two large observational studies that analyzed growth and/or survival measurements in tree species at sites in the eastern U.S. or across the country reported negative associations of tree survival for 9 of the 10 species' functional type groupings with the S deposition metric and of tree survival and growth for nearly half of the species individually (Dietze and Moorcroft, 2011; Horn et al., 2018).[48] Interestingly, survival for the same 9 species groups was also negatively associated with long-term average O_3 (Dietze and Moorcroft, 2011). The S deposition metrics for the two studies were mean annual average deposition estimates for total S or sulfate (wet deposition) during different, but overlapping, time periods of roughly 10-year durations. The full range of average SO_4^{2-} deposition estimated for the 1994–2005 period assessed by Dietze and Moorcroft (2011) for the eastern U.S. study area was 4 to 30 kg S/ha-yr. The second study covered the more recent time period (2000–2013) and 71 species distributed across the U.S. To draw on this study with regard to S deposition levels of interest, the distribution of S deposition estimates for each species were considered in the PA; the range of median S deposition for sites of those species for which negative associations with growth or survival were reported was 5 to 12 kg S/ha-yr, with few exceptions (Appendix 5B, section 5B.2 and Attachments 2A and 2B; Horn et al., 2018).[49]

Regarding N deposition, the three large observational studies that analyzed growth and/or survival measurements in tree species samples at sites in the northeastern or eastern U.S., or across the country, reported associations of tree survival and growth with several N deposition metrics (Dietze and Moorcroft, 2011; Thomas et al., 2010; Horn et al., 2018). Estimates of average N deposition across the full set of sites analyzed by Thomas et al. (2010) in 19 states in the northeastern quadrant of the U.S. ranged from 3 to 11 kg N/ha-yr for the period 2000–2004. The N deposition metrics for these three studies were mean annual average deposition estimates for total N or nitrate (wet deposition) during different, but overlapping, time periods that varied from 5 to more than 10 years. The full range of average NO_3^- deposition estimated for the 1994–2005 period assessed by Dietze and Moorcroft (2011) for the eastern U.S. study area was 6 to 16 kg N/ha-yr. Median N deposition estimated (measurement interval average [falling within the years 2000–2013]) at sites of nonwestern species for which associations with growth or survival were negative (either over full range or at median for species) ranged from 7 to 12 kg N/ha-yr (Horn et al., 2018).

In considering what can be drawn from these studies with regard to deposition levels of potential interest for tree species effects, such as the ranges identified above, a number of uncertainties are recognized. For example, several factors were not accounted for that have potential to influence tree growth and survival. Although O_3 was analyzed in one of the three studies, soil characteristics and other factors with potential to impact tree growth and survival (other than climate) were not assessed, contributing uncertainty to their interpretations. Also, the influence of historical deposition patterns and associated impacts is unknown.[50] Further, differences in findings for the various species (or species' groups) may relate to differences in geographic distribution of sampling locations, which may

[47] Uncertainties associated with the 2009 REA analyses include those associated with the limited dataset of laboratory-generated data on which the BC:Al target values are based (PA, section 5.3.2) as well as in the steady-state modeling parameters, most prominently those related to base cation weathering and acid neutralizing capacity (2009 REA, section 4.3.9). A new approach to estimating weathering has more recently been employed and reported to reduce the uncertainty associated with this parameter (*e.g.,* Phelan et al., 2014; McDonnell et al., 2012; ISA, Appendix 4, sections 4.6.2.1 and 4.8.4 and Appendix 5, section 5.4).

[48] The study by Horn et al. (2018) constrained the S analyses to preclude a positive association with S.

[49] This range is for median S deposition estimates (based on measurement interval average, occurring within the years 2000–2013) of nonwestern species with negative associations with growth or survival ranged (Horn et al., 2018).

[50] The influence of historically higher deposition (*e.g.,* versus deposition over the measurement interval) on observations is unknown. Given the influence of deposition on soil conditions that affect tree growth and survival, and generally similar geographic variation for recent and historic deposition, a quantitative interpretation of uncertainty is the extent to which similarity of the two studies' findings indicate a potential for both metrics to reflect geographic variation in impacts stemming from historic deposition. Although geographic deposition patterns have changed little across the time period of the studies, annual S and N deposition rates have changed appreciably (*e.g.,* PA, Appendix 5B, Figures 5B–9 through 5B–12), which may also contribute uncertainty to interpretation of specific deposition rates associated with patterns of tree growth and survival. Few studies on recovery in historically impacted areas that might address such uncertainties are available (*e.g.,* ISA, section IS.11).

contribute to differences in ranges of deposition history, geochemistry etc.

(b) Deposition Studies of Herbs, Shrubs and Lichens

Studies evaluating the effects of N addition on herbs, shrubs and lichens include observational studies of herbaceous species richness at sites in a multi-state study area and of grassland or coastal sage scrub communities in southern California, and experimental addition studies in several western herb or shrub ecosystems. The experimental addition studies indicate effects on community composition associated with annual N additions of 10 kg N/ha-yr (in the context of background deposition on the order of 6 kg N/ha-yr [PA, Appendix 5B, Table 5B–7]) and higher (PA, sections 5.3.3.1 and 5.3.4.2; ISA, Appendix 6, section 6.3.6). Experiments involving additions of 5 kg N/ha-yr variously reported no response or increased cover for one species (in context of background deposition estimated at 5 kg N/ha-yr). The landscape-level analysis of coastal sage scrub community history in southern California observed a greater likelihood of recovery of sites with relatively low levels of exotic invasive grasses when the N deposition metric level was below 11 kg N/ha-yr. Lastly, the multi-state analysis of herbaceous species richness reported a negative association with N deposition metric values above 8.7 kg N/ha-yr at open-canopy sites and above 6.5 kg/ha-yr and low pH sites. In forested sites, negative associations were found above 11.6 kg N/ha-yr in sites with acidic soil pH at or above 4.5 (PA, section 5.3.3).

Limitations and associated uncertainties vary between the two types of studies (experimental addition and observational), but both are limited with regard to consideration of the impacts of long-term deposition. Such studies are necessarily limited in scope with regard to species and ecosystem, and while there are some experimental addition studies lasting more than 20 years, many are for fewer than 10 years. In the case of observational studies, these studies generally have not accounted for the influence of historical pollution (including decades of S and N deposition and elevated concentrations of O_3 and N oxides) on the associations observed with more recent deposition metrics. Further, there is uncertainty associated with the extent to which the exposure metric utilized reflects the particular conditions that may be eliciting the ecosystem response quantified by the ecosystem metric.

The few studies of lichen species diversity and deposition-related metrics, while contributing to the evidence that relates deposition to relative abundance of different lichen species, are more limited in the extent to which they inform an understanding of specific exposure conditions in terms of deposition rates that may elicit specific responses. Related factors include uncertainties related to the methods employed to represent N deposition, the potential role of other unaccounted-for environmental factors (including O_3, SO_2, S deposition and historical air quality and associated deposition), and uncertainty concerning the independence of any effect of deposition levels from residual effects of past patterns of deposition (PA, section 5.3.3.2). Information on exposure conditions associated with effects of oxides of N such as HNO_3 on lichen species is also addressed in section II.A.3.c.(3) below.

(3) Other Effects of N Oxides, SO_X and PM in Ambient Air

The evidence related to exposure conditions for other effects of SO_X, N oxides and PM in ambient air includes concentrations of SO_2 and NO_2 associated with effects on plants, concentrations of NO_2 and HNO_3 associated with effects on plants and lichens, and concentrations of PM mass or PM loading (much higher than those associated with the existing standard) that affect plant photosynthesis. With regard to oxides of N and S, we note that some effects described as direct may be related to dry deposition of SO_2 and HNO_3 onto plant and lichen surfaces, exposure pathways that would be captured in observational studies and could also be captured in some fumigation experiments.

With regard to SO_2, the evidence primarily includes field studies for the higher concentrations associated with visible foliar injury and laboratory studies for other effects, *e.g.,* depressed photosynthesis and reduced growth or yield (ISA, Appendix 3, section 3.2; 1982 AQCD, section 8.3). The recently available information also includes observational studies reporting increased tree growth in association with reductions in SO_2 emissions, although these studies do not generally report the SO_2 concentrations in ambient air or account for the influence of changes in concentrations of co-occurring pollutants such as O_3 (ISA, Appendix 3, section 3.2). With regard to foliar injury, the current ISA states there to be limited research since the 1982 AQCD and ''no clear evidence of acute foliar injury below the level of the current standard'' (ISA, p. IS–37). Few studies report yield effects from acute exposures, with the available ones reporting relatively high concentrations, such as multiple hours with concentrations above 1 ppm or 1000 ppb (1982 AQCD, section 8.3). Effects have also been reported on photosynthesis and other functions in a few lichen species groups, although recovery of these functions was observed from short, multi-hour exposures to concentrations below about 1 ppm (ISA, Appendix 3, section 3.2).

With regard to oxides of N, the evidence indicates that effects on plants and lichens occur at much lower exposures to HNO_3 (than to NO_2). The laboratory and field studies of oxides of N vary regarding their limitations; field studies are limited regarding identification of threshold exposures for the reported effects, and uncertainties associated with controlled experiments include whether the conditions under which the observed effects occur would be expected in the field. Plant studies reported in the ISA did not report effects on photosynthesis and growth resulting from exposures of NO_2 concentrations below 0.1 ppm (ISA, Appendix 3, section 3.3).

With regard to the HNO_3, the elevated concentrations of NO_2 and HNO_3 in the Los Angeles area in the 1970s–90s are well documented as is the decline of lichen species in the Los Angeles Basin during that time, although such an analysis is not available elsewhere in the U.S. (PA, section 5.4.2; ISA, Appendix 3).[51] Other evidence specific to HNO_3, which can deposit on and bind to leaf or needle surfaces, includes controlled exposure studies describing foliar effects on several tree species. Studies of ponderosa pine, white fir, California black oak and canyon live oak involving continuous chamber exposure over a month to 24-hour average HNO_3 concentrations generally ranging from 10 to 18 $\mu g/m^3$ (moderate treatment) or 18 to 42 $\mu g/m^3$ (high treatment), with the average of the highest 10% of concentrations generally ranging from 18 to 42 $\mu g/m^3$ (30–60 $\mu g/m^3$ peak) or 89 to 155 $\mu g/m^3$ (95–160 $\mu g/m^3$ peak), resulted in damage to foliar surfaces of the 1 to 2-year old plants (ISA, Appendix 3, section 3.4; Padgett et al., 2009). Available evidence for lichens

[51] For example, concentrations of HNO_3 reported in forested areas of California in the 1980s ranged up to 33 ug/m^3, and annual average NO_2 concentrations in the Los Angeles area ranged from 0.078 ppm in 1979 to 0.053 ppm in the early 1990s (PA, section 5.4.2). Ambient air concentrations of HNO_3 in the Los Angeles metropolitan area have declined markedly, as shown in Figure 2–23 of the PA, which compares concentrations at CASTNET monitoring sites between 2019 and 1996 (PA, section 2.4.1).

also includes a recent laboratory study of daily HNO_3 exposures for 18 to 78 days, with daily peaks near 50 ppb (~75 $\mu g/m^3$) that reported decreased photosynthesis, among other effects (ISA, Appendix 6, section 6.2.3.3; Riddell et al., 2012). Based on studies extending back to the 1980s, HNO_3 has been suspected to have had an important role in the dramatic declines of lichen communities that occurred in the Los Angeles basin (ISA, Appendix 3, section 3.4; Nash and Sigal, 1999; Riddell et al., 2008; Riddell et al., 2012). In more recent studies, variation in eutrophic lichen abundance has been associated with variation in N deposition metrics (ISA, Appendix 6, section 6.2.3.3), although the extent to which these associations are influenced by residual impacts of historic air quality is unclear and the extent to which similar atmospheric conditions and ecological relationships exist in other locations in the U.S. is uncertain.

Little information is available on welfare effects of airborne PM at concentrations commonly occurring in the U.S. today, and the available information does not indicate effects to occur under such conditions. The concentrations at which PM has been reported to affect vegetation (*e.g.,* through effects on leaf surfaces, which may affect function, or through effects on gas exchange processes) are generally higher than those associated with conditions meeting the current standards and may be focused on specific particulate chemicals rather than on the mixture of chemicals in PM occurring in ambient air (ISA, Appendix 15, sections 15.4.3 and 15.4.6). Studies involving ambient air PM have generally involved conditions that are much higher than those common to the U.S. today (ISA, Appendix 15, sections 15.4.3 and 15.4.4).

4. Overview of Exposure and Risk Assessment for Aquatic Acidification

Our consideration of the scientific evidence available in the current review is informed by results from quantitative analyses of estimated acidic deposition and associated risk of aquatic acidification (PA, section 5.1 and Appendix 5A). These REA analyses, like those in the last review, make use of well-established modeling tools and assessment approaches for this endpoint. Other categories of effects of S and N deposition have been the subject of quantitative analyses, both in the last review (*e.g.,* terrestrial acidification) and in other contexts (*e.g.,* eutrophication of large rivers and estuaries), each with associated complexities and specificity. The PA, while focusing the new analyses on aquatic acidification risks, as summarized here, also draws on findings of available analyses for the other categories of effects.

The REA analyses, summarized here and presented in detail in Appendix 5A of the PA, have focused on ANC as an indicator of aquatic acidification risk (PA, section 5.1 and Appendix 5A). This focus is consistent with such analyses performed in the 2012 review and with the longstanding evidence that continues to demonstrate a causal relationship between S and N deposition and alteration of freshwater biogeochemistry and between acidifying S and N deposition and changes in biota, including physiological impairment and alteration of species richness, community composition, and biodiversity in freshwater ecosystems (ISA, Table ES–1), as summarized in section II.A.3 above.

Section II.A.4.a. summarizes key aspects of the assessment design, including the conceptual approach and tools, indicator reference or benchmark concentrations, the assessment scales, study areas and waterbodies analyzed, and exposure and risk metrics derived. Key limitations and uncertainties associated with the assessment are identified in section II.A.4.b. and the exposure and risk estimates are summarized in section II.A.4.c. An overarching focus of these analyses is characterization of aquatic acidification risk in sensitive ecoregions associated with different deposition conditions.

a. Key Design Aspects

The REA for this review entailed a multi-scale analysis of waterbodies in the contiguous U.S. that assessed waterbody-specific aquatic acidification at three spatial scales: national, ecoregion, and case study area (PA, Appendix 5A). The assessment involved evaluation of deposition and water quality response (ANC) at the waterbody site level. The results are then summarized at the national, ecoregion, and case study level. The national-scale analysis included all waterbody sites across the U.S. for which relevant data were available.[52] The ecoregion-scale analysis focused on waterbodies with relevant data in a set of 25 ecoregions generally characterized as acid-sensitive; and the more localized case study-scale analysis focused on such waterbodies in five case study areas across the U.S., within each of which were Class I areas.

The impact of acidifying S or N deposition estimated for five different time periods (2001–03, 2006–08, 2010–12, 2014–16 and 2018–20) was evaluated using a CL approach that relied on comparison of waterbody location-specific deposition estimates to waterbody location-specific CL estimates derived for other applications and available in the National Critical Loads Database (NCLD)[53] (PA, Appendix 5A). The CL estimates used in the assessment were largely based on steady-state modeling, and the modeling applications focused on ANC, producing CL estimates (acidifying deposition in terms of kg/ha-yr or meq/m^2-yr [milliequivalents per square meter per year] for S and N compounds) for different target or threshold ANC concentrations (also termed benchmarks). Of the 84 ecoregions in the contiguous U.S., 64 have at least one waterbody site with a CL estimate (PA, Appendix 5A). Given its common use in categorizing waterbody sensitivity, ANC was used as the indicator of acidification risk in this assessment (PA, section 5.1.2.2). Deposition estimates, as 3-year averages of annual TDep estimates for each site, were compared to the CL estimates for three different ANC benchmark concentrations (targets or thresholds), in recognition of the watershed variability and associated uncertainties, as an approach for characterizing aquatic acidification risk (PA, section 5.1).

The available evidence and scientific judgments were considered in identifying the three ANC benchmark concentrations: 20 µeq/L, 30 µeq/L, 50 µeq/L (PA, section 5.1.2.2). Selection of these benchmark ANC concentrations reflects several considerations. For example, most aquatic CL studies conducted in the U.S. since 2010 use an ANC of 20 and/or 50 µeq/L, because 20 µeq/L has been suggested to provide

[52] The national-scale analysis focused on the contiguous U.S. as there are insufficient data available for Hawaii, Alaska, and the territories. Of the four hierarchical levels of ecoregion categorization, the REA utilized level III which divides the contiguous U.S. into 84 ecoregions (Omernik and Griffith, 2014). The 69 of these 84 ecoregions in which there was at least one site with sufficient data comprised the national scale.

[53] The NCLD is comprised of CLs calculated from several common models: (1) steady-state mass-balance models such as the Steady-State Water Chemistry (SSWC), (2) dynamic models such as Model of Acidification of Groundwater In Catchments (MAGIC) (Cosby et al., 1985) or Photosynthesis EvapoTranspiration Biogeochemical model (PnET–BGC) (Zhou et. al., 2015) run out to year 2100 or 3000 to model steady-state conditions and (3) regional regression models that use results from dynamic models to extrapolate to other waterbodies (McDonnell et. al., 2012; Sullivan et al., 2012a). Data and CL estimates in the NCLD are generally focused on waterbodies impacted by deposition-driven acidification and are described in documentation for the database version (PA, section 5.1.2.3; Lynch et al., 2022).

protection for a ''natural'' or ''historical'' [54] range of ANC, and 50 μeq/L to provide greater protection, particularly from episodic acidification events [55] (Dupont et al., 2005; Fakhraei et al., 2014; Lawrence et al., 2015; Lynch et al., 2022; McDonnell et al., 2012, 2014; Sullivan et al., 2012a, 2012b). For example, levels below 20 μeq/L have been associated with fish species reductions in some sensitive waterbodies of the Shenandoah and Adirondack Mountains. Levels of ANC ranging from 30 to 40 μeq/L have been reported to provide sufficient buffering to withstand acidic inputs associated with episodic springtime rain or snowmelt events. An ANC value of 50 μeq/L has often been cited in the literature as a target for many areas, and in the 2012 review, ANC values at or above 50 μeq/L were described as providing an additional level of protection although with increasingly greater uncertainty for values at/above 75 μeq/L [56] (2011 PA, pp. 7–47 to 7–48). In the western U.S., lakes and streams vulnerable to deposition-driven aquatic acidification are often found in the mountains where surface water ANC levels are naturally low and typically vary between 0 and 30 μeq/L (Williams and Labou, 2017; Shaw et al., 2014). For these reasons, this assessment also develops results for an ANC threshold of 50 μeq/L for sites in the East and 20 μeq/L for sites in the West (denoted as ''50/20'' μeq/L).[57] Thus, the set of benchmark concentrations used in this REA includes ANC concentrations that are naturally occurring in many areas and also includes concentrations that, depending on watershed characteristics, may provide additional buffering in times of episodic acidification events.

Since acidification of waterbodies is controlled by local factors such as geology, hydrology, and other landscape factors, aquatic CLs for acidification were determined at the waterbody level (based on site-specific data) and then summarized at the national, ecoregion, and case study level. National-scale analyses were performed using two approaches: one considering acid deposition of N and S compounds combined and one for S deposition only. Findings from these analyses indicated that across the five different time periods analyzed, the percent of waterbodies exceeding their CLs was similar for the two approaches (PA, Appendix 5A, sections 5A.1.6.2 and 5A.2.1). Thus, to facilitate interpretation of the results, further analysis of the results focused on the findings for S only deposition.

Critical load estimates for specific waterbody sites across the contiguous U.S. were drawn from the NCLD (version 3.2.1) [58] for comparison to total deposition estimates in the same locations for the five time periods. Comparisons were only performed for sites at which CL estimates were greater than zero, indicating that achievement of the associated ANC benchmark concentration would be feasible.[59] The results of these analyses are summarized with regard to the spatial extent and severity of deposition-related acidification effects and the protection from these effects associated with a range of annual S deposition.

The ecoregion-scale analyses focused on 25 ecoregions,[60] 18 in the East and 7 in the West. Ecoregions are areas of similarity regarding patterns in vegetation, aquatic, and terrestrial ecosystem components. The 25 ecoregions in this analysis each had more than 50 waterbody sites (or locations) for which a prior modeling application had developed a CL estimate, which was available in the NCLD (PA, section 5A.2.2.2). Although a total of 32 ecoregions had more than 50 CL sites,[61] four in the West were excluded as having very low deposition that resulted in no CL exceedances across the complete 20-year analysis period. An additional three ecoregions (*i.e.,* Southeastern Plains, Southern Coastal Plain, and Atlantic Coastal Pine Barrens) were excluded as they are known to have naturally acidic surface waters, and the low CL estimates for these ecoregions (and resulting CL exceedances) are likely driven by natural acidity linked to high levels of dissolved organic carbon, hydrology, and natural biogeochemical processes rather than atmospheric deposition (2008 ISA, section 3.2.4.2; Baker et al., 1991; Herlihy et al., 1991).

The case study scale represents the smallest scale at which CLs and their comparison to deposition estimates were summarized and is intended to give some insight into potential local impacts of aquatic acidification. Five case study areas across the U.S. were examined: Shenandoah Valley Area, White Mountain National Forest, Northern Minnesota, Sierra Nevada Mountains, and Rocky Mountain National Park (details presented in PA, section 5.1.3.3 and Appendix 5A, section 5A.2.1). These areas include a number of national parks and forests that vary in their sensitivity to acidification but represent high value or protected ecosystems, such as Class 1 areas, wilderness, and national forests (PA, Appendix 5A, section 5A.2.1). The most well studied of these, the Shenandoah Valley Area case study, includes the Class I area, Shenandoah National Park, and waterbodies in each of three ecoregions. The number of waterbody sites with CLs available in the NCLD for the Shenandoah study area (4,977 sites) is nearly an order of magnitude greater than the total for the four other areas combined (524 sites).

The analyses at different scales differed in how results were summarized and evaluated. For example, at the national scale, percentages of water bodies with deposition estimates exceeding their CLs (for the different ANC benchmarks) were reported for each of the five time periods for which deposition was assessed (PA, Table 5–1). From the case

[54] For example, dynamic modeling simulations in acid-sensitive streams of the southern Blue Ridge Mountains have predicted all streams to have pre-industrial time ANC levels above 20 μeq/L, while also predicting more than a third of the streams to have pre-industrial ANC levels below 50 μeq/L (Sullivan et al., 2011).

[55] As noted in section II.A.3.a. above, events such as spring snowmelt and heavy rain events can contribute to episodic acidification events. For example, in some impacted northeastern waterbodies, particularly headwater streams, ANC levels may dip below zero for hours to days or weeks in response to such events, while waterbodies labeled chronically acidic have ANC levels below zero throughout the year (ISA, Appendix 6, section 6.1.1.1; Driscoll et al., 2001).

[56] In considering higher ANC levels (*e.g.,* up to 80 μeq/L and higher), it was also recognized that many waterbodies, particularly in acid-sensitive regions of the contiguous U.S., never had an ANC that high and would never reach an ANC that high naturally (Williams and Labou 2017; Shaw et al., 2014; PA, section 5.1.2.2). Additionally, in conveying its advice in the 2012 review, the CASAC expressed its view that ''[l]evels of 50 μeq/L and higher would provide additional protection, but the Panel has less confidence in the significance of the incremental benefits as the level increases above 50 μeq/L'' (Russell and Samet, 2010a; pp. 15–16).

[57] This approach is also used in multiple studies and the NCLD (PA, section 5.1.2.2).

[58] A waterbody is represented as a single CL value. In many cases, a waterbody has more than one CL value calculated for it because different studies determined a value for the same waterbody. When more than one CL exists, the CL from the most recent study was selected, while the CL values were averaged when the publications are from the same timeframe (PA, Appendix 5A, section 5A.1.5).

[59] Critical load estimates are estimates of the S deposition rate at which a particular waterbody site is estimated to be able to achieve a specified ANC level. A CL estimate at or below zero would indicate that no S deposition estimate would provide for such a result.

[60] The ecoregion classification scheme used to group waterbody sites into ecoregions is based on that described in Omernik (1987), which classifies regions through the analysis of the patterns and the composition of biotic and abiotic characteristics that affect or reflect differences in ecosystem quality and integrity (*e.g.,* geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology).

[61] In light of the size of the level III ecoregions, 50 was identified as an appropriate minimum number of CL sites within an ecoregion to include it in the analysis.

study scale analyses, we focused primarily on the distribution of CL estimates in each study area. In so doing, the CLs for each case study area were characterized in terms of the average and two lower percentiles (*e.g.,* the 30th percentile CL, which is the value below 70% of the CL estimates for that study area, and the 10th percentile).

In the ecoregion-scale analyses, percentages of waterbody sites per ecoregion that exceeded their estimated CLs and percentages of waterbody sites that fell at or below them—for each of the three ANC benchmarks—were summarized by ecoregion for each of the five time periods: 2001–2003, 2006–2008, 2010–2012, 2014–2016 and 2018–2020 (PA, section 5.1.3.2 and Appendix 5A, section 5A.2.2). Percentages of waterbody sites that did not exceed their estimated CLs were described as achieving the associated ANC benchmark (or target). These results of the site-specific ANC modeling were then considered in two ways. The first is based on a binning of this dataset of percentages of waterbodies per ecoregion-time period combinations that were estimated to achieve each of the ANC targets by the median deposition for that ecoregion during that time period (*e.g.,* percentage achieving ANC target of 20 μeq/L when ecoregion median deposition was at/below 5 kg/ha-yr).[62] The second approach involved summarizing ecoregion-specific trends in percentage of waterbodies per ecoregion estimated to achieve the three threshold or target ANC values (or estimated to exceed the associated CLs).

b. Key Limitations and Uncertainties

The nature and magnitude of associated uncertainties and their impact on the REA estimates are characterized with a mainly qualitative approach, informed by several quantitative sensitivity analyses (PA, Appendix 5A, section 5A.3). The mainly qualitative approach used to characterize uncertainty here and in quantitative analyses in other NAAQS reviews is described by World Health Organization (WHO, 2008). Briefly, with this approach, we have identified key aspects of the assessment approach that may contribute to uncertainty in the conclusions and provided the rationale for their inclusion. Then, we characterized the magnitude and direction of the influence on the assessment for each of these identified sources of uncertainty. Consistent with the WHO (2008) guidance, we scaled the overall impact of the uncertainty by considering the degree of uncertainty as implied by the relationship between the source of uncertainty and the exposure and risk estimates. A qualitative characterization of low, moderate, and high was assigned to the magnitude of influence and knowledge base uncertainty descriptors, using quantitative observations relating to understanding the uncertainty, where possible. The direction of influence, whether the source of uncertainty was judged to potentially over-estimate (''over''), under-estimate (''under''), or have an unknown impact to exposure/risk estimates was also characterized. Two types of quantitative analyses of the variability and uncertainty associated with the CL estimates used in the REA support the overall uncertainty characterization. The first type of analysis is a sensitivity analysis using Monte Carlo techniques to quantify CL estimate uncertainty associated with several model inputs, and the second is an analysis of the variation in CL estimates among the three primary modeling approaches on which the CLs used in this assessment were based.

As overarching observations regarding uncertainty associated with this REA, we note two overarching aspects of the assessment. The first relates to interpretation of specific thresholds of ANC, and the second to our understanding of the biogeochemical linkages between deposition of S and N compounds and waterbody ANC, and the associated estimation of CLs. While ANC is an established indicator of aquatic acidification risk, there is uncertainty in our understanding of relationships between ANC and risk to native biota, particularly in waterbodies in geologic regions prone to waterbody acidity. Such uncertainties relate to the varying influences of site-specific factors other than ANC, such as soil type. Uncertainty associated with our understanding of the biogeochemical linkages between deposition and ANC and the determination of steady-state CLs is difficult to characterize and assess. Uncertainty in CL estimates is associated with parameters used in the steady-state CL models. While the Steady-State Water Chemistry (SSWC) and other CL models are well conceived and based on a substantial amount of research and applications available in the peer-reviewed literature, there is uncertainty associated with the availability of the necessary data to support certain model components.

The strength of the CL estimates and the exceedance calculation rely on the ability of models to estimate the catchment-average base-cation supply (*i.e.,* input of base cations from weathering of bedrock and soils and air), runoff, and surface water chemistry. The uncertainty associated with runoff and surface water parameters relates to availability of measurements; however, the ability to accurately estimate the catchment supply of base cations to a water body is still difficult and uncertain (PA, Appendix 5A, section 5A.3). This area of uncertainty is important because the catchment supply of base cations from the weathering of bedrock and soils is the factor with the greatest influence on the CL calculation and has the largest uncertainty (Li and McNulty, 2007). For example, the well-established models generally rely on input or simulated values for BCw rate, a parameter the ISA notes to be ''one of the most influential yet difficult to estimate parameters in the calculation of critical acid loads of N and S deposition for protection against terrestrial acidification'' (ISA, section IS.14.2.2.1). Obtaining accurate estimates of weathering rates is difficult because weathering is a process that occurs over very long periods of time, and the estimates on an ecosystem's ability to buffer acid deposition rely on accurate estimates of weathering. Although the approach to estimate base-cation supply for the national case study (*e.g.,* F-factor approach) has been widely published and analyzed in Canada and Europe and has been applied in the U.S. (*e.g.,* Dupont et al., 2005 and others), the uncertainty in this estimate is unclear and could be large in some cases.

In light of the significant contribution of this input to the CL estimates, a quantitative uncertainty analysis of CL estimates based on state-steady CL modeling was performed (PA, Appendix 5A, section 5A.3.1). This analysis, involving many model simulations for the more than 14,000 waterbodies, drawing on Monte Carlo sampling, provided a description of the uncertainty around the CL estimate in terms of the confidence interval for each waterbody mean result. The size of the confidence interval for S CL estimates ranged from 0.1 kg S/ha-yr at the 5th percentile to 5.3 kg S/ha-yr at the 95th percentile. Smaller confidence intervals were associated with CLs determined with long-term water quality data and low variability in runoff measurements. Estimates of CL determined by one or very few water quality measurements, and in areas where runoff is quite variable (*e.g.,* the western U.S.), had larger confidence intervals, indicating greater uncertainty. Critical load estimates with the lowest uncertainty

[62] The percentages of waterbodies in an ecoregion with estimated ANC at/above a target ANC is paired with the median deposition for that ecoregion. The percentages are then binned by the median deposition values.

were for waterbody sites in the eastern U.S., particularly along the Appalachian Mountains, in the Upper Midwest, and in the Rocky Mountains, which are areas for which there are relatively larger site-specific datasets (*e.g.,* for water quality parameters). Greater uncertainty is associated with CLs in the Midwest and South and along the California to Washington coast. This uncertainty in the Midwest is associated with most of the CLs in waterbodies in this area being based on one or a few water quality measurements, while the high uncertainty for sites along the California and Washington coasts relates to variability in runoff values. On average, the size of the confidence interval for the vast majority of CLs (those based on the widely used steady-state water chemistry model) was 7.68 meq S/m^2-yr or 1.3 kg S/ha-yr, giving a confidence interval of ±3.84 meq/m^2-yr or ±0.65 kg S/ha-yr. While a comprehensive analysis of uncertainty had not been completed for these estimates prior to this assessment, judgment by EPA experts suggested the uncertainty for combined N and S CLs to be on average about ±0.5 kg/ha-yr (3.125 meq/m^2-yr), which is generally consistent with the range of uncertainty determined from this quantitative uncertainty analysis (PA, Appendix 5A, section 5A.3).

At the ecoregion scale, 51 ecoregions had sufficient data to calculate the 5th to 95th percentile (PA, Appendix 5A, Table 5A–56). Smaller confidence intervals around the mean CL (*i.e.,* lower uncertainty CLs) were associated with ecoregions in the Appalachian Mountains (*e.g.,* Northern Appalachian and Atlantic Maritime Highlands, Blue Ridge, Northern Lakes and Forests, and North Central Appalachians) and Rockies (*e.g.,* Sierra Nevada, Southern Rockies, and Idaho Batholith). Ecoregions with more uncertain CLs included the Northeastern Coastal Zone, Cascades, Coast Range, Interior Plateau, and Klamath Mountains/California High North Coast Range.

Although the vast majority of CLs in this assessment were based on the SSWC model, an analysis was conducted to understand differences in the CLs calculated with the different methods. There are three main CL approaches, all based on the watershed mass-balance approach where acid-base inputs are balanced. The three approaches include: (1) SSWC model and F-Factor that is based on quantitative relationships to water chemistry (Dupont et al., 2005; Scheffe et al., 2014; Lynch et al., 2022), (2) Statistical Regression Model that extrapolated weathering rates across the landscape using water quality or landscape factors (Sullivan et al., 2012b; McDonnell et al., 2014), and (3) Dynamic Models (Model of Acidification of Groundwater In Catchments [MAGIC)] or Photosynthesis EvapoTranspiration Biogeochemcial model [Pnet-BGC]). Critical load values were compared between these models to determine model biases. Results from the comparison between different CL methods that were used to calculate the critical loads in the NCLD are summarized in PA Appendix 5A, section 5A.3.1, for lakes in New England and the Adirondacks and streams in the Appalachian Mountains. Overall, good agreement was found between the three methods used to calculate CLs, indicating there was not a systematic bias between the methods and that they should produce comparable results when used together as they were in these analyses (PA, Appendix 5A, section 5A.3).

c. Summary of Results

The findings from the aquatic acidification REA are summarized in terms of S deposition due to the finding of a negligible additional influence of N deposition compared to S deposition on acidification in this assessment[63] (PA, Appendix 5A, section 5A.2.1). As summarized more fully below, the analyses of five case study areas, including the acidification-impacted Shenandoah Valley area, indicate that with annual average S deposition below 12 and 10 kg/ha yr, the average waterbody in each area (average as to acid-sensitivity) would be estimated to achieve the ANC benchmarks of 20 and 50 μeq/L, respectively. Seventy percent of waterbodies in each area would be estimated to achieve these benchmarks with deposition below 10 and 7 kg/ha-yr, respectively. At the ecoregion-scale, the results from the analysis of 25 ecoregions, dominated by acid-sensitive waterbodies, indicate acid buffering capabilities to have improved substantially over the past 20 years, and particularly between the first and second decades of the period. By the 2010–2012 period, the percentages of waterbodies achieving the three ANC benchmarks in all 25 ecoregions exceeded 80%, 80% and 70% (for 20, 30 and 50 μeq/L, respectively). By the subsequent analysis period (2014–2016), these percentages were 90%, 80% and 80%. The ecoregion median annual average deposition in all 25 ecoregions was below 8 kg/ha-yr for 2010–2012 and below 5 kg/ha-yr for 2014–2016. An alternate approach to analyzing these estimates (for the 25 ecoregions across all five time periods) suggested that the three ANC benchmarks could be met in more than 80%, 80% and 70% (for 20, 30 and 50 μeq/L, respectively) of waterbodies per ecoregion in all ecoregions and time periods for which annual average ecoregion median deposition is estimated to be at or below 7 kg/ha-yr.

Between the three-year period of 2000–2002, which was the analysis year for the 2009 REA, and 2018–2020, the latest period considered in the REA for this review, national average sulfur deposition has declined appreciably across the U.S. This decline in deposition is reflected in the very different aquatic acidification impact estimates for the two periods. Unlike the findings for 2000–2002 in the 2009 REA, in the national-scale analysis of the current REA, few waterbody sites are estimated to be receiving deposition in excess of their CLs for relevant ANC targets under recent S deposition levels. While recognizing inherent limitations and associated uncertainties of any such analysis, the national-scale assessment performed as part of the current review indicates that under deposition scenarios for the 2018–2020 period, the percentage of waterbodies nationwide that might not be able to maintain an ANC of 50 μeq/L is less than 5% (table 1; PA, Table 5–1).

[63] More specifically, the percentage of waterbodies across the contiguous U.S. estimated to exceed a CL for combined total S and N are very similar or just slightly higher (*e.g.,* by 1–2%) than S only percentages of the waterbodies estimated to not meet the ANC benchmarks. This indicates that most of the N deposition entering the watershed is retained within the watershed and/or converted to gaseous N (PA, Appendix 5A, section 5A.2.1).

TABLE 1—PERCENTAGE OF WATERBODIES NATIONALLY FOR WHICH ANNUAL AVERAGE S DEPOSITION DURING THE FIVE TIME PERIODS ASSESSED EXCEED THE WATERBODY CL (FOR CLS GREATER THAN 0) FOR EACH OF THE SPECIFIED ANC TARGETS

ANC (μeq/L)	2001–2003 %	2006–2008 %	2010–2012 %	2014–2016 %	2018–2020 %
20	22	16	5	3	1
30	25	19	7	4	2
50	28	24	11	6	4
50/20 *	28	23	10	6	4

* This combination refers to the use of a target of 50 μeq/L in eastern ecoregions and 20 μeq/L in western ecoregions.

The case study analyses provide estimates of S deposition (with associated uncertainties) that might be expected to allow these geographically diverse locations to meet the three ANC targets (PA, Table 5–6). Focusing on the three eastern case studies, the CL modeling indicates that at an annual average S deposition of 9–10 kg/ha-yr, the sites in these areas, on average,[64] might be expected to achieve an ANC at or above 50 μeq/L. At an annual average S deposition of about 6–9 kg/ha-yr, 70% of the sites in the areas are estimated to achieve an ANC at or above 20 μeq/L and at about 5–8 kg S/ha-yr, 70% are estimated to achieve an ANC at or above 30 μeq/L. Lower S deposition values are estimated to achieve higher ANC across more sites. Across the three eastern areas, the CL estimates for each ANC target are lowest for the White Mountains National Forest study area, and highest for the Shenandoah Valley study area.

The ecoregion-level analyses of 25 acid-sensitive ecoregions for the five periods from 2001–2003 through 2018–2020 illustrate the spatial variability and magnitude of the findings for the three target ANC levels and the temporal changes across the 20-year period, as described in the PA, section 5.1.3.2. For example, during the two most recent 3-year periods, the median S deposition estimates for each of the 25 ecoregions were all below 5 kg/ha-yr in 2014–2016 and all below 4 kg/ha-yr in 2018–2020 (table 2). Across all five time periods, the range of ecoregion median S deposition extended from below 2 kg/ha-yr up to nearly 18 kg/ha-yr, with the higher values occurring in the eastern ecoregions (table 2).

TABLE 2—SUMMARY OF ECOREGION MEDIANS DERIVED AS MEDIAN OF S DEPOSITION ESTIMATES AT CL SITES WITHIN AN ECOREGION

	Ecoregion median * total sulfur deposition (kg S/ha-yr)				
	2001–03	2006–08	2010–12	2014–16	2018–20
All 25 Ecoregions:					
Minimum	1.18	1.22	1.02	1.08	0.62
Maximum	17.27	14.44	7.25	4.58	3.88
Median	7.77	6.50	3.71	2.32	1.73
18 Eastern Ecoregions:					
Minimum	4.01	3.10	2.34	1.88	1.31
Maximum	17.27	14.44	7.25	4.58	3.88
Median	11.08	9.36	4.76	2.97	2.04
7 Western Ecoregions:					
Minimum	1.18	1.22	1.02	1.08	0.62
Maximum	1.94	1.83	1.47	1.56	1.19
Median	1.40	1.52	1.29	1.17	0.87

* The ecoregion medians for which descriptive statistics are presented here are medians of the deposition estimates across each ecoregion's waterbody sites with CL estimates.

The ecoregion-scale results (*e.g.,* percentage of waterbodies per ecoregion estimated to achieve the various ANC targets, or alternatively to exceed the associated CLs) for the 18 eastern and 7 western ecoregions are summarized in two ways. One approach, summarized further below, is framed by the temporal trends in median S deposition per ecoregion, and the second approach is in terms of ecoregion-time period combinations, using ecoregion S deposition estimates (medians of deposition estimates at waterbodies with CLs in each ecoregion) as the organizing parameter. For example, table 3 presents the percentages of waterbody sites per ecoregion estimated to achieve the three ANC target levels, summarized by bins for different magnitudes of ecoregion median annual average S deposition (regardless of the 3-year period in which it occurred). For the 18 eastern ecoregions and five time periods, there are 90 ecoregion-time period combinations, and for each of these, there are waterbody percentages for each of the three ANC targets. In table 3, the three percentages (for the three ANC targets) for each of the 18

[64] The term ''average'' here refers to the average CL estimated for the specified ANC across all sites with CL estimates in each case study area (PA, Table 5–6).

eastern ecoregions in each of the five time periods are grouped in the bins describing the median S deposition in that ecoregion and time period. As can be seen from this table, fewer than half of the eastern ecoregion-time period combinations had an ecoregion median S deposition estimate at or below 4 kg/ha-yr.[65] Table 3 indicates that lower levels of S deposition at the ecoregion scale are associated with improved ANC values and greater percentages of waterbodies expected to reach ANC targets. Across the ecoregion-time period dataset of CL exceedances for the three ANC targets for all 90 eastern ecoregion-time period combinations (for which ecoregion median S deposition was at or below 18 kg/ha-yr), 73% of the combinations had at least 90% of waterbodies per ecoregion estimated to achieve ANC at or above 20 μeq/L, and 60% had at least 90% of the waterbodies estimated to achieve ANC at or above 50 μeq/L (table 3). For ecoregion median S deposition estimates at or below 9 kg/ha-yr (approximately three quarters of the combinations), at least 90% of all waterbodies per ecoregion were estimated to achieve ANC at or above 20, 30 and 50 μeq/L in 87%, 81% and 72% of combinations, respectively. For S deposition estimates at or below 5 kg S/ha-yr (the lowest ecoregion median deposition bin that includes at least half of the full dataset), these values are 96%, 92% and 82% of combinations. For the 75 western ecoregion-time period combinations, all of which had ecoregion median S deposition estimates below 4 kg/ha-yr, at least 90% of waterbodies per ecoregion were estimated to achieve an ANC at or above 50 μeg/L (PA, Table 5–5).

TABLE 3—PERCENTAGE OF ECOREGION-TIME PERIODS COMBINATIONS WITH AT LEAST 90, 85, 80, 75 AND 70% OF WATERBODIES ESTIMATED TO ACHIEVE AN ANC AT/ABOVE THE ANC TARGETS OF 20, 30 AND 50 μEQ/L AS A FUNCTION OF ANNUAL AVERAGE S DEPOSITION FOR 18 EASTERN ECOREGIONS (90 ECOREGION-TIME PERIOD COMBINATIONS)

Total sulfur deposition (kg S/ha-yr) at/below:	Number of ecoregion-time periods	% Waterbodies per ecoregion-time period meeting specified ANC target														
		90%	85%	80%	75%	70%	90%	85%	80%	75%	70%	90%	85%	80%	75%	70%
		ANC target of 20 μeq/L					ANC target of 30 μeq/L					ANC target of 50 μeq/L				
2	10	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
3	29	100	100	100	100	100	100	100	100	100	100	97	100	100	100	100
4	41	100	100	100	100	100	95	100	100	100	100	93	98	100	100	100
5	51	96	98	100	100	100	92	98	100	100	100	82	94	96	98	100
6	59	93	98	100	100	100	88	98	100	100	100	78	93	97	98	100
7	63	92	98	100	100	100	87	97	100	100	100	78	92	95	98	100
8	67	87	94	100	100	100	82	91	99	100	100	73	87	93	96	100
9	69	87	94	100	100	100	81	91	99	100	100	72	87	93	96	100
10	73	85	92	99	99	99	78	89	97	99	99	70	85	92	95	99
11	76	83	91	97	99	99	76	88	96	99	99	68	83	91	95	99
12	79	81	89	95	96	97	73	86	94	96	96	66	81	89	92	96
13	81	80	88	95	96	98	73	85	94	96	96	65	80	88	93	96
14	84	77	86	93	95	96	70	83	92	94	95	63	79	86	90	94
15	86	76	84	91	93	95	69	81	90	92	93	62	77	84	88	92
16	88	75	83	90	92	94	68	81	89	91	92	61	76	83	88	91
17	88	75	83	90	92	94	68	81	89	91	92	61	76	83	88	91
18	90	73	81	88	90	92	67	79	87	89	90	60	74	81	86	89

Given the decreasing temporal trend in S deposition across all ecoregions, we also analyzed the aquatic acidification results at the ecoregion scale across the 20 years represented by the five time periods (2001–03, 2006–08, 2010–12, 2014–16, 2018–20) from a temporal perspective. With regard to percentages of waterbodies per ecoregion estimated to achieve the three ANC targets, an appreciable improvement is observed for the latter three time periods compared to the initial two time periods (*e.g.,* PA, Figure 5–13). By the 2010–2012 time period, more than 70% of waterbodies in all 25 ecoregions are estimated to achieve an ANC at or above 50 μeq/L, and at least 85% are able to achieve an ANC at or above 20 μeq/L (figure 1; PA, Table 7–2). By the 2014–2016 period, the percentages are 85% and nearly 90%, respectively. The median deposition for the CL sites in each of the 18 eastern ecoregions during the latter three time periods ranges from 1.3 kg S/h-yr to 7.3 kg S/h-yr, and with each reduction in S deposition in each subsequent time period, more waterbodies in each of the eastern ecoregions are estimated to be able to achieve the ANC targets. Nearly 90% of the 18 eastern ecoregions are estimated to have at least 90% of their waterbodies achieving an ANC of 20 μeq/L in the 2010–12 period and achieving an ANC of 50 μeq/L in the 2014–16 period. When the 7 western ecoregions are included in a summary based on ANC targets of 20 μeq/L for the West and 50 μeq/L for the East,[66] over 70% of the full set of ecoregions are estimated to have at least 90% of their waterbodies achieving the ANC targets by the 2010–12 period. More than 90% of the ecoregions are estimated to have at least 90% of their waterbodies achieving the ANC targets by the 2014–16 period (figure 1;[67] PA, Table 7–2).

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[65] The ecoregion median S deposition in all seven of the western ecoregions in all five time periods were at or below 2 kg/ha-yr (PA, Table 5–4).

[66] This combination of targets recognizes the naturally and typically low ANC levels observed in western waterbodies while also including a higher target for the East (as described in the PA, section 5.1.2.2).

[67] The right panel of this figure has been corrected from the version that was in the proposal. The right panel of this figure in the proposal (89 FR 26656, April 15, 2024) had a few extraneous datapoints in the space between the 2006–2008 and 2010–2012 vertical lines. These extraneous datapoints are also in the right panel of an earlier version of this figure in the PA (PA, Figure 7–1). Also, in the left panel of the PA, Figure 7–1, the datapoints for the 2018–2020 period were placed to the left of the 2018–*COM007*2020 vertical line.

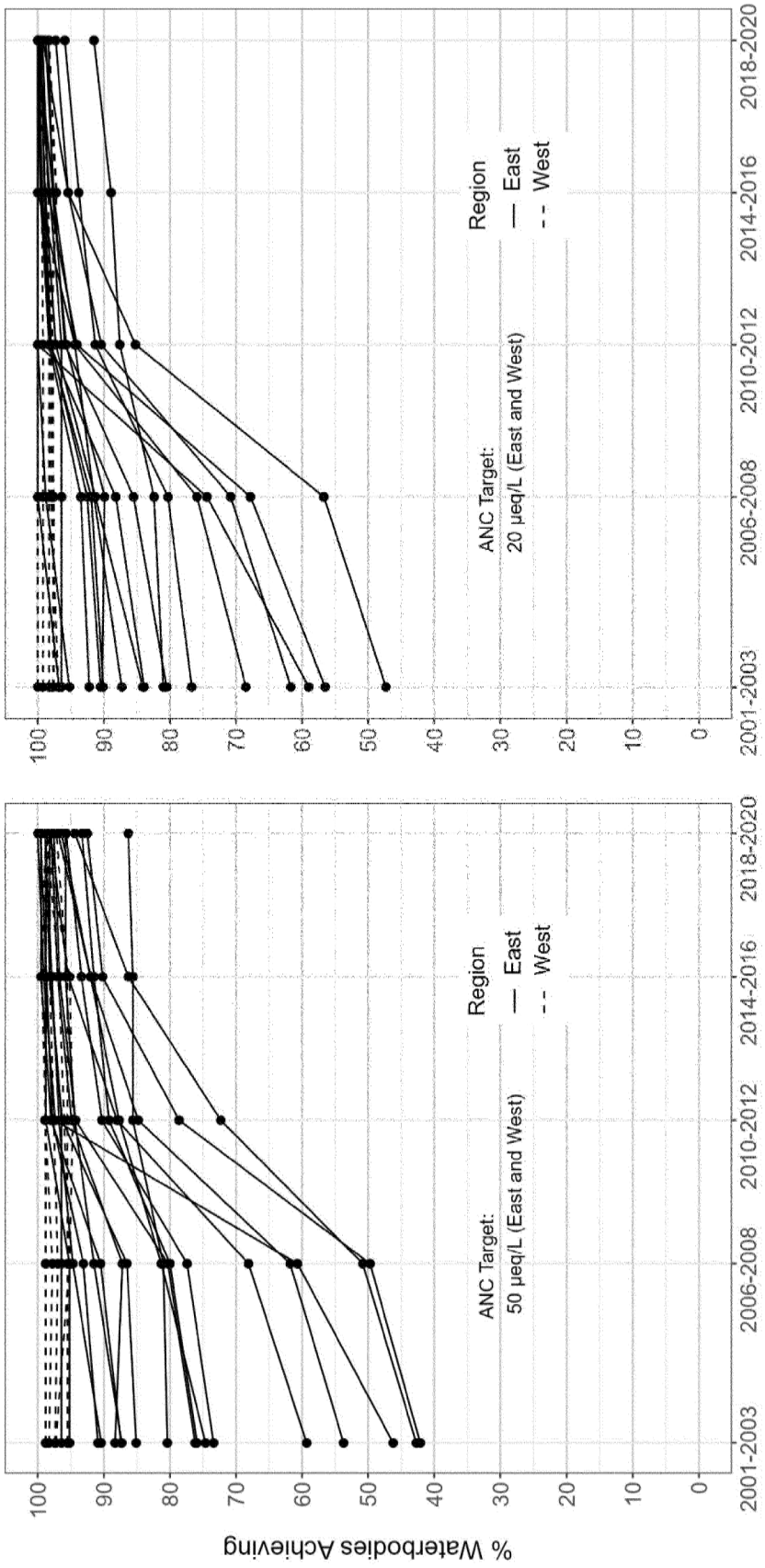

Figure 1. Percent of Waterbodies per Ecoregion Estimated to Achieve ANC at or Above 50 µeq/L (left panel) or 20 µeq/L (right panel). Western Ecoregions have Dashed Lines (Versus Solid Lines for Eastern Ecoregions). Each Line Represents One of the 25 Ecoregions.

