Integrated Review Plan for the Review of the Ozone National Ambient Air Quality Standards

EPA-452/R-19-002
August 2019

Integrated Review Plan for the Review of the Ozone National Ambient Air Quality Standards

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1 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is conducting a review of the air quality criteria and the national ambient air quality standards (NAAQS) for photochemical oxidants including ozone (O_3). This Integrated Review Plan (IRP) contains the current plans for this review. The review will provide an integrative assessment of relevant scientific information and will focus on key aspects of the O_3 NAAQS, including the basic elements of the standards: the indicator,[1] averaging time, form,[2] and level. These elements, which together serve to define each ambient air quality standard, are considered collectively in evaluating the protection to public health and public welfare afforded by the standards.

This document is organized into eight chapters. Chapter 1 presents introductory information on the legislative requirements for reviews of the NAAQS, an overview of the review process, and a summary of the status and projected schedule for the current review. Chapter 2 provides background information on prior reviews of the criteria and standards for photochemical oxidants, including O_3, key aspects of the ambient air monitoring requirements, and an overview of current O_3 air quality. Chapter 3 presents the general approach and a set of policy-relevant questions intended to focus this review on the critical scientific and policy issues. Chapters 4 through 7 discuss the planned scope and organization of key assessment documents, the planned approaches for preparing the documents, and plans for scientific and public review of the documents. The complete citations for references cited throughout the document are provided in chapter 8.

1.1 LEGISLATIVE REQUIREMENTS

Two sections of the Clean Air Act (CAA) govern the establishment and revision of the NAAQS. Section 108 (42 U.S.C. 7408) directs the Administrator to identify and list certain air pollutants 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

[1] The "indicator" of a standard defines the chemical species or mixture that is to be measured in determining whether an area attains the standard. The indicator of the current NAAQS for photochemical oxidants is O_3.

[2] 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 $PM_{2.5}$ NAAQS is the three-year average of the weighted annual mean $PM_{2.5}$ concentrations, while the form of the current three-month Pb NAAQS is a three-month average concentration not to be exceeded during a three-year period.

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 [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)]. Section 109(b)(1) defines primary standards as ones "the attainment and maintenance of which in the judgment of the Administrator, based on such criteria and allowing an adequate margin of safety, are requisite to protect the public health."[3] 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."[4]

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 Associations*, 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). At the same time, courts have clarified the EPA may consider "relative proximity to peak background … concentrations" as a factor 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. *American Trucking Associations, Inc. v. EPA*, 283 F.3d 355, 379 (D.C. Cir. 2002).

The requirement that primary standards provide an adequate margin of safety was intended to address uncertainties associated with inconclusive scientific and technical information available at the time of standard setting. It was also intended to provide a reasonable degree of protection against hazards that research has not yet identified. See *Lead Industries Association v. EPA*, 647 F.2d 1130, 1154 (D.C. Cir 1980), *cert. denied*, 449 U.S. 1042 (1980);

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

[4] 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."

American Petroleum Institute v. Costle, 665 F.2d at 1186 (D.C. Cir. 1981), *cert. denied*, 455 U.S. 1034 (1982); *Coalition of Battery Recyclers Ass'n v. EPA*, 604 F.3d 613, 617-18 (D.C. Cir. 2010); *Mississippi v. EPA*, 744 F.3d 1334, 1353 (D.C. Cir. 2013). Both kinds of uncertainties are components of the risk associated with pollution at levels below those at which human health effects can be said to occur with reasonable scientific certainty. Thus, in selecting primary standards that include an adequate margin of safety, the Administrator is seeking not only to prevent pollution levels that have been demonstrated to be harmful but also to prevent lower pollutant levels that may pose an unacceptable risk of harm, even if the risk is not precisely identified as to nature or degree. The CAA does not require the Administrator to establish a primary NAAQS at a zero-risk level or at background concentration levels, see *Lead Industries v. EPA*, 647 F.2d at 1156 n.51, *Mississippi v. EPA*, 744 F.3d at 1351, but rather at a level that reduces risk sufficiently so as to protect public health with an adequate margin of safety.

In addressing the requirement for an adequate margin of safety, the EPA considers such factors as the nature and severity of the health effects involved, the size of the sensitive population(s), and the kind and degree of uncertainties. The selection of any particular approach to providing an adequate margin of safety is a policy choice left specifically to the Administrator's judgment. See *Lead Industries Association v. EPA*, 647 F.2d at 1161-62; *Mississippi v. EPA*, 744 F.3d at 1353.

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.[5]

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 Clean Air Scientific Advisory Committee (CASAC) of the EPA's Science Advisory Board. A number of other advisory functions are also identified for the committee by section 109(d)(2)(C), which reads:

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

> Such committee shall also (i) advise the Administrator of areas in which additional knowledge is required to appraise the adequacy and basis of existing, new, or revised national ambient air quality standards, (ii) describe the research efforts necessary to provide the required information, (iii) advise the Administrator on the relative contribution to air pollution concentrations of natural as well as anthropogenic activity, and (iv) advise the Administrator of any adverse public health, welfare, social, economic, or energy effects which may result from various strategies for attainment and maintenance of such national ambient air quality standards.

As previously noted, the Supreme Court has held that section 109(b) "unambiguously bars cost considerations from the NAAQS-setting process" (*Whitman v. Am. Trucking Associations,* 531 U.S. 457, 471 [2001]). Accordingly, while some of these issues regarding which Congress has directed the CASAC to advise the Administrator are ones that are relevant to the standard setting process, others are not. Issues that are not relevant to standard setting may be relevant to implementation of the NAAQS once they are established.[6]

1.2 OVERVIEW OF THE NAAQS REVIEW PROCESS

The process for reviewing the NAAQS has three general phases: (1) planning, (2) assessment, and (3) decision making. Each of these phases is described in this section. The Agency maintains a web site on which key documents developed in each phase of each NAAQS review are made available (https://www.epa.gov/naaqs). This website also makes available information regarding the process for NAAQS reviews, including the May 2018 memorandum from the Administrator to Assistant Administrators (Pruitt, 2018) that describes five areas for emphasis (principles) in the reviews and that builds on prior memoranda concerning the process for NAAQS reviews (Peacock, 2006; Jackson, 2009).

The planning phase of each NAAQS review begins with a call for information and the identification of issues and questions to frame the review. Drawing on this information and issues raised in the last review, a draft IRP is prepared jointly by the EPA's National Center for Environmental Assessment (NCEA), within the Office of Research and Development (ORD),

[6] Some aspects of CASAC advice may not be relevant to EPA's process of setting primary and secondary standards that are requisite to protect public health and welfare. Indeed, were EPA to consider costs of implementation when reviewing and revising the standards "it would be grounds for vacating the NAAQS." *Whitman*, 531 U.S. at 471 n.4. At the same time, the Clean Air Act directs CASAC to provide advice on "any adverse public health, welfare, social, economic, or energy effects which may result from various strategies for attainment and maintenance" of the NAAQS to the Administrator under section 109(d)(2)(C)(iv). In *Whitman*, the Court clarified that most of that advice would be relevant to implementation but not standard setting, as it "enable[s] the Administrator to assist the States in carrying out their statutory role as primary *implementers* of the NAAQS." *Id.* at 470 (emphasis in original). However, the Court also noted that CASAC's "advice concerning certain aspects of 'adverse public health … effects' from various attainment strategies is unquestionably pertinent" to the NAAQS rulemaking record and relevant to the standard setting process. *Id.* at 470 n.2.

and the EPA's Office of Air Quality Planning and Standards (OAQPS), within the Office of Air and Radiation (OAR). The draft IRP is made available for consultation with the CASAC and for public comment. The final IRP, prepared in consideration of CASAC and public comments, presents the current plan, projected timeline, and process for conducting the review, and also identifies key policy-relevant issues or questions intended to guide the review.

The assessment phase of the review involves assessments of scientific information, exposure or risk, and policy, which are described in key documents for the review. The Integrated Science Assessment (ISA), prepared by the NCEA, provides a focused review, synthesis, and evaluation of the most policy-relevant scientific information, including key scientific judgments that are important to the design and scope of any exposure and risk assessments, as well as other aspects of the NAAQS review. The ISA[7] provides a comprehensive assessment of the current scientific literature pertaining to known and anticipated effects on public health and welfare associated with the presence of the pollutant in the ambient air, emphasizing information that has become available since the last air quality criteria review in order to reflect the current state of knowledge. As such, the ISA forms the scientific foundation for each NAAQS review and is intended to provide information useful in forming policy-relevant judgments about air quality indicator(s), form(s), averaging time(s) and level(s) for the NAAQS. Prior to its completion in final form, the ISA, in draft form, is reviewed by the CASAC and made available for public comment. Chapter 4 below provides a more detailed description of the planned scope, organization and assessment approach for the ISA and its supporting materials in this review of the air quality criteria and O_3 NAAQS.

Based on the information and conclusions presented in the ISA, the EPA considers the support provided for the development of quantitative assessments of the risks and/or exposures for health and/or welfare effects. In so doing, the EPA considers the extent to which newly available scientific evidence and tools/methodologies may warrant the conduct of new quantitative risk and exposure assessments for the review.[8] Key to the EPA's decision on exposure or risk analyses that may be appropriate to develop in the review is consideration of the newly available data, methods and tools in light of areas of uncertainty in the assessments conducted for the last review and of the potential for new or updated assessments to provide

[7] The ISA functions in the current NAAQS review process as the Air Quality Criteria Document (AQCD) did in reviews completed prior to 2009.

[8] In some reviews this consideration, and, as warranted, a general plan, including scope and methods, for conducting the assessments, have been described in a planning document (e.g., REA Planning Document) that has been provided to the CASAC for consultation and made available for public comment. The EPA is not planning to prepare such a separate document in this review of the O_3 NAAQS; the EPA's general considerations for identifying the quantitative air quality exposure and risk analyses to be performed in this review are discussed in Chapter 5 of this IRP.

notably different exposure and/or risk estimates with lower associated uncertainty. Any exposure/risk analyses performed for the review, and/or exposure/risk information developed in the prior review that remains relevant in the current review, are considered in the policy assessment (PA) for the review. The details regarding methods, key results, observations, and related uncertainties are documented in a separate document accompanying the PA[9] or in an appendix to the PA. Chapter 5 includes preliminary consideration of quantitative human health- and welfare-related assessments for this review.

The PA, prepared by the OAQPS, is a document that provides a transparent analysis regarding the adequacy of the current standards and, as appropriate, potential alternatives for Agency consideration prior to the issuance of proposed and final decisions. The PA integrates and interprets the information from the ISA and from any risk and exposure analyses to frame policy options for consideration by the Administrator. Such an evaluation of policy implications is intended to help "bridge the gap" between the Agency's scientific assessments, presented in the ISA and quantitative analyses, and the judgments required of the EPA Administrator in determining whether it is appropriate to retain or revise the NAAQS. In so doing, the PA is also intended to facilitate CASAC advice to the Agency and recommendations to the Administrator on the adequacy of the existing standards or revisions that may be appropriate to consider, as provided for in the CAA. In evaluating the adequacy of the current standards and, as appropriate, a range of alternative standards, the PA considers the available scientific evidence and, as available, quantitative risk-based analyses, together with related limitations and uncertainties. The PA focuses on the information that is most pertinent to evaluating the basic elements of NAAQS: indicator, averaging time, form, and level. The PA, in draft form, is released for CASAC review and public comment prior to completion of the final PA.

The May 2018 NAAQS process memorandum identified a set of general charge questions to be posed to the CASAC in the NAAQS review process, while recognizing that these would be supplemented with more detailed requests as necessary (Pruitt, 2018). The general questions cited in the May 2018 memo are as follows:

- Are there areas in which additional knowledge is required to appraise the adequacy and basis of existing, new, or revised NAAQS? Please describe the research efforts necessary to provide the required information.
- What scientific evidence has been developed since the last review to indicate if the current primary and/or secondary NAAQS need to be revised or if an alternative level or form of these standards is needed to protect public health and/or public welfare? Please recommend to the Administrator any new NAAQS or revisions of existing criteria and standards as may be appropriate.

[9] In reviews conducted since 2008, the separate, stand-alone document presenting these analyses has been termed the Risk and Exposure Assessment (REA).

In providing advice, please consider a range of options for standard setting, in terms of indicators, averaging times, form, and ranges of levels for any alternative standards, along with a description of the alternative underlying interpretations of the scientific evidence and risk/exposure information that might support such alternative standards and that could be considered by the Administrator in making NAAQS decisions.

- Do key studies, analyses, and assessments which may inform the Administrator's decision to revise the NAAQS properly address or characterize uncertainty and causality? Are there appropriate criteria to ensure transparency in the evaluation, assessment and characterization of key scientific evidence for this review?
- What is the relative contribution to air pollution concentrations of natural as well as anthropogenic activity? In providing advice on any recommended NAAQS levels, please discuss relative proximity to peak background levels.
- Please advise the Administrator of any adverse public health, welfare, social, economic, or energy effects which may result from various strategies for attainment and maintenance of such NAAQS.

The memo recognized that the last two charge questions may elicit information which is not relevant to the standard-setting process under the interpretation of section 109(b) articulated by the Supreme Court in *Whitman*, noting that the EPA should consider an appropriate mechanism, including opportunities after the CASAC has provided its final advice on the standards, to facilitate robust feedback on these topics (Pruitt, 2018). In order to facilitate meaningful advice on these questions, the EPA issued a call for information in June 2018 that requested interested parties to submit information on any adverse public health, welfare, social, economic, or energy effects which may result from various strategies for attainment and maintenance of existing, new, or revised NAAQS for consideration by the CASAC (83 FR 29784, June 26, 2018). Separately, the EPA issued a separate call for scientific and policy-relevant information for the current O_3 NAAQS review, as noted in section 1.3 below (83 FR 29785, June 26, 2018).

Following issuance of the final PA and consideration of conclusions presented therein, the Agency develops and publishes a notice in the *Federal Register* that communicates the Administrator's proposed decisions regarding the review. A draft of this notice may undergo interagency review involving other federal agencies prior to publication (e.g., in cases when the proposed decision in a NAAQS review involves revision of a standard).[10] Materials upon which

[10] Where the proposed or final action involves NAAQS revisions for which implementation would have a large economic effect (e.g., an annual effect on the economy of $100 million or more), such as by necessitating the implementation of emissions controls, EPA develops and releases a regulatory impact analysis (RIA) concurrent with the notice of proposed or final action. This activity is conducted under Executive Order 12866. The RIA is conducted completely independent of and, by statute, is not considered in decisions regarding the review of the NAAQS.

this proposed decision is based, including the documents described above, are made available to the public in the docket for the review. A public comment period, during which public hearings are generally held, follows publication of the notice of the proposed action. Taking into account comments received on the proposed decision,[11] the Agency develops a notice of its final action, which communicates the Administrator's final decisions on the review. As with the notice of proposed action, a draft of this notice may undergo interagency review prior to publication in the *Federal Register* to complete the process. Chapter 6 discusses the development of the PA and Chapter 7 the anticipated steps for issuing a proposed and then final decision for the review.

1.3 PLANNED PROCESS AND PROJECTED TIMELINE FOR THIS REVIEW

In May 2018, the Administrator directed his Assistant Administrators to initiate this review of the O_3 NAAQS (Pruitt, 2018). In conveying this direction, the Administrator further directed the EPA staff to expedite the review, implementing an accelerated schedule to ensure completion of the review in 2020 (Pruitt, 2018). Accordingly, the EPA took immediate steps to proceed with the review. In June 2018, the EPA's NCEA announced the initiation of the current periodic review of the air quality criteria for photochemical oxidants and the O_3 NAAQS and issued a call for information in the *Federal Register* (83 FR 29785, June 26, 2018). Two types of information were called for: information regarding significant new O_3 research to be considered for the ISA for the review, and policy-relevant issues for consideration in this NAAQS review. Based in part on the information received in response to the call for information, the EPA developed the draft IRP which was made available for consultation with the CASAC and for public comment (83 FR 55163, November 2, 2018; 83 FR 55528, November 6, 2018). Consultative comments from the CASAC (Cox, 2018), as well as public comments on the draft document were considered in preparing the final IRP.

Under the plan outlined here, the current review of the O_3 NAAQS is progressing on an accelerated schedule and the EPA is incorporating a number of efficiencies in various aspects of the review process to ensure completion within the statutorily required period (Pruitt, 2018). For example, the kick-off workshop has been replaced with the addition of a call for policy-relevant information coincident with the call for scientific information that traditional initiates a NAAQS review (83 FR 29785, June 26, 2018). Also coincident with preparation of the IRP, the EPA has begun review of the literature for consideration in the ISA, as described in Chapter 4 below. The EPA is not planning to develop a Risk and Exposure Assessment (REA) Planning Document in

[11] When issuing the final action, the Agency responds to all significant comments on the proposed decision. Where a separate Response to Comments document is created for this purpose, it is added to the public docket for the review, along with any additional materials upon which the final decision is based.

this review; key considerations with regard to development of quantitative analyses are discussed in Chapter 5 of this document, which was the subject of a consultation with the CASAC. Further, the EPA has also considered combining the reviews by the CASAC and the public for some of the main documents in a review (Pruitt, 2018). As a result, the EPA is planning to incorporate the REA-related analyses into the PA, combining what had been two documents into a single document for review by the CASAC and the public. Further, we are striving to ensure that initial draft documents are sufficiently robust and complete to support a single, full review by the CASAC and the public. The successfulness of these and other efficiencies implemented in this review will be considered by the EPA in planning for other future NAAQS reviews (Pruitt, 2018).

The current timeline projects release of a draft ISA for CASAC review and public comment in the latter half of 2019, with CASAC advice and public comment informing completion of the final ISA. Comments and recommendations from the CASAC, and public comment, on the draft PA will inform completion of the final PA, including its presentation of options appropriate for the Administrator to consider in this review of the O_3 NAAQS. The current timeline also projects a proposed decision in the spring of 2020 and completion of the review with a final decision in the subsequent winter.

Table 1-1. Projected timeline for completion of the review.

Key Milestones in the Review	
May 2018	Administrator's memo directing initiation of the review
June 2018	Announcement and Call for Information in *Federal Register*
August 2018	End comment period for Call for Information
October 2018	**Draft IRP** for CASAC and public comment
November 2018	CASAC consultation on draft IRP
Summer 2019	**Final IRP**
September 2019	**Draft ISA** for CASAC review and public comment
October 2019	**Draft PA** for CASAC review and public comment
November/December 2019	CASAC review meeting on draft ISA and draft PA
Early Spring 2020	**Final ISA**
	Final PA
Late Spring 2020	**Proposed decision**
Winter 2020/2021	**Final decision**

2 BACKGROUND

Air quality criteria were developed for photochemical oxidants in 1970 (U.S. DHEW, 1970; 35 FR 4768, March 19, 1970), and primary and secondary NAAQS were first established in 1971 (36 FR 8186, April 30, 1971). Based on the scientific information in the 1970 air quality criteria document (AQCD), the EPA set both primary and secondary standards at 0.08 parts per million (ppm), as a 1-hour average of total photochemical oxidants, not to be exceeded more than one hour per year. As summarized in section 2.1, the EPA has reviewed the air quality criteria and standards a number of times since then, with the most recent review being completed in 2015. An overview of the requirements for ambient air monitoring and data analysis for the current standards are summarized in section 2.2 and current ozone air quality is summarized in section 2.3.

2.1 PRIOR REVIEWS OF AIR QUALITY CRITERIA AND STANDARDS FOR PHOTOCHEMICAL OXIDANTS INCLUDING O_3

The EPA initiated the first periodic review of the NAAQS for photochemical oxidants in 1977. Based on the 1978 AQCD (U.S. EPA, 1978), the EPA published proposed revisions to the original NAAQS in 1978 (43 FR 26962, June 22, 1978) and final revisions in 1979 (44 FR 8202, February 8, 1979). At that time, the EPA changed the indicator from photochemical oxidants to O_3, revised the level of the primary and secondary standards from 0.08 to 0.12 ppm and revised the form of both standards from a deterministic (i.e., not to be exceeded more than one hour per year) to a statistical form. With these changes, attainment of the standards was defined to occur when the average number of days per calendar year (across a 3-year period) with maximum hourly average O_3 concentration greater than 0.12 ppm equaled one or less (44 FR 8202, February 8, 1979; 43 FR 26962, June 22, 1978).

Following the EPA's decision in the 1979 review, several petitioners sought judicial review. Among those, the city of Houston challenged the Administrator's decision arguing that the standard was arbitrary and capricious because natural O_3 concentrations and other physical phenomena in the Houston area made the standard unattainable in that area. The U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) rejected this argument, holding (as noted in section 1.1 above) that attainability and technological feasibility are not relevant considerations in the promulgation of the NAAQS (*American Petroleum Institute v. Costle*, 665 F.2d at 1185). The court also noted that the EPA need not tailor the NAAQS to fit each region or locale, pointing out that Congress was aware of the difficulty in meeting standards in some locations and had addressed this difficulty through various compliance related provisions in the CAA (*id.* at 1184-86).

The next periodic reviews of the criteria and standards for O_3 and other photochemical oxidants began in 1982 and 1983, respectively (47 FR 11561, March 17, 1982; 48 FR 38009, August 22, 1983). The EPA subsequently published the 1986 AQCD (U.S. EPA, 1986) and the 1989 Staff Paper (U.S. EPA, 1989). Following publication of the 1986 AQCD, a number of scientific abstracts and articles were published that appeared to be of sufficient importance concerning potential health and welfare effects of O_3 to warrant preparation of a supplement to the 1986 AQCD (U.S. EPA, 1992). In August of 1992, the EPA proposed to retain the existing primary and secondary standards based on the health and welfare effects information contained in the 1986 AQCD and its 1992 Supplement (57 FR 35542, August 10, 1992). In March 1993, the EPA announced its decision to conclude this review by affirming its proposed decision to retain the standards, without revision (58 FR 13008, March 9, 1993).

In the 1992 notice of its proposed decision in that review, the EPA announced its intention to proceed as rapidly as possible with the next review of the air quality criteria and standards for O_3 and other photochemical oxidants in light of emerging evidence of health effects related to 6- to 8-hour O_3 exposures (57 FR 35542, August 10, 1992). The EPA subsequently published the AQCD and Staff Paper for that next review (U.S. EPA, 1996a, b). In December 1996, the EPA proposed revisions to both the primary and secondary standards (61 FR 65716, December 13, 1996). With regard to the primary standard, the EPA proposed to replace the then-existing 1-hour primary standard with an 8-hour standard set at a level of 0.08 ppm (equivalent to 0.084 ppm based on the proposed data handling convention) as a 3-year average of the annual third-highest daily maximum 8-hour concentration. The EPA proposed to revise the secondary standard either by setting it identical to the proposed new primary standard or by setting it as a new seasonal standard using a cumulative form. The EPA completed this review in 1997 by setting the primary standard at a level of 0.08 ppm, based on the annual fourth-highest daily maximum 8-hour average concentration, averaged over three years, and setting the secondary standard identical to the revised primary standard (62 FR 38856, July 18, 1997).

On May 14, 1999, in response to challenges by industry and others to the EPA's 1997 decision, the D.C. Circuit remanded the O_3 NAAQS to the EPA, finding that section 109 of the CAA, as interpreted by the EPA, effected an unconstitutional delegation of legislative authority (*American Trucking Assoc. v. EPA*, 175 F.3d 1027, 1034-1040 [D.C. Cir. 1999]). In addition, the court directed that, in responding to the remand, the EPA should consider the potential beneficial health effects of O_3 pollution in shielding the public from the effects of solar ultraviolet (UV) radiation, as well as adverse health effects (*id.* at 1051-53). In 1999, the EPA petitioned for rehearing *en banc* on several issues related to that decision. The court granted the request for rehearing in part and denied it in part, but declined to review its ruling with regard to the potential beneficial effects of O_3 pollution (*American Trucking Assoc. v. EPA*,195 F.3d 4, 10

[D.C Cir., 1999]). On January 27, 2000, the EPA petitioned the U.S. Supreme Court for *certiorari* on the constitutional issue (and two other issues), but did not request review of the ruling regarding the potential beneficial health effects of O_3. On February 27, 2001, the U.S. Supreme Court unanimously reversed the judgment of the D.C. Circuit on the constitutional issue. *Whitman v. American Trucking Assoc*., 531 U. S. 457, 472-74 (2001) (holding that section 109 of the CAA does not delegate legislative power to the EPA in contravention of the Constitution). The Court remanded the case to the D.C. Circuit to consider challenges to the O_3 NAAQS that had not been addressed by that court's earlier decisions. On March 26, 2002, the D.C. Circuit issued its final decision on the remand, finding the 1997 O_3 NAAQS to be "neither arbitrary nor capricious," and so denying the remaining petitions for review. See *American Trucking Associations, Inc. v. EPA*, 283 F.3d 355, 379 (D.C Cir. 2002, hereafter referred to as "*ATA III*").

Specifically, in *ATA III*, the D.C. Circuit upheld the EPA's decision on the 1997 O_3 standard as the product of reasoned decision making. With regard to the primary standard, the court made clear that the most important support for the EPA's decision to revise the standard was the health evidence of insufficient protection afforded by the then-existing standard ("the record [is] replete with references to studies demonstrating the inadequacies of the old one-hour standard"), as well as extensive information supporting the change to an 8-hour averaging time (*id.* at 378). The court further upheld the EPA's decision not to select a more stringent level for the primary standard noting "the absence of *any* human clinical studies at ozone concentrations below 0.08 [ppm]" which supported the EPA's conclusion that "the most serious health effects of ozone are 'less certain' at low concentrations, providing an eminently rational reason to set the primary standard at a somewhat higher level, at least until additional studies become available" (*id.* at 379, emphasis in original, internal citations omitted). The court also pointed to the significant weight that the EPA properly placed on the advice it received from the CASAC (*id.* at 379). In addition, the court noted that "although relative proximity to peak background O_3 concentrations did not, in itself, necessitate a level of 0.08 [ppm], EPA could consider that factor when choosing among the three alternative levels" (*id.* at 379).

Coincident with the continued litigation of the other issues, the EPA responded to the court's 1999 remand to consider the potential beneficial health effects of O_3 pollution in shielding the public from effects of UV radiation (66 FR 57268, Nov. 14, 2001; 68 FR 614, January 6, 2003). The EPA provisionally determined that the information linking changes in patterns of ground-level O_3 concentrations to changes in relevant patterns of exposures to UV radiation of concern to public health was too uncertain, at that time, to warrant any relaxation in 1997 O_3 NAAQS. The EPA also expressed the view that any plausible changes in UV-B radiation exposures from changes in patterns of ground-level O_3 concentrations would likely be very small from a public health perspective. In view of these findings, the EPA proposed to leave the 1997 primary standard unchanged (66 FR 57268, Nov. 14, 2001). After considering public comment on the proposed decision, the EPA published its final response to this remand in 2003, re-affirming the 8-hour primary standard set in 1997 (68 FR 614, January 6, 2003).

The EPA initiated the fourth periodic review of the air quality criteria and standards for O_3 and other photochemical oxidants with a call for information in September 2000 (65 FR 57810, September 26, 2000). In 2007, the EPA proposed to revise the level of the primary standard within a range of 0.075 to 0.070 ppm (72 FR 37818, July 11, 2007). The EPA proposed to revise the secondary standard either by setting it identical to the proposed new primary standard or by setting it as a new seasonal standard using a cumulative form. Documents supporting these proposed decisions included the 2006 AQCD (U.S. EPA, 2006a) and 2007 Staff Paper (U.S EPA, 2007) and related technical support documents. The EPA completed the review in March 2008 by revising the levels of both the primary and secondary standards from 0.08 ppm to 0.075 ppm while retaining the other elements of the prior standards (73 FR 16436, March 27, 2008).

In May 2008, state, public health, environmental, and industry petitioners filed suit challenging the EPA's final decision on the 2008 O_3 standards. On September 16, 2009, the EPA announced its intention to reconsider the 2008 O_3 standards,[12] and initiated a rulemaking to do so. At the EPA's request, the court held the consolidated cases in abeyance pending the EPA's reconsideration of the 2008 decision.

In January 2010, the EPA issued a notice of proposed rulemaking to reconsider the 2008 final decision (75 FR 2938, January 19, 2010). In that notice, the EPA proposed that further revisions of the primary and secondary standards were necessary to provide a requisite level of protection to public health and welfare. The EPA proposed to revise the level of the primary standard from 0.075 ppm to a level within the range of 0.060 to 0.070 ppm, and to revise the secondary standard to one with a cumulative, seasonal form. At the EPA's request, the CASAC reviewed the proposed rule at a public teleconference on January 25, 2010 and provided additional advice in early 2011 (Samet, 2010, 2011). In view of the need for further consideration and the fact that the Agency's next periodic review of the O_3 NAAQS required under CAA section 109 had already begun (as announced on September 29, 2008), the EPA decided to consolidate the reconsideration with its statutorily required periodic review.[13]

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[12] The press release of this announcement is available at: https://archive.epa.gov/epapages/newsroom_archive/newsreleases/85f90b7711acb0c88525763300617d0d.html.

[13] This rulemaking, completed in 2015, concluded the reconsideration process.

In light of the EPA's decision to consolidate the reconsideration with the current review, the D.C. Circuit proceeded with the litigation on the 2008 final decision. On July 23, 2013, the court upheld the EPA's 2008 primary O_3 standard, but remanded the 2008 secondary standard to the EPA (*Mississippi v. EPA*, 744 F. 3d 1334 [D.C. Cir. 2013]). With respect to the primary standard, the court first rejected arguments that the EPA should not have lowered the level of the existing primary standard, holding that the EPA reasonably determined that the existing primary standard was not requisite to protect public health with an adequate margin of safety, and consequently required revision. The court went on to reject arguments that the EPA should have adopted a more stringent primary standard. With respect to the secondary standard, the court held that the EPA's explanation for the setting of the secondary standard identical to the revised 8-hour primary standard was inadequate under the CAA because the EPA had not adequately explained how that standard provided the required public welfare protection.

At the time of the court's decision, the EPA had already completed significant portions of its next statutorily required periodic review of the O_3 NAAQS. This review had been formally initiated in 2008 with a call for information in the *Federal Register* (73 FR 56581, September 29, 2008). In late 2014, based on the Integrated Science Assessment (ISA), Risk and Exposure Assessments (REAs) for health and welfare, and PA[14] developed for this review, the EPA proposed to revise the 2008 primary and secondary standards by reducing the level of both standards to within the range of 0.070 to 0.065 ppm (79 FR 75234, December 17, 2014).

The EPA's final decision in this review was published in October 2015, establishing the now-current standards (80 FR 65292, October 26, 2015). In this decision, based on consideration of the health effects evidence on respiratory effects of O_3 in at-risk populations, the EPA revised the primary standard from a level of 0.075 ppm to a level of 0.070 ppm, while retaining all the other elements of the standard (80 FR 65292, October 26, 2015). The EPA's decision on the level for the standard was based on the weight of the scientific evidence and quantitative exposure/risk information. The level of the secondary standard was also revised from 0.075 ppm to 0.070 ppm based on the scientific evidence of O_3 effects on welfare, particularly the evidence of O_3 impacts on vegetation, and quantitative analyses available in the review.[15] The other elements of the standard were retained. This decision on the secondary standard also incorporated the EPA's response to the D.C. Circuit's remand of the 2008 secondary standard in *Mississippi v. EPA*, 744 F.3d 1344 (D.C. Cir. 2013). The 2015 revisions to the NAAQS were

[14] The final versions of these documents, released in August 2014, were developed with consideration of the comments and recommendations from the CASAC, as well as comments from the public on the draft documents (U.S. EPA 2014a; U.S. EPA, 2014b; U.S. EPA, 2014c; Frey, 2014a; Frey, 2014b; Frey, 2014c).

[15] The standards set in 2015 (generally referred to as the current standards in this document) are specified at 40 CFR 50.19.

accompanied by revisions to the data handling procedures, and the ambient air monitoring requirements[16] (80 FR 65292, October 26, 2015).[17]

After publication of the final rule, a number of industry groups, environmental and public health organizations, and certain states filed petitions for judicial review in the D.C. Circuit. The industry and state petitioners filed briefs arguing that the revised standards are too stringent, while the environmental and health petitioners' brief argued that the revised standards are not stringent enough to protect public health and welfare as the Act requires. On August 23, 2019, the court issued an opinion that denied all the petitions for review with respect to the 2015 primary standard while also concluding that the EPA had not provided a sufficient rationale for aspects of its decision on the 2015 secondary standard and remanding that standard to the EPA (*Murray Energy v. EPA*, No. 15-1385, Order, Doc. No. 1803352 [D.C. Cir. Aug. 23, 2019]).

2.2 AMBIENT AIR MONITORING AND DATA HANDLING CONVENTIONS FOR THE CURRENT STANDARDS

2.2.1 Monitoring Requirements and the Current Monitoring Network

State and local environmental agencies operate O_3 monitors at state or local air monitoring stations (SLAMS) as part of the SLAMS network. The requirements for the SLAMS network depend on the population and most recent O_3 design values[18] in the area. The minimum number of O_3 monitors required in a metropolitan statistical area (MSA) ranges from zero for areas with a population less than 350,000 and no recent history of an O_3 design value greater than 85 percent of the level of the standard, to four for areas with a population greater than 10 million and an O_3 design value greater than 85 percent of the standard level.[19] Within an O_3 monitoring network, at least one site for each MSA must be designed to record the maximum concentration for that particular metropolitan area. Since the highest O_3 concentrations tend to be associated with a particular season for various locations, the EPA requires O_3 monitoring during

[16] The current federal regulatory measurement methods for O_3 are specified in 40 CFR 50, Appendix D and 40 CFR part 53. Consideration of ambient air measurements with regard to judging attainment of the standards is specified in 40 CFR 50, Appendix U. The O_3 monitoring network requirements are specified in 40 CFR 58.

[17] This decision additionally announced revisions to the exceptional events scheduling provisions, as well as changes to the air quality index and the regulations for the prevention of significant deterioration permitting program.

[18] A design value is a statistic that describes the air quality status of a given area relative to the level of the standard, taking the averaging time and form into account, as well as any data handling requirements (e.g., for the 2015 O_3 NAAQS, these requirements are specified in Appendix U to 40 CFR Part 50), Design values are typically used to classify nonattainment areas as meeting or not meeting the standard, to assess progress towards meeting the NAAQS, and to develop control strategies.

[19] The SLAMS minimum monitoring requirements to meet the O_3 design criteria are specified in 40 CFR Part 58, Appendix D. The minimum O_3 monitoring network requirements for urban areas are listed in Table D-2 of Appendix D to 40 CFR Part 58 (accessible at https://www.ecfr.gov).

specific O_3 monitoring seasons which vary by state from five months (May to September in Oregon and Washington) to all twelve months (in a number of states).[20]

Most of the state, local, and tribal air monitoring stations that report data to the EPA use ultraviolet Federal Equivalent Methods. The Federal Reference Method (FRM) was revised in 2015 to include a new chemiluminescence by nitric oxide (NO-CL) method. The previous ethylene (ET-CL) method is no longer commonly used due to lack of availability and safety concerns with ethylene.[21] The NO-CL method is beginning to be implemented in the SLAMS network.

In 2017, there were over 1,300 federal, state, local, and tribal ambient air monitors reporting O_3 concentrations to the EPA. Figure 2-1 shows the locations of such monitoring sites that reported data to the EPA at any time during the 2015-2017 period. About 80% of this network are SLAMS monitors operated by state and local governments to meet regulatory requirements and provide air quality information to public health agencies; these sites are largely focused on urban and suburban areas.

Two important subsets of SLAMS sites separately make up the National Core (NCore) multi-pollutant monitoring network and the Photochemical Assessment Monitoring Stations (PAMS) network. Each state is required to have at least one NCore station, and O_3 monitors at NCore sites are required to operate year-round. At each NCore site located in a CBSA with a population of 1 million or more (based on the most recent census), a PAMS network site is required.[22] Monitors at PAMS are required to operate during the months of June, July and August, although monitoring may extend over longer periods of time to improve the usefulness of data collected during an area's O_3 season (U.S. EPA, 2018a).

In addition to reporting O_3 concentrations, the NCORE and PAMS networks provide data on O_3 precursor chemicals. The NCore sites feature co-located measurements of chemical species such as nitrogen oxide and total reactive nitrogen, along with meteorological measurements. The additional data collected at the PAMS sites include measurements of nitrogen oxides (NO_X), and a target set of volatile organic compounds (VOC). The enhanced monitoring at sites in these two networks informs our understanding of local O_3 formation.

[20] The required O_3 monitoring seasons for each state are listed in Table D-3 of Appendix D to 40 CFR Part 58.

[21] The current FRM for O_3 (established in 2015) is a chemiluminescence method. This is an automated method allowing for the measurement of O_3 concentrations in ambient air using continuous (real-time) sampling and analysis. This method is based on continuous automated measurement of the intensity of the characteristic chemiluminescence released by the gas phase reaction of O_3 in sampled air with either ethylene or nitric oxide gas. This method is fully described in Appendix D to 40 CFR Part 50.

[22] The requirements for PAMS, which were most recently updated in 2015, is fully described in Appendix D to 40 CFR Part 58.

While the SLAMS network has a largely urban and population-based focus, there are monitoring sites in other networks that can be used to track compliance with the NAAQS in rural areas (see Figure 2-1). For example, the Clean Air Status and Trends Network (CASTNET) monitors which are located in rural areas. There were about 80 CASTNET sites operating in 2017, with most of the sites in the eastern U.S. being operated by the EPA, and most of the sites in the western U.S. being operated by the National Park Service (NPS). Finally, there are also a number of Special Purpose Monitoring Stations (SPMs), which are not required but are often operated by air agencies for short periods of time (less than 3 years) to collect data for human health and welfare studies, as well as other types of monitoring sites, including monitors operated by tribes and industrial sources. The SPMs are typically not used to assess compliance with the NAAQS.[23]

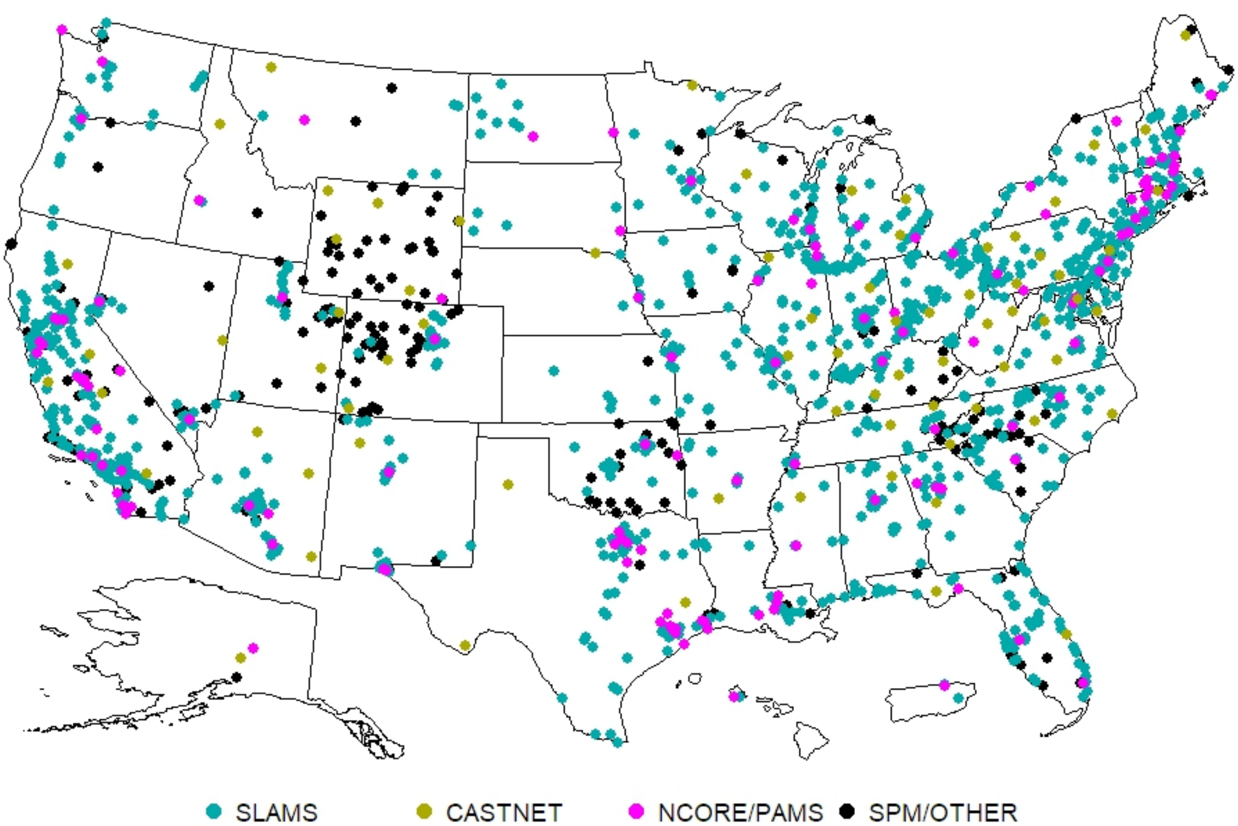

Figure 2-1. Map of U.S. ambient air O_3 monitoring sites reporting data to the EPA during the 2015-2017 period.

[23] However, SPMs that use federal reference or equivalent methods, meet all applicable requirements in 40 CFR Part 58, and operate continuously for at least 3 years may be used to assess compliance with the NAAQS.

2.2.2 Data Handling Conventions for Comparison to the Standards

To assess whether a monitoring site or geographic area meets or exceeds a NAAQS, the monitoring data are analyzed consistent with the established regulatory requirements for the handling of monitoring data for the purposes of deriving a design value. A design value expresses ambient air concentrations in terms of the averaging time and form for a given standard such that its comparison to the level of the standard indicates whether the location meets or exceeds the standard. Consistent with the form and averaging time of the O_3 standards, O_3 design values for the standards established in the last review are calculated as the 3-year average of the annual fourth highest daily maximum 8-hour average O_3 concentration.

Hourly average O_3 concentrations at the monitoring sites used for assessing compliance with the NAAQS are required to be reported in ppm to the third decimal place, with additional digits truncated, consistent with the typical measurement precision associated with most O_3 monitoring instruments. The hourly average concentrations are used to compute moving 8-hour average concentrations for each day, with the daily maximum 8-hour average identified as the highest of the 17 consecutive, valid[24] 8-hour averages that begin with the 8-hour period from 7am to 3pm and end with the 8-hour period from 11pm to 7am the subsequent day.[25] An O_3 monitoring site meets the standard if its design value is less than or equal to the level of the standard. A geographic area meets the NAAQS if all ambient air monitoring sites in the area have valid[26] design values meeting the standard, and if one or more monitors has a design value exceeding the standard, then the area exceeds the NAAQS.

2.3 OVERVIEW OF OZONE AIR QUALITY

Ozone is a gas composed of three oxygen atoms (O_3). It is naturally present in the Earth's atmosphere, both in the stratospheric layer occurring roughly 10 to 30 miles above the Earth's surface as well as in the closer tropospheric layer. The stratosphere contains a large reservoir of O_3 (i.e. the "ozone layer") that results naturally from photochemical reactions between ultraviolet

[24] An 8-hour average is considered valid if at least six of the hourly concentrations are available or if substitution of zero for the missing hourly concentrations yields an 8-hour average above the level of the standard. The 8-hour averages are required to be reported to three decimal places with additional digits to right of third decimal place truncated (Appendix U to 40 CFR Part 50).

[25] A daily maximum concentration is considered valid if at least 13 of the 17 consecutive 8-hour averages are available or if the daily maximum based on fewer than 13 is greater than the level of the standard (Appendix U to 40 CFR Part 50).

[26] An O_3 design value less than or equal to the level of the standard is valid if daily maximum values are available for at least 90% of the days in the O_3 monitoring season on average over the 3 years, with a minimum of 75% data completeness in any individual year (Appendix U to 40 CFR Part 50). A design value greater than the level of the standard is always valid.

light (UV) and molecular oxygen (O_2).[27] Under specific meteorological conditions, this reservoir can contribute to O_3 concentrations at the Earth's surface (Langford et al., 2017). Ozone is also produced near the earth's surface due to chemical interactions involving solar radiation and pollution resulting from human activity. These chemical reactions involve specific O_3 precursors, such as NO_X, VOC, and carbon monoxide, which can be emitted from both natural and anthropogenic sources.[28]

Global air quality models have estimated that natural sources of O_3 precursors, such as vegetation, lightning, and wildfires, can produce daily 8-hour peak O_3 concentrations of 15-35 parts per billion by volume (ppb) across the U.S. during the warm season (2014 PA, section 2.4.1). Human activity from combustion of fossil fuels or biomass and the use of industrial and consumer chemicals can also lead to emissions of these O_3 precursors, which can then yield O_3 concentrations substantially above naturally occurring levels. The EPA conducted air quality modeling analyses in the last review to assess the role of natural sources (i.e., natural background) and the combined impacts of natural background plus anthropogenic sources outside of the U.S. (i.e., U.S. background) on O_3 concentrations (2014 PA, section 2.4).[29] These 2007-based annual modeling analyses (presented in the 2014 PA) estimated that seasonal mean natural background levels ranged from 15 to 35 ppb over the U.S. This modeling also estimated that seasonal mean daily maximum 8-hour average concentrations of U.S. background O_3 ranged from 25 to 50 ppb. While the majority of modeled events greater than 70 ppb were primarily driven by local and regional O_3 precursor emissions, there were some events with substantial U.S. background contributions where O_3 concentrations approached or exceeded 75 ppb (80 FR 65300, October 26, 2015).[30]

As part of the current review, the EPA plans to utilize state-of-the-science air quality modeling for a more recent time period, 2016, to provide updated estimates of the relative contributions of natural and anthropogenic sources of O_3 in the U.S. Specifically, the EPA intends to use the Community Multiscale Air Quality (CMAQ) modeling system (Appel et al.,

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[27] This layer of O_3 in the upper atmosphere helps to protect the earth's populations and ecosystems from the damaging effects of UV radiation (Norval et al., 2011; Bais et al., 2017).

[28] Methane emissions can also contribute to O_3 formation, but its impacts are more frequently observed at the global scale over longer time periods (e.g., decadal scale).

[29] The difference between natural and U.S. background is that U.S. background also includes, along with contributions from natural sources, the impacts from anthropogenic emissions outside the U.S.

[30] Noting the infrequency of such events, and of the statutory and regulatory provisions that allow for the exclusion of air quality monitoring data substantially affected by certain background influences (e.g., wildfires or stratospheric intrusions) from design value calculations when they meet certain criteria, the EPA explained in the 2015 decision that background concentrations of O_3 were not expected to preclude attainment of a revised O_3 standard with a level of 70 ppb (80 FR 65328, October 26, 2015).

2017) over a Northern Hemisphere domain to provide boundary conditions for a finer-scale national application of CMAQ to estimate current levels of background ozone using recently available emissions estimates and meteorological data.[31] Using this model configuration, the EPA plans to conduct, evaluate,[32] and summarize the results of a series of "zero-out" sensitivity runs[33] designed to isolate natural background and U.S. background.[34] While the model estimates of background O_3 will be based on a single year (2016), the EPA will also consider the potential implications of interannual variability on these estimates.

Based on estimates compiled in version 2 of the 2014 National Emissions Inventory (NEI) (U.S. EPA, 2018b), biogenic and fire emissions comprise 78 percent[35] of the total VOC emissions in the U.S., but only 9% of the NO_X emissions.[36] Mobile sources, such as on-road vehicles and non-road equipment, are the largest contributors of NO_X emissions. Figures 2-2 and 2-3 show the downward trends in anthropogenic source emissions of NO_X and VOC based on estimates for the last 15 years.[37] Emissions of NO_X decreased by more than 40% and VOC emissions by more than 15% since 2002.

[31] The modeling analyses conducted in the review completed in 2015 used boundary conditions from the global GEOS-Chem model (Henderson et al., 2014) as inputs into regional models (e.g., CMAQ) to estimate background levels (2014 PA, section 2.4).

[32] Model performance will be assessed using a variety of O_3 measurements, including data from upper atmosphere monitoring tools (e.g., global ozonesonde networks) and surface air monitoring sites within and outside the U.S.

[33] Zero-out sensitivity modeling refers to a commonly used method for isolating the O_3 impacts of specific emissions source categories or sources from specific regions. To accomplish this, O_3 concentrations are estimated from model simulations in which emissions of interest are set to zero. As an example, natural background could be estimated from a simulation in which all anthropogenic emissions are zeroed out in the simulation.

[34] These analyses can be used to facilitate CASAC advice on CAA Section 109(d)(2)(c)(iii) (e.g., as discussed Pruitt [2018]).

[35] In locations near large concentrations of anthropogenic VOC sources (e.g., in certain urban areas or oil and gas development basins), the relative contribution of anthropogenic sources can be much higher than the national average.

[36] The NEI is updated every three years based on emissions estimate data provided by state, local, and tribal air agencies for sources in their jurisdiction and supplemented by national data developed by the EPA. The 2014 version of the NEI is the latest currently NEI dataset.

[37] The estimates of long-term annual emissions are drawn from https://gispub.epa.gov/air/trendsreport/2018/#naaqs_trends (as of March 2019). The process for deriving these estimates from the NEI is described at https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data

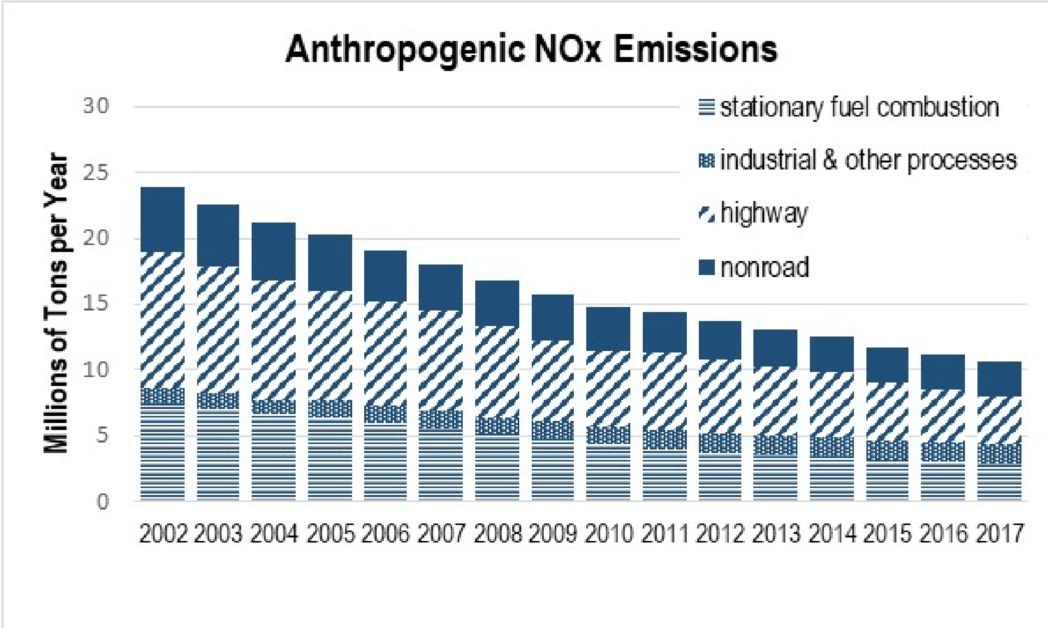


Figure 2-2. Trends in anthropogenic emissions of NO_X (2002-2017).

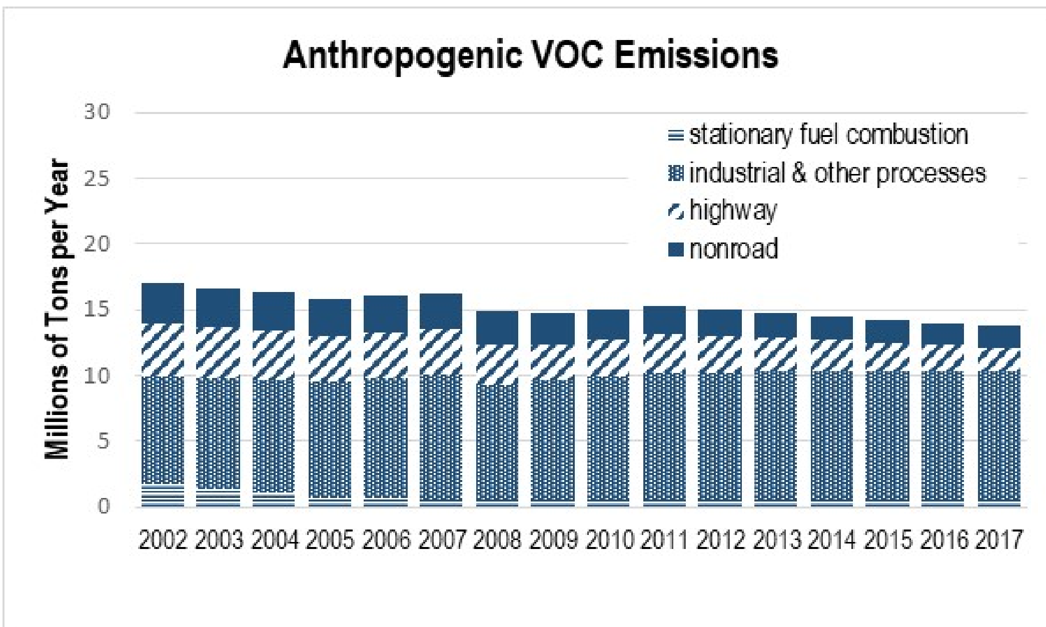


Figure 2-3. Trends in anthropogenic emissions of VOC (2002-2017).

The chemistry that leads to O_3 formation is complex and can vary depending upon the relative proportions of different types of precursor pollutants as well as external conditions such as temperature and sunlight. Over most areas of the U.S., daytime O_3 production typically increases as NO_X concentrations increase (2013 ISA, section 3.2.4). Formation of O_3 in this regime is described as “NO_X-limited.” At other times and locations, where NO_X concentrations are higher, O_3 formation may be only weakly dependent on NO_X emissions, or even inversely correlated (i.e., NO_X emissions actually deplete O_3 locally[38]). O_3 formation in these regimes increases as VOC concentrations increase and is described as "VOC-limited." Once formed, O_3 near the Earth's surface can be transported by the prevailing winds before eventually being removed from the atmosphere over the course of hours to weeks via chemical reactions or deposition to surfaces.

As described in section 2.2.1, to assess O_3 concentrations across the U.S., state and local environmental agencies operate O_3 monitors at various locations and subsequently submit the data to the EPA for analyses and storage. As shown in Figure 2-4, several locations across the U.S. have design values in 2015-2017 that exceeded the standard level of 70 ppb. California contains numerous monitoring sites where design values exceeded 70 ppb in 2015-2017, but high O_3 was also measured in Texas, the Northeast Corridor, along the Lake Michigan shoreline, and certain urban areas in the western U.S. These locations include some of the most densely populated areas in the country that also experience conducive meteorology for O_3 formation. The highest daily peak 8-hour average O_3 concentrations most commonly occur during the afternoon within the warmer months due to higher solar radiation and other conducive meteorological conditions during these times. However, there can be exceptions such as the Uintah Basin in Utah where the highest O_3 concentrations occur during the winter on sunny days with strong temperature inversions and ample snow cover.

[38] In these cases, NO_x generally results in eventual net ozone production downwind of the emissions sources over longer time scales.

2015-2017 O_3 design values across the U.S.

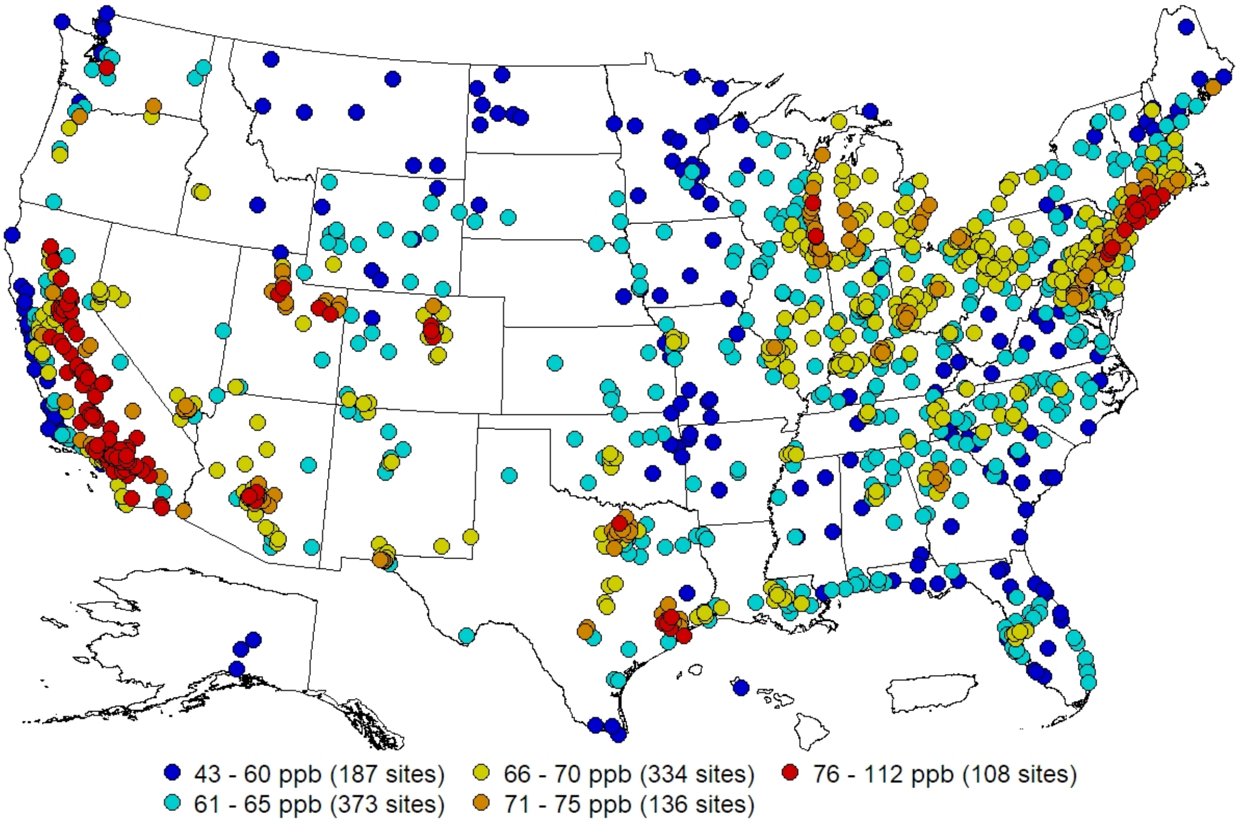


Figure 2-4. 2015-2017 O_3 design values across the U.S. Red and orange circles indicate locations exceeding the standard. Design values available at: https://www.epa.gov/air-trends/air-quality-design-values.

Concentrations of O_3 in the U.S. have trended downward over the past several decades due to reductions in precursor emissions noted above. The average downward trend in annual fourth highest 8-hour daily maximum O_3 concentration has been 17% between 2000 and 2017 (U.S. EPA, 2018c), as shown in Figure 2-5 (based on 809 monitoring sites that operated for the full 18-year period). Downward trends in this metric have been even more substantial in the Eastern U.S. and in California. Air quality model simulations estimate that O_3 air quality will continue to improve over the next decade as additional reductions in O_3 precursors from mobile sources, industrial processes, and other sources are realized as a result of “on-the-books” EPA regulations (U.S. EPA, 2015b; Collet et al., 2017) and other technological changes. In addition to being affected by changing emissions, future O_3 concentrations may also be affected by climate change (Nolte et al., 2018) as well as any changes in the amount of O_3 transported into the U.S. from other countries (He et al., 2016).

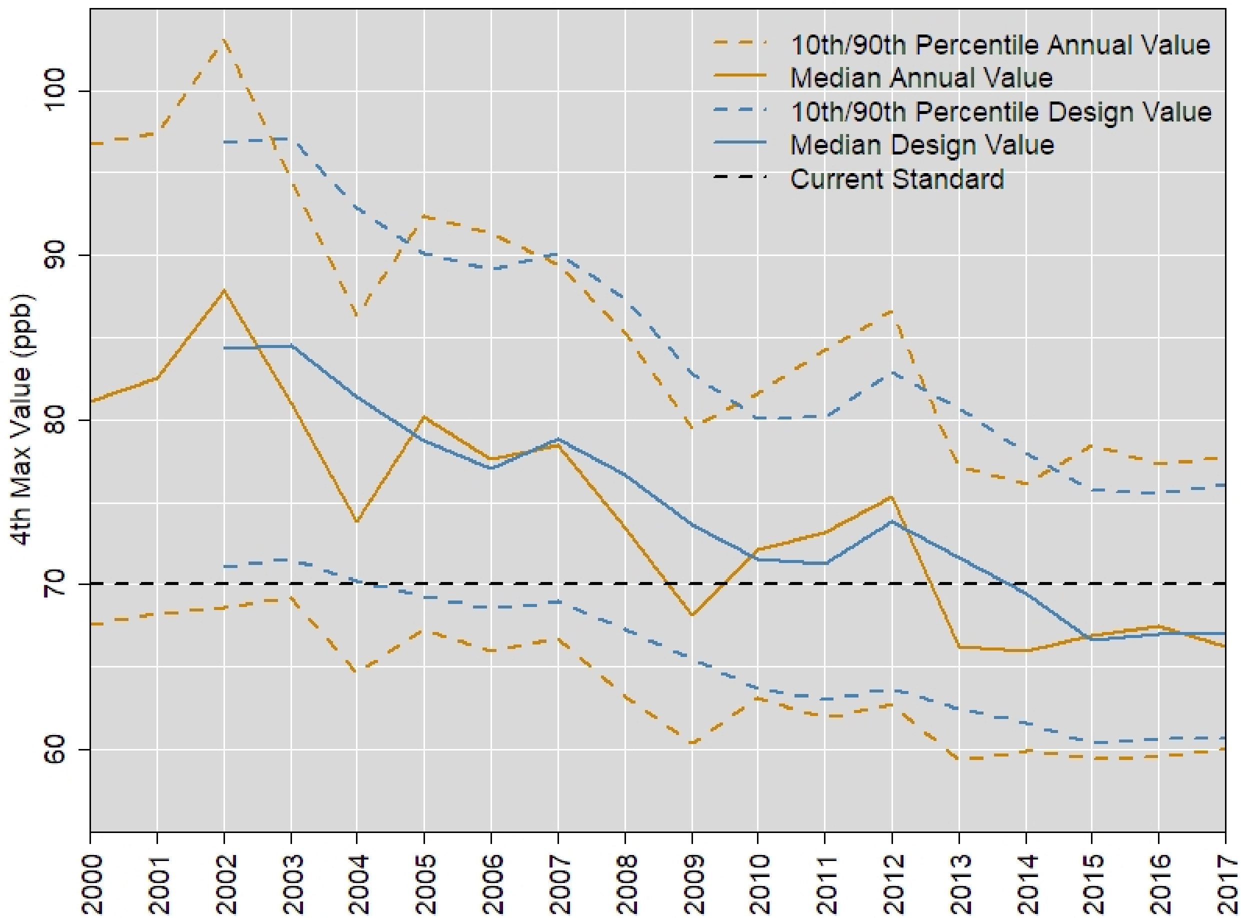


Figure 2-5. Trends in annual 4th highest daily maximum 8-hour average O_3 concentrations and design values at all sites across the U.S. with complete data (2000-2017).

3 KEY POLICY-RELEVANT ISSUES FOR THE CURRENT REVIEW

The overarching question in each NAAQS review is:

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

As appropriate, a review also addresses a second overarching question:

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

In considering these overarching questions, a series of key policy-relevant issues particular to a given review are addressed.

The policy-relevant issues thus far identified for this review of the O_3 standards are presented in sections 3.1.1 and 3.2.1 below as series of questions intended to frame our approach to considering the information available in this review of the current primary and secondary standards for O_3. The ISA and PA developed in this new review[39] will provide the basis for addressing these questions and will inform the Administrator's judgment as to whether the current primary and secondary standards for O_3 provide the requisite protection of public health and public welfare, and his decisions as to whether to retain or revise these standards. These assessments focus on policy-relevant scientific information and analyses that address key questions related to the adequacy of the O_3 standards.[40] In this chapter, the primary standard is discussed in section 3.1 and the secondary standard in section 3.2.