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B. Conclusions

1. Basis for Proposed Decision

In reaching his proposed decision on the existing secondary standards for SO_X, N oxides and PM (presented in section II.B.1.c.), the Administrator took into account the available evidence in the ISA, along with the policy-relevant, evidence-based and air quality-, exposure- and risk-based considerations discussed in the PA (summarized in section II.B.1.a.), as well as advice from the CASAC (section II.B.1.b.). In general, the role of the PA is to help ''bridge the gap'' between the Agency's assessment of the current evidence and quantitative analyses of air quality, exposure and risk, and the judgments required of the Administrator in determining whether it is appropriate to retain or revise the NAAQS. Evidence-based considerations draw upon the EPA's integrated assessment of the scientific evidence presented in the ISA (summarized in section II.A.3. above) to address key policy-relevant questions in the review. Similarly, the air quality-, exposure- and risk-based considerations draw upon our assessment of air quality, exposure, and associated risk (summarized in section II.A.4. above).

This approach to reviewing the secondary standards is consistent with requirements of the provisions of the CAA related to the review of the NAAQS and with how the EPA and the courts have historically interpreted the CAA. As discussed in section I.A. above, these provisions require the Administrator to establish secondary standards that, in the Administrator's judgment, are requisite (*i.e.,* neither more nor less stringent than necessary) to protect the public welfare from known or anticipated adverse effects associated with the presence of the pollutant in the ambient air. Consistent with the Agency's approach across all NAAQS reviews, the EPA's approach to informing these judgments is based on a recognition that the available welfare effects evidence generally reflects a continuum that includes ambient air-related exposures for which scientists generally agree that effects are likely to occur, through lower levels at which the likelihood and magnitude of response become increasingly uncertain. The CAA does not require the Administrator to establish secondary standards at a zero-risk level, but rather at levels that reduce risk sufficiently so as to protect the public welfare from known or anticipated adverse effects. The proposed decision on the secondary standards for SO_X, N oxides and PM described below is a public welfare policy judgment by the Administrator that draws upon the scientific evidence for welfare effects, quantitative analyses of air quality, exposure, and risks, as available, and judgments about how to consider the uncertainties and limitations that are inherent in the scientific evidence and quantitative analyses. The four basic elements of the NAAQS (*i.e.,* indicator, averaging time, form, and level) have been considered collectively in evaluating the public welfare protection afforded by the current standards. The Administrator's final decision additionally considers public comments received on this proposed decision.

a. Policy-Relevant Evaluations in the Policy Assessment

The PA presented an evaluation of the evidence and quantitative analyses of air quality, exposure and potential risk related to ecological effects of SO_X, N oxides and PM. These ecological effects include both direct effects of the three criteria pollutants on biota and ecological effects of ecosystem deposition of N and S associated with these pollutants. The PA identified an array of policy options for consideration by the Administrator. For SO_X, the PA identified options for adoption of an annual average SO_2 standard, averaged over three years, with a level within the range extending below 15 ppb and down to 5 ppb. For N oxides and $PM_{2.5}$, the PA identified options for retention of the existing standards, without revision, and options for revision, although with recognition of appreciable associated uncertainty. The PA also considered the potential for establishment of a revised secondary standard or suite of standards with alternate indicator(s) that might target specific N or S containing chemicals (*e.g.,* particulate NO_3^-, SO_4^{2-}, NH_4^+), but recognized there to be a number of associated uncertainties and complications, including uncertainties in how to interpret air measurements and deposition estimates from remote areas in the context of concentrations near sources, without finding there to be a clear advantage to this approach. The PA additionally recognized that, in secondary NAAQS reviews in general, decisions by the Administrator on the adequacy of existing standards or the appropriateness of new or revised standards depend in part on public welfare policy judgments, science policy judgments regarding aspects of the evidence and exposure/risk estimates, and judgments about the level of public welfare protection that is requisite under the CAA.

In its evaluation of policy options, the PA considered the evidence, as evaluated in both the current and prior reviews, with regard to the EPA's overall conclusions on the ecological effects of SO_X, N oxides and PM in ambient air and once deposited into ecosystems. The PA also considers the available information related to the general approach or framework in which to evaluate public welfare protection of the standard and the currently available quantitative information on environmental exposures likely to occur in areas of the U.S. where the standards are met. In so doing, the PA takes into account associated limitations and uncertainties, as well as the significance of these exposures with regard to the potential for effects, their potential severity and any associated public welfare implications. The PA also considers judgments about the uncertainties in the scientific evidence and quantitative analyses that are integral to consideration of whether the currently available information supports or calls into question the adequacy of the current secondary standards.

(1) Effects Not Related to S and N Deposition

In considering the currently available evidence and quantitative information pertaining to ecological effects of SO_X, N oxides and PM in ambient air, other than those associated with ecosystem deposition of S and N, the PA focused on the extent to which the newly available information alters our scientific understanding of the ecological effects of SO_X, N oxides and PM in ambient air; the extent to which the currently available information indicates the potential for exposures associated with ecological effects under air quality meeting the existing standards and whether such effects might be of sufficient magnitude, severity, extent and/or frequency such that they might reasonably be judged to be adverse to public welfare; and to what extent important uncertainties identified in past reviews have been reduced and/or whether new uncertainties emerged. These considerations are summarized below, first for SO_X, followed by N oxides and then PM.

(a) Sulfur Oxides

Most of the available evidence for the direct effects of SO_X on vegetation is not new to the current review. Among the gaseous SO_X—which include SO, SO_2, sulfur trioxide, and disulfur monoxide—only SO_2 is present in the lower troposphere at concentrations

relevant for environmental considerations (ISA, Appendix 2, section 2.1). The available evidence is focused primarily on the effects of SO_2 on vegetation, including foliar injury, depressed photosynthesis and reduced growth or yield (ISA, Appendix 3, section 3.2). The newer studies continue to support the determination that the evidence is sufficient to infer a causal relationship between gas-phase SO_2 and injury to vegetation (ISA, section 3.6.1). In general, direct effects on plants, including foliar injury, occur at SO_2 exposures higher than a 3-hour average concentration of 0.5 ppm (500 ppb).

Uncertainties associated with the current information relate to limitations in reflecting the natural environment and in untangling effects of SO_2 from those of other pollutants that may have influenced the analyzed effects. Even with these uncertainties, the evidence indicates effects are generally associated with air concentrations and durations not expected to occur when the existing standard (0.5 ppm, as a 3-hour average, not to be exceeded more than once per year) is met (PA, section 7.1.1; ISA, Appendix 2, section 2.1).

(b) Nitrogen Oxides

The currently available information on direct effects of gaseous N oxides in ambient air on plants and lichens is composed predominantly of studies of NO_2, HNO_3, and PAN. The very few studies newly available in this review do not alter our prior understanding of effects of these N oxides, which include visible foliar injury, as well as effects on photosynthesis and growth at exposures much higher than current levels in ambient air (ISA, section 3.3). Thus, as in the last review, the body of evidence is sufficient to infer a causal relationship between gas-phase NO, NO_2, and PAN and injury to vegetation (ISA, section IS.4.2).

Information is limited regarding the potential for exposure levels associated with ecological effects to occur under air quality meeting the existing NO_2 secondary standard. With regard to the risk posed by N oxides, and particularly HNO_3, the evidence summarized in the ISA indicates the potential for effects on lichen species related to air quality occurring during periods when the current secondary standard was not met. Evidence is more limited for consideration of effects under conditions meeting the current standard (PA, section 7.1.2). Uncertainties also remain in our interpretation of the evidence, including those related to limitations and uncertainties of the various study types.

(c) Particulate Matter

The evidence for ecological effects of PM is consistent with that available in the last review and focused on effects associated with PM loading (*e.g.,* to leaf surfaces), rather than direct effects of PM suspended in ambient air. In this review, as in the last one, the ecological effects evidence was found to be sufficient to conclude there is likely to exist a causal relationship between deposition of PM (other than N and S deposition) and a variety of effects on individual organisms and ecosystems (ISA, Appendix 15; 2012 p.m. ISA, section 9.4). While some uncertainties remain, new uncertainties have not emerged since the last review. There is little information available on effects of PM concentrations likely to occur under conditions meeting the current secondary standards, and the limited available information does not indicate effects to occur under those conditions (PA, section 7.1.3).

(2) Evidence of Ecosystem Effects of S and N Deposition

The evidence base of ecological effects related to atmospheric deposition of N and S compounds has expanded since the last review with regard to acidic deposition in aquatic and terrestrial ecosystems and regarding ecosystem N enrichment. Both S and N compounds have contributed to ecosystem acidification, with relative contributions varying with emissions, air concentrations, and atmospheric chemistry, among other factors. Ecological effects have been documented comprehensively in waterbodies of the Adirondack and Appalachian Mountains, and in forests of the Northeast, at the organism to ecosystem scale. With regard to N enrichment, research on its effects in estuaries and large river systems across the U.S. extends back at least four decades, and there is longstanding evidence of effects in estuaries along the East and Gulf Coasts of the U.S., as summarized in more detail in Chapters 4 and 5 of the PA (ISA, Appendix 7, section 7.2.9; 2008 ISA, section 3.3.2.4; Officer et al., 1984). Information on the effects of N enrichment in terrestrial ecosystems, primarily in grassland and forested ecosystems, augmented in the current review, also includes evidence that was available in the last review (*e.g.,* 2008 ISA, sections 3.3.3 and 3.3.5; ISA, Appendix 6).

With regard to uncertainties, some that were associated with the evidence available in the 2012 review remain, and some additional important uncertainties have been identified. In addition to uncertainties related to the specific air quality circumstances associated with effects (*e.g.,* magnitude, duration, and frequency of concentrations associated with effects), there are also uncertainties associated with the effects of N and S deposition expected under changing environmental circumstances. Such uncertainties include atmospheric loading that has declined since 2000, with associated changes to soil and waterbody biogeochemistry and meteorological changes associated with changing climate (ISA, section IS.12; PA section, 7.2.1). The PA also recognizes important uncertainties associated with the various assessment approaches employed by different study types (PA, sections 5.3 and 7.2.1). Additionally, there are uncertainties contributed by variation in physical, chemical, and ecological responses to N and S deposition and by the potential influence of unaccounted-for stressors on response measures.

In sum, a wealth of scientific evidence, spanning many decades, demonstrates effects of acidifying deposition associated with N and S compounds in aquatic and terrestrial ecosystems (ISA, sections ES.5.1, IS.5.1, IS.5.3, IS.6.1 and IS.6.3; 2008 ISA, section 3.2; U.S. EPA, 1982b, Chapter 7). This evidence base supports conclusions also reached in the 2008 ISA (for the review completed in 2012) of causal relationships between N and S deposition and alteration of soil and aquatic biogeochemistry, alteration of the physiology and growth of terrestrial organisms and of associated productivity, changes in aquatic biota, including physiological impairment, and alteration of species richness, community composition, and biodiversity in both aquatic and terrestrial ecosystems (ISA, Table ES–1). Similarly, a robust evidence base demonstrates effects of N enrichment in both estuarine and freshwater ecosystems, supporting conclusions also reached in the last review of a causal relationship between N deposition and changes in biota, including altered growth and productivity, and alteration of species richness, community composition and biodiversity due to N enrichment (ISA, sections ES.5.2, IS.6, and IS.7, and Table ES–1). Additional effects of N deposition in wetlands, also recognized in the last review, include alteration of biogeochemical cycling, growth, productivity, species physiology, species richness, community composition, and biodiversity (ISA, Table ES–1).

In terrestrial ecosystems, as in the last review, the now expanded evidence

base supports determination of a causal relationship between N deposition and alteration of species richness, community composition, and biodiversity (ISA, Table ES–1). The ISA additionally determines there to be a causal relationship for alteration of the physiology and growth of terrestrial organisms and associated productivity, a category of effects not included in the 2008 ISA (ISA, Table ES–1). Other evidence of effects causally associated with S deposition in wetland and freshwater ecosystems includes that related to chemical transformation and associated toxicity, most specifically alteration of mercury methylation, which was also recognized in the last review. The other category of effects, not included in the last review, is related to sulfide phytotoxicity and its associated effects in wetland and freshwater ecosystems (ISA, Table ES–1).

Thus, while an array of effects is associated with S and N deposition, information important for quantitative analysis varies across the array. For some categories of effects (*e.g.,* sulfide phytotoxicity) the information regarding environmental levels that relate to effects is limited and/or quite variable across locations, thus hindering analysis. For other effect categories, the information on linkages to criteria pollutants is limited and/or quite variable. The information with clearest implications to NAAQS decisions pertains to SO_X and S deposition-related ecosystem acidification. While the information regarding effects associated with N loading to ecosystems is extensive, information to support quantitative analysis to inform NAAQS decisions regarding N oxides and PM is not clear, with multiple complicating factors. Such factors include contributions from other, non-criteria pollutants (such as NH_3) and challenges in assessing N deposition-related effects of ambient air concentrations of N oxides and PM. While the role of N deposition in aquatic acidification is evaluated in the REA, the available information does not provide effective support for analysis of other N deposition-related effects of N oxides and PM independent of effects from other (non-criteria) pollutants or, in some cases, from other (non-air) sources.

(3) Sulfur Deposition and SO_X

Evidence- and exposure/risk-based considerations discussed in the PA pertaining to S deposition and SO_X in ambient air are summarized in the subsections below. These considerations reflect discussion in the PA, which draws on the available welfare effects evidence described in the current ISA, the 2008 NO_X/SO_X ISA, the 2009 p.m. ISA, and past AQCDs, as well as information available from quantitative analyses (summarized in Chapters 5 and 6 of the PA), both analyses developed in this review and those available from the 2009 REA.

In considering potential public welfare protection from S deposition-related acidification effects in aquatic ecosystems and forested areas, the PA recognizes the public welfare implications of various effects of acidifying deposition on the natural resources in these areas, including the differences in response between waterbodies and trees, as well as the severity and extent of such effects. Given the more extensive quantitative analyses for aquatic acidification in this review, the PA discusses the public welfare implications of S deposition-related effects in aquatic ecosystems with an eye toward their prominence for decision-making in this review (PA, sections 4.5 and 7.2.2.2). In its consideration of options for S deposition-related effects and in recognizing linkages between watershed soils and waterbody acidification, as well as terrestrial effects, the PA conveys that focusing on public welfare protection from aquatic acidification-related effects may reasonably be expected to also contribute protection for terrestrial effects (PA, section 7.4).

The PA notes that, as also recognized in the 2012 review, aquatic ecosystems provide a number of services important to the public welfare, ranging from recreational and commercial fisheries to recreational activities engaged in by the public (77 FR 20232, April 3, 2012). Because aquatic acidification affects the diversity and abundance of aquatic biota, it also affects the ecosystem services that are derived from the fish and other aquatic life found in these surface waters (PA, section 4.5; ISA, Appendix 14, section 14.3.1). Fresh surface waters support several cultural services, such as aesthetic and educational services; the type of service that is likely to be most widely and significantly affected by aquatic acidification is recreational fishing, with associated economic and other benefits. Other potentially affected services include provision of food for some recreational and subsistence fishers and for other consumers, as well as non-use services, including existence (protection and preservation with no expectation of direct use) and bequest values (PA, section 4.5).

The PA recognizes that some level of S deposition and associated risk of aquatic acidification, including those associated with past decades of acidifying deposition in the Northeast, can impact the public welfare and thus might reasonably be judged adverse to the public welfare. Depending on magnitude and associated impacts, there are many locations in which S deposition and associated aquatic acidification can adversely affect the public welfare. For example, there is evidence in some waterbodies that aquatic acidification resulting in reduced acid buffering capacity can adversely affect waterbodies and associated fisheries, which in addition to any commercial ramifications can have ramifications on recreational enjoyment of affected areas (PA, sections 5.1.1 and 4.5).

In other secondary NAAQS reviews, the EPA's consideration of the public welfare significance of the associated effects has recognized a particular importance of Class I areas and other similarly protected areas. Accordingly, we note that waterbodies that have been most affected by acidic deposition are in the eastern U.S., including in several Class I areas and other national and State parks and forests (PA, section 5.1.2.1),[68] with two such areas included as case studies in the aquatic acidification REA (PA, section 5.1.3.3). Assuring continued improvement of affected waterbodies throughout the U.S. (*e.g.,* through lower S deposition than the levels of the past) may reasonably be considered to be of public welfare importance and may be particularly important in Class I and similarly protected areas. In this review, in considering the potential public welfare significance of aquatic acidification effects of differing levels of S deposition, the PA summarizes the REA ecoregion-scale results in terms of percentages of ecoregions in which differing percentages of waterbodies are estimated to achieve the three acid buffering capacity targets. The PA summarized results in this way to inform identification of S deposition estimates in the context of potential policy options.

The first subsection below, II.B.1.a.(3)(a), focuses on the aquatic acidification REA analyses (summarized in section II.A.4. above), considering first the use of ANC as an indicator of acidification risk, then evaluating the risk estimates as to what they indicate about acidification risks in freshwater streams and lakes of the contiguous U.S. for S deposition rates estimated to have occurred over the past two decades

[68] A comparison of Figures 4–4 and 5–6 of the PA indicates multiple Class I areas in ecoregions considered acid sensitive.

(much of which is newly assessed in this review),[69] and lastly identifying important uncertainties associated with the estimates. Section II.B.1.a.(3)(b) considers the evidence and quantitative exposure/risk information from a public welfare protection perspective, focusing first on what might be indicated regarding deposition conditions under which waterbodies in acid-sensitive ecoregions might be expected to achieve acid buffering capacity of interest and what the available information indicates pertaining to the consideration of public welfare protection from S deposition related effects in aquatic ecosystems. Section II.B.1.a.(3)(b) also considers what the published quantitative information regarding S deposition and terrestrial acidification indicates regarding deposition levels of potential concern, along with associated uncertainties in this information. Section II.B.1.a.(3)(c) then summarizes considerations in relating SO_X air quality metrics to deposition of S compounds.

(a) Quantitative Information for Ecosystem Risks Associated With S Deposition

As in the last review, the PA gives primary attention to the quantitative assessment of aquatic acidification (including particularly that attributable to S deposition) and recognizes these results to be informative to the identification of S deposition levels associated with potential for aquatic acidification effects of concern, as summarized below. This assessment of quantitative linkages between S deposition and potential for aquatic acidification is one component of the approach implemented in the PA for informing judgments on the likelihood of occurrence of such effects under differing air quality conditions. Although the approaches and tools for assessing aquatic acidification have often been applied for S and N deposition in combination, the REA approach for this review focused on S deposition. This focus is supported by analyses in the PA indicating the relatively greater contribution of S deposition than N deposition to aquatic acidification risk under the more recent air quality conditions that are the focus of this review (PA, Appendix 5A). As summarized in section II.A.4. above, the aquatic acidification REA relied on well-established site-specific water quality modeling applications with a widely recognized indicator of aquatic acidification, ANC.

Quantitative tools are also available for the assessment of terrestrial acidification related to S deposition (PA, section 5.3.2.1; 2009 REA, section 4.3).[70] In the last review, analyses that related estimated atmospheric deposition of acidic N and S compounds (during the early 2000s) to terrestrial effects, or indicators of terrestrial ecosystem risk, were generally considered to be more uncertain than conceptually similar modeling analyses for aquatic ecosystems (2009 REA, section 7.5; 2011 PA, section 1.3). The PA for this review also notes that quantitative tools and approaches are not well developed for other ecological effects associated with atmospheric deposition of S compounds, such as mercury methylation and sulfide toxicity in aquatic systems (PA, sections 4.2.3.1 and 4.2.3.2).

As described in sections II.A.3.a.(2)(a) and II.A.4. above, ANC is an indicator of susceptibility or risk of acidification-related effects in waterbodies, with lower levels indicating relatively higher potential for acidification and related waterbody effects. The PA recognized strong support in the evidence for use of ANC for purposes of making judgments regarding risk to aquatic biota in streams impacted by acidifying deposition and for consideration of the set of targets analyzed in the aquatic acidification REA: 20, 30, and 50 μeq/L (PA, section 5.1). There is longstanding evidence of an array of impacts on aquatic biota and species richness reported in surface waters with ANC values below zero and in some historically impacted waterbodies with ANC values below 20 μeq/L (PA, section 5.1.2.2). The severity of impacts is greatest at the lowest ANC levels. This evidence derives primarily from lakes and streams of the Adirondack Mountains and areas along the Appalachian Mountains. As recognized in the 2012 review, in addition to providing protection during base flow situations, ANC is a water quality characteristic that affords protection against the likelihood of decreased pH from episodic events in impacted watersheds. For example, some waterbodies with ANC below 20 μeq/L have been associated with increased probability of low pH events, that, depending on other factors as noted above, may have potential for reduced survival or loss of fitness of sensitive biota or lifestages (2008 ISA, section 5.1.2.1). As noted in the ISA, ''[s]treams that are designated as episodically acidic (chronic ANC from 0 to 20 μeq/L) are considered marginal for brook trout because acidic episodes are likely'' (ISA, Appendix 8, p. 8–26). In general, the higher the ANC level above zero, the lower the risk presented by episodic acidity. In summarizing and considering the acidification risk estimates for the different scales of analysis (national, ecoregion and case study) and using the water quality modeling-based CLs derived for three different ANC targets (20, 30 and 50 μeq/L), the PA recognizes both the differing risk that might be ascribed to the different ANC targets and the variation in ANC response across waterbodies that may be reasonable to expect with differences in geology, history of acidifying deposition, and patterns of S deposition.

The PA also recognizes limitations and uncertainties in the use of ANC as an indicator for model-based risk assessments (PA, section 7.2.2.1). The support is strongest in aquatic systems low in organic material such as historically affected waterbodies in the eastern U.S. (*e.g.,* in the Adirondack Mountains) and Canada. In waterbodies with relatively higher levels of dissolved organic material, the presence of organic acid anions contributes to reduced pH, but these organic acids can also create complexes with dissolved aluminum that protect resident biota against aluminum toxicity such that biota in such systems tolerate lower ANC values (and pH) than biota in waterbodies with low dissolved organic carbon (ISA, Appendix 8, section 8.3.6.2; PA, section 7.2.2.1). Thus, while the evidence generally supports the use of ANC as an acidification indicator and as a useful metric for judging the potential for ecosystem acidification effects to occur, the relationship between ANC and potential risk varies depending on the presence of naturally occurring organic acids, which can affect the responsiveness of ANC to acidifying deposition. For these reasons, ANC is less well supported as an indicator for acidic deposition-related effects (and waterbodies are less responsive to changes in acidic deposition) due to dissolved organic material in some areas, including the Middle Atlantic Coastal Plain, Southern Coastal Plains, and Atlantic Coastal Pine Barrens ecoregions (PA, section 5.1.2.2).

The REA national-scale analysis of more than 13,000 waterbody sites in 69 ecoregions demonstrated an appreciable

[69] Aquatic acidification risk analyses in the last review considered deposition estimates for 2002 and 2006 derived from CMAQ modeling, 2002 emissions estimates (2009 REA, Appendix 1).

[70] Given findings from the 2009 REA that aquatic acidification provided a more sensitive measure for use in assessing deposition related to ecosystem acidification, and consideration of recent information not likely to result in a different finding, the REA for the current review focused on aquatic acidification.

reduction in risk over the 20-year period of analysis (PA, section 5.1.3) with the percentage of waterbodies unable to achieve an ANC of 20 μeq/L or greater declining from 20% for the 2001–2003 period to 1% by the 2018–20 period (table 1). The 25 ecoregions included in the ecoregion-scale analyses (*i.e.,* 18 in the East and 7 in the West in which there are at least 50 waterbody sites with CL estimates) are dominated by ecoregions categorized as acid sensitive (PA, Table 5A–5) and exclude the three ecoregions identified above as having natural acidity related to organic acids (PA, section 5.1.2.1). Due to the dominance of the acid-sensitive ecoregions among the 25 ecoregions analyzed, the percentages of waterbodies not able to meet the ANC targets are higher than the national percentages. Specifically, in the most affected ecoregion (Central Appalachians), more than 50% of waterbodies were estimated to be unable to achieve an ANC of 20 μeq/L or greater based on S deposition estimates for the 2001–2003 period (figure 1 above, and PA, Figure 5–13). By the 2018–2020 period, less than 10% of waterbodies in any of the 25 ecoregions (and less than 5% in all but one) were estimated to be unable to achieve an ANC of 20 μeq/L, and less than 15% of waterbodies in the most affected ecoregion were estimated to be unable to achieve an ANC of 50 μeq/L (figure 1 above and PA, Figure 5–13).

The PA recognizes uncertainty associated with two overarching aspects of the aquatic acidification assessment of effects (PA, section 5.1.4 and Appendix 5A, section 5A.3). The first relates to interpretation of specific thresholds or benchmark concentrations of ANC with regard to aquatic acidification risk to aquatic biota. While ANC is a well-established indicator of aquatic acidification risk, uncertainty remains in our understanding of relationships between ANC and risk to native biota, particularly in waterbodies in geologic regions prone to waterbody acidity. Such uncertainties relate to the varying influences of site-specific factors, such as the prevalence of organic acids in the watershed, and to historical loading to watershed soils that can influence acidity of episodic high-flow events (PA, sections 5.1.4 and 7.2.2.1 and Appendix 5A, section 5A.3). The second overarching aspect of uncertainty relates to our understanding of the biogeochemical model linkages between deposition of S and N compounds and waterbody ANC, which is reflected in the modeling employed, and the associated estimation of CLs, as described in section II.A.4.b. above. Although the approaches to estimate base-cation supply in the REA (*e.g.,* the F-factor approach) have been widely published and analyzed in Canada and Europe, and have been applied in the U.S. (*e.g.,* Dupont et al., 2005), the magnitude of uncertainty in the base-cation supply estimate is unclear and could be large in some cases. The REA's quantitative analysis of uncertainty in CL estimates indicates lower uncertainty associated with CLs estimated for sites with more extensive and longer-term water quality datasets and relatively low variability in the runoff measurements, such as CLs for waterbody sites in the eastern U.S. (PA, Appendix 5A, section 5A.3.1).

(b) General Approach for Considering Public Welfare Protection

In discussing key considerations in judging public welfare protection from S deposition associated with the secondary standard for SO_X, the PA first focused on what the aquatic acidification REA indicated about deposition conditions under which waterbodies in sensitive ecoregions might be expected to achieve ANC levels of interest. Particular focus was given to the ecoregion and case-study analyses, which use the waterbody-specific comparisons of estimated deposition and waterbody CLs to provide ecoregion wide and cross-ecoregion summaries of estimated waterbody responses to ecoregion estimates of deposition. The PA also considered the extent to which waterbodies in each ecoregion analyzed were estimated to achieve or exceed the three target ANC levels in the context of the variation in ANC response reasonably expected across waterbodies in an ecoregion due to differences in watershed sensitivity to S deposition impacts and different spatial or geographic patterns of S deposition.

Based on the array of CL-based analyses, the PA provides a general sense of the ANC values that waterbodies in sensitive regions across the continental U.S. may be able to achieve, including for areas heavily affected by a long history of acidifying deposition, such as waterbodies in the well-studied Shenandoah Valley area (4,977 sites distributed across three ecoregions). For the other case study areas (White Mountain National Forest, Northern Minnesota, Sierra Nevada Mountains and Rocky Mountain National Park), there are appreciably fewer waterbody sites for which modeling has been performed to estimate CLs, and accordingly greater uncertainty. Yet, the case study area averages of waterbody CLs for achieving ANC at or above each of the three targets (20, 30 or 50 μeq/L) are quite similar across the five case studies (PA, Table 5–6). The PA found the case study estimates to suggest that a focus on S deposition below 10 kg/ha-yr may be appropriate.

Findings from the ecoregion-scale analyses of 25 ecoregions (18 East and 7 West), nearly all of which are considered acid sensitive, indicated ranges of deposition (summarized in terms of ecoregion medians) associated with high percentages of waterbodies estimated to achieve the three ANC targets that are similar to the case study results immediately above. This was true when considering the ecoregion-scale analysis results in both of the ways they were presented: (1) in terms of ecoregion median deposition regardless of time period or ecoregion (ecoregion-time period combinations), and (2) in terms of temporal trends in S deposition and waterbody percentages achieving ANC targets. In total, the ecoregion-time periods presentation indicates the likelihood of appreciably more waterbodies achieving the acid buffering capacity targets among the combinations with ecoregion median deposition at or below 9 kg/ha-yr (and for the bins for lower values) in eastern ecoregions compared to the estimates of waterbodies achieving acid buffering targets based on the full dataset that includes ecoregion median deposition estimates up to 18 kg/ha-yr (table 4 below). For example, in the ecoregion-time period combinations presentation, at least 90% of waterbody sites in 87% of the eastern ecoregion-time period combinations are estimated to be able to achieve an ANC at or above 20 μeq/L with ecoregion median S deposition at or below 9 kg/ha-yr and in 96% of those combinations for ecoregion median S deposition at or below 5 kg/ha-yr (table 4). Additionally, these percentages increase across the bins for the lower deposition estimates, although they are also based on smaller proportions of the supporting dataset (*i.e.,* fewer ecoregion-time period combinations in each subsequently lower deposition bin) contributing to increased uncertainty for those results.

TABLE 4—SUMMARY OF THE EASTERN ECOREGION AND TIME PERIOD COMBINATIONS ACHIEVING DIFFERENT ANC TARGETS WITH ESTIMATED S DEPOSITION AT OR BELOW DIFFERENT VALUES

S deposition (kg/ha-yr) *	% of combinations included	% of Eastern ecoregion-time period combinations ** with at least 90%, 80% or 70% waterbodies per ecoregion achieving ANC target								
		>90% of waterbodies			>80% of waterbodies			>70% of waterbodies		
		20	30	50	20	30	50	20	30	50
ANC (μeq/L) at/below:										
≤18	100	73	67	60	88	87	81	92	90	89
≤13	90	80	73	65	95	94	88	98	96	96
≤11	84	83	76	68	97	96	91	99	99	99
≤9	77	87	81	72	100	99	93	100	100	100
≤7	70	92	87	78	100	100	95	100	100	100
≤6	66	93	88	78	100	100	97	100	100	100
≤5	57	96	92	82	100	100	96	100	100	100

* These values are ecoregion median estimates across all waterbody sites in an ecoregion with a CL estimate.
** These percentages are from the more extensive presentation of results in PA, Table 5–5.

The PA observes that estimates from the temporal trend perspective similarly indicate appreciable percentages of waterbodies per ecoregion being estimated to achieve the acid buffering capacity targets with ecoregion median deposition below a range of approximately 5 to 8 kg/ha-yr. For example, by the 2010–2012 period, by which time all 25 ecoregions are estimated to have more than 70% of waterbodies able to achieve an ANC at or above 50 μeq/L (and at least 85% able to achieve an ANC at or above 20 μeq/L), median deposition in the ecoregions analyzed was below 8 kg S/ha-yr, ranging from 1.3 to 7.3 kg S/ha-yr (PA, Table 7–2). As shown in table 5 below, with each reduction in S deposition in each subsequent time period, more waterbodies in each of the eastern ecoregions are estimated to be able to achieve the ANC targets. Nearly 90% of the 18 eastern ecoregions are estimated to have at least 90% of their waterbodies achieving an ANC of 20 μeq/L in the 2010–12 period and achieving an ANC of 50 μeq/L in the 2014–16 period. When the 7 western ecoregions are included in a summary based on ANC targets of 20 μeq/L for the West and 50 μeq/L for the East,[71] over 70% of the full set of ecoregions are estimated to have at least 90% of their waterbodies achieving the ANC targets by the 2010–12 period (table 5). By the 2014–2016 and 2018–2020 periods, 24 of the 25 ecoregions were estimated to have more than 90% of waterbodies able to achieve an ANC at/above 50 μeq/L, and median S deposition in all 25 ecoregions was below 5 kg/ha-yr (table 5).

TABLE 5—ECOREGIONS ESTIMATED TO HAVE DIFFERENT PERCENTAGES OF WATERBODIES ACHIEVING DIFFERENT ANC TARGETS FOR THE FIVE DEPOSITION PERIODS ANALYZED

Time period	% (n) of ecoregions with specified percentage of waterbodies per ecoregion achieving specified ANC											
	ANC:		20 μeq/L			30 μeq/L			50 μeq/L			
	Ecoregion median S deposition (kg/ha-yr)		Percent of waterbodies per ecoregion			Percent of waterbodies per ecoregion			Percent of waterbodies per ecoregion			
	Min	Max	90%	80%	70%	90%	80%	70%	90%	80%	70%	
	East		Of 18 Eastern Ecoregions									
2001–03	4.0	17.3	39% (7)	67% (12)	72% (13)	28% (5)	61% (11)	72% (13)	22% (4)	50% (9)	72% (13)	
2006–08	3.1	14.4	44 (8)	72 (13)	89 (16)	33 (6)	72 (13)	78 (14)	33 (6)	67 (12)	72 (13)	
2010–12	2.3	7.3	89 (16)	100 (18)	100 (18)	83 (15)	100 (18)	100 (18)	61 (11)	89 (16)	100 (18)	
2014–16	1.9	4.6	94 (17)	100 (18)	100 (18)	94 (17)	100 (18)	100 (18)	89 (16)	100 (18)	100 (18)	
2018–20	1.3	3.9	100 (18)	100 (18)	100 (18)	94 (17)	100 (18)	100 (18)	94 (17)	100 (18)	100 (18)	
	All		Of 25 Ecoregions (18 East, 7 West)									
2001–03	1.2	17.3	56 (14)	76 (19)	80 (20)	48 (12)	72 (18)	80 (20)	44 (11)	64 (16)	80 (20)	
2006–08	1.2	14.4	60 (15)	80 (20)	92 (23)	52 (13)	80 (20)	84 (21)	52 (13)	76 (19)	80 (20)	
2010–12	1.0	7.3	92 (23)	100 (25)	100 (25)	88 (22)	100 (25)	100 (25)	72 (18)	92 (23)	100 (25)	
2014–16	1.1	4.6	96 (24)	100 (25)	100 (25)	96 (24)	100 (25)	100 (25)	92 (23)	100 (25)	100 (25)	
2018–20	0.62	3.9	100 (25)	100 (25)	100 (25)	96 (24)	100 (25)	100 (25)	96 (24)	100 (25)	100 (25)	

Note: Estimates for ANC of 50 μeq/L (East) and 20 μeq/L (West) are identical to those for 50 in all 25 ecoregions.

The temporal trends in percentage of waterbodies estimated to achieve the target ANC levels for each of the 25 individual ecoregions document a large difference between the time periods prior to 2010 and subsequent time periods (figure 1 above). For the S deposition estimated for the 2010–2012 period, more than 70% of waterbodies are estimated to be able to achieve an ANC of 50 ueq/L in all 25 ecoregions (figure 1, left panel), and 85% to 100% of waterbodies in all ecoregions are estimated to be able to achieve an ANC of 20 ueq/L (figure 1, right panel).

Given the dependency of the ANC estimates on S deposition estimates, this distinction between the period prior to 2010 and the subsequent decade is also seen in the ecoregion deposition

[71] This combination of targets recognizes the naturally and typically low ANC levels observed in western waterbodies while also including a higher target for the East, as described in section 5.1.2.2 of the PA.

estimates for the 25 REA ecoregions (figure 2; PA, Figure 7–2).[72] The distribution of deposition estimates at waterbody sites assessed in each ecoregion, and particularly the temporal pattern for the upper percentiles, illustrates the deposition estimates that are driving temporal pattern in the REA estimates.[73] For example, across the 25 ecoregions (figure 2, left panel), the median of the ecoregion 90th percentiles[74] of S deposition during the two earliest periods ranged from approximately 14 to 17 kg/ha-yr and the highest ecoregion 90th percentile values were above 20 kg/ha-yr. In contrast, during the latter three periods (2010–2020), the median of ecoregion 90th percentile values ranged from approximately 2 to 5 kg/ha-yr and all ecoregion 90th percentile estimates were below approximately 8 kg/ha-yr (figure 2). The contrast is less sharp for the ecoregion medians, as the median is a statistic less influenced by changes in the magnitude of values at the upper end of the distribution (figure 2). Overall, this indicates the significant reduction in the highest levels of deposition within each ecoregion over the time periods analyzed.

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[72] In Figure 7–2 of the PA (which is an earlier version of figure 2), the box and whiskers presented for the medians were incorrect. They are correct in figure 2 here, and they were also correct in figure 2 of the proposal.

[73] Figure 2 presents temporal trends for three different statistics for deposition within the REA ecoregions. For example, the leftmost box and whiskers among the set of three presents the distribution of values that are the 90th percentile deposition estimates (at REA assessed waterbodies) in the 25 ecoregions. The rightmost box and whiskers presents the distribution of median deposition estimates for these ecoregions (figure 2, left panel).

[74] The median of the ecoregion 90th percentiles is the horizontal line in the leftmost box of the set of three. This is a measure of the central tendency of the 90th percentile deposition (across REA sites) in the 25 assessed ecoregions.

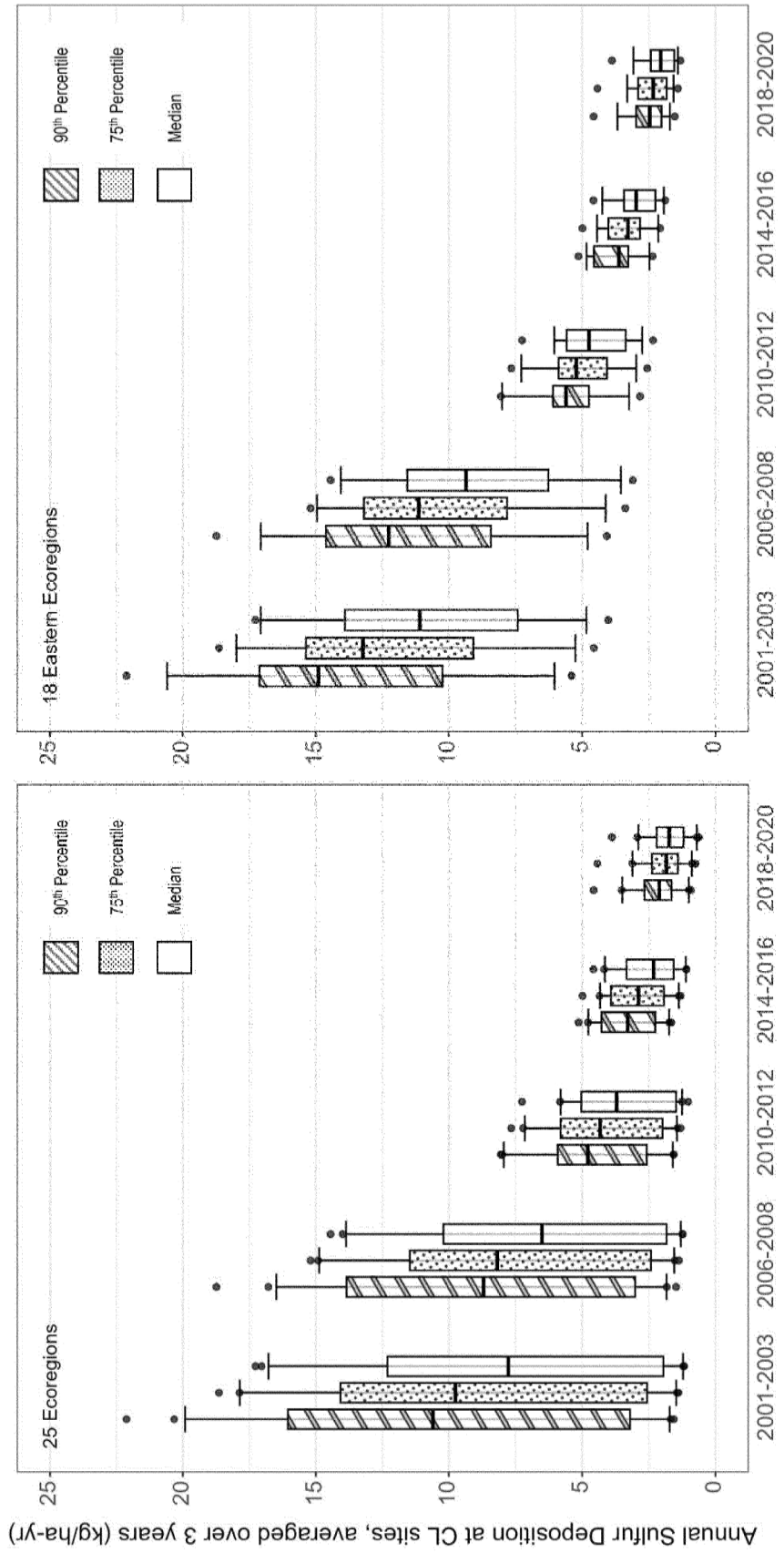

Figure 2. Ecoregion 90th, 75th and 50th Percentile S Deposition Estimates at REA Waterbody Sites Summarized for all 25 Ecoregions (left) and the 18 Eastern Ecoregions (right).

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Thus, in considering identification of S deposition levels that may be associated with a desired level of ecosystem protection for a SO_X

standard, the PA took note of the increased percentages of waterbodies estimated to achieve more protective ANC levels across the five time periods. The pattern of estimated improving water quality over the 20-year study period is paralleled by the pattern of declining deposition (figure 2). This temporal pattern indicates an appreciable reduction in ecoregion S deposition between the first and second decades of the period with associated reduction in aquatic acidification risk. As noted immediately above, the risk estimates associated with the deposition estimates of the second decade indicate generally high percentages of waterbodies per ecoregion as able to achieve or exceed the three ANC targets. Similarly, the ecoregion-time period binning summary also indicates generally high percentages of waterbodies achieving ANC targets for ecoregion median S deposition at or below about 8 or 9 kg/ha-yr (table 4). Thus, in light of these observations,[75] the PA describes S deposition, on an areawide basis (*i.e.,* ecoregion median), that falls at or below approximately 5 to 9 (differing slightly depending on the supporting analysis), as being associated with the potential to achieve acid buffering capacity levels of interest in an appreciable portion of sensitive areas.

In considering what the quantitative information for S deposition and terrestrial acidification indicates regarding deposition levels of potential concern for acidification-related effects (and the associated uncertainties), the PA considers soil chemistry modeling analyses (both in published studies and in the 2009 REA), studies involving experimental additions of S compounds to defined forestry plots, and observational studies of potential relationships between terrestrial biota assessments and metrics for S deposition (PA, section 5.3). With regard to soil chemistry modeling analyses performed in the last review, the PA found the 2009 soil acidification modeling to indicate that a focus on aquatic acidification might reasonably be expected to also provide protection from soil acidification effects on terrestrial biota. With regard to studies involving S additions to experimental forested areas, the PA observes that effects on the sensitive tree species analyzed have not been reported with S additions below 20 kg/ha-yr (which is in addition to the atmospheric deposition occurring during the experiment).

The PA also considers the recently available quantitative information on S deposition and terrestrial acidification drawn from recent observational studies that report associations of tree growth and/or survival metrics with various air quality or S deposition metrics (PA, section 5.3.2.3 and Appendix 5B, section 5B.3.2). The metrics used in the two largest studies include site-specific estimates of average SO_4^{2-} deposition and of average total S deposition over the interval between tree measurements, generally on the order of 10 years (Dietze and Moorcroft, 2011; Horn et al., 2018). In the study that used SO_4^{2-} as the indicator of acidic S deposition, and for which the study area was the eastern half of the contiguous U.S., site-specific average SO_4^{2-} deposition (1994–2005) ranged from a minimum of 4 kg/ha-yr to a maximum of 30 kg/ha-yr (Dietze and Moorcroft, 2011). Review of the study area for this study and a map indicating geographic patterns of deposition during the period of the deposition data indicate the lowest deposition areas to be west of the Mississippi River, northern New England (*e.g.,* Maine) and southern Georgia and Florida (in which S deposition in the 2000–2002 period was estimated to fall below 8 kg/ha-yr), and the highest deposition areas to be a large area extending from New York through the Ohio River valley (PA, Appendix 5B, Figures 5B–1 and 5B–11). In the second study, deposition at the sites with species for which growth or survival was negatively associated with S deposition ranged from a minimum below 5 kg/ha-yr to a site maximum above 40 kg/ha-yr, with medians for these species generally ranging from around 5 to 12 kg S/ha-yr (PA, Appendix 5B, section 5B.3.2.3; Horn et al., 2018).

In considering these study observations, the PA notes the history of appreciable acidic deposition in the eastern U.S., with its associated impacts on soil chemistry, that has the potential to be exerting a legacy influence on tree growth and survival more recently (PA, section 5.3.2 and Appendix 5B). Further, the PA notes that, at a national scale, the geographic deposition patterns (*e.g.,* locations of relatively greater *versus* relatively lesser deposition) in more recent times appear to be somewhat similar to those of several decades ago (*e.g.,* PA, sections 2.5.4 and 6.2.1). This similarity in patterns is recognized to have the potential to influence findings of observational studies that assess associations between variation in tree growth and survival with variation in levels of a metric for recent deposition at the tree locations, and to contribute uncertainty with regard to interpretation of these studies as to a specific magnitude of deposition that might be expected to elicit specific tree responses, such as those for which associations have been found. The PA notes that, as recognized in the study by Dietze and Moorcroft (2011), which grouped species into plant functional groups, acidification impacts on tree mortality rates are the result of cumulative long-term deposition, and patterns reported by their study should be interpreted with that in mind (PA, section 5.3.1 and Appendix 5B).

(c) Relating Air Quality Metrics to S Deposition

In considering what the available information and air quality analyses indicate regarding relationships between air quality metrics and S deposition, the PA evaluated trends over the past two decades as well as a series of analyses of relationships between S deposition and ambient air concentrations of SO_2 (in terms of 3-year averages of the existing SO_2 standard and of an annual average),[76] and between S deposition and ambient air concentrations of other S compounds (*e.g.,* SO_4^{2-} or the sum of SO_4^{2-} and SO_2) at 27 Class I area sites (collocated CASTNET and IMPROVE network sites), as summarized in section II.B. above. With regard to the latter, lower correlations were observed for total S deposition estimates collocated with ambient air concentrations of S-containing pollutants (SO_4^{2-} and the sum of S in SO_2 and SO_4^{2-}) in 27 Class I areas than between S deposition and annual average SO_2 concentrations (averaged over three years) at SLAMS monitors (PA, Figure 6–31, center and right panels, and Table 6–4). Thus, while information for S compounds other than SO_2 are available at the Class I area sites, the analyses based on data from SLAMS are considered particularly relevant given that those sites are primarily in areas of higher SO_2 concentrations (near emissions sources) and collect FRM/FEM measurements for

[75] The PA also suggested, based on the case study CL estimates, a focus on deposition below 10 kg/ha-yr, although the deposition estimates discussed in the case study analysis are smaller scale, *e.g.,* site-level (PA, section 5.1.3.3).

[76] The air quality metrics include one based on the current secondary SO_2 NAAQS, which is the second highest 3-hour daily maximum in a year, as well as an annual average SO_2 air quality metric (averaged over three years). Since many factors contribute variability to S deposition, the analyses focus on a 3-year average of all of the air quality and deposition metrics and include multiple years of data, generally on the order of 20 years and covering a period of declining concentrations and deposition. Of the two air quality metrics analyzed, the PA focused primarily on the annual average of SO_2 concentrations, averaged over 3 years, given the focus on control of long-term S deposition and the greater stability of the metric (PA, section 7.2.2.3).

existing NAAQS monitoring. Data from these monitoring sites informed the PA consideration of how changes in SO_2 emissions, reflected in ambient air concentrations, may relate to changes in deposition and, correspondingly, what secondary standard options might best relate to ambient air concentrations such that deposition in areas of interest is maintained at or below range of levels identified above (PA, section 7.2.2.3).