[39] As summarized in sections 1.2 and 1.3 above, stand-alone REA documents will not be developed for this review. Rather, any exposure and risk analyses performed for this review will be presented in the PA along with any such information from the last review that remains informative in this review, taking into account the newly available evidence presented in the ISA and any other technical documents prepared for the review.

[40] Several examples of policy-relevant analyses in NAAQS reviews, generally, are noted in Pruitt (2018): "EPA's Integrated Science Assessments (ISA), Risk and Exposure Assessments (REA), and Policy Assessments (PA) should focus on policy-relevant science and on studies, causal determinations, or analyses that address key questions related to the adequacy of primary and secondary NAAQS, including levels near – both above and below—the current standard(s). Policy-relevant science may also include information that directly relates to the indicator, averaging time, form and level of a NAAQS as well as alternative policy approaches."; "In developing additional analyses in the REA or elsewhere, EPA should focus on policy-relevant including consideration of issues such as thresholds or background levels, as appropriate for context."

3.1 THE PRIMARY STANDARD

The approach planned for this review of the primary standard is most fundamentally based on using the Agency's assessment of the current scientific evidence, quantitative assessments of exposures and/or risks, and other associated analyses (e.g., air quality analyses) to inform the Administrator's judgments regarding a primary standard that is requisite to protect public health with an adequate margin of safety. This approach involves translating scientific and technical information into the basis for addressing a series of key policy-relevant questions using both evidence- and exposure-/risk-based considerations. This series of key questions related to the primary standard is presented in section 3.1.1, along with a summary of the general approach for the review. Additionally, to provide context for this review of the current primary O_3 standard, section 3.1.2 summarizes key aspects of the decisions made in the last review, including the Agency's consideration of important policy judgments concerning the scientific evidence and exposure/risk information, and associated uncertainties and limitations, as well as the Administrator's public health policy judgments regarding an adequate margin of safety.

3.1.1 Key Issues Related to the Primary Standard

The approach planned for this review of the primary O_3 standard will build on the substantial body of work developed during the course of the last review, taking into account the more recent scientific information and air quality data now available to inform our understanding of the key-policy relevant issues in this review. The ISA, risk and exposure analyses (as warranted), and PA developed in this review will provide the basis for addressing the key policy-relevant questions in the review and these documents will inform the Administrator's decisions as to whether to retain or revise the primary O_3 standard. As summarized in section 1.2, and also described in chapter 6, evaluations in the PA are intended to inform the Administrator's public health policy judgments and decisions. In so doing, the PA considers the potential implications of various aspects of the scientific evidence, the exposure/risk-based information, and the associated uncertainties and limitations.

In building upon the conclusions from the last review, the current review takes into account the updated evidence and information that has become available since that review. The Agency's consideration of the full set of evidence and information available in this review will inform the answer to the following initial overarching question for the review:

- **Do the currently available scientific evidence and exposure-/risk-based information support or call into question the adequacy of the public health protection afforded by the current primary O_3 standard?**

In reflecting on this question, we will consider the available body of scientific evidence, assessed in the ISA, and used as a basis for developing or interpreting risk/exposure analyses, including whether it supports or calls into question the scientific conclusions reached in the last review regarding health effects related to exposure to ambient air-related O_3. Information available in this review that may be informative to public health judgments regarding significance or adversity of key effects will also be considered. Additionally, the currently available exposure and risk information, whether newly developed in this review or predominantly developed in the past and interpreted in light of current information, will be considered, including with regard to the extent to which it may continue to support judgments made in the last review. Further, in considering this question with regard to the primary O_3 standard, as in all NAAQS reviews, we give particular attention to exposures and health risks to at-risk populations.[41]

Evaluation of the available scientific evidence and risk/exposure information with regard to this consideration of the current standard will focus on key policy-relevant issues by addressing a series of questions including the following:

- Is there newly available evidence that indicates the importance of photochemical oxidants other than O_3 with regard to abundance in ambient air, and potential for human exposures and health effects?
- Does the currently available scientific evidence alter our conclusions from the last review regarding the nature of health effects attributable to human exposure to O_3 from ambient air?
- Does the current evidence alter our understanding of populations that are particularly at risk from O_3 exposures?
- Does the current evidence alter our conclusions from the previous review regarding the exposure duration and concentrations associated with health effects? To what extent does the currently available scientific evidence indicate health effects attributable to exposures to O_3 concentrations lower than previously reported and what are important uncertainties in that evidence?
- To what extent have previously identified uncertainties in the health effects evidence been reduced or do important uncertainties remain? Have new ones been identified?
- What are the nature and magnitude of O_3 exposures and associated health risks associated with air quality conditions just meeting the current standard?
- To what extent are the estimates of exposures and risks to at-risk populations associated with air quality conditions just meeting the current standard reasonably judged important from a public health perspective?
- What are the important uncertainties associated with any risk/exposure estimates?

[41] As used here and similarly throughout this document, the term *population* refers to persons having a quality or characteristic in common, such as a specific pre-existing illness or a specific age or life stage. Some populations may be at increased risk of health effects occurring with exposure to O_3 as a result of any of a variety of factors, including genetic or developmental aspects, disease or smoking status, and factors related to socioeconomic status, reduced access to health care or increased exposure.

If the information available in this review suggests that revision of the current primary standard would be appropriate to consider, the PA will evaluate how the standard might be revised based on the available scientific information, air quality assessments, and exposure/risk information, and also considering what the available information indicates as to the health protection expected to be afforded by the current or potential alternative standards. Such an evaluation may consider the effect of revision of one or more elements of the standard (indicator, averaging time, level and form), with the effect being evaluated based on the resulting potential standard and all of its elements collectively. Based on such evaluations, the PA would then identify potential alternative standards (specified in terms of indicator, averaging time, level, and form) intended to reflect a range of alternative policy judgments as to the degree of protection that is requisite to protect public health with an adequate margin of safety, and options for standards expected to achieve it. The specific policy-relevant questions that frame such evaluation of what revision of the standard might be appropriate to consider include:

- Does the currently available information call into question the identification of ozone as the indicator for photochemical oxidants? Is support provided for considering a different indicator?
- Does the currently available information call into question the current averaging time? Is support provided for considering different averaging times for the standard?
- What does the currently available information indicate with regard to a range of levels and forms of alternative standards that may be supported and what are the uncertainties and limitations in that information?
- What do the available analyses indicate with regard to exposure and risk associated with specific alternative standards? What are the associated uncertainties? To what extent might such alternatives be expected to reduce adverse impacts attributable to O_3, and what are the uncertainties in the estimated reductions?

The approach to reaching conclusions on the current primary standard and, as appropriate, on potential alternative standards is summarized in general terms in Figure 3-1.

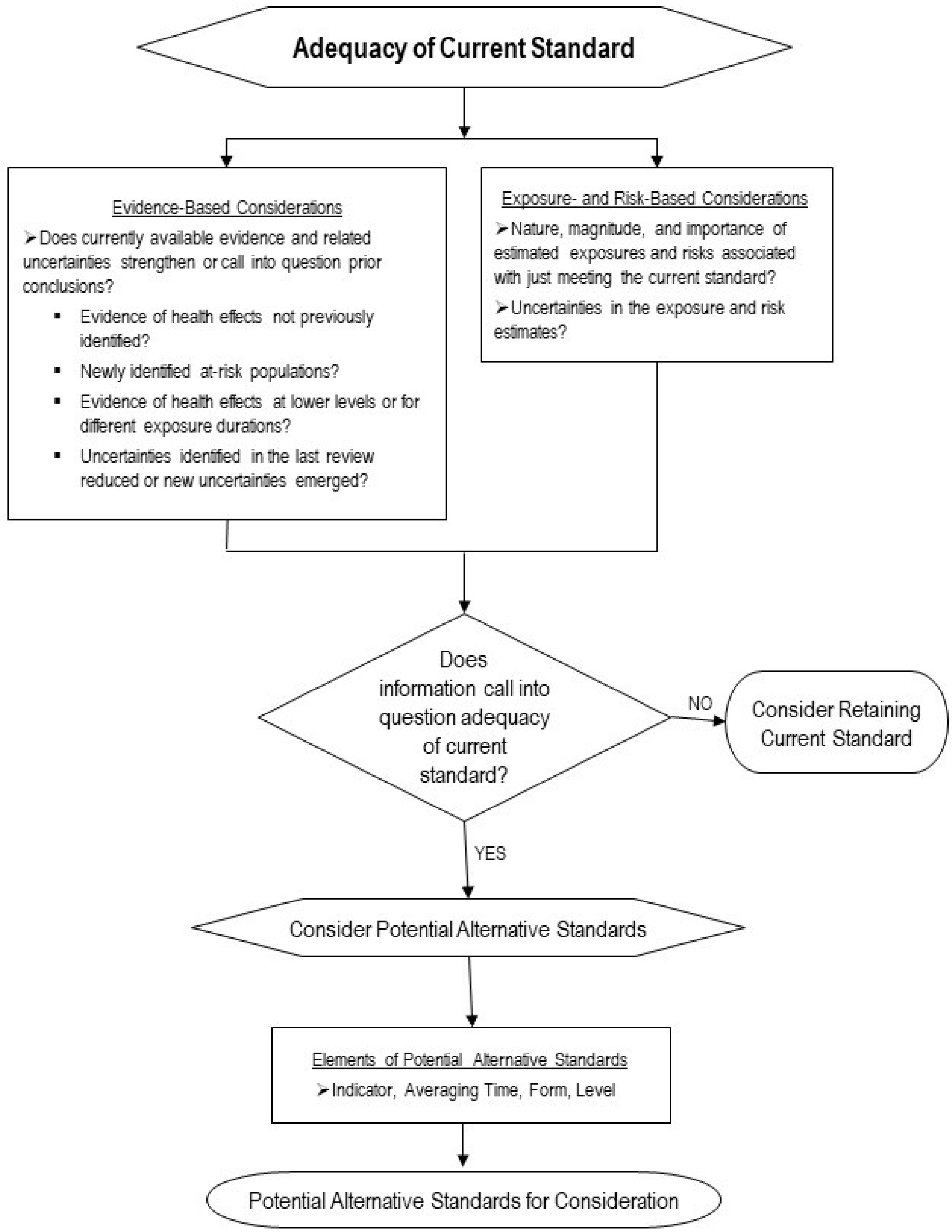


Figure 3-1. Overview of general approach for review of the primary O_3 standard.

The Agency's approach in reviewing primary 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 1.1 above, these provisions require the Administrator to establish primary standards that, in the Administrator's judgment, are requisite (i.e., neither more nor less stringent than necessary) to protect public health with an adequate margin of safety. The CAA does not require the Administrator to establish a primary standard at a zero-risk level or at background concentration levels, but rather at a level that reduces risk sufficiently so as to protect public health with an adequate margin of safety. The decisions on the adequacy of the current primary standard and, on any alternative standards considered in a review, are largely public health policy judgments made by the Administrator. The four basic elements of the NAAQS (i.e., indicator, averaging time, form, and level) are generally considered collectively in evaluating the health protection afforded by the current standard, and by any alternatives considered. The Administrator's final decisions in a review draw upon the scientific evidence for health effects, quantitative analyses of populations exposures and/or health risks, as available, and judgments about how to consider the uncertainties and limitations that are inherent in the scientific evidence and quantitative analyses.

3.1.2 Background on the Current Primary Standard (Considerations and Conclusions in the Last Review)

The 2015 decision to strengthen the primary standard was based on the scientific evidence and quantitative exposure and risk analyses available at the time of the last review, the Administrator's judgments regarding the available scientific evidence, the appropriate degree of public health protection for the revised standard, and the available exposure and risk information regarding the exposures and risk that may be allowed by such a standard (80 FR 65292, October 26, 2015). With the 2015 decision, the EPA revised the level of the primary standard from 0.075 to 0.070 ppm,[42] in conjunction with retaining the then-current indicator (O_3), averaging time (eight hours), and form (fourth-highest daily maximum 8-hour average concentration, averaged across three consecutive years). The 2015 decision drew upon the available scientific evidence assessed in the 2013 ISA, the exposure and risk information presented and assessed in the 2014 health REA (HREA), the consideration of that evidence and information in the 2014 PA, the advice and recommendations of the CASAC, and public comments on the proposed decision (80 FR 65292, October 26, 2015; U.S. EPA., 2015a).

[42] Although ppm are the units in which the level of the standard is defined, the units ppb are more commonly used throughout the next three chapters for greater consistency with their use in the more recent literature. The level of the current primary and secondary standards, 0.070 ppm, is equivalent to 70 ppb.

The health effects evidence base available in the 2015 review included extensive longstanding evidence from previous reviews as well as the evidence that had emerged since the prior review had been completed in 2008. This evidence base, spanning several decades, documents the causal relationship between exposure to O_3 and a broad range of respiratory effects (2013 ISA, p. 1-14). Such effects range from small, reversible changes in pulmonary function and pulmonary inflammation (documented in controlled human exposure studies involving exposures ranging from 1 to 8 hours) to more serious effects such as emergency department visits and hospital admissions, which have been associated with ambient air concentrations of O_3 in epidemiologic studies (2013 ISA, section 6.2). In addition to extensive controlled human exposure and epidemiologic studies, the evidence base includes experimental animal studies that provide insight into potential modes of action for these effects, contributing to the coherence and robust nature of the evidence. Based on this evidence base, the 2013 ISA concluded there to be a causal relationship between short-term O_3 exposures and respiratory effects and a likely causal relationship between longer-term exposure and respiratory effects, and also between short-term exposure and mortality (2013 ISA, p. 1-14).[43]

With regard to the short-term respiratory effects, that were the primary focus of the 2015 decision, the controlled human exposure studies were recognized to provide the most certain evidence indicating the occurrence of health effects in humans following specific O_3 exposures (80 FR 65343, October 26, 2015; 2014 PA, section 3.4). These studies additionally illustrate the role of ventilation rate in eliciting responses to O_3 exposure at the lowest studied concentrations. The exposure concentrations eliciting a given level of response in subjects at rest are higher than for subjects exposed while at elevated ventilation, such as while exercising (2013 ISA, section 6.2.1.1).[44] Further, while the study subjects in the vast majority of the controlled human exposure studies (and in all of these studies conducted at the lowest exposures) are healthy

[43] The 2013 ISA also concluded that there is likely to be a causal relationship between short-term exposure and cardiovascular effects, including related mortality, and that the evidence at that time was suggestive of causal relationships between long-term O_3 exposures and total mortality, cardiovascular effects and reproductive and developmental effects, and between O_3 exposure and central nervous system effects (2013 ISA, section 2.5.2).

[44] In the controlled human exposure studies, the magnitude of respiratory effects (e.g., size of lung function decrements and prevalence in symptomatic responses) is influenced by ventilation rate and exposure duration as well as exposure concentration, with physical activity increasing ventilation and potential for effects. In studies of healthy young adults exposed while at rest for 2 hours, 500 ppb is the lowest concentration eliciting a statistically significant O_3-induced group mean lung function decrement, while a much lower concentration produces a statistically significant response in lung function when the ventilation rate of the group of study subjects is sufficiently increased with exercise (2013 ISA, section 6.2.1.1). For example, the lowest exposure concentration examined that elicited a statistically significant O_3-induced group mean lung function decrement in an exposure of 2 hours or less was 120 ppb in a 1-hour exposure of trained cyclists who maintained a high exertion level throughout the exposure period (2013 ISA, section 6.2.1.1; Gong et al., 1986).

adults, the 2013 ISA identified several groups as being at increased risk of O_3-related effects. In light of this finding with regard to children and adults with asthma, the HREA exposure-based analyses included these population groups as being among those modeled (2014 HREA, p. 3-14).

The exposure and risk information available in the 2015 review included exposure and risk estimates for air quality conditions just meeting the then-existing standard, and also for air quality conditions just meeting potential alternative standards. Estimates were derived for two exposure-based analyses, the first of which involved comparison of population exposure estimates at elevated exertion to exposure benchmarks (exposures of concern)[45] based on exposure concentrations from controlled human exposure studies in which lung function changes and other effects were measured in healthy, young adult volunteers exposed to O_3 while engaging in quasi-continuous moderate physical activity for a defined period (generally 6.6 hours).[46] The second exposure-based analysis provided population risk estimates of the occurrence of days with O_3-attributable lung function decrements of varying magnitudes.[47] Risk estimates were also derived from ambient air concentrations based on concentration-response functions from epidemiologic studies but were given less weight by the Administrator in her decision on the standard, given conclusions reached in the PA and the HREA which reflected lower confidence in these estimates (80 FR 65316-17, October 26, 2015).

The 2014 HREA developed the exposure-based estimates for several population groups including all children and all adults. The estimates involving comparison of exposures to benchmarks were also derived for children with asthma and adults with asthma. The estimates of percentages of children with exposures above benchmarks were virtually indistinguishable from the corresponding estimates of percentages of children with asthma.[48] When considered in terms of the absolute number of children, the estimates for all children were much higher than those for children with asthma, with the magnitude of the differences varying based on asthma prevalence in each study area (2014 HREA, sections 5.3.2, 5.4.1.5 and section 5F-1). The estimates for percent of children above the benchmarks were higher than percent of adults due to the greater

[45] The benchmark concentrations to which exposure concentrations experienced while at moderate or greater exertion were compared were 60, 70 and 80 ppb. This comparison-to-benchmarks analysis, performed in the 2015 review, is summarized in section 5.1.1.1 below.

[46] The studies given primary focus were those for which O_3 exposures occurred over the course of 6.6 hours during which the subjects engaged in six 50-minute exercise periods separated by 10-minute rest periods, with a 35-minute lunch period occurring after the third hour (e.g., Follinsbee et al., 1988 and Schelegle et al., 2009). Responses after O_3 exposure were compared to those involving filtered air.

[47] Both exposure-based analyses are described further in section 5.1 below.

[48] This reflects use of the same time-location-activity diary pool to construct each simulated individual's time-activity series, which is based on the similarities observed in the available diary data with regard to time spent outdoors and exertion levels (2014 HREA, sections 5.3.2 and 5.4.1.5).

time that children spend outdoors and engaged in exertion (2014 HREA, section 5.3.2). Thus, consideration of the exposure-based results in the 2015 decision focused on the results for all children and children with asthma.

In weighing the 2013 ISA conclusions with regard to the health effects evidence and making judgments regarding the public health significance of the quantitative estimates of exposures and risks allowed by the then-existing and alternative standards, as well as judgments regarding margin of safety, the Administrator considered the currently available information and commonly accepted guidelines or criteria within the public health community, including the American Thoracic Society (ATS), an organization of respiratory disease specialists,[49] advice from the CASAC and public comments. In so doing, she recognized that the determination of what constitutes an adequate margin of safety is expressly left to the judgment of the EPA Administrator (*Lead Industries Association* v. *EPA*, 647 F.2d at 1161-62; *Mississippi*, 744 F. 3d at 1353). In NAAQS reviews generally, evaluations of how particular primary standards address the requirement to provide an adequate margin of safety include consideration of such factors as the nature and severity of the health effects, the size of the sensitive population(s) at risk, and the kind and degree of the uncertainties present. Consistent with past practice and long-standing judicial precedent, the Administrator took the need for an adequate margin of safety into account as an integral part of her decision-making.

The Administrator's initial decision in the last review was with regard to the adequacy of protection provided by the then-existing primary standard. Considerations related to that decision are summarized in section 3.1.2.1 below. The considerations and decisions on revisions to the then-existing standard in order to provide the requisite protection under the Act, including an adequate margin of safety, is summarized in section 3.1.2.2.

3.1.2.1 Considering the Need for Revision

The approach to considering the adequacy of the then-current primary standard in the last review involved the careful consideration of the available evidence, analyses and conclusions contained in the 2013 ISA, including information newly available in the review; the quantitative exposure and risk analyses in the 2014 HREA; the information, evaluations, considerations and conclusions presented in the 2014 PA; advice from the CASAC; and public comment. Key considerations informing the Administrator's decision on the need for revision of the then-current standard are summarized below.

The Administrator gave primary consideration to the evidence of respiratory effects from controlled human exposure studies, including those newly available in the review, and for which

[49] With regard to commonly accepted guidelines or criteria within the public health community, the PA considered statements issued by the ATS that had also been considered in prior reviews (ATS, 2000; ATS, 1985).

the exposure concentrations were at the lower end of those studied (80 FR 65343, October 26, 2015). This emphasis was consistent with CASAC comments on the strength of this evidence (Frey, 2014, p. 5). In placing weight on these studies, the Administrator took note of the variety of respiratory effects reported from the studies of healthy adults engaged in six 50-minute periods of moderate exertion within a 6.6-hour exposure to O_3 concentrations of 60 and higher. The most severe respiratory effects have been reported, and the broadest range of effects have been studied and reported (lung function decrements, respiratory symptoms, airway inflammation, airway hyperresponsiveness, and impaired lung host defense) following exposures to 80 ppb O_3 or higher, with most exposure studies conducted at these higher concentrations. The combination of lung function decrements and respiratory symptoms was reported following exposures for which the average concentration during the exercise periods was 72 ppb,[50] and lung function decrements and pulmonary inflammation were reported following exposures to O_3 concentrations as low as 60 ppb. In considering these findings, the Administrator noted that the combination of O_3-induced lung function decrements and respiratory symptoms meets ATS criteria for an adverse response.[51] She additionally recognized the CASAC comments on this point and also its caution that these study findings were for healthy adults indicating the potential for such effects in some people, such as people with asthma, at lower exposures (Frey, 2014c, pp. 5-6). In light of this, the Administrator concluded that "the controlled human exposure studies indicate that adverse effects are likely to occur following exposures to O_3 concentrations below the level of the [then-current] standard" (80 FR 65343, October 26, 2015).

The 2013 ISA indicated that the pattern of effects observed across the range of exposures assessed in the controlled human exposure studies, increasing with severity at higher exposures, is coherent with (i.e., reasonably related to) the health outcomes reported to be associated with ambient air concentrations in epidemiologic studies (e.g., respiratory-related hospital admissions, emergency department visits). With regard to the available epidemiologic studies, the Administrator noted analyses of O_3 air quality in the 2014 PA indicating that, while most O_3 epidemiologic studies reported health effect associations with O_3 concentrations in ambient air that violated the then-current standard, a small number of single-city U.S. studies indicate the occurrence of asthma-related hospital admissions and emergency department visits at ambient air O_3 concentrations below the level of the then-current standard. In particular, the Administrator took note of a study that reported associations between short-term O_3 concentrations and asthma

[50] For the 70 ppb target exposure, Schelegle et al. (2009) reported that the mean O_3 concentration for the six 50-minute exercise periods was 72 ppb.

[51] The most recent statement from the ATS available at the time of the 2015 decision stated that "[i]n drawing the distinction between adverse and nonadverse reversible effects, this committee recommended that reversible loss of lung function in combination with the presence of symptoms should be considered as adverse" (ATS, 2000).

emergency department visits in children and adults in a U.S. location that would have met the then-current standard over the entire 5-year study period (80 FR 65344, October 26, 2015; Mar and Koenig, 2009).[52] [53] While uncertainties[54] limited the extent to which the Administrator based her conclusions on air quality in locations of multicity epidemiologic studies, she additionally noted some support from several multicity studies of morbidity or mortality in which the majority of study locations would have met the then-current standard (80 FR 65344, October 26, 2015; 2014 PA, section 3.1.4.2). Accordingly, looking across the body of epidemiologic evidence, the Administrator reached the conclusion that analyses of air quality in some study locations supported the occurrence of adverse O_3-associated effects at O_3 concentrations in ambient air that met, or are likely to have met, the then-current standard (80 FR 65344, October 26, 2016). Taken together, the Administrator concluded that the scientific evidence from controlled human exposure and epidemiologic studies called into question the adequacy of the public health protection provided by the then-current standard.

In considering the exposure and risk information, the Administrator gave particular attention to the estimates of exposures of concern, focusing on the estimates for children, in 15 urban areas for air quality conditions just meeting the then-current standard. Consistent with the finding that larger percentages of children than adults were estimated to experience exposures above benchmarks, the Administrator focused on the results for all children and for children with asthma, noting that the results for these two groups, in terms of percent of the population group, are virtually indistinguishable (2014 HREA, sections 5.3.2, 5.4.1.5 and section 5F-1). In considering these estimates, she placed greatest weight on estimates of two or more days with occurrences of exposures above benchmarks, in light of her increased concern about the potential for adverse responses with repeated occurrences of such exposures. In particular, she noted that the types of effects shown to occur following exposures to O_3 concentrations from 60 ppb to 80

[52] The design values in this location over the study period were at or somewhat below 75 ppb (Wells et al., 2012).

[53] The Administrator also took note of analyses in the PA for some single-city study locations where the then-current standard was not met during the study period (i.e., those evaluated in Silverman and Ito, 2010; Strickland et al., 2010), finding support for the association of hospital admissions and emergency department visits with short-term O_3 on subsets of days with virtually all ambient air O_3 concentrations below the level of the then-current standard. These analyses generally focused on the range of short-term concentrations for which the confidence intervals for the concentration-response relationship were tightest, finding these to be on many days with O_3 concentrations below the level of the standard (80 FR 65344, October 26, 2015).

[54] Compared to the single-city epidemiologic studies the Administrator noted additional uncertainty in interpreting the relationships between short-term O_3 air quality in individual study cities and reported O_3 multicity effect estimates. This uncertainty applied specifically to interpreting air quality analyses within the context of multicity effect estimates for short-term O_3 concentrations, where effect estimates for individual study cities are not presented (as is the case for the key O_3 studies analyzed in the PA, with the exception of the study by Stieb et al. (2009) where none of the city-specific effect estimates for asthma emergency department visits were statistically significant) (80 FR 65344; October 26, 2015).

ppb, such as inflammation, if occurring repeatedly from repeated exposure, could potentially result in more severe effects based on the ISA conclusions regarding mode of action (80 FR 65343, 65345, October 26, 2015; 2013 ISA, section 6.2.3). While generally placing greatest weight on estimates of repeated exposures, the Administrator also considered estimates for single exposures above the higher benchmarks of 70 and 80 ppb (80 FR 65345, October 26, 2015).

With regard to multiple exposures, the HREA found that under conditions just meeting the then-current standard, fewer than 1% of children in the 15 study areas would be estimated to experience multiple days in a year with 8-hour exposures at or above 70 ppb while at elevated ventilation, while the percentage was as high as approximately 2% in the year and location with the highest exposure estimates (80 FR 65345 and Table 1, October 26, 2015). Although she expressed less concern with single occurrences, the Administrator noted that the then-current standard could allow just over 3% of children to experience one or more days, averaged over the years of analysis, with an 8-hour exposure at or above 70 ppb (while at moderate or greater exertion), based on the worst-case location, and up to 8% in the worst-case year and location (80 FR 65345, October 26, 2015). She additionally noted that, that in the worst-case year and location across the 15 study areas, the then-current standard could allow up to about 1% of children to experience at least one day per year with 8-hour exposures at elevated ventilation at or above 80 ppb, the highest benchmark evaluated (80 FR 65345, October 26, 2015).[55]

In considering the HREA estimates of days with exposures at or above 60 ppb, while expressing less confidence in the adversity of effects observed following exposures as low as 60 ppb, particularly single exposures, she judged the potential for adverse effects to increase with repeated exposures, as noted above (80 FR 65345, October 26, 2015). In that light, she noted that the HREA found that under air quality conditions just meeting the then-current standard, approximately 3 to 8% of children in the 15 urban study areas (including approximately 3 to 8% of asthmatic children), on average across the years of analysis, were estimated to experience two or more days per year with 8-hour exposures at or above 60 ppb, while at elevated ventilation (80 FR 65345; October 26, 2015).

In considering these exposure estimates with regard to public health implications, the Administrator concluded that the exposures and risks projected to remain upon meeting the then-current standard could reasonably be judged to be important from a public health perspective. In particular, this conclusion was based on her judgment that it is appropriate to set a standard that would be expected to eliminate, or almost eliminate, the occurrence of exposures, while at moderate exertion, at or above 70 and 80 ppb. In addition, given that the average percent of

[55] The Administrator additionally noted that the then-current standard could allow up to about 3% of children to experience one or more days with 8-hour exposures at elevated ventilation at or above 70 ppb, averaged over the years of analysis across the 15 study areas (80 FR 65313, Table 1, October 26, 2015).

children estimated to experience two or more days with exposures at or above the 60 ppb benchmark approaches 10% in some urban study areas (on average across the analysis years), the Administrator concluded that the then-current standard does not incorporate an adequate margin of safety against the potentially adverse effects that could occur following repeated exposures at or above 60 ppb (80 FR 65345-46; October 26, 2015).

With regard to the HREA estimates of lung function risk in terms of decrements in forced expiratory volume in one second (FEV_1), the Administrator also gave greater weight to estimates of multiple occurrences than to single occurrences, while additionally noting CASAC advice regarding uses of FEV_1 decrement estimates as scientifically relevant surrogates for adverse health outcomes (Frey, 2014c, p. 3). The Administrator noted that, when averaged over the years of evaluation, the then-current standard was estimated to allow about 1 to 3% of children in the 15 urban study areas to experience two or more O_3-induced lung function decrements $\geq$15%, and to allow about 8 to 12% of children to experience two or more O_3-induced lung function decrements $\geq$10% (80 FR 65346, October 26, 2015). The Administrator concluded that these HREA estimates for lung function risk, as well as the epidemiologic-study-based risk estimates (although she recognized increased uncertainty in and placed less weight on both types of estimates) further support a conclusion that the O_3-associated health effects estimated to remain upon just meeting the then-current standard are an issue of public health importance on a broad national scale. Thus, she concluded that O_3 exposure and risk estimates, when taken together, support a conclusion that the exposures and health risks associated with just meeting the then-current standard can reasonably be judged to be of public health significance, such that the then-current standard was not sufficiently protective and did not incorporate an adequate margin of safety.

In addition to the evidence and exposure/risk information, the Administrator also took note of CASAC advice, which included the finding that “the current NAAQS for ozone is not protective of human health” and the unanimous recommendation “that the Administrator revise the current primary ozone standard to protect public health” (Frey, 2014c, p. 5). She further noted similar CASAC advice in the prior 2008 review.[56]

In consideration of all of the above, the Administrator concluded that the then-current primary O_3 standard was not requisite to protect public health with an adequate margin of safety, and that it should be revised to provide increased public health protection. This decision was based on the Administrator’s conclusions that the available evidence and exposure and risk information clearly called into question the adequacy of public health protection provided by the

[56] The CASAC O_3 Panel for the 2008 review likewise recommended revision of the standard to one with a level below 75 ppb. This earlier recommendation was based entirely on the evidence and information in the record for the 2008 decision, which had been expanded in the 2015 review (Samet, 2011; Frey and Samet, 2012).

then-current primary standard such that it was “not appropriate, within the meaning of section 109(d)(1) of the CAA, to retain the current standard” (80 FR 65346, October 26, 2015).

3.1.2.2 Considering Revisions to the Standard

The following subsections summarize the Administrator’s key considerations and conclusions in considering revisions to the indicator, averaging time, form and level of the primary standard in the 2015 review.

3.1.2.2.1 Indicator

In considering whether O_3 continued to be the most appropriate indicator for a standard meant to provide protection against photochemical oxidants in ambient air, the Administrator considered findings and assessments in the 2013 ISA and 2014 PA, as well as advice from the CASAC and public comment. The 2013 ISA specifically noted that O_3 is the only photochemical oxidant (other than nitrogen dioxide) that is routinely monitored and for which a comprehensive database exists (2013 ISA, section 3.6; 80 FR 65347, October 26, 2015). The PA additionally noted that, since the precursor emissions that lead to the formation of O_3 also generally lead to the formation of other photochemical oxidants, measures leading to reductions in population exposures to O_3 can generally be expected to lead to reductions in other photochemical oxidants. The CASAC indicated its view that O_3 is the appropriate indicator “based on its causal or likely causal associations with multiple adverse health outcomes and its representation of a class of pollutants known as photochemical oxidants” (Frey, 2014c, p. ii). Based on all of these considerations and public comments, the Administrator concluded that O_3 remains the most appropriate indicator for a standard meant to provide protection against photochemical oxidants in ambient air, and she retained O_3 as the indicator for the primary standard (80 FR 65347, October 26, 2015).

3.1.2.2.2 Averaging time

The 8-hour averaging time for the primary O_3 standard was established in 1997 with the decision to replace the then-existing 1-hour standard with an 8-hour standard (62 FR 38856, July 18, 1997). The decision in that review was based on evidence from numerous controlled human exposure studies reporting associations between adverse respiratory effects and 6- to 8-hour exposures, as well as quantitative analyses indicating the control provided by an 8-hour averaging time of both 8-hour and 1-hour peak exposures and associated health risk (62 FR 38861, July 18, 1997; U.S. EPA, 1996b). The decision at that time was also consistent with advice from the CASAC (62 FR 38861, July 18, 1997; 61 FR 65727; December 13, 1996). The EPA reached similar conclusions in the subsequent 2008 review in which the 8-hour averaging time was retained (73 FR 16436, March 27, 2008).

In the review completed in 2015, the Administrator considered the averaging time for the standard in light of both the strong evidence for O_3-associated respiratory effects following short-term exposures and the available evidence related to effects following longer-term exposures (80 FR 65347-50, October 26, 2015). In so doing, the Administrator noted the substantial health effects evidence from controlled human exposure studies that demonstrate that a wide range of respiratory effects (e.g., pulmonary function decrements, increases in respiratory symptoms, lung inflammation, lung permeability, decreased lung host defense, and airway hyperresponsiveness) occur in healthy adults following exposures ranging from 1 to 8 hours (80 FR 65348, October 26, 2015; 2013 ISA, section 6.2.1.1). The Administrator also noted the strength of evidence from epidemiologic studies that evaluated a wide variety of populations (e.g., including at-risk lifestages and populations, such as children and people with asthma, respectively) using a number of different short-term averaging times, including the maximum 1-hour concentration within a 24-hour period (1-hour max), the maximum 8-hour average concentration within a 24-hour period (8-hour max), and the 24-hour average (80 FR 65348, October 26, 2015; 2013 ISA, chapter 6). It was recognized that an 8-hour averaging time is similar to the exposure periods evaluated in the more recent controlled human exposure studies conducted at the lowest concentrations, and the Administrator noted that the epidemiologic evidence alone did not provide a strong basis for distinguishing between the appropriateness of 1-hour, 8-hour and 24-hour averaging times. Thus, in consideration of the then-available health effects information, the Administrator concluded that an 8-hour averaging time remained appropriate for addressing health effects associated with short-term exposures to ambient air O_3 (80 FR 65348, October 26, 2015).

In considering the evidence related to longer-term exposures, the Administrator initially considered the extent to which currently available evidence and exposure/risk information suggested that a standard with an 8-hour averaging time can provide protection against respiratory effects associated with longer-term exposures to ambient air O_3. As in previous reviews, the review completed in 2015 recognized and further evaluated changes in long-term air quality patterns in response to attaining an 8-hour standard and the reduction in potential risk of health effects associated with long-term exposures in areas meeting an 8-hour standard (80 FR 65348, October 26, 2015). Analyses described in detail in the HREA suggested that reductions in O_3 precursors emissions in order to meet a standard with an 8-hour averaging time, coupled with the appropriate form and level, would be expected to reduce long-term O_3 concentrations reported in epidemiologic studies to be associated with respiratory morbidity and mortality (80 FR 65348, October 26, 2015).

In summary, based on the then-available evidence and information discussed in detail in the 2013 ISA, 2014 HREA, and 2014 PA, along with CASAC advice and public comments, the

Administrator concluded that a standard with an 8-hour averaging time could effectively limit health effects attributable to both short- and long-term O_3 exposures. Furthermore, the Administrator observed that the CASAC agreed with the choice of averaging time (Frey, 2014c, p. ii). Therefore, the Administrator concluded it to be appropriate to retain the 8-hour averaging time and to not set a separate standard with a different averaging time (80 FR 65350, October 26, 2015).

3.1.2.2.3 Form

While giving foremost consideration to the adequacy of public health protection provided by the combination of all elements of the standard, including the form, the Administrator placed considerable weight on the findings from prior reviews with regard to the use of the *n*th-high metric, as described below (80 FR 65350-65352, October 26, 2015). Based on these findings and consideration of CASAC advice, the Administrator judged it appropriate to retain the fourth-high form, more specifically the fourth-highest daily maximum 8-hour O_3 average concentration, averaged over 3 years (80 FR 65352, October 26, 2015).

The concentration-based form was established in the 1997 review when it was recognized that such a form better reflects the continuum of health effects associated with increasing O_3 concentrations than an expected exceedance form, which had been the form of the standard prior to 1997. Unlike an expected exceedance form, a concentration-based form gives proportionally more weight to years when 8-hour O_3 concentrations are well above the level of the standard than years when 8-hour O_3 concentrations are just above the level of the standard. More weight was given to high O_3 concentrations, in light of the available health evidence that indicated a continuum of effects associated with exposures to varying concentrations of O_3, and because the extent to which public health is affected by exposure to O_3 in ambient air is related to the actual magnitude of the O_3 concentration, not just whether the concentration is above a specified level. With regard to a specific concentration-based form, the fourth-highest daily maximum was selected in 1997, recognizing that a less restrictive form (e.g., fifth highest) would allow a larger percentage of sites to experience O_3 peaks above the level of the standard, and would allow more days on which the level of the standard may be exceeded when the site attains the standard (62 FR 38868-38873, July 18, 1997).

In the subsequent 2008 review, the EPA considered the potential value of a percentile-based form, recognizing that such a statistic is useful for comparing datasets of varying length because it samples approximately the same place in the distribution of air quality values, whether the dataset is several months or several years long (73 FR 16474, March 27, 2008). However, the EPA concluded that, because of the differing lengths of the monitoring season for O_3 across the U.S., a percentile-based statistic would not be effective in ensuring the same degree of public health protection across the country. Specifically, a percentile-based form would allow more days with higher air quality values (i.e., higher O_3 concentrations) in locations with longer O_3 seasons relative to locations with shorter O_3 seasons. Thus, the EPA concluded in the 2008 review that a form based on the *n*th-highest maximum O_3 concentration would more effectively ensure that people who live in areas with different length O_3 seasons received the same degree of public health protection (73 FR 16474-75, March 27, 2008). At that time, it was also recognized that it is important to have a form that provides stability with regard to implementation of the standard. In the case of O_3, for example, it was noted that it was important to have a form that provides stability and insulation from the impacts of extreme meteorological events that are conducive to O_3 formation. Such events could have the effect of reducing public health protection, to the extent they result in frequent shifts in and out of attainment due to meteorological conditions because such frequent shifting could disrupt an area's ongoing implementation plans and associated control programs (73 FR 16475, March 27, 2008).

In the 2015 review, the Administrator continued to recognize the considerations supporting the decisions in 1997 and 2008, and additionally noted recent CASAC advice in which the CASAC indicated that the O_3 standard should be based on the fourth-highest, daily maximum 8-hour average value (averaged over 3 years), by stating that this form "provides health protection while allowing for atypical meteorological conditions that can lead to abnormally high ambient ozone concentrations which, in turn, provides programmatic stability" (Frey, 2014c, p. 6; 80 FR 65352, October 26, 2015).

3.1.2.2.4 Level

The Administrator's decision to revise the level of the primary O_3 standard to 70 ppb built upon her conclusion (summarized in section 3.1.2.1 above) that the overall body of scientific evidence and exposure/risk information called into question the adequacy of the public health protection afforded by the then-current standard, particularly for at-risk populations and lifestages (80 FR 65362, October 26, 2015). In her decision on level, the Administrator placed the greatest weight on the results of controlled human exposure studies and on quantitative analyses based on information from these studies, particularly analyses of O_3 exposures of concern. The Administrator viewed the results of the lung function risk assessment, analyses of O_3 air quality in locations of epidemiologic studies, and epidemiology-based quantitative health risk assessment as providing information in support of her decision to revise the then-current standard, but of less utility for selecting a particular standard level among a range of options (80 FR 65362, October 26, 2015). In placing weight on information from controlled human exposure studies and analyses based on information from these studies, the Administrator noted that controlled human exposure studies provide the most certain evidence indicating the occurrence of health effects in humans following specific O_3 exposures, noting in particular that the effects reported in the controlled human exposure studies are due solely to O_3 exposures, and are not complicated by the presence of co-occurring pollutants or pollutant mixtures (as is the case in epidemiologic studies). The Administrator's emphasis on the information from the controlled human exposure studies was consistent with the CASAC's advice and interpretation of the scientific evidence (80 FR 65362, October 26, 2015; Frey, 2014c). In this regard, the Administrator recognized that (1) the largest respiratory effects, and the broadest range of effects, have been studied and reported following exposures to 80 ppb O_3 or higher (i.e., decreased lung function, increased airway inflammation, increased respiratory symptoms, airway hyperresponsiveness, and decreased lung host defense); (2) exposures to O_3 concentrations somewhat above 70 ppb have been shown to both decrease lung function and to result in respiratory symptoms; and (3) exposures to O_3 concentrations as low as 60 ppb have been shown to decrease lung function and to increase airway inflammation (80 FR 65363, October 26, 2015). The Administrator considered both ATS recommendations and CASAC advice to inform her judgments on the potential adversity to public health of effects reported in controlled human exposure studies (80 FR 65363, October 26, 2015). In doing so, the Administrator concluded that the evidence from controlled human exposure studies provided strong support for the conclusion that a revised standard with a level of 70 ppb is requisite to protect public health with an adequate margin of safety. This conclusion was based, in part, on the fact that such a standard level would be well below the O_3 exposure concentration documented to result in the widest range of respiratory effects (i.e., 80 ppb), and below the lowest O_3 exposure concentration shown to result in the adverse combination of lung function decrements and respiratory symptoms (80 FR 65363, October 26, 2015).

In considering the degree of protection provided by a revised primary O_3 standard, the Administrator considered the extent to which that standard would be expected to limit population exposures to the broad range of O_3 exposures shown to result in health effects (80 FR 65363, October 26, 2015). In considering the exposure estimates from the HREA, the Administrator focused on the estimates of two or more exposures of concern in order to provide a health-protective approach to considering the potential for repeated occurrences of exposures that could result in adverse effects. In so doing, she placed the most emphasis on setting a standard that appropriately limits repeated occurrences of exposures while at elevated ventilation at or above the 70 and 80 ppb benchmarks. She noted that a revised standard with a level of 70 ppb was estimated to eliminate the occurrence of two or more days with exposures at or above 80 ppb and to virtually eliminate the occurrence of two or more days with exposures at or above 70 ppb for all children and children with asthma, even in the worst-case year and location evaluated.[57] Given the considerable protection provided against repeated exposures of concern for all benchmarks evaluated in the HREA, the Administrator judged that a standard with a level of 70 ppb incorporated a margin of safety against the adverse O_3-induced effects shown to occur in the controlled human exposure studies (80 FR 65364, October 26, 2015).

While she was less confident that adverse effects would occur following exposures to O_3 concentrations as low as 60 ppb,[58] as discussed above, the Administrator judged it to also be appropriate to consider estimates of exposures (while at moderate or greater exertion) for the 60 ppb benchmark (80 FR 65363-64, October 26, 2015). In so doing, she recognized that while CASAC advice regarding the potential adversity of effects observed in studies of 60 ppb was less definitive than for effects observed at the next higher concentration studied, the CASAC did clearly advise the EPA to consider the extent to which a revised standard is estimated to limit the effects observed in studies of 60 ppb exposures (80 FR 65364, October 26, 2015; Frey, 2014c). The Administrator's consideration of exposures at or above the 60 ppb benchmark was primarily in the context of considering the extent to which the health protection provided by a revised standard included a margin of safety against the occurrence of adverse O_3-induced effects. In this context, the Administrator noted that a revised standard with a level of 70 ppb was estimated to protect the vast majority of children in urban study areas (i.e., about 96% to more than 99% of children in individual areas) from experiencing two or more days with exposures at or above 60 ppb (while at moderate or greater exertion). Compared to the estimates for the then-current standard, this represented a reduction of more than 60%. Given the considerable protection provided against repeated exposures of concern for all of the benchmarks evaluated, including the 60 ppb benchmark, the Administrator judged that a standard with a level of 70 ppb would incorporate a margin of safety against the adverse O_3-induced effects shown to occur following exposures (while at moderate or greater exertion) to a somewhat higher concentration. The Administrator also judged the HREA results for one or more exposures at or above 60 ppb to provide further support for her somewhat broader conclusion that "a standard with a level of 70

[57] Under conditions just meeting an alternative standard with a level of 70 ppb across the 15 urban study areas, the estimate for two or more days with exposures at or above 70 ppb was 0.4% of children, in the worst year and worst area (80 FR 65313, Table 1, October 26, 2015).

[58] The Administrator was "notably less confident in the adversity to public health of the respiratory effects that have been observed following exposures to O_3 concentrations as low as 60 ppb," based on her consideration of the ATS recommendation on judging adversity from transient lung function decrements alone, the uncertainty in the potential for such decrements to increase the risk of other, more serious respiratory effects in a population (per ATS recommendations on population-level risk), and the less clear CASAC advice regarding potential adversity of effects at 60 ppb compared to higher concentrations studied (80 FR 65363, October 26, 2015).

ppb would incorporate an adequate margin of safety against the occurrence of O_3 exposures that can result in effects that are adverse to public health" (80 FR 65364, October 26, 2015).[59]

While placing limited weight on the lung function risk estimates,[60] epidemiologic evidence[61] and quantitative estimates based on information from the epidemiologic studies, the Administrator additionally considered that information in the context of her consideration of a standard with a level of 70 ppb. For example, she judged that a standard with a level of 70 ppb would be expected to result in important reductions in the population-level risk of O_3-induced lung function decrements in children, including children with asthma (80 FR 65364, October 26, 2015). With regard to the epidemiologic evidence, the Administrator noted that a revised standard with a level of 70 ppb would provide additional public health protection, beyond that provided by the then-current standard, against the clearly adverse effects analyzed in epidemiologic studies (80 FR 65364, October 26, 2015). With regard to the epidemiology-based risk estimates, the Administrator judged that a revised standard with a level of 70 ppb would result in meaningful reductions in the mortality and respiratory morbidity risk that is associated with short- or long-term concentrations of O_3 in ambient air (80 FR 65365, October 26, 2015).

In summary, given her consideration of the evidence, exposure and risk information, advice from the CASAC, and public comments, the Administrator judged a primary standard of 70 ppb in terms of the 3-year average of fourth-highest daily maximum 8-hour average O_3

[59] While the Administrator was less concerned about single occurrences of O_3 exposures of concern, especially for the 60 ppb benchmark, she judged that estimates of one or more exposures of concern can provide further insight into the margin of safety provided by a revised standard. In this regard, she noted that "a standard with a level of 70 ppb is estimated to (1) virtually eliminate all occurrences of exposures of concern at or above 80 ppb; (2) protect the vast majority of children in urban study areas from experiencing any exposures of concern at or above 70 ppb (i.e., ≥ about 99%, based on mean estimates; Table 1); and (3) to achieve substantial reductions, compared to the then-current standard, in the occurrence of one or more exposures of concern at or above 60 ppb (i.e., about a 50% reduction; Table 1)" (80 FR 65364, October 26, 2015).

[60] The Administrator noted important uncertainties in using lung function risk estimates as a basis for considering the occurrence of adverse effects in the population (also recognized in the prior review) that limited her reliance on these estimates to distinguish between the appropriateness of the health protection afforded by a standard level of 70 ppb versus lower levels (80 FR 65364, October 26, 2015). These uncertainties related to (1) the ATS recommendation that "a small, transient loss of lung function, by itself, should not automatically be designated as adverse" (ATS, 2000); (2) uncertainty in the extent to which a transient population-level decrease in FEV_1 would increase the risk of other, more serious respiratory effects in that population (i.e., per ATS recommendations on population-level risk); and (3) that CASAC did not advise considering a standard that would be estimated to eliminate O_3-induced lung function decrements ≥10 or 15% (Frey, 2014c); 80 FR 65364, October 26, 2015).

[61] While the Administrator concluded that analyses of air quality in single-city epidemiologic studies support a level at least as low as 70 ppb, based on a study (Mar and Koenig, 2009) reporting health effect associations in a location that met the then-current standard over the entire study period but that would have violated a revised standard with a level of 70 ppb, she further judged that they are of more limited utility for distinguishing between the appropriateness of the health protection estimated for a standard level of 70 ppb and the protection estimated for lower levels (80 FR 65364, October 26, 2015).

concentrations to be requisite to protect public health, including the health of at-risk populations, with an adequate margin of safety (80 FR 65365, October 26, 2015).

3.2 THE SECONDARY STANDARD

The approach planned for this review of the secondary standard is most fundamentally based on using the Agency's assessment of the current scientific evidence and associated quantitative analyses to inform the Administrator's judgments regarding a secondary standard that is requisite to protect the public welfare from known or anticipated adverse effects. This approach involves translating scientific and technical information into the basis for addressing a series of key policy-relevant questions using both evidence- and exposure/risk-based considerations. This series of key questions related to the secondary standard is presented in section 3.2.1, along with a summary of the general approach for the review. Additionally, to provide context for this review of the current secondary standard, section 3.2.2 below summarizes key aspects of the decisions made in the last review, including the Agency's consideration of important policy judgments on effects that may be adverse to the public welfare, as well as uncertainties and limitations in the scientific evidence and in the air quality and exposure/risk information.

3.2.1 Key Issues Related to the Secondary Standard

The approach planned for this review of the secondary O_3 standard will build on the substantial body of work developed during the course of the last review, taking into account the more recent scientific information and air quality data now available to inform our understanding of the key policy-relevant issues in this review. The ISA, risk and exposure analyses (as warranted), and PA developed in this new review will provide the basis for addressing the key policy-relevant questions and these documents will inform the Administrator's decisions as to whether to retain or revise this standard. As summarized in section 1.2, and also described in chapter 6, evaluations in the PA are intended to inform the Administrator's public welfare policy judgments and decisions. In so doing, the PA considers the potential implications of various aspects of the scientific evidence, the exposure/risk-based information, and the associated uncertainties and limitations.

In building upon the conclusions from the last review, the current review of the secondary standard, as with the review of the primary standard, takes into account the updated evidence and information that has become available since the last review. The Agency's consideration of the full set of evidence and information available in this review will inform the answer to the following initial overarching question for the review:

- **Do the currently available scientific evidence and exposure-/risk-based information support or call into question the adequacy of the public welfare protection afforded by the current secondary O_3 standard?**

In reflecting on this question, we will consider the available body of scientific evidence, assessed in the ISA, and considered as a basis for developing or interpreting risk and exposure analyses, including whether it supports or calls into question the scientific conclusions reached in the last review regarding welfare effects related to exposure to O_3 in ambient air. Information available in this review that may be informative to public policy judgments regarding significance or adversity of key effects on the public welfare will also be considered. Additionally, the currently available exposure and risk information, whether newly developed in this review or predominantly developed in the past and interpreted in light of current information, will be considered, including with regard to the extent to which it may continue to support judgments made in the last review. Further, in considering this question with regard to the secondary O_3 standard, we give particular attention to exposures and risks for effects with the greatest potential for public welfare significance.

Evaluation of the available scientific evidence and risk/exposure information with regard to consideration of the current standard will focus on key policy-relevant issues by addressing a series of questions including the following:

- Is there newly available evidence that indicates the importance of photochemical oxidants other than O_3 with regard to abundance in ambient air, and potential for welfare effects?
- Does the current evidence alter our conclusions from the last review regarding the nature of welfare effects attributable to O_3 in ambient air? Is there new evidence on welfare effects beyond those identified in the last review?
- What information is newly available in this review relevant to consideration of public welfare implications? Does it alter our understanding of locations or ecosystems where the presence of species sensitive to O_3-related effects indicates the potential for effects on the public welfare?
- Does the current evidence continue to support a cumulative, seasonal exposure index as a biologically-relevant and appropriate metric for assessment of the evidence or exposure/risk information for vegetation? Does the W126 index continue to be supported for this purpose?
- To what extent does the available evidence indicate the occurrence of O_3-related effects attributable to cumulative O_3 exposures lower than previously established or that might be expected to occur under the current standard?
- Is there new evidence on factors that influence relationships between O_3 concentrations and vegetation-related or other welfare effects?
- What are important uncertainties in the evidence? To what extent have important uncertainties in the evidence identified in the last review been reduced and/or have new uncertainties been recognized?

- What are the nature and magnitude of exposure- and risk-related estimates for vegetation associated with conditions just meeting the current standard, and what do they indicate regarding the potential for O_3-related vegetation impacts?
- Are such exposures and risks reasonably judged important from a public welfare perspective?
- What are the important uncertainties associated with any exposure estimates and associated characterization of potential for public welfare effects?

If the information available in this review suggests that revision of the current secondary standard would be appropriate to consider, the PA will include evaluation of how the standard might be revised, based on the currently available scientific information, air quality assessments and exposure/risk information, and also considering what the available information indicates as to public welfare protection expected to be afforded by the current or potential alternative standards. In such an evaluation, the PA may consider the effect of revision of one or more elements of the standard (indicator, averaging time, level and form), with the effect being evaluated based on the resulting potential standard and all of its elements collectively. Based on such evaluations, the PA would then identify potential alternative standards (in terms of indicator, averaging time, level, and form) that would reflect a range of alternative policy judgments as to the degree of protection that is requisite to protect public welfare from known or anticipated adverse effects, and options for standards expected to achieve it. The specific policy-relevant questions that frame such evaluation of what revision of the standard might be appropriate to consider include:

- Does the currently available information call into question the identification of ozone as the indicator for photochemical oxidants? Is support provided for considering a different indicator?
- To what extent does the currently available information call into question the current averaging time? Is support provided for considering different averaging times for the standard?
- What does the currently available information indicate with regard to a range of levels and forms of alternative standards that may be supported and what are the uncertainties and limitations in that information?
- What do the available analyses indicate with regard to exposure and risk associated with specific alternative standards? What are the associated uncertainties? To what extent might such alternatives be expected to reduce adverse impacts attributable to O_3, and what are the uncertainties in the estimated reductions?

The approach to reaching conclusions on the current secondary O_3 standard and, as appropriate, on potential alternative standards, including consideration of the policy-relevant questions which will frame the current review, is illustrated in Figure 3-2.

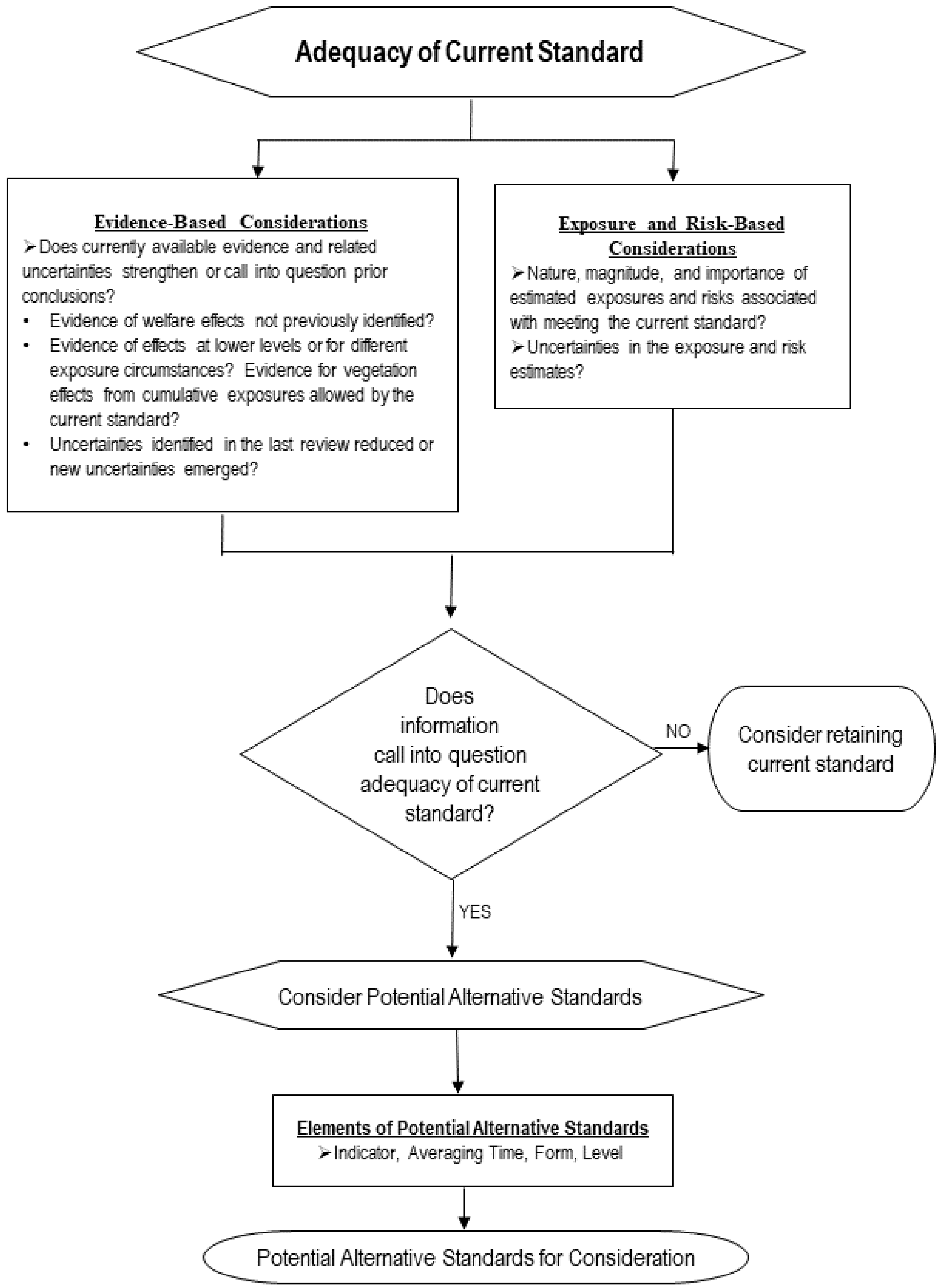


Figure 3-2. Overview of general approach for review of the secondary O_3 standard.

The Agency's approach in review 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. As discussed in section 1.1 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. The CAA does not require that standards be set at a zero-risk level, but rather at a level that reduces risk sufficiently so as to protect the public welfare from known or anticipated adverse effects. The Agency's decisions on the adequacy of the current secondary standard and, as appropriate, on any potential alternative standards considered in a review, are largely public welfare policy judgments made by the Administrator. The four basic elements of the NAAQS (i.e., indicator, averaging time, form, and level) will be considered collectively in evaluating the protection afforded by the current standard, or any alternative standards considered. The Administrator's final decisions in a review 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 analyses.

3.2.2 Background on the Current Secondary Standard (Considerations and Conclusions in the Last Review)

The 2015 decision to revise the secondary O_3 standard was based on the scientific and technical information available at that time, as well as the Administrator's judgments regarding the available welfare effects evidence, the appropriate degree of public welfare protection for the revised standard, and available air quality information on seasonal cumulative exposures that may be allowed by such a standard (80 FR 65292, October 26, 2015). With the 2015 decision, the Administrator revised the level of the secondary standard from 0.075 to 0.070 ppm, in conjunction with retaining the then-current indicator, averaging time (8 hours) and form (fourth-highest daily maximum 8-hour average concentration, averaged across three years).

The welfare effects evidence base available in the 2015 review includes more than fifty years of extensive research on O_3's phytotoxic effects, conducted both in and outside of the U.S. that documents the impacts of O_3 on plants and their associated ecosystems (U.S. EPA, 1978, 1986, 1996, 2006, 2013). As was established in prior reviews, O_3 can interfere with carbon gain (photosynthesis) and allocation of carbon within the plant, making fewer carbohydrates available for plant growth, reproduction, and/or yield. For seed-bearing plants, these reproductive effects will culminate in reduced seed production or yield (U.S. EPA, 1996, pp. 5-28 and 5-29). The strongest evidence for effects from O_3 exposure on vegetation is from controlled exposure studies, which “have clearly shown that exposure to O_3 is causally linked to visible foliar injury, decreased photosynthesis, changes in reproduction, and decreased growth” in many species of vegetation (2013 ISA, p. 1-15). Such effects at the plant scale can also be linked to an array of effects at larger spatial scales, with the evidence available in the last review indicating that “ambient O_3 exposures can affect ecosystem productivity, crop yield, water cycling, and ecosystem community composition” (2013 ISA, p. 1-15, Chapter 9, section 9.4).

In light of this robust evidence base, the 2013 ISA concluded there to be causal relationships between O_3 and visible foliar injury, reduced vegetation growth, reduced productivity in terrestrial ecosystems, reduced yield and quality of agricultural crops and alteration of below-ground biogeochemical cycles. The 2013 ISA additionally found there to likely be a causal relationship between O_3 and reduced carbon sequestration in terrestrial ecosystems, alteration of terrestrial ecosystem water cycling and alteration of terrestrial community composition (2013 ISA, Table 9-19). Further, based on the then-available evidence with regard to O_3 effects on climate, the 2013 ISA also found there to be a causal relationship between changes in tropospheric O_3 concentrations and radiative forcing, found there likely to be a causal relationship between tropospheric O_3 concentrations and effects on climate as quantified through surface temperature response, and found the evidence to be inadequate to determine if a causal relationship exists between tropospheric O_3 concentrations and health and welfare effects related to UV-B shielding (2013 ISA, section 10.5).

The 2015 decision was a public welfare policy judgment made by the Administrator, which drew upon the available scientific evidence for O_3-attributable welfare effects and on analyses of exposures and public welfare risks based on impacts to vegetation, ecosystems and their associated services, as well as judgments about the appropriate weight to place on the range of uncertainties inherent in the evidence and analyses. Such judgments in the context of that review included judgments on the weight to place on the evidence of specific vegetation-related effects estimated to result across a range of cumulative seasonal concentration-weighted O_3 exposures; on the weight to give associated uncertainties, including those related to the variability in occurrence of such effects in areas of the U.S., especially areas of particular public welfare significance; and on the extent to which such effects in such areas may be considered adverse to public welfare.

The decision was based on a thorough review, in the 2013 ISA, of the scientific information on O_3-induced environmental effects. The decision also took into account: (1) staff assessments in the 2014 PA of the most policy-relevant information in the 2013 ISA regarding evidence of adverse effects of O_3 to vegetation and ecosystems, information on biologically-relevant exposure metrics, 2014 welfare REA (WREA) analyses of air quality, exposure, and ecological risks and associated ecosystem services, and staff analyses of relationships between levels of a W126-based exposure index[62] and potential alternative standard levels in combination with the form and averaging time of the then-current standard; (2) additional air quality analyses of the W126 index and design values based on the form and averaging time of the then-current standard (3) CASAC advice and recommendations; and (4) public comments received during the development of these documents and on the proposal notice. In addition to reviewing the most recent scientific information as required by the CAA, the 2015 rulemaking also incorporated the EPA's response to the judicial remand of the 2008 secondary O_3 standard in *Mississippi v. EPA*, 744 F.3d 1334 (D.C. Cir. 2013) and, in accordance with the court's decision in that case, fully explained the Administrator's conclusions as to the level of air quality that provides the requisite protection of public welfare from known or anticipated adverse effects.

Consistent with the general approach routinely employed in NAAQS reviews, the initial consideration in the last review of the secondary standard was with regard to the adequacy of protection provided by the then-existing standard. Key aspects of that consideration are summarized in section 3.2.2.1 below. The subsequent selection of a standard concluded by the Administrator to provide the requisite protection under the Act is summarized in section 3.2.2.2.