Together the air quality and deposition data and analyses in the PA indicate a significant association of S deposition with SO_2 concentrations, with statistically significant correlation coefficients ranging from approximately 0.5 to 0.7 from the trajectory-based and SLAMS analyses for the five 3-year time periods (during 2001–2020) across all ecoregions. Higher correlations were observed for dry S deposition and at sites in the eastern U.S. (PA, section 7.2.2.3). As summarized in section II.A.2. above, S deposition is generally higher in the East and dry S deposition is generally higher near SO_2 emissions sources. A strength of the analyses for concentrations and deposition estimates at SLAMS locations is the capturing of near-source deposition, while a strength of the trajectory-based analyses is accounting for the role of transport and transformation in contributing to downwind deposition.

While recognizing the significant correlations between SO_2 concentrations and S deposition, the PA additionally took note of the variability in, and uncertainty associated with, these relationships. The variability derives from the complexity of the atmospheric chemistry, pollutant transport, and deposition processes (PA, sections 2.1.1 and 2.5). The uncertainty in these relationships relates to a number of factors, including uncertainty in our estimates of S deposition (PA, section 2.5.2) and spatial distribution of monitor sites, including the representation of significant SO_2 emissions sources, as well as elements of the trajectory-based analysis, *e.g.,* inclusion criteria for identifying monitoring sites of influence (PA, section 6.3 and Table 6–13). The PA concluded that it is unclear how much and in what way each of these various uncertainties in the data and analyses, and the inherent variability of the physical and chemical processes involved, might impact the conclusions concerning ambient air SO_2 concentrations related to S deposition estimates at different scales (PA, section 7.2.2.3). In light of such uncertainty and variability, the REA aquatic acidification analyses and discussion of S deposition levels focused on statistics for deposition estimates representing large areas (*e.g.,* at the ecoregion median and 75th or 90th percentile, and case study area average or 70th and 90th percentile CLs). While uncertainty may be greater for relating concentrations to higher points on the distribution of deposition in an ecoregion, the PA recognized that it is the higher deposition estimates, if focused on individual waterbodies, that will contribute most to aquatic acidification risk. The PA additionally observed that the distribution of S deposition estimates within ecoregions has narrowed in more recent years, with 90th percentile estimates falling much closer to the medians than in the first decade of the 20-year period (figure 2 above).

In identifying levels for consideration for a potential annual average SO_2 standard, the PA first considered SO_2 concentrations at SLAMs and associated S deposition levels, focusing on the most recent of the five time periods analyzed (*i.e.,* since 2010) when the REA indicated appreciably improved levels of acid buffering capability in the waterbodies of the 25 analyzed ecoregions (when ANC targets were met or exceeded in a high percentage of water bodies across a high percentage of ecoregions). Since 2010 (when ecoregion median and 90th percentile S deposition estimates for the 25 REA ecoregions were below 10 kg/ha-yr), the highest 3-year average annual SO_2 concentrations were generally somewhat below 10 ppb (with some exceptions during the 2019–2021 period) (PA, Figure 7–5, left panel).[77] The PA also considered SO_2 concentrations at monitoring sites of influence identified in the trajectory-based analyses across different ranges of downwind ecoregion S deposition estimates. Across all 84 ecoregions in the contiguous U.S., the maximum annual average SO_2 concentrations, as 3-year averages, at sites of influence to downwind ecoregions with median S deposition below 9 kg down to 6 kg/ha-yr,[78] were all below 15 ppb, and 75% of the concentrations at these sites were at or below 10 ppb (PA, Figure 7–3).[79] In the 25 REA ecoregions, for the ecoregion median S deposition below 9 down to 6 kg/ha-yr, the concentrations for the metric based on maximum concentration at upwind sites of influence (EAQM-max) range as high as 15 ppb, with more than half below 10 ppb (PA, Figure 7–4, left panel). The EAQM-max concentrations associated with ecoregion median S deposition below 6 kg/ha-yr were all below 10 ppb. This PA presentation further indicates that for the 25 REA ecoregions, when the highest EAQM-max concentration is at approximately 11 or 10 ppb, both the median and 90th percentile deposition are both below 9 kg/ha-yr, with the overwhelming majority below 6 kg/ha-yr (PA, Figure 7–4).

In its use of the trajectory-based analyses to identify a range of annual average SO_2 EAQM-max concentrations associated with an ecoregion median S deposition target range, the PA recognizes several important considerations. First, monitor concentrations of SO_2 can vary substantially across the U.S., complicating consideration of the relationship between maximum contributing monitors identified in the trajectory-based analysis and S deposition levels in downwind ecosystems. Additionally, the substantial scatter in the relationship between S deposition estimates and measured SO_2 concentrations with ecoregion median S deposition values below about 5 kg/ha-yr contributes increased uncertainty to conclusions regarding potential secondary standard SO_2 metric levels intended to relate to ecoregion median deposition levels at or below 5 kg/ha-yr (PA, section 7.2.2.3). The PA additionally discusses limitations in the context of the two metrics (weighted and max). Between these metrics, somewhat stronger correlations were found for the annual average SO_2 weighted EAQM (which provides for proportional weighting of air concentrations from locations projected to contribute more heavily to a particular ecoregion), compared to the EAQM-max, particularly for the first two to three time periods of the 20-year period. This difference is related to the extent to which monitor concentrations can be indicative of atmospheric loading. The weighted EAQM is intended to more closely represent the atmospheric loading for the locations (and associated sources) of the contributing (sites of influence) monitors than a single contributing monitor can. However, the weighted metric is not directly translatable to a standard level (which is an upper limit

[77] The similar pattern observed for annual average SO_2 concentrations as 3-year averages suggests little year-to-year variability in this metric (PA, Figure 7–5).

[78] The bin for ''<9–6 kg/ha-yr'' is discussed here as it is the bin closest to the deposition target range of 10 or 8 to 5 kg/ha-yr identified above.

[79] Figure 7–3 of the PA presents the pairs of median deposition estimates and associated upwind sites of influence EAQM-max SO_2 concentrations from the trajectory-based analysis in section 6.2.4 of the PA (specifically, the combined datasets presented in PA, Figure 6–41).

on concentrations in individual locations).

The PA also considered relationships between S deposition and $PM_{2.5}$, noting the poor correlations for total S deposition estimates with $PM_{2.5}$ at the 27 Class I area sites (r = 0.33, PA, Figure 6–31), and not much stronger correlations for ecoregion S deposition estimates with $PM_{2.5}$ at upwind sites of influence from the trajectory-based analysis (r = −0.22 and 0.48, PA, Table 6–12). The PA also considered relationships between total S deposition and ambient air SO_4^{2-} concentrations noting that they are focused on remote locations (Class I areas), distant from sources of SO_2 emissions, and that the relationship is not stronger than that for SO_2 at the SLAMS, which are generally near sources monitoring SO_2 (the source for atmospheric SO_4^{2-}). In light of these considerations, the PA found that the available analyses did not indicate an advantage for an indicator based on SO_4^{2-} measurements (or SO_4^{2-} and SO_2 combined), such as is currently collected at CASTNET sites, or $PM_{2.5}$ mass over options for a potential annual average standard metric focused on SO_2 concentrations (based on FRM/FEMs).[80]

(4) Nitrogen Deposition and N Oxides and PM

The evidence and exposure/risk-based considerations of the PA pertaining to N deposition and concentrations of N oxides and PM in ambient air draw on the available welfare effects evidence described in the current ISA (as well as prior ISAs and AQCDs), and discussed in Chapters 4, 5 and 6 of the PA. The focus of these considerations is primarily on N deposition and effects other than aquatic acidification (PA, sections 4.3, 5.2 and 5.3). As recognized in section II.A.4. above, the PA finds S deposition to be the dominant influence on aquatic acidification risk in the 20-year period analyzed (2001–2020), based on the finding that the inclusion of acidic N deposition to the aquatic acidification risk analyses did not appreciably change patterns and percentages of waterbodies estimated to exceed CLs for the three ANC targets (PA, section 5.1.2.4).

In considering potential public welfare protection from N deposition-related effects (in light of the evidence summarized in sections II.A.3. and II.A.3.c. above), the PA recognizes the potential public welfare implications of the effects of N deposition in both aquatic and terrestrial ecosystems (PA, section 7.2.3.2). For example, the public welfare significance of eutrophication in large estuaries and coastal waters of the eastern U.S. related to decades of N loading is illustrated by the broad state, local and national government engagement in activities aimed at assessing and reducing the loading (PA, section 5.2.3). This significance relates both to the severity of the effects and the wide-ranging public uses dependent on these waters, including as important sources of fish and shellfish production, providing support for large stocks of resident commercial species, serving as breeding grounds and interim habitat for several migratory species, and providing an important and substantial variety of cultural ecosystem services. The public also benefits from water-based recreational uses and aesthetic values placed on aquatic systems. Many impacts of eutrophication relate to reduced waterbody oxygen, which contributes to fish mortality, and changes in aquatic habitat related to changes in resident plant and animal species, with associated ecosystem effects (PA, section 4.3; ISA, Appendix 7).

The relative contribution of atmospheric deposition to total N loading, however, varies widely among estuaries and has declined in recent years, contributing a complexity to considerations in this review. While N loading in smaller, more isolated fresh waterbodies is primarily from atmospheric deposition, the evidence with regard to public welfare significance of any small deposition-related effects in these systems is less clear and well established. For example, the public welfare implications of relatively subtle effects of N enrichment in aquatic systems, such as shifts in phytoplankton species communities in remote alpine lakes, are not clear. Additionally, the public welfare implications of HNO_3 effects on lichens (which might be considered to be ''direct'' effects or the result of deposition onto plant surfaces) are also not clear and might depend on the extent to which they impact whole communities, other biota, or ecosystem structure and function (PA, section 7.2.3.2).

The effects of N enrichment in terrestrial ecosystems may vary with regard to public welfare implications. As noted above with regard to impacts of aquatic acidification, the PA recognizes that some level of N deposition and associated effects on terrestrial ecosystems can impact the public welfare and thus might reasonably be judged adverse to the public welfare. Depending on magnitude and the associated impacts, there are situations in which N deposition and associated nutrient enrichment-related impacts might reasonably be concluded to be significant to the public welfare, such as N deposition that alters forest ecosystem community structures in ways that appreciably affect use and enjoyment of those areas by the public (PA, section 7.2.3.2). A complication to consideration of public welfare implications that is specific to N deposition in terrestrial systems is its potential to increase growth and yield of plants that, depending on the plant and its use by human populations (*e.g.,* trees for lumber, food for livestock or human populations), may be considered beneficial to the public. Nitrogen enrichment in natural ecosystems can, by increasing growth of N limited plant species, change competitive advantages of species in a community, with associated impacts on the composition of the ecosystem's plant community. The public welfare implications of such effects may vary depending on their severity, prevalence or magnitude. For example, only those rising to a particular severity (*e.g.,* with associated significant impact on key ecosystem functions or other services), magnitude or prevalence may be considered of public welfare significance (PA, section 7.2.3.2).

(a) Quantitative Information for Ecosystem Risks Associated With N Deposition

The PA considers the available information regarding air quality and atmospheric deposition and risk or likelihood of occurrence of ecosystem effects under differing conditions. In so doing, the PA notes the varying directionality of some of the N enrichment-related effects in terrestrial ecosystems, such that some effects can, in particular ecosystems and for particular species, seem beneficial (*e.g.,* to growth or survival of those species), although in a multispecies system, effects are more complex with potential for alteration of community composition. The information is also considered with regard to the key limitations and associated uncertainties of this evidence.

Beginning with the appreciable evidence base documenting assessments of N loading to waterbodies across the U.S., the PA notes the waterbody-specific nature of such responses and the relative role played by atmospheric deposition, among other N sources. For example, the relative contribution to such loading from atmospheric

[80] It is also of note that use of SO_4^{2-} measurements, alone or in combination with SO_2 concentrations, as an indicator of a new standard would entail development of sample collection and analysis FRM/FEMs and of a surveillance network.

deposition compared to other sources (*e.g.,* agricultural runoff and wastewater discharges) varies among waterbody types and locations, which can be a complicating factor in quantitative analyses. Additionally, characteristics of resident biota populations and other environmental factors are influential in waterbody responses to N loading, *e.g.,* temperature, organic microbial community structure, and aquatic habitat type, among others (ISA, Appendix 7). Based on identification of eutrophication as a factor in impacts on important fisheries in some estuaries across the U.S., multiple government and nongovernment organizations have engaged in research and water quality management activities over the past several decades in large and small estuaries and coastal waters across the U.S. These activities have generally involved quantitative modeling of relationships between N loading and water quality parameters such as dissolved oxygen (ISA, Appendix 7, section 7.2). This research documents both the impacts of N enrichment in these waterbodies and the relationships between effects on waterbody biota, ecosystem processes and functions, and N loading (PA, section 5.2.3). The evidence base recognizes N loading to have contributions from multiple types of sources to these large waterbodies and their associated watersheds, including surface and ground water discharges, as well as atmospheric deposition. Accordingly, loading targets or reduction targets identified for these systems have generally been identified in light of policy and management considerations related to the different source types, as discussed further in section II.B.1.(4)(b) below.

Focused assessments in freshwater lakes, including alpine lakes, where atmospheric deposition may be the dominant or only source of N loading, also provide evidence linking N loading with seemingly subtle changes, such as whether P or N is the nutrient limiting phytoplankton growth (and productivity) and shifts in phytoplankton community composition (PA, section 5.2.2); public welfare implications of such changes are less clear (PA, section 7.2.3.1).

With regard to terrestrial ecosystems and effects on trees and other plants, the PA recognizes the complexity, referenced above, that poses challenges to approaches for simulating terrestrial ecosystem responses to N deposition across areas diverse in geography, geology, native vegetation, deposition history, and site-specific aspects of other environmental characteristics. In its consideration of the different types of quantitative analysis, the PA recognizes limitations particular to each and associated uncertainties. Uncertainties associated with the soil acidification modeling analyses in the last review include those associated with the limited dataset of laboratory-generated data on which the BC:Al targets are based, as well as the steady-state modeling parameters, most prominently those related to base cation weathering and acid-neutralizing capacity (PA, section 5.3.4.1). Uncertainties associated with experimental addition analyses include the extent to which the studies reflect steady-state conditions, as well as a lack of information regarding historic deposition at the study locations (PA, section 5.3.4.1). Several aspects of observational or gradient studies of tree growth and survival (or of species richness for herbs, shrubs and lichens) contribute uncertainties to identification of deposition levels of potential concern for tree species effects, including unaccounted-for factors with potential influence on tree growth and survival (*e.g.,* ozone and soil characteristics), as well as the extent to which associations may reflect the influence of historical deposition patterns and associated impact. Thus, while the evidence is robust as to ecological effects of ecosystem N loading, a variety of factors, including the history of deposition and variability of response across the landscape, complicate our ability to quantitatively relate specific N deposition rates, associated with various air quality conditions, to N enrichment-related risks of harm to forests and other plant communities in areas across the U.S. (PA, section 5.3.4).

(b) General Approach for Considering Public Welfare Protection

In considering public welfare protection with regard to N enrichment, the PA notes, as an initial matter, that the effects of acidification on plant growth and survival, at the individual level, are generally directionally harmful, including reduced growth and survival. In contrast, the effects of N enrichment can, in particular ecosystems and for particular species, be beneficial or harmful (*e.g.,* to growth or survival of those species). Accordingly, the PA recognizes added complexity to risk management policy decisions for this category of effects, including the lack of established risk management targets or objectives, particularly in light of historical deposition and its associated effects that have influenced the current status of terrestrial ecosystems and their biota, structure, and function.

Further, the PA recognizes the complication posed by the contribution to N deposition of atmospheric pollutants other than the criteria pollutants N oxides and PM, most significantly the contribution of NH_3 (PA, section 6.2.1). In light of the contrasting temporal trends for emissions of oxidized and reduced N compounds, the PA observes a declining influence of ambient air concentrations of N oxides and PM on N deposition over the past 20 years, complicating consideration of the protection from N deposition-related effects that can be provided by secondary NAAQS for these pollutants. This declining trend in N oxides emissions and associated oxidized N deposition coincides with increases in NH_3 emissions and deposition of reduced N compounds, such that reduced N deposition has generally been more than half of total N deposition at CASTNET sites since 2015 (PA, Figures 6–3, 6–17, 6–18 and 6–19). In 2021, estimated dry deposition of NH_3 was as much as 65% of total N deposition across the 92 CASTNET sites (PA, Figure 6–19). At 25% of the CASTNET sites, more than 30% of N deposition is from dry deposition of NH_3 (PA, Figure 6–19), a noteworthy observation given the preponderance of CASTNET sites in the West and relatively few in the areas of highest NH_3 emissions where the percentage would be expected to be higher still (PA, Figures 2–9 and 2–17). In light of this information, the PA finds that NH_3, which is not a criteria pollutant, and its contribution to total N deposition, particularly in parts of the U.S. where N deposition is highest, are complicating factors in considering policy options related to NAAQS for addressing ecological effects related to N deposition (*e.g.,* PA, Figure 6–18 and 6–13).

In considering what the currently available quantitative information regarding terrestrial ecosystem responses to N deposition indicates about levels of N deposition that may be associated with increased concern for adverse effects, the PA focuses first on the evidence for effects of N deposition on trees that is derived from experimental addition studies and observational studies of potential relationships between tree growth and survival and metrics for N deposition. With regard to the experimental addition studies, while recognizing study limitations and associated uncertainties, the PA notes that the lowest N addition that elicited forest effects was 15 kg/ha-yr over the 14 years from 1988 to 2002 (PA, sections 5.3.2

and 7.2.3.2 and Appendix 5B, Table 5B–1; McNulty et al., 2005). Based on the estimates from several observational studies, the PA observed that N deposition ranging from 7 to 12 kg/ha-yr, on a large area basis, reflects conditions for which statistical associations have been reported for terrestrial effects, such as reduced tree growth and survival.[81] (PA, sections 5.3.4 and 7.2.3.2).

With regard to studies of herb and shrub community metrics, the PA considered several recently available addition experiments, recent gradient studies of coastal sage scrub in southern California, and a larger observational study of herb and shrub species richness in open- and closed-canopy communities. As summarized in section II.A.3.c.(2)(b) above, N deposition estimates ranging from 6.5 kg/ha-yr to 11.6 kg/ha-yr were identified from these studies as reflecting conditions for which statistical associations have indicated potential for effects in herb and shrub communities (PA, section 5.3.3.1 and Appendix 5B, sections 5B.3.1 and 5B.3.2; Cox et al., 2014; Fenn et al., 2010). Lastly, the PA notes the observational studies that have analyzed variation in lichen community composition in relation to indicators of N deposition, but recognize limitations with regard to interpretation, as well as uncertainties such as alternate methods for utilizing N deposition estimates as well as the potential influence of unaccounted-for environmental factors, *e.g.,* ozone, SO_2, and historical air quality and associated deposition (PA, section 5.3.3.2 and Appendix 5B, section 5B.4.2).

With regard to the evidence for effects of N deposition in aquatic ecosystems, the PA recognizes several different types of information including the observational studies utilizing statistical modeling to estimate critical loads, such as those related to subtle shifts in the composition of phytoplankton species communities in western lakes. There are also many decades of research on the impacts and causes of eutrophication in large rivers and estuaries. As noted above, the public attention, including government expenditures, that has been given to N loading and eutrophication in multiple estuarine and coastal systems are indicative of the recognized public welfare implications of related impacts. In large aquatic systems across the U.S., the relationship between N loading and algal blooms, and associated water quality impacts (both short- and longer-term), has led to numerous water quality modeling projects to inform water quality management decision-making in multiple estuaries, including the Chesapeake Bay, Narraganset Bay, Tampa Bay, Neuse River Estuary and Waquoit Bay (ISA, Appendix 7, section 7.2). These projects often use indicators of nutrient enrichment, such as chlorophyll a, dissolved oxygen, and abundance of submerged aquatic vegetation (ISA, section IS.7.3 and Appendix 10, section 10.6). For these estuaries, the available information regarding atmospheric deposition and the establishment of associated target loads varies across estuaries (ISA, Appendix 7, Table 7–9), and in many cases atmospheric loading has decreased since the initial modeling analyses.

As summarized in section II.A.3.c.(1) above, analyses in multiple East Coast estuaries—including the Chesapeake Bay, Tampa Bay, Neuse River Estuary and Waquoit Bay—have addressed atmospheric deposition as a source of N loading (ISA, Appendix 7, section 7.2.1). Total estuary loading or loading reductions were established in TMDLs developed under the Clean Water Act for these estuaries. Levels identified for allocation of atmospheric N loading in the first three of these estuaries were 6.1, 11.8 and 6.9 kg/ha-yr, respectively, and atmospheric loading estimated to be occurring in the fourth was below 5 kg/ha-yr (PA, section 7.3). This information, combined with the information from terrestrial studies summarized above, led to the PA identifying 7–12 kg/ha-yr as an appropriate N deposition range on which to focus in considering policy options (PA, section 7.2.3.2).

(c) Relating Air Quality Metrics to N Deposition Associated With N Oxides and PM

In exploring how well various air quality metrics relate to N deposition, the PA finds the analyses utilizing data from monitors using FRM/FEM to collect ambient air concentration data for evaluation with the NAAQS (*e.g.,* to identify violations) to be particularly relevant given that the current standards are judged using design values derived from FRM/FEM measurements at existing SLAMS (PA, section 7.2.3.3). Given their role in monitoring for compliance with the NAAQS, most or many of these monitors are located in areas of relatively higher pollutant concentrations, such as near large sources of NO_2 or PM. Accordingly, the PA recognized the information from these monitoring sites as having potential for informing how changes in NO_2 and/or PM emissions, reflected in ambient air concentrations, may relate to changes in deposition and, correspondingly, for informing consideration of secondary standard options that might best regulate ambient air concentrations such that deposition in sensitive ecosystems of interest is maintained at or below levels of potential concern.

In considering the information and findings of these analyses of N deposition and N oxides and PM in ambient air, the PA notes, as an initial matter, that relationships between N deposition and NO_2 and PM air quality are affected by NH_3 emissions and non-N-containing components of PM (PA, section 6.4.2). The PA further notes that the influence of these factors on the relationships has varied across the 20-year evaluation period and varies across different regions of the U.S. (PA, section 6.2.1). Both factors (NH_3 emissions and non-N-containing components of PM) are recognized to influence relationships between total N deposition and NO_2 and PM air quality metrics. For example, for total N deposition estimated for TDep grid cells with collocated SLAMS monitors, the correlations with annual average NO_2 concentrations, averaged over three years, are generally low across all sites and particularly in the East (PA, Table 6–6). This likely reflects the relatively greater role of NH_3 in N deposition in the East, which for purposes of the analyses in this PA extends across the Midwest (PA, section 6.4.2). The correlation between estimates of total N deposition in eastern ecoregions and annual average NO_2 concentrations at upwind monitor sites of influence for the five periods from 2001–2020 is low to moderate, with the earlier part of the 20-year period, when NO_2 concentrations were higher and NH_3 emissions were lower (as indicated by Figures 6–6 and 6–5 of the PA), having relatively higher correlation than the later part (*e.g.,* correlation coefficients below 0.4, except for EAQM-weighted in 2001–03 [PA, Table 6–10]). The correlation is negative or near zero for the western ecoregions (PA, section 6.2.4).

Based on the decreasing trends in NO_2 emissions and oxidized N deposition in

[81] The largest study reported associations of tree survival and growth with N deposition that varied from positive to negative across the range of deposition at the measurement plots for some species, and also varied among species (PA, section 5.3.2, Appendix 5B, section 5B.3.2.3; Horn et al., 2018). Among the species for which the association varied from negative to positive across deposition levels, this is the range for those species for which the association was negative at the median deposition value (PA, section 5.3.4). This also excluded species for which sample sites were limited to the western U.S. based on recognition by the study authors of greater uncertainty in the west (Horn et al., 2018).

the past 10 years, and coincident trend of increased NH_3 emissions and deposition of reduced N (NH_3 and NH_4^+), most particularly in areas of the Midwest, Texas, Florida and North Carolina (PA, Figures 6–16 and 6–17), the PA finds NO_2 emissions to have much less influence on total N deposition now than in the past (PA, sections 6.2.1 and 6.4). In terms of ecoregion median statistics, the PA observes the decreasing trend in ecoregion median total N deposition across the period from 2001 through 2012, while taking note that from 2012 onward, total N deposition increases, most particularly in ecoregions where most of the total deposition is from reduced N (PA, Figure 7–6). The PA also considers the impact of increasing deposition of reduced N on the 20-year trend in total N deposition as illustrated by TDep estimates at the 92 CASTNET sites. At these sites, the median percentage of total N deposition comprised by oxidized N species, which is driven predominantly by N oxides, has declined from more than 70% to less than 45% (PA, Figure 6–19). Based on examination of the trends for components of reduced N deposition, the PA notes that the greatest influence on the parallel increase in N deposition percentage composed of reduced N is the increasing role of NH_3 dry deposition. The percentage of total N deposition at the CASTNET sites that is from NH_3 has increased, from a median below 10% in 2000 to a median somewhat above 25% in 2021 (PA, Figure 6–19).

Recognizing limitations in the extent to which CASTNET sites can provide information representative of the U.S. as a whole, the PA also analyzed TDep estimates across the U.S. for the most recent period assessed (2018–2020). In areas with ecoregion median total N deposition above 9 kg/ha-yr (PA, Figure 7–7, upper panel), the ecoregion median percentage of total N deposition composed of reduced N is greater than 60% (PA, Figure 7–7, lower panel). The 2019–2021 TDep estimates across individual TDep grid cells similarly show that the areas of the U.S. where total N deposition is highest and greater than potential N deposition targets (identified in section 7.2.3.2 of the PA) are also the areas with the greatest deposition of NH_3 (PA, Figure 7–8), comprising more than 30% of total N deposition. That is, the PA finds that NH_3 driven deposition is greatest in regions of the U.S. where total deposition is greatest (PA, section 7.2.3.3).

Turning to $PM_{2.5}$, the PA notes that the correlation for ecoregion median N deposition and $PM_{2.5}$ concentrations at upwind sites of influence is poor and negative or moderate (r=0.45) depending on the metric (PA, section 6.2.4). For total N deposition and $PM_{2.5}$ concentrations at SLAMS, a low to moderate correlation is observed (PA, section 6.2.3). In considering NH_3 emissions and non-N containing components of PM, the PA notes that some NH_3 transforms to NH_4^+, which is a component of $PM_{2.5}$, while also noting that, in the areas of greatest N deposition, the portion represented by deposition of gaseous NH_3 generally exceeds 30%. Additionally, while NH_3 emissions have been increasing over the past 20 years, the proportion of $PM_{2.5}$ that is composed of N compounds has declined. The median percentage of $PM_{2.5}$ comprised by N compounds has declined from about 25% in 2006–2008 to about 17% in 2020–2022 and the highest percentage across sites declined from over 50% to 30% (PA, section 6.4.2 and Figure 6–56). Further, the percentages vary regionally, with sites in the nine southeast states having less than 10% of $PM_{2.5}$ mass composed of N compounds (PA, Figure 6–56).

In summary, the PA concludes that in recent years, NH_3 contributes appreciably to total N deposition, particularly in parts of the country where N deposition is highest (as illustrated by comparison of Figures 6–13 and 6–18 of the PA). The PA finds that this situation—of an increasing, and spatially variable, portion of N deposition not being derived from N oxides or PM—complicates assessment of policy options for protection against ecological effects related to N deposition associated with N oxides and PM, and for secondary standards for those pollutants that may be associated with a desired level of welfare protection. The PA recognizes that the available information as a whole also suggests the potential for future reductions in N oxide-related N deposition to be negated by increasing reduced N deposition. Further, the PA notes that the results also suggest that while the $PM_{2.5}$ annual average standard may provide some control of N deposition associated with PM and N oxides, $PM_{2.5}$ monitors also capture other non-S and non-N related pollutants (*e.g.,* organic and elemental carbon) as part of the $PM_{2.5}$ mass (PA, section 7.2.3.3). The amounts of each category of compounds vary regionally (and seasonally), and as noted above, N compounds generally comprise less than 30% of total $PM_{2.5}$ mass (PA, section 6.3 and 6.4).

In considering relationships between air quality metrics based on indicators other than those of the existing standards and N deposition (and associated uncertainties), the PA drew on the analyses of relationships for collocated measurements and modeled estimates of N compounds other than NO_2 with N deposition in a subset of 27 CASTNET sites located in 27 Class I areas, the majority of which (21 of 27) are located in the western U.S. (PA, sections 6.2.2, 6.3 and 6.4.2). The analyses indicate that total N deposition in these rural areas has a moderate correlation with air concentrations of nitric acid and particulate nitrate for the 20-year dataset (2000–2020) (PA, Figure 6–32). The correlations are comparable to the correlation of NO_2 with total N deposition at western SLAMS, a not unexpected observation given that more than 75% of the 27 CASTNET sites are in the West. A much lower correlation was observed at SLAMS in the East, and with the trajectory-based dataset. The PA notes that deposition at the western U.S sites is generally less affected by NH_3 (PA, section 6.4.2). Further, the observed trend of increasing contribution to N deposition of NH_3 emissions over the past decade suggests that such correlations of N deposition with oxidized N may be still further reduced in the future. Thus, the PA concludes that the evidence does not provide support for the oxidized N compounds (as analyzed at the 27 Class I sites) as indicators of total atmospheric N deposition, especially in areas where NH_3 is prevalent (PA, section 7.2.3.3).

The analyses involving N deposition and N-containing PM components at the 27 Class I area sites do not yield higher correlation coefficients than those for N deposition (TDep) and $PM_{2.5}$ at SLAMS monitors (PA, section 7.2.3.3 and Figures 6–33, 6–39 [upper panel], and 6–32 [left panel]). Further, the graphs of total N deposition estimates *versus* total particulate N in ambient air at the 27 Class I area sites indicate the calculated correlations (and slopes) likely to be appreciably influenced by the higher concentrations occurring in the first decade of the 20-year timeframe (PA, Figure 6–33). Thus, the PA concludes that the available analyses of N-containing $PM_{2.5}$ components at the small dataset of sites remote from sources also do not indicate an overall benefit or advantage of N-containing $PM_{2.5}$ components over consideration of $PM_{2.5}$ (PA, section 7.4). As a whole, the PA finds that the limited dataset with varying analytical methods and monitor locations, generally distant from sources, does not clearly support a conclusion that such alternative indicators might provide better control of N deposition related to N oxides and

PM over those used for the existing standards (PA, section 7.2.3.3). The PA also notes that use of the NO_3^- or particulate N measurements analyzed with deposition estimates at the 27 Class I area sites, alone or in combination with NO_2, as an indicator for a new standard would entail development of sample collection and analysis FRM/FEMs [82] and of a surveillance network.

b. CASAC Advice

The CASAC provided advice and recommendations regarding the standards review based on the CASAC's review of the draft PA. In the letter conveying its advice, the CASAC first recognized that ''translation of deposition-based effects to an ambient concentration in air is fraught with difficulties and complexities'' (Sheppard, 2023, pp. 1–2). Further, the CASAC expressed its view that, based on its interpretation of the CAA, NAAQS could be in terms of atmospheric deposition, which it concluded ''would be a cleaner, more scientifically defensible approach to standard setting.'' Accordingly, the CASAC recommended that direct atmospheric deposition standards be considered in future reviews (Sheppard, 2023, pp. 2 and 5). The CASAC then, as summarized below, provided recommendations regarding standards based on air concentrations.

With regard to protection from effects other than those associated with ecosystem deposition of S and N compounds, the CASAC concluded that the existing SO_2 and NO_2 secondary standards provide adequate protection for direct effects of those pollutants on plants and lichens, providing consensus recommendations that these standards should be retained without revision for this purpose (Sheppard, 2023, p. 5 of letter and p. 23 of Response to Charge Questions). With regard to deposition-related effects of S and N compounds, the CASAC members did not reach consensus, with their advice divided between a majority opinion and a minority opinion. Advice conveyed from both the majority and minority groups of members concerning deposition-related effects is summarized here.

With regard to deposition-related effects of S and standards for SO_X, the majority of CASAC members recommended a new annual SO_2 standard with a level in the range of 10 to 15 ppb,[83] which these members concluded would generally maintain ecoregion median S deposition below 5 kg/ha-yr [84] based on consideration of the trajectory-based SO_2 analyses (and associated figures) in the draft PA (Sheppard, 2023, Response to Charge Questions, p. 25). They concluded that such a level of S deposition would afford protection for tree and lichen species [85] and aquatic ecosystems. Regarding aquatic ecosystems, these members cited the ecoregion-scale estimates (from the aquatic acidification REA analyses) associated with median S deposition bins for the 90 ecoregion-time period combinations (PA, section 5.1.3.2) in conveying that for S deposition below 5 kg/ha-yr, 80%, 80% and 70% of waterbodies per ecoregion are estimated to achieve an ANC at or above 20, 30 and 50 μeq/L, respectively, in all ecoregion-time period combinations (Sheppard, 2023, Response to Charge Questions, p. 25).[86] In recommending an annual SO_2 standard with a level in the range of 10 to 15 ppb, these members stated that such a standard would ''preclude the possibility of returning to deleterious deposition values as observed associated with the emergence of high annual average SO_2 concentrations near industrial sources in 2019, 2020, and 2021,'' citing Figure 2–25 of the draft PA [87] (Sheppard, 2023, Response to Charge Questions, p. 24).

One CASAC member dissented from this recommendation for an annual SO_2 standard [88] and instead recommended adoption of a new 1-hour SO_2 secondary standard identical in form, averaging time, and level to the existing primary standard based on the conclusion that the ecoregion 3-year average S deposition estimates for the most recent periods are generally below 5 kg/ha-yr and that those periods correspond to the timing of implementation of the existing primary SO_2 standard (established in 2010), indicating the more recent lower deposition to be a product of current regulatory requirements (Sheppard, 2023, Appendix A, p. A–2).[89]

With regard to N oxides and protection against deposition-related welfare effects of N, the majority of CASAC members recommended revision of the existing annual NO_2 standard to a level ''<10–20 ppb'' (Sheppard, 2023, Response to Charge Questions, p.24). The justification these members provided was related to their consideration of the relationship presented in the draft PA of median ecosystem N deposition with the weighted [90] annual average NO_2 metric concentrations, averaged over three years, at monitoring sites linked to the ecosystems by trajectory-based analyses and a focus on total N deposition estimates at or below 10 kg/ha-yr [91] (Sheppard, 2023, Response to Charge Questions, p. 24). These members

[82] For example, sampling challenges have long been recognized for particulate NH_4^+ (*e.g.,* ISA, Appendix 2, sections 2.4.5; 2008 ISA, section 2.7.3).

[83] Although the CASAC letter does not specify the form for such a new annual standard, the justification provided for this recommendation cites two figures in the draft PA (Figures 6–17 and 6–18) which presented annual average SO_2 concentrations averaged over three consecutive years (Sheppard, 2023, Response to Charge Questions, p. 25). Therefore, we are interpreting the CASAC majority recommendation to be for an annual standard, averaged over three years.

[84] Although the CASAC letter does not specify the statistic for the 5 kg/ha-yr value, the draft PA analyses referenced in citing that value, both the trajectory analyses and the ecoregion-scale summary of aquatic acidification results, focus on ecoregion medians. Further, the draft PA presentations of ecoregion percentages of waterbodies achieving the three ANC targets were for bins at or below specific deposition values (*e.g.,* ''at/below'' 5, 6 or 7 kg/ha-yr [draft PA, table 5–4]). Therefore, we are interpreting the CASAC advice on this point to pertain to ecoregion median at or below 5 kg/ha-yr.

[85] In making this statement, these CASAC members cite two observational data studies with national-scale study areas published after the literature cut-off date for the ISA: one study is on lichen species richness and abundance and the second is on tree growth and mortality (Geiser et al., 2019; Pavlovic et al., 2023). The lichen study by Geiser et al. (2019) relies on lichen community surveys conducted at U.S. Forest Service sites from 1990 to 2012. The tree study by Pavlovic et al. (2023) uses machine learning models with the dataset from the observational study by Horn et al. (2018) to estimate confidence intervals for CLs for growth and survival for 108 species based on the dataset first analyzed by Horn et al. (2018).

[86] As seen in tables 3 and 4 in this preamble, these levels of protection are also achieved in ecoregion-time period combinations for which the ecoregion median S deposition estimate is at or below 7 kg/ha-yr (PA, section 7.2.2.2 and Table 7–1).

[87] The figure cited by the CASAC majority is the prior version of Figure 2–28 in section 2.4.2 of the final PA. The figure presents temporal trend in distribution (box and whiskers) of annual average SO_2 concentrations since 2000 at SLAMS.

[88] Also dissenting from this advice was a member of the CASAC Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter Secondary NAAQS Panel who was not also a member of the CASAC (Sheppard, 2023, Response to Charge Questions, p. 23). The former is a Panel formed for this review, while the latter is the standing Committee specified in the CAA.

[89] This member stated that the existing primary NAAQS for the three pollutants were significantly more restrictive than the existing secondary standards and provide adequate protection for deposition-related effects (Sheppard, 2023, Appendix A).

[90] The weighted metric is constructed by applying weighting to concentrations to the monitors identified as sites of influence, with the weighting equal to the relative contribution of air from the monitor location to the downwind ecoregion based on the trajectory analysis (PA, section 6.2.4). Values of this metric are not directly translatable to individual monitor concentrations or to potential standard levels.

[91] The metric for N deposition in these analyses is the median of the TDep estimates across each ecoregion (PA, section 6.2.4).

additionally recognized, however, that ''when considering all ecoregions, there is no correlation between annual average NO_2 and N deposition'' (Sheppard, 2023, Response to Charge Questions, p. 24). Their focus on total N deposition estimates at or below 10 kg/ha-yr appears to relate to consideration of TMDL analyses in four East Coast estuaries: Chesapeake Bay, Tampa Bay, Neuse River Estuary and Waquoit Bay (Sheppard, 2023, Response to Charge Questions, pp. 12–14 and 29). Levels identified for allocation of atmospheric N loading in the first three of these estuaries were 6.1, 11.8 and 6.9 [92] kg/ha-yr, respectively, and atmospheric loading estimated in the fourth was below 5 kg/ha-yr (Sheppard, 2023, Response to Charge Questions, pp. 12–14). These members also concluded that 10 kg N/ha-yr is ''at the middle to upper end of the N critical load threshold for numerous species effects (*e.g.,* richness) and ecosystem effects (*e.g.,* tree growth) in U.S. forests grasslands, deserts, and shrublands (*e.g.,* Pardo et al., 2011; Simkin et al., 2016) and thus 10 kg N/ha-yr provides a good benchmark for assessing the deposition-related effects of NO_2 in ambient air'' (Sheppard, 2023, Response to Charge Questions, p. 23).

One CASAC member disagreed with revision of the existing annual NO_2 standard and instead recommended adoption of a new 1-hour NO_2 secondary standard identical in form, averaging time and level to the existing primary standard based on the conclusion that the N deposition estimates for the most recent periods generally reflect reduced deposition that is a product of current regulatory requirements, including implementation of the existing primary standards for NO_2 and PM (Sheppard, 2023, Appendix A). This member additionally noted that bringing into attainment the areas still out of attainment with the 2013 primary annual $PM_{2.5}$ standard (12.0 μg/m³) will provide further reductions in N deposition. This member also noted his analysis of NO_2 annual and 1-hour design values for the past 10 years (2013–2022) as indicating that the current primary NO_2 standard provides protection for annual average NO_2 concentrations below 31 ppb (Sheppard, 2023, Appendix A).

With regard to PM and effects related to deposition of N and S, the CASAC focused on the $PM_{2.5}$ standards and made no recommendations regarding the PM_{10} standard. In considering the annual $PM_{2.5}$ standard, the majority of CASAC members recommended revision of the annual secondary $PM_{2.5}$ standard to a level of 6 to 10 μg/m³. In their justification for this range, these members focus on rates of total N deposition at or below 10 kg/ha-yr and total S deposition at or below 5 kg/ha-yr that they state would ''afford an adequate level of protection to several species and ecosystems across the U.S.'' (Sheppard, 2023, Response to Charge Questions, p. 23). In reaching this conclusion for protection from N deposition, the CASAC majority cited studies of U.S. forests, grasslands, deserts and shrublands that are included in the ISA. For S deposition, the CASAC majority notes the Pavlovic et al. (2023) analysis of the dataset used by Horn et al. (2018). Conclusions of the latter study (Horn et al., 2018), which is characterized in the ISA and discussed in sections 5.3.2.3 and 7.2.2.2 of the PA (in noting median deposition of 5–12 kg S/ha-yr in ranges of species for which survival and/or growth was observed to be negatively associated with S deposition), are consistent with the more recent analysis in the 2023 publication (ISA, Appendix 6, sections 6.2.3 and 6.3.3).

As justification for their recommended range of annual $PM_{2.5}$ levels (6–10 μg/m³), this group of CASAC members provided several statements, without further explanation, regarding $PM_{2.5}$ annual concentrations and estimates of S and N deposition for which they cited several figures in the draft PA. Citing figures in the draft PA with TDep deposition estimates and IMPROVE and CASTNET monitoring data, they stated that ''[i]n remote areas, IMPROVE $PM_{2.5}$ concentrations in the range of 2–8 μg/m³ for the periods 2014–2016 and 2017–2019 correspond with total S deposition levels <5 kg/ha-yr (Figure 6–12), with levels generally below 3 kg/ha-yr, and with total N deposition levels ≤10 kg/ha-yr (Figure 6–13)'' (Sheppard, 2023, Response to Charge Questions, p. 23). With regard to S deposition, these members additionally cited a figure in the draft PA as indicating ecosystem median S deposition estimates at/below 5 kg/ha-yr occurring with $PM_{2.5}$ EAQM-max values in the range of 6 to 12 μg/m³ (Sheppard, 2023, Response to Charge Questions, pp. 23–24). With regard to N deposition, these members additionally cited figures in the draft PA as indicating that areas of 2019–2021 total N deposition estimates greater than 15 kg/ha-yr (''in California, the Midwest, and the East'') correspond with areas where the annual $PM_{2.5}$ design values for 2019–2021 range from 6 to 12 μg/m³,[93] and other figures (based on trajectory analyses) as indicating ecosystem median N deposition estimates below 10 kg N/ha-yr occurring only with $PM_{2.5}$ weighted EAQM values below 6 μg/m³,[94] and $PM_{2.5}$ EAQM-max values below 8 μg/m³ (Sheppard, 2023, Response to Charge Questions, pp. 23–24). The CASAC also noted the correlation coefficient for N deposition with the EAQM weighted metric (which was a moderate value of about 0.5), while also recognizing that the correlation coefficient for the EAQM-max was ''minimal.'' The bases for the N and S deposition levels targeted in this CASAC majority recommendation are described in the paragraphs earlier in this section.

One CASAC member recommended revision of the annual secondary $PM_{2.5}$ standard to a level of 12 μg/m³ based on his interpretation of figures in the draft PA that present S and N deposition estimates for five different 3-year time periods from 2001 to 2020. This member observed that these figures indicate ecoregion median S and N deposition estimates in the last 10 years below 5 and 10 kg/ha-yr, respectively. This member concluded this to indicate that the 2013 primary annual $PM_{2.5}$ standard of 12.0 μg/m³ provides adequate protection against long-term annual S and N deposition-related effects (Sheppard, 2023, Appendix A).

Regarding the existing 24-hour $PM_{2.5}$ secondary standard, the majority of CASAC members recommended revision of the level to 25 ug/m³ or revision of the indicator and level to deciviews [95] and 20 to 25, respectively (Sheppard, 2023, Response to Charge Questions, p 25). These members variously cited ''seasonal variabilities'' of ''[e]cological sensitivities,'' describing sensitive lichen species to be influenced by fog or cloud water from which they state S and N contributions to be highly episodic, and visibility impairment (Sheppard, 2023, Response to Charge Questions, p 25). These members did not provide further specificity regarding their reference to lichen species and fog or cloud water. With regard to visibility impairment, these members described

[92] The CASAC letter states that the Neuse River Estuary TMDL specified a 30% reduction from the 1991–1995 loading estimate of 9.8 kg/ha-yr, yielding a remaining atmospheric load target of 6.9 kg/ha-yr (Sheppard, 2023, Response to Charge Questions, p. 13).

[93] We note, however, that the design value figure cited by these members indicate California sites to have design values as high as 17.8 μg/m³, *i.e.,* violating the current $PM_{2.5}$ secondary standard (draft PA, Figure 2–27; PA, Figure 2–31).

[94] As noted earlier in this section, weighted EAQM values are not directly translatable to concentrations at individual monitors or to potential standard levels.

[95] Deciviews, units derived from light extinction, are frequently used in the scientific and regulatory literature to assess visibility (U.S. EPA 2019, section 13.2).

the EPA solicitation of comments that occurred with the separate EPA action to reconsider the 2020 decision to retain the existing $PM_{2.5}$ standards as the basis for their recommendations on the secondary 24-hr $PM_{2.5}$ standard (Sheppard, 2023, Response to Charge Questions, p 25; 88 FR 5562–5663, January 27, 2023).[96] One CASAC member dissented from this view and supported retention of the existing secondary 24-hr $PM_{2.5}$ standard.

Among the CASAC comments on the draft PA[97] was the comment that substantial new evidence has been published since development of the 2020 ISA that supports changes to the draft PA conclusions on N deposition effects. Accordingly, in the final PA, a number of aspects of Chapters 4 and 5 were revised from the draft PA; these changes took into account the information emphasized by the CASAC while also referring to the ISA and studies considered in it (PA, section 7.3). More recent studies cited by the CASAC generally concerned effects described in the ISA based on studies available at that time. While the newer studies include additional analyses and datasets, the ISA and studies in it also generally support the main points raised and observations made by the CASAC (PA, section 7.3).

c. Administrator's Proposed Conclusions

In reaching his proposed conclusions on the adequacy of the existing secondary standards for SO_X, N oxides, and PM, and on what revisions or alternatives may be appropriate, the Administrator drew on the ISA conclusions regarding the weight of the evidence for both the direct effects of SO_X, N oxides, and PM in ambient air and for effects associated with ecosystem deposition of N and S compounds, and associated areas of uncertainty; quantitative analyses of aquatic acidification risk and of air quality and deposition estimates, and associated limitations and uncertainties; staff evaluations of the evidence, exposure/risk information, and air quality information in the PA; CASAC advice; and public comments received by that time. The Administrator recognized the evidence of direct biological effects associated with elevated short-term concentrations of SO_X and N oxides that formed the basis for the existing secondary SO_2 and NO_2 standards, the evidence of ecological effects of PM in ambient air, primarily associated with loading on vegetation surfaces, and also the extensive evidence of ecological effects associated with atmospheric deposition of N and S compounds into sensitive ecosystems. The Administrator also took note of the quantitative analyses and policy evaluations documented in the PA that, with CASAC advice, informed his judgments in reaching his proposed decisions in this review.

With regard to the secondary standard for SO_X and the adequacy of the existing standard for providing protection of the public welfare from direct effects on biota and from ecological effects related to ecosystem deposition of S compounds, the Administrator considered the evidence regarding direct effects, as described in the ISA and evaluated in the PA, which is focused on SO_2. He took note of the PA finding that the evidence indicates SO_2 concentrations associated with direct effects to be higher than those allowed by the existing SO_2 secondary standard (PA sections 5.4.1, 7.1.1 and 7.4). Additionally, he took note of the CASAC unanimous conclusion that the existing standard provides protection from direct effects of SO_X in ambient air, as summarized in section II.B.1.b. above. Based on all of these considerations, he judged the existing secondary SO_2 standard to provide the needed protection from direct effects of SO_X.

The Administrator next considered the ISA findings for ecological effects related to ecosystem deposition of S compounds. He first recognized the long-standing evidence of the role of SO_X in ecosystem acidification and related ecological effects. While he additionally noted the ISA determinations of causality for S deposition with two other categories of effects related to mercury methylation and sulfide phytotoxicity (ISA, Table ES–1; PA, section 4.4), he recognized that quantitative assessment tools and approaches are not well developed for ecological effects associated with atmospheric deposition of S other than ecosystem acidification (PA, section 7.2.2.1). Accordingly, he gave primary attention to effects related to acidifying deposition, given the robust evidence base and available quantitative tools, as well as the longstanding recognition of impacts in acid-sensitive ecosystems across the U.S. In so doing, the Administrator focused on the findings of the aquatic acidification REA and related policy evaluations in the PA. The range of ecoregion deposition estimates across the contiguous U.S. analyzed during the 20-year period from 2001 through 2020 extended up to as high as 20 kg S/ha-yr,[98] and design values for the existing SO_2 standard (second highest 3-hour average in a year), in all States except Hawaii,[99] were below its current level of 500 ppb, and generally well below (PA, section 6.2.1). The Administrator took note of the aquatic acidification risk estimates that indicate that the pattern of S deposition, estimated to have occurred during periods when the existing standard was met (*e.g.,* 2001–2003), is associated with 20% to more than half of waterbody sites in each affected eastern ecoregion[100] being unable to achieve even the lowest of the three acid buffering capacity targets or benchmarks (ANC of 20 μeq/L), and he judged such risks to be of public welfare significance. The Administrator also considered the advice from both the majority and the minority of CASAC that recommended adoption of a new SO_2 standard for this purpose in light of conclusions that the existing standard did not provide such needed protection. Thus, based on the findings of the REA, associated policy evaluations in the PA with regard to S deposition and acidification-related effects in sensitive ecosystems, and in consideration of advice from the CASAC, the Administrator proposed to judge that the current SO_2 secondary standard is not requisite to protect the public welfare from adverse effects associated with acidic deposition of S compounds in sensitive ecosystems.