3.2.2.1 Considering the Need for Revision

The approach to considering the adequacy of the secondary O_3 standard in the 2015 review involved the careful consideration of the available evidence, analyses and conclusions contained in the 2013 ISA, including information newly available in the review; the information, quantitative assessments, considerations and conclusions presented in the 2014 WREA and 2014 PA; additionally available air quality analyses; the advice and recommendations from the CASAC; and public comments. The Administrator gave primary consideration to the evidence of growth effects in well-studied tree species and information on cumulative seasonal O_3 exposures occurring in Class I areas[63] when the then-current standard was met (80 FR 65385-65386, October 26, 2015). The exposure information for Class I areas evaluated in terms of the W126 cumulative seasonal exposure index, an index recognized by the 2013 ISA as a mathematical approach "for summarizing ambient air quality information in [a] biologically meaningful form[] for O_3 vegetation effects assessment purposes'' (2013 ISA, section 9.5.3). The EPA focused on

[62] The W126 index is a cumulative seasonal metric described as the sigmoidally weighted sum of all hourly O_3 concentrations observed during a specified daily and seasonal time window, where each hourly O_3 concentration is given a weight that increases from zero to one with increasing concentration (80 FR 65373-74, October 26, 2015). Accordingly, W126 index values are in the units of ppm-hours (ppm-hrs).

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

the W126 index for this purpose consistent with the evidence in the 2013 ISA and advice from the CASAC (80 FR 65375, October 26, 2015).

In her decision making, the Administrator considered the effects of O_3 on tree seedling growth, as suggested by the CASAC, as a surrogate or proxy for the full array of vegetation-related effects of O_3, ranging from effects on sensitive species to broader ecosystem-level effects (80 FR 65369, 65406, October 26, 2015). The metric used for quantifying effects on tree seedling growth in the review was relative biomass loss (RBL), with the evidence base providing robust and established exposure-response (E-R) functions for seedlings of 11 tree species (80 FR 65391-92, October 26, 2015; 2014 PA, Appendix 5C).[64] The Administrator used this proxy in making her judgments on O_3 effects to the public welfare.

In considering the public welfare protection provided by the then-current standard, the Administrator gave primary consideration to an analysis of cumulative seasonal exposures in or near Class I areas during periods when the then-current standard was met and the associated estimates of growth effects, in terms of the O_3 attributable reductions in RBL in the median species for which exposure-response (E-R) functions have been established (80 FR 65389-65390, October 26, 2015). [65] The Administrator noted the occurrence of exposures for which the associated estimates of growth effects in the median species extend above a magnitude considered to be “unacceptably high” by CASAC.[66] This analysis estimated such cumulative exposures occurring under the then-current standard for nearly a dozen areas, distributed across two NOAA climatic regions of the U.S (80 FR 65385-86, October 26, 2015). The Administrator gave particular weight to this analysis because of its focus in Class I areas, lands that Congress set aside for specific uses intended to provide benefits to the public welfare, including lands that are to be protected so as to conserve the scenic value and the natural vegetation and wildlife within such areas, and to leave them unimpaired for the enjoyment of future generations. Such an emphasis on lands afforded special government protections, such as national parks and forests,

[64] These functions for RBL estimate the reduction in a year’s growth as a percentage of that expected in the absence of O_3 (2013 ISA, section 9.6.2; 2014 WREA, section 6.2).

[65] In specifically evaluating exposure levels in terms of the W126 index as to potential for impacts on vegetation, the Administrator focused on RBL estimates for the median across the eleven tree species for which robust E-R functions were available. The presentation of robust established E-R functions for growth effects on tree seedlings (and crops) included estimates of RBL (and RYL) at a range of W126-based exposure levels (2014 PA, Tables 5C-1 and 5C-2). The median tree species RBL or crop RYL was presented for each W126 level (2014 PA, Table 5C-3; 80 FR 65391 [Table 4], October 26, 2015). The Administrator focused on RBL as a surrogate or proxy for the broader array of vegetation-related effects of potential public welfare significance, which include effects on growth of individual sensitive species and extend to ecosystem-level effects, such as community composition in natural forests, particularly in protected public lands, as well as forest productivity (80 FR 65406, October 26, 2015).

[66] In the CASAC’s consideration of RBL estimates presented in the draft PA, it characterized an estimate of 6% RBL in the median studied species as “unacceptably high” (Frey, 2014c).

wildlife refuges, and wilderness areas, some of which are designated Class I areas under the CAA, was consistent with a similar emphasis in the 2008 review of the standard (73 FR 16485, March 27, 2008). The Administrator additionally recognized that states, tribes and public interest groups also set aside areas that are intended to provide similar benefits to the public welfare for residents on those lands, as well as for visitors to those areas (80 FR 65390, October 26, 2015).

As noted across reviews of O_3 secondary standards, the Administrator's judgments regarding effects that are adverse to public welfare consider the intended use of the ecological receptors, resources and ecosystems affected (80 FR 65389, October 26, 2015). Thus, in the 2015 review, the Administrator utilized the median RBL estimate for the studied species as a quantitative tool within a larger framework of considerations pertaining to the public welfare significance of O_3 effects. She recognized such considerations to include effects that are associated with effects on growth and that the 2013 ISA determined to be causally or likely causally related to O_3 in ambient air, yet for which there are greater uncertainties affecting our estimates of impacts on public welfare. These other effects included reduced productivity in terrestrial ecosystems, reduced carbon sequestration in terrestrial ecosystems, alteration of terrestrial community composition, alteration of below-grown biogeochemical cycles, and alteration of terrestrial ecosystem water cycles. Thus, in giving attention to the CASAC's characterization of a 6% estimate for tree seedling RBL in the median studied species as "unacceptably high", the Administrator, while mindful of uncertainties with regard to the magnitude of growth impact that might be expected in mature trees, was also mindful of related, broader, ecosystem-level effects for which the available tools for quantitative estimates are more uncertain and those for which the policy foundation for consideration of public welfare impacts is less well established. As a result, the Administrator considered tree growth effects of O_3, in terms of RBL as a surrogate for the broader array of O_3 effects at the plant and ecosystem levels (80 FR 65389, October 26, 2015).

Based on all of these considerations, and taking into consideration CASAC advice, the Administrator concluded that the protection afforded by the then-current standard was not sufficient and that the standard needed to be revised to provide additional protection from known and anticipated adverse effects to public welfare, related to effects on sensitive vegetation and ecosystems, most particularly those occurring in Class I areas, and also in other areas set aside by states, tribes and public interest groups to provide similar benefits to the public welfare for residents on those lands, as well as for visitors to those areas. In so doing, she further noted that a revised standard would provide increased protection for other growth-related effects, including for crop yield loss, reduced carbon storage and for areas for which it is more difficult to determine public welfare significance, as well as for other welfare effects of O_3, such as visible foliar injury (80 FR 65390, October 26, 2015).

3.2.2.2 Considering Revisions to the Standard

Consistent with the approach employed for considering the adequacy of the then-current secondary standard, the approach for considering revisions that would result in a standard providing the requisite protection under the Act also focused on growth-related effects of O_3, using RBL as a surrogate for the broad array of vegetation-related effects and included judgments on the magnitude of such effects that would contribute to public welfare impacts of concern. In considering the adequacy of potential alternative standards to provide protection from such effects, the approach also focused on considering the cumulative seasonal O_3 exposures likely to occur with different alternative standards.

In light of the judicial remand of the 2008 secondary O_3 standard referenced above, the 2015 decision on selection of a revised secondary standard first considered the available evidence and quantitative analyses in the context of an approach for considering and identifying public welfare objectives for such a standard (80 FR 65403-65408, October 26, 2015). The robust and longstanding evidence of O_3 effects on vegetation and associated terrestrial ecosystems, including evidence newly available in the 2015 review, provided the foundation for the Administrator's consideration of O_3 effects, associated public welfare protection objectives, and the revisions to the standard needed to achieve those objectives. In light of the extensive evidence base in this regard, the Administrator focused on protection against adverse public welfare effects of O_3 related effects on vegetation. In so doing, she took note of effects that compromise plant function and productivity, with associated effects on ecosystems. She had particular concern about such effects in natural ecosystems, such as those in areas with protection designated by Congress for current and future generations, as well as areas similarly set aside by states, tribes and public interest groups with the intention of providing similar benefits to the public welfare. The Administrator additionally recognized that providing protection for this purpose will 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).

As an initial matter, the Administrator considered the use of a cumulative seasonal exposure index for purposes of assessing potential public welfare risks, and similarly, for assessing potential protection achieved against such risks on a national scale. In consideration of conclusions of the 2013 ISA and 2014 PA, as well as advice from the CASAC and public comments, the focus was on a W126 index described as a maximum 3-month, 12-hour index, defined by the 3-consecutive-month period within the O_3 season with the maximum sum of W126-weighted hourly O_3 concentrations during the period from 8:00 a.m. to 8:00 p.m. each day (80 FR 65404, October 26, 2015). While recognizing that no one definition of an exposure metric used for the assessment of protection for multiple effects at a national scale will be exactly tailored to every species or each vegetation type, ecosystem and region of the country, the Administrator judged that on balance, a W126 index derived in this way, and averaged over three years would be appropriate for such purposes. Thus, in considering revisions to the secondary standard that would specify a level of air quality to provide the necessary public welfare protection, the Administrator focused on use of a cumulative seasonal concentration-weighted exposure index, including specifically the W126 index, for assessing exposure, both for making judgments with regard to the potential harm to public welfare posed by conditions allowed by various levels of air quality and for making the associated judgments regarding the appropriate degree of protection against such potential harm (80 FR 65403, October 26, 2015).

Based on a number of considerations, the Administrator recognized greater confidence in judgments related to public welfare impacts based on a 3-year average metric than a single year metric, and consequently concluded it to be appropriate to use an index averaged across three years for judging public welfare protection afforded by a revised secondary standard (80 FR 65404, October 26, 2015). For example, while recognizing that the scientific evidence documents the effects on vegetation resulting from individual growing season exposures of specific magnitude, including those that can affect the vegetation in subsequent years, the Administrator was also mindful of both the strengths and limitations of the evidence and of the information on which to base her judgments with regard to adversity of effects on the public welfare. In this regard, she recognized uncertainties associated with interpretation of the public welfare significance of effects resulting from a single-year exposure, and that the public welfare significance of effects associated with multiple years of critical exposures are potentially greater than those associated with a single year of such exposure. While recognizing the potential for effects on vegetation associated with a single-year exposure, the Administrator concluded that use of a 3-year average metric can address the potential for adverse effects to public welfare that may relate to shorter exposure periods, including a single year (80 FR 65404, October 26, 2015).[67]

In reaching a conclusion on the amount of public welfare protection from the presence of O_3 in ambient air that is appropriate to be afforded by a revised secondary standard, the Administrator gave particular consideration to the following: (1) the nature and degree of effects

[67] While the Administrator recognized the scientific information and interpretations, as well as CASAC advice, with regard to a single-year exposure index, she also took note of uncertainties associated with judging the degree of vegetation impacts for annual effects that would be adverse to public welfare. It was noted that even in the case of annual crops, the assessment of public welfare significance is unclear due to the role of crop management and related agricultural practices. The Administrator was also mindful of the variability in ambient air O_3 concentrations from year to year, as well as year-to-year variability in environmental factors, including rainfall and other meteorological factors, that influence the occurrence and magnitude of O_3-related effects in any year, and contribute uncertainties to interpretation of the potential for harm to public welfare over the longer term (80 FR 65404, October 26, 2015).

of O_3 on vegetation, including her judgments as to what constitutes an adverse effect to the public welfare; (2) the strengths and limitations of the available and relevant information; (3) comments from the public on the Administrator's proposed decision, including comments related to identification of a target level of protection; and (4) CASAC's views regarding the strength of the evidence and its adequacy to inform judgments on public welfare protection. The Administrator recognized that such judgments include judgments about the interpretation of the evidence and other information, such as the quantitative analyses of air quality monitoring, exposure and risk. She also recognized that such judgments should neither overstate nor understate the strengths and limitations of the evidence and information nor the appropriate inferences to be drawn as to risks to public welfare. It was also noted that the CAA does not require that a secondary standard be protective of all effects associated with a pollutant in the ambient air but rather those known or anticipated effects judged adverse to the public welfare. She additionally recognized 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 the uncertainties (80 FR 65404-05, October 26, 2015).

With regard to the extensive evidence of welfare effects of O_3, including the established evidence base regarding O_3 and visible foliar injury, in addition to the long-standing evidence base on O_3-attributable crop yield loss, the information available for forest tree species was judged to be more useful in informing judgments regarding the nature and severity of effects associated with different air quality conditions and associated public welfare significance. Accordingly, the Administrator gave particular attention to the effects related to native tree growth and productivity, recognizing their relationship to a range of ecosystem services, including forest and forest community composition (80 FR 65405-06, October 26, 2015).

In so doing, the Administrator recognized that the robust evidence base documented a broad array of O_3-induced vegetation effects, among which were the occurrence of visible foliar injury and growth and/or yield loss in O_3-sensitive annual and perennial species, including crops and other commercial species, such as timber, horticultural and landscaping plants, as well as native species in unmanaged natural areas (80 FR 65405, October 26, 2015). In regard to visible foliar injury, as stated in the 2013 ISA, "[e]xperimental evidence has clearly established a consistent association of visible injury with O_3 exposure, with greater exposure often resulting in greater and more prevalent injury" (2013 ISA, p. 9–41). The Administrator recognized the potential for this effect to affect the public welfare in the context of affecting values pertaining to natural forests, particularly those afforded special government protection, with the significance of O_3-induced visible foliar injury depending on the extent and severity of the injury (80 FR 65407, October 26, 2015). In so doing, however, the Administrator also took note of limitations in the available visible foliar injury information, including the lack of robust E-R functions that would allow prediction of visible foliar injury severity and incidence under varying air quality and environmental conditions, a lack of clear quantitative relationships linking visible foliar injury with other O_3-induced vegetation effects, such as growth or related ecosystem effects, and a lack of established criteria or objectives that might inform consideration of potential public welfare impacts related to this vegetation effect (80 FR 65407, October 26, 2015). Similarly, while O_3-related growth effects on agricultural and commodity crops had been extensively studied and robust E-R functions developed for a number of species, the Administrator found this information less useful in informing her judgments regarding an appropriate level of public welfare protection (80 FR 65405, October 26, 2015).[68]

Thus, and in light of the extensive evidence base in this regard, the Administrator focused on trees and associated ecosystems in identifying the appropriate level of protection for the secondary standard. Accordingly, the Administrator found the estimates of tree seedling growth impacts (in terms of RBL) associated with a range of W126-based index values developed from the robust E-R functions for 11 tree species to be appropriate and useful for considering the appropriate public welfare protection objective for a revised standard (80 FR 65391-92, Table 4, October 26, 2015). The Administrator also incorporated into her considerations the broader evidence base associated with forest tree seedling biomass loss, including other less quantifiable effects of potentially greater public welfare significance. That is, in drawing on these RBL estimates, the Administrator recognized she was not simply making judgments about a specific magnitude of growth effect in seedlings that would be acceptable or unacceptable in the natural environment. Rather, though mindful of associated uncertainties, the Administrator used the RBL estimates as a surrogate or proxy for consideration of the broader array of related vegetation and ecosystem effects of potential public welfare significance that include effects on growth of individual sensitive species and extend to ecosystem-level effects, such as community composition in natural forests, particularly in protected public lands, as well as forest productivity (80 FR 65406, October 26, 2015).

Thus, the Administrator used the RBL estimates as a proxy for the array of vegetation-related effects, including those for which public welfare implications are more significant but for which the tools for quantitative estimates were more uncertain. In so doing, the Administrator

[68] With respect to commercial production of commodities, the Administrator noted that judgments about the extent to which O_3-related effects on commercially managed vegetation are adverse from a public welfare perspective are particularly difficult to reach, given that the extensive management of such vegetation (which, as the CASAC noted, may reduce yield variability) may also to some degree mitigate potential O_3-related effects. The management practices used on these lands are highly variable and are designed to achieve optimal yields, taking into consideration various environmental conditions. In addition, changes in yield of commercial crops and commercial commodities, such as timber, may affect producers and consumers differently, further complicating the question of assessing overall public welfare impacts (80 FR 65405, October 26, 2015).

recognized that the CASAC gave weight to these relationships in formulating its advice and she took particular note of the characterization by the CASAC of the 6% RBL level in the median studied species as "unacceptably high," as this comment was provided in the context of the CASAC's consideration of the significance of effects associated with a range of alternatives for the secondary standard (Frey, 2014c, pp. iii, 13, 14; 80 FR 65406, October 26, 2015). Moreover, the range recommended by the CASAC excluded W126 index values for which the median species was estimated to have a 6% RBL in the draft PA (which was the context for the CASAC advice) (Frey, 2014c, p. 12-13; 80 FR 65406, October 26, 2015). In consideration of CASAC advice; strengths, limitations and uncertainties in the evidence; and the linkages of growth effects to larger population, community and ecosystem impacts, the Administrator considered it appropriate to focus on a standard that would generally limit cumulative exposures to those for which the median RBL estimate would be somewhat below 6% (80 FR 65406-07, October 26, 2015).

In focusing on cumulative exposures associated with a median RBL estimate somewhat below 6%, the Administrator considered the relationships between W126-based exposure and RBL in the studied species (presented in the final PA and proposal notice), noting that the median RBL estimate was 6% for a cumulative seasonal W126 exposure index of 19 part per million-hours (ppm-hrs) (80 FR 65391-92, Table 4, October 26, 2015).[69] Given the information on median RBL at different W126 exposure levels, using a 3-year cumulative exposure index for assessing vegetation effects, the potential for single-season effects of concern, and CASAC comments on the appropriateness of a lower value for a 3-year average W126 index, the Administrator concluded it was appropriate to identify a standard that would restrict cumulative seasonal exposures to 17 ppm-hrs or lower, in terms of a 3-year W126 index, in nearly all instances (80 FR 65407, October 26, 2015). Based on such then-current information to inform consideration of vegetation effects and their potential adversity to public welfare, the Administrator additionally judged that the RBL estimates associated with marginally higher exposures in isolated, rare instances are not indicative of effects that would be adverse to the public welfare, particularly in light of variability in the array of environmental factors that can influence O_3 effects in different systems and uncertainties associated with estimates of effects associated with this magnitude of cumulative exposure in the natural environment (80 FR 65407, October 26, 2015).

The Administrator's decisions regarding the revisions to the then-current standard that would appropriately achieve these public welfare protection objectives were based on extensive

[69] The median RBL estimate was 5.7% (which rounds to 6%) for a cumulative seasonal W126 exposure index of 18 ppm-hrs and the median RBL estimate was 5.3% (which rounds to 5%) for 17 ppm-hrs (80 FR 65407, October 26, 2015).

air quality analyses that extended from the then most recently available data (monitoring year 2013) back more than a decade (80 FR 65408, October 26, 2015; Wells, 2015). These analyses evaluated the cumulative seasonal exposure levels in locations meeting different alternative levels for a standard of the then-current form and averaging time, indicating reductions in cumulative exposures associated with air quality meeting lower levels of a standard of the existing form and averaging time. Based on these analyses, the Administrator judged that the desired level of public welfare protection could be achieved with a secondary standard having a revised level in combination with the existing form and averaging time (80 FR 65408, October 26, 2015).

The air quality analyses described the occurrences of 3-year W126 index values of various magnitudes at monitor locations where O_3 concentrations met potential alternative standards defined by different levels combined with the current form and averaging time (Wells, 2015). In the then-most recent period, 2011-2013, across the monitor locations meeting the then-current standard (with a level of 75 ppb), the 3-year W126 index values were above 17 ppm-hrs in 25 sites distributed across different NOAA climatic regions, and above 19 ppm-hr at nearly half of these sites, with some well above. In comparison, among sites meeting an alternative standard of 70 ppb, there were no occurrences of a W126 value above 17 ppm-hrs and fewer than a handful of occurrences that equaled 17 ppm-hrs.[70] For the longer time period (extending back to 2001), among the nearly 4000 locations meeting a standard level of 70 ppb, there was only a handful of isolated occurrences of 3-year W126 index values above 17 ppm-hrs, all but one of which were below 19 ppm-hrs.[71] The Administrator concluded that that single higher value of 19.1 ppm-hrs, observed at a monitor for the 3-year period of 2006-2008, was reasonably regarded as an extremely rare and isolated occurrence, and, as such, it was unclear whether it would recur, particularly as areas across U.S. took further steps to reduce O_3 to meet revised primary and secondary standards. Further, based on all of the then available information, as noted above, the Administrator did not judge RBL estimates associated with marginally higher exposures in isolated, rare instances to be indicative of adverse effects to the public welfare. The Administrator concluded that a standard with a level of 70 ppb and the current form and averaging time may be expected to limit cumulative exposures, in terms of a 3-year average W126 exposure index, to values at or below 17 ppm-hrs, in nearly all instances, and accordingly,

[70] The more than 500 monitors that would meet an alternative standard of 70 ppb during the 2011-2013 period were distributed across all nine NOAA climatic regions and 46 of the 50 states (Wells, 2015 and associated dataset in the docket [document identifier, EPA-HQ-OAR-2008-0699-4325]).

[71] Among sites meeting a level of 65 ppb, there were no occurrences above 11 ppm-hrs, well below the objectives identified for affording public welfare protection. For this level, the appreciably smaller and less geographically extensive database contributes uncertainty to conclusions based on such analysis (80 FR 65409, October 26, 2015).

to eliminate or virtually eliminate cumulative exposures associated with a median RBL of 6% or greater (80 FR 65409, October 26, 2015). Thus, using RBL as a proxy in judging effects to public welfare, the Administrator judged that a standard with a level of 70 ppb would provide the requisite protection from adverse effects to public welfare by limiting cumulative seasonal exposures to 17 ppm-hrs or lower (in terms of a 3-year W126 index) in nearly all instances.

In summary, the Administrator judged that the revised standard would protect natural forests in Class I and other similarly protected areas against an array of adverse vegetation effects, most notably including those related to effects on growth and productivity in sensitive tree species. The Administrator additionally judged that a revised standard set at a level of 70 ppb, in combination with the then-existing form and averaging time, would be sufficient to protect public welfare from known or anticipated adverse effects. This judgment by the Administrator appropriately recognized that the CAA does not require that standards be set at a zero-risk level, but rather at a level that reduces risk sufficiently so as to protect the public welfare from known or anticipated adverse effects. Thus, based on the conclusions drawn from the air quality analyses which demonstrated a strong, positive relationship between the 8-hour and W126 metrics and the findings that indicated the significant amount of control provided by the fourth-high metric, the evidence base of O_3 effects on vegetation and her public welfare policy judgments, as well as public comments and CASAC advice, the Administrator decided to retain the existing form and averaging time and revise the level to 0.070 ppm, judging that such a standard would provide the requisite protection to the public welfare from any known or anticipated adverse effects associated with the presence of O_3 in ambient air (80 FR 65409-10, October 26, 2015).

4 SCIENCE ASSESSMENT

Integrated Science Assessments serve as the scientific foundation of the NAAQS review process and are developed by the EPA's NCEA. This assessment focuses on reviewing and updating the air quality criteria associated with primary (health-based) and secondary (welfare-based[72]) effects evidence to inform science policy judgments about the primary and secondary standards for O_3 and other photochemical oxidants. This chapter provides an overview of the ISA development process and discusses key aspects of the EPA's planned approach for the ISA in this review.

4.1 PURPOSE OF THE ISA

The purpose of the ISA is to draw upon the existing body of evidence to synthesize and provide a critical evaluation of the current state of scientific knowledge on the most relevant issues pertinent to the review of the NAAQS for O_3 and other photochemical oxidants, to identify changes in the scientific evidence bases since the previous review, and to describe remaining or newly identified uncertainties. The ISA will identify, critically evaluate and synthesize the most policy-relevant current scientific literature (e.g., epidemiology, controlled human exposure, animal toxicology, atmospheric science, exposure science, ecology and climate-related science), including key science judgments that are important to inform the development of risk and exposure analyses (as warranted) and the PA, as well as other aspects of the NAAQS review process (summarized in section 1.2 above). The ISA will provide a focused assessment of the scientific evidence to address specific scientific questions (section 4.4) and inform the overall policy-relevant questions for the PA (as described in Chapter 3).

4.2 ORGANIZATION OF THE ISA

The general organization of the ISA for the current review will be consistent with the 2nd External Review Draft ISA for Oxides of Nitrogen, Oxides of Sulfur, and Particulate Matter-Ecological Criteria (U.S. EPA, 2018d). Accordingly, the ISA will begin with a Preface discussing major legal and historical aspects of prior O_3 NAAQS reviews. An executive summary targeted to a wide range of audiences will succinctly summarize the conclusions of the ISA. An integrated synthesis will serve as the main body of the ISA and provide a detailed summary of the key information for each topic area, including background concentrations of O_3

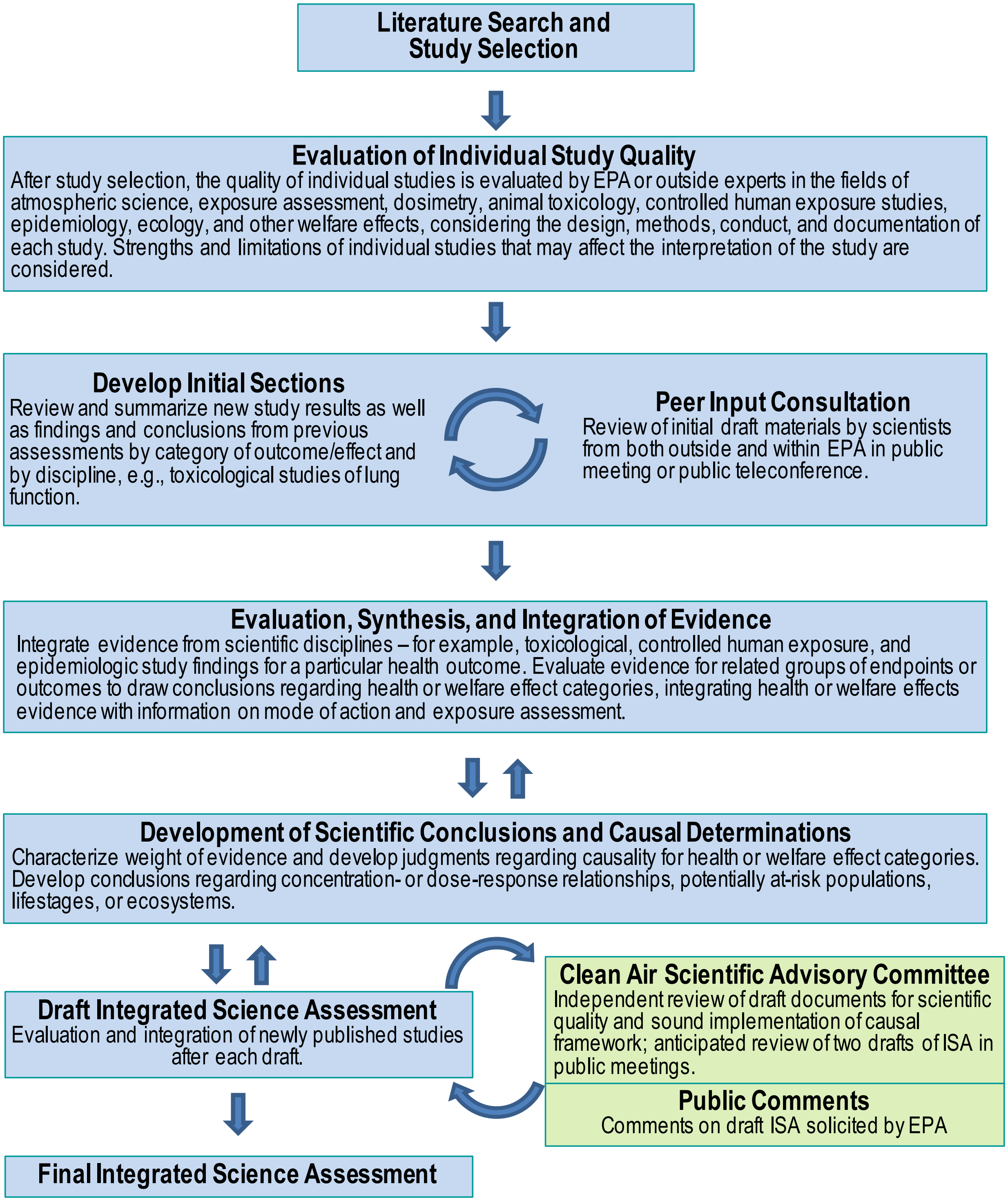
[72] Under Clean Air Act, section 302(h) (42 U.S.C. § 7602(h)), effects on welfare include, but are not limited to, "effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

in the U.S., conclusions regarding the nature of health and welfare effects associated with O_3 exposure (including causality determinations for relationships between exposure to O_3 and specific types of health and welfare effects), and identification of the human lifestages and populations at increased risk of the effects of O_3. The integrated synthesis will discuss additional policy-relevant issues, such as the exposure durations, metrics, and concentrations eliciting health and welfare effects; the concentration-response relationships for specific effects, including the overall shape and whether or not there is evidence of a discernible threshold below which effects are not likely to occur; and the public health and welfare impact of effects associated with exposure to O_3. The synthesis will also discuss important issues for different types of studies, such as the air quality metrics and the lag structure of epidemiologic associations with health effects. Subsequent appendices will be organized by subject area, with the detailed assessment of atmospheric science, exposure, health, and welfare evidence presented in separate appendices. Thus, the focused integrated synthesis will make the ISA more concise than in the past, improve its clarity and also its emphasis on policy-relevant scientific information and analyses; the ISA scope, as addressed in section 4.3.2 is also more focused than in past ISAs (e.g., as discussed in Pruitt [2018]). Each of the appendices will contain an evaluation of results from recent studies integrated with previous findings (see section 4.4 for specific issues to be addressed). Appendices for each broad health effect category (e.g., respiratory effects) will conclude with a causal determination describing the strength of the evidence between exposure to O_3 and the health effect(s) [more detail on the types of causal determinations applied in the ISA is given in the Preamble to the ISAs (U.S. EPA, 2015c) and in section 4.3.6 and Figure 4-1 of this chapter]. Likewise, the appendices devoted to ecological and climate evidence for welfare effects will conclude with causality determinations for multiple effects on ecosystems and climate, respectively.

4.3 ASSESSMENT APPROACH

4.3.1 Introduction

In developing ISAs, the EPA employs systematic review methodologies to identify and evaluate relevant scientific information and produces summary text and figures to communicate the state of the science to varied audiences. The process begins with a “Call for Information” published in the *Federal Register* that announces the start of a NAAQS review and invites the public to assist in this process through the submission of research studies in identified subject areas. For the current O_3 NAAQS review, this notice was published on June 26, 2018 (83 FR 29785). The subsequent ISA development steps are generally presented in Figure 4-1 and are described in greater detail in the Preamble to the Integrated Science Assessments (U.S. EPA, 2015c), which provides a general overview of the ISA development process. The plan for developing the ISA for the current review is described in detail in the following sections. The process for review of the draft ISA is described in Section 4.5.



Source: Modified from Figure II of the Preamble to the Integrated Science Assessments (U.S. EPA, 2015c).

Figure 4-1. General process for development of Integrated Science Assessments.

The ISA is developed by authors who are EPA scientists in NCEA with extensive knowledge in their respective fields and extramural scientists who are solicited by the EPA for their subject matter expertise. The ISA authors apply systematic review methodologies to identify relevant scientific findings that have emerged since the previous assessment. The process is further described in sections below, including clear definition of the scope (Section 4.3.2), literature search and identification of relevant studies (Section 4.3.3), evaluation of individual study quality (Section 4.3.5), evaluation of relevant studies (Section 4.3.6) and evidence integration and determination of causality (Section 4.3.7).

4.3.2 Scope of the ISA

Through periodic reviews of the available scientific evidence, ISAs build on the data and conclusions of previous assessments. The previous O_3 ISA was published in 2013 (U.S. EPA, 2013) and included peer-reviewed literature published through July 2011. The ISA for the current review will identify and evaluate studies published since 2011, synthesizing and integrating the new evidence in the context of the conclusions from the previous review. Key findings, conclusions, and uncertainties from the 2013 ISA will be briefly summarized at the beginning of individual sections. Important older studies may be discussed to reinforce key concepts and conclusions. Older studies also may be the primary focus in some subject areas or scientific disciplines where research efforts have subsided, and these older studies remain the definitive works available in the literature.

Scientific information will be identified and evaluated in order to provide a better understanding of the following issues: (1) the natural and anthropogenic sources of O_3 precursors in the ambient air; (2) formation, transport, and fate of O_3 in the environment; (3) measurement methods and ambient air concentrations of O_3; (4) how exposure assessment methods used in epidemiologic studies can influence inferences drawn about O_3 health effects; (5) the independent effect of O_3 exposure on health and welfare; (6) the potential influence of other factors (e.g., other pollutants in the ambient air, ambient air temperature) shown to be correlated with O_3 and health or welfare effects; (7) the shape of the concentration-response relationship at O_3 concentrations at the low end of the distribution; and (8) populations and lifestages at increased risk of O_3-related health effects. As was the case for previous reviews, the ISA for this review will focus mainly on the assessment of health and welfare effects resulting from exposure to surface-level concentrations of tropospheric O_3 whereas less emphasis will be accorded to other photochemical oxidants because the available information is much more limited compared to that for O_3. Ozone is currently the indicator for the current NAAQS for photochemical oxidants, and the primary literature evaluating the health and ecological effects of photochemical oxidants includes O_3 almost exclusively as an indicator of photochemical oxidants[73].

In the 2013 ISA, evidence from across scientific disciplines for related health and welfare effects was evaluated, synthesized, and integrated to develop conclusions and causality determinations. As described in the Preamble to the ISAs (U.S. EPA, 2015c) and in section 4.3.6 and Figure 4-1 of this chapter, the EPA uses a structured framework to provide a consistent and transparent basis for classifying the weight of available evidence for health and welfare effects according to a five-level hierarchy: (1) causal relationship; (2) likely to be a causal relationship; (3) suggestive of, but not sufficient to infer, a causal relationship; (4) inadequate to infer the presence or absence of a causal relationship; and (5) not likely to be a causal relationship. This framework will be applied in the ISA for the current review.

In this review, the EPA will fully evaluate the available evidence for those health and welfare effects for which the evidence in the 2013 ISA was *less certain* (i.e., effects where the causality determination was "likely to be causal", "suggestive", or "inadequate" as described in section 4.4.1) and where there is now a larger body of evidence. In doing so, the EPA aims to evaluate the available evidence in order to address uncertainties and limitations in the evidence identified in the prior review.

For those health and welfare effects for which the 2013 ISA concluded that the evidence was *sufficient to infer a causal relationship* (i.e., for the health evidence: short-term O_3 exposures [i.e., days to weeks] and respiratory effects; and for the welfare evidence: O_3 exposures and ecological effects and effects on climate), the ISA for the current review will integrate and synthesize the new evidence, placing emphasis on policy-relevant considerations, such as the exposure conditions at which effects are observed, and characterizing the extent to which new studies address key uncertainties and limitations identified in the previous review or provide insight on new issues.

The scope of the health and welfare portions of the ISA is explicitly defined by scoping tools that generally define the relevant Population, Exposure, Comparison, Outcome, and Study Design (PECOS) (The PECOS tools for each category of information are provided in Section 4.3.3). The PECOS tool characterizes the parameters and provides a framework to aid in identifying the relevant evidence in the literature to inform the ISA. There are discipline-specific PECOS tools for experimental studies, epidemiologic studies, ecological studies and for studies

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[73]Ozone is the only photochemical oxidant other than nitrogen dioxide (NO_2) that is routinely monitored in ambient air (i.e., EPA's AQS database; https://www.epa.gov/aqs). Data for other photochemical oxidants (e.g., PAN, H_2O_2, etc.) typically have been obtained only as part of special field studies. Consequently, no data on nationwide patterns of ambient air concentrations are available for these other photochemical oxidants; nor are extensive data available on the relationships of concentrations and patterns of these photochemical oxidants to those of O_3.

on the effects of tropospheric O_3 on climate, which differ depending on the types of questions to be answered and are influenced by *a priori* knowledge related to that question. The use of PECOS tools is a widely accepted and rapidly growing approach to systematic review in risk assessment, and consistent with recommendations by the National Academy of Sciences for improving the design of risk assessment through planning, scoping, and problem formulation to better meet the needs of decision-makers (National Research Council 2009). The PECOS tools serve as guides for several aspects of the ISA process, including the literature search strategy, criteria for the inclusion or exclusion of studies in the ISA, the types of data extracted from studies, and the integration and synthesis of the results.

4.3.3 Literature Search and Identification of Relevant Studies

4.3.3.1 Systematic Literature Search

The EPA uses a structured approach to identify relevant studies for consideration and inclusion in the ISAs. The search for relevant literature in this review began with publication of the *Federal Register* notice announcing the initiation of this O_3 review and requesting information from the public including relevant literature (83 FR 29785, June 26, 2018). In addition, the EPA identifies publications by conducting a multi-tiered systematic literature search that includes extensive mining of literature databases on specific topics in a variety of disciplines. The search strategies are designed *a priori* to optimize identification of pertinent published papers. Studies identified in the literature search are documented in the Health and Environmental Research Online (HERO) database. The HERO project page for this ISA (https://hero.epa.gov/hero/index.cfm/project/page/project_id/2737) will contain the references that will be considered for inclusion in the ISA and electronic links to bibliographic information and abstracts. It is accessible to the public.

For this ISA, discipline-specific approaches will be used to identify literature. In each case, careful consideration will be given to literature search strategies used in the development of previous assessments and the methods that resulted in the best precision and recall for each of the disciplines, including atmospheric science (section 4.3.4.1), exposure assessment (section 4.3.4.2), experimental health studies (section 4.3.4.3), epidemiology (section 4.3.4.4), ecology (section 4.3.4.5), and climate (section 4.3.4.6). The literature identification approaches include broad keyword searches in routinely used databases with Automatic Topic Classification, and citation mapping (see section 4.3.4 for specific approaches used for each discipline).

As has been done for past ISAs, a broad keyword search was developed as a starting point to capture literature pertinent to the pollutant of interest. In this case, the main keyword string to be used is "ozone OR O3", which is sufficiently broad to capture O_3-relevant literature in each database (i.e., PubMed, Web of Science, TOXLINE). Following the broad keyword search for O_3, automatic topic classification will be used to categorize references by discipline (e.g., epidemiology, toxicology, etc.). This step employs machine learning where positive and negative seed references[74] for a particular discipline are used to train an algorithm to identify discipline-specific references based on word use and frequency in titles and abstracts. This method varies in effectiveness across disciplines due to the broad range of topics and variability in term usage in some evidence bases. However, it is invaluable when effective, and has been used in several prior ISAs.

Another approach used in past ISAs that will be employed in this review is citation mapping, or relational reference searching. In this approach, a set of relevant published references are identified as a seed set and then more recent literature that has cited any of the references in the seed set are collected. References from the previous ISA for the respective pollutant comprise the seed set for the new ISA. Because the seed set is highly relevant to the topic of interest, this targeted approach to reference identification is more precise than keyword searches, and it further allows for relevance ranking based on the number of references in a bibliography that match references in the seed set.

References may be identified for inclusion in several additional ways including: identification of relevant literature by EPA expert scientists; recommendations received in response to the call for information and the external review process for the ISA; and review of citations included in previous assessments.

All of these search methods will be used to identify recent research published or accepted for publication starting January 1, 2011, providing some overlap with the July 2011 cutoff date from the last review. Although published after the literature cutoff date (March 30, 2018 for this review), studies published after this date that were identified by comments submitted in response to the Call for Information will be considered. Further, studies may also be considered in subsequent phases of the NAAQS review (e.g., studies identified by CASAC members during review of the draft ISA), particularly to the extent that they provide new information that affects key scientific conclusions.

4.3.3.2 Initial Screening (Level 1) of Studies from Literature Search

Once studies are identified, ISA authors (EPA staff and extramural scientists) will review the studies for relevance. For the primary O_3 NAAQS, relevant studies include epidemiologic, toxicological, and controlled human exposure studies, including studies of dosimetry and mode

[74] Positive seed references are those that are examples of references that are relevant, i.e., the references would be selected for full-text screening. Negative seed references are those that are examples of references that are not relevant, i.e., they would not be selected for full-text screening. For ISAs, the positive seed set includes references from the prior ISA for the discipline of interest. The negative seed set includes the references from all of the other disciplines in the prior ISA.

of action, or those that examine ambient air O_3 exposure assessment, atmospheric chemistry, sources and emissions. For the review of the secondary O_3 NAAQS, relevant studies are those that examine ecological effects and the effects of O_3 on climate. Specific information detailing the scope of the ISA for the current review, and subsequently those studies that will be evaluated within it, are detailed above in section 4.3.2.

As described above, the literature search methods will be targeted for discipline-relevant references to the extent possible, and the subsequent screening will result in a further refined list of references to be included in the ISA. References for each discipline will first undergo title and abstract screening using SWIFT-ActiveScreener (SWIFT-AS), which is referred to as Level 1 screening. Level 1 screening criteria for inclusion will be broad and err on the side of inclusion. For each discipline, title and abstracts will be selected for inclusion if there is indication of O_3 and a quantifiable effect relevant to that discipline. SWIFT-AS is a software application that employs machine learning in real-time to identify relevant literature. The machine learning feature builds a model to predict relevant references based on inclusion/exclusion screening decisions in real-time as scientists screen each reference. As title/abstract screening is conducted, references are queued based on the predicted relevance and SWIFT-AS further predicts when a 95% recall threshold has been reached[75], a level often used to evaluate the performance of machine learning applications and considered comparable to human error rates (Cohen et al. 2006, Howard et al. 2016).

The application of SWIFT-AS will be tailored for each discipline. This will include using a specific seed set of 50-100 relevant references from the 2013 ISA to train the SWIFT-AS algorithm and developing specific screening questions for each discipline to allow for the categorization of references based on the information available in the title and abstract. Understanding the volume and topics of the recent literature on O_3 will be important information to consider in refining the scope of the ISA. Specific details about inclusion/exclusion criteria and the screening questions for each discipline are described in more detail below.

Following Level 1 screening, references identified for inclusion will be acquired and compiled in HERO for full-text Level 2 screening conducted by NCEA subject matter experts. The Level 2 screening decisions for each discipline will be based on the scoping decisions (see section 4.3.4). References will be tracked for both relevance to the broad ISA and for the defined scope for each topic area (e.g., outcome category).

[75] A 95% recall threshold represents the point at which 95% of the potentially relevant references have been identified.

4.3.3.3 Criteria of In-Scope Studies

To be included in the ISA, relevant studies and reports must have undergone scientific peer review and have been published or accepted for publication before the cutoff date. Some publications retrieved from the literature search will be excluded as not being relevant in Level 1 screening based on the title/abstract (e.g., not about air pollution, conference abstract, review articles, commentaries). For other publications, decisions about relevance will be made in Level 2 screening as they require reading beyond the title. These publications will be labeled as "considered" for inclusion in the ISA. Inclusion and exclusion decisions will be documented in the HERO database (https://hero.epa.gov/hero/index.cfm/project/page/project_id/2737).

4.3.4 Discipline-Specific Scoping, Searching and Screening

4.3.4.1 Atmospheric Science

4.3.4.1.1 Scope

The ISA will present and evaluate relevant data and summarize the current scientific understanding, based on evidence available from previous reviews and new evidence that has emerged since the 2013 ISA concerning the sources and concentrations of O_3 in the lower troposphere and surface boundary layer. Ozone present in the lower troposphere is predominantly formed through photochemical reaction between oxides of nitrogen (NO_x) and volatile organic precursor gases. This ISA discussion will focus on: O_3 that would be present in the lower atmosphere in the absence of any manmade emissions in the U.S. (i.e., O_3 that has been transported across international boundaries, produced by natural processes such as lightning or drawn down from the stratosphere, or forms from natural or internationally transported precursors), referred to as "U.S. background" O_3; and ambient air O_3 sources, measurements, and concentration trends.

4.3.4.1.2 Search and Screen

Literature related to atmospheric science topics will be identified by citation mapping methods that will rely upon references cited in the 2013 ISA. More specifically, references will be collected from the atmospheric science sections of the 2013 ISA, including sub-topics on physical and chemical processes, atmospheric modeling, monitoring, and background O_3 concentrations. Citation mapping will be conducted in Web of Science. The focus for evaluation of the recent literature will be on background concentration of O_3 in ambient air.

4.3.4.2 Exposure Assessment

4.3.4.2.1 Scope

The ISA will describe the commonly employed exposure assessment methods in the epidemiologic evidence, including strengths and limitations of the methods, study designs in which those methods are used, and how errors and uncertainties inherent in those methods influence the bias and precision of health effect estimates for short-term and long-term O_3 exposure studies. The exposure assessment appendix includes a summary table that describes each method, how it is used in epidemiologic studies, and how strengths and limitations of each method may impact interpretation of the epidemiologic results.

4.3.4.2.2 Search and Screen

Exposure literature relevant to O_3 will be identified using the broad keyword search described in Section 4.3.2 and Automatic Topic Classification. Automatic Topic Classification for exposure references will include a sufficiently large set of positive and negative seeds from previous ISAs. More specifically, positive seeds will include references from the exposure chapter from the 2016 NO_x ISA[76] and the 2013 ISA; the negative seeds will include non-relevant references (i.e., those from other disciplines in these two ISAs). Following identification and binning of the literature, SWIFT-AS will be used for Level 1 screening. Positive seeds to train the SWIFT-AS algorithm will include a subset of the exposure references cited in the 2013 ISA. Additionally, references will be categorized in Level 1 screening in SWIFT-AS by study type, study location, and exposure duration. The references identified for inclusion in Level 1 will then undergo Level 2 full-text screening.

4.3.4.3 Health – Experimental Studies

4.3.4.3.1 Scope

For experimental studies, specifically controlled human or animal exposure studies, the evaluation will focus on those studies that also address key uncertainties and limitations in the evidence identified in the previous review. For example, does the new evidence advance understanding of or call into question prior conclusions regarding the biological mechanisms by which O_3 elicits a health effect or provide coherence for the effects assessed in epidemiologic studies? The scope of the experimental evidence encompasses studies of short-term (i.e., hours to weeks) and long-term (i.e., months to years) exposures conducted at concentrations of O_3 that are relevant to the range of human exposures to ambient air (up to 2 ppm, which is one to two orders of magnitude above ambient air concentrations) (Table 4-1).

[76] The 2016 NO_X ISA is the most recent ISA that had the appropriate level of detail comparative to what is needed for this current review.

Table 4-1. PECOS tool to define the parameters and provide a framework for identifying relevant experimental studies.

Exposure Duration and Health Effect	Population, Exposure, Comparison, Outcome, Study Design (PECOS)
Short-term exposure and respiratory, cardiovascular, metabolic, nervous system, reproductive or developmental effects	**Population:** study populations of any controlled human exposure or animal toxicological study of mammals at any lifestage **Exposure:** short-term (in the order of minutes to weeks) inhalation exposure to relevant O_3 concentrations (i.e., 0.4 ppm or below for humans, 2 ppm or below for other mammals) **Comparison:** human subjects that serve as their own controls with an appropriate washout period or when comparison to a reference population exposed to lower levels is available, or, in toxicological studies of mammals, an appropriate comparison group that is exposed to a negative control (i.e., clean air or filtered air control) **Outcome:** respiratory, cardiovascular, metabolic, nervous system, reproductive or developmental effects **Study Design:** controlled human exposure (i.e., chamber) studies; In vivo acute, subacute or repeated-dose toxicity studies in mammals, reproductive toxicity or immunotoxicity studies
Long-term exposure and respiratory, cardiovascular, metabolic, nervous system, carcinogenic, reproductive or developmental effects	**Population:** study population of any animal toxicological study of mammals at any lifestage **Exposure:** long-term (in the order of months to years) inhalation exposure to relevant O_3 concentrations (i.e., 2 ppm or below) **Comparison:** appropriate comparison group exposed to a negative control (i.e., clean air or filtered air control) **Outcome:** respiratory, cardiovascular, metabolic or nervous system, carcinogenic, reproductive or developmental effects **Study Design:** In vivo chronic, subchronic or repeated-dose toxicity studies in mammals; reproductive toxicity or immunotoxicity studies; genotoxicity/mutagenicity studies
Population: in controlled human exposure studies, generally healthy adults approved for study participation by the appropriate institutional review board or ethics committee; for toxicological studies, well-defined/well-characterized strains of mammals at any lifestage. **Exposure:** O_3 concentrations deliberately delivered to subjects for a predefined duration **Comparator:** in controlled human exposure studies, subjects serve as their own controls with an appropriate washout period, or a reference population exposed to lower O_3 concentrations, or, in toxicological studies, an appropriate comparison group that is exposed to a negative control (i.e., clean air or filtered air control) **Outcome:** clearly measurable health endpoint. **Study design:** controlled human exposure (i.e., chamber) studies; In vivo acute, subacute, subchronic, chronic or repeated-dose toxicity studies in mammals; reproductive toxicity or immunotoxicity studies; genotoxicity/mutagenicity studies	

4.3.4.3.2 Search and Screen

Identification of experimental (i.e., controlled human exposure and animal toxicology) studies examining the health effects of O_3 exposure will be identified using the broad keyword search described in Section 4.3.2 and Automatic Topic Classification. The Automatic Topic Classification for experimental references will include a sufficiently large set of positive seeds, including controlled human exposure and animal toxicology references cited in the 2016 NO_X ISA and the 2013 ISA, and a sufficiently large set of negative seeds, including nonexperimental references cited in these two ISAs. Following identification of the literature, SWIFT-AS will be used for Level 1 screening. The SWIFT-AS algorithm will be trained using a set of positive seed references from a selection of controlled human exposure and animal toxicology studies cited in the 2013 ISA. Additionally, references will be categorized in Level 1 screening in SWIFT-AS by health outcome category (e.g., respiratory, cardiovascular, metabolic, etc.), exposure duration (e.g., short-term, long-term), and study type (e.g., controlled human exposure, animal toxicology, etc.). The references identified for inclusion at Level 1 will then undergo Level 2 full-text screening, for each health outcome category, for relevance to the defined scope as described above.

4.3.4.4 Health – Observational (Epidemiologic) Studies

4.3.4.4.1 Scope

The evaluation of epidemiologic studies will focus on the associations between short- and long-term exposure to O_3 and a range of health effects, including respiratory, cardiovascular, reproductive and developmental, metabolic, and nervous system outcomes (Table 4-2). In instances when a “causal” or “likely to be a causal” relationship was concluded in the 2013 Ozone ISA (e.g., short-term O_3 exposure and respiratory and cardiovascular effects and total mortality, and long-term O_3 exposure and respiratory effects), the epidemiologic studies evaluated for those outcomes are more limited in scope (i.e., targeted towards study locations that include U.S. airsheds or airsheds that are similar to those found in the U.S.), as reflected in the PECOS tool. For outcomes for which the 2013 Ozone ISA concluded that evidence was “suggestive of” or “inadequate to infer” a causal relationship, the epidemiologic studies evaluated are not limited geographically or by airshed characteristics, as reflected in the PECOS tool. The discussion of epidemiologic results will emphasize the impact of exposure assessment techniques on associations observed; evaluating potential copollutant confounding; examining heterogeneity in O_3 associations; and the shape of the concentration-response relationship.

Table 4-2. PECOS tool to define the parameters and provide a framework for identifying relevant epidemiologic studies.

Exposure Duration and Health Effect	Population, Exposure, Comparison, Outcome, Study Design (PECOS)
Short-term exposure and respiratory effects	**Population:** any U.S. or Canadian population, including populations or lifestages that might be at increased risk **Exposure:** short-term (on the order of one to several days) ambient air concentration of O_3 **Comparison:** per unit increase (in ppb) **Outcome:** change in risk (incidence/prevalence) of respiratory effects **Study Design**: epidemiologic studies consisting of panel, case-crossover, time-series studies, and case-control studies; cross-sectional studies with appropriate timing of exposure for the health endpoint of interest
Short-term exposure and mortality	**Population:** any U.S. or Canadian population, including populations or lifestages that might be at increased risk **Exposure:** short-term exposure (on the order of one to several days) to ambient air concentrations of O_3 **Comparison:** per unit increase (in ppb) **Outcome:** change in risk (incidence) of mortality **Study Design:** epidemiologic studies consisting of case-crossover or time-series studies with appropriate timing of exposure for the health endpoint of interest
Long-term exposure and respiratory effects	**Population:** any U.S. or Canadian population, including populations or lifestages that might be at increased risk **Exposure:** long-term (on the order of months to years) ambient air concentration of O_3 **Comparison:** per unit increase (in ppb) **Outcome:** change in risk (incidence/prevalence) of respiratory effects **Study Design:** epidemiologic studies consisting of cohort and case-control studies; time-series, case-crossover, and cross-sectional studies with appropriate timing of exposure for the health endpoint of interest
Short-term exposure and cardiovascular effects	**Population:** any U.S., Canadian, European or Australian population, including populations or lifestages that might be at increased risk **Exposure:** short-term (on the order of one to several days) ambient air concentration of O_3 **Comparison:** per unit increase (in ppb) **Outcome:** change in risk (incidence/prevalence) of cardiovascular effects **Study Design:** epidemiologic studies consisting of panel, case-crossover, time-series studies, and case-control studies; cross-sectional studies with appropriate timing of exposure for the health endpoint of interest
Short-term exposure and nervous system effects	**Population:** any population, including populations or lifestages that might be at increased risk **Exposure:** short-term (on the order of one to several days) ambient air concentration of O_3 **Comparison:** per unit increase (in ppb) **Outcome:** change in risk (incidence/prevalence) of a nervous system effect **Study Design:** epidemiologic studies consisting of panel, case-crossover, time-series studies, and case-control studies; cross-sectional studies with appropriate timing of exposure for the health endpoint of interest
Long-term exposure and cardiovascular, nervous system, reproductive or developmental effects, cancer, or mortality	**Population:** any population, including populations or lifestages that might be at increased risk **Exposure:** long-term (on the order of months to years) ambient air concentration of O_3 **Comparison:** per unit increase (in ppb) **Outcome:** change in risk (incidence/prevalence) of a cardiovascular, nervous system, reproductive or developmental, cancer or mortality effect **Study Design:** epidemiologic studies consisting of cohort and case-control studies; time-series, case-crossover, and cross-sectional studies with appropriate timing of exposure for the health endpoint of interest

Population: the general population, all age groups, living both in urban and in rural areas exposed on a daily basis to O_3 through outdoor (ambient) air, and not exclusively in occupational settings or as a result of indoor exposure. Populations and lifestages at increased risk are included, such as those with specific pre-existing health conditions (e.g. respiratory or cardiovascular diseases), children, or older adults.
Exposure: ambient air O_3 from any source measured as short-term (minutes to weeks) or long-term (months to years).
Comparator: the health effect observed by unit increase in concentration of O_3 in the same or in a control population.
Outcome: clearly measurable health endpoint.
Study design: epidemiologic studies on health effects of O_3 consisting of cross-sectional, case-control, case-crossover, cohort, panel and time-series studies.

4.3.4.4.2 Search and Screen

Identification of recent epidemiologic studies examining a health effect and ambient air exposure to O_3 will be identified using the broad keyword search described in Section 4.3.3 and Automatic Topic Classification. The approach for Automatic Topic Classification to identify epidemiologic studies from the broad literature search results parallels the approach described in Section 4.3.4.3.2 for the experimental studies. A sufficiently large set of seed references cited in the 2016 NO_x and 2013 ISAs will be used, with positive seeds comprised of epidemiologic references in those ISAs and negative seeds comprised of all references other than epidemiologic references. Following identification of the literature, SWIFT-AS will be used for Level 1 screening. Positive seeds will also be used to train the SWIFT-AS algorithm and will include select epidemiologic references cited in the 2013 ISA. Additionally, references will be categorized in Level 1 SWIFT-AS screening by health outcome category (e.g., mortality, respiratory, cardiovascular, etc.), exposure duration (e.g., short-term, long-term), and study location (e.g., U.S., Canada, Europe, etc.). The references identified for inclusion in Level 1 screening will then undergo Level 2 full-text screening, for each health effect category, for relevance to the defined scope.

4.3.4.5 Welfare Effects – Ecological Studies

4.3.4.5.1 Scope

With respect to ecological effects, this ISA will build on information available during the last review describing the effect of O_3 exposure on vegetation and ecosystems. For research evaluating ecological effects, emphasis will be placed on recent studies that: (1) evaluate effects of exposures resulting from O_3 concentrations comparable to those occurring in North American airsheds and (2) investigate effects on any individual, population (in the sense of a group of individuals of the same species), community, or ecosystem in North America (Table 4-3). In instances when a “causal relationship” was concluded in the 2013 ISA (i.e., visible foliar injury, vegetation growth, reduced yield/quality of agricultural crops, reduced productivity, alteration of belowground biogeochemical cycles) the current review will only evaluate studies conducted in North America. For all other ecological endpoints in Table 4-3 (terrestrial water cycling, carbon sequestration, terrestrial community composition, plant reproduction, phenology, or mortality, insects, other wildlife, plant-animal signaling) there are no geographic constraints and all available evidence will be considered.

4.3.4.5.2 Search and Screen

Studies relevant to the ecological effects of O_3 exposure will be identified by citation mapping. The broad keyword searches and Automatic Topic Classification have not resulted in a well-targeted set of references for Level 1 screening in past ISAs for ecological endpoints. Citation mapping in Web of Science based on ecological studies cited in the 2013 ISA is expected to yield a more refined set of references. Following citation mapping, Level 1 screening of the identified references will be conducted in SWIFT-AS, including the use of a seed set of ecological references from the 2013 ISA. Screening questions to facilitate organization of the literature will include effect category (e.g., foliar injury, plant growth, biodiversity, etc.), exposure conditions, location, and ecosystem type (e.g., wetland, crop, etc.). As will be the case for the other disciplines, Level 2 full-text screening will be conducted for references included in Level 1 screening, and full-text inclusion criteria will be defined by the scope.

Table 4-3. PECOS tool to define the parameters and provide a framework for identifying relevant ecological studies.

Ecological Endpoint	Population, Exposure, Comparison, Outcome, Study Design (PECOS)
Visible foliar injury, vegetation growth, yield/quality of agricultural crops, productivity, belowground biogeochemical cycling	**Population:** For any species, an individual, population (in the sense of a group of individuals of the same species), community, or ecosystem in North America **Exposure:** Concentrations occurring in the environment or experimental O_3 concentrations within an order of magnitude of recent concentrations (as described in Appendix 1) **Comparison:** Relevant control sites, treatments, or parameters **Outcome:** Visible foliar injury, alteration of vegetative growth, yield/quality of agricultural crops, productivity, belowground biogeochemical cycles **Study Design:** Laboratory, greenhouse, OTC, FACE, field, gradient, or modeling studies
Terrestrial water cycling; carbon sequestration; terrestrial community composition; plant reproduction, phenology, or mortality; insects, other wildlife, plant-animal signaling	**Population:** For any species, an individual, population (in the sense of a group of individuals of the same species), community, or ecosystem in any continent[1] **Exposure:** Concentrations occurring in the environment or experimental O_3 concentrations within an order of magnitude of recent concentrations (as described in Appendix 1) **Comparison:** Relevant control sites, treatments, or parameters **Outcome:** Alteration of: terrestrial water cycling; carbon sequestration; terrestrial community composition; plant reproduction, phenology, mortality; growth reproduction and survival of insects and other wildlife; plant-animal signaling **Study Design:** Laboratory, greenhouse, OTC, FACE, field, gradient, or modeling studies

Population = unit of study;
Exposure = environmental variable to which population is exposed;
Comparator = change in endpoint observed by unit increase in concentration of O_3 in the same or in a control population;
Outcome = measurable endpoint resulting from exposure;
Study design = laboratory, field, gradient, open top chamber (OTC), Free-Air Carbon Dioxide Enrichment (FACE), greenhouse, and modeling studies.

Notes: This definition of population is for the purpose of applying PECOS to ecology. Ecological populations are defined as a group of individuals of the same species.

[1.] In cases where a comprehensive list of affected species was available, non-agricultural North American species were separated out from the larger datasets and the evidence was evaluated (e.g. foliar injury, biomass)

4.3.4.6 Welfare – Effects on Climate

4.3.4.6.1 Scope

For effects on climate, the ISA will focus on effects of tropospheric O_3 on climate, consistent with the inclusion of “climate” in the list of effects on welfare in section 302(h) of the Clean Air Act. The ISA will not focus on downstream ecosystem effects, human health effects, or future air quality projections resulting from changes in climate. Studies that inform the independent role of O_3 in climate forcing as well as effects on U.S. national and regional climate are within the scope of the literature to be considered in the review (Table 4-4). In addition, the ISA will assess available evidence on the effects of tropospheric O_3 as an absorber of UV-B radiation in the troposphere, though a PECOS tool is no anticipated to be necessary to assist in narrowing and scoping the consideration of the limited available evidence.

Table 4-4. PECOS tool to define the parameters and provide a framework for identifying relevant studies on the effects of tropospheric O_3 on climate.

Effect on Climate	Population, Exposure, Comparison, Outcome, Study Design (PECOS)
Changes in radiative forcing (RF)	**Population/Geographical scope:** evaluations of radiative forcing at the regional, continental, and/or global scale **Exposure:** tropospheric O_3 concentration distributions in 3D (observed/modeled) **Comparison:** relevant baseline or unperturbed scenarios/conditions **Outcome:** changes in RF resulting from change in tropospheric O_3 **Study Design:** observations or modeling studies
Changes in climate (e.g., surface temperature, hydrological cycle)	**Population/Geographical scope:** evaluations of climate effects at the regional, continental, and/or global scale **Exposure:** tropospheric O_3 concentration distributions in 3D (observed/modeled) **Comparison:** relevant baseline or unperturbed scenarios/conditions **Outcome:** subsequent climate effects (via radiative forcing) (e.g., global surface temperature) resulting from change in tropospheric O_3 **Study Design:** observational or modelling studies
Population/Geographical scope: spatial extent of study **Exposure:** environmental variable (tropospheric O_3 concentrations) **Comparator:** radiative forcing or climate effects observed from unit change in tropospheric O_3 concentration. **Outcome:** relevant radiative forcing or climate outcomes resulting from change in tropospheric O_3. **Study design:** observations/satellite, modelling	

4.3.4.6.2 Search and Screen

Studies examining the effect of tropospheric O_3 on climate will be identified in two ways. First, references will be identified by citation mapping in Web of Science using references cited in the 2013 ISA. In addition, relevant references will be identified from recent national and international climate assessments, such as the National Climate Assessment (USGCRP, 2017) and Intergovernmental Panel on Climate Change (IPCC, 2013), and other recent, more focused reports relevant to O_3 climate forcing. Level 1 screening of the identified references will be conducted in SWIFT-AS aided by a seed set of select references from the climate section of the 2013 ISA and screening questions to facilitate organization of the literature. The screening questions will pertain to the following topics: radiative forcing, climate impacts, precursor and copollutant effects, and factors and feedbacks. Level 2 screening will be conducted for references included in Level 1 and full-text inclusion criteria will be defined by the scope.

4.3.5 Identification of Policy-Relevant Studies

From the group of "considered" references (see section 4.3.4), studies and reports will be selected for inclusion in the ISA based on review of the full text. The selection process will be based on the extent to which the study is potentially policy-relevant and informative. Potentially policy-relevant and informative studies will include those that provide a basis for or describe the relationship between exposure to O_3 and effects, particularly, those studies that reduce uncertainty or address limitations of critical issues. Also pertinent are studies that offer innovation in method or design or present novel information on effects or issues previously not identified. Uncertainty can be addressed to some extent, for example, by analyses informing the independent effect of O_3 on health and welfare effects, analyses of potential confounding or effect modification by co-pollutants or other factors, analyses of concentration-response or dose-response relationships, or analyses related to time between exposure and response. In keeping with the ISA's intent to accurately reflect the latest scientific knowledge, the focus of the discussion in the ISA will be on studies published since July 2011 (i.e., the literature cutoff date for the 2013 ISA). Building on the last review, the EPA plans to evaluate the recent evidence in the context of the conclusions from the 2013 ISA. In some cases, evidence from older studies may be the key policy-relevant information in a particular subject area or scientific discipline and will be included. Analyses conducted by the EPA using publicly available data—for example, air quality and emissions data—will also be considered for inclusion in the ISA. Informative studies will not be limited to specific study designs, model systems, or outcomes.