Having reached this proposed conclusion that the existing secondary SO_2 standard does not provide the

[96] Protection from impairment of visibility effects was one of the welfare effects within the scope of the PM NAAQS reconsideration rather than the scope of this review (U.S. EPA, 2016, 2017). In that action, the Administrator proposed not to change the 24-hour secondary PM NAAQS for visibility protection and also solicited comment on revising the level of the current secondary 24-hour $PM_{2.5}$ standard to a level as low as 25 $\mu g/m^3$; in the final action, the Administrator concluded that the current secondary PM standards provide requisite protection against PM-related visibility effects and retained the existing standards without revision (88 FR 5558, January 27, 2023; 89 FR 16202, March 6, 2024).

[97] Consideration of CASAC comments and areas of the PA in which revisions have been made between the draft and this final document are described in section 1.4 of the PA.

[98] During 2001–2003, the 90th percentile S deposition per ecoregion of sites assessed in the REA was at or above 15 kg/ha-yr in half of the 18 eastern ecoregions and ranged up above 20 kg/ha-yr (figure 2).

[99] This analysis excluded Hawaii where it is not uncommon for there to be high SO_2 values in areas with recurring volcanic eruptions (PA, section 2.4.2).

[100] Aquatic acidification risk estimates for the 2001–2020 deposition estimates in the eight western ecoregions indicated ANC levels achieving all three targets in at least 90% of all sites assessed in each ecoregion (PA, Table 5–4). Ecoregion median deposition estimates were at or below 2 kg/ha-yr in all eight western ecoregions (PA, Table 5–3).

requisite protection of the public welfare from adverse S deposition-related effects, most prominently those associated with aquatic acidification, the Administrator then considered options for a secondary standard that would provide the requisite protection from S deposition-related effects (*i.e.,* a standard that is neither more nor less stringent than necessary, as discussed in section II.A. above). In so doing, the Administrator turned first to the policy evaluations and staff conclusions in the PA, and the quantitative analyses and information described in Chapter 5 of the PA, for purposes of identifying S deposition rates that might be judged to provide an appropriate level of public welfare protection from acidification-related effects. In this context, he took note of the PA focus on the aquatic acidification risk estimates and recognition of linkages between watershed soils and waterbody acidification, as well as terrestrial effects. He concurred with the PA view regarding such linkages and what they indicate with regard to the potential for a focus on protecting waterbodies from reduced acid buffering capacity (with ANC as the indicator) to also provide protection for watershed soils and terrestrial effects. Accordingly, he focused on the PA evaluation of the risk estimates in terms of waterbodies estimated to achieve the three acid buffering capacity benchmarks (20, 30 and 50 μeq/L). In so doing, he concurred with the PA consideration of the ecosystem-scale estimates as appropriate for his purposes in identifying conditions that provide the requisite protection of the public welfare.

The Administrator gave particular attention to the findings of the aquatic acidification REA for the 18 well-studied, acid-sensitive eastern ecoregions, and considered the PA evaluation of ecoregion median S deposition values at and below which the risk estimates indicated a high proportion of waterbodies in a high proportion of ecoregions would achieve ANC values at or above the three benchmarks (20, 30 and 50 μeq/L), as summarized in Tables 7–1 and 5–5 of the PA. In so doing, he recognized a number of factors, as described in the PA, which contribute variability and uncertainty to waterbody estimates of ANC and to interpretation of acidification risk associated with different values of ANC (PA, section 5.1.4 and Appendix 5A, section 5A.3). The Administrator additionally took note of the approach taken by the CASAC majority in considering the ecoregion-scale risk estimates. These members considered the summary of results for the ecoregion-scale analysis of ecoregion median deposition bins (in the draft PA)[101] and focused on the results with acid buffering capacity at or above the three ANC benchmarks in 80% (for ANC of 20 and 30 μeq/L) or 70% (for ANC of 50 μeq/L) of waterbodies in all ecoregion-time period combinations[102] (Sheppard, p. 25 of the Response to Charge Questions). As recognized in the PA, these results are observed for median S-deposition at or below 7 kg/ha-yr for all time periods for the 18 eastern ecoregions. When considering all 25 analyzed ecoregions, somewhat higher percentages are achieved (as seen in tables 4 and 5 above).[103] The Administrator additionally considered the PA evaluation of the temporal trend (or pattern) of ecoregion-scale risk estimates across the five time periods in relation to the declining S deposition estimates for those periods. Based on the PA observation of appreciably improved acid buffering capacity (*i.e.,* increased ANC) estimates by the third time period (2010–2012), the PA focused on the REA risk and deposition estimates for this and subsequent periods. By 2010–2012, ecoregion median S deposition (across CL sites) ranged from 2.3 to 7.3 kg/ha-yr in the 18 eastern ecoregions (with the highest ecoregion 90th percentile at approximately 8 kg/ha-yr) and more than 70% of waterbodies per ecoregion were estimated to be able to achieve an ANC of 50 μeq/L in all 25 ecoregions, and more than 80% of waterbodies per ecoregion in all ecoregions were estimated to be able to achieve an ANC of 20 μeq/L (table 5 and figures 1 and 2 above). The Administrator observed that these estimates of acid buffering capacity achievement for the 2010–12 period deposition—achieving the ANC benchmarks in at least 70% to 80% (depending on the specific benchmark) of waterbodies per ecoregion—are consistent with the objectives identified by the CASAC majority (in considering estimates from the ecoregion-scale analysis). By the 2014–2016 period, when deposition estimates were somewhat lower, the ANC benchmarks were estimated to be achieved in 80% to 90% of waterbodies per ecoregion. In his consideration of these ANC achievement percentages identified by the CASAC majority, while noting the variation across the U.S. waterbodies with regard to site-specific factors that affect acid buffering (as summarized in sections II.A.3.a.(2) and II.A.4. above and section 5.1.4 of the PA), the Administrator concurred with the PA conclusion on considering ecoregion-scale ANC achievement results of 70% to 80% and 80% to 90% with regard to acid buffering capacity objectives for the purposes of protecting ecoregions from aquatic acidification risk of a magnitude with potential to be considered of public welfare significance.

With regard to the variation in deposition across areas within ecoregions, the Administrator noted the PA observation that the sites estimated to receive the higher levels of deposition are those most influencing the extent to which the potential objectives for aquatic acidification protection are or are not met. He further noted the PA observation of an appreciable reduction across the 20-year analysis period in the 90th percentile deposition estimates, as well as the median, for REA sites in the 25 ecoregions analyzed (figure 2 above). In this context, the Administrator took note of the PA findings that the ecoregion-scale acid buffering objectives identified by the CASAC (more than 70% to 80% of waterbody sites in all ecoregions assessed achieving or exceeding the set of ANC benchmarks) might be expected to be met when ecoregion median and upper (90th) percentile deposition estimates at sensitive ecoregions are generally at and below about 5 to 8 kg/ha-yr. He also took note of the PA identification of deposition rates at and below about 5 to 8 or 10 kg/ha-yr[104] as associated with a potential to achieve acid buffering capacity benchmarks in an appreciable portion of acid sensitive areas based on consideration of uncertainties associated with the deposition estimates and associated aquatic acidification risk estimates at individual waterbody sites

[101] While the final PA provides additional presentations of aquatic acidification risk estimates, including those at the ecoregion-scale, the estimates are unchanged from those in the draft PA (PA, section 5.1.3).

[102] The presentation of such percentages in the draft PA (reviewed by the CASAC) were specific to the 90 ecoregion-time period combinations for the 18 eastern ecoregions. Inclusion of the 7 western ecoregions yields higher percentages, as more than 90% of waterbodies in those ecoregions were estimated to achieve all three ANC concentration in all time periods (PA, Table 5–4).

[103] Ecoregion median deposition was below 2 kg S/ha-yr in all 35 ecoregion-time period combinations for the eight western ecoregions (PA, Table 5–4).

[104] The PA's consideration of the case study analyses as well as the ecoregion-scale results for both the ecoregion-time period groups and the temporal perspectives indicated a range of S deposition below approximately 5 to 8 or 10 kg/ha-yr to be associated with a potential to achieve acid buffering capacity levels of interest in an appreciable portion of acid sensitive areas (PA, section 7.4).

(PA, section 5.1.4), as well as the REA case study analysis estimates.

Based on all of the above considerations, the Administrator focused on identification of a secondary standard that might be associated with S deposition of such a magnitude. In so doing he recognized the complexity of identifying a NAAQS focused on protection of the public welfare from adverse effects associated with national patterns of atmospheric deposition (rather than on protection from national patterns of ambient air concentrations directly). In light of the influence of emissions from multiple, distributed sources, atmospheric chemistry and transport on air concentrations and the influence of air concentrations and other factors on atmospheric deposition (ecosystem loading), the Administrator concurred with the PA judgment that consideration of the location of source emissions and expected pollutant transport (in addition to the influence of physical and chemical processes) is important to understanding relationships between SO_2 concentrations at ambient air monitors and S deposition rates in sensitive ecosystems of interest. Accordingly, the Administrator concurred with the PA that to achieve a desired level of protection from aquatic acidification effects associated with S deposition in sensitive ecosystems, SO_2 emissions must be controlled at their sources, and that associated NAAQS compliance monitoring includes regulatory SO_2 monitors generally sited near large SO_2 emissions sources.

The Administrator considered findings of the PA analyses of relationships between ambient air concentrations and S deposition estimates, conducted in recognition of the variation across the U.S. in the source locations and magnitude of SO_X emissions, as well as the processes that govern transport and transformation of SO_X to eventual deposition of S compounds. Recognizing the linkages connecting SO_X emissions and S deposition-related effects, the Administrator considered the current information with regard to support for SO_2 as the indicator for a new or revised standard for SO_X that would be expected to provide protection from aquatic acidification-related risks of S deposition in sensitive ecoregions. The Administrator noted the PA analyses demonstrated there to be an association between SO_2 concentrations and nearby or downwind S deposition (PA, section 7.4) based on the general association of higher local S deposition estimates with higher annual average SO_2 concentrations at SLAMS, in addition to the correlations observed for ecoregion median S deposition with upwind SO_2 monitoring sites of influence in the EAQM analyses (PA, sections 6.4.1 and 7.4). He additionally took note of the PA findings of parallel trends of SO_2 emissions and S deposition in the U.S. over the past 20 years, including the sharp declines, that indicate the strong influence of SO_2 in ambient air on S deposition (PA, sections 6.4.1 and 7.4), and of the PA finding of parallel temporal trends of ecoregion S deposition estimates and REA aquatic acidification risk estimates across the five time periods analyzed. In light of all of these considerations, the Administrator judged SO_2 to be the appropriate indicator for a standard addressing S deposition-related effects.

With regard to the appropriate averaging time and form for such a standard, the Administrator took note of the PA focus on a year's averaging time based on the recognition that longer-term averages (such as over a year) most appropriately relate to ecosystem deposition and associated effects, and of the recommendation from the CASAC majority for an annual average standard. The quantitative analyses of air quality and deposition in the PA also used a 3-year average form based on a recognition in the NAAQS program that such a form affords a stability to air quality management programs that contributes to effective environmental protection.[105] Similarly, the CASAC majority recommendation focused on a 3-year average form. In consideration of these conclusions of the PA and the CASAC majority, the Administrator focused on annual average SO_2 concentrations, averaged over three years, as the appropriate averaging time and form for a revised standard providing public welfare protection from adverse effects associated with long-term atmospheric deposition of S compounds.

In considering a level for such a standard, the Administrator again noted the complexity associated with identifying a NAAQS focused on protection from national patterns of atmospheric deposition. As discussed further in the PA and the proposal, in identifying a standard to provide a pattern of ambient air concentrations that together contribute to deposition across the U.S., it is important to consider the distribution of air concentrations to which the standard will apply.[106] In identifying an appropriate range of concentrations for a standard level, the Administrator considered the evaluations and associated findings of the PA and advice from the CASAC. In so doing, he considered the two PA options of somewhat below 15 ppb to a level of 10 ppb and a level ranging below 10 ppb to 5 ppb, with a 3-year average form. He additionally recognized that uncertainties in aspects of the aquatic acidification risk modeling contribute uncertainty to the resulting estimates, and that uncertainty in the significance of aquatic acidification risk is greater with lower deposition levels (PA, section 5.1.4). Accordingly, the Administrator took note of additional and appreciably greater uncertainty associated with consideration of a standard level below 10 ppb, including uncertainties in the relationships between S deposition and annual average SO_2 concentrations below 10 ppb (PA, Chapter 6, section 7.4). Thus, the Administrator recognized there to be, on the whole across the various linkages, increased uncertainty for lower SO_2 concentrations and S deposition rates. The Administrator additionally considered the CASAC majority recommended range of 10 to 15 ppb for an annual average SO_2 standard to address S deposition-related ecological effects, as described in section II.B.1.b. above. These members indicated that this range of levels was ''generally'' associated with S deposition ''at <5 kg/ha-yr'' in the two most recent trajectory analysis periods in the PA, and that a standard level in this range would afford protection against ecological effects in terrestrial ecosystems as well as aquatic ecosystems. These members also stated that such a standard would ''preclude the possibility of returning to deleterious deposition values'' (Sheppard, Response to Charge Questions, pp. 24–25). Thus, based on analyses and evaluations in the PA, including judgments related to uncertainties in relating ambient air concentrations to deposition estimates for the purpose of identifying a standard level associated with a desired level of ecological protection, and based on advice from the CASAC majority, the

[105] A 3-year form, common to recently adopted NAAQS, provides a desired stability to the air quality management programs which is considered to contribute to improved public health and welfare protection (*e.g.,* 78 FR 3198, January 15, 2013; 80 FR 65352, October 26, 2015; 85 FR 87267, December 31, 2020).

[106] As recognized in section II.B.1.a. above, the trajectory analyses relate contributions from individual monitor locations to deposition in receiving ecosystems (without explicitly addressing the multiple factors at play), with the somewhat higher correlations of the EAQM-weighted than the EAQM-max metric likely reflecting the weighting of concentrations across multiple upwind monitors to represent relative loading.

Administrator judged that a level within the range from 10 to 15 ppb would be appropriate for an annual average SO_2 standard requisite to protect the public welfare from adverse effects related to S deposition.

The Administrator also considered the extent to which a new annual average standard might be expected to control short-term concentrations (*e.g.,* of three hours duration) and accordingly provide protection from direct effects that is currently provided by the existing 3-hour secondary standard. In this context, he noted the analyses and conclusions of the PA with regard to the extent of control for short-term concentrations (*e.g.,* of three hours duration) that might be expected to be provided by an annual secondary SO_2 standard. These analyses indicate that in areas and periods when the annual SO_2 concentration (annual average, averaged over three years) is below 15 ppb, design values for the existing 3-hour standard are well below the existing secondary standard level of 0.5 ppm SO_2 (PA, Figure 2–29). Based on these findings of the PA, the Administrator proposed that it is appropriate to consider revision of the existing secondary SO_2 standard to an annual standard, with a 3-year average form and a level in the range from 10 to 15 ppb.

The Administrator also took note of the recommendation from the CASAC minority to establish a 1-hour SO_2 secondary standard, identical to the primary standard (section II.B.1.b. above; Sheppard, 2023, p. A–2), based on its observation that most of the S deposition estimates for the last 10 years are less than 5 kg/ha-yr and a judgment that this indicates that the existing 1-hour primary SO_2 standard adequately protects against long-term annual S deposition-related effects. The Administrator preliminarily concluded an annual standard to be a more appropriate form to address deposition-related effects, but also recognized that greater weight could be given to consideration of the effectiveness of the existing 1-hour primary standard in controlling emissions and associated deposition. In light of these considerations, the EPA solicited comment on such an alternate option for the secondary SO_2 standard.

In summary, based on all of the considerations identified above, including the currently available evidence in the ISA, the quantitative and policy evaluations in the PA, and the CASAC advice, the Administrator proposed to revise the existing secondary SO_2 standard to an annual average standard, with a 3-year average form and a level within the range from 10 to 15 ppb as requisite to protect the public welfare. The EPA also solicited comment on a lower level for a new annual standard down to 5 ppb, as well as on whether the existing 3-hour secondary standard should be retained in addition to establishing a new annual SO_2 standard. The EPA also solicited comment on the option of revising the existing secondary SO_2 standard to be equal to the current primary standard in all respects.

With regard to the secondary PM standards, the Administrator considered the available information and the PA evaluations and conclusions regarding S deposition-related effects. In so doing, he took note of the information indicating the variation in $PM_{2.5}$ composition across the U.S. (PA, section 2.4.3), with non-S containing compounds typically comprising more than 70% of total annual $PM_{2.5}$ mass in much of the country. Further, he considered the PA findings of appreciable variation in associations, and generally low correlations, between S deposition and $PM_{2.5}$, as summarized in section II.A.2. above (PA, sections 6.2.2.3 and 6.2.4.2). He also took note of the discussion above in support of his decision regarding a revised secondary SO_2 standard, including the atmospheric chemistry information which indicates the dependency of S deposition on airborne SO_X, as evidenced by the parallel trends of SO_2 emissions and S deposition. Based on all of these considerations, the Administrator judged that protection of sensitive ecosystems from S deposition is more effectively achieved through a revised SO_2 standard than a standard for PM, and that a revised PM standard is not warranted to provide protection against the effects of S deposition.

Based on his consideration of the secondary standards for N oxides and PM with regard to the protection afforded from direct ecological effects and from ecological effects related to ecosystem N deposition, the Administrator proposed to retain the existing NO_2 and PM standards. With regard to protection from direct effects of N oxides in ambient air, the Administrator noted that the evidence of welfare effects at the time this standard was established in 1971 indicated the direct effects of N oxides on vegetation and that the currently available information continues to document such effects, as summarized in section II.B.1.a.(1) above (ISA, Appendix 3, sections 3.3 and 3.4; PA, sections 4.1 and 5.4.2). With regard to the direct effects of NO_2 and NO, the Administrator concurred with the PA conclusion that the evidence does not call into question the adequacy of protection provided by the existing standard. With regard to the N oxide, HNO_3, consistent with the conclusion in the PA, the Administrator judged the limited evidence to lack a clear basis for concluding that effects associated with air concentrations and associated HNO_3 dry deposition on plant and lichen surfaces might have been elicited by air quality that met the secondary NO_2 standard. Thus, the Administrator recognized the limitations of the evidence for these effects, and associated uncertainties, and judges them too great to provide support to a revised secondary NO_2 standard, additionally taking note of the unanimous view of the CASAC that the existing secondary NO_2 standard provides protection from direct effects of N oxides (section II.B.1.b. above).

The Administrator next turned to consideration of the larger information base of effects related to N deposition in ecosystems. In so doing, he recognized the complexities and challenges associated with quantitative characterization of N enrichment-related effects in terrestrial or aquatic ecosystems across the U.S. that might be expected to occur due to specific rates of atmospheric deposition of N over prolonged periods, and the associated uncertainties (PA, section 7.2.3). The Administrator also found there to be substantially more significant limitations and uncertainties associated with the evidence base for ecosystem effects related to N deposition associated with N oxides and PM, and with the available air quality information related to the limited potential for control of N deposition in areas across the U.S., in light of the impacts of other pollutants (*i.e.,* NH_3) on N deposition. The first set of limitations and uncertainties relates to quantitative relationships between N deposition and ecosystem effects, based on which differing judgments may be made in decisions regarding protection of the public welfare. In the case of protection of the public welfare from adverse effects associated with nutrient enrichment, there is also complexity associated with identification of appropriate protection objectives in the context of changing conditions in aquatic and terrestrial systems as recent deposition has declined from the historical rates of loading. The second set of limitations and uncertainties relates to the emergence of NH_3, which is not a criteria pollutant, as a greater influence on N deposition than N oxides

and PM over the more recent years,[107] and the variation in PM composition across the U.S.

Additionally, the Administrator recognized additional complexities in risk management and policy judgments, including with regard to identifying risk management objectives for public welfare protection from an ecosystem stressor like N enrichment, for which as the CASAC recognized, in terrestrial systems, there are both ''benefits and disbenefits'' (Sheppard, 2023, p. 8). As noted in the PA, the existence of benefits complicates the judgment of effects that may be considered adverse to the public welfare (PA, section 7.4). For aquatic systems, identification of appropriate public welfare protection objectives is further complicated by N contributions to many of these systems from multiple sources other than atmospheric deposition, as well as by the effects of historical deposition that have influenced the current status of soils, surface waters, associated biota, and ecosystem structure and function.

In considering the evidence and air quality information related to N deposition, the Administrator took note of the fact that ecosystem N deposition is influenced by air pollutants other than N oxides, particularly, NH_3, which is not a CAA criteria pollutant (PA, sections 6.1, 6.2.1 and 7.2.3.3). As noted above, the extent of this contribution varies appreciably across the U.S. and has increased during the past 20 years, with the areas of highest N deposition appearing to correspond to the areas with the greatest deposition of NH_3 (PA, Figure 7–8).[108] The Administrator concurred with the PA conclusion that this information complicates his consideration of the currently available information with regard to protection from N deposition-related effects that might be afforded by the secondary standard for N oxides, particularly when considering the information since 2010 (and in more localized areas prior to that). That is, while the information regarding recent rates of ecoregion N deposition may in some individual areas (particularly those for which reduced N, specifically NH_3, has a larger role) indicate rates greater than the range of values identified in the PA for consideration (*e.g.,* 7–12 kg/ha-yr based on the considerations in section 7.2.3 of the PA and the benchmark of 10 kg/ha-yr, as conveyed in the advice from the CASAC), the PA notes that the extent to which this occurrence relates to the existing NO_2 secondary standard is unclear. The lack of clarity is both because of uncertainties in relating ambient air NO_2 concentrations to rates of deposition, and because of the increasing contribution of NH_3 to N deposition.

The Administrator additionally noted the PA finding that the temporal trend in ecoregion N deposition differs for ecoregions in which N deposition is driven by reduced N compared to those where reduced N comprises less of the total (*e.g.,* PA, Figures 7–6 and 7–7). In light of the PA evaluations of N deposition and relative contribution from reduced and oxidized N compounds, the Administrator concurred with the PA conclusion that, based on the current air quality and deposition information and trends, a secondary standard for N oxides cannot be expected to effectively control total N deposition (PA, section 7.4).

The Administrator additionally considered the two sets of advice from the CASAC regarding an NO_2 annual standard in consideration of N deposition effects (section II.B.1.b. above). The CASAC majority recommended revision of the existing annual NO_2 standard level to a value ''<10 to 20 ppb'' (Sheppard, 2023, p. 24). The basis for this advice, however, relates to a graph in the draft PA of the dataset of results from the trajectory-based analyses for the weighted annual NO_2 metric (annual NO_2 EAQM-weighted), which, as noted in section II.B.1.b. above, is not directly translatable to concentrations at individual monitors or to potential standard levels. Additionally, these results found no correlation between the ecoregion deposition and the EAQM-weighted or EAQM-max values at upwind locations, as also recognized by CASAC members and indicated in the final PA (PA, Table 6–10). Accordingly, based on the lack of a correlation for N deposition with the EAQMs, as well as the lack of translatability of the EAQM-weighted values to monitor concentrations or standard levels, the PA did not find the information highlighted by the CASAC majority for relating N deposition levels to ambient air concentrations to provide scientific support for their recommended levels. In light of this, the Administrator did not find agreement with the CASAC majority recommendations on revisions to the annual NO_2 standard.

The CASAC minority recommended revision of the secondary NO_2 standard to be identical to the primary standard based on their conclusion that the recent N deposition levels meet its desired objectives and that the primary standard is currently the controlling standard (Sheppard, 2023, Appendix A). As noted in the PA, among the NO_2 primary and secondary NAAQS, the 1-hour primary standard (established in 2010) may currently be the controlling standard for ambient air concentrations, and annual average NO_2 concentrations, averaged over three years, in areas that meet the current 1-hour primary standard, have generally been below approximately 35 to 40 ppb.[109] The Administrator also considered the PA revision option (*i.e.,* revision to a level below the current level of 53 ppb to as low as 35 to 40 ppb [PA, section 7.4]), taking note of the PA characterization that support for this option is ''not strong'' (PA, section 7.4). He further noted the PA conclusion that while the option may have potential to provide some level of protection from N deposition related to N oxides, there is significant uncertainty as to the level of protection that would be provided, with this uncertainty relating most prominently to the influence of NH_3 on total N deposition separate from that of N oxides (PA, section 7.2.3.3). The Administrator further recognized the PA statement that the extent to which the relative roles of these two pollutants (N oxides and NH_3) may change in the future is not known. As evaluated in the PA, these factors together affect the extent of support for, and contribute significant uncertainty to, a judgment as to a level of N oxides in ambient air that might be expected to provide requisite protection from N deposition-related effects on the public welfare.

In light of the considerations recognized above, the Administrator found that the existing evidence does not clearly call into question the adequacy of the existing secondary NO_2 standard, additionally noting that recent median N deposition estimates are below the N deposition benchmark identified by the CASAC majority of 10 kg/ha-yr in ecoregions for which approximately half or more of recent total N deposition is estimated to be

[107] Further, this influence appears to be exerted in areas with some of the highest N deposition estimates for those years.

[108] This associated lessening influence of N oxides on total N deposition is also evidenced by the lower correlations between N deposition and annual average NO_2 concentrations than observed for S deposition and SO_2 concentrations (PA, sections 6.2.3 and 6.2.4), which may be related to increasing emissions of NH_3 in more recent years and at eastern sites (PA, section 2.2.3 and Figure 6–5).

[109] The air quality information regarding annual average NO_2 concentrations at SLAMS monitors indicates more recent NO_2 concentrations are well below the existing standard level of 53 ppb. As noted in the PA, the temporal trend figures indicate that, subsequent to 2011–2012, when median N deposition levels in 95% of the eastern ecoregions of the continental U.S. have generally been at or below 11 kg N/ha-yr, annual average NO_2 concentrations, averaged across three years, have been at or below 35 ppb (PA, section 7.2.3.3).

oxidized N, driven by N oxides (PA, section 7.2.3.3). In addition to the substantial uncertainty described above regarding the need for control of N deposition from N oxides that might be provided by a secondary standard for N oxides, the PA found there to be substantial uncertainty about the effect of a secondary standard for N oxides on the control of N deposition, such that it is also not clear whether the available information provides a sufficient basis for a revised standard that might be judged to provide the requisite protection. In light of this PA finding, the current information on air quality and N deposition, and all of the above considerations, the Administrator proposed to also judge that the available evidence in this review is sufficient to conclude a revision to the secondary annual NO_2 standard is not warranted. Based on all of these considerations, he proposed to retain the existing secondary NO_2 standard, without revision. The EPA also solicited comments on the alternative of revising the level and form of the existing secondary NO_2 standard to a level within the range from 35 to 40 ppb with a 3-year average form.

Lastly, the Administrator considered the existing standards for PM. He took note of the PA discussion and conclusion that the available information does not call into question the adequacy of protection afforded by the secondary $PM_{2.5}$ standards from direct effects and deposition of pollutants other than S and N compounds (PA, sections 7.1.3 and 7.4). The evidence characterized in the ISA and summarized in the PA indicates such effects to be associated with conditions associated with concentrations much higher than the existing standards. Thus, the Administrator proposed to conclude that the current evidence does not call into question the adequacy of the existing PM standards with regard to direct effects and deposition of pollutants other than S and N compounds.

With regard to N deposition and $PM_{2.5}$, the Administrator considered the analyses and evaluations in the PA, as well as advice from the CASAC. He took note of the substantial and significant limitations and uncertainties associated with the evidence base for ecosystem effects related to N deposition associated with PM and with the available air quality information related to the limited potential for control of N deposition in areas across the U.S. in light of the impacts of NH_3 on N deposition, and the variation in PM composition across the U.S., as summarized earlier. For example, as noted in the PA, the variable composition of $PM_{2.5}$ across the U.S. contributes to geographic variability in the relationship between N deposition and $PM_{2.5}$ concentrations, and there is an appreciable percentage of $PM_{2.5}$ mass that does not contribute to N deposition. The PA further notes that this variability in percentage of $PM_{2.5}$ represented by N (or S) containing pollutants contributes a high level of uncertainty to our understanding of the potential effect of a $PM_{2.5}$ standard on patterns of N deposition.

In considering the advice from the CASAC for revision of the existing annual secondary $PM_{2.5}$ standard, the Administrator noted that the CASAC provided two different recommendations for revising the level of the standard: one for a level in the range from 6 to 10 $\mu g/m^3$ and the second for a level of 12 $\mu g/m^3$. As summarized in the PA, the specific rationale for the range from 6 to 10 ug/m^3 is unclear, with levels within this range described as both relating to N deposition in a preferred range (at or below 10 kg N/ha-yr) and relating to deposition above that range.[110] The PA noted that this ''overlap'' illustrates the weakness and variability of relationships of $PM_{2.5}$ with N deposition across the U.S. (PA, section 7.4). Further, the PA notes the low correlation for total N deposition estimates with annual average $PM_{2.5}$ design values in the last 10 years at SLAMS (PA, Table 6–7). The second recommendation, from the CASAC minority, was based on their conclusion that the recent N (and S) deposition levels meet their desired targets and that the primary annual $PM_{2.5}$ standard, which has been 12 $\mu g/m^3$ since 2013, has been the controlling standard for annual $PM_{2.5}$ concentrations (Sheppard, 2023, Appendix A).

Based on the currently available information, taking into account its limitations and associated uncertainties, and in consideration of all of the above, the Administrator proposed to conclude that $PM_{2.5}$ is not an appropriate indicator for a secondary standard intended to provide protection of the public welfare from adverse effects related to N deposition. In reaching this proposed conclusion, the Administrator focused in particular on the weak correlation between annual average $PM_{2.5}$ design values and N deposition estimates in recent time periods, and additionally noted the PA conclusion that the available evidence, as evaluated in the PA, is reasonably judged insufficient to provide a basis for revising the $PM_{2.5}$ annual standard with regard to effects of N deposition related to PM. Thus, based on consideration of the PA analyses and conclusions, as well as consideration of advice from the CASAC, the Administrator further proposed to conclude that no change to the annual secondary $PM_{2.5}$ standard is warranted, and he proposed to retain the existing $PM_{2.5}$ secondary standard, without revision. The EPA solicited comment on this proposed decision and also solicited comment on revising the existing standard level to a level of 12 $\mu g/m^3$, in light of the recommendation and associated rationale provided by the CASAC minority.

With regard to other PM standards, the Administrator concurred with the PA's finding of a lack of information that would call into question the adequacy of protection afforded by the existing PM_{10} secondary standard for ecological effects, and thus concluded it is appropriate to propose retaining this standard without revision. With regard to the 24-hour $PM_{2.5}$ standard, the Administrator took note of the PA conclusion that the evidence available in this review, as documented in the ISA, or cited by the CASAC,[111] does not call into question the adequacy of protection provided by the 24-hour $PM_{2.5}$ standard from ecological effects (PA, section 7.4). The Administrator also considered the comments of the CASAC majority and recommendations for revision of this standard to a lower level or to an indicator of deciviews, as summarized in section II.B.1.b. The Administrator noted the PA consideration of the lack of quantitative information in the ISA related to the specific type of N deposition raised by the CASAC comments. Further, the specific revision options recommended by the CASAC majority were based on visibility considerations, although the adequacy of protection provided by the secondary $PM_{2.5}$ standard from visibility effects has been addressed in the

[110] For example, the justification provided for the range of levels recommended by the CASAC majority for a revised $PM_{2.5}$ annual standard (6 to 10 $\mu g/m^3$) refers both to annual average $PM_{2.5}$ concentrations (3-yr averages) ranging from 2 to 8 $\mu g/m^3$ in 27 Class I areas (as corresponding to N deposition estimates at or below 10 kg/ha-yr) and to annual average $PM_{2.5}$ concentrations (3-year averages) ranging from 6 to 12 $\mu g/m^3$ (at design value sites in areas of N deposition estimates greater than 15 kg/ha-yr), as summarized in section II.B.1.b. above.

[111] As summarized in section II.B.1.b. above, the CASAC majority, in its recommendation for revision of the existing standard, did not provide specificity regarding the basis for its statements on lichen species and fog or cloud water, and the available evidence as characterized in the ISA does not provide estimates of this deposition or describe associated temporal variability, or specifically describe related effects on biota (ISA, Appendix 2).

reconsideration of the 2020 p.m. NAAQS decision (89 FR 16202, March 6, 2024) and is not included in this review. The Administrator additionally noted the recommendation from the CASAC minority to retain the existing 24-hour secondary $PM_{2.5}$ standard without revision. Based on all of these considerations, the Administrator proposed to retain the existing 24-hour secondary $PM_{2.5}$ standard, without revision. Additionally, based on the lack of evidence calling into question the adequacy of the secondary PM_{10} standards, he also proposed to retain the secondary PM_{10} standards without revision.

In reaching the proposed conclusions regarding protection of the public welfare from ecological effects associated with ecosystem deposition of N and S compounds, the Administrator also noted the PA consideration of the potential for indicators different from those for the current standards that may target specific chemicals that deposit N and S, *e.g.,* NO_3^-, SO_4^{2-}, NH_4^+ (PA, sections 7.2.2.3, 7.2.3.3 and 7.4). In so doing, however, he recognized a number of uncertainties and gaps in the available information important to such consideration. Based on these, the Administrator judged that the currently available information does not support standards based on such indicators at this time. In so doing, he also recognized that additional data collection and analysis is needed to develop the required evidence base to inform more comprehensive consideration of such alternatives.

2. Comments on the Proposed Decisions

Over 27,000 individuals and organizations indicated their views in public comments on the proposed decision. Nearly all of these are associated with mass mail campaigns or petitions. Approximately 20 separate submissions were also received from individuals, organizations, or groups of organizations. Many of the individual commenters made a general recommendation to ''strengthen'' the standards under review, emphasizing giving attention to the scientific information and recommendations from the CASAC, and protection of natural ecosystems and associated wildlife. Among the organizations commenting were State and federal agencies, a Tribal organization, environmental protection advocacy organizations, industry organizations and regulatory policy-focused organizations.

Some commentors expressed the overarching view that none of the standards for the three pollutants in this review should be revised, generally stating that the implementation work by State agencies associated with new standards would be for no environmental gain in light of the emissions reductions and ''dramatic improvements'' in associated air quality that have already occurred since 2000. While the EPA recognizes that air quality has improved over the last two decades, we note that the existence of such trends and the fact of the CAA requirements for implementation of NAAQS, alone or in combination, are not appropriate bases for the Administrator's decision under section 109 of the Act. Accordingly, in finding that revision to the existing SO_X standard is necessary to provide the requisite public welfare protection for SO_X, while revisions to the N oxides and PM standards are not necessary to provide the requisite public welfare protection for those pollutants, the Administrator has based his decisions on the evidence of welfare effects, air quality information and the extent of public welfare protection provided by the existing standards, as described in section II.B.3. below. Other comments on the proposed decisions in the review of the secondary standards for protection of ecological effects of SO_X, N oxides and PM are addressed below.

Comments regarding the proposed decision to revise the secondary standard for SO_X are addressed in section II.B.2.a., and those regarding the proposed decision to retain the secondary standards for N oxides and PM are addressed in sections II.B.2.b. and II.B.2.c., respectively. Other comments, including comments related to other legal, procedural, or administrative issues, those related to issues not germane to this review, and comments related to the Endangered Species Act are addressed in the separate Response to Comments document.

a. Sulfur Oxides

(1) Comments Regarding Adequacy of the Existing Secondary Standard

With regard to welfare effects associated with SO_X in ambient air, including those related to deposition of S compounds, in consideration of the welfare effects evidence, quantitative analyses of ecosystem exposure and risk and advice from the CASAC, the Administrator proposed to judge that the existing 3-hour secondary SO_2 standard is not requisite to protect the public welfare from adverse effects associated with acidic deposition of S compounds in sensitive ecosystems. An array of comments was received regarding the Administrator's proposed decision to address this insufficiency in protection through revision to an annual average standard. These comments are addressed in the following section.

(2) Comments in Support of Proposed Adoption of a New Annual Standard

In consideration of the welfare effects evidence, quantitative analyses of ecosystem exposure and risk, and advice from the CASAC majority to adopt an annual standard with a level within the range of 10 to 15 ppb to address the deposition-related effects of SO_X, the Administrator proposed revision of the existing standard to be an annual standard, as summarized in section II.B.1.c. above. Commenters expressed several views concerning the level of such a standard; these comments are addressed in the subsections below.

(a) Comments Agreeing With a Level Within the Proposed Range

The EPA received multiple comments in support of the proposed establishment of an annual standard, with a 3-year form and level within the proposed range. Some of these comments concurred with the full range of levels as proposed, while some recommended a range of levels that overlapped with the lower end of the proposed range and also extended below it. The commenters in agreement with the full proposed range variously cited, concurred with, and expanded upon information discussed in the proposal, in addition to noting consistency of the proposed decision with recommendations from the majority of CASAC. In so doing, one commenter expressed the view that the proposed new standard would provide protection for direct vegetation effects and ecosystem deposition-related effects including aquatic acidification, which they noted affects the diversity and abundance of fish and aquatic life, thus providing support to cultural services and recreational fishing, which have long-term societal and economic benefits. Another comment expressed the view that the new standard would support Tribal efforts to protect lakes and streams from deposition-related effects including potential impacts to cultural fishing practices. One comment, in advocating for a level within the range of 5 to 10 ppb (which overlaps with the proposed range at a level of 10 ppb), expressed the view that ''to meet statutory requirements and act rationally and respond to CASAC consensus scientific expertise, EPA must,'' among several recommendations, ''[s]et an annual secondary SO_2 standard of 5–10 ppb to

protect against deposition effects and maintain total sulfur deposition at <5 kg/ha on an annual basis.''

The EPA agrees with the comment that a new annual standard with a level in the proposed range (of 10–15 ppb) would be expected to provide protection for direct effects on vegetation and for ecosystem deposition-related effects, including specifically those associated with aquatic acidification. The EPA also agrees that such a standard, by protecting against acidifying atmospheric deposition in aquatic and terrestrial ecosystems, can be expected to impact an array of societal and economic benefits from this protection. As summarized in section II.A.3.b. above and recognized in the Administrator's conclusions in section II.B.3. below, such benefits include providing protection for recreational and subsistence fisheries, as well as for recreational uses of sensitive forests and protected waterbodies.

Additionally, with regard to the lower end of the proposed range and its overlap with the commenter-recommended-range of 5 to 10 ppb, the EPA agrees with the commenter that a standard with a level of 10 ppb would generally be associated with S deposition at or below 5 kg/ha annually in sensitive ecosystems, consistent with comments by the CASAC majority in its rationale for recommending a new annual standard with a level in the range of 10 to 15 ppb, which it described as ''generally'' maintaining S deposition below 5 kg/ha-yr (as summarized in section II.B.1.b. above). The CASAC majority based its conclusion regarding annual SO_2 standard levels associated with S deposition at/below 5 kg/ha-yr on analyses in the draft PA, as described in section II.B.1.b.

In reaching his proposed decision for a level in the range of 10 to 15 ppb, the Administrator considered the expanded analyses and conclusions in the final PA. In reaching his final decision, as described in section II.B.3. below, the Administrator also considered additional analyses in a technical memorandum to the docket that extend the PA air quality and deposition analyses (Sales et al., 2024). These ecoregion-based analyses of air quality and deposition from five 3-year time periods from 2001 through 2020 indicate that when annual average SO_2 concentrations (as a 3-year average) are at or below 10 ppb, median S deposition in associated downwind ecoregions is generally at or below 5 kg/ha-yr. Specifically, more than 85% of associated downwind ecoregions are at or below 5 kg/ha-yr, with 95% below about 6 kg/ha-yr and all below about 8 kg/ha-yr. This analysis additionally found that in every instance of the upwind maximum annual SO_2 concentration above 10 ppb, the associated downwind ecoregion median deposition was greater than 5 kg/ha-yr, ranging from about 6 kg/ha-yr up to about 18 kg/ha-yr and with 75% of occurrences greater than 9 kg/ha-yr (Sales et al., 2024). In consideration of these findings, among other considerations, the Administrator judged a level of 10 ppb to provide the requisite protection of public welfare for the new annual secondary SO_2 standard, as described in section II.B.3.

(b) Comments in Support of a Level Below the Proposed Range

Three comments indicated support or potential support for a new annual standard with a level below 10 ppb (*i.e.,* below the proposed range). In addition to the comment referenced above that expressed support for a level in the range from 5 to 10 ppb, a second comment, that expressed support for an annual standard with a level within the proposed range of 10 to 15 ppb, additionally expressed support for a level as low as 5 ppb to the extent it could ''be supported by the current science.'' A third comment expressed support for an annual standard level of 5 ppb, stating the view that such a standard could provide necessary protection for the public welfare and for resources managed by the U.S. National Park Service. Beyond a statement by one of these comments (also discussed in section II.B.2.a.(2)(a) above) that their recommended range of 5 to 10 ppb was needed to ''maintain sulfur deposition at <5 kg/ha on an annual basis,'' none of these commenters presented a specific scientific rationale for a specific standard level below 10 ppb. One comment stated that 71% of national parks are experiencing wet deposition of S greater than 1 kg/ha-yr and suggested that this indicates harmful impacts to park soil, waterbodies, and associated wildlife.

With regard to the latter comment regarding wet S deposition above 1 kg/ha-yr, the commenter did not provide evidence to support their conclusion of harmful impacts for such a level, and the EPA has not found the available evidence to support such a finding in this review. In describing the 1 kg/ha-yr value (for wet deposition of both S and N), the comment cited two papers that are focused on N deposition as a basis for the conclusion that conditions of wet deposition below 1 kg/ha-yr are ''good'' while greater levels indicate acidification conditions. These papers—Baron et al. (2011) and Sheibley et al. (2014)—are summarized in addressing another comment in section II.B.2.b.(2)(b) below. Neither paper, however, addresses S deposition. Based on this and consideration of the evidence and quantitative analyses available in this review, the EPA does not find that wet S deposition greater than 1 kg/ha-yr in national parks indicates adverse impacts to the public welfare.

We note that the phrase regarding maintaining S deposition ''at <5 kg/ha'' on an annual basis is consistent with the phrase used by the CASAC majority in its justification for its recommended range of 10–15 ppb, for which it cited analyses in the draft PA. As summarized above, and discussed in section II.B.3. below, the Administrator has considered the CASAC advice and the findings of the analyses in the final PA, in combination with additional presentations in Sales et al (2024), which he judged to provide support for his decision to adopt an annual SO_2 standard with a level of 10 ppb, a value within the commenter-supported range of 5 to 10 ppb.

The commenter that recommended a level of 5 ppb additionally expressed their view that a standard with a higher level (within the proposed range of 10 to 15 ppb) would not prevent effects of S deposition in Class I areas that they described as harmful, improve air quality, or reduce S deposition in Class I areas. Based on this view and their judgment that a further reduction in ambient air concentrations is needed, this commenter recommended that EPA set the level for a new annual standard below recent annual average SO_2 concentrations, stating that a standard level of 5 ppb ''could'' reduce S deposition from current levels. However, this commenter did not elaborate as to what magnitude of S deposition would be expected to be associated with a standard level of 5 ppb or why such a magnitude would provide an appropriate level for protection of the public welfare from S deposition-related effects. As a basis for their conclusion that harmful effects of S deposition are associated with current S deposition rates in national parks that are Class I areas, this commenter referred to National Park Services analyses that assign grades or ''conditions'' to these areas based on S deposition estimates and ''park-specific critical loads'' and stated that current S deposition levels in National Park Service managed Class I areas are above these loads for multiple ecosystem components. This commenter indicated that these analyses show that natural

resources in these parks are in fair or poor condition and that a standard with a level around 5 ppb ''could improve air quality and reduce S deposition levels'' in areas that the commenter states are already experiencing S deposition impacts.

Although the commenter provided tables listing numbers of areas that they stated are in poor or fair condition for various ecosystem components (*e.g.,* aquatic systems, trees) and potential threats (*e.g.,* acidification by S deposition, growth effects and S deposition), the commenter submitted no information (beyond their statement that there are critical load exceedances) on how they reach such conclusions. As support for the general statement that the term critical load describes the amount of pollution above which harmful changes in sensitive ecosystems occur, the commenter cited a publication that discusses the concept of critical loads and the potential for their usefulness in natural resources management. We note, however, that this publication does not provide details (*e.g.,* specific deposition rates associated with specific types of effect in specific types of ecosystems) that might inform the EPA's consideration of the type, severity and prevalence of particular effects that would be expected from specific levels of deposition. Such information, as that provided by the aquatic acidification REA and the evidence underlying it, is needed in judgments regarding deposition levels and deposition-related effects of public welfare significance, which are integral to the Administrator's decision on the secondary standard for SO_X. Further, the commenter did not provide or refer to evidence relating a standard level of 5 ppb to expected S deposition levels. As discussed in section II.B.3. below, the Administrator has based his decision for an annual secondary SO_2 standard with a level of 10 ppb on his consideration of the available evidence and quantitative analyses supporting the Agency's understanding of relationships between S deposition-related effects and S deposition levels and SO_2 concentrations, and also on his judgments regarding the public welfare significance of the S deposition-related effects assessed in his decision.

As we describe in section II.A.3.c. above, the term critical load has multiple interpretations and applications (ISA, p. IS–14). The variety in meanings stems in part from differing judgments and associated identifications regarding the ecological effect (both type and level of severity) on which the critical load focuses and from judgment of its significance or meaning. Accordingly, all CLs are not comparable with regard to severity or significance of harm or, as is more pertinent to decision-making in this review, with regard to potential for adversity to the public welfare. Rather, science policy judgments in these areas are required in order to reach conclusions regarding impacts for which secondary standards should be established. For example, the analysis in the PA which utilized CLs—the aquatic acidification REA—described their basis in detail. Further, in the Administrator's consideration of the REA results, he recognized the variation and uncertainty associated in the CLs and their relevance to different waterbodies. Thus, while we appreciate the comment, we find the information provided by the commenter to be insufficient for reaching judgments as to the significance and strength of the various CLs in their technical analysis, and likewise insufficient for concluding that reduced deposition levels are necessary to avoid adverse public welfare effects in Class I areas (or for assessing what level of deposition would be associated with a 5 ppb standard).

(3) Comments in Disagreement With Proposed Adoption of a New Annual Standard

Several public comments expressed disagreement with the proposed adoption of a new annual secondary standard to address S deposition-related effects of SO_X in ambient air. These comments cited a variety of reasons in support of this position, including the view that the EPA lacks authority to set a secondary standard to address public welfare effects of acid deposition. This comment is addressed in section II.B.2.a.(3)(a) below. Other reasons described in some comments advocating this position include the view that the proposed standard has no ''benefits'' and is therefore not ''necessary'' or ''requisite.'' Some other comments variously cite implementation burdens (*e.g.,* SIP preparation), uncertainties in the scientific basis, and a lack of CASAC consensus. Another commenter expressed the view that the proposal did not adequately discuss how effects are adverse to the public welfare and additionally stated that the ANC targets used in reaching conclusions on the need for protection from acid deposition relied on the judgments of others, rather than EPA. These other comments are addressed in section II.B.2.a.(3)(b) Some comments in opposition to a new annual standard expressed support for a secondary standard identical in all respects to the primary standard. Those comments are addressed in section II.B.2.a.(3)(c).

(a) Authority for a Secondary Standard Based on Acid Deposition

A few commenters that disagreed with the proposed decision to adopt a new annual standard to address deposition-related effects expressed the view that the EPA lacks authority to set a secondary standard based on acid deposition, stating that the specific focus of the Acid Rain Program (CAA, title IV) on acidification preempts action on the same issue through the secondary NAAQS.[112] These commenters argue that the enactment of title IV of the CAA in 1990 displaced the EPA's authority to address acidification through the setting of NAAQS, contending that the existence of a specific regulatory program to address the acidification effects of oxides of nitrogen and sulfur, that was established subsequent to the establishment of the NAAQS program in 1970, supplants the EPA's general authority under the Act. In support of this contention, the commenters cite a Supreme Court decision pertaining to regulation of tobacco by the FDA (*Food & Drug Admin.* v. *Brown & Williamson Tobacco Corp.,* 529 U.S. 120 (2000)) and also claim that their view regarding a lack of authority for the NAAQS program is demonstrated by the legislative history and a close reading of section 404 of the Act, which required the EPA to report to Congress on the feasibility of developing an acid deposition standard and the actions that would be required to integrate such a program into the CAA. The required report described in section 404, commenters argue, demonstrates that Congress had concluded that the EPA lacked the authority under section 109 of the CAA to establish a secondary NAAQS to address acid deposition. Commenters also claimed that the EPA has in the past recognized that the NAAQS program does not provide an effective mechanism for addressing acid deposition and has not adequately explained its change in position. These commenters additionally cite comments from the CASAC, made in its review of the draft PA for this NAAQS review, regarding challenges in identifying a concentration-based standard to address deposition-related effects as supporting

[112] One comment additionally cited the CASAC statement (in its advice to the Administrator in this review, summarized in section II.B.1.b.) that the CASAC's view was that a standard in terms of atmospheric deposition would be a more appropriate means of addressing deposition-related effects as indicative of a lack of CASAC support for a revised SO_2 standard to address deposition-related effects of SO_X.

the commenter's view that the CASAC also recognized a mismatch between the NAAQS program and regulation of acid deposition.