While study quality is important, it is not the sole criteria for study inclusion. The combination of approaches described above are intended to produce a comprehensive collection of pertinent studies needed to address the key scientific issues that form the basis of the ISA. References for the included studies will be cited in the ISA with a hyperlink to the HERO database.

4.3.6 Evaluation of Individual Study Quality

After selecting studies for inclusion, individual study quality is evaluated by considering the design, methods, conduct, and documentation of each study, but not the study results. In the ISA for the current review, conclusions about the strength of inference from study results will be made by independently evaluating the overall quality of each study (U.S. EPA, 2015c). This uniform approach aims to consider the strengths, limitations, and possible roles of chance, confounding, and other biases that may affect the interpretation of individual studies and the strength of inference from the results of the study.

More specifically, NCEA will employ a structured, narrative approach to evaluate a subset of health studies (i.e., animal toxicology, controlled human exposure, and epidemiology studies) using specific study domains, including study design, study population, exposure, outcome assessment, potential confounding, and statistical analysis. For a subset of studies that are the most policy relevant, the evaluation will be documented in a narrative format to transparently convey the overall conclusion on study quality that determines if the study should be included in the ISA. These narrative study quality evaluations will document study details for specific study domains (e.g., study population, study design) and will record expert judgments as well. The study quality evaluations will be publicly available and accessible via the HERO website.

In general, in assessing the scientific quality of studies on health and welfare effects, the following questions are considered.

- Were the study design, study groups, methods, data, and results clearly presented in relation to the study objectives to allow for study evaluation? Were limitations and any underlying assumptions of the design and other aspects of the study stated?
- Were the ecosystems, study site(s), study populations, subjects, or organism models adequately selected, and are they sufficiently well-defined to allow for meaningful comparisons between study or exposure groups?
- Are the air quality, exposure, or dose metrics of adequate quality and are they sufficiently representative of or pertinent to ambient air?
- Are the health or welfare effect measurements meaningful, valid, and reliable?
- Were likely covariates or modifying factors adequately controlled or taken into account in the study design and statistical analysis?
- Do the analytical methods provide adequate sensitivity and precision to support conclusions?
- Were the statistical analyses appropriate, properly performed, and properly interpreted?

Additional considerations in evaluating individual study quality specific to particular scientific disciplines are discussed in detail in the Preamble to the ISAs (U.S. EPA, 2015c) and will be further described in Appendix 10 of the ISA.

4.3.7 Integration of Evidence and Determination of Causality

As described in the Preamble to the ISAs (U.S. EPA, 2015c), the EPA uses a structured framework to provide a consistent and transparent basis for classifying the weight of available evidence for health and welfare effects according to a five-level hierarchy: (1) causal relationship; (2) likely to be a causal relationship; (3) suggestive of, but not sufficient to infer, a causal relationship; (4) inadequate to infer a causal relationship; and (5) not likely to be a causal relationship (Table 4-5).

Table 4-5. Weight of evidence determinations.

	Health Effects	Welfare Effects
Causal relationship	Evidence is sufficient to conclude that there is a causal relationship with relevant pollutant exposures (e.g., doses or exposures generally within one to two orders of magnitude of recent concentrations). That is, the pollutant has been shown to result in health effects in studies in which chance, confounding, and other biases could be ruled out with reasonable confidence. For example: (1) controlled human exposure studies that demonstrate consistent effects, or (2) observational studies that cannot be explained by plausible alternatives or that are supported by other lines of evidence (e.g., animal studies or mode of action information). Generally, the determination is based on multiple high-quality studies conducted by multiple research groups.	Evidence is sufficient to conclude that there is a causal relationship with relevant pollutant exposures. That is, the pollutant has been shown to result in effects in studies in which chance, confounding, and other biases could be ruled out with reasonable confidence. Controlled exposure studies (laboratory or small- to medium-scale field studies) provide the strongest evidence for causality, but the scope of inference may be limited. Generally, the determination is based on multiple studies conducted by multiple research groups, and evidence that is considered sufficient to infer a causal relationship is usually obtained from the joint consideration of many lines of evidence that reinforce each other.
Likely to be a causal relationship	Evidence is sufficient to conclude that a causal relationship is likely to exist with relevant pollutant exposures. That is, the pollutant has been shown to result in health effects in studies where results are not explained by chance, confounding, and other biases, but uncertainties remain in the evidence overall. For example: (1) observational studies show an association, but copollutant exposures are difficult to address and/or other lines of evidence (controlled human exposure, animal, or mode of action information) are limited or inconsistent, or (2) animal toxicological evidence from multiple studies from different laboratories demonstrate effects but limited or no human data are available. Generally, the determination is based on multiple high-quality studies.	Evidence is sufficient to conclude that there is a likely causal association with relevant pollutant exposures. That is, an association has been observed between the pollutant and the outcome in studies in which chance, confounding, and other biases are minimized but uncertainties remain. For example, field studies show a relationship, but suspected interacting factors cannot be controlled, and other lines of evidence are limited or inconsistent. Generally, the determination is based on multiple studies by multiple research groups.
Suggestive of, but not sufficient to infer, a causal relationship	Evidence is suggestive of a causal relationship with relevant pollutant exposures but is limited, and chance, confounding, and other biases cannot be ruled out. For example: (1) when the body of evidence is relatively small, at least one high-quality epidemiologic study shows an association with a given health outcome and/or at least one high-quality toxicological study shows effects relevant to humans in animal species, or (2) when the body of evidence is relatively large, evidence from studies of varying quality is generally supportive but not entirely consistent, and there may be coherence across lines of evidence (e.g., animal studies or mode of action information) to support the determination.	Evidence is suggestive of a causal relationship with relevant pollutant exposures, but chance, confounding, and other biases cannot be ruled out. For example, at least one high-quality study shows an effect, but the results of other studies are inconsistent.
Inadequate to infer a causal relationship	Evidence is inadequate to determine that a causal relationship exists with relevant pollutant exposures. The available studies are of insufficient quantity, quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an effect.	Evidence is inadequate to determine that a causal relationship exists with relevant pollutant exposures. The available studies are of insufficient quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an effect.

	Health Effects	Welfare Effects
Not likely to be a causal relationship	Evidence indicates there is no causal relationship with relevant pollutant exposures. Several adequate studies, covering the full range of levels of exposure that human beings are known to encounter and considering at-risk populations and lifestages, are mutually consistent in not showing an effect at any level of exposure.	Evidence indicates there is no causal relationship with relevant pollutant exposures. Several adequate studies examining relationships with relevant exposures are consistent in failing to show an effect at any level of exposure.
Source: U.S. EPA (2015c)		

Determination of causality involves evaluating and integrating evidence for different types of health or welfare effects associated with short- and long-term exposure periods. Key considerations in drawing conclusions about causality include consistency of findings for an endpoint across studies, coherence of the evidence across disciplines and across related endpoints, and biological plausibility. As judged by these parameters, studies in which chance, confounding, and other biases could be ruled out with reasonable confidence are sufficient to infer a causal relationship. Increasing uncertainty due to limited available information, inconsistency across the body of evidence, and/or limited coherence and biological plausibility may lead to conclusions lower in the causality hierarchy. Causality determinations are based on the confidence in the integrated body of evidence, considering study design and quality and strengths and weaknesses in the overall collection of previous and recent studies across disciplines. In discussing each determination of causality, the EPA characterizes the evidence upon which the judgment is based, including the extent of and weight of evidence for individual endpoints within the health or welfare effect category or group of related endpoints.

For evaluation of human health effects, determinations of causality are made for major health effect categories or groups of related endpoints (e.g., respiratory effects) and for the range of exposure concentrations of O_3 defined to be relevant to ambient air concentrations (e.g., up to 2 ppm). The main lines of evidence for use in causality determinations for human health are controlled human exposure, epidemiologic, and animal toxicological studies. Evidence is integrated from previous and recent studies. Other information including mechanistic evidence, toxicokinetics, and exposure assessment may be drawn upon if relevant to the evaluation of health effects and if of sufficient importance to affect the overall evaluation. The relative importance of different sources of evidence to the conclusions varies by pollutant or assessment, as does the availability of different sources of evidence when making a causality determination. In forming judgments of causality, NCEA scientists will also evaluate uncertainty in the scientific evidence, considering issues such as generalizing results from a small number of controlled human exposure subjects to the larger population; extrapolations of observed pollutant-induced pathophysiological alterations from laboratory animals to humans;

confounding by co-exposure to other ambient air pollutants, meteorological factors, or other factors; the potential for effects to be due to exposure to air pollution mixtures; and the influence of exposure measurement error on epidemiologic study findings. Judgments of causality also are informed by the extent to which uncertainty in one line of evidence (e.g., potential copollutant confounding in epidemiologic results) is addressed by another line of evidence (e.g., coherence of effects observed in epidemiologic studies with experimental findings, mode of action information). Thus, evidence integration is not a unidirectional process but occurs iteratively within and across scientific disciplines and related outcomes.

A similar process is used for the integration of evidence and determination of causality for welfare-related effects. For ecological effects this includes evaluating evidence relevant to quantitative relationships between pollutant exposures and ecological effects. This also includes reviewing concentration-response relationships and, to the extent possible, drawing conclusions on the levels at which effects are observed. Also evaluated are O_3 effects on biological levels of organization from species to populations to biological communities and ecosystems. Both laboratory and field studies (including field experiments and observational studies) can provide useful data for causality determination. Integration of evidence for effects on climate draws upon modeling and monitoring data as well as experimental approaches designed to characterize the role of O_3 in atmospheric processes. Generally, a causality determination is made based on many lines of evidence that reinforce each other and are based on integrating evidence from both previous and recent studies.

4.3.8 Quality Management

Within the EPA, Quality Management Plans (QMP) are developed to ensure that all Agency materials meet a high standard for quality. NCEA participates in the Agency-wide Quality Management System, which requires the development of a QMP. Implementation of the NCEA QMP ensures that all data generated or used by NCEA scientists are "of the type and quality needed and expected for their intended use" and that all information disseminated by NCEA adheres to a high standard for quality including objectivity, utility, and integrity. Quality assurance (QA) measures detailed in the QMP will be employed for the development of the ISA. NCEA QA staff will be responsible for the review and approval of quality-related documentation. NCEA scientists will be responsible for the evaluation of all inputs to the ISA, including primary (new) and secondary (existing) data, to ensure their quality is appropriate for their intended purpose. NCEA adheres to Data Quality Objectives, which identify the most appropriate inputs to the science assessment and provide QA instruction for researchers citing secondary information. The approaches utilized to search the literature and criteria applied to select and evaluate studies were detailed in the two preceding subsections. Generally, NCEA scientists rely on scientific information found in peer-reviewed journal articles, books, and government reports. The ISA also can include information that is integrated or summarized from multiple sources to create new figures, tables, or summation, which is subject to rigorous quality assurance measures to ensure their accuracy.

4.4 SPECIFIC SCIENCE ISSUES TO BE ADDRESSED IN THE ISA

The ISA will provide the scientific foundation for this NAAQS review process and inform the consideration of whether it is appropriate to retain or revise the current primary and secondary O_3 NAAQS. Decisions on the specific content of the ISA will be guided by policy-relevant questions that frame the entire NAAQS review as outlined in Chapter 3. Policy-relevant questions for the ISA are related to two overarching issues: (1) the adequacy of the standard to protect public health, and (2) reductions in uncertainties identified in the previous review or new sources of uncertainties. The initial overarching policy-relevant question for the primary and secondary standards concerns the adequacy of public health or public welfare protection afforded by the standard. In considering this overarching question, the PA addresses a series of more specific questions (sections 3.1.2 and 3.2.2). The more specific questions relate to the nature of health and welfare effects attributable to O_3; the populations, ecosystems or species particularly at risk of such effects and the exposure concentrations of O_3 associated with health and welfare effects. Another question concerns whether uncertainties from the last review have been reduced and/or whether new uncertainties have emerged. In the integrated synthesis and each of the health and welfare effects appendices, the current ISA will evaluate uncertainties and limitations in the scientific data, as described below.

In order to evaluate potential confounding by other ambient air pollutants in epidemiologic studies, the ISA will examine whether epidemiologic associations with O_3 are observed in copollutant models. Copollutant models are the predominant method used in air pollution epidemiology to estimate the effect of one pollutant controlling for a given concentration of a copollutant. The ISA also will evaluate whether O_3 has either interactions with copollutants or joint effects in associations with health outcomes. The assessment of potential confounding, interactions, or joint effects will draw upon results from health effects studies, available information on copollutant interactions in the atmosphere that influence the spatial distributions of O_3 and copollutants, as well as information from experimental studies that examine the health effects of O_3 exposures alone and O_3 in combination with other pollutants. In the absence of these methods, the ISA will examine whether single-pollutant epidemiologic associations with health effects in a given study differ between O_3 and copollutants, and if insights regarding potential copollutant confounding can be gained by examining the magnitude of correlation between pollutants.

The ISA will consider the strengths and limitations of various exposure assessment methods. Monitoring data and model output will be used to characterize ambient air O_3 concentrations used as surrogates for human exposures. Additionally, the ISA will evaluate the strength of inference in epidemiologic studies by considering information such as the exposure duration being examined, the extent of temporal and/or spatial variability in O_3 in the study area, the distribution of monitoring sites in the study area, the performance of exposure models used, and time-activity patterns of the study population. The adequacy of exposure assessment in epidemiologic studies will be considered in weighing the quality of evidence, and in turn, forming causality determinations.

Epidemiologic evidence is unlikely to completely address the uncertainties mentioned above. Any individual study is unlikely to evaluate all potentially correlated copollutants, and the limitations of epidemiologic methods in separating effects of highly correlated pollutants or separating the effects of more than two pollutants in the same model are well recognized. Thus, coherence with other lines of evidence may strengthen inferences when there are uncertainties in epidemiologic evidence due to copollutant confounding. Controlled human exposure and toxicological studies that demonstrate similar effects at relevant O_3 exposures may demonstrate an independent effect of O_3 exposure, provide coherence with epidemiologic evidence. Further, experimental results may provide biological plausibility.

In the previous O_3 review, a number of uncertainties were identified with respect to quantitative relationships between O_3 and effects on public welfare. Variation in O_3 effects on vegetation arises from the influence of co-occurring environmental stressors (e.g., drought, nitrogen deposition), as well as from variation in O_3 sensitivity at different vegetative growth stages or between genotypes. The 2013 ISA identified uncertainties in the magnitude of O_3 effects on climate, including the net radiative forcing due to changes in O_3 concentrations and the resulting surface temperature response. The ISA will evaluate the status of these uncertainties and limitations in each of the welfare effects sections and this information will be used in the development of causality determinations.

The ISA also will address a set of more specific policy-relevant questions related to the available scientific evidence, as described in the following sections. These questions were derived from the last O_3 NAAQS review.

4.4.1 Causality Determinations from 2013 ISA

The causality determinations in the 2013 ISA, based on the causal framework and integration of available evidence from previous and recent studies, were presented with a summary of the available evidence at the end of the sections for each broad health and welfare effect category and in the integrative synthesis chapter at the beginning of the ISA (U.S. EPA, 2013).

In the 2013 ISA, for human health effects, the EPA concluded that the findings of epidemiologic, controlled human exposure, and animal toxicological studies collectively provided evidence of a "causal relationship" for short-term O_3 exposures and respiratory effects. In evaluating a broader range of health effects for O_3, the 2013 ISA concluded there was evidence of a "likely to be causal relationship" for long-term O_3 exposures and respiratory effects and for short-term O_3 exposures and cardiovascular effects and mortality. Additionally, there was evidence "suggestive of a causal relationship" for O_3 exposures and other health effects, including developmental and reproductive effects (e.g., low birth weight, infant mortality) and central nervous system effects (e.g., cognitive development).

In the 2013 ISA, for welfare effects, the evidence indicated a "causal relationship" between O_3 exposure and visible foliar injury effects on vegetation, reduced vegetation growth, reduced productivity in terrestrial ecosystems, reduced yield and quality of agricultural crops, and alteration of below-ground biogeochemical cycles. The evidence indicated a "likely to be causal relationship" for reduced carbon sequestration in terrestrial ecosystems, alteration of terrestrial ecosystem water cycling and alteration of terrestrial community composition. For climate there was a causal relationship between changes in tropospheric O_3 concentration and radiative forcing and likely to be a causal relationship between changes in tropospheric O_3 concentration and effects on climate.

In the current review, specific science questions related to the causality determinations that we plan to address include:

- Does the evidence base from recent studies contain new information to support or call into question the causality determinations made for relationships between O_3 exposure and various health and welfare effects in the 2013 ISA?
- Is there new information to extend causality determinations to other ecological endpoints?
- Does new evidence confirm, extend, or call into question prior conclusions on the biological plausibility for specific O_3-related health effects?
- What is the strength of inference from epidemiologic studies based on the extent to which they have:
    - Examined exposure metrics that capture the spatial and/or temporal pattern of O_3 in the study area?
    - Assessed potential confounding by other pollutants and factors?
- What does the available information indicate with regard to changes in population health status that may be associated with a decrease in ambient air O_3 concentrations that might inform causality determinations?

4.4.2 Ambient Air Concentrations of O_3

The ISA will present and evaluate relevant data, and summarize the current scientific understanding concerning the sources and ambient air concentrations of O_3 in the U.S. lower troposphere and surface boundary layer. Ozone present in the lower troposphere is predominantly formed through photochemical reaction involving reactive volatile organic compounds and/or NO_X as precursor gases. The discussion divides atmospheric O_3 into two classes: U.S. background O_3 and non-background O_3 (see section 4.3.4.1.1). Specific science questions that we plan to address in the ISA include:

- What are the origins of U.S. background O_3 concentrations, especially related to international transport into the U.S., stratospheric exchange, and natural emissions from biogenic sources, wildfires, and lightning? How well quantified are contributions from these sources on overall tropospheric O_3 concentrations?
- What modeling strategies have been used to estimate U.S. background O_3 concentrations? What are the sources of bias and uncertainty associated with the models used to estimate U.S. background O_3 concentrations? What observations or alternative estimates are available that quantify U.S. background O_3 concentrations and characterize its spatiotemporal patterns?
- What data are available to characterize precursor emissions of non-background O_3? How does recent evidence contribute to what is known about the photochemical production of non-background O_3? How has modeling non-background O_3 evolved since the last ISA? Are there new models, or recent studies that have evaluated the validity of existing models?
- Have methods for measuring non-background O_3 substantively changed since the last ISA? What are recent O_3 concentrations and longitudinal trends in O_3 concentrations?

4.4.3 Human Exposure

The ISA will evaluate methods for estimating exposure to ambient air O_3, as well as the ability to make inferences about personal exposure to ambient O_3 when extrapolating from ambient air concentration data, particularly in the context of interpreting results from epidemiologic studies. The issues surrounding the ability to make inferences about personal exposure differ by the exposure period of interest. Short-term exposure studies (i.e., exposures ranging from hours up to weeks) examine how temporal variation in exposure is associated with temporal variation in a health outcome while long-term exposure studies (i.e., exposures ranging from months to years) typically examine how spatial variability of exposure is associated with spatial variation in a health outcome averaged over time. Specific science questions related to human exposure that we plan to address in the ISA include:

- What new developments have occurred with respect to chemical transport modeling of short-term and long-term O_3 concentrations for use in exposure assessment? How might modeling and satellite data supplement monitoring data for understanding human exposures? What are the limitations of using modeling or satellite data in lieu of monitoring data? What advancements have been made with respect to techniques for fusing modeling, monitoring, and/or satellite data for assessing exposures to ambient air O_3? What are the uncertainties in data from chemical transport models and satellites at the extremes of the concentration distribution, such as in high and low concentration areas (e.g., near roadways, rural areas) and times?

- What are the errors and uncertainties associated with extrapolating from stationary O_3 monitoring instruments to personal exposure to O_3 of ambient air origin? Issues may arise from instrument error in outdoor ambient air monitors, the use of fixed-site monitors for estimating community concentrations across different spatial scales (e.g., neighborhood scale, urban scale), spatial misalignment from using fixed-site monitors as a surrogate for personal exposure to O_3 of ambient air origin, and uncertainty in the time-activity patterns of exposed individuals whose exposure is represented by fixed-site monitors.
- What new developments have been made in assessing and/or correcting the influence of exposure measurement error on health effect estimates for epidemiologic studies of short-term and long-term exposure? How do these methods reduce the uncertainty and/or bias in the health effect estimates for O_3 exposure?

4.4.4 Health Effects

In the 2013 ISA, the health effects evidence indicated that a "causal relationship exists" for short-term exposures to O_3 and respiratory effects, and a "likely to be causal relationship exists" for long-term O_3 exposures and respiratory effects and short-term O_3 exposures and cardiovascular effects and mortality. More limited evidence with a larger degree of uncertainty formed the basis for the determinations for other health effects. The EPA will build on the conclusions of the 2013 ISA by evaluating the newly available literature related to O_3 exposures and health effects, including, but not limited to respiratory, cardiovascular, nervous system, reproductive and developmental effects, mortality, and cancer. Depending on data availability and resources, other health effects may be evaluated.

The ISA will evaluate health effects that occur following both short- and long-term exposures as examined in epidemiologic, controlled human exposure, and animal toxicological studies. Efforts will be directed towards identifying the concentrations at which effects are observed, particularly in potential at-risk lifestages and populations, and assessing the role of O_3 within the broader mixture of ambient air pollutants. The discussion of health effects will be integrated with relevant information on exposure, dosimetry and biological plausibility.

In the current review, specific science questions that we plan to address in consideration of health effects associated with short- and long-term exposure to O_3, include the following:

<u>Short-Term Exposure</u>

- What recent evidence is available to inform policy-relevant considerations of the O_3 NAAQS (summarized in Chapter 3) for short-term O_3 exposures and respiratory effects?

Do recent controlled human exposure and toxicological studies continue to provide support for or call into question prior conclusions on relationships between short-term O_3 exposures and respiratory health effects? Do recent studies report O_3-attributable effects at lower O_3 exposure concentrations or for different durations or patterns of exposure than indicated by studies available in the last review?

- How do results of recent studies expand understanding of the relationship between short-term exposure to O_3 and cardiovascular effects, such as ischemic heart disease, heart failure, or vascular effects? Does recent evidence improve coherence across disciplines for heart rate variability, blood pressure, and outcomes such as cardiovascular hospital admissions or emergency department visits?
- To what extent is short-term exposure to O_3 related to or associated with the progression of diabetes, other metabolic diseases, and/or to other endocrine system effects? To what extent does the newly available evidence identify health outcomes related to or associated with O_3 exposures that were not previously identified?
- Across the evaluated health effects, what new evidence is available on effects occurring from exposures of different durations than indicated by the previously available evidence?

Long-Term Exposure

- What new evidence is available to inform policy-relevant considerations of the O_3 NAAQS (summarized in Chapter 3) for long-term O_3 exposures and respiratory effects? Do new epidemiologic and toxicological studies continue to provide support for biologically plausible relationships between long-term O_3 exposures and respiratory health effects? Do new studies report O_3-attributable effects at lower O_3 concentrations than indicated by studies available in the last review?
- To what extent do recent studies improve understanding of the relationships between long-term O_3 exposure and the development of asthma or to the impairment of lung development? Do recent studies improve coherence across disciplines for respiratory disease incidence, pulmonary inflammation and oxidative stress, and allergic responses?
- To what extent do recent studies improve understanding of the relationship between O_3 exposure and reproductive and developmental health outcomes, such as adverse birth outcomes, fertility and pregnancy outcomes (e.g., infertility, sperm quality, preeclampsia, gestational hypertension), or developmental outcomes (e.g., neurocognitive effects)? Are there new studies linking exposures during critical windows of development to increased risk of O_3-related health effects later in life?
- To what extent does new literature support or call into question the existence of a biologically plausible relationship between long-term O_3 exposures and nervous system effects (e.g., cognitive decline and autism)?
- How do results of recent studies expand our understanding of the relationship between long-term O_3 exposure and mortality? To what extent does the evidence indicate that long-term exposure to O_3 can increase the risk of respiratory-related mortality or other cause-specific mortality?
- To what extent is long-term exposure to O_3 related to or associated with the development of diabetes and other metabolic diseases, as well as to health effects in the endocrine

system or other organ systems? To what extent are new health outcomes related to or associated with O_3 exposures?

Additional Science Considerations

- Do epidemiologic studies of mortality, hospital admissions, or emergency department visits provide new information to improve our understanding of the potential heterogeneity in effects assessed in U.S. multicity studies?
- How do the results of recent studies inform the shape of the concentration-response relationship for O_3 and various health outcomes (e.g., mortality, hospital admissions, etc.), especially for exposures relevant to O_3 concentrations near the current O_3 NAAQS?
- What new evidence adds to the understanding of which lifestages and populations are at increased risk of O_3-related health effects?
- What new evidence informs conclusions regarding inter-individual variability in response to O_3 exposures?
- What is the relationship between short- and long-term exposures and O_3-related health effects? More specifically, across health effects, what new information is available to delineate the effects of chronic exposure to lower concentrations versus acute, repeated exposures to higher concentrations of O_3?
- What is the nature of health effects in persons exposed to multipollutant mixtures that contain O_3 in comparison to exposure to O_3 alone?

4.4.5 At-Risk Lifestages and Populations and Public Health Impact

The NAAQS are intended to protect public health with an adequate margin of safety, including protection for the populations or lifestages potentially at increased risk for O_3-related health effects. Thus, the ISA will evaluate evidence for an array of factors that may contribute to increased risk of O_3-related health effects for various lifestages or populations (e.g., populations with preexisting disease). The evaluation of recent evidence will build on the conclusions from the 2013 ISA, where application of the at-risk framework[77] to classify evidence demonstrated that there was adequate evidence that children, older adults, people with pre-existing asthma, people with certain genetic variants, people with nutritional deficiencies, and outdoor workers are at increased risk of O_3-related health effects. The ISA will evaluate recent evidence that informs the identification of at-risk factors (e.g., lifestage, preexisting disease) in each of the health appendices. Key considerations in characterizing the evidence include consistency of findings for a factor within a discipline and, where available, coherence of the evidence across

[77] In recent reviews, the term “at-risk” has been used to define populations and lifestages potentially at increased risk of an air pollutant-related health effect (e.g., see 2013 O_3 ISA and 2016 NO_X ISA; U.S. EPA, 2013; U.S. EPA, 2016). At-risk populations can include those with intrinsic factors that make them more susceptible to pollutant-related effects (e.g., pre-existing disease, genetic characteristics) or that increase pollutant dose (e.g., breathing patterns), and extrinsic factors that could increase pollutant exposures (e.g., personal activity patterns) (U.S. EPA, 2016, pp. 1xiii to 1xiv).

disciplines as well as biological plausibility. When evaluating evidence to inform the identification of at-risk lifestages or populations, emphasis will be placed on the health effects for which there is a causal or likely to be a causal relationship with exposure to O_3. Specific questions we plan to address include:

- What new evidence is available to further support or call into question the at-risk determination made for lifestages or populations in the 2013 ISA?
- What new evidence is available regarding additional lifestages or populations (e.g., pre-existing diseases such as diabetes) potentially at increased risk of an O_3-related health effect?
- Is there new information that identifies a combination of factors (i.e., co-occurring) that can lead to one lifestage or population being at greater risk compared to another?

4.4.6 Welfare Effects

In the 2013 ISA, the welfare effects evidence for O_3 focused on effects on vegetation and ecosystems, and the role of tropospheric O_3 in climate change and supplemental shielding of UV-B radiation. The EPA will build on the 2013 ISA by evaluating the newly available literature related to O_3 exposures and these welfare effects.

4.4.6.1 Ecological Effects

The ISA will evaluate the literature related to O_3 exposures at levels of biological organization from the organism to the ecosystem. Evidence from experimental (e.g. laboratory, greenhouse, OTC, FACE) and field, gradient or modeling studies that address effects of O_3 on ecological endpoints will be considered to identify concentrations at which effects are observed (Table 4-5). The focus will be on information necessary for interpretation of effects and on newly available information since the last ISA.

4.4.6.1.1 Plant-level Effects

Ambient air O_3 concentrations have long been known to cause foliar injury and decreased growth and biomass accumulation in annual, perennial and woody plants, including agronomic crops, annuals, shrubs grasses, and trees. In the 2013 ISA the evidence was sufficient to infer a causal relationship between O_3 exposure and endpoints on vegetation including, visible foliar injury, reduced growth, and reduced yield and quality from individual plants that are agricultural crop species. Evidence for foliar injury includes data from field, lab and chamber studies dating back to the 1960's. Decreased growth at the plant scale has been well established for several decades and may translate to damages at the stand and then ecosystem scales. In the current review specific policy-relevant questions related to O_3 effects on plant-level effects include the following:

- Is there any additional information on foliar injury or biomass growth in U.S. species attributable to O_3 in ambient air?
- Is there additional information on the factors influencing the relationship between O_3 and visible foliar injury?
- Is there additional information regarding a relationship between visible foliar injury and growth?
- Is there any additional information on interspecies differences in responses to O_3?

4.4.6.1.2 Ecosystem-level Effects

Effects at the individual plant level can result in changes in ecosystems such as productivity, below-ground processes, carbon storage, water cycling and nutrient cycling. The 2013 ISA determined there was a causal relationship between O_3 exposure and reduced productivity. Results of long-term experiments provided evidence of the association of O_3 exposure and reduced productivity at the ecosystem level of organization which were supported by decreased plant growth and modeling studies. The 2013 ISA also determined there was a causal relationship between O_3 exposure and alteration of below-ground biogeochemical cycles including altered carbon allocation to below-ground tissues; and altered rates of leaf and root production, turnover, and decomposition. These shifts can affect overall carbon loss and nitrogen loss from the ecosystem. Studies from the leaf and plant level provided biologically plausible mechanisms and results from experimental studies consistently showed responses of below-ground processes to O_3 exposure. The 2013 ISA determined there was a likely causal relationship between O_3 exposure and reduced carbon sequestration. Evidence for that conclusion was primarily from global and regional modeling simulations. The 2013 ISA determined there was a likely causal relationship between O_3 and alteration of terrestrial water cycling. Alteration of stomatal functioning may affect water use in leaves, whole plants, and at the watershed level based on field and modeling studies. In the current review specific policy-relevant questions related to O_3 effects on ecosystem processes include the following:

- What new information is available, including that for O_3-related effects on ecosystem services, on alteration of below-ground biogeochemical cycles, decreased productivity, reduced carbon sequestration, and alteration of terrestrial ecosystem water cycling?
- Are there newly identified ecological endpoints or processes affected by O_3?

4.4.6.1.3 Community Composition

Ozone exposure can lead to loss of sensitive species and alter community composition of plants and microorganisms in some ecosystems. In the 2013 ISA the evidence was sufficient to infer a likely causal relationship between O_3 and alteration of terrestrial community composition. Studies of the impact of O_3 on species competition and community composition showed declines in community composition of above-ground and below-ground communities. In the current review specific policy-relevant questions related to O_3 effects on ecosystems include the following:

- Is there additional evidence with respect to O_3 effects on ecosystem structure and terrestrial community composition
- Is there additional evidence with respect to O_3 effects on other organisms such as insects or other wildlife?

4.4.6.1.4 Air Quality Indices and Exposure-Response Relationships

Exposure indices are metrics that quantify exposure as it relates to measured plant response (e.g., reduced growth). In the 2013 ISA, exposure indices that cumulated and differentially weighted the higher hourly average concentrations and included the mid-level values offered the most reliable approach for use in developing response functions and comparing studies, as well as for defining future indices for vegetation protection. Exposure-response relationships were available for several tree and crop species from a variety of experiments. In the current review specific policy-relevant questions related to air quality indices and exposure-response include the following:

- Are there new U.S. studies which use various O_3 metrics to further characterize O_3 effects on plant foliar injury and/or growth?
- Are there new studies which improve the characterization of O_3 exposure-response at the local, regional and/or national scale for the effects determined to be causal or likely causal? Which are the relevant exposure indices for such relationships?