The EPA does not agree with commenters that the enactment of title IV of the Act displaced the EPA's authority under section 109 to adopt NAAQS to address adverse effects on public welfare associated with deposition of SO_X from the ambient air. We note that the purpose of title IV ''is to reduce the adverse effects of acid deposition'' by reducing sulfur dioxide emissions by 10 million tons (and NO_X emissions by 2 million tons) from 1980 levels (CAA section 401(b)). By contrast, section 109 directs the Administrator to set a standard that is ''requisite to protect public welfare from any known or anticipated adverse effects,'' based on the air quality criteria (CAA section 109(b)(2)). Congress explicitly requires the air quality criteria and standards be reviewed every five years, and has thus required secondary standards to reflect the latest scientific information (CAA section 109(d)(1)). There is no reason to believe that a Congressional effort to achieve 10 million tons in reductions of SO_2 was intended to supersede EPA's ongoing obligations to assess the impact of SO_2 on public welfare. See *Whitman* v. *Am. Trucking Ass'ns,* 531 U.S. 457, 468 (2001) (''Congress, we have held, does not alter the fundamental details of a regulatory scheme in vague terms or ancillary provisions—it does not, one might say, hide elephants in mouseholes.'').

These two provisions are not in conflict, but represent the combined approach often taken by Congress to address the frequently complex problems of air pollution. There is nothing unusual about the CAA relying on multiple approaches to improve air quality, and in particular relying on the NAAQS to identify the requisite level of air quality and relying on both State implementation plans as well as federal CAA programs to control emissions of criteria pollutants in order to attain and maintain the NAAQS. For example, the existence of title II of the Act (Emission Standards for Moving Sources) does not divest the EPA of authority to set a NAAQS for ozone, despite the fact that many mobile source controls are adopted to control ozone precursors and indeed may be sufficient in some areas to attain and maintain the ozone NAAQS. Had Congress wanted to channel the EPA's authority to address acidification exclusively through title IV it could have done so explicitly. For example, it generally excluded criteria pollutants from regulation under section 111(d) and 112. Instead, at the same time that it enacted title IV, Congress also added section 108(g) to the CAA, specifying that the air quality criteria used for setting the NAAQS ''may assess the risks to ecosystems from exposure to criteria air pollutants.''

In adding title IV to the CAA, Congress created a new program to reduce the emissions of SO_2 and NO_X from electric generating units, the most significant sources of acidifying pollution in 1990. Nothing in the text or the legislative history of title IV of the Act indicates that in creating additional authority Congress intended to foreclose the EPA's authority to address acid deposition through the NAAQS process. Indeed, to the extent that Congress addressed the impact of title IV on other provisions of the CAA, it made clear that title IV had no impact on the compliance obligations of covered sources under other CAA provisions. See CAA section 413, ''Except as expressly provided, compliance with the requirements of this subchapter shall not exempt or exclude the owner or operator of any source subject to this subchapter from compliance with any other applicable requirements of this chapter.''

The legislative history of the title IV program makes clear that Congress was acting to provide the EPA with additional tools to address the problem of acidification more effectively. See, *e.g.,* S. Rep. No.101–228, at 289–291 (1989). Congress did not conclude that the EPA lacked the regulatory authority to address acidification but rather concluded that ''a major acid deposition control program [was] warranted . . . because of the evidence of damage that had already occurred as well the likelihood of further damage in the absence of Congressional action'' (H.R. Rep. No 101–490, at 360 (1990)). The Senate Report made it clear that while the EPA envisioned CAA section 109 as providing authority to adopt a secondary NAAQS to address the effects of acid deposition, the EPA remained concerned about the effectiveness of this and other regulatory approaches (S. Rep. No. 101–228, at 290–291). Congress addressed these issues by adding the new authorities found in title IV but made no mention of supplanting the EPA's authority under section 109 to address acidification effects. There is no discussion in the legislative history of title IV of curtailing the EPA's authority under the NAAQS program.

As such, the requirement in section 404 of the 1990 CAA Amendments that the EPA send to Congress ''a report on the feasibility and effectiveness of an acid deposition standard or standards'' does not demonstrate that Congress concluded that an amendment to the CAA would be necessary to give the EPA the authority to issue standards addressing acidification under section 109. See CAA section 401. The significance of the report required by section 404 can be understood in the overall context of (1) the history of Congress' and the EPA's attempts to understand and to address the causes and effects of acid deposition; (2) the distinction between an acid deposition standard (expressed as kg/ha-yr) and an ambient air quality standard addressing effects of deposition (expressed as ppb); [113] and (3) the EPA's proposed conclusion in 1988 that the scientific uncertainties associated with acid deposition were too great to allow the Agency to establish a secondary NAAQS at that time to address those effects. The EPA notes that it was clear at the time of the 1990 CAA Amendments that a program to address acid deposition was needed and that the primary and most important of these provisions is title IV of the Act, establishing the Acid Rain Program. The Report required under section 404 of the Amendments reflects this concern and requires an evaluation of an acid deposition standard and a comparison of its effectiveness to the effectiveness of various other regulatory authorities under the Act, including the authority for a secondary NAAQS under section 109 (CAA Amendments, Public Law 101–549, 104 Stat. 2399, 2632 (1990) (describing that ''Reports'' under CAA 404 (42 U.S.C. 7651), should include ''(6) . . . other control strategies including ambient air quality standards'')). This indicates the existence of an ongoing authority under section 109. Likewise, in preparing the Report itself, EPA concluded that ''[i]t may be possible to set acid deposition standards under existing statutory authority'' (U.S. EPA, 1995b, at 100).

For these reasons, the commenters' analogy to tobacco regulation, at issue in *FDA* v. *Brown & Williamson Tobacco Corp.,* 529 U.S. 120 (2000), is entirely inapt. The issue before the Supreme Court in that case was whether the FDA had authority to regulate tobacco at all, and the Court held that where the FDA consistently took the position it did not have such authority, and Congress enacted multiple statutes consistent with that position, Congress had ratified the FDA's understanding of its authority and had created a separate regulatory structure. By contrast, while the EPA has on multiple occasions noted the

[113] For example, the 1995 Report discusses potential ranges for an acid deposition standard as measured by kg/ha/year (*e.g.,* U.S. EPA [1995b] at 118).

scientific difficulties associated with identifying a standard to protect against acid deposition, EPA has engaged with those scientific difficulties because the EPA's longstanding interpretation of section 109 is that acid deposition is within the scope of adverse effects on public welfare to be addressed under section 109. There is no reason to understand Congressional action to establish programs to reduce emissions of SO_X under title IV as depriving EPA of authority to specify a level of air quality the attainment and maintenance of which is requisite to protect the public welfare against effects of SO_X under section 109. See *Massachusetts* v. *EPA,* 549 U.S. 497, 530 (2007) (distinguishing *Brown & Williamson* where EPA jurisdiction would not lead to extreme results, was not counterintuitive and EPA had never disavowed its authority).

The EPA now concludes, as discussed in section II.B.2.b.(2)(a) below, that it does not have the authority to set a deposition standard under the existing CAA, and the EPA is not adopting a deposition standard in this action. Rather, consistent with the Agency's longstanding approach, the EPA has concluded that it must consider the effects of acid deposition in setting an air quality standard. Section 109 of the Act requires the Administrator to set an ambient air quality standard the attainment of which protects against ''any known or anticipated adverse effects associated with the presence of [the] air pollutant in the ambient air.'' The EPA has concluded that the best interpretation of this language is that a deposition standard is not an ''air quality'' standard because a deposition standard focuses not on concentrations of the pollutant in the ambient air but rather on quantities deposited on surfaces (as discussed in section II.B.2.b.(2)(a) below). Rather, the EPA has consistently viewed the best interpretation of this language to require consideration of the adverse effects that can be anticipated from presence of the pollutant in the ambient air, including via deposition of the pollutant to aquatic and other ecosystems. The CASAC indicated in its comments to the Administrator (as summarized in section II.B.1.b. above) that a deposition standard would be more scientifically appropriate, and it may be that Congress will at some point revisit the question of whether the EPA should also have authority to adopt an acid deposition standard, but such a question is independent of the scope of the authority, and obligation, the EPA currently has under section 109.

In assessing the import of section 404, the EPA has noted in the past that ''Congress reserved judgment as to whether further action might be necessary or appropriate in the longer term'' to address any problems remaining after implementation of the title IV program, and ''if so, what form it should take'' (58 FR 21356, April 21, 1993; 77 FR 20223, April 3, 2012). Such reservation of judgment by Congress concerned whether Congress should adopt additional statutory provisions to address the effects of acid deposition, as it did in 1990. It does not indicate a view that the EPA lacked authority under CAA section 109 to establish a secondary NAAQS to address acid deposition.

The EPA's decision in both the 1993 and 2012 reviews reflects the view that there is ongoing authority to address the effects of acid deposition under section 109 of the Act and does not indicate that the EPA believed that title IV implicitly amended the CAA and removed all such regulatory authority outside of title IV. In both the 1993 and 2012 decisions on the question of whether to revise the secondary NAAQS to address acid deposition-related effects, the EPA decided not to adopt a standard targeting deposition-related effects. The EPA noted the consistency of this decision with Congress' actions in the 1990 amendments but nowhere indicated that Congress' actions meant the EPA no longer had the authority to adopt a secondary NAAQS to address acid deposition. Instead, in the 1993 and 2012 decisions, the EPA stated that due to scientific uncertainty, the Agency would not at those times adopt a secondary NAAQS targeting deposition-related effects but would instead gather additional data and perform research and would determine in the future what further action to take under CAA section 109 (77 FR 20263, April 3, 2012; 75 FR 28157–58, April 21, 1993).

Although substantial progress was made between the 1993 and 2012 reviews addressing some areas of uncertainty, the Administrator again concluded in 2012 that uncertainties associated with setting a NAAQS to address acidification were too substantial to allow her to set a standard that in her judgment would be requisite to protect the welfare from such effects. More than 10 years later, the evidence base on air quality, deposition and deposition-related effects has progressed substantially. That evidence base and associated quantitative analyses developed in the current review provide the foundation for the current decision for a NAAQS to protect against acid deposition. Thus, although we recognize the CASAC's view to be that a deposition standard would be a more appropriate means of addressing deposition-related effects, we find that for SO_2 the relationship between ambient air concentrations and deposition is sufficiently well established to support a revised secondary SO_2 NAAQS.[114]

We do not understand the CASAC as suggesting that, in the absence of a deposition standard, the EPA should decline to set an air quality standard to address deposition-related effects. Rather, contrary to the implication of the commenter that the CASAC did not support a NAAQS to address deposition, the CASAC expressed strong consensus support for the EPA setting a NAAQS for this purpose and recommended concentration-based standards to the EPA for consideration. In summary, the EPA disagrees with the commenters' interpretation of the information cited and does not agree that the Administrator lacks the authority to set a secondary standard to address acid deposition-related effects.

(b) Other Comments in Opposition to the Proposed Annual Standard

In addition to the view discussed immediately above regarding the EPA's authority to set a NAAQS to address effects related to atmospheric deposition, some commenters cited other reasons in opposition to the proposed annual secondary SO_2 standard. For example, based on the EPA's analyses indicating that the proposed revision of the secondary standard would not require emissions reductions beyond those needed to meet the primary standard, some commenters stated that revision of secondary standard has no ''benefits'' and is therefore not ''necessary'' and not ''requisite.'' Some additionally cited implementation requirements on States (*e.g.,* SIP preparation) as a reason that the standard should not be revised, in light of the view that current air quality conditions do not pose a risk of adverse welfare effects. Some commenters expressed the view that the uncertainties are too great and the scientific basis for a standard to address acid deposition-related effects is lacking. One commenter stated that the EPA should thoroughly review the scientific studies published since the cut-off publication date for studies included in the ISA, and that to allow for this, the EPA should retain the existing standard pending that review

[114] We have explained in section II.B.2.b.(2)(a), below, why we do not view section 109 as authorizing a deposition standard.

and the associated creation of an up-to-date record in the next NAAQS review. One commenter additionally noted the lack of CASAC consensus on recommendations for a standard to address deposition-related effects and stated the view that this lack of consensus further weakens support for such a new standard. One comment expressed the view that the proposal did not adequately discuss how effects are adverse to public welfare and additionally stated that the ANC targets used in reaching conclusions regarding the need for protection from acid deposition relied on the judgments of others, rather than the EPA.

Regarding the view that a new annual standard to address deposition-related effects is not ''necessary'' or ''requisite,'' the EPA disagrees that simply because current or projected air quality in areas that meet the existing primary standard is expected to achieve the new standard, the current standard is already requisite to protect the public welfare, and a revised standard is unnecessary. The CAA requires secondary NAAQS to be set at the level of air quality requisite to protect the public welfare from known or anticipated adverse effects (CAA, section 109(b)(2)). The EPA recognizes the clear evidence, the CASAC consensus conclusions, and the Administrator's judgment, described in section II.B.3. below, that the current secondary standard does not provide protection for deposition-related effects of SO_X and is therefore not requisite. Accordingly, based on the available information and CASAC advice, the Administrator proposed to revise the existing standard to reflect a level of air quality that would provide the needed protection (89 FR 26620, April 15, 2024). Such a revision is ''necessary'' to address the requirements of the Act. In adopting a new annual standard, as described in section II.B.3. below, the Administrator has considered a range of options for limiting deposition-related effects with an air quality standard and identified such a standard that, in his judgment, is neither more nor less stringent than necessary to achieve the desired level of protection from welfare effects, most particularly those associated with atmospheric deposition of S compounds in sensitive ecosystems.

With regard to implementation requirements, while the Administrator's decision on revision of the secondary standard to provide the requisite public welfare protection is not expected to result in changes to existing air quality, he has not considered implementation requirements in reaching his decision on the revised standard. Consistent with the CAA requirements described in section I.A. above, the Administrator is barred by CAA section 109 from considering costs of implementation in judging the adequacy of a standards, and he has not done so.

The EPA additionally disagrees with the view that the secondary SO_2 standard should not be revised because a revised standard would not be expected to require emissions reductions beyond those already required for meeting the primary SO_2 standard, such that there would be little or no emissions reductions. As the D.C. Circuit has held in a prior challenge to SO_2 NAAQS, ''Nothing in the CAA requires EPA to give the current air quality such a controlling role in setting NAAQS'' (*Nat'l Envtl. Dev. Association's Clean Air Project* v. *EPA,* 686 F.3d 803, 813 ([D.C. Cir. 2012]). In this review, the EPA is engaged in the task of identifying a secondary standard that provides the requisite public welfare protection under the Act. The fact that the existing primary SO_2 standard is expected, based on recent data, to control air quality such that the new annual secondary SO_2 standard may also be met does not satisfy the requirements of CAA section 109(b)(2) or *a priori* make the secondary standard not requisite or without benefit. The benefit is assurance of the protection of the public welfare that is required of the secondary standard separate from the protection of the public health that is required of the primary standard. Further, the CAA requires the establishment of secondary standards requisite to protect against known or anticipated effects, and that requirement is separate and independent of the obligation to establish primary standards to protect the public health with an adequate margin of safety. The implication of the comment is that when the EPA next revises the primary NAAQS for SO_X, the Administrator would be required to consider the effect of any revisions to the primary NAAQS on both public health and welfare, a consideration inconsistent with the entire purpose of having distinct standards, as well as the text of section 109.

Furthermore, while air quality is currently expected to meet the new annual secondary standard when the primary standard is met, patterns of SO_2 concentrations may change in some areas in the future, such that both the new annual secondary standard and the existing primary standard are violated or such that the secondary standard could be violated without a violation of the primary standard. The analyses of SO_2 concentrations described in the PA illustrate how SO_2 concentration patterns have changed over the past two decades in response to various changes in the largest emissions sources and in emissions controls implemented on such sources. Thus, sometimes changes occur over the long term in the multiple factors that influence air quality, that can contribute to future air quality patterns that may differ from those prevalent currently. Regardless, we recognize that section 109 of the Act does not only require establishment of standards that will result in changes in existing air quality. Rather, the Act specifies that there be secondary standards in place that will provide the requisite protection in the face of current and future air quality. And, as discussed above and in section II.B.3. below, the existing secondary SO_2 standard does not provide the requisite protection from known or anticipated adverse effects on the public welfare related to atmospheric deposition of S compounds associated with SO_X in ambient air. The Administrator's decision is therefore to revise the standard to one that in his judgment will provide that protection, as described in section II.B.3. below.

The EPA disagrees with the comment stating that the Agency should retain the existing secondary SO_2 standard pending review of the scientific studies that have been published since the cut-off date for studies considered in the ISA. Given the need for thorough consideration and CASAC review of studies that are part of the air quality criteria on which NAAQS must be based, there is always a cut-off date for studies to be considered in the ISA, and there are always studies published after the cut-off date. The NAAQS are subject to regular review precisely to allow for EPA to base its review of the standards on the latest available science and to also revisit the standards in the future based on additional scientific information. As noted in section I.D. above, in consideration of public comments received on this action, the EPA has provisionally considered all such ''new'' studies cited in comments and concluded that they do not materially change the broad scientific conclusions of the ISA (Weaver, 2024). Thus, the EPA has concluded that reopening the air quality criteria is not warranted. Therefore, as discussed in section II.B.3. below, the Administrator has considered the available evidence, as summarized in the ISA, the quantitative and policy evaluations in the PA, and the related additional analyses (Sales et al., 2024), as well as CASAC advice and public comment on

the proposed decision and judged this an appropriate basis for his decision in the current review.

The EPA also disagrees with commenters' claims that the uncertainties are too great to provide the necessary scientific support for a new annual secondary standard or that consensus advice is needed from the CASAC. With regard to the advice from the CASAC, we disagree that consensus is needed before the Administrator can make a decision in a NAAQS review. The CAA does not require the CASAC to reach consensus in its advice on revisions to the standards. The EPA has made decisions on NAAQS in multiple reviews in which the CASAC did not reach consensus on its advice for the standards (*e.g.,* 85 FR 87256, December 31, 2020 and 89 FR 16202, March 6, 2024). In reaching his decision in this review, as described in section II.B.3. below, the Administrator has considered advice provided from both the majority and the minority of the CASAC.

In support of their claim that uncertainties are too great, commenters list statements from the proposal that recognize specific technical areas of uncertainty in our understanding of deposition-related effects of SO_2 in ambient air. We note that many of these statements are simply recognizing aspects of the evidence base that illustrate the complexity of addressing deposition-related effects. For example, one statement cited by commenters as indicative of significant uncertainty that should preclude action in this review recognized that there is not a simple one-to-one relationship between ambient air concentrations and any one indicator of S or N deposition. This statement simply recognizes the complexity inherent in analyses supporting this review. This complexity relates in part to the complex atmospheric chemistry and meteorology as well as aspects of ambient air monitoring and deposition estimation datasets (ISA, Appendix 2; PA, Chapters 2 and 6). In light of these factors, as summarized in the proposal and in section II.A.2. and II.B.1.a. above, we analyzed multiple datasets that investigate relationships between concentrations for different metrics in different types of locations.

While we recognize the uncertainties and complexities of the evidence base and quantitative information, we have taken them into account in our evaluations, and we disagree that the available information is insufficient to permit a reasoned judgment about a secondary SO_2 standard that may be considered to provide the appropriate protection from adverse effects on the public welfare. For example, some of the areas cited by commenters relate to uncertainty in how quickly sensitive ecosystems might respond to the already reduced deposition. While we recognize there to be uncertainty in estimates related to ecosystem response times, the EPA does not find predictions of this to be necessary in this decision, and accordingly has not considered timing of future recoveries as a factor in determining the standard that would provide the desired level of protection. Other areas cited by commenters simply recognize the inherent variability of environmental response to varying patterns of SO_2 concentrations. The Agency has recognized this variability in its focus on a year's averaging time for the new standard, which will not be affected by short-term variability, and in its focus on medians in characterizing ecosystem deposition targets.

Lastly, the commenters noted uncertainty associated with the trajectory-based analysis (or EAQM approach), citing areas of uncertainty identified in the PA or proposal, and comments by the CASAC in its review of the draft PA, which stated that the description in the draft PA was insufficiently detailed and that sensitivity analyses were needed to characterize associated uncertainty. In addition to CASAC comments, these public comments quoted statements by three individual members of the CASAC Panel for this review that state there are uncertainties and shortcomings of the EAQM approach, state that there are poor correlations of S deposition with ambient air concentrations and suggest a need for peer review. With regard to correlations, we disagree that the correlation coefficients for the two SO_2 EAQMs in the final PA analyses (0.49 and 0.56 when considering the full dataset in the final PA), which are statistically significant at the 0.05 level, are fairly characterized as ''poor'' (PA, Table 6–8). That said, the use of such relationships in this review is not for the development of a function to generate precise predictions of S deposition associated with individual monitor air concentrations. Rather, the analyses and the statistical significance of the deposition-to-EAQM value associations support the conclusion that higher upwind SO_2 concentrations contribute to higher downwind S deposition. With this support, they also inform judgments regarding standard levels through consideration of the patterns of downwind deposition rates that have occurred during periods associated with different maximum upwind SO_2 concentrations.

With regard to peer review, in addition to noting the scientific peer review provided by the CASAC Panel for this review which resulted in substantial improvements in the analyses from the draft to the final PA, we also note that the trajectory analyses are based on a well-established and peer-reviewed model, HYSPLIT (Stein et al., 2015). This model, as described further in the PA, is commonly used to compute simple air parcel trajectories using historical meteorological data and to simulate the trajectories of air parcels as they are transported through the atmosphere for a given set of meteorological conditions (PA, Appendix 6A).

In consideration of the robust scientific and technical peer review provided by the CASAC and its Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter Secondary National Ambient Air Quality Standards Panel in their review of the draft PA, several improvements were implemented. For example, sensitivity analyses were conducted to judge the influence of key aspects of the approach employed (*e.g.,* duration of the trajectory simulations and criteria used to identify influential upwind monitors), and findings from these analyses informed development of the trajectory-based approach for the final PA. As a result, the final PA includes substantially more detail in describing the approach and in the presentation of results, including for the various sensitivity analyses. Thus, as noted in the final PA, analyses presented in that document were revised and additional information added to address the CASAC concerns (PA, section 1.4).

While the PA includes multiple approaches for analyzing relationships between ambient air concentrations and ecosystem deposition of S compounds, the trajectory-based approach is the only one that accounts for pollutant transport, which is integral to how SO_2 emissions and associated concentrations contribute to acidic precipitation and acidification of ecosystems many miles away.[115] Such transport modeling has been used for years, with its use verified twenty years ago by a study documenting the movement of air

[115] The importance of this transport, with co-occurring transformation of SO_2 to SO_4^{2-}, in contributing to ecosystem acidification was recognized decades ago in the 1982 AQCD for PM and SO_X which stated that ''[b]ecause of long range transport, acidic precipitation in a particular state or region can be the result of emissions from sources in states or regions many miles away, rather than from local sources'' (1982 p.m. and SO_X AQCD, p. 7–2; Altshuller 1976).

masses containing elevated concentrations of SO_4^{2-} from the Ohio River Valley to the eastern U.S. and Canada (Hennigan et al., 2006), where acid-sensitive waterbodies have been impacted by acidification (ISA, Appendix 16, section 16.2). Thus, consideration of the trajectory-based analyses by the Administrator in reaching his proposed and final conclusions rely on different analyses (from those described in the draft PA) that have been improved to address comments by the CASAC, and consideration of these analyses (in addition to the other approaches) presented in the final PA is important to identifying a secondary standard that accounts for pollutant transport to downwind sensitive ecosystems.

With regard to our recognition of the uncertainties associated with issues in this review, we note that Congress and the courts have recognized that some uncertainties in assessing the effects of air pollution are inevitable, and the Administrator is required to exercise his judgment in the face of imperfect information. See, *e.g., Lead Indus. Ass'n, Inc.* v. *EPA,* 647 F.2d 1130, 1155 & n.50 (D.C. Cir. 1980) (quoting H.R. Rep. No. 95–294, at 50). Only when the Administrator judges that the uncertainties are so great as to preclude the ability to identify a standard that would be expected to provide the requisite protection do uncertainties justify a decision to not act. See, *Center for Biological Diversity* v. *EPA,* 749 F.3d 1079, 1087 (D.C. Cir. 2014). As discussed further in section II.B.3. below, that is not the case for this standard. Thus, the EPA's judgment is that the available information, including evidence of the effect of SO_X on sensitive ecosystems and the analyses of transport of pollutants across airsheds, is sufficient to allow the Administrator to make a reasoned judgment about where to set a revised SO_2 NAAQS, while recognizing that substantial uncertainties remain.[116]

Regarding the comment that the proposal insufficiently evaluated or discussed how the effects to be addressed by the new annual secondary standard are adverse to public welfare, we note the evidence of aquatic acidification and its effects on fisheries in lakes and streams across the northeast and Appalachian Mountains. This evidence was evaluated and documented in the current and last ISA and prior AQCDs (*e.g.,* ISA, Appendix 8, section 8.5.2 and Appendix 16, section 16.2.3.2.1; 2008 ISA, sections 3.2.4.4 and 3.2.4.5; 1982 AQCD, section 7.1.1.1). For example, acidified aquatic habitats have a lower number of species (species richness) of fishes, including culturally and recreationally important species, as well as shifts in biodiversity of both flora and fauna. This evidence and the findings of the quantitative aquatic acidification REA, as well as the analyses of relationships between air quality and S deposition, and advice from the CASAC were considered by the Administrator in reaching his proposed decision that the existing SO_2 standard does not provide the requisite protection of the public welfare from known or anticipated adverse effect. This information, and public comments, have also been considered in his decision on revisions to the SO_2 standard, as discussed further in section II.B.3. below. Further, the public welfare implications of aquatic acidification-related effects, including the influence of their severity and geographic extent, on harm posed to the public welfare, are described in the PA, the proposal and section II.A.3.b. above (PA, section 4.5; 89 FR 26641–26644, April 15, 2024). In reaching his decision on the existing standard and on the revisions that would provide the requisite protection, the Administrator has considered these factors (severity and geographic extent of acidification-related effects), as well as the evidence of varying sensitivity of ecoregions across the U.S. In the end, as noted in sections I.A. and II.A. above, the CAA recognizes that judgments on effects to the public welfare that are adverse are within the purview of the Administrator in reaching his decision on secondary standards.

In judging the existing standard to not provide the requisite protection of the public welfare, the Administrator has considered the evidence, evaluations in the PA, strengths and uncertainties in the evidence, and quantitative analyses. In so doing, he focused particularly on the REA findings for aquatic acidification risk estimates for the earliest part of the 20-year assessment period. With the pattern of deposition estimated for this period (when the existing standard was met), the REA found more than a third of waterbody sites in the five most affected ecoregions unable to achieve even the lowest of the three acid buffering capacity benchmarks used as risk indicators (below which the increased risk of episodic acidification events may threaten survival of sensitive aquatic species), and more than half of waterbody sites unable to meet this benchmark in the single most affected ecoregion. The Administrator judged that this level of aquatic acidification risk, associated with deposition levels estimated to have occurred when the existing standard was met, can be anticipated to cause adverse effects on the public welfare.

Lastly, we disagree with the view of one commenter that the ANC benchmarks used in reaching conclusions regarding the need for protection from acid deposition relied on the judgments of others, rather than the EPA. Rather, as described in the PA and summarized in section II.A.4. above, the quantitative REA employed an array of ANC benchmarks in recognition of variation among waterbodies in their ability to achieve different benchmarks and in the associated risk to fisheries, to specifically avoid putting undue weight on a single value. In characterizing risk and levels of protection associated with different S deposition circumstances in the REA, we reported the percentages of waterbodies per ecoregion estimated to achieve the different benchmarks. The PA focused on this pattern of percentages in characterizing risk and the CASAC majority also considered this pattern in expressing its recommendations for a revised standard. Similarly, in weighing the evidence and the REA findings, the Administrator also considered these patterns and the weight to place on different benchmarks for ANC as an indicator of acidification risk, as well as the CASAC majority consideration of them in its recommendation of a range of standards expected to achieve a desired level of public welfare protection. In so doing, as described in section II.B.3. below, he judged it appropriate to consider patterns of ANC across ecoregion waterbodies, rather than limiting his judgment to consideration of a single ANC benchmark in all areas. Thus, contrary to the view of the commenter, the Administrator made all relevant judgments on the weight to place on different tools for indicating acidification risk, including ANC benchmarks in reaching a decision on the secondary SO_2 standard.

(c) Comments Recommending Revision To Be Identical to the Primary Standard

In disagreeing with the EPA's proposal to revise the 3-hour secondary SO_2 standard to an annual standard for the reasons discussed in the two

[116] As recognized in section II.A. above, the Administrator's decisions in secondary NAAQS reviews draw upon scientific information and analyses about welfare effects, exposures and risks, as well as judgments about the appropriate response to the range of uncertainties that are inherent in the scientific evidence and analyses. As described in section II.B.3. below, the Administrator's decision reflects these considerations.

sections above, a few commenters additionally expressed support for an alternate revision that would set the secondary standard to be identical to the primary standard, in all respects. One commenter stated that this option would be supported by a finding of no locations in the U.S. that would not achieve an annual standard with a level at the low end of the proposed range. The other commenter cited comments from the minority of CASAC that also recommended this option based on a judgment that the 1-hour primary standard is currently controlling of air quality and the view that most deposition values during the period since the primary standard was established have been less than 5 kg/ha-yr. This commenter additionally quoted the EPA's March 9, 2024, technical memorandum [117] regarding the highest annual average concentrations observed during the period 2017–2022 in areas that do not violate the primary standard. Additionally, one commenter expressed support for ''any alternatives,'' including revising the secondary standard to be identical to the primary standard in all respects, ''that can be supported by the current science,'' without providing further elaboration.

While the EPA agrees with the commenters regarding the air quality and deposition estimates in recent years, the EPA considered the available quantitative analyses, including the additional analyses presented in the technical memorandum to the docket (Sales et al., 2024), and finds that a secondary standard identical to the existing primary standard (75 ppb, as the annual 99th percentile daily maximum 1-hour concentration, averaged over three consecutive years) would be expected to provide a greater stringency in SO_2 concentrations than required to generally maintain S deposition levels of interest. As indicated by the additional analyses, a higher level (*e.g.,* of 120 ppb) for a 1-hour standard, with averaging time and form identical to the primary standard, is associated with downwind ecoregion median S deposition levels more like those associated with an annual SO_2 standard of 10 ppb than is such a 1-hour standard with a level of 75 ppb (Sales et al., 2024). Thus, the EPA disagrees with these commenters that a 1-hour secondary standard identical in all respects to the existing primary standard would provide the requisite protection of the public welfare, noting that it may provide more control than necessary to achieve the desired protection. As described in section II.B.3. below, the Administrator judges that an annual average standard, averaged over three years, with a level of 10 ppb can be expected to provide the needed protection of the public welfare.

(4) Comments Regarding Retaining the Existing Secondary Standard

The very few comments that addressed the issue of retaining the existing 0.5 ppm (500 ppb) 3-hour standard recommended retention, variously noting that this standard is important for short-term direct impacts of SO_2, that such a standard would prevent peak episodic events, and that in the past this standard was the controlling standard for many areas and its retention would ensure those areas maintain adequate protections. With regard to protection from the short-term direct impacts of SO_2 in ambient air, the EPA agrees that the existing standard provides such protection, as concluded by the Administrator in the proposal and by the CASAC. We further note, however, that the additional air quality analyses conducted in response to public comments indicate that in areas with SO_2 concentrations from 2000 through 2021 that would meet an annual standard of 10 ppb (excluding Hawaii),[118] virtually all 3-hour standard design values (the second highest annual 3-hour concentration at regulatory monitors) are less than 0.25 ppm (Sales et al., 2024, Figure 10). These analyses further indicate that more than 99% of the highest 3-hour concentrations at monitored sites in each of the more recent years of the analysis period (2011–2021) are below 0.2 ppm (Sales et al., 2024, Table 6). Reflecting the evidence in the ISA and prior AQCDs for SO_X, the PA summary of the lowest short-term concentrations (*e.g.,* over a few hours) associated with effects on plants or lichens does not include any concentrations below 0.25 ppm (PA, section 5.4.2; ISA, Appendix 3, section 3.2; 1982 AQCD, section 8.3). Together this information indicates that short-term concentrations in areas that would be expected to meet an annual standard of 10 ppb are well below those that have been associated with effects on plants or lichens. In light of information such as this, as described in section II.B.3. below, the Administrator judges that short-term peak concentrations of potential concern for welfare effects are adequately controlled by an annual average standard of 10 ppb, such that revision of the secondary standard to this annual standard provides requisite protection from both short-term effects of SO_2 in the ambient air and effects related to the deposition of S compounds in sensitive ecosystems.

b. Nitrogen Oxides and Particulate Matter

(1) Comments in Support of the Proposed Decisions

(a) Nitrogen Oxides

Among the few comments received on the proposed judgment that the existing secondary NO_2 standard provides the needed protection from direct effects of N oxides in ambient air on plant and lichen surfaces, all expressed support. In the context of ecological effects of N oxides more broadly, including deposition-related effects, several public comments expressed support for the proposed decision to retain the existing standard, which was based on the Administrator's proposed judgment that the available evidence does not clearly call into question the adequacy of the existing standard. In expressing support for the proposed decision, commenters raised several uncertainties, referencing the discussion in the proposal. These uncertainties include those related to the weak relationship between NO_2 concentrations and N deposition; the increasing contribution of NH_3 to N deposition; the expected impacts of current deposition levels absent residual historic impacts and the identification of appropriate protection objectives in this context of changing conditions; and the role of N benefits and disbenefits. We agree that these are important uncertainties in the evidence base, and, as discussed in section II.B.3. below, these factors are among those the EPA considered in reaching the decision to retain the existing NO_2 standard.

Some other commenters, in support of their position that the N oxides standard should not be revised, further expressed the view that N oxides emissions is one of the principal sources of acidic compounds and that the EPA lacks authority to set standards based on acidic deposition, citing CAA section 401(a). As discussed in section II.B.2.a.(3)(a) above, the EPA disagrees with the view that NAAQS cannot be established to provide protection for acidic deposition-related effects. We additionally note the REA conclusion, however, that under current air quality and based on the current information, as discussed in section 5.1.2.4 and

[117] This memorandum in the docket (Docket ID No. EPA–HQ–OAR–2014–0128–0039) describes the basis for the EPA's decision that a Regulatory Impact Analysis was not warranted for the proposed decision (89 FR 26692, April 15, 2024).

[118] This analysis excluded Hawaii where it is not uncommon for there to be high SO_2 values in areas with recurring volcanic eruptions (PA, section 2.4.2).

Appendix 5A, section 5A.2.1 of the PA, the contribution of N compounds to acidification is negligible.

(b) Particulate Matter

Among the public comments on the proposed decisions to retain the current secondary PM standards, only a few were received on the proposed judgment that the existing secondary PM standards provide the needed protection from the effects of PM in ambient air associated with direct contact with and loading onto plant and lichen surfaces. All of these comments expressed support for that judgment. In the context of ecological effects of PM more broadly, including deposition-related effects, comments received in support of the Administrator's proposed decision to retain the current secondary PM standards, without revision, generally noted aspects of the rationale presented in the proposal. For example, some comments noted uncertainties in the relationship between concentrations of $PM_{2.5}$ and deposition of N or S compounds. One comment, focused on the PM_{10} standard, expressed the view that the scientific information does not support revision of the PM_{10} standard. The EPA agrees with the view that the available information does not support revision of the PM NAAQS.

In support of their position that the PM standards should not be revised, one commenter, noting a PA statement regarding PM components that may contribute to ecosystem acidification risk, expressed the view that the EPA lacks authority to set standards based on acidic deposition. As discussed in section II.B.2.a.(3)(a) above, the EPA disagrees with the view that NAAQS cannot be established to provide protection from acidic deposition-related effects. Accordingly, as discussed in section II.B.3. below, the decision to retain the existing PM standards without revision is not based on such a premise.

(2) Comments in Disagreement With the Proposed Decisions

Most of the comments received in opposition to the proposed decisions to retain the existing secondary NO_2 and PM standards, without revision, expressed the view that the standards should be revised to address N deposition and associated effects. Some of these comments additionally take note of the information indicating that the contribution of reduced N compounds has increased such that NH_4^+ is a greater contributor to N deposition than in the past. Further, some commenters expressed the views that the CAA supports a standard in terms of N deposition and that the CAA also supports consideration of NH_3 as a criteria pollutant.

(a) Nitrogen Deposition

Most of the commenters that disagreed with the proposed decisions on the secondary standards for N oxides and PM focus on N deposition and related effects in describing their rationales. Some commenters expressed the view that current N deposition is having impacts on resources in national parks (including parks that are also Class I areas); this comment is addressed in section II.B.2.b.(2)(b) below. These commenters also generally expressed the view that setting a deposition standard would be the best and/or a more scientifically defensible approach to standard setting, noting the CASAC advice in this regard. In so doing, one group of commenters noted the increasing role of NH_3 in N deposition in recent times and expressed the view that the most effective way to address the NH_3 contribution to N deposition and associated effects would be to set a standard in terms of total N deposition. Some other commenters expressed disagreement with the CASAC advice regarding establishment of a deposition standard under section 109 of the CAA, stating that given the EPA's definition of ambient air as a portion of the atmosphere, an ambient air standard cannot be defined in terms of deposition rate.

As also discussed in section II.B.2.a.(3)(a) above, we disagree with the premise that the CAA supports setting a NAAQS in terms of rates of deposition of a pollutant from the air onto surfaces. In addition, it is important to note that the criteria pollutants under review are PM and oxides of nitrogen, not nitrogen. Thus, the EPA is reviewing the standards intended to address the anticipated effects resulting from the presence of PM and N oxides in the ambient air, not the anticipated effects of NH_3 in the ambient air, nor the effects of total N deposition in aquatic and terrestrial ecosystems generally. With regard to setting a NAAQS in terms of deposition rate, the commenters note the view of the CASAC in claiming the Act does not prevent the EPA from setting a standard in terms of atmospheric deposition rates. In so claiming, and in expressing their view on interpretation of the term ''level of air quality,'' the commenters indicate that the term might variously (depending on the impact a pollutant has on the public welfare) be interpreted as ''the pollution carried in the air that is deposited,'' or the pollutant suspended in the air. Without further explanation, the commenters cite section 108 of the CAA as providing support for such a view.

We disagree with the commenter's interpretation of the Act. The EPA agrees that under section 108 the air quality criteria shall ''reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of such pollutant in the ambient air.'' However, (as noted in section I.A above) section 109(b)(2) of the Act specifies that ''[a]ny national secondary ambient air quality standard prescribed under subsection (a) 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 protect the public welfare from any known or anticipated adverse effects associated with the presence of such air pollutant in the ambient air.'' Consistent with this statutory direction, the EPA has always understood the goal of the NAAQS is to identify a requisite level of air quality, and the means of achieving a specific level of air quality is to set a standard expressed as a concentration of a pollutant in the ambient air, such as in terms of parts per million (ppm), parts per billion (ppb), or micrograms per cubic meter ($\mu g/m^3$). Additionally, as noted by some other commenters, the definition of ambient air in 40 CFR 50.1(e) describes ambient air as a portion of ''the atmosphere'' (''external to buildings, to which the general public has access'').[119] Thus, taking section 108 and section 109 together, the EPA concludes that deposition-related effects are included within the ''adverse effects associated with the presence of such air pollutant in the ambient air,'' but the standard itself must define a level of air quality. The EPA disagrees that a standard that quantifies atmospheric

[119] In expressing their disagreement with the CASAC position that a NAAQS in terms of deposition rate is supported by the Act, some commenters emphasize that deposition is a process rather than a ''level of air quality'' as specified by section 109 of the CAA, and also cite the definition of ambient air under 40 CFR 50.1(e). These commenters additionally express the view that if the CASAC's position were correct and the Act supported NAAQS in terms of deposition rate, then Congress would not have adopted title IV of the Act to address control of acid deposition. We do not agree with this latter view. Regardless of the role of NAAQS or of a potential role of acid deposition standards, as discussed more fully in section II.B.2.a.(3)(a), the action of Congress in adopting title IV into the Act simply provided the EPA with additional tools to address the problem of acid deposition more effectively.

deposition onto surfaces qualifies as such an air quality standard.

In support of their disagreement with the EPA's proposed decisions to retain the NO_2 and $PM_{2.5}$ standards without revision, commenters claim that the EPA's ''approach to N deposition'' is unlawful and arbitrary because in their view if NH_3 is a precursor to PM then, under the definition of ''air pollutant'' in CAA section 302(g), NH_3 ''effectively'' becomes a criteria pollutant. The EPA disagrees that precursors to criteria pollutants should be themselves treated as criteria air pollutants for all purposes. Section 108 of the Act is quite explicit that only air pollutants that have been listed by the Administrator are criteria air pollutants, and the Administrator has never listed NH_3 as a criteria pollutant. Of course, criteria air pollutants may have precursors and in considering strategies to attain and maintain the NAAQS, it is important to understand whether criteria pollutants are emitted into the air or formed in the atmosphere from precursor pollutants. However, those precursors are controlled to attain and maintain the NAAQS for the criteria pollutants—not because they themselves ''effectively'' become criteria pollutants that must be controlled.[120] For example, in some areas, ozone formation is NO_X limited, such that controls on VOC emissions may have little or no impact on ozone formation. State implementation plans for such an area will differ from those in an area where ozone formation is VOC-limited, because control of precursors is a means to the end of controlling ozone.[121] It would be unnecessary to require controls on both VOCs and NO_X in every area simply to control ozone. Thus, EPA disagrees that it should treat every precursor, including NH_3, as a criteria pollutant.

(b) Nitrogen Oxides

The public comments that disagreed with the proposed decision to retain the secondary NO_2 standard, without revision, expressed support for revision of the standard level to a value within the range that was recommended by the CASAC majority, with some commenters additionally citing the CASAC majority comments on the draft PA. In support of the position that the NO_2 standard should be revised as recommended by the CASAC majority, commenters variously claimed that in not revising the standard, the EPA is not fully considering CASAC recommendations, or that the scientific evidence for N deposition demonstrates ''harmful'' or concerning impacts of current N deposition in national parks. Also, some of the commenters that support revision of the NO_2 standard to a level within the range recommended by the CASAC majority (''<10–20 ppb'') stated that the existing standard does not include all forms of nitrogen that contribute to acidification, eutrophication, or nutrient enrichment, and the standard would need to be much lower in consideration of relationships with total nitrogen deposition. One comment also expressed support for both retaining the existing standard and for revising the standard to a level of 35–40 ppb, averaged over three years, ''as supported by the scientific evidence,'' without elaboration. Another comment recommended revision of the indicator of the existing standard to include nitric oxide (NO) in addition to NO_2, while recommending no other revisions.

We disagree with the commenters' position that the NO_2 standard needs revision to provide public welfare protection from total N deposition. As an initial matter, we note that, as discussed in section II.B.2.b.(2)(a) above, not all nitrogen compounds are criteria pollutants and accordingly, the CAA does not require the consideration of NAAQS for all N compounds or for total N deposition. Further, the secondary standard for N oxides is not required by the Act to address pollutants other than N oxides. Additionally, the air quality and deposition analyses developed in this review (*e.g.,* PA, Chapter 6 and Sales et al., 2024) describe appreciable geographic (and temporal) variation in the portion of total N deposition contributed by N oxides, potentially explaining the poor or lack of correlation between NO_2 concentrations and total N deposition observed in the PA analyses,[122] which indicates that a NO_2 standard would have little likelihood of efficacy in such a use.

One commenter stated that the current N deposition is resulting in harm to national park resources and expressed the view that the scientific evidence of N deposition adverse effects outweighs uncertainties associated with N critical loads. In so doing, the commenter claimed that justifications described in the PA for the option of retaining the NO_2 standard, without revision, included (1) a lack of clarity of the role of current and legacy deposition in causing harm, and (2) the position that CLs involve designations of harm based on ''arbitrary'' levels of change. In so stating, the commenter conveyed their view that CLs are often based on studies that they stated demonstrate that reducing N deposition improves the resource condition even if N deposition continues to exceed a resource-specific CL.

As an initial matter, the EPA disagrees that the PA conclusions relied on a judgment that critical loads are ''arbitrary'' to support the option of retaining the NO_2 standard and notes that is also not part of the basis for the proposed decision to retain this standard. As described in sections II.A.3.c. and II.B.2.a.(2)(a), the EPA recognizes the usefulness of the CL concept in appropriate contexts and has utilized CLs in the aquatic acidification REA. The findings from the REA, based on the use of CLs for a set of ANC benchmarks, are a critical aspect of the Administrator's decision on the secondary SO_X standard, as discussed in section II.B.3. below. Thus, while this concept can inform decision-making in NAAQS reviews, the science policy judgments associated with secondary NAAQS decisions, including those regarding risk levels associated with CL values and the weight to place on the evidence supporting them (with its various limitations and associated uncertainties), are to be made by the Administrator. The EPA does not agree with the view that a deposition rate identified as a CL is necessarily synonymous with environmental loading anticipated to elicit effects that are adverse to public welfare. Simply being labelled a CL does not confer such a status on a level of ecosystem loading without, for example, consideration of the strength of the evidence on which the CL is based, and a characterization of the ecological response (including severity and scale) for which it is estimated.

[120] To the extent CAA section 302(g) is relevant it simply provides discretion to the Administrator to treat precursors as pollutants where appropriate. While treating precursors as pollutants may be appropriate in some circumstances when implementing the NAAQS, the Administrator does not find it appropriate to treat precursors as criteria pollutants for purposes of reviewing and revising the NAAQS.

[121] Additionally, precursors may be regulated in their own right as pollutants. For example, oxides of nitrogen are both a criteria pollutant and precursors to ozone, and VOCs may be regulated both as NESHAP and as ozone precursors. See CAA section 112(b)(2). However, in those cases the pollutant has independently satisfied the prerequisites for regulation under the relevant programs.

[122] For example, as recognized by the CASAC majority ''when considering all ecoregions, there is no correlation between annual average NO_2 and N deposition'' (Sheppard, 2023, Response to Charge Questions, p. 24). The final PA reported negative correlation coefficients for both NO_2 EAQMs and a coefficient below 0.4 for SLAMS NO_2 concentrations.

In making their statement that assignment of a ''poor'' or ''fair'' conditions rating indicates impacts on national park resources, the commenter referred to a National Park Service technical analysis of ''park-specific critical loads'' and deposition, without providing that analysis or describing the basis for their judgments of harm for instances when estimated deposition in a specific area exceeds the critical loads they have derived.[123] In addition, the commenter also did not provide any evidence specific to N oxides or deposition of oxidized N to support their claim regarding the N oxides standard. Rather the comment implied the view that impacts associated with total N deposition are attributable to N oxides. We disagree with the commenter's view that deposition from N oxides under the existing standard is causing harm. As described in the proposal (section II.E.3.), in the PA, and, in greater detail, in the additional analyses presented in Sales et al. (2024), for the areas of highest total N deposition, such as areas where average total N deposition is above 10 kg/ha-yr, which is the benchmark emphasized by the CASAC in making its recommendations regarding standards to address the ecological effects of N compounds (as described in section II.B.1.b. above), oxidized N is no longer playing the leading role. Rather, reduced N contributes the majority of N deposition in these areas.[124] Unlike the situation in 2000–2002, when oxidized N deposition accounted for up to approximately 80% of total N deposition, on average, in States with average total N deposition greater than 10 kg/ha-yr, oxidized N deposition is now approximately half or less of total N deposition (Sales et al., 2024, Table 5). In fact, in the most recent period analyzed (2019–2021), mean oxidized N deposition is below 5 kg/ha-yr in all States of the CONUS; this is also the case for median oxidized N deposition in all CONUS ecoregions (Sales et al., 2024).

Another group of commenters also referenced the National Park Service descriptions of park conditions related to N (and S) deposition in stating that 95% of parks are experiencing wet deposition of N greater than 1 kg/ha-yr. They claimed that the occurrence of this level of deposition indicates harmful impacts to park soil, waterbodies and associated wildlife and indicated that such an occurrence supports their position that the secondary NO_2 (and PM) standards should be revised as recommended by the CASAC majority. As support for the 1 kg/ha-yr benchmark below which a ''good'' condition is assigned (and above which is assigned a ''fair'' or ''poor'' rating which the commenters characterized as indicative of harm), the commenters cited two studies.

The EPA notes, however, that the cited studies are limited in scope (to a lake in Washington State and a group of high-altitude lakes in some western and eastern regions) and include judgments by the authors of specific measures on which the authors base their CLs. One of the two studies actually identifies CLs ranging up to 8 kg/ha-yr (Baron et al., 2011).[125] Yet, the comment focuses on 1 kg/ha-yr, without consideration of 8 kg/ha-yr. In light of the limited scope of these studies, and the fact that a number of the identified CLs exceed 1 kg/ha-yr, among other factors, the EPA does not agree that these studies provide a basis for concluding that adverse public welfare effects are occurring in 95% of parks based on estimated deposition at/above 1 kg/ha-yr (a level far below the level referenced by the CASAC majority in advice regarding protective standards). These commenters also did not indicate how the National Park Service assignments of conditions in parks support the position that the NO_2 standard should be revised to a level of <10–20 ppb, and we are unaware of any linkage. Further, as noted above, an appreciable amount of total N deposition is deposition of reduced N which is not influenced by N oxides in ambient air and consequently would not be affected by changes in a NAAQS for N oxides.

With regard to acidification risk posed by deposition of N compounds, we additionally note the REA finding that recent deposition conditions indicate negligible contribution of N compounds to aquatic acidification risk. Accordingly, as discussed in section II.B.3. below, the decision to revise the SO_2 standard is intended to address the main contributor to ecosystem acidification, S compounds associated with ambient air concentrations of SO_X. Thus, in consideration of the preceding discussion and other factors further discussed in section II.B.3. below, the Administrator judges that, based on the available evidence in this review, revision to the secondary annual NO_2 standard is not warranted.

The commenter recommending revision of the standard indicator to include NO, in addition to NO_2, expressed the view that the EPA should not assume that effects reported to be associated with short-term NO_2 concentrations in ambient air have no relationship to NO, which the commenter stated is also present in ambient air. In so doing, the commenter cited a controlled human exposure study of diesel exhaust and brain function indicator changes, additionally cites an epidemiologic study that reports an association of health care costs with ambient air concentrations of NO_2 and NO and noted that NO concentrations are higher than NO_2 concentrations (in terms of ppb) in areas near traffic or oil and methane gas extraction activities. The EPA disagrees with the commenter that the effects on which the commenter focused—subtle changes in cellular activity in a specific region of human brain as reported in a controlled human exposure study of short-duration diesel exhaust exposures (in which NO_2 [but not NO] was one of the components analyzed) and health care costs—are welfare effects; thus, their relevance for this review is unclear.

Further, in support of their statement that NO_2 concentrations in ambient air have no relationship to NO concentrations,[126] the commenter simply referenced tables of hourly NO and NO_2 concentrations available from Colorado Department of Public Health and Environment, which are clearly labeled as data collected in real-time that ''have not been corrected nor validated.'' We note that, although the data have not been validated, they generally illustrate the expected diurnal pattern for these pollutants near combustion sources (*e.g.,* with NO initially increasing with morning traffic, and then declining as it is converted to NO_2 [1971 AQCD, p. 6–1]). While recognizing these common patterns in the relationship between the two

[123] The comment did not discuss why this approach to assigning a ''poor,'' or other than ''good,'' rating is evidence of N deposition-related impacts that could be addressed by revision of the NO_2 or $PM_{2.5}$ national ambient air quality standards or that indicates a potential for adverse effect to the public welfare.

[124] For example, in the 14 ecoregions with median N deposition estimated to be above 10 kg/ha-yr in the 2019–2021 period, reduced N comprises more than 50% of total N deposition (Sales et al., 2024, Table 3).

[125] This study estimates multiple CLs that differ for nutrient enrichment- and acidification-related effects and for eastern and western lakes, relying on data generally dating from 1997 to 2006 (Baron et al., 2011). The second study uses a lake sediment core indicating a period of changed phytoplankton composition, estimated to be around 1969–75, and N deposition estimates for the 1969–75 period (Sheibley et al., 2014).

[126] In describing their position that the indicator should be revised, the commenter also suggests that the NAAQS ambient air monitoring system is inadequate. The commenter provided no evidence in support of this suggestion, and we continue to find that the current ambient air monitoring network for NAAQS is appropriate.

chemicals, we further note that the form of the existing standard is an annual average, and the commenter did not provide validated data or analyses that might assess the existence of a, or support their view that there is no, relationship between annual average concentrations of NO and NO_2.

The comment also does not include any information related to concentrations of either pollutant, or both in combination, at which welfare effects of concern may occur and relate that to ambient air concentrations associated with the existing secondary NO_2 standard. The evidence in 1971 when the existing standard was set describes the conversion of NO to NO_2 in the presence of oxygen, with NO_2 being the more stable air pollutant away from sites of combustion and the one for which analytical methodology existed for its direct analysis at that time (1971 AQCD). While there is a study from the mid-1980s for effects of NO on photosynthesis, which indicates a potential for greater toxicity of NO to some plant species, the NO concentrations reported for this study are nearly two orders of magnitude greater than those found in ambient air. Further, the vegetation effects evidence base is much more extensive (with regard to species and specific effects studied) for NO_2 and includes studies that investigate both NO and NO_2 together (ISA, Appendix 3, section 3.3). The NO_2 standard is intended to provide protection from anticipated effects of oxides of nitrogen, including NO and NO_2, but the commenter does not provide a basis for concluding that an annual average NO_2 standard is insufficient to provide the requisite protection. Thus, we find no support in the available information in this review that might support their claim that the existing standard should be revised to be an annual average concentration of 53 ppb, in terms of the sum of NO and NO_2.

(c) Particulate Matter

Comments opposed to the proposed decision to retain the secondary PM standards generally focused on $PM_{2.5}$ and called for more stringent secondary standards. In so doing, these commenters cited the specific $PM_{2.5}$ standard revisions recommended by the CASAC majority, summarized in II.B.1.b. above. With regard to the annual $PM_{2.5}$ standard, these commenters also discussed analyses presented in the PA, which they stated provide support to the use of the annual $PM_{2.5}$ standard to address total N deposition. In support of a revision to the $PM_{2.5}$ standard, some commenters noted the increased role of NH_3 in total N deposition, including in estuaries and coastal waters where eutrophication has been reported or in national parks. These commenters expressed the view that the contribution of NH_3 to N deposition and related effects can be addressed through revisions to the $PM_{2.5}$ standard. In so doing, they further stated that the EPA's proposed decision to retain the existing standard is based on uncertainties and complexities related to NH_3 and that such uncertainties and complexities are an insufficient basis for retaining the existing standard, additionally citing a 2002 court decision regarding EPA acting when it has enough information to do so (*Am. Trucking Ass'ns* v. *EPA,* 283 F.3d 355, 380 [D.C. Cir. 2002]). In support of their position, the commenters stated that the EPA must act when enough information is available to anticipate such effect, and deciding not to revise is inconsistent with the Act's protective direction. Commenters additionally suggest that the EPA inappropriately imposed limits on its consideration of the trajectory-based analyses so as to provide support for the EPA conclusion that the NO_2 and $PM_{2.5}$ metrics do not provide adequate vehicles for regulating N deposition. Another commenter, in support of their position that the existing $PM_{2.5}$ standards should be revised as recommended by the CASAC majority, expressed the view that reduced N deposition has become the dominant form of N deposition, which they stated is impacting national park resources in many areas of the U.S. such that a revised standard would help to reduce such pollutants. Additionally, a comment recommending revision of the $PM_{2.5}$ standard stated that the range of revised levels suggested by the CASAC majority would keep S deposition below 5 kg/ha-yr and N deposition at or below 10 kg/ha-yr and stated that the CASAC majority range was based on NADP and IMPROVE monitoring data and modeled results, without further explanation. Another comment recommended revision of the annual $PM_{2.5}$ standard to 12 $\mu g/m^3$,[127] based on their view that it would add no additional requirements and could streamline implementation plan development and compliance. Lastly, some commenters additionally expressed that the 24-hour $PM_{2.5}$ standard should be revised, again citing recommendations from the CASAC majority and protection against short-term episodic deposition and visibility impairment.

For the reasons stated below, elsewhere in section II.B.2., in section II.B.3. and in the Response to Comments document, the EPA disagrees that these comments provide a sufficient justification for revising the PM secondary standards. In support of their position that the $PM_{2.5}$ standard is an appropriate tool for controlling particulate N and should be revised to a value within the range of 6 to 10 $\mu g/m^3$ recommended by the CASAC majority, some commenters state that NH_4^+ has been increasing in cloud water and in $PM_{2.5}$ and reference statistically significant correlation coefficients for total N deposition estimates and concentrations of $PM_{2.5}$ mass (and N components) in remote Class I areas (PA, Figure 6–32), which they suggest supports their view that use of $PM_{2.5}$ ''as an ambient air quality indicator to total nitrogen deposition is not unreasonable.'' They also claim that Figure 6–32 in the final PA, and Figure 6–33 presenting total N deposition estimates versus total particulate N and NH_4^+ at 27 Class I area sites, provide support for the CASAC majority recommendation on revising the $PM_{2.5}$ standard, which they endorse.

As an initial matter, we disagree with the view that effects of total N deposition (from all contributing pollutants) are a determinative consideration in judging the adequacy of the secondary $PM_{2.5}$ standard, as discussed in section II.B.2.b.(2)(a) above. Further, we disagree that NH_4^+ in $PM_{2.5}$ has been increasing, finding instead that the contribution of NH_4^+ to $PM_{2.5}$ mass at sites across the U.S. has been decreasing over the past decade (Sales et al., 2024). Further, to the extent the commenters are claiming the CASAC majority recommended range of annual $PM_{2.5}$ standard levels, which they endorse, to be supported by the pattern of $PM_{2.5}$ concentrations and total N deposition estimates at 27 Class I area IMPROVE monitoring sites (in either draft PA Figure 6–13 or final PA Figure 6–32), we disagree that this information provides a basis for decisions on the standard. The commenters are overlooking several relevant aspects of the available information.[128]

[127] This was also the advice of the CASAC minority, with 12 $\mu g/m^3$ being the level of the annual primary standard when CASAC provided its advice.

[128] One aspect overlooked is that the PA Figure 6–32 cited by the commenter in referencing correlation coefficients presents a different metric than the figure in the draft PA cited by the CASAC majority in conveying its $PM_{2.5}$ standard recommendations. Figure 6–13 in the draft PA that was cited by the CASAC majority presents 3-year average concentrations of data from 2002 to 2019 (using different 3-year periods than those used throughout the rest of the PA), while the final figure

Particularly important is that the monitoring sites represented by these figures comprise just a small subset of the more than a thousand $PM_{2.5}$ monitoring sites across the U.S., and this subset of monitors is in remote areas. Accordingly, these monitors are not in areas where $PM_{2.5}$ concentrations are highest. Thus, the $PM_{2.5}$ concentrations in the remote area figure are not representative of $PM_{2.5}$ concentrations that would need to be controlled to limit deposition across the U.S., including in these areas. Such deposition is necessarily related to atmospheric transport, among other factors, and a focus solely on remote areas cannot be expected to identify the level for a $PM_{2.5}$ standard (that would need to be met across the U.S.) with the potential to yield the desired deposition rate in these areas. This is because at the time of the deposition levels observed in these areas, the $PM_{2.5}$ concentrations are higher in areas not represented in the figure that may contribute to deposition at the sites in the figure (and at other sites).[129] Further, the PA analyses of N deposition and $PM_{2.5}$ concentrations at SLAMs also do not provide a basis for identifying 3-year average annual $PM_{2.5}$ concentrations that might be expected to constrain nearby N deposition below certain target levels (*e.g.,* PA, Figure 6–39).[130] For all of these and related reasons, the Administrator, in making his proposed and final judgments regarding the secondary PM standards, did not find the CASAC majority focus on remote area analyses to be informative in making decisions on the annual $PM_{2.5}$ standard.

Regarding the commenters' criticism of the EPA's consideration of the trajectory-based analyses for N deposition and the $PM_{2.5}$ metric, we note that the commenters do not identify a technical flaw in EPA's considerations or state what they conclude from the trajectory-based analyses and how they do so. The EPA has fully considered the trajectory-based analysis results presented in the PA (PA, section 6.2.4.2, 6.4, 7.2.3.3 and 7.4) and summarized in section II.A.2. above. We note that, while, when considering the full dataset, there is a positive correlation of downwind total N deposition and upwind values of the EAQM-weighted metric, with a low-moderate coefficient value, the correlation coefficient value is essentially zero in the most recent time period (PA, Table 6–11). And, importantly, there is a poor and negative correlation for the EAQM-max metric; this correlation is negative both for the overall dataset inclusive of all five time periods and for each of the five time periods individually (PA, Table 6–11). Thus, we disagree with commenters that we have inappropriately or inadequately considered the trajectory-based analyses for $PM_{2.5}$ and N deposition. Also, rather than limiting consideration of these results to a narrow temporal window, as claimed by the commenters, we have considered multiple aspects of the full results. As described in section II.B.3. below, these considerations were part of the basis for the Administrator's conclusion on the PM standards.

Also overlooked by the commenters is the fact, as discussed in section II.A.2. above, that the percentage of $PM_{2.5}$ mass comprised of N compounds is no higher than about 30% in the recent period, and ranges down to less than 5% across the U.S., varying widely from region to region (PA, Figure 6–56 [upper panel]; Sales et al., 2024). We note that focus by the commenters (and the CASAC majority) on a small subset of the $PM_{2.5}$ monitors across the U.S. (*i.e.,* monitors in 27 Class I area sites [PA Figure 6–32]) would not necessarily reflect the variability of $PM_{2.5}$ mass composition occurring across the U.S. Nonetheless, the percentage of $PM_{2.5}$ mass comprised of N compounds affects the extent to which a particular level for an annual secondary $PM_{2.5}$ standard levels can be expected to control N deposition rates to meet a particular objective for protection from deposition-related effects. As described in section I.A. above, the Administrator is required to set a NAAQS that is neither more stringent nor less stringent that necessary. Given the fact that up to 95% of $PM_{2.5}$ in some regions of the U.S. (and no more than 70% in others) is not N compounds, we are unable to make a reasoned judgment about levels of N deposition that would result from control measures to reduce $PM_{2.5}$ concentrations to any particular level. In fact, based on the information available, annual average $PM_{2.5}$ concentrations could be reduced in some areas, *e.g.,* to meet a lower standard, without reducing concentrations of the N components of $PM_{2.5}$ and, therefore, without affecting N deposition derived from $PM_{2.5}$. Thus, contrary to the commenters' claims, including that revision to a level within the CASAC majority recommended range would keep N deposition at or below 10 kg/ha-yr, the current information indicates that a $PM_{2.5}$ standard would not be expected to provide effective control of particulate N compounds.

With regard to the comment that the EPA should revise the $PM_{2.5}$ standard to address the effects of N deposition contributed by NH_3, we first note that while some NH_3 (a gas) transforms to NH_4^+ (a particulate N compound in $PM_{2.5}$), some NH_3 is directly deposited in dry deposition. Further, some NH_3 is captured in raindrops, where it transforms into NH_4^+ as it is deposited in wet deposition (PA, section 2.5.2; Sales et al., 2024). We additionally note, as discussed in section II.B.2.b.(2)(a), that NH_3 is not a criteria pollutant. As described above and discussed in section II.B.3., the Administrator has considered the $PM_{2.5}$ standard with regard to ecological effects of N deposition associated with PM and protection of the public welfare from such effects. In so doing, he has understood that the percentage of $PM_{2.5}$ relevant to such effects ranges from 30% down to 5% or less that is N compounds, and that this percentage varies across the U.S. In light of this and other relevant factors, the Administrator has judged that the $PM_{2.5}$ standard would be ineffective with regard to control of deposition of particulate N compounds, and, as discussed more fully in section II.B.3., has decided to retain the existing standard, without revision.

The EPA also disagrees with the view that the uncertainties and complexities (and limitations) associated with the evidence base and air quality information that were cited by the EPA in its proposed decision to retain the PM standards are an insufficient basis for retaining the existing standard. Although these uncertainties and complexities include those related to NH_3, they are not, as the commenter suggests, limited to those related to NH_3. In support of the commenters' view, they note that the EPA must act when enough information is available to anticipate such effect and then assert that to not revise the secondary $PM_{2.5}$ standards ''is inconsistent with the Act's protective direction.'' While we agree

in the final PA presents annual averages from 2000 to 2019 (PA, Figure 6–32).

[129] In the period from 2014 through 2019 (the period emphasized in the CASAC majority justification that relied on draft PA Figure 6–13) when TDep estimated N deposition is at/below 10 kg/ha-yr and annual average $PM_{2.5}$ concentrations are at/below 10 $\mu g/m^3$ at the 27 Class I area sites, annual average $PM_{2.5}$ concentrations are much higher in other areas of the U.S. that are more fully represented in the regulatory monitoring network (PA, Figure 2–37). As indicated by recent $PM_{2.5}$ design values, the highest concentrations sites are generally in the far west of the country, which given prevailing wind patterns, are generally upwind from the Class I areas (PA, Figures 2–31 and 2–32).

[130] Concentrations at SLAMS from just above 15 $\mu g/m^3$ down to approximately 4 $\mu g/m^3$ since 2010 had nearby total N deposition (in same grid cell) both above and at/below 10 kg/ha-yr (PA, Figure 6–39), and the SLAMS analyses did not provide information on ecoregion median deposition for the ecoregion of SLAMS monitor.

that the EPA must act when enough information is available to anticipate effects, and we recognize that revising the NAAQS generally requires acting in the face of uncertainties to provide necessary protection (as the Administrator is doing in setting a new SO_2 standard), the Administrator cannot set a standard if he lacks any ability to make a reasoned judgment about the effect of the standard. As recognized above and discussed in section II.B.3. below, the uncertainties and limitations of the information with regard to support for a $PM_{2.5}$ standard that can be concluded to provide control for deposition-related effects of particulate N compounds, including NH_4^+, preclude our ability to characterize the extent of control that can be expected.

In addition, the EPA disagrees with commenters who support revising the $PM_{2.5}$ standard based on their view that this would maintain S deposition generally at/below 5 kg/ha-yr. First, we find that the $PM_{2.5}$ indicator is not an appropriate tool and cannot be expected to be an effective tool for controlling S deposition in light of the fact that, in recent periods, SO_4^{2-} (the predominant particulate S compound) is not the dominant component of $PM_{2.5}$ across the U.S. and is a small component in many areas (ISA, Appendix 2, Figure 2–5 [panel B, 2013–2015]; PA, Figure 2–30 [2019–2021]). The variability in the fraction of $PM_{2.5}$ comprised of S compounds likely contributes to the PA findings on correlations of S deposition with $PM_{2.5}$ concentrations (PA, Chapter 6). The correlation coefficients for this relationship in the trajectory-based analyses are lower than those for the relationship between S deposition and SO_2 concentrations, with the correlation for the $PM_{2.5}$ EAQM-max actually being negative (PA, Tables 6–12 and 6–8). In light of such findings, the Administrator has not found $PM_{2.5}$ to be an appropriate indicator for a secondary standard to provide protection from ecosystem effects of S compound deposition. Rather, as discussed in section II.B.3. below, based on the available information and analyses, the Administrator has judged that a new annual secondary SO_2 standard of 10 ppb can be expected to achieve the target identified by the CASAC majority of generally maintaining S deposition at/below approximately 5 kg/ha-yr. This new SO_2 standard provides a much more explicit and precise approach for controlling S deposition-related effects of SO_X and particulate S compounds.

The comment that recommended revision of the annual $PM_{2.5}$ standard to be 12 $\mu g/m^3$, based on the view that it would not present additional requirements and could streamline implementation plan development and compliance, provided no information related to the extent of public welfare protection that might be provided by such a revision, or information indicating that the existing standard does not provide adequate protection. As explained in section II.B.3. below, the EPA disagrees with the commenter's recommendation for such a revision, and the Administrator finds that the available information supports retaining the current standard.

The comment regarding revision of the 24-hour $PM_{2.5}$ standard to address short-term episodic deposition and visibility impairment expresses support for the CASAC majority recommendation on this. Beyond this reference to the CASAC majority recommendation, the comment provided no evidence to support their view that there are adverse effects of episodic deposition that would be appropriately addressed by revision of the standard level to 25 $\mu g/m^3$ (from 35 $\mu g/m^3$). As described in section II.B.1.b. above, the CASAC majority recommendation, while alluding to a potential for seasonal variability in deposition and in sensitivity of some species, did not provide evidence for such potentials or evidence to support the conclusion that a revised standard is needed to protect against adverse ecological effects on the public welfare, and the EPA is not aware of such evidence. Thus, as described in section II.B.3. below, the Administrator has decided to retain the existing 24-hour secondary $PM_{2.5}$ standard.

Regarding visibility impairment, as conveyed in the IRP, PA and proposed decision document for this review, $PM_{2.5}$ effects on visibility are outside the scope and are not being addressed in this review because they were addressed in the recently completed PM NAAQS review, which also revised the primary NAAQS for $PM_{2.5}$ (89 FR 16202, March 6, 2024). The commenters advocating for consideration of visibility here erroneously state that these effects were addressed in setting the primary $PM_{2.5}$ NAAQS and further state that this is not a reason for excluding them from consideration in this review. We note, however, that the primary $PM_{2.5}$ NAAQS are not intended to address visibility impairment. Rather, the recently completed review covered both the primary $PM_{2.5}$ NAAQS as well as review of the secondary NAAQS for visibility, materials damage and climate effects. See 89 FR 16202 at 16311–16343 (rationale for decisions on the secondary NAAQS). Thus, visibility is a welfare effect that has been addressed in assessing the protection provided for the public welfare by the secondary $PM_{2.5}$ standard in the 2020 PM NAAQS decision and the reconsideration of that decision which was completed earlier this year (89 FR 16202, March 6, 2024) and is outside the scope of this review.

3. Administrator's Conclusions

Having carefully considered the public comments, as discussed above, the Administrator believes that the fundamental scientific conclusions on the ecological effects of SO_X, N oxides, and PM reached in the ISA and summarized in the PA and in section II.C. of the proposal remain valid. Additionally, the Administrator believes that the judgments he reached in the proposal (section II.E.3.) with regard to consideration of the evidence and quantitative assessments and advice from the CASAC remain appropriate. Thus, as described below, the Administrator concludes that the current secondary SO_2 standard is not requisite to protect the public welfare from known and anticipated adverse effects associated with the presence of SO_X in the ambient air and that the standard should be revised. Further, based on the information available in this review and summarized in the proposal, including advice from the CASAC, as well as public comment and additional analyses developed in consideration of public comments, the Administrator concludes that revision of the existing 3-hour secondary SO_2 standard to an annual standard of 10 ppb, averaged over three years, is required to provide additional needed protection from atmospheric deposition-related effects. He additionally concludes that it is appropriate to retain the existing secondary standards for N oxides and PM.

In his consideration of the adequacy of the existing secondary standards for SO_X, N oxides, and PM, and what revisions or alternatives are appropriate, the Administrator has carefully considered the available evidence and conclusions contained in the ISA regarding the weight of the evidence for both the direct effects of SO_X, N oxides, and PM on plants and lichens and for effects related to atmosphere deposition in ecosystems of N and S compounds associated with the presence of these pollutants in ambient air, and associated areas of uncertainty. In so doing, he recognizes the evidence of direct biological effects associated with elevated short-term concentrations of SO_X and N oxides that formed the basis for the existing secondary SO_2 and NO_2 standards, the evidence of ecological effects of PM in ambient air, primarily

associated with loading on vegetation surfaces, and also the extensive evidence of ecological effects associated with atmospheric deposition of N and S compounds into sensitive ecosystems. He has also considered the quantitative analyses of aquatic acidification risk and of air quality and deposition estimates, with associated limitations and uncertainties; policy evaluations of the evidence, exposure/risk information, and air quality information in the PA; and the related additional analyses (Sales et al., 2024). Together, these conclusions, analyses, and evaluations, along with CASAC advice and public comments, inform his judgments in reaching his decisions on secondary standards for SO_X, N oxides, and PM that provide the requisite protection under the CAA.

In recognizing that a prominent part of this review is the consideration of secondary NAAQS with regard to ecological effects related to deposition of S and N compounds, the Administrator notes the view of the CASAC regarding deposition standards. In its advice to the Administrator in this review, the CASAC expressed the view that the CAA does not preclude the establishment of a NAAQS in terms of atmospheric deposition (section II.B.1.b. above). As discussed in sections II.B.2.b.(2)(a) and II.B.2.b.(3)(a) above, the EPA disagrees with this view. Rather, the EPA concludes that it does not have the authority to set a deposition standard under the existing CAA, and the EPA is not adopting a deposition standard in this action.

With regard to the adequacy of public welfare protection provided by the existing secondary SO_2 standard, the Administrator first considers the adequacy of protection the existing standard provides for ecological effects related to ecosystem deposition of S compounds associated with the presence of SO_X in ambient air. As an initial matter, the Administrator recognizes the long-standing evidence of the role of SO_X in ecosystem acidification and related ecological effects. While he also notes the ISA determinations of causality for S deposition with two other categories of effects related to mercury methylation and sulfide phytotoxicity (ISA, Table ES–1; PA, section 4.4), he recognizes, as noted in section II.A.3.c. above, that quantitative tools and approaches are not well developed for ecological effects associated with atmospheric deposition of S other than ecosystem acidification (PA, section 7.2.2.1).[131] In this context, he notes that the current evidence does not indicate such effects to be associated with S deposition at lower rates than those posing risks of ecosystem acidification, and judges that a decision focused on providing the requisite protection for acidification-related effects will also contribute protection for other effects. Thus, he gives primary consideration to effects related to acidifying deposition, given the robust evidence base and available quantitative tools, as well as the longstanding recognition of historical impacts in acid-sensitive ecosystems across the U.S.

As an initial matter, the Administrator notes that, during the 20-year period from 2001 through 2020, the range of median S deposition estimates for the 84 ecoregions in the contiguous U.S. extend up to 20 kg S/ha-yr (PA, Appendix 5A, Table 5A–11) and that during this period the existing secondary SO_2 standard was met (Sales et al., 2024). Over this 20-year period in the contiguous U.S., design values for the existing secondary SO_2 standard (second highest 3-hour average in a year) were generally well below the standard level of 500 ppb (PA, section 6.2.1). For example, in the earliest 3-yr period analyzed (2001–2003), when median total S deposition was estimated to be approximately 20 kg/ha-yr in the Western Allegheny Plateau ecoregion (which includes the Ohio River Valley) and just over 16 kg/ha-yr in the Central Appalachians ecoregion (PA, Appendix 5A, Table 5A–11), virtually all design values for the existing 3-hour secondary standard were below 400 ppb (across the CONUS) and the 75th percentile of 3-hour design values was below 100 ppb (PA, Figure 2–27). With regard to the 18 eastern ecoregions assessed in the REA, the Administrator notes that during this period, the ecoregion median deposition ranged above 15 kg/ha-yr and the 90th percentile[132] S deposition estimates for half of these 18 ecoregions were at or above 15 kg/ha-yr, ranging up above 20 kg/ha-yr in the highest ecoregion (figure 2 above).

In considering the extent to which this magnitude of estimated S deposition (summarized immediately above) indicates a potential for effects on the public welfare, the Administrator turns to consideration of the aquatic acidification risk indicated for such estimates by the REA. Specifically, he takes note of the REA estimates of aquatic acidification risk associated with the S deposition estimated to have occurred in 2001–2003, when the existing standard was met. In this time period, the REA finds that across the 18 acid-sensitive ecoregions analyzed, the pattern of S deposition in the five most affected ecoregions is associated with more than about a third of waterbody sites in the ecoregions being unable to achieve even the lowest of the three acid buffering capacity benchmarks used as risk indicators (ANC of 20 μeq/L). And, in the single most affected ecoregion, more than half of waterbody sites are unable to meet this benchmark. In considering these results, the Administrator recognizes the use of ANC as an indicator of aquatic acidification risk and as a quantitative tool within a larger framework of considerations pertaining to the public welfare significance of acid deposition-related effects. In this framework, he takes note of the PA description of the three benchmarks used in the REA, with the value of 20 μeq/L considered to represent a level of acid buffering capacity consistent with a natural or historically occurring ANC range and 50 μeq/L to provide greater protection, particularly from episodic acidification events, additionally recognizing that ANC levels below 20 μeq/L have been associated with reductions in number of fish species (and species population sizes) in some sensitive waterbodies of the Shenandoah and Adirondack Mountains (as summarized in section II.A.4.a. above).[133]

The Administrator also takes note of the PA discussion of the potential public welfare impacts of aquatic acidification that can include reductions in recreational and subsistence fisheries, and related reductions in recreational and cultural usage of these areas by the public, summarized in sections II.A.3.b. and II.B.1.a.(3) above. For example, he

[131] For example, there are no studies in the available evidence investigating linkages of S deposition, in terms of quantitative estimates, such as CLs, with other non-acidifying effects (ISA, Appendix 12, section 12.6); these effects, in wetland and freshwater ecosystems, include the alteration of Hg methylation in surface water, sediment, and soils; and changes in biota due to sulfide phytotoxicity including alteration of growth and productivity, species physiology, species richness, community composition, and biodiversity (ISA, Appendix 12, section 12.7).

[132] This refers to the 90th percentile in the distribution of S deposition estimates for TDep grid cells in each ecoregion in which there were waterbody sites assessed in the REA.

[133] Effects of elevated acid deposition have been evident for decades in the Adirondack region of New York, USA (Driscoll et al 2016). Fisheries surveys by NY DEC in the 1980s indicated reductions in fish populations in Adirondack lakes which researchers indicate may relate to acidification in these lakes (Baker and Schofield, 1985). For example, a survey of 1469 Adirondack lakes conducted in 1984–87 found chronic acidity (ANC below 0 μeq/L) in 27% of lakes (Kretser et al., 1989). An additional 21% of Adirondack lakes were found to have summertime ANC values between 0 and 50 μeq/L, indicating a potential for ANC to dip to values near or below 0 μeq/L during periods of high discharge, such as snowmelt or precipitation events (Kretser et al., 1989).

recognizes that aquatic acidification affects the diversity and abundance of fish and other aquatic biota in the affected waters, and consequently also affects the array of public uses of these waterbodies. With this in mind, he focuses on the prevalence of elevated aquatic acidification risk across multiple waterbodies in multiple ecoregions (with ANC as the acidification risk indicator) recognizing that the significance of aquatic acidification-related impacts on the public welfare (*e.g.,* associated with reductions in public usage of aquatic ecosystems in which fisheries have been affected by acidification) increases with greater prevalence of affected waterbodies and ecoregions. In this context, the Administrator judges that the prevalence of waterbodies concluded to be unable to achieve the lowest ANC benchmark (below which the increased risk of episodic acidification events may threaten survival of sensitive aquatic species) during the 2001–2003 period—extending from more than 30% to just over 50% in the five most affected eastern ecoregions (figure 1 above)—can be anticipated to cause adverse effects on the public welfare. The Administrator also considers the advice from the CASAC in considering deposition-related effects of S compounds, noting the CASAC consensus that the existing standard does not provide protection from such effects. Lastly, he notes the lack of public comments conveying the position that the existing standard provides protection from deposition-related effects (section II.B.2.a. above). Thus, based on the findings of the REA, associated policy evaluations in the PA with regard to S deposition and acidification-related effects in sensitive ecosystems, and in consideration of advice from the CASAC and public comments on the proposed decision, the Administrator judges that the current SO_2 secondary standard is not requisite to protect the public welfare from adverse effects associated with acidic deposition of S compounds in sensitive ecosystems.

Having reached this conclusion that the existing secondary SO_2 standard does not provide the requisite protection of the public welfare from adverse S deposition-related effects, most prominently those associated with aquatic acidification, the Administrator next turns to identification of a secondary standard to provide such protection. In so doing, consistent with the approach employed in the PA, he focuses first on identifying S deposition rates that might be judged to provide an appropriate level of public welfare protection from deposition-related effects. As in reaching his proposed decision, the Administrator focuses primarily on the aquatic acidification risk estimates as presented and evaluated in the PA (PA, sections 5.1, 7.1 and 7.3, and Appendix 5A) and summarized in sections II.A.4. and II.B.1.a.(3) above. In this context and consistent with his consideration of these estimates in judging the existing SO_2 standard to be inadequate, he finds the PA evaluation of the risk estimates in terms of waterbodies estimated to achieve the three acid buffering capacity benchmarks (20, 30 and 50 μeq/L) to be an appropriate basis for his consideration of levels of protection. Further, he judges that a focus on the ecosystem-scale estimates, in particular, is appropriate for his purposes in identifying conditions that provide the requisite protection of the public welfare.

The Administrator recognizes that the CAA requires the establishment of secondary standards that are, in the Administrator's judgment, requisite (*i.e.,* neither more nor less stringent than necessary) to protect the public welfare from known or anticipated adverse effects associated with the presence of the pollutant in the ambient air. As in all NAAQS reviews, the EPA's approach to informing these judgments is based on a recognition that the available welfare effects evidence generally reflects a continuum that includes ambient air-related exposures for which scientists generally agree that effects are likely to occur, through lower levels at which the likelihood and magnitude of response become increasingly uncertain. The Administrator recognizes that the CAA does not require establishment of secondary standards at a zero-risk level, but rather at levels that reduce risk sufficiently so as to protect the public welfare from known or anticipated adverse effects. Thus, the Administrator recognizes that his decision on the secondary standard for SO_X is inherently a public welfare policy judgment that draws upon the scientific evidence for welfare effects, quantitative analyses of air quality, exposure, and risks, as available, and judgments about how to consider the uncertainties and limitations that are inherent in the scientific evidence and quantitative analyses.

In his consideration of deposition conditions that provide the requisite protection of the public welfare, as in reaching his proposed decision, the Administrator focuses on the ecoregion-scale findings of the aquatic acidification REA, with particular attention to the waterbody-specific risk estimates summarized in the PA for each of the 18 well-studied, acid-sensitive eastern ecoregions and the five time periods. The PA summarizes the percentages of waterbodies per ecoregion estimated to achieve (*i.e.,* to meet or exceed) the three ANC benchmarks in each time period in terms of the ecoregion median S deposition value for that time period, which are grouped into bins (*e.g.,* percentages for ecoregion-time period combinations with median ecoregion S deposition at/below 10 kg/ha-yr, or 8 kg/ha-yr or 5 kg/ha-yr). The Administrator considers particularly the ecoregion median S deposition values at and below which the associated waterbody-specific risk estimates indicated a high proportion of waterbodies in a high proportion of ecoregions would achieve ANC values at or above the three acid buffering capacity benchmarks (as summarized in tables 3 and 4 above). In so doing, he recognizes a number of factors, as described in the PA, which contribute variability and uncertainty to waterbody estimates of ANC and to interpretation of acidification risk associated with different values of ANC (PA, section 5.1.4 and Appendix 5A, section 5A.3). In light of these factors, rather than focusing on REA ecoregion-scale results for a single ANC benchmark, he finds it appropriate to consider the pattern of REA results across all three benchmarks, as evaluated in the PA and considered by the CASAC majority (summarized in section II.B.1.b. above).

In considering the summary of results for the ecoregion-scale analysis of ecoregion median deposition bins (in the draft PA),[134] the CASAC majority focused on a level of S deposition estimated to achieve acid buffering capacity at or above the three ANC benchmarks in 80% (for ANC of 20 and 30 μeq/L) or 70% (for ANC of 50 μeq/L) of waterbodies in all ecoregion-time period combinations [135] (Sheppard, p. 25 of the Response to Charge

[134] While the final PA provides additional presentations of aquatic acidification risk estimates, including those at the ecoregion-scale, the estimates for percentages of waterbodies per ecoregion achieving ANC targets at or below different S deposition values are unchanged from those in the draft PA (PA, section 5.1.3; Table 5–5 [draft PA, Table 5–4]).

[135] The presentation of such percentages in the draft PA (reviewed by the CASAC) were specific to the 90 ecoregion-time period combinations for the 18 eastern ecoregions (draft PA, Table 5–4; PA, Table 5–5). Inclusion of the 7 western ecoregions would yield higher percentages, as more than 90% of waterbodies in those ecoregions were estimated to achieve all three ANC concentration in all time periods (PA, Table 5–4).

Questions). The CASAC majority identify S deposition levels ''generally'' at or below 5 kg/ha-yr as associated with this pattern of acid buffering. The Administrator notes that, as recognized in the PA and the proposal, the REA found ecoregion median S deposition at or below 7 kg/ha-yr in the 18 eastern ecoregions also yields these percentages of waterbodies achieving the three ANC benchmarks (as seen in tables 3 and 4 above).[136]

The Administrator additionally takes note of the PA evaluation of the temporal trend of the ecoregion-scale risk estimates across the five time periods, in the 20 years analyzed, which shows a decline in response to the declining S deposition estimates for those periods. As summarized in the PA and the proposal, the vast majority of the decline occurred across the first decade of the 20-year period. The S deposition estimated to be occurring in the 2010–2012 period included ecoregion medians (across CL sites) ranging from 2.3 to 7.3 kg/ha-yr in the 18 eastern ecoregions (and lower in the 7 western ecoregions), and the highest ecoregion 90th percentile was approximately 8 kg/ha-yr (table 5 and figure 2 above). For this pattern of deposition, the REA estimated more than 70% of waterbodies in all 25 ecoregions assessed to be able to achieve an ANC of 50 ueq/L (figure 1, left panel, above), and more than 80% of waterbodies in all ecoregions to be able to achieve an ANC of 20 ueq/L (figure 1, right panel). The Administrator observes that these estimates of acid buffering capacity achievement for the 2010–12 period deposition—achieving the ANC benchmarks in at least 70% to 80% (depending on the specific benchmark) of waterbodies per ecoregion—are consistent with the objectives identified by the CASAC majority (in emphasizing ecoregion ANC achievement estimates of 70%, 80% and 80% for ANC benchmarks of 50, 30 and 20 μeq/L, respectively). Based on these evaluations of the REA estimates in the PA and advice from the CASAC majority, the Administrator judges that these ecoregion-scale ANC achievement estimates for the three ANC benchmarks (70%, 80% and 80% for ANC benchmarks of 50, 30 and 20 μeq/L, respectively) are reasonable acid buffering capacity objectives for the purposes of protecting ecoregions from aquatic acidification risk of a magnitude of potential public welfare significance. Further, as discussed earlier in this section, the Administrator recognizes that the significance of aquatic acidification-related impacts on the public welfare, including those associated with reductions in public usage of aquatic ecosystems with fisheries affected by acidification, increases with greater prevalence of affected waterbodies and ecoregions. Thus, he finds the CASAC-identified percentages of waterbodies per ecoregion that meet (or exceed) the three ANC benchmarks to be appropriate minimum percentages (for each ANC benchmark) for ecoregions across the U.S. for use in his identification of a secondary NAAQS that will provide the appropriate level of protection against risks of potential public welfare significance. In so doing, he additionally notes that these percentages are met (or exceeded) for the most recent time periods analyzed in the REA (through 2018–2020).

In turning to his consideration of S deposition levels that might be expected to maintain such a level of protection from aquatic acidification risk, the Administrator considers the CASAC majority recommended range of annual average secondary SO_2 standard levels (*i.e.,* 10–15 ppb) that, in the view of these members, would generally maintain S deposition at or below 5 kg/ha-yr. As recognized in the PA, the CASAC majority reference to S deposition associated with their acid buffering objectives was in terms of ecoregion median values in the REA ecoregion-scale analysis.[137] The Administrator additionally takes note of the PA observation of an appreciable reduction in S deposition across the 20-year analysis period in the 25 REA ecoregions, both in terms of the 90th percentile across REA sites in each ecoregion and in terms of the median such that in the second decade of the period (since 2010), the difference in S deposition value between the ecoregion median and 90th percentile is much reduced from what it was in the 2001–2003 period. Although the ecoregion 90th percentile and median estimates for the REA ecoregions ranged up to approximately 22 and 17 kg/ha-yr, respectively, in the 2001–2003 period, both types of estimates fall below approximately 7 to 8 kg/ha-yr by the 2010–2012 period (figure 2 above). In light of this trend, as well as the temporal trend in the REA estimates, and also while recognizing the uncertainties associated with the deposition estimates at individual waterbody sites and with the associated estimates of aquatic acidification risk (PA, section 5.1.4), the Administrator concurs with the PA findings that the ecoregion-scale acid buffering objectives identified above (more than 70% to 80% of waterbody sites in all ecoregions assessed achieving or exceeding the set of ANC benchmarks) can be expected to be met when the median and upper (90th) percentile deposition estimates for sensitive ecoregions are generally at and below about 5 kg/ha-yr with a few occurrences as high as about 8 kg/ha-yr. Thus, he considers it appropriate to focus on S deposition generally at or below about 5 kg/ha-yr, with infrequent occurrences as high as about 8 kg/ha-yr. Based on all of these considerations, the Administrator judges that a secondary standard that would generally maintain a pattern of ecoregion median S deposition consistent with these objectives (at or below 5 kg/ha-yr, with only infrequent occurrences as high as 8 kg/ha-yr) would provide the appropriate level of public welfare protection from aquatic acidification risk.

In his consideration of deposition levels that might provide for protection from aquatic acidification consistent with his identified objectives, the Administrator also considers protection of terrestrial ecosystems from effects related to S deposition. In so doing, he notes that in primarily focusing on the aquatic acidification risk estimates in its evaluation of options for a standard to address deposition-related effects, the PA recognized the linkages between watershed soils and waterbody acidification, suggesting that such linkages indicate that protecting waterbodies from reduced acid buffering capacity (with ANC as the indicator) will also, necessarily, provide protection for watershed soils (PA, section 7.4).[138] The Administrator also notes that a revised standard that would be associated with lower S deposition in sensitive ecoregions than the existing standard (consistent with his decision reached above) would necessarily be associated with lower S deposition in both terrestrial and aquatic ecosystems.

[136] The results for median S deposition at or below 7 kg/ha-yr further indicate that 90% of waterbodies per ecoregion achieve ANC at or above 20, 30 and 50 μeq/L in 96%, 92% and 82%, respectively, of eastern ecoregion-time period combinations (as summarized in section II.A.4.c.).

[137] While the REA ecoregion-scale analysis summarizes risk estimates for each ecoregion in terms of the ecoregion median of the sites analyzed in each ecoregion, the PA notes that the sites estimated to receive the higher levels of deposition are those most influencing the extent to which the potential objectives for aquatic acidification protection are or are not met.

[138] The PA additionally considered the terrestrial acidification risk analyses in the last review which found that total deposition estimates in recent years appear to meet all but the most restrictive of acid deposition target values, with which the PA observed uncertainties to be the greatest (PA, section 5.3.2.1).

He also notes the PA evaluation of the current evidence, particularly with regard to terrestrial plants, including the PA's identification of S deposition levels extending from 5 kg/ha-yr (up to 12 kg/ha-yr), as summarized in section II.A.3.c.(2) above.[139] He further recognizes that this range includes the benchmark referenced by the CASAC majority (generally at or below 5 kg/ha-yr) as affording protection to various tree and lichen species (as summarized in section II.B.1.b. above). In so doing, he recognizes the overlap of these values with his objectives identified above (S deposition generally at or below about 5 kg/ha-hr, with infrequent higher occurrences). Thus, based on the PA, and in consideration of CASAC advice and public comments, the Administrator judges that his focus on aquatic acidification risk and on a pattern of ecoregion median S deposition consistent with his objectives identified above will also provide protection for terrestrial ecosystems, such that a different standard is not needed to provide protection for terrestrial effects.

The Administrator next turns to identification of a secondary standard that can be expected to generally maintain a pattern of ecoregion median S deposition at or below 5 kg/ha-yr, with potentially very few occurrences up to about 8 kg/ha-yr. In so doing, he recognizes the complexity of identifying a national ambient air quality standard focused on protection of the public welfare from adverse effects associated with national patterns of atmospheric deposition, particularly given the degree to which those patterns are influenced by transport and chemical transformation of emissions. As more specifically described in the PA, atmospheric deposition (ecosystem loading) of S is, in a simple sense, the product of atmospheric concentrations of S compounds, factors affecting S transfer from air to surfaces, and time. Further, atmospheric concentrations in an ecosystem are, themselves, the result of emissions from multiple, distributed sources both near and far, atmospheric chemistry, and transport. Accordingly, the Administrator concurs with the PA that consideration of the location of source emissions and expected pollutant transport, in addition to the influence of physical and chemical processes, is important to understanding relationships between SO_2 concentrations at ambient air monitors and S deposition rates in sensitive ecosystems of interest.

Based on these considerations, the Administrator concurs with the PA conclusion that to achieve the requisite level of protection from aquatic acidification effects associated with S deposition in sensitive ecosystems, SO_2 emissions must be controlled at their sources. Accordingly, the Administrator considers findings of the PA analyses of relationships between S deposition estimates and SO_2 concentrations near SO_2 monitors, including at NAAQS regulatory monitors, which are often near large sources of SO_2 emissions. To account for the relationship between upwind concentrations near sources and deposition in downwind areas, the Administrator also considers PA analyses of relationships between ecoregion S deposition estimates and SO_2 concentrations at upwind sites of influence, identified by trajectory analyses (sections II.A.2. and II.B.1.a.(3) above, and PA, sections 6.2.2 through 6.2.4). As evidence of the influence of SO_2 in ambient air on S deposition, all of these analyses demonstrated a positive association between SO_2 concentrations and nearby or downwind S deposition (PA, section 7.4).

With regard to an indicator for a standard to address the effects of S deposition associated with SO_X in ambient air, the Administrator finds his proposed decision for an SO_2 indicator to be appropriate. He reaches this decision based on consideration of the PA evaluations of the linkages connecting SO_X emissions and S deposition-related effects, including the parallel trends of SO_2 emissions and S deposition in the U.S. over the past 20 years that indicate the strong influence of SO_2 in ambient air on S deposition (PA, sections 6.4.1 and 7.4) and the PA finding of SO_2 as a good indicator for a secondary standard to address S deposition (PA, sections 6.4.1 and 7.4). Specific aspects of the PA findings include the declining trend of S deposition that is consistent with and parallel to the sharp declines in annual average SO_2 emissions across the 20-year period, as well as the general association of higher annual average SO_2 concentrations (averaged over three years) at SLAMS with higher local S deposition estimates, in addition to the statistically significant positive correlations observed for ecoregion median S deposition with SO_2 concentrations at upwind monitoring sites of influence in the EAQM analyses. In reaching this decision, the Administrator also notes the CASAC consensus advice and public comments that recommended a standard with SO_2 as an indicator to address ecosystem effects of sulfur deposition.

The Administrator has also considered $PM_{2.5}$ with regard to its potential to be an effective indicator for a standard providing public welfare protection from S deposition-related effects. In so doing, he recognizes that the S species that deposits in ecosystems, SO_4^{2-}, is a component of $PM_{2.5}$. However, he also recognizes that SO_4^{2-} constitutes less than half of $PM_{2.5}$, by mass, across the country, with non-S containing compounds most typically comprising more than 70% of the total annual $PM_{2.5}$ mass in the East and even more in the West (PA, section 2.4.3). He finds that this generally low presence of SO_4^{2-} in $PM_{2.5}$ and the extent to which it varies across the country inhibit his ability to identify a $PM_{2.5}$ standard level that might be expected to provide the desired level of protection from S deposition related effects, an inhibition that does not exist in his use of the SO_2 standard for this purpose. In addition, he takes note of the discussion above in support of his decision regarding a revised secondary SO_2 standard, including the atmospheric chemistry information which indicates the dependency of S deposition on airborne SO_X, as evidenced by the parallel trends of SO_2 emissions and S deposition. Based on all of these considerations, the Administrator judges that protection of sensitive ecosystems from S deposition-related effects is more effectively achieved through a revised SO_2 standard than a standard for PM. Thus, the Administrator judges SO_2 to be the appropriate indicator for a standard addressing S deposition-related effects.

With regard to averaging time and form, the Administrator continues to find his proposed decision (for an averaging time of a year and a form that averages the annual values across three consecutive years) to be appropriate, based on consideration of the PA findings and related analyses, advice from the CASAC majority, and public comments. Among the public commenters that supported adoption of a standard to address deposition-related effects, none objected to the conclusion of the PA that an annual standard would be appropriate for this purpose, although some commenters did support a secondary standard with the same averaging time, form and level of the primary standard, apparently for implementation reasons (discussed in

[139] This range of S deposition levels reflects the PA analysis of studies of effects on terrestrial biota (PA, section 5.3.4 and Appendix 5B). For example, from the most recent observational study evaluated in the ISA and PA, for the non-western tree species that were reported to have a negative association of growth or survival with S deposition, this encompasses the species-specific median deposition estimates for the sites where these species were assessed (PA, section 5.3.4.1 and Appendix 5B, sections 5B.2.2.3 and 5B.2.3).

section II.B.2.a.(3)(c) above).[140] In the quantitative analyses of air quality and deposition, the PA generally focused on a year's averaging time based on the recognition that longer-term averages (such as over a year, compared to one or a few hours) most appropriately relate to deposition and associated ecosystem effects. The PA analyses also used a 3-year form based on a recognition in the NAAQS program that such a form affords stability to the associated air quality management programs that contributes to effective environmental protection. Similarly, in the advice of the CASAC majority on a standard addressing S deposition, these members recommended an annual average standard, and, while these members did not explicitly address form, the information cited in the justification for their recommendation focused on a 3-year form (section II.B.1.b. above). In consideration of these conclusions of the PA and the CASAC majority, and public comments (as discussed in section II.B.2.a. above), the Administrator judges an averaging time and form in terms of annual average SO_2 concentrations, averaged over three years,[141] to be appropriate for a secondary standard providing public welfare protection from adverse effects associated with long-term atmospheric deposition of S compounds.

In turning to consideration of a level for such a standard, as an initial matter, the Administrator again notes the complexity associated with identifying a national ambient air quality standard focused on protection from national patterns of atmospheric deposition, and the associated uncertainty, as described in section II.E.3. of the proposal. Particularly in this case of identifying a standard to provide a pattern of ambient air concentrations that as a whole contributes to deposition across the U.S., it is important to consider the distribution of air concentrations to which the standard will apply. The Administrator considers the evaluations and associated findings of the PA, as well as findings of the related additional analyses, advice from the CASAC, and public comments on the proposed decision for a level within the range of 10 to 15 ppb.

With regard to the advice from the CASAC, the Administrator notes that, as described in section II.B.1.b. above, the majority of the CASAC recommended adoption of an annual SO_2 standard with a level within the range of 10 to 15 ppb. These members indicated their view that this range of levels ''generally maintains'' S deposition at or below 5 kg/ha-yr (based on their consideration of the draft PA).[142] The CASAC majority further conveyed that a standard level in this range would afford protection to tree and lichen species, as well as achieve the acid buffering targets in waterbodies of sensitive ecoregions (described above), and further stated that such a standard would ''preclude the possibility of returning to deleterious deposition values'' (Sheppard, Response to Charge Questions, pp. 24–25).

The Administrator also takes note of the air quality and deposition analyses described in the PA and summarized in sections II.A.2. and II.B.1.a.(3) above. In so doing, the Administrator focused particularly on the results of the PA's trajectory-based analyses for the EAQM-max metric, including the related additional analyses developed in consideration of public comments (Sales et al., 2024). He notes that these results indicate that when the maximum upwind annual SO_2 concentration (3-year average) was no higher than 10 ppb, median deposition in the downwind ecoregion was below 5 kg/ha-yr in more than 90% of the ecoregion-time period combinations in the analysis and below about 6 kg/ha-yr in at least 95% of combinations, with deposition in the remaining few combinations no higher than about 8 kg/ha-yr. Further, he notes the analysis finding that in every instance of upwind maximum annual SO_2 concentrations (averaged over three years) above 10 ppb, the associated estimates of downwind ecoregion median S deposition are all above 5 kg/ha-yr, extending from about 6 kg/ha-yr to as high as approximately 18 kg/ha-yr with 75% of the occurrences above 9 kg/ha-yr (Sales et al., 2024). He judges this magnitude of ecoregion S deposition associated with standard levels above 10 ppb to be well above his objectives. Thus, he finds that a standard level greater than 10 ppb would provide insufficient control of S deposition and related effects and accordingly would not provide the requisite public welfare protection. With regard to a level of 10 ppb, however, the Administrator finds these analyses to indicate that such a level is associated with a pattern of ecoregion median deposition consistent with his previously identified objectives of ecoregion median deposition generally below about 5 kg/ha-yr, with few occurrences of higher levels up to or below about 8 kg/ha-yr. The Administrator additionally finds a level of 10 ppb and the ecoregion median estimates of associated S deposition to be in general agreement with the advice from the CASAC majority including their recommended range of 10–15 ppb for an annual standard level, and their characterization of ''generally'' maintaining S deposition at or below 5 kg/ha-yr.

Before reaching his decision on a standard that in his judgment would provide the requisite protection from deposition-related effects, the Administrator also considered the protection that might be afforded by an annual SO_2 standard, averaged over three years, with a level below 10 ppb. In so doing, he focused on consideration of the level of 5 ppb that was raised in public comment, as discussed in section II.B.2.a.(2) above, considering the findings of the additional analyses of the PA trajectory-based dataset that summarize the ecoregion median S deposition associated with maximum annual average concentrations, averaged over three years, no higher than 5 ppb at upwind sites of influence (Sales et al., 2024). The Administrator notes that for a maximum upwind annual average concentration no higher than 5 ppb, the trajectory-based analyses indicate downwind ecoregions to have ecoregion median S deposition appreciably below his objectives, which as noted above are for such deposition generally at or below 5 kg/ha-yr, with infrequent higher occurrences, very rarely as high as about 8 kg/ha-yr. Specifically, the analyses indicate ecoregion median deposition below approximately 4.5 kg/ha-yr in all of the ecoregion-time period combinations, with 75% below approximately 2.5 kg/ha-yr. The Administrator judges this magnitude of ecoregion S deposition associated with a standard level of 5 ppb to be well below his identified objectives. Thus, in light of his judgments, described above, regarding the pattern of ecoregion deposition associated with his and the CASAC majority's acidification protection targets, the Administrator finds an annual SO_2 standard, averaged over three years, with a level below 10 ppb, to be associated with air quality

[140] As discussed further below, the EPA is not adopting such a standard identical to the existing primary standard because such as standard would be more stringent than necessary.

[141] A 3-year form is common to NAAQS adopted over the more recent past. This form provides a desired stability to the air quality management programs which is considered to contribute to improved public health and welfare protection (*e.g.,* 78 FR 3198, January 15, 2013; 80 FR 65352, October 26, 2015; 85 FR 87267, December 31, 2020).

[142] As noted in section II.B.1.b. above, the PA analyses the CASAC majority cited were in terms of ecoregion median S deposition at/below values. Accordingly, the PA and the Administrator, in his judgments here, focuses on consideration of S deposition values in terms of such ecoregion medians.

more stringent than necessary to provide the requisite protection of the public welfare under the Act.

Further, in consideration of public comments and the recommendation from the CASAC minority, the Administrator additionally considered the public welfare protection that might be afforded by an alternate secondary standard in terms of a standard identical to the existing primary standard in all respects. In so doing, he notes the PA observations that most of the ecoregion median S deposition estimates for the last 10 years are less than 5 kg/ha-yr, and he notes the views expressed by the CASAC minority and in public comments that this indicates that the existing 1-hour primary SO_2 standard adequately protects against long-term annual S deposition-related effects. He additionally notes the additional analyses related to the PA trajectory-based analyses that indicate the stringency, with regard to expected control of associated S deposition, associated with a 1-hour standard identical to the primary standard (Sales et al., 2024, section 4.2). As discussed in II.B.2.a.(3)(c) above, such a standard is associated with ecoregion median S deposition well below the Administrator's objectives (summarized above). Specifically, the trajectory analyses indicate that for upwind sites of influence at or below 75 ppb, in terms of the existing primary standard (3-year average of 99th percentile daily maximum 1-hour average concentrations), the downwind ecoregion median S deposition estimates for all ecoregion-time period combinations are below 3 kg/ha-yr, with 95% of them below 2 kg/ha-yr. Thus, he judges such a standard would be more stringent than necessary and accordingly not provide the requisite protection of the public welfare.

In light of all of the above, along with analyses and evaluations in the PA, including judgments related to uncertainties in relating ambient air concentrations to deposition estimates for the purpose of identifying a standard level associated with a desired level of ecological protection, advice from the CASAC majority, and consideration of public comment, the Administrator judges that a SO_2 standard in terms of an annual average, averaged over three years, with a level of 10 ppb would provide the requisite protection of the public welfare from adverse effects related to S deposition.

The Administrator also considered the extent to which a new annual average standard might be expected to control short-term SO_2 concentrations (*e.g.,* of three hours duration) and accordingly also provide the necessary protection from direct effects of SO_X that is currently provided by the existing 3-hour secondary standard. In this context, he notes the analyses and conclusions of the PA, and particularly the related additional analyses, with regard to the extent of control for short-term concentrations that might be expected to be provided by an annual secondary standard (Sales et al., 2024). The Administrator also notes that these analyses are of air quality data from across the U.S. collected over the past 20 years, thus capturing a broad array of air quality conditions and their influences on relationships between the short-term and annual air quality metrics. As also discussed in section II.B.2.a.(4) above, these analyses indicate that in areas and periods when the annual SO_2 concentration (annual average, averaged over three years) is at or below 10 ppb, design values for the existing 3-hour standard are well below the existing secondary standard level of 0.5 ppm SO_2 and short-term SO_2 concentrations are below those associated with direct effects on vegetation or lichens (PA, Figure 2–29; Sales et al., 2024). Based on these findings, the Administrator judges that revision of the existing standard to a new annual standard, with a 3-year average form and a level of 10 ppb, will provide the necessary protection for direct effects of SO_X on plants and lichens, as well as effects associated with longer-term deposition of S compounds in ecosystems. Thus, based on all of the considerations identified above, including the currently available evidence in the ISA, the quantitative and policy evaluations in the PA, related analyses, the advice from the CASAC, and public comment, the Administrator judges it appropriate to revise the existing secondary SO_2 standard, to be an annual average standard, with a 3-year average form and a level of 10 ppb in order to provide the requisite protection of the public welfare from known or anticipated adverse effects.

Having reached his decision with regard to the welfare effects of SO_X, including those related to deposition of S compounds in sensitive ecosystems, the Administrator now turns to consideration of the secondary standards for N oxides and PM. As described below, the Administrator has decided to retain the existing NO_2 and PM standards. These decisions are based on his consideration of the welfare effects evidence as characterized in the ISA and evaluated in the PA; the public welfare implications of these effects; the quantitative information concerning N oxides, PM and N deposition presented in the ISA and PA, and additional analyses developed in consideration of public comments (*e.g.,* Sales et al., 2024); the majority and minority advice from the CASAC; and public comments (as discussed in section II.B.2.b. above and in the Response to Comments document).

With regard to the secondary standard for N oxides, the Administrator turns first to consideration of the protection afforded for effects of N oxides associated with direct contact on surfaces of plants and lichens. In so doing, he notes that the evidence of such effects was the basis for the establishment of the existing standard in 1971, and that the currently available information, summarized in section II.A.3.a.(1) above, continues to document such effects (ISA, Appendix 3, sections 3.3 and 3.4; PA, sections 4.1, 5.4.2 and 7.4). With regard to the adequacy of the existing standard in protecting against such effects, the Administrator's conclusions reflect those in the proposal, which he notes are consistent with the unanimous view of the CASAC (summarized in section II.B.1.b. above). Specifically, he finds that the evidence for NO_2 and NO does not indicate effects associated with ambient air concentrations allowed by the existing standard. With regard to the N oxide, HNO_3, he considered the PA evaluation of the evidence of effects associated with air concentrations and associated HNO_3 dry deposition on plant and lichen surfaces, and uncertainty as to the extent to which exposures associated with such effects may be allowed by the existing secondary NO_2 standard (PA sections 7.1.2 and 5.4.2, and Appendix 5B, section 5B.4). In so doing, the Administrator judges that the limited evidence, with associated uncertainties, are insufficient to conclude that air quality that meets the secondary NO_2 standard will nevertheless elicit such effects. Thus, he concludes that the existing standard continues to provide the needed protection from the direct effects of N oxides.

The Administrator next turns to consideration of the welfare effects related to atmospheric N deposition and the contribution of N oxides to such effects. In so doing, he notes that the information for N deposition and N oxides includes substantially more significant complexities, limitations of the available information, and related uncertainties than is the case for S deposition and S oxides. These complexities and limitations are generally technical or science policy in

nature, or both. Those of a technical nature include the untangling of historic N deposition impacts (*e.g.,* in terrestrial ecosystems) from impacts that might be expected from specific annual deposition rates absent that history, and also the complexity—more prominent for many aquatic systems, including those receiving some of the highest N loading—associated with estimating the portion of N inputs, and associated contribution to effects, derived from atmospheric sources (and specifically sources of N oxides). The science policy-related complexities relate to judgments regarding the implications of N deposition-related biological or ecological effects in the context of the Administrator's judgments concerning protection of the public welfare from adverse effects. Lastly, both technical and science policy challenges are presented by the coincidence in this review of the substantially reduced influence of N oxides on N deposition and the emergence of NH_3, which is not a criteria pollutant, as a major N deposition influence, particularly in areas with some of the highest N deposition estimates.

With regard to science policy judgments, the Administrator recognizes particular complexity associated with judging the requisite public welfare protection for an ecosystem stressor like N enrichment, for which as the CASAC recognized, in terrestrial systems there are both ''benefits and disbenefits'' (Sheppard, 2023, p. 8). As noted by the CASAC, ''[b]enefits include fertilization of crops and trees and the potential for improved sequestration of carbon in soils and plant biomass'' (Sheppard, 2023, p. 8). As noted in the PA, this also complicates conclusions regarding the extent to which some ecological effects may be judged adverse to the public welfare (PA, section 7.4). In many aquatic systems, identification of appropriate public welfare protection objectives is further complicated by N contributions to these systems from multiple sources other than atmospheric deposition,[143] as well as by the effects of historical deposition that have influenced the current status of soils, surface waters, associated biota, and ecosystem structure and function. For example, changes to ecosystems that have resulted from past, appreciably higher levels of atmospheric deposition in those areas have the potential to affect how the ecosystem responds to current, lower levels of deposition or to different N inputs in the future.

Further, the Administrator notes that his decision under the Act regarding the secondary NAAQS for N oxides is necessarily based on his judgments related to protection from the effects associated with N oxides. Yet, he recognizes that there are contributions to ecosystem N deposition, and related effects, from pollutants other than—and not derived from—N oxides in ambient air, most prominently NH_3. He additionally notes that the influence of NH_3 on N deposition varies appreciably across the U.S. and has grown over the past 20 years, while the contribution of N oxides to N deposition has declined. In a related manner, he takes note of the findings of the PA and the additional analyses that indicate ecoregions and States with highest N deposition (*e.g.,* above 10 kg/ha-yr) include areas with some of the highest deposition rates for reduced N and NH_3 (PA, Figure 7–8; Sales et al., 2024). This associated lessening influence of N oxides on total N deposition is also evidenced by the generally poor ($r<0.4$) or negative correlations between N deposition and annual average NO_2 concentrations, in the SLAMS and full trajectory-based datasets, respectively,, and also in the most recent period analyzed, 2018–2020(PA, sections 6.2.3 and 6.2.4). While low-moderate positive correlations are observed in both sets of analysis for eastern sites when including all time periods, correlations are only statistically significant in the earlier periods, prior to 2014, which may be related to increasing emissions of NH_3 in more recent years (PA, section 2.2.3 and Figure 6–5).

More specifically, the analyses of N deposition over the years since 2002 period [144] document the reductions in N deposition that correspond to reductions in emissions of N oxides, while additionally documenting the increased role of NH_3 in N deposition and the co-occurring and associated tempering of total N deposition reductions nationwide. For example, in all 14 ecoregions with median total N deposition in 2019–2021 greater than 10 kg/ha-yr, deposition of NH_3 has increased since 2000 (Sales et al., 2024).[145] And, in five of these 14 ecoregions, the increases in NH_3 deposition and associated NH_4^+ deposition are greater than the reductions in oxidized N deposition such that overall N deposition, in terms of ecoregion median, has increased. In the 14 ecoregions with total N deposition greater than 10 kg/ha-yr, the N deposition arising directly from N oxides (oxidized N deposition) constitutes the minority (approximately 23 to 42%) of total N deposition (Sales et al., 2024, Table 3). Across the other 70 ecoregions in CONUS [146] with median total N deposition below 10 kg/ha-yr in 2019–2021, ecoregion median oxidized N deposition, on average, declined (from 4.7 to 2.4 kg N/ha-yr) while ecoregion median NH_3 deposition, on average, more than doubled (from 0.7 to 1.6 kg N/ha-yr) (Sales et al., 2024, Table 4). At a State-level scale, average rates of oxidized N deposition have also declined in all 48 States of the CONUS, including where total N deposition has increased as a result of increased deposition from reduced N compounds associated with NH_3. In the most recent period, oxidized N deposition, in terms of Statewide average, is below 5 kg N/ha-yr in all 48 States (Sales et al., 2024). And in the six States with average total N deposition above 10 kg/ha-yr in the 2019–2021 period, oxidized N deposition comprises less than 40% (Sales et al., 2024, Table 5). The Administrator recognizes that these findings augment those of the PA analyses and indicate a much lower influence of N oxides on total N deposition relative to the influence of reduced N compounds in areas of the U.S. where N deposition is currently the highest (PA, section 7.2.3.3).

The Administrator also considers both the majority and minority advice from the CASAC regarding an NO_2 annual standard in consideration of total N deposition effects. In so doing, he notes that in considering the justification provided by the CASAC majority for its recommendation, the PA did not find the information highlighted by the CASAC for relating total N deposition levels to ambient air concentrations of NO_2 to provide scientific support for their recommended revision. The Administrator additionally notes that, as summarized in section II.B.1.b. above,

[143] For example, a study of the Chesapeake Bay and its sources of N loading concluded that '' 'about one-third' of the total N load for the Bay is the result of direct deposition to the Bay or deposition to the watershed which is transported to the Bay'' (U.S. EPA, 2010, p. 4–33), indicating that two thirds of N loading comes from non-air sources.

[144] Modeling estimates of N deposition in 2002 were the basis for the risk analyses in the 2013 review (2009 REA, sections 3.2.3 and 3.3.3). After also considering estimates and wet deposition measurements for 2003–2005, the 2009 REA concluded ''overall, for each case study area, the amount of nitrogen deposition in 2002 is generally representative of current conditions'' (2009 REA, p. 3–30). The total deposition estimates at that time relied on a different and less advanced modeling approach than that used in the current review (PA, section 2.5).

[145] Ecoregion median NH_3 deposition has also increased since 2002 in 68 of the other 70 CONUS ecoregions; in the remaining two ecoregions, it is unchanged (Sales et al., 2024).

[146] The TDep estimates of N deposition are only available for the CONUS and not for parts of the U.S. outside of the CONUS.

notwithstanding the CASAC majority recognition of a lack of correlation between NO_2 concentrations and ecoregion total N deposition, these members recommend an annual NO_2 standard with a level of ''<10–20 ppb'' based on their objective of N deposition below 10 kg/ha-yr based on studies of total N deposition. He finds their recommendation less than persuasive because for an NO_2 standard to exert control of N deposition, there would need to be a significant positive relationship (*e.g.,* correlation) between NO_2 concentrations and N deposition. As discussed above, the correlations reported in the PA between NO_2 concentrations and downwind ecoregions are generally low or negative, particularly in recent periods. Further, the justification provided by the CASAC majority for its recommended revision focuses on the results of the trajectory-based analysis in the draft PA, about which they also expressed concerns, with a focus on the EAQM-weighted metric, although, as described in section II.B.1.a.(2), concentrations of this metric are not directly translatable to potential standard levels due to the weighting across multiple monitors. In light of these limitations in the CASAC majority advice and based on current air quality and deposition information and trends as summarized above, the Administrator judges that, a secondary standard for N oxides cannot be expected to effectively control total N deposition.

With regard to the minority CASAC recommendation to revise the secondary standard to be identical to the primary NO_2 standard in all respects, the Administrator notes the justification provided by the minority CASAC, which observed that the primary standard has been met over the last 10 years and indicated that ''most of the N deposition values within the last 10 years'' are less than 10 kg/ha-yr. The Administrator does not find this rationale sufficient to support a decision for revision as the CASAC minority recommended. The fact that N deposition has declined in many locations to less than 10 kg/ha-yr and that all areas meet the current primary standard does not signify that a secondary standard set equal to the primary would be effective in controlling total N deposition, given the rise in reduced N deposition just discussed, or that such a standard would be requisite for protection of the public welfare.

In this context, the Administrator considers the implications of N deposition directly related to N oxides with regard to welfare effects. In so doing, he notes that the information available at the time of proposal (presented in the PA) was unclear with regard to the extent to which occurrences of ecoregion median N deposition greater than the total N deposition values identified by the CASAC majority (10 kg/ha-yr) and in section 7.2.3. of the PA (7–12 kg/ha-yr) may relate to the existing NO_2 secondary standard (89 FR 26682, April 15, 2024). However, the more recent additional analyses (developed in consideration of public comments) now provide clarification. These additional analyses indicate that ecoregion median levels of oxidized N (the component of total N deposition directly related to N oxides) are well below the PA-identified range of values (Sales et al., 2024). Specifically, median oxidized N deposition in all ecoregions of the CONUS is below 5 kg N/ha-yr, less than half of the N deposition benchmark considered by the CASAC (and below the lower end of the N deposition range [7–12 kg/ha-yr] identified by the PA), with the majority of ecoregions (45 of 84) having a median below 3 kg N/ha-yr (Sales et al., 2024). These analyses further indicate that the Statewide averages of oxidized N deposition in all 50 States are below the CASAC identified N deposition benchmark and the PA identified range, with the average across States well below half these values (Sales et al., 2024, Table 5).

In light of all of the considerations above, the Administrator notes first that the N deposition benchmark identified by the CASAC majority, and the range of levels identified in the PA for consideration, are in terms of total N deposition. He notes that most ecoregions have total N deposition levels below the CASAC majority and PA identified levels (that might be considered appropriate levels of protection for effects associated with total N deposition) but that some areas have higher total N deposition with levels above such benchmarks of potential public welfare significance. He notes that in areas with total N deposition above the CASAC majority and PA identified levels, available evidence indicates the level of total N deposition is predominantly the result of deposition from reduced N, which is increasing, while deposition of oxides of N is playing a notably smaller role (with such contributions decreasing over recent years). Based on these patterns and the current analyses, he notes his conclusion above, that, based on the information available in this review, a secondary standard for N oxides cannot be expected to effectively control total N deposition. Further, he notes that recent levels of oxidized N deposition (N deposition derived from N oxides in ambient air) are well below the CASAC majority and PA identified levels. With respect to the adequacy of protection for effects related to oxidized N deposition, he does not find a basis in the evidence for concluding that revisions to the current ambient air standard for N oxides are necessary. Therefore, based on all the considerations above, including the minority contribution of N oxides to total N deposition and the general lack of correlation between ambient air NO_2 concentrations and such deposition, the Administrator finds that the existing evidence does not call into question the adequacy of protection of the existing secondary NO_2 standard with regard to deposition-related effects of N oxides. Further, based on the findings of the PA and additional analyses of recent information on air quality and N deposition, and all the above considerations, the Administrator judges, based on the available evidence in this review, that revision to the secondary annual NO_2 standard is not warranted and the existing secondary NO_2 standard should be retained, without revision.

Lastly, the Administrator turns to consideration of the existing secondary standards for PM. As an initial matter, he takes note of the PA discussion and conclusion that the available information does not call into question the adequacy of protection afforded by the secondary $PM_{2.5}$ standards from direct effects and deposition of pollutants other than S and N compounds (PA, sections 7.1.3 and 7.4). As also discussed in the proposal, the evidence characterized in the ISA and summarized in the PA indicates such effects to be associated with conditions associated with concentrations much higher than those associated with the existing standards. Thus, as in the proposal, the Administrator judges that the current evidence does not call into question the adequacy of the existing PM standards with regard to direct effects and deposition of pollutants other than S and N compounds.

With regard to S deposition and PM, as noted earlier in this section, the Administrator judges that protection of sensitive ecosystems from S deposition-related effects is more effectively achieved through a revised SO_2 standard than a standard for PM. Accordingly, as discussed above, the Administrator has decided to revise the existing secondary SO_2 standard to provide for such protection. Thus, the Administrator judges that revising one or more of the secondary PM standards

in consideration of protection of the public welfare from effects related to S deposition is not warranted.

With regard to N deposition and adequacy of the secondary PM standards, the Administrator considers the analyses and evaluations in the PA, related analyses conducted in consideration of public comments, advice from the CASAC, and public comments. As an initial matter, the Administrator takes note of the substantial and significant limitations and uncertainties associated with the evidence base for ecosystem effects related to N deposition associated with PM (similar to those recognized above for N oxides). With regard to limitations and associated uncertainties of the current information related to N deposition arising from PM, the Administrator notes, as an initial matter, the PA findings, based on the full 20-year dataset, of negative to barely moderate correlations between N deposition estimates and annual average $PM_{2.5}$ concentrations at upwind locations, with low or a negative correlation in the most recent time period (PA, sections 6.2.4 and 7.2.3.3). Across the SLAMS sites, the strength of a N deposition estimates with nearby $PM_{2.5}$ concentrations is also seen to consistently decline across the five time periods analyzed since 2001 (PA, Table 6–7).[147] As discussed in the PA, these findings are likely related to both the increased impacts of NH_3 on N deposition (as summarized earlier), and the declining presence of N compounds in PM (specifically in $PM_{2.5}$) over the past two decades, as well as the current relatively low and variable representation of N compounds in PM (PA, section 6.4.2).

While the Administrator recognizes that NH_4^+, a transformation product of NH_3, exists in particles and is a component of $PM_{2.5}$, he also recognizes that the combined presence of all N-containing compounds in $PM_{2.5}$ constitutes less than 30% of total $PM_{2.5}$ mass at sites across the U.S. (PA, section 6.2.4; Sales et al., 2024). The Administrator additionally takes note of the finding that the composition of $PM_{2.5}$ across the U.S. varies appreciably. Specifically, the percentage of $PM_{2.5}$ represented by N compounds at the 120 CSN sites in the 2020–2022 period (that inform our current understanding for the various regions across the U.S.) ranges from a high of about 30% down to 5 to 15% across the South and Northwest and just below 5% in some areas (PA, section 6.4.2; Sales et al., 2024). As discussed in the PA, this contributes to geographic variability in the relationship between N deposition and annual $PM_{2.5}$ concentrations (PA, section 6.4.2; Sales et al., 2024). The Administrator recognizes these findings together to indicate that an appreciable percentage of $PM_{2.5}$ mass does not contribute to N deposition, and that the contributing amount varies across regions of the U.S. He further recognizes that this indicates that $PM_{2.5}$ concentrations can be controlled or reduced without necessarily having any effect on concentrations of particulate N compounds. The Administrator also takes note that while deposition of the particulate N species associated with NH_3 emissions (*i.e.,* NH_4^+) has increased since 2000–2002, the percentage of $PM_{2.5}$ mass comprised by nitrogen compounds has declined, as has the percentage comprised by NH_4^+, alone (Sales et al., 2024). In this context, he additionally notes that deposition of NH_3 (which is not particulate) is estimated to be more than a third of total N deposition in some ecoregions and States, including those the highest total deposition (Sales et al., 2024). The Administrator concludes that collectively, this information indicates that a PM mass standard is unlikely to achieve a predictable or specified amount of control on N deposition across the U.S.

In considering the advice from the CASAC for revision of the annual $PM_{2.5}$ secondary standard, the Administrator notes that, as discussed in the PA, summarized in section II.B.1.b. above and recognized in reaching his proposed decision, the specific rationale for the range of standard levels recommended by the CASAC majority is unclear. The EPA does not find the CASAC majority observations regarding $PM_{2.5}$ concentrations in remote areas or in areas of higher concentrations in 2019–2021 or in the trajectory-based analyses to demonstrate that an annual $PM_{2.5}$ standard, with a level of 6 to 10 $\mu g/m^3$, would be expected to control total N deposition at or below 10 kg/ha-yr. As recognized in the proposal, in the CASAC majority comments, $PM_{2.5}$ concentrations within its recommended range were both described as relating to N deposition at/below its recommended benchmark (10 kg N/ha-yr) and relating to deposition above that range (as summarized in II.B.1.c. above). Additionally, as discussed in section II.B.2.b.(2)(c) above, the EPA disagrees that the PA analyses of $PM_{2.5}$ concentrations and N deposition estimates in remote areas, without consideration of information for areas where $PM_{2.5}$ is emitted or produced, are informative in this regard.[148] Regarding the trajectory-based analyses, as discussed in section II.B.1.b. above, and noted above, the correlation coefficient for N deposition with $PM_{2.5}$ concentrations at the maximum upwind monitor (the EAQM-Max metric) does not indicate a positive relationship. In light of these limitations in the information cited by the CASAC majority and based on the broader consideration above of the variability of $PM_{2.5}$ composition across the U.S., including with regard to N components, among other factors, the Administrator disagrees with the CASAC majority's recommendation on revision of the annual $PM_{2.5}$ standard. In so doing, he also notes that the recommendation by these members to consider a new total N $PM_{2.5}$ indicator, based on their view that it would achieve a better measure of total reactive N deposition, was offered in the context of such consideration ''in the next review'' (Sheppard, 2023, Letter, p. 5), and notes that the record in this review does not provide a basis for considering, much less adopting, a new indicator in the current review.

The CASAC minority recommendation, based on a conclusion that the 2013 annual primary $PM_{2.5}$ standard was controlling N deposition as needed since its establishment (as described in section II.B.1.b. above), cited scatterplots in the draft PA of N deposition estimates and annual average $PM_{2.5}$ concentrations and did not address the issue of variable PM composition or lack of analyses for a 1-hour metric. As described earlier, the Administrator finds the issue of variability in $PM_{2.5}$ composition to be an important consideration in his decision and accordingly, he finds the minority CASAC recommendation to not be well supported by the full record at this time in this review.

Based on the currently available information, taking into account its limitations and associated uncertainties, and in consideration of all of the above,

[147] Further, as noted in section II.B.2.b.(2)(c) above, the PA analysis of N deposition and $PM_{2.5}$ concentrations at SLAMs does not provide a basis for identifying 3-year average annual $PM_{2.5}$ concentrations that might be expected to constrain nearby N deposition below certain levels, such as an ecoregion median of 10 kg/ha-yr (*e.g.,* PA, Figure 6–39).

[148] The CASAC majority reference to concentrations in non-remote areas was with regard to the range of recent design values observed in areas where N deposition estimates ranged above 15 kg/ha-yr in California, the Midwest and the East; although not noted in the justification, design values at California sites were as high as 17.3 $\mu g/m^3$ (as summarized in section II.B.1.c. above), and the justification does not address how this may relate to a relationship of these concentrations to N deposition.

the Administrator concludes that given the variable composition of $PM_{2.5}$ across the U.S., the relatively low percentage of $PM_{2.5}$ represented by N compounds (lower now than in the past), and the contributors to total N deposition that are not PM components, a $PM_{2.5}$ standard could not, as discussed above, be expected to provide predictable and effective control of total N deposition. Accordingly, he judges that $PM_{2.5}$ is not an appropriate indicator for a secondary standard intended to provide protection of the public welfare from adverse effects related to N deposition. Additionally, he notes that while it is unclear whether any PM standard would provide an appropriate indicator for consideration of N deposition-related effects, this issue may warrant evaluation in future reviews.

Further, as in his decision for N oxides above, the Administrator recognizes the factors identified here to contribute appreciable uncertainty to an understanding of the level of protection from N deposition-related effects associated with PM that might be afforded by the existing or an alternate secondary standard for $PM_{2.5}$. Thus, he is unable to identify a standard that would provide requisite protection from known or anticipated adverse N-deposition-related effects to the public welfare associated with the presence of PM in the ambient air. In summary, based on all these considerations, the Administrator concludes after considering the available evidence as assessed in the ISA, the quantitative analyses and associated evaluations in the PA and related more recent additional analyses, that no change to the annual secondary $PM_{2.5}$ standard is warranted and he is retaining the existing $PM_{2.5}$ secondary standard, without revision.

With regard to the 24-hour $PM_{2.5}$ standard, the Administrator takes note of the PA conclusion that the evidence available in this review, as documented in the ISA, does not call into question the adequacy of protection provided by the 24-hour $PM_{2.5}$ standard from ecological effects (PA, section 7.4). He additionally notes the agreement of this finding with the recommendation of the CASAC minority to retain the existing standard. The Administrator also considers the comments of the CASAC majority and recommendations for revision of this standard to a lower level or to an indicator of deciviews (with a level of 20 to-25 deciviews), based on the CASAC majority's consideration of visibility impairment and short-term fog or cloud-related deposition events that these members indicate may threaten sensitive lichen species, as summarized in section II.B.1.b. above. With regard to short-term fog or cloud-related events, the Administrator considers the PA finding in evaluating these recommendations, that, while the available evidence in the ISA recognizes there to be N deposition associated with cloud water or fog, it does not provide estimates of this deposition, describe associated temporal variability, or present evidence of effects on biota from such events (ISA, Appendix 2; PA, section 7.3).[149] Thus, he does not find a basis in the evidence base for this review for the CASAC majority revisions or their stated intention of addressing short-term events and lichen sensitivity. Further, the justification of the specific revision options recommended by the CASAC majority focuses on consideration of visibility impairment, and the Administrator notes that the adequacy of protection provided by the secondary $PM_{2.5}$ standard from visibility effects has been addressed in his reconsideration of the 2020 p.m. NAAQS decision (89 FR 16202, March 6, 2024) and is not included in this review. Thus, based on his judgment that the evidence does not call the existing standard into question, the Administrator retains the existing 24-hour secondary $PM_{2.5}$ standard, without revision.

Regarding the PM_{10} standard, the Administrator concurs with the PA's finding of a lack of information that calls into question the adequacy of protection afforded by the existing PM_{10} secondary standard for ecological effects. Thus, he also retains the secondary PM_{10} standard without revision.

C. Decision on the Secondary Standards

For the reasons discussed above and considering the evidence assessed in the ISA, the qualitative assessments and policy evaluations presented in the PA and associated technical memorandum, the advice and recommendations of the CASAC, and the public comments, the Administrator is revising the secondary standard for SO_X to provide the requisite protection of the public welfare from known and anticipated adverse effects. More specifically, the Administrator is revising the secondary SO_2 standard to be an annual average, averaged over three years, with a level of 10 ppb SO_2. With this decision, the Agency is also making corresponding revisions to data handling conventions are specified in revisions to appendix T, discussed in section III. below.

With regard to the secondary standards for N oxides and PM, based on the evidence assessed in the ISA, the qualitative assessments and policy evaluations presented in the PA and associated technical memorandum, the advice and recommendations of the CASAC, and the public comments, and for the reasons discussed above, the Administrator concludes that no changes are warranted, and is retaining the existing standards, without revision.

III. Interpretation of the Secondary SO_2 NAAQS

The EPA received no comments regarding the proposed data handling procedures for SO_2 monitoring data for purposes of determining when the new annual secondary SO_2 NAAQS is met. Therefore, the EPA is finalizing the proposed revisions to appendix T to 40 CFR part 50, Interpretation of the Primary National Ambient Air Quality Standards for Oxides of Sulfur, to establish data handling procedures for the new annual secondary SO_2 standard. The regulatory text at 40 CFR 50.21, which sets the averaging period, level, indicator, and form of the annual standard, refers to this appendix T. The revised appendix T details the computations necessary for determining when the annual secondary SO_2 NAAQS is met. The revised appendix T also addresses data reporting, data completeness considerations, and rounding conventions.

A. Background

The general purpose of a data interpretation appendix is to provide the practical details on how to make a comparison between multi-day and possibly multi-monitor ambient air concentration data and the level of the NAAQS, so that determinations of attainment and nonattainment are as objective as possible. Data interpretation guidelines also provide criteria for determining whether there are sufficient data to make a NAAQS level comparison at all. The regulatory language for the secondary SO_2 NAAQS adopted in 1971 does not contain detailed data interpretation instructions. This situation contrasts with the primary NO_2, ozone, $PM_{2.5}$, PM_{10}, lead, and primary SO_2 NAAQS regulations, for which there are detailed data interpretation appendices in 40 CFR part 50 addressing issues that can arise in comparing monitoring data to the NAAQS. The existing appendix T includes these detailed data interpretation requirements for the 1-hour primary SO_2 NAAQS, thus the

[149] As noted in the PA and summarized in section II.B.1.b. above, the CASAC majority, in its justification for revision of the existing standard, did not identify studies in support of its statements related to lichen species and fog or cloud water.

revision provides similar information for the new annual secondary SO_2 NAAQS. The EPA has used its experience developing and applying this data interpretation appendix to develop the revisions to the text in appendix T to address the new annual secondary SO_2 standard.

B. Interpretation of the Secondary SO_2 Standard

The purpose of the data interpretation provisions for the secondary SO_2 NAAQS is to give effect to the form, level, averaging time, and indicator specified in the regulatory text at 40 CFR 50.21, anticipating and resolving in advance various future situations that could occur. The revised appendix T provides definitions and requirements that apply to the annual secondary standard for SO_2. The requirements clarify how ambient air data are to be reported, what ambient air data are to be used for comparisons with the SO_2 NAAQS, and how to calculate design values for comparisons with the SO_2 NAAQS. The data already required to be reported by ambient air SO_2 monitors for use in calculating design values for the current 1-hour primary SO_2 NAAQS are also sufficient for use in calculating design values for the new annual secondary SO_2 NAAQS.

The revised appendix T specifies that the annual secondary SO_2 NAAQS is met at an ambient air quality monitoring site when the valid annual secondary standard design value is less than or equal to 10 ppb. The annual secondary standard design value for an ambient air quality monitoring site is described as the mean of the annual means for three consecutive years, with the annual mean derived as the annual average of daily means, with rounding and data completeness specified as described below. The use of a daily mean value in deriving the design value is consistent with the existing data handling requirements for the current 1-hour primary SO_2 NAAQS.

Data completeness requirements for the annual secondary standard in the revised appendix T follow past EPA practice for other NAAQS pollutants by requiring that in general at least 75% of the monitoring data that should have resulted from following the planned monitoring schedule in a period must be available for the key air quality statistic from that period to be considered valid. These data completeness requirements are consistent with the current data completeness requirements for the 1-hour primary SO_2 NAAQS in appendix T, and the revised appendix T does not change those requirements. For the annual secondary SO_2 NAAQS, the key air quality statistics are the annual average of daily mean (24-hour average, midnight-to-midnight) concentrations in three successive years. It is important that daily means are representative of the 24-hour period and that all seasons of the year are well represented. Hence, the 75% requirement is applied at the daily and quarterly levels. These completeness requirements, including the calculation of the daily mean, are consistent with existing completeness requirements for the current 1-hour primary SO_2 NAAQS.

Recognizing that there may be years with incomplete data, the text provides that a design value derived from incomplete data will nevertheless be considered valid if at least 75 percent of the days in each quarter of each of three consecutive years have at least one reported hourly value, and the 3-year annual average design value calculated according to the procedures specified in the revised appendix T is above the level of the secondary annual standard. Additionally, following provisions in the revised appendix T, a substitution test may be used to demonstrate validity of incomplete design values above the level of the standard by substituting a ''low'' daily mean value from the same calendar quarter in the 3-year design value period. Similarly, another substitution test may be used to demonstrate validity of incomplete design values below the level of the standard by substituting a ''high'' daily mean value from the same calendar quarter in the 3-year design value period. These substitution tests are consistent with existing substitution tests for the current 1-hour primary SO_2 NAAQS.

It should be noted that one possible outcome of applying the substitution test is that a year with incomplete data may nevertheless be determined to not have a valid design value and thus to be unusable in making annual secondary NAAQS compliance determinations for that 3-year period. However, the intention of the substitution test is to reduce the frequency of such occurrences.

The EPA Administrator has general discretion to use incomplete monitoring data to calculate design values that would be treated as valid for comparison to the NAAQS despite the incompleteness, either at the request of a State or at the Administrator's own initiative. Similar provisions exist already for the $PM_{2.5}$, NO_2, lead, and 1-hour primary SO_2 NAAQS. The EPA may consider monitoring site closures/moves, monitoring diligence, and nearby concentrations in determining whether to use such data.

The rounding conventions for the new annual secondary SO_2 NAAQS are consistent with rounding conventions used for the current 1-hour primary SO_2 NAAQS. Specifically, hourly SO_2 measurement data shall be reported to EPA's regulatory database in units of ppb, to at most one place after the decimal, with additional digits to the right being truncated with no further rounding. Daily mean values and the annual mean of those daily values are not rounded. Further, the annual secondary standard design value is calculated pursuant to the revised appendix T and then rounded to the nearest whole number or 1 ppb (decimals 0.5 and greater are rounded up to the nearest whole number, and any decimal lower than 0.5 is rounded down to the nearest whole number).

IV. Ambient Air Monitoring Network for SO_2

In the NPRM, the EPA did not propose any changes to the minimum monitoring requirements as part of the proposal to revise the secondary SO_2 NAAQS. Based on a review of the network history, current network design, reported data, and monitoring objectives (Watkins et al., 2024), and in recognition of the network's adaptability and flexibility provided in 40 CFR part 58, the Agency proposed and took comment on its determination that the current network is adequate to provide the data needed to implement the new secondary SO_2 standard. The EPA also concluded that the Agency, along with State, local, Tribal, and industry stakeholders, have the authority and ability to adjust monitoring efforts and redirect resources needed to ensure that the monitoring objectives of the SO_2 network continue to be met, and thus no changes to minimum monitoring requirements are necessary.

A. Public Comments

The EPA received a few comments related to the ambient air monitoring network design prescribed by the minimum monitoring requirements in 40 CFR part 58, section 4.4 as it relates to supporting the implementation of the new standard. The commenters recognized the value and importance of the network, with one stating that they support the use of ambient air quality monitoring data in designation activities, and that they believe ''the existing monitoring network is adequate for making attainment decisions.'' Another commenter expressed the view that ''EPA must maintain a ground monitoring network that supports science-based decision making in the NAAQS standard setting process, as

well as for compliance with a standard once it is set,'' and concurred with a CASAC comment that monitoring networks, including the SLAMS, which are required through 40 CFR part 58, are ''essential to provide the scientific basis for this review'' (Sheppard, 2023).

Another commenter recommended that EPA ''[i]ncrease monitoring in high-risk areas and ensure strict enforcement of the NAAQS,'' including by deploying monitors in areas the commenter calls ''frontline and fence-line communities,'' and making the data publicly accessible. With regard to this comment, the EPA notes that the current network already has a significant subset of sites with monitoring objectives that provide for measurements in areas of higher SO_2 emissions and in locations of expected maximum concentrations. Measurements from monitors with those objectives provide the data needed to support the new standard. However, the same monitors, sited in locations of expected maximum concentrations, can also be in ''frontline and fence-line communities.'' Further, all monitoring conducted by State, local, and Tribal air agencies, as well as data from industry that fulfill the requirements of 40 CFR parts 50, 53, and 58, the regulations that set out minimum monitoring requirements, and other requirements are publicly available through various means. These include but are not limited to obtaining the data directly from the air monitoring agencies themselves, from EPA's Air Data website, or from EPA's Air Quality System (AQS) database.

B. Conclusion on the Monitoring Network

The EPA stated in the proposal that it believes that the current ambient air SO_2 monitoring network design, deployment, and monitoring objectives are adequate to provide the data needed to implement the new secondary SO_2 NAAQS. After consideration of public comments, and with reliance on EPA's assessment of the monitoring network provided as part of the proposal for this review, the Agency still asserts that the network is adequate and that no network design changes are necessary because EPA, State, local, Tribal, and industry stakeholders have the authority and ability to adjust monitoring efforts and redirect resources as needed to ensure that the monitoring objectives of the SO_2 network continue to be met. The Administrator has therefore chosen to retain the existing minimum monitoring requirements for SO_2 without modification, as currently prescribed, operated, and maintained in accordance with 40 CFR parts 50, 53, and 58, as proposed.

V. Clean Air Act Implementation Considerations for the Revised Secondary SO_2 Standard

The EPA's revision to the secondary SO_2 NAAQS will trigger a number of implementation-related activities that were described in the proposal. The two most immediate implementation impacts following a final new or revised NAAQS are related to stationary source permitting and the initial area designations process. Permitting implications are discussed in section V.C., and designation implications are discussed in section V.A. The Agency is finalizing an action retaining the secondary NO_2 and PM NAAQS. Retention of existing secondary standards does not trigger any new implementation actions. Additional implementation information is available in the proposal preamble in section V.

At the outset, promulgation of a new or revised NAAQS triggers a process through which States [150] would make recommendations to the Administrator regarding initial area designations. States also would be required to make a new SIP submission to establish that they meet the necessary structural requirements for such new or revised NAAQS pursuant to CAA section 110(a)(1) and (2), also referred to as the ''infrastructure SIP submission'' (more on this submission below). This section provides background information for understanding the implementation implications of the secondary SO_2 NAAQS changes and describes the EPA's intentions for providing guidance regarding implementation.

A. Designation of Areas

As described in section II.B.3., the EPA is revising the secondary SO_2 NAAQS to 10 ppb, as an annual average, averaged over three consecutive years. After the EPA establishes a new or revised NAAQS (primary or secondary), the CAA requires the EPA and States to take steps to ensure that the new or revised NAAQS is met. The timeline for initial area designations begins with promulgation of the new NAAQS, as stated in CAA section 107(d)(1)(A). Initial area designations involve identifying areas of the country that either meet or do not meet the new or revised NAAQS, along with the nearby areas contributing to NAAQS violations. The following includes additional information regarding the designations process described in the CAA.

Section 107(d)(1)(A) of the CAA states that, ''By such date as the Administrator may reasonably require, but not later than 1 year after promulgation of a new or revised [NAAQS] for any pollutant under [section 109], the Governor of each State shall . . . submit to the Administrator a list of all areas (or portions thereof) in the State'' and make recommendations for whether the EPA should designate those areas as ''nonattainment,'' ''attainment,'' or ''unclassifiable.'' [151] A nonattainment area is any area that does not meet (or that contributes to ambient air quality in a nearby area that does not meet) a NAAQS; an attainment area is any area (other than an area identified as a nonattainment area) that meets a NAAQS; and an unclassifiable area is any area that cannot be classified on the basis of available information as meeting or not meeting a NAAQS.[152] The CAA provides the EPA with discretion to require States to submit their designations recommendations within a reasonable amount of time not exceeding 1 year after the promulgation of a new or revised NAAQS. CAA section 107(d)(1)(B)(a) also stipulates that ''the Administrator may not require the Governor to submit the required list sooner than 120 days after promulgating a new or revised [NAAQS].'' This same section further provides, ''Upon promulgation or revision of a [NAAQS], the Administrator shall promulgate the designations of all areas (or portions thereof) . . . as expeditiously as practicable, but in no case later than 2 years from the date of promulgation . . . . Such period may be extended for up to one year in the event the Administrator has insufficient information to promulgate the designations.'' With respect to the NAAQS setting process, courts have interpreted the term ''promulgation'' to be signature and widespread dissemination of a final rule.[153]

If the EPA agrees that the State's designations recommendations are consistent with all relevant CAA requirements, then the EPA may proceed to promulgate the designations for such areas. However, if the EPA disagrees that a State's recommendation is consistent with all relevant CAA requirements, then the EPA may make

[150] This and all subsequent references to ''state'' are meant to include State, local and Tribal agencies responsible for the implementation of a SO_2 control program.

[151] While the CAA says ''designating'' with respect to the Governor's letter, in the full context of the CAA section it is clear that the Governor makes a recommendation to which the EPA must respond via a specified process if the EPA does not accept it.

[152] See 42 U.S.C. 7407(d)(1)(A)(i)–(iii).

[153] *API* v. *Costle,* 609 F.2d 20 (D.C. Cir. 1979).

modifications to the recommended designations by following the process outlined in the CAA. By no later than 120 days prior to promulgating the final designations, the EPA is required to notify States of any intended modifications to the designations of any areas or portions thereof, including the boundaries of areas, as the EPA may deem necessary. States then have an opportunity to comment on the EPA's intended designations decisions. If a State elects not to provide designations recommendations, then the EPA must timely promulgate the designations that it deems appropriate. CAA section 107(d)(1)(B)(ii).

While section 107(d) of the CAA specifically addresses the designations process for States, the EPA intends to follow the same process for Tribes to the extent practicable, pursuant to section 301(d) of the CAA regarding Tribal authority, and the Tribal Authority Rule (63 FR 7254, February 12, 1998). To provide clarity and consistency in doing so, the EPA issued a guidance memorandum to our Regional Offices on working with Tribes during the designations process.[154]

Consistent with the process used in previous initial area designations efforts for both primary and secondary standards, the EPA will employ a nationally consistent framework and approach to evaluate each State's designations recommendations. Section 107(d) of the CAA explicitly requires that the EPA designate as nonattainment not only the area that is violating the pertinent standard, but also those nearby areas that contribute to ambient air quality in the violating area. Consistent with past practice, the EPA plans to address issues relevant to the initial area designations more fully in a separate designations-specific memorandum.

The EPA intends to issue the designations for the secondary SO_2 NAAQS based on the most recent 3 years of complete, certified, and valid air quality monitoring data in the areas where monitors are installed and operating. The EPA intends to use such available air quality monitoring data from the current SO_2 monitoring network. For further information on the adequacy of the monitoring network, refer to the memorandum in the docket for this action titled ''Ambient Air SO_2 Monitoring Network Review and Background'' (Watkins et al., 2024). Monitoring data are currently available from existing FEM and FRM monitors sited and operated in accordance with 40 CFR parts 50 and 58 to determine compliance with the revised secondary SO_2 NAAQS.

State or Tribal air agencies may flag air quality data for certain days in the Air Quality System (AQS) database due to potential impacts from exceptional events. CAA section 319(b) defines an exceptional event as an event that (i) affects air quality; (ii) is not reasonably controllable or preventable; (iii) is an event caused by human activity that is unlikely to recur at a particular location or a natural event; and (iv) is determined by the Administrator through the process established in the regulations to be an exceptional event (*e.g.,* volcanic activity for SO_2). For emissions affecting air quality to be considered an exceptional event, there must be a clear causal relationship between the specific event and the monitored exceedance or violation. Air quality monitoring data affected by exceptional events may be excluded from use in determinations of exceedances or violations if the data meet the criteria for exclusion under CAA section 319(b) and EPA's ''Treatment of Data Influenced by Exceptional Events'' Final Rule (81 FR 68216; October 3, 2016) (Exceptional Events Rule) codified at 40 CFR 50.1, 50.14, and 51.930. For events affecting initial area designations, the air agency is required to follow the exceptional events demonstration submission deadlines that are identified in table 2 to 40 CFR 50.14(c)(2)(vi), ''Schedule for Initial Notification and Demonstration Submission for Data Influenced by Exceptional Events for Use in Initial Area Designations.'' The EPA encourages air agencies to work collaboratively with the appropriate EPA Regional office after identifying any exceptional event influencing ambient air quality concentrations in a way that could affect area designations for the annual SO_2 secondary NAAQS.

B. Section 110(a)(1) and (2) Infrastructure SIP Requirements

As discussed in the proposal preamble section V.B., the CAA directs States to address basic SIP requirements to implement, maintain, and enforce the NAAQS. Under CAA sections 110(a)(1) and (2), States are required to have State implementation plans that provide the necessary air quality management infrastructure including, among other things, enforceable emissions limitations, an ambient air monitoring program, an enforcement program, air quality modeling capabilities, and adequate personnel, resources, and legal authority to carry out the implementation of the SIP. After the EPA promulgates a new or revised NAAQS, States are required to make a new SIP submission to establish that they meet the necessary structural requirements for such new or revised NAAQS or make changes to do so. The EPA refers to this type of SIP submission as an ''infrastructure SIP submission.'' Under CAA section 110(a)(1), all States are required to make these infrastructure SIP submissions within 3 years after promulgation of a new or revised standard. While the CAA authorizes the EPA to set a shorter time for States to make these SIP submissions, the EPA is requiring submission of infrastructure SIPs within 3 years of the promulgation date of this revised secondary SO_2 NAAQS. Section 110(b) of the CAA also provides that the EPA may extend the deadline for the ''infrastructure'' SIP submission for a revised secondary NAAQS by up to 18 months beyond the initial 3 years. If a state requests an extension pursuant to CAA section 110(b) and 40 CFR 51.341 and the Administrator determines an extension is necessary, the EPA will set additional time for that state for the infrastructure SIP submittal in a separate action from this final rule. The EPA does not anticipate that extensions will be necessary as most, if not all, states' existing infrastructure SIPs may already be sufficient to satisfy the infrastructure SIP requirements for this revised secondary SO_2 NAAQS, and those states can reiterate that they have met the requirements in their infrastructure SIP submissions.

Under CAA sections 110(a)(1) and (2), States are required to make SIP submissions that address requirements pertaining to implementation, maintenance, and enforcement of a new or revised NAAQS. The specific subsections in CAA section 110(a)(2) require States to address a number of requirements, as applicable: (A) emissions limits and other control measures; (B) ambient air quality monitoring/data system; (C) programs for enforcement of control measures and for construction or modification of stationary sources; (D)(i) interstate pollution transport and (ii) interstate and international pollution abatement; (E) adequate resources and authority, conflict of interest, and oversight of local governments and regional agencies; (F) stationary source monitoring and reporting; (G) emergency powers; (H) SIP revisions; (I)

[154] ''Guidance to Regions for Working with Tribes during the National Ambient Air Quality Standards (NAAQS) Designations Process,'' December 20, 2011, Memorandum from Stephen D. Page to Regional Air Directors, Regions 1–X available at *https://www.epa.gov/sites/default/files/2017-02/documents/12-20-11_guidance_to_regions_for_working_with_tribes_naaqs_designations.pdf.*

plan revisions for nonattainment areas; (J) consultation with government officials, public notification, Prevention of Significant Deterioration (PSD) and visibility protection; (K) air quality modeling and submission of modeling data; (L) permitting fees; and (M) consultation and participation by affected local entities. These requirements apply to all SIP submissions in general, but the EPA has provided specific guidance to States concerning its interpretation of these requirements in the specific context of infrastructure SIP submissions for a new or revised NAAQS.[155]

As a reminder, States are not required to address nonattainment plan requirements for purposes of the revised secondary SO_2 NAAQS on the same schedule as infrastructure SIP requirements. For the reasons explained below, the EPA interprets the CAA such that (1) the portion of CAA section 110(a)(2)(C), programs for enforcement of control measures and for construction or modification of sources that applies to permit programs applicable in designated nonattainment areas, (known as ''nonattainment new source review'') under part D; and (2) CAA section 110(a)(2)(I) in its entirety are not subject to the 3-year submission deadline of CAA section 110(a)(1), and thus States are not required to address them in the context of an infrastructure SIP submission. Accordingly, the EPA does not expect States to address the requirement for a new or revised NAAQS in the infrastructure SIP submissions to include regulations or emissions limits developed specifically for attaining the relevant standard in areas designated nonattainment for the revised secondary SO_2 NAAQS. States are required to submit infrastructure SIP submissions for the secondary SO_2 NAAQS before they are required to submit nonattainment plan SIP submissions to demonstrate attainment with the same NAAQS. As a general matter, states would be required to submit nonattainment plans to provide for attainment and maintenance of the revised secondary SO_2 NAAQS within 3 years from the effective date of nonattainment area designations as required under CAA section 172(b). In addition, because this NAAQS is a secondary standard, CAA section 110(b) also provides that the EPA may extend the deadline for the nonattainment plan for up to 18 months beyond the initial 3 years. If a state requests an extension pursuant to CAA section 110(b) and 40 CFR 51.341 and the Administrator determines an extension is necessary, the EPA will set additional time for the nonattainment plan submittal in a separate action from this final rule. The EPA reviews and acts upon these later SIP submissions through a separate process. For these reasons, the EPA does not expect States to address new nonattainment area emissions controls per CAA section 110(a)(2)(I) in their infrastructure SIP submissions.

Another required infrastructure SIP element is that each State's SIP must contain adequate provisions to prohibit, consistent with the provisions of title I of the CAA, emissions from within the State that will significantly contribute to nonattainment in, or interfere with maintenance by, any other State of the primary or secondary NAAQS.[156] This element is often referred to as the ''good neighbor'' or ''interstate transport'' provision.[157] The provision has two prongs: significant contribution to nonattainment (prong 1) and interference with maintenance (prong 2). The EPA and States must give independent significance to prong 1 and prong 2 when evaluating downwind air quality problems under CAA section 110(a)(2)(D)(i)(I).[158] Further, case law has established that the EPA and States must implement requirements to meet interstate transport obligations in alignment with the applicable statutory attainment schedule of the downwind areas impacted by upwind-State emissions.[159] The EPA anticipates coordinating with States with respect to the requirements of CAA section 110(a)(2)(D)(i)(I) for implementation of the secondary SO_2 NAAQS.

Each State has the authority and responsibility to review its air quality management program's existing SIP provisions in light of each new or revised NAAQS to determine whether any revisions to the State's regulations or program are necessary to implement a new or revised NAAQS. Most States have revised and updated their SIPs in recent years to address requirements associated with other revised NAAQS. For some States, it may be the case that, for a number of infrastructure elements, the State may believe it already has adequate State regulations adopted and approved into the SIP to address a particular requirement with respect to any new or revised NAAQS. For such portions of the State's infrastructure SIP submission, the State could provide an explanation of how its existing SIP provisions are adequate.

If a State determines that existing SIP-approved provisions, such as those approved for the 1-hour primary SO_2 NAAQS, remain adequate in light of the new annual secondary SO_2 NAAQS with respect to a given infrastructure SIP element (or sub-element), then the State may make a SIP submission containing relevant supporting information ''certifying'' that the existing SIP contains provisions that address those requirements of the specific CAA section 110(a)(2) infrastructure elements.[160] In the case of such a certification submission, the State would not have to include a copy of the relevant provision (*e.g.,* rule or statute) itself. Rather, this certification submission should provide citations to the EPA-approved State statutes, regulations, or non-regulatory measures, as appropriate, in or referenced by the already EPA-approved SIP that meet particular infrastructure SIP element requirements. The State's infrastructure SIP submission should also include an explanation as to how the State has determined that those existing provisions meet the relevant requirements.

Like any other SIP submission, that State can make such an infrastructure SIP submission certifying that it has already met some or all of the applicable requirements only after it has provided reasonable notice and opportunity for public hearing. This ''reasonable notice and opportunity for public hearing'' requirement for infrastructure SIP submissions is to meet the requirements of CAA sections 110(a) and 110(l). Under the EPA's regulations at 40 CFR part 51, if a public hearing is held, an infrastructure SIP submittal must include a certification by the State that the public hearing was held in accordance with the EPA's procedural requirements for public hearings. See 40 CFR part 51, appendix V, 2.1(g); and see 40 CFR 51.102.

In consultation with its EPA Regional Office, a State should follow all applicable EPA regulations governing infrastructure SIP submissions in 40 CFR part 51—*e.g.,* subpart I (Review of New Sources and Modifications), subpart J (Ambient Air Quality

[155] *See* ''Guidance on Infrastructure State Implementation Plan (SIP) Elements under Clean Air Act sections 110(a)(1) and 110(a)(2)'' September 2013, Memorandum from Stephen D. Page to Regional Air Directors, Regions 1–10.

[156] CAA section 110(a)(2)(D)(i)(I).

[157] CAA section 110(a)(2)(D)(i)(II) also addresses certain interstate effects that States must address and thus is also sometimes referred to as relating to ''interstate transport.''

[158] *See North Carolina* v. *EPA,* 531 F.3d 896, 909–11 (D.C. Cir. 2008).

[159] *See id.* at 911–13. *See also Wisconsin* v. *EPA,* 938 F.3d 303, 313–20 (D.C. Cir. 2019); *Maryland* v. *EPA,* 958 F.3d 1185, 1203–04 (D.C. Cir. 2020).

[160] A ''certification'' approach would not be appropriate for the interstate pollution control requirements of CAA section 110(a)(2)(D)(i).

Surveillance), subpart K (Source Surveillance), subpart L (Legal Authority), subpart M (Intergovernmental Consultation), subpart O (Miscellaneous Plan Content Requirements), subpart P (Protection of Visibility), and subpart Q (Reports). For the EPA's general criteria for infrastructure SIP submissions, refer to 40 CFR part 51, appendix V, Criteria for Determining the Completeness of Plan Submissions. The EPA recommends that States electronically submit their infrastructure SIPs to the EPA through the State Plan Electronic Collaboration System (SPeCS),[161] an online system available through the EPA's Central Data Exchange. The EPA acknowledges that the timeline for submission of infrastructure SIPs for the secondary SO_2 NAAQS may overlap in part with the timeline for submission of infrastructure SIPs for the recently revised primary $PM_{2.5}$ NAAQS. Air Agencies may elect to streamline their infrastructure SIP submittal and development by combining the two distinct infrastructure SIP submissions for both NAAQS into one submission. The EPA appreciates the obligations may differ for some infrastructure elements, and simply notes that this option may represent a more streamlined approach for some areas.

C. Prevention of Significant Deterioration and Nonattainment New Source Review Programs for the Revised Secondary SO_2 Standard

The CAA, at parts C and D of title I, contains preconstruction review and permitting programs applicable to new major stationary sources and major modifications of existing major sources. The preconstruction review of each new major stationary source and major modification applies on a pollutant-specific basis, and the requirements that apply for each pollutant depend on whether the area in which the source is situated is designated as attainment (or unclassifiable) or nonattainment for that pollutant. In areas designated attainment or unclassifiable for a pollutant, the PSD requirements under part C apply to construction at major sources. In areas designated nonattainment for a pollutant, the Nonattainment New Source Review (NNSR) requirements under part D apply to major source construction. Collectively, those two sets of permit requirements are commonly referred to as the ''major New Source Review'' or ''major NSR'' programs.

The statutory requirements for a PSD permit program set forth under part C of title I of the CAA (sections 160 through 169) are implemented through the EPA's PSD regulations found at 40 CFR 51.166 (minimum requirements for an approvable PSD SIP) and 40 CFR 52.21 (PSD permitting program for permits issued under the EPA's Federal permitting authority). Whenever a proposed new major source or major modification triggers PSD requirements for SO_2, either 40 CFR 52.21 or State regulations based on 40 CFR 51.166 will apply for undesignated areas and for areas that are designated as attainment or as unclassifiable for the revised secondary SO_2 NAAQS.

For PSD, a ''major stationary source'' is one with the potential to emit 250 tons per year (tpy) or more of any regulated NSR pollutant, unless the new or modified source is classified under a list of 28 source categories contained in the statutory definition of ''major emitting facility'' in CAA section 169(1). For those 28 source categories, a ''major stationary source'' is one with the potential to emit 100 tpy or more of any regulated NSR pollutant. A ''major modification'' is a physical change or a change in the method of operation of an existing major stationary source that results, first, in a significant emissions increase of a regulated NSR pollutant and, second, in a significant net emissions increase of that pollutant. *See* 40 CFR 51.166(b)(2)(i), 52.21(b)(2)(i). The EPA PSD regulations define the term ''regulated NSR pollutant'' to include any pollutant for which a NAAQS has been promulgated and any pollutant identified in the EPA regulations as a constituent or precursor to such pollutant. *See* 40 CFR 51.166(b)(49), 52.21(b)(50). Thus, the PSD program currently requires the review and control of emissions of SO_2, as applicable. Among other things, for each regulated NSR pollutant emitted or increased in a significant amount, the PSD program requires a new major stationary source or a major modification to apply the ''best available control technology'' (BACT) and to conduct an air quality impact analysis to demonstrate that the proposed major stationary source or major modification will not cause or contribute to a violation of any NAAQS or PSD increment.[162] *See* CAA section 165(a)(3)–(4), 40 CFR 51.166(j) and (k), 52.21(j) and (k). The PSD requirements may also include, in appropriate cases, an analysis of potential adverse impacts on Class I areas. *See* CAA sections 162(a) and 165, 40 CFR 51.166(p), 52.21(p)).[163]

With regard to nonattainment NSR, the EPA's regulations for the NNSR programs are contained in 40 CFR 51.165, 40 CFR 52.24, and 40 CFR part 51, appendix S. Specifically, the EPA developed minimum program requirements for a NNSR program that is approvable in a SIP, and those requirements, which include requirements for SO_2, are contained in 40 CFR 51.165. In addition, 40 CFR part 51, appendix S contains requirements constituting an interim NNSR program. This program enables NNSR permitting in nonattainment areas by States that lack a SIP-approved NNSR permitting program (or a program that does not apply to the relevant pollutant) during the time between the date of the relevant designation and the date that the EPA approves into the SIP a NNSR program. *See* 40 CFR part 51, appendix S, part I; 40 CFR 52.24(k). Any new NNSR requirements for SO_2 associated with the revised secondary standard would become applicable upon the effective date of any nonattainment designation for the final standard.

As stated in the proposal section V.C., the EPA is not making any changes to the NSR program regulations to implement the revised secondary SO_2 NAAQS. Under the PSD program, any permit issued on and after the effective date of the new annual secondary SO_2 NAAQS will require a demonstration that the emissions from the proposed major stationary source or major modification would not cause or contribute to violation of that standard. The EPA has regulations, models, guidance, and other tools for making this showing, and anticipates that sources and reviewing authorities will be able to use most of these existing tools to demonstrate compliance with the revised secondary SO_2 NAAQS. However, as provided in the NPRM, the EPA developed a separate technical

[161] *https://cdx.epa.gov/.*

[162] By establishing the maximum allowable level of ambient air pollutant concentration increase in a particular area, an increment defines ''significant deterioration'' of air quality in that area. Increments are defined by the CAA as maximum allowable increases in ambient air concentrations above a baseline concentration and are specified in the PSD regulations by pollutant and area classification (Class I, II and III). 40 CFR 51.166(c), 52.21(c); 75 FR 64864; October 20, 2010. The EPA has developed the Guideline on Air Quality Models and other documents to, among other things, provide methods and guidance for demonstrating compliance the NAAQS and PSD increments including the annual SO_2 standard. See 40 CFR part 51, appendix W; 82 FR 5182, January 17, 2017.

[163] Congress established certain Class I areas in section 162(a) of the CAA, including international parks, national wilderness areas, and national parks that meet certain criteria. Such Class I areas, known as mandatory Federal Class I areas, are afforded special protection under the CAA. In addition, states and Tribal governments may establish Class I areas within their own political jurisdictions to provide similar special air quality protection.

document (Tillerson et al., 2024),[164] which provides a technical justification for how a demonstration of compliance with the 1-hour primary SO_2 standard can suffice to demonstrate compliance with the new SO_2 secondary standard. The EPA has determined that this alternative compliance demonstration approach is technically justified and can provide for streamlined implementation of the new secondary SO_2 NAAQS under the PSD program in all areas of the country. Accordingly, the EPA plans to issue a memorandum that explains how permit applicants and permitting authorities may use this alternative compliance demonstration approach and supporting technical analysis in making the required demonstration for the new secondary SO_2 NAAQS. The EPA intends to issue this memorandum close in time to the effective date of the new secondary SO_2 NAAQS to help provide for a smooth transition to implementing the revised secondary standard under the PSD program.

D. Transportation Conformity Program

As discussed in the proposal section V.E., transportation conformity is required under CAA section 176(c) (42 U.S.C. 7506(c)) to ensure that federally supported highway and transit activities are consistent with (''conform to'') the purpose of the SIP. Transportation conformity applies to areas that are designated as nonattainment areas and to nonattainment areas that have been redesignated to attainment with an approved CAA section 175A maintenance plan (*i.e.,* maintenance areas) for transportation-related criteria pollutants: carbon monoxide, ozone, NO_2, $PM_{2.5}$, and PM_{10}. Motor vehicles are not significant sources of SO_2, and thus transportation conformity does not apply to any SO_2 NAAQS (40 CFR 93.102(b)(1)), either the existing NAAQS or this revised secondary SO_2 NAAQS.[165] Therefore, this final rule does not affect the transportation conformity rule (40 CFR 51.390 and 40 CFR part 93, subpart A).

E. General Conformity Program

The General Conformity program applies to federal activities that cause emissions of the criteria or precursor pollutants to originate within designated nonattainment areas [166] or redesignated attainment areas that operate under approved CAA section 175A maintenance plans (*i.e.,* maintenance areas). The General Conformity program requirements at 40 CFR part 93, subpart B establish criteria and procedures for determining conformity as required under CAA section 176(c),[167] which prohibits a Federal agency from taking an action that would interfere with the ability of a State or Tribe to attain or maintain the NAAQS. General Conformity applies only to Federal activities not defined as transportation plans, programs, or projects under 40 CFR 93.102. The program requirements apply to emissions of all six criteria pollutants and their precursors, including NO_X, SO_X, and PM, per 40 CFR 93.153(b)(1) and (2), but only to the extent the emissions can be characterized as ''direct emissions'' or ''indirect emissions'' as defined under 40 CFR 93.152. General federal activities that cause emissions of SO_2 are subject to General Conformity; however, no change to the regulations is necessary to accommodate any changes to the secondary SO_2 NAAQS made by this rulemaking.

VI. Statutory and Executive Order Reviews

Additional information about these statutes and Executive orders can be found at *https://www.epa.gov/laws-regulations/laws-and-executive-orders.*

A. Executive Order 12866: Regulatory Planning and Review and Executive Order 14094: Modernizing Regulatory Review

This action is a ''significant regulatory action'' as defined in Executive Order 12866, as amended by Executive Order 14094. Accordingly, EPA submitted this action to the Office of Management and Budget (OMB) for Executive Order 12866 review. Documentation of any changes made in response to the Executive Order 12866 review is available in the docket. The EPA prepared an analysis to determine if additional emission reductions would be needed to meet the revised secondary SO_2 NAAQS. This analysis is contained in the document ''Air Quality Analyses Using Sulfur Dioxide (SO_2) Air Quality Data, Updated'' which is available in the docket for this NAAQS review (ID No. EPA–HQ–OAR–2014–0128). The analysis concluded that no additional emissions reductions beyond any needed to meet the current 1-hour primary SO_2 NAAQS are expected to be necessary to meet the new annual secondary SO_2 NAAQS of 10 ppb, averaged over three years. Thus, there are no pollution controls expected to be necessary, and accordingly no costs or monetized benefits associated with this NAAQS revision. Accordingly, no regulatory impact analysis has been prepared for this final rule.

B. Paperwork Reduction Act (PRA)

This action does not impose any new information collection burden under the PRA. The OMB has previously approved the information collection activities contained in the existing regulations and has assigned OMB control number 2060–0084. The data collected through the information collection activities in the existing regulations consist of ambient air concentration measurements for the seven air pollutants with national ambient air quality standards (*i.e.,* ozone, sulfur dioxide, nitrogen dioxide, lead, carbon monoxide, $PM_{2.5}$ and PM_{10}), ozone precursors, air toxics, meteorological variables at a select number of sites, and other supporting measurements. Accompanying the pollutant concentration data are quality assurance/quality control data and air monitoring network design information. The EPA and others (*e.g.,* State and local air quality management agencies, Tribal entities, environmental organizations, academic institutions, and industrial groups) use the ambient air quality data for many purposes including informing the public and other interested parties of an area's air quality, judging an area's air quality in comparison with the established health or welfare standards, evaluating an air quality management agency's progress in achieving or maintaining air pollutant levels below the national and local standards, developing and revising State Implementation Plans (SIPs), evaluating air pollutant control strategies, developing or revising national control policies, providing data for air quality model development and validation,

[164] This technical memo (Tillerson et al., 2024) is available in the docket for this NAAQS review (Docket ID No. EPA–HQ–OAR–2014–0128–0041).

[165] See ''VII. Description of the Proposal'' in ''Criteria and Procedures for Determining Conformity to State or Federal Implementation Plans of Transportation Plans, Programs, and Projects funded or Approved Under Title 23 U.S.C. or the Federal Transit Act.'' (58 FR 3768, January 11, 1993). The EPA finalized the original transportation conformity regulations on November 24, 1993 (58 FR 62188). The rule has subsequently been revised and the current provisions of the transportation conformity rule are found at 40 CFR part 93, subpart A.

[166] Applicability of the General Conformity program to any newly designated nonattainment area for a specific NAAQS begins one year following the effective date of the final nonattainment designation, as allowed under CAA section 176(c)(6) and 40 CFR 93.153(k).

[167] Under CAA section 176(c)(1), Federal agencies have the affirmative responsibility to assure their actions achieve conformity to the purpose of an implementation plan, where the term ''conformity to an implementation plan'' is defined at CAA sections 176(c)(1)(A) and 176(c)(1)(B). Under CAA section 176(c)(4), the EPA is required to establish criteria and procedures for determining conformity.

supporting enforcement actions, documenting episodes and initiating episode controls, assessing air quality trends, and conducting air pollution research.

C. Regulatory Flexibility Act (RFA)

I certify that this action will not have a significant economic impact on a substantial number of small entities under the RFA. This action will not impose any requirements on small entities. Rather, this final rule establishes national standards for allowable annual average concentrations of SO_2 in ambient air as required by section 109 of the CAA. See also *American Trucking Associations* v. *EPA,* 175 F.3d 1027, 1044–45 (D.C. Cir. 1999) (NAAQS do not have significant impacts upon small entities because NAAQS themselves impose no regulations upon small entities), rev'd in part on other grounds, *Whitman* v. *American Trucking Associations,* 531 U.S. 457 (2001).

D. Unfunded Mandates Reform Act (UMRA)

This action does not contain an unfunded mandate as described in UMRA, 2 U.S.C. 1531–1538, and does not significantly or uniquely affect small governments. Furthermore, as indicated previously, in setting a NAAQS the EPA cannot consider the economic or technological feasibility of attaining ambient air quality standards, although such factors may be considered to a degree in the development of state plans to implement the standards. See also *American Trucking Associations* v. *EPA,* 175 F. 3d at 1043 (noting that because the EPA is precluded from considering costs of implementation in establishing NAAQS, preparation of the RIA pursuant to the Unfunded Mandates Reform Act would not furnish any information that the court could consider in reviewing the NAAQS).

E. Executive Order 13132: Federalism

This action does not have federalism implications. It will not have substantial direct effects on the states, on the relationship between the national government and the states, or on the distribution of power and responsibilities among the various levels of government. However, the EPA recognizes that states will have a substantial interest in this action and any future revisions to associated requirements.

F. Executive Order 13175: Consultation and Coordination With Indian Tribal Governments

This action does not have Tribal implications, as specified in Executive Order 13175. It does not have a substantial direct effect on one or more Indian Tribes as Tribes are not obligated to adopt or implement any NAAQS. In addition, Tribes are not obligated to conduct ambient monitoring for SO_2 or to adopt the ambient air monitoring requirements of 40 CFR part 58. Thus, Executive Order 13175 does not apply to this action. However, consistent with the *EPA Policy on Consultation and Coordination with Indian Tribes,* the EPA offered consultation to all 574 Federally Recognized Tribes during the development of this action. Although no Tribes requested consultation, the EPA provided informational meetings and provided information on the monthly National Tribal Air Association calls, and during the public comment period we received comments on the proposed rule from this Tribal organization.

G. Executive Order 13045: Protection of Children From Environmental Health Risks and Safety Risks

EPA interprets Executive Order 13045 as applying only to those regulatory actions that concern environmental health or safety risks that EPA has reason to believe may disproportionately affect children, per the definition of ''covered regulatory action'' in section 2–202 of the Executive order.

Therefore, this action is not subject to Executive Order 13045 because it does not concern an environmental health risk or safety risk. Since this action does not concern human health, EPA's Policy on Children's Health also does not apply.

H. Executive Order 13211: Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution or Use

This action is not a ''significant energy action'' because it is not likely to have a significant adverse effect on the supply, distribution, or use of energy. The purpose of this action is to revise the existing secondary SO_2 standard, and also to retain the current secondary standards for NO_2, $PM_{2.5}$ and PM_{10}. The action does not prescribe specific pollution control strategies by which these ambient air standards and monitoring revisions will be met. Such strategies will be developed by states on a case-by-case basis, and the EPA cannot predict whether the control options selected by states will include regulations on energy suppliers, distributors, or users. Thus, the EPA concludes that this action does not constitute a significant energy action as defined in Executive Order 13211.

I. National Technology Transfer and Advancement Act (NTTAA)

This action involves environmental monitoring or measurements. The EPA has decided to use the existing indicator, SO_2, for measurements in support of this action and is not revising the SO_2 FRMs or FEMs for measurement of this air pollutant. The EPA employs a Performance-Based Measurement System (PBMS) when designating monitoring methods as either FRM or FEM, which does not require the use of specific, prescribed analytic methods. This performance-based assessment of candidate methods is described in 40 CFR part 50 and the reference and equivalency criteria described in 40 CFR part 53. The EPA does not preclude the use of other methods, whether it constitutes a voluntary consensus standard or not, as long as it meets the specified performance criteria defined in 40 CFR part 53 and is approved by EPA as an FRM or FEM. Our approach in the past has resulted in multiple brands of monitors being approved as FRM for SO_2, and we expect this trend to continue.

J. Executive Order 12898: Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations and Executive Order 14096: Revitalizing Our Nation's Commitment to Environmental Justice for All

The EPA believes that the human health and environmental conditions that exist prior to this action do not result in disproportionate and adverse effects on communities with Environmental Justice (EJ) concerns. As discussed in sections II.A.4. and II.B. above, and chapters 5 and 7 of the PA, the acid buffering capacity of waterbodies in key acid-sensitive ecoregions in recent years is estimated to meet protection targets in high percentages. As discussed in section II.A.3.b. above, impacts on acid-sensitive waterbodies, if sufficiently severe, would have the potential to impact the public welfare through impacts to fisheries. Although recent conditions do not indicate such a level of severity, to the extent local communities relied on such fisheries disproportionately to their representation in the population, such effects of the past (*e.g.,* effects associated with acidification risks of 20 or more years ago) would have had the potential

for disproportionate impacts. Recent conditions do not indicate risk of aquatic acidification to such a level of severity, and the available information for recent acid buffering capacity levels does not include evidence of disproportionate and adverse impacts on communities with EJ concerns. As the action is to establish a new, more stringent standard to protect acid-sensitive waterbodies to recent levels and protect against recurrence of acidification effects from the past, for which the potential for disproportionate and adverse effects on local communities is unknown, the EPA believes that this action is not likely to result in new disproportionate and adverse effects on communities with EJ concerns. The information supporting this Executive order review is contained in the PA for this review and sections II.A.3., II.A.4., II.B.1. and II.B.3. of this document.

K. Congressional Review Act (CRA)

This action is subject to the CRA, and the EPA will submit a rule report to each House of the Congress and to the Comptroller General of the United States. This action is not a ''major rule'' as defined by 5 U.S.C. 804(2).

L. Judicial Review

Under section 307(b)(1) of the CAA, this final action is ''nationally applicable'' and petitions for judicial review of this action must be filed in the U.S. Court of Appeals for the District of Columbia Circuit within 60 days from the date this final action is published in the **Federal Register**. Filing a petition for reconsideration by the Administrator of this final action does not affect the finality of the action for the purposes of judicial review, nor does it extend the time within which a petition for judicial review must be filed and shall not postpone the effectiveness of such action.

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List of Subjects in 40 CFR Part 50

Environmental protection, Air pollution control, Nitrogen dioxide, Particulate matter, Sulfur oxides.

Michael S. Regan,

Administrator.

For the reasons set forth in the preamble, the Environmental Protection Agency is amending chapter I of title 40 of the Code of Federal Regulations as follows:

PART 50—NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS

■ 1. The authority citation for part 50 continues to read as follows:

Authority: 42 U.S.C. 7401, *et seq.*

■ 2. Add § 50.21 to read as follows:

§ 50.21 National secondary ambient air quality standards for sulfur oxides (sulfur dioxide).

(a) The level of the annual secondary national ambient air quality standard for oxides of sulfur is 10 parts per billion (ppb), measured in the ambient air as sulfur dioxide (SO_2) by a reference method based on appendix A–1 and appendix A–2 of this part, or by a Federal Equivalent Method (FEM) designated in accordance with part 53 of this chapter.

(b) The annual secondary standard is met when the 3-year average of the annual SO_2 concentration is less than or equal to 10 ppb, as determined in accordance with appendix T of this part.

■ 3. Revise appendix T to part 50 to read as follows:

Appendix T to Part 50—Interpretation of the Primary and Secondary National Ambient Air Quality Standards for Oxides of Sulfur (Sulfur Dioxide)

1. General

(a) This appendix explains the data handling conventions and computations necessary for determining when the primary and secondary national ambient air quality standards for Oxides of Sulfur as measured by Sulfur Dioxide (''SO_2 NAAQS'') specified in § 50.17 are met at an ambient air quality monitoring site. Sulfur dioxide (SO_2) is measured in the ambient air by a Federal reference method (FRM) based on appendix A–1 or A–2 to this part or by a Federal equivalent method (FEM) designated in accordance with part 53 of this chapter. Data handling and computation procedures to be used in making comparisons between reported SO_2 concentrations and the levels of the SO_2 NAAQS are specified in the following sections.

(b) Decisions to exclude, retain, or make adjustments to the data affected by exceptional events, including natural events, are made according to the requirements and process deadlines specified in §§ 50.1, 50.14 and 51.930 of this chapter.

(c) The terms used in this appendix are defined as follows:

Annual mean refers to the annual average of all the daily mean values as defined in section 5.2 of this appendix.

Daily maximum 1-hour values for SO_2 refers to the maximum 1-hour SO_2 concentration values measured from midnight to midnight (local standard time) that are used in NAAQS computations.

Daily mean values for SO_2 refers to the 24-hour average of 1-hour SO_2 concentration values measured from midnight to midnight (local standard time) that are used in NAAQS computations.

Design values are the metrics (*i.e.,* statistics) that are compared to the NAAQS levels to determine compliance, calculated as specified in section 5 of this appendix. The design value for the primary 1-hour NAAQS is the 3-year average of annual 99th percentile daily maximum 1-hour values for a monitoring site (referred to as the ''1-hour primary standard design value''). The design value for the secondary annual NAAQS is the 3-year average of the annual mean of daily mean values for a monitoring site (referred to as the ''annual secondary standard'').

99th percentile daily maximum 1-hour value is the value below which nominally 99 percent of all daily maximum 1-hour concentration values fall, using the ranking and selection method specified in section 5.1 of this appendix.

Pollutant Occurrence Code (POC) refers to a numerical code (1, 2, 3, *etc.*) used to distinguish the data from two or more monitors for the same parameter at a single monitoring site.

Quarter refers to a calendar quarter.

Year refers to a calendar year.

2. Requirements for Data Used for Comparisons With the SO_2 NAAQS and Data Reporting Considerations

(a) All valid FRM/FEM SO_2 hourly data required to be submitted to EPA's Air Quality System (AQS), or otherwise available to EPA, meeting the requirements of part 58 of this chapter including appendices A, C, and E shall be used in design value calculations. Multi-hour average concentration values collected by wet chemistry methods shall not be used.

(b) Data from two or more monitors from the same year at the same site reported to EPA under distinct Pollutant Occurrence Codes shall not be combined in an attempt to meet data completeness requirements. The Administrator will combine annual 99th percentile daily maximum concentration values from different monitors in different years, selected as described here, for the purpose of developing a valid 1-hour primary standard design value. If more than one of the monitors meets the completeness requirement for all four quarters of a year, the steps specified in section 5.1(a) of this appendix shall be applied to the data from the monitor with the highest average of the four quarterly completeness values to derive a valid annual 99th percentile daily maximum concentration. If no monitor is complete for all four quarters in a year, the steps specified in sections 3.1(c) and 5.1(a) of this appendix shall be applied to the data from the monitor with the highest average of the four quarterly completeness values in an attempt to derive a valid annual 99th percentile daily maximum concentration. Similarly, the Administrator will combine annual means from different monitors in different years, selected as described here, for the purpose of developing a valid annual secondary standard design value. If more than one of the monitors meets the completeness requirement for all four quarters of a year, the steps specified in section 5.2(a) of this appendix shall be applied to the data from the monitor with the highest average of the four quarterly completeness values to derive a valid annual mean. If no monitor is complete for all four quarters in a year, the steps specified in sections 3.2(c) and 5.2(a) of this appendix shall be applied to the data from the monitor with the highest average of the four quarterly completeness values in an attempt to derive a valid annual mean. This paragraph does not

prohibit a monitoring agency from making a local designation of one physical monitor as the primary monitor for a Pollutant Occurrence Code and substituting the 1-hour data from a second physical monitor whenever a valid concentration value is not obtained from the primary monitor; if a monitoring agency substitutes data in this manner, each substituted value must be accompanied by an AQS qualifier code indicating that substitution with a value from a second physical monitor has taken place.

(c) Hourly SO_2 measurement data shall be reported to AQS in units of parts per billion (ppb), to at most one place after the decimal, with additional digits to the right being truncated with no further rounding.

3. Comparisons With the NAAQS

3.1 Comparisons With the 1-Hour Primary SO_2 NAAQS

(a) The 1-hour primary SO_2 NAAQS is met at an ambient air quality monitoring site when the valid 1-hour primary standard design value is less than or equal to 75 parts per billion (ppb).

(b) An SO_2 1-hour primary standard design value is valid if it encompasses three consecutive calendar years of complete data. A year meets data completeness requirements when all four quarters are complete. A quarter is complete when at least 75 percent of the sampling days for each quarter have complete data. A sampling day has complete data if 75 percent of the hourly concentration values, including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator, are reported.

(c) In the case of one, two, or three years that do not meet the completeness requirements of section 3.1(b) of this appendix and thus would normally not be useable for the calculation of a valid 3-year 1-hour primary standard design value, the 3-year 1-hour primary standard design value shall nevertheless be considered valid if one of the following conditions is true.

(i) At least 75 percent of the days in each quarter of each of three consecutive years have at least one reported hourly value, and the design value calculated according to the procedures specified in section 5.1 is above the level of the primary 1-hour standard.

(ii)(A) A 1-hour primary standard design value that is equal to or below the level of the NAAQS can be validated if the substitution test in section 3.1(c)(ii)(B) of this appendix results in a ''test design value'' that is below the level of the NAAQS. The test substitutes actual ''high'' reported daily maximum 1-hour values from the same site at about the same time of the year (specifically, in the same calendar quarter) for unknown values that were not successfully measured. *Note* that the test is merely diagnostic in nature, intended to confirm that there is a very high likelihood that the original design value (the one with less than 75 percent data capture of hours by day and of days by quarter) reflects the true under-NAAQS-level status for that 3-year period; the result of this data substitution test (the ''test design value,'' as defined in section 3.1(c)(ii)(B) of this appendix) is not considered the actual design value. For this test, substitution is permitted only if there are at least 200 days across the three matching quarters of the three years under consideration (which is about 75 percent of all possible daily values in those three quarters) for which 75 percent of the hours in the day, including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator, have reported concentrations. However, maximum 1-hour values from days with less than 75 percent of the hours reported shall also be considered in identifying the high value to be used for substitution.

(B) The substitution test is as follows: Data substitution will be performed in all quarter periods that have less than 75 percent data capture but at least 50 percent data capture, including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator; if any quarter has less than 50 percent data capture then this substitution test cannot be used. Identify for each quarter (*e.g.,* January–March) the highest reported daily maximum 1-hour value for that quarter, excluding State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator, looking across those three months of all three years under consideration. All daily maximum 1-hour values from all days in the quarter period shall be considered when identifying this highest value, including days with less than 75 percent data capture. If after substituting the highest reported daily maximum 1-hour value for a quarter for as much of the missing daily data in the matching deficient quarter(s) as is needed to make them 100 percent complete, the procedure in section 5 yields a recalculated 3-year 1-hour standard ''test design value'' less than or equal to the level of the standard, then the 1-hour primary standard design value is deemed to have passed the diagnostic test and is valid, and the level of the standard is deemed to have been met in that 3-year period. As noted in section 3.1(c)(i) of this appendix, in such a case, the 3-year design value based on the data actually reported, not the ''test design value,'' shall be used as the valid design value.

(iii)(A) A 1-hour primary standard design value that is above the level of the NAAQS can be validated if the substitution test in section 3.1(c)(iii)(B) of this appendix results in a ''test design value'' that is above the level of the NAAQS. The test substitutes actual ''low'' reported daily maximum 1-hour values from the same site at about the same time of the year (specifically, in the same three months of the calendar) for unknown hourly values that were not successfully measured. Note that the test is merely diagnostic in nature, intended to confirm that there is a very high likelihood that the original design value (the one with less than 75 percent data capture of hours by day and of days by quarter) reflects the true above-NAAQS-level status for that 3-year period; the result of this data substitution test (the ''test design value,'' as defined in section 3.1(c)(iii)(B) of this appendix) is not considered the actual design value. For this test, substitution is permitted only if there are a minimum number of available daily data points from which to identify the low quarter-specific daily maximum 1-hour values, specifically if there are at least 200 days across the three matching quarters of the three years under consideration (which is about 75 percent of all possible daily values in those three quarters) for which 75 percent of the hours in the day have reported concentrations. Only days with at least 75 percent of the hours reported shall be considered in identifying the low value to be used for substitution.

(B) The substitution test is as follows: Data substitution will be performed in all quarter periods that have less than 75 percent data capture. Identify for each quarter (*e.g.,* January–March) the lowest reported daily maximum 1-hour value for that quarter, looking across those three months of all three years under consideration. All daily maximum 1-hour values from all days with at least 75 percent capture in the quarter period shall be considered when identifying this lowest value. If after substituting the lowest reported daily maximum 1-hour value for a quarter for as much of the missing daily data in the matching deficient quarter(s) as is needed to make them 75 percent complete, the procedure in section 5.1 of this appendix yields a recalculated 3-year 1-hour standard ''test design value'' above the level of the standard, then the 1-hour primary standard design value is deemed to have passed the diagnostic test and is valid, and the level of the standard is deemed to have been exceeded in that 3-year period. As noted in section 3.1(c)(i) of this appendix, in such a case, the 3-year design value based on the data actually reported, not the ''test design value'', shall be used as the valid design value.

(d) A 1-hour primary standard design value based on data that do not meet the completeness criteria stated in section 3.1(b) of this appendix and also do not satisfy section 3.1(c) of this appendix, may also be considered valid with the approval of, or at the initiative of, the Administrator, who may consider factors such as monitoring site closures/moves, monitoring diligence, the consistency and levels of the valid concentration measurements that are available, and nearby concentrations in determining whether to use such data.

(e) The procedures for calculating the 1-hour primary standard design values are given in section 5.1 of this appendix.

3.2 Comparisons With the Annual Secondary SO_2 NAAQS

(a) The annual secondary SO_2 NAAQS is met at an ambient air quality monitoring site when the valid annual secondary standard design value is less than or equal to 10 parts per billion (ppb).

(b) An SO_2 annual secondary standard design value is valid if it encompasses three consecutive calendar years of complete data. A year meets data completeness requirements when all four quarters are complete. A quarter is complete when at least 75 percent of the sampling days for each quarter have complete data. A sampling day has complete data if 75 percent of the hourly concentration values, including State-flagged data affected

by exceptional events which have been approved for exclusion by the Administrator, are reported.

(c) In the case of one, two, or three years that do not meet the completeness requirements of section 3.2(b) of this appendix and thus would normally not be useable for the calculation of a valid 3-year annual secondary standard design value, the 3-year annual secondary standard design value shall nevertheless be considered valid if one of the following conditions is true.

(i) At least 75 percent of the days in each quarter of each of three consecutive years have at least one reported hourly value, and the design value calculated according to the procedures specified in section 5.2 of this appendix is above the level of the secondary annual standard.

(ii)(A) An annual secondary standard design value that is equal to or below the level of the NAAQS can be validated if the substitution test in section 3.2(c)(ii)(B) of this appendix results in a ''test design value'' that is below the level of the NAAQS. The test substitutes actual ''high'' reported daily mean values from the same site at about the same time of the year (specifically, in the same calendar quarter) for unknown or incomplete (less than 75 percent of hours reported) daily mean values. *Note* that the test is merely diagnostic in nature, intended to confirm that there is a very high likelihood that the original design value (the one with less than 75 percent data capture of hours by day and of days by quarter) reflects the true under-NAAQS-level status for that 3-year period; the result of this data substitution test (the ''test design value,'' as defined in section 3.2(c)(ii)(B)) of this appendix is not considered the actual design value. For this test, substitution is permitted only if there are at least 200 days across the three matching quarters of the three years under consideration (which is about 75 percent of all possible daily values in those three quarters) for which 75 percent of the hours in the day, including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator, have reported concentrations. However, daily mean values from days with less than 75 percent of the hours reported shall also be considered in identifying the high daily mean value to be used for substitution.

(B) The substitution test is as follows: Data substitution will be performed in all quarter periods that have less than 75 percent data capture but at least 50 percent data capture, including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator; if any quarter has less than 50 percent data capture then this substitution test cannot be used. Identify for each quarter (*e.g.,* January–March) the highest reported daily mean value for that quarter, excluding State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator, looking across those three months of all three years under consideration. All daily mean values from all days in the quarter period shall be considered when identifying this highest value, including days with less than 75 percent data capture. If after substituting the highest daily mean value for a quarter for as much of the missing daily data in the matching deficient quarter(s) as is needed to make them 100 percent complete, the procedure in section 5 of this appendix yields a recalculated 3-year annual standard ''test design value'' less than or equal to the level of the standard, then the annual secondary standard design value is deemed to have passed the diagnostic test and is valid, and the level of the standard is deemed to have been met in that 3-year period. As noted in section 3.2(c)(i) of this appendix, in such a case, the 3-year design value based on the data actually reported, not the ''test design value,'' shall be used as the valid design value.

(iii)(A) An annual secondary standard design value that is above the level of the NAAQS can be validated if the substitution test in section 3.2(c)(iii)(B) of this appendix results in a ''test design value'' that is above the level of the NAAQS. The test substitutes actual ''low'' reported daily mean values from the same site at about the same time of the year (specifically, in the same three months of the calendar) for unknown or incomplete (less than 75 percent of hours reported) daily mean values. Note that the test is merely diagnostic in nature, intended to confirm that there is a very high likelihood that the original design value (the one with less than 75 percent data capture of hours by day and of days by quarter) reflects the true above-NAAQS-level status for that 3-year period; the result of this data substitution test (the ''test design value,'' as defined in section 3.2(c)(iii)(B) of this appendix) is not considered the actual design value. For this test, substitution is permitted only if there are a minimum number of valid daily mean values from which to identify the low quarter-specific daily mean values, specifically if there are at least 200 days across the three matching quarters of the three years under consideration (which is about 75 percent of all possible daily values in those three quarters) for which 75 percent of the hours in the day have reported concentrations. Only days with at least 75 percent of the hours reported shall be considered in identifying the low daily mean value to be used for substitution.

(B) The substitution test is as follows: Data substitution will be performed in all quarter periods that have less than 75 percent data capture. Identify for each quarter (*e.g.,* January–March) the lowest reported daily mean value for that quarter, looking across those three months of all three years under consideration. All daily mean values from all days with at least 75 percent capture in the quarter period shall be considered when identifying this lowest value. If after substituting the lowest reported daily mean value for a quarter for as much of the missing daily data in the matching deficient quarter(s) as is needed to make them 75 percent complete, the procedure in section 5.2 of this appendix yields a recalculated 3-year annual standard ''test design value'' above the level of the standard, then the annual secondary standard design value is deemed to have passed the diagnostic test and is valid, and the level of the standard is deemed to have been exceeded in that 3-year period. As noted in section 3.2(c)(i) of this appendix, in such a case, the 3-year design value based on the data actually reported, not the ''test design value,'' shall be used as the valid design value.

(d) An annual secondary standard design value based on data that do not meet the completeness criteria stated in section 3.2(b) of this appendix and also do not satisfy section 3.2(c) of this appendix, may also be considered valid with the approval of, or at the initiative of, the Administrator, who may consider factors such as monitoring site closures/moves, monitoring diligence, the consistency and levels of the valid concentration measurements that are available, and nearby concentrations in determining whether to use such data.

(e) The procedures for calculating the annual secondary standard design values are given in section 5.2 of this appendix.

4. Rounding Conventions

4.1 Rounding Conventions for the 1-Hour Primary SO_2 NAAQS

(a) Hourly SO_2 measurement data shall be reported to AQS in units of parts per billion (ppb), to at most one place after the decimal, with additional digits to the right being truncated with no further rounding.

(b) Daily maximum 1-hour values and, therefore, the annual 99th percentile of those daily values are not rounded.

(c) The 1-hour primary standard design value is calculated pursuant to section 5.1 of this appendix and then rounded to the nearest whole number or 1 ppb (decimals 0.5 and greater are rounded up to the nearest whole number, and any decimal lower than 0.5 is rounded down to the nearest whole number).

4.2 Rounding Conventions for the Annual Secondary SO_2 NAAQS

(a) Hourly SO_2 measurement data shall be reported to AQS in units of parts per billion (ppb), to at most one place after the decimal, with additional digits to the right being truncated with no further rounding.

(b) Daily mean values and the annual mean of those daily values are not rounded.

(c) The annual secondary standard design value is calculated pursuant to section 5.2 of this appendix and then rounded to the nearest whole number or 1 ppb (decimals 0.5 and greater are rounded up to the nearest whole number, and any decimal lower than 0.5 is rounded down to the nearest whole number).

5. Calculation Procedures

5.1 Calculation Procedures for the 1-Hour Primary SO_2 NAAQS

(a) *Procedure for identifying annual 99th percentile values.* When the data for a particular ambient air quality monitoring site and year meet the data completeness requirements in section 3.1(b) of this appendix, or if one of the conditions of section 3.1(c) of this appendix is met, or if the Administrator exercises the discretionary authority in section 3.1(d) of this appendix, identification of annual 99th percentile value is accomplished as follows.

(i) The annual 99th percentile value for a year is the higher of the two values resulting from the following two procedures.

(A) *Procedure 1.* For the year, determine the number of days with at least 75 percent of the hourly values reported.

(1) For the year, determine the number of days with at least 75 percent of the hourly values reported including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator.

(2) For the year, from only the days with at least 75 percent of the hourly values reported, select from each day the maximum hourly value excluding State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator.

(3) Sort all these daily maximum hourly values from a particular site and year by descending value. (For example: (x[1], x[2], x[3], . . . x[n]). In this case, x[1] is the largest number and x[n] is the smallest value.) The 99th percentile is determined from this sorted series of daily values which is ordered from the highest to the lowest number. Using the left column of table 1, determine the appropriate range (*i.e.,* row) for the annual number of days with valid data for year y (cn_y). The corresponding ''n'' value in the right column identifies the rank of the annual 99th percentile value in the descending sorted list of daily site values for year y. Thus, $P_{0.99,\ y}$ = the nth largest value.

(B) *Procedure 2.* For the year, determine the number of days with at least one hourly value reported.

(1) For the year, determine the number of days with at least one hourly value reported including State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator.

(2) For the year, from all the days with at least one hourly value reported, select from each day the maximum hourly value excluding State-flagged data affected by exceptional events which have been approved for exclusion by the Administrator.

(3) Sort all these daily maximum values from a particular site and year by descending value. (For example: (x[1], x[2], x[3], . . . x[n]). In this case, x[1] is the largest number and x[n] is the smallest value.) The 99th percentile is determined from this sorted series of daily values which is ordered from the highest to the lowest number. Using the left column of table 1, determine the appropriate range (*i.e.,* row) for the annual number of days with valid data for year y (cn_y). The corresponding ''n'' value in the right column identifies the rank of the annual 99th percentile value in the descending sorted list of daily site values for year y. Thus, $P_{0.99,y}$ = the nth largest value.

(b) The 1-hour primary standard design value for an ambient air quality monitoring site is mean of the three annual 99th percentile values, rounded according to the conventions in section 4.1 of this appendix.

TABLE 1

Annual number of days with valid data for year ''y'' (cn_y)	$P_{0.99,y}$ is the nth maximum value of the year, where n is the listed number
1–100	1
101–200	2
201–300	3
301–366	4

5.2 Calculation Procedures for the Annual Secondary SO_2 NAAQS

(a) When the data for a site and year meet the data completeness requirements in section 3.2(b) of this appendix, or if the Administrator exercises the discretionary authority in section 3.2(c), the annual mean is simply the arithmetic average of all the daily mean values.

(b) The annual secondary standard design value for an ambient air quality monitoring site is the mean of the annual means for three consecutive years, rounded according to the conventions in section 4.2 of this appendix.

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