4.4.6.2 Effects on Climate and UV-B Shielding Effects

The ISA will present information on how changes in tropospheric O_3 might affect radiative forcing, subsequent effects on climate endpoints such as surface air temperature, and UV-B shielding. The focus will be on information necessary for interpretation of effects and on newly available information since the last ISA. Specific questions include:

- What new information is available to decrease uncertainties in the magnitude of the radiative forcing and climate response attributed to tropospheric O_3?
- What new information is available on tropospheric O_3 as an absorber of UV-B radiation?
- To what extent do we understand the independent effects of O_3 on climate in the broader context of other climate forcers, including copollutants and O_3 precursors?
- What feedbacks affect the climate response to radiative perturbations from tropospheric O_3 concentration changes?
- What recent advancements have been made in understanding O_3 effects on regional climate in the U.S.?

4.5 SCIENTIFIC AND PUBLIC REVIEW

4.5.1 Peer Input Workshop

As an early step in development of the draft ISA, the EPA has held a preliminary peer-input meeting. This meeting brought together subject matter experts from a variety of disciplines to review initial draft materials for the ISA. This workshop spanned multiple days (October 29 and 31, November 1 and 5, 2018), covering a different topic area each day. This workshop occurred prior to the integration of evidence across scientific disciplines and the consideration of the collective body of evidence for the purposes of making causality determinations. Therefore, the peer input review is different than what will be provided by the CASAC and the public following the release of the completed draft ISA. During the peer input meeting, expert panelists were asked to address the following overarching questions:

- Do the initial draft materials capture the key new studies from the peer-reviewed literature that have been published since the completion of the 2013 O_3 ISA? Are there additional studies published since the 2013 O_3 ISA that should be included?
- Are there specific issues that should be considered or highlighted that will be important for integrating evidence across disciplines?

4.5.2 Peer Review

The EPA's Peer Review Handbook dictates the process for scientific peer review of all EPA products (U.S. EPA, 2015d). Accordingly, a draft of the ISA will be made available for review by the CASAC, as well as by the public. Availability of the draft document will be announced in the *Federal Register*. The CASAC will review the draft ISA at a public meeting that will be announced in the *Federal Register*. The EPA will consider comments, advice, and recommendations received from the CASAC and from the public in revising the draft ISA document. The EPA has established a public docket for the development of the ISA.[78] After appropriate revision based on comments received from the CASAC and the public, the final document will be made available on the EPA website. A notice announcing the availability of the final ISA will be published in the *Federal Register*.

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[78] The ISA docket can be accessed at www.regulations.gov using Docket ID number EPA-HQ-ORD-2018-0274.

5 QUANTITATIVE RISK AND EXPOSURE ASSESSMENTS

In NAAQS reviews, quantitative REAs[79] are generally designed to assess human exposure and health risk, as well as ecological exposures and risks to public welfare, for air quality conditions associated with the existing standards, and as appropriate, for conditions associated with potential alternative standards. The objective for such assessments is generally to provide quantitative estimates of impacts that inform judgments on the public health and public welfare significance of exposures likely to occur under air quality conditions reflective of the current NAAQS, and, as appropriate, any alternative standards under consideration. Accordingly, the assessments are also intended to provide a basis for judgments as to the extent of public health and public welfare protection afforded by such standards.

In developing REAs in each NAAQS review, we draw upon the currently available health effects evidence that is characterized in the ISA. This includes information on atmospheric chemistry, air quality, human and environmental exposures, dosimetry and mode of action, and information on health and welfare effects associated with exposures considered likely to occur because of pollutant concentrations in ambient air. We additionally employ current methods and tools to support the quantitative modeling and assessment.

The REAs commonly rely on a case study approach which involves quantitative analyses focused on populations and pollutant concentrations in one or more specific geographic areas under air quality conditions that just meet the existing standards (and alternatives as appropriate). Reliance on this approach is intended to provide assessments of the air quality scenario(s) of interest for a set of study areas and associated exposed at-risk populations and ecosystems that will be informative to the EPA's consideration of potential exposures and risks that may be associated with the stated air quality conditions. For example, we are interested in the exposure and risk associated with air quality conditions that just meet the current standard(s); such information is useful in interpreting the degree of protectiveness given by the current standard(s), the adequacy of such standard(s), and the need to consider alternatives. Further, the REA analyses employ a case study approach that addresses practical considerations, such as employing a tractable scale and considering resource constraints, while providing estimates for populations and geographic areas of interest and also having broader applicability (e.g., offering risk perspective for similar study areas that were not assessed). Thus, REA analyses are not

[79] While the term REA has in the past several NAAQS reviews referred to assessments presented in a stand-alone REA document, in this review, we are also using this term, or the phrase "REA analyses" to simply refer to the analyses which we intend to present in appendices or as supplemental materials to the PA.

generally intended to provide a comprehensive national assessment of such conditions, nor are they necessarily intended to provide such an assessment of existing air quality. Rather, the purpose is to assess population exposure and risk for particular air quality conditions based on currently available scientific information, modeling tools, and other technical information. As a result, the REA can provide extended perspective on potential exposures and risks in geographic areas across the U.S. not analyzed but with similarity in the attributes that primarily influence exposures and risks, such as ambient air concentrations, population demographics, and the degree of correlation in their spatial distributions.

In planning any REA analyses that may be appropriate for a new NAAQS review, we first consider the analyses conducted in the last review and the extent to which they provided important insights that were informative to the Agency's decision on the current standard. Conclusions in this regard are generally influenced by an assessment of the uncertainties associated with each type of analysis and the corresponding consideration of each type's relative strength, as documented in the notice of the decision for the prior review and associated assessment documents such as the PA and REA. In considering whether new analyses are warranted for particular types of assessments, we evaluate the availability of new scientific evidence and technical information in this review, as well as improved methods and tools, that may provide support for conducting updates to address key limitations or uncertainties in analyses from the last review, or to provide additional insight beyond those provided by the prior REA. Thus, we focus on identifying the new analyses that are warranted in consideration of factors such as those raised here, while also bearing in mind practical and logistical considerations such as available resources and timeline for the review.

The purpose of this chapter is to briefly summarize the comprehensive, complex, and resource-intensive quantitative health and welfare assessments completed in the last review of the O_3 NAAQS, giving attention to those analyses concluded to be most informative to the decisions reached on the standards in that review. In considering the issues raised above, we additionally summarize key uncertainties and limitations of the analyses conducted for the last review and consider the extent to which newly available information, tools or methodologies might address those areas. For example, the scope of any analyses for this review would be informed by the new scientific information characterized in the upcoming ISA; recent air quality data; the availability of improved data, methods, tools, and models that can be used to address limitations and uncertainties from the last review; and any constraints on resources and the review timeline. The goal is to focus on those analyses that may be particularly policy relevant and informative to decision-making in this review and to identify the types of analyses for which updates are warranted and will be conducted in this review (in contrast to, for example, other types of analyses for which the assessments presented in the 2014 REAs may remain appropriately informative).

We are planning that the quantitative exposure and risk analyses newly developed in this review will be presented in the draft PA, and to consider them along with any previously conducted analyses that remain pertinent and informative to consideration of the adequacy of the current standards (and alternative standards, as appropriate). We intend to provide associated technical details for any new exposure and risk analyses in appendices or supplemental materials for the PA, while analyses from the last review are documented in the 2014 REAs, 2014 PA, and technical memos available in the O_3 docket for the last review. Any quantitative assessments newly developed in this review would then be made available for public comment and reviewed by the CASAC in the context of the draft PA. Public comments and CASAC advice on such REA-related analyses in the draft PA would be considered in finalizing analyses for presentation in the final PA.

In this chapter, quantitative exposure and risk assessments for informing the primary standard are discussed in section 5.1 and those pertaining to the secondary standard are discussed in section 5.2. Both of those sections present overviews of the types of analyses performed in the last review and highlight some considerations for analyses in this review.

5.1 ASSESSMENTS INFORMING REVIEW OF THE PRIMARY STANDARD

In reviews of primary NAAQS, quantitative exposure and health risk assessments are generally intended to inform consideration of key policy relevant questions (see section 3.1), such as the following:

- What are the nature and magnitude of exposures and health risks associated with air quality conditions just meeting the current standard?
- To what extent are the estimates of exposures and risks to at-risk populations associated with air quality conditions just meeting the current standard reasonably judged important from a public health perspective?

In considering exposure and risk estimates in this context, an accompanying consideration is:

- What are the important uncertainties associated with any risk/exposure estimates?

The types of analyses performed generally reflect the nature and strength of the evidence in various aspects. For example, for the health effects pertaining to exposures associated with the presence of the pollutant in ambient air, the availability and type of information from the health effects literature on relationships between internal dose, exposure, or ambient air concentration and health response influences the types of exposure assessment and risk characterization that are performed. The health assessments focus on exposure metrics that are appropriate for effects of concern for the subject pollutant, and along with available ambient air concentration measurements and model estimates, where appropriate, are used to generate estimates of exposure. Consistent with the health risk approaches that have been used in NAAQS reviews (illustrated in Figure 5-1), assessments of ambient air O_3-related health risks have been conducted in past reviews (including the last review) based on two different types of risk approaches. The first approach is based on relating areawide average ambient air concentrations to results from air quality epidemiologic studies by linking ambient air quality concentrations with concentration-response functions. The second approach is based on relating population exposure estimates to results from controlled human exposure studies and employing either a benchmark concentration or exposure-response (E-R) function-based approach to estimate risk.

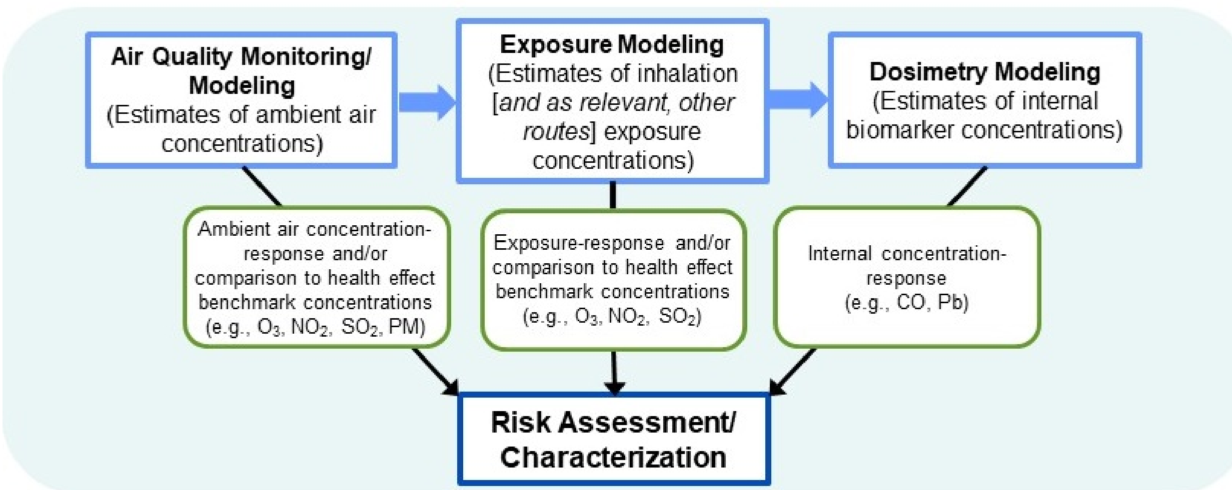

Figure 5-1. Summary of health risk assessment approaches that have been employed in NAAQS reviews.

In the review of the primary O_3 standard completed in 2015, the different types of analyses that were performed varied in the extent to which they informed consideration of the policy-relevant questions posed above. Accordingly, they also varied in the extent to which they informed conclusions and judgments related to revision of the then-existing primary O_3 standard. For example, the EPA generally expressed higher confidence in the 2014 HREA results for exposure-based analyses, which were based on evidence from controlled human exposure studies, as compared to HREA estimates derived from the ambient air concentrations and epidemiologic study associations (2014 HREA, section 9.6; 80 FR 65316).[80] These two types of

[80] The 2015 decision notice recognized key uncertainties in utilizing the estimated air concentrations and epidemiologic study relationships (often called epidemiologic-based risk estimates) with potentially important implications for the Administrator's consideration of epidemiology-based risk estimates (80 FR 65316; 79 FR 75277-75279; 2014 HREA, sections 3.2.3.2 and 9.6). These included the heterogeneity in effect estimates between locations, the potential for exposure measurement errors, and uncertainty in the interpretation of the shape of concentration-response functions at lower O_3 concentrations, as well as uncertainties related to the public

analyses are described below in sections 5.1.1.1 and 5.1.1.2, respectively. The roles of the analyses in conclusions reached and judgments made in the 2015 O_3 NAAQS review are summarized in section 5.1.2, as are key uncertainties and limitations of the analyses, along with considerations related to the availability of information, methods or tools in this review that may address them.

5.1.1 Overview of Assessments in Last Review

The HREA completed for the last review included two types of analyses. The first type was based on assessment of population exposure using exposure modeling (section 5.1.1.1), while the second relied on relating ambient air concentrations to adverse health outcomes using ambient air concentration-response functions drawn from epidemiologic studies (section 5.1.1.2). Figure 5-2 illustrates the conceptual model for these types of assessments in the framework of the traditional source to dose to health effects model.

health importance of increases in relatively low O_3 concentrations following air quality adjustment. Additionally, as noted in section 5.1.1.2 below, lower confidence was placed in the results of the epidemiologic-based assessment of respiratory mortality risks associated with long-term O_3 exposures in consideration of several factors.

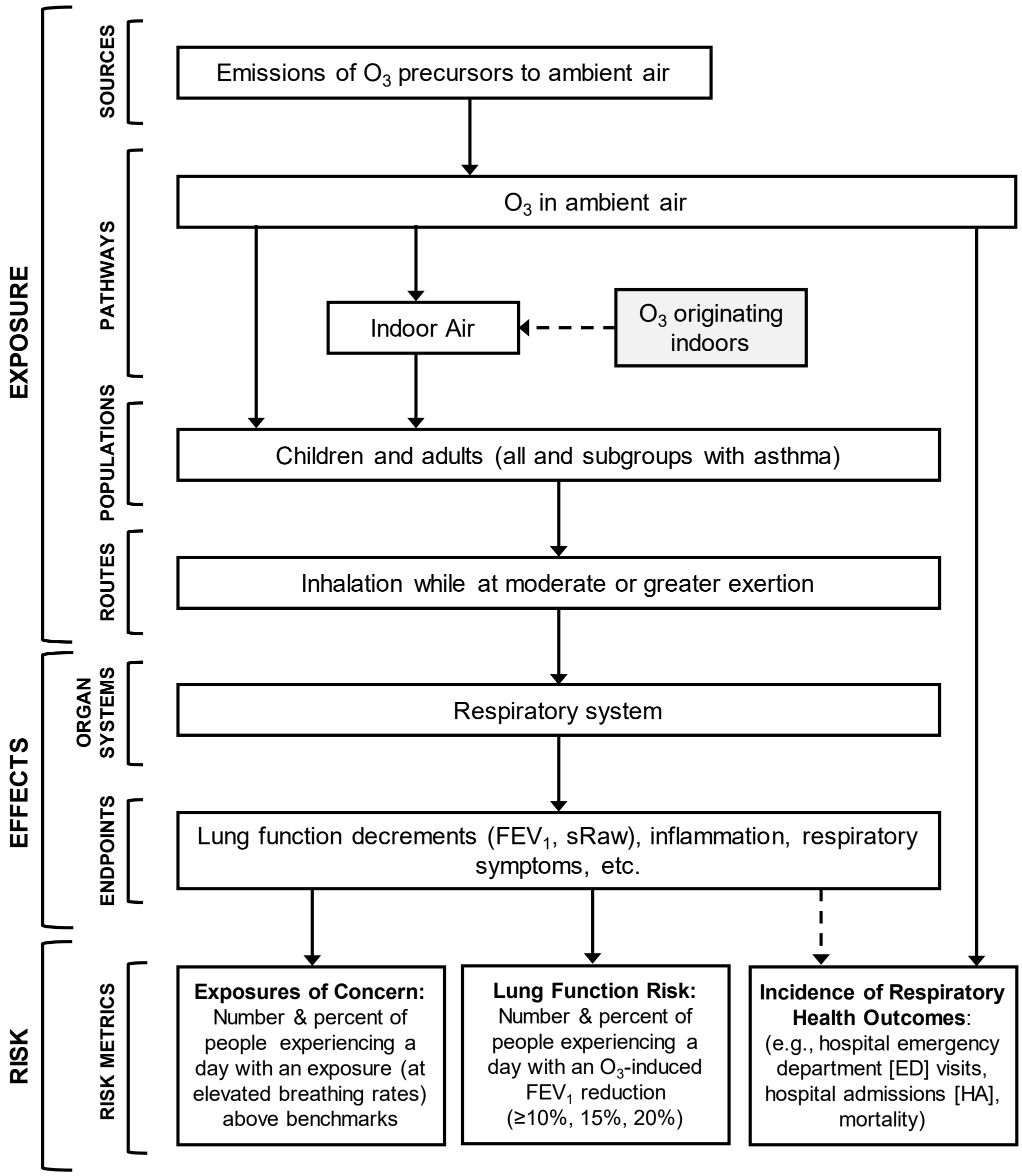

Figure 5-2. Conceptual model for 2014 O_3 health risk assessment. Solid lines indicate processes included in the 2014 assessment.

The long-standing evidence base for O_3-related adverse health effects is built from a large assemblage of controlled human exposure studies, laboratory animal research studies, and air quality epidemiologic studies. Together, these health effect studies lead to the strongly supported conclusion that O_3-related exposure causes respiratory effects (2013 ISA, section 6.2.9; 80 FR 65302). The controlled human exposure studies document the occurrence of an array of respiratory effects in humans in a variety of exposure circumstances, and additionally, in combination with the laboratory animal research studies, inform our understanding of the mode of action for O_3-attributable effects. The air quality epidemiologic studies provide additional support for the causal conclusion regarding effects of O_3 in ambient air (2013 ISA, section 6.2.9).

The quantitative characterizations of health risk or potential risk for which the support in the evidence has been strongest are those based on the exposure-based risk analyses, including the analysis used in the last three O_3 NAAQS reviews that involves the comparison of estimated population-based O_3 exposures experienced while at elevated exertion[81] to benchmark concentrations drawn from the controlled human exposure studies. A second set of exposure-based risk analyses performed for the last three O_3 reviews, has been those that employ a lung function risk estimation approach that also draws on results of the controlled human exposure studies. Another type of analysis that has been used is a risk approach based on ambient air concentration-response functions from air quality epidemiologic studies. This approach was also employed in the last two O_3 NAAQS reviews (e.g., to estimate risk for various health outcomes, such as hospital admissions), with a recognition of the uncertainties associated with the quantitative concentration-response functions used in that approach. In initial planning for the current review, we consider support for both types of health risk approaches (i.e., exposure-based and air quality epidemiologic-based), evaluating the extent to which the information newly available in this review provides support for developing updated or enhanced analyses that would substantially improve the utility of risk estimates for informing the current review.

In the 2014 HREA, the two exposure-based risk analyses were performed in a set of 15 urban study areas and the air quality epidemiologic-based risk analyses were performed for a subset of those areas.[82] Both approaches were performed for five different air quality scenarios: unadjusted air quality conditions, air quality adjusted to just meet the then-existing standard (75 ppb O_3 as a 3-year average of annual fourth highest daily maximum 8-hour average concentrations), and air quality adjusted to just meet potential alternative standards with levels of 70, 65 and 60 ppb.[83] The scenarios were based on air quality representing two 3-year periods: 2006-2008 and 2008-2010.

[81] As summarized in section 3.1 above, the focus on exposures while at elevated exertion reflects the evidence from controlled human exposure studies in which exposures to O_3 concentrations of a magnitude relevant to those occurring in ambient air have only been shown to result in respiratory effects if the ventilation rates of people in the exposed populations are raised to a sufficient degree, such as through physical exertion (2013 ISA, section 6.2.1.1).

[82] The 15 urban study areas assessed were Atlanta, Baltimore, Boston, Chicago, Cleveland, Dallas, Denver, Detroit, Houston, Los Angeles, New York, Philadelphia, Sacramento, St. Louis, and Washington, DC. The three not included in the epidemiologic-based assessment were Chicago, Dallas, and Washington, DC.

[83] These scenarios reflect air quality with design values – 8-hour values using the existing form of the NAAQS – that meet the level of the current or potential alternative standards. These simulations are illustrative and do not reflect any consideration of specific control programs designed to meet the specified standards. Further, these simulations do not represent predictions of when, whether, or how areas might meet the specified standards.

For the air quality scenarios that used adjusted air quality, ambient air O_3 concentrations that would just meet the then-current and potential alternative standards were estimated using a photochemical model-based adjustment approach (2014 HREA, Chapter 4). This approach employed the Community Multiscale Air Quality Model version 4.7.1 (CMAQv4.7.1) instrumented with the higher order decoupled direct method (CMAQ-HDDM).[84] The CMAQ-HDDM was used to estimate sensitivities[85] of O_3 concentrations to changes in precursor emissions; using this approach, we estimated hourly O_3 concentrations at each monitor location resulting from reductions in U.S. anthropogenic precursor emissions (i.e., NO_X, VOC).[86] This approach to adjusting air quality reflects the physical and chemical atmospheric processes that influence O_3 concentrations in ambient air (2014 HREA, Chapter 4).[87,88] For the exposure-based analyses, the adjusted air quality for census tracts comprising each study area was derived from the adjusted estimates at the ambient air monitor locations using the Voronoi Neighbor Averaging (VNA) spatial interpolation technique (2014 HREA, Chapter 4). For the air quality epidemiologic-based analyses, areawide average concentrations were developed from the adjusted concentrations at the ambient air monitoring sites in each study area.

[84] Details on model set-up, configuration, and input data are provided in 2014 HREA, Appendix 4B.

[85] Sensitivities of O_3 refer to predicted incremental changes in O_3 concentrations in response to incremental changes in emissions. The "higher order" aspect of the HDDM tool refers to the capability of capturing nonlinear response curves.

[86] Exposure and risk analyses for most of the urban study areas focus on reducing U.S. anthropogenic NO_X emissions alone. The exceptions are Chicago and Denver. Exposure and risk analyses for Chicago and Denver are based on reductions in emissions of both NO_X and VOC (2014 HREA, section 4.3.3.1; Appendix 4D).

[87] Compared to the statistical approaches that have been used in the past (e.g., a quadratic equation used in the 2007 REA to adjust high concentrations downwards at a greater rate than lower concentrations), the photochemical model adjustment approach provides more realistic estimates of the spatial and temporal responses of O_3 to reductions in precursor emissions. Because NO_X in ambient air can contribute to both the formation and the destruction of O_3 (2014 HREA, Chapter 4), the response of ambient air O_3 concentrations to reductions in NO_X emissions is more variable than indicated by the previously used quadratic adjustment. This improved approach to adjusting O_3 air quality is consistent with recommendations from the National Research Council of the National Academies of Sciences (NRC, 2008). In addition, the CASAC strongly supported the new approach as an improvement and endorsed the way it was utilized in the HREA, stating that "the quadratic rollback approach has been replaced by a scientifically more valid Higher-order Decoupled Direct Method (HDDM)" and that "[t]he replacement of the quadratic rollback procedure by the HDDM procedure is important and supported by the CASAC" (Frey, 2014a, pp. 1 and 3).

[88] Within urban study areas, the model-based air quality adjustments show reductions in the O_3 levels at the upper ends of ambient air concentrations and increases in the O_3 levels at the lower ends of those distributions (2014 HREA, section 4.3.3.2, Figures 4-9 and 4-10). It is important to note that sensitivity analyses in the HREA indicate that the increases in low O_3 concentrations are smaller when NO_X and VOC emissions are reduced together than when only NO_X emissions are reduced (2014 HREA, Appendix 4-D, section 4.7). Seasonal means of daily O_3 concentrations generally exhibit only modest changes upon model adjustment, reflecting the seasonal balance between daily decreases in relatively higher concentrations and increases in relatively lower concentrations (2014 HREA, Figures 4-9 and 4-10).

5.1.1.1 Exposure-based Risk Analyses

As noted above, two exposure-based risk analyses were performed for the 2014 HREA in the last review: one involving comparison of population exposures, while at elevated exertion, to benchmark concentrations, and the second involving estimated population occurrences of ambient air O_3-related lung function decrements (Figure 5-3). The exposure-to-benchmark comparison characterizes the extent to which individuals in at-risk populations could experience exposures of concern (i.e., concentrations at or above specific benchmarks while at moderate or greater exertion levels) while engaging in their daily activities in study areas with air quality adjusted to just meet the current and alternative O_3 standards. The lung function risk analysis provides estimates of the extent to which populations in such areas could experience decrements in lung function. For the former, results were characterized using three benchmark concentrations (60, 70, and 80 ppb O_3), exposures to which in controlled human exposure studies yielded different occurrences and severity of respiratory effects in the human subjects (2014 HREA, section 3.2). Similarly, based on the range of health effects considered clinically relevant and the potential for varied responses in healthy individuals versus people with asthma, the lung function risk analysis reported estimates for risk of lung function decrement at or above three different magnitudes, i.e., FEV_1 reductions of at least 10%, 15%, and 20% (2014 HREA, section 6.2.1).

The risk analysis involving comparison of 8-hour average exposure concentrations that coincide with an 8-hour average elevated ventilation rates to benchmark concentrations (section 5.1.1.1.1) provides perspective on the extent to which air quality adjusted to just meet different standards could be associated with discrete exposures to O_3 concentrations reported to result in respiratory effects. For example, estimates of such exposures can provide a sense of the potential for O_3-related effects in the exposed population, including effects for which we do not have E-R functions that could be used in quantitative risk analyses (e.g., airway inflammation). The exposure benchmark analysis differs from the second exposure-based risk analysis which estimates the population incidence of days with lung function decrements of magnitudes of interest. In the lung function risk analysis (section 5.1.1.1.2), the time-series of exposures and ventilation rates (rather than 8-hour average exposures and 8-hour average ventilation rates) for each modeled individual is used to estimate the associated occurrence of lung function decrements in that simulated individual.

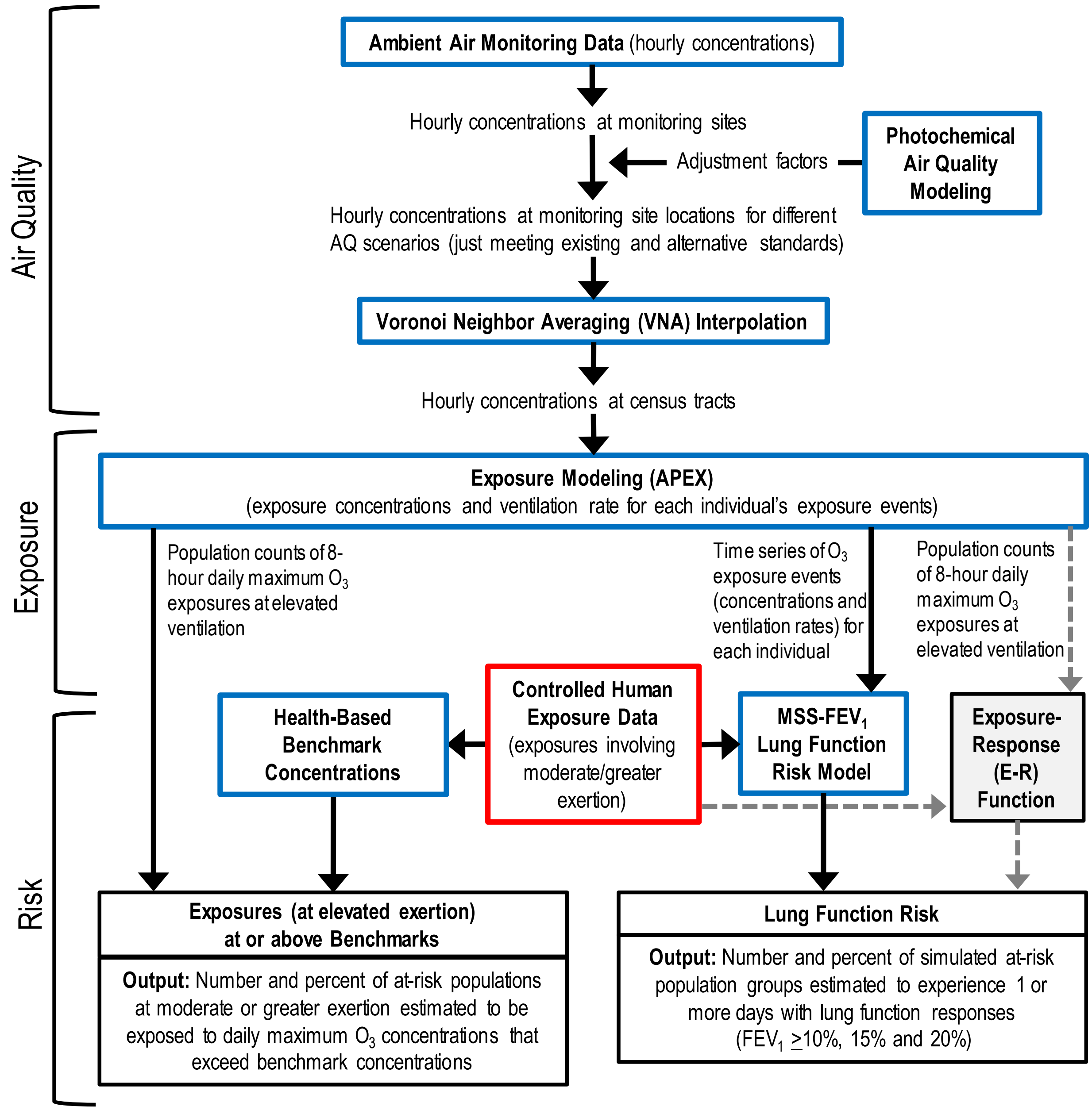

Figure 5-3. Analytical approach for exposure-based risk analyses. Dashed lines and gray box indicate the sole lung function risk approach used prior to 2014 HREA.

The 2014 HREA derived results for both types of exposure-based analysis for a set of populations in the 15 study areas under the specified conditions for each of the air quality scenarios. Population-based exposures used for analyses in the 2014 HREA were estimated using the Air Pollutants Exposure (APEX) model.[89] The APEX model is a probabilistic model that

[89] Exposure modeling has been employed in the past several reviews of the O_3 NAAQS, as well as reviews of the primary NAAQS for sulfur oxides, oxides of nitrogen, and carbon monoxide (U.S. EPA, 2008, 2009, 2010, 2018e). In the absence of large-scale exposure studies that encompass the general population, as well as at-risk

simulates a large number of randomly sampled individuals residing within a given study area (i.e., 50,000 to 200,000 people, depending on the simulated study group). U.S. Census demographic data are used by APEX, typically at a census tract level, to weight the population distribution within the geographic area and best represent area-wide population exposures. The APEX model simulates the movement of individuals through time and space by accounting for the places they may visit and the activities they may perform, and then estimates their time-series of O_3 exposures occurring within indoor, outdoor, and in-vehicle microenvironments (2014 HREA, section 5.1.3). By incorporating individual activity patterns, the model estimates physical exertion associated with each exposure event.[90] This aspect of the exposure modeling is critical in assessing exposure, ventilation rate, intake dose, and estimated health risk for ambient air concentrations of O_3.

The APEX model accounts for the most important factors that contribute to human exposure to O_3 from ambient air, including the temporal and spatial distributions of people and ambient air O_3 concentrations throughout a study area, the variation of ambient air-related O_3 concentrations within various microenvironments in which people conduct their daily activities, and the effects of activities involving different levels of exertion on breathing rate (or ventilation rate) for the exposed individuals of different sex, age, and body mass in the study area (2014 HREA, section 5.1.3). To the extent spatial and/or temporal patterns of ambient air O_3 concentrations are modified by the air quality adjustment as discussed above, exposure estimates reflect population exposures to those modified patterns of ambient air O_3 concentrations.

To represent personal time-location-activity patterns of simulated individuals, the APEX model draws from the consolidated human activity database (CHAD) developed and maintained by the EPA (McCurdy et al., 2000; U.S. EPA, 2017).[91] The activity patterns of individuals are an important determinant of their exposure due to the influence of exposure concentration, event duration, and ventilation rate (2013 ISA, section 4.4.1). Because of variation in O_3 concentrations among the various microenvironments in which individuals are active, the amount of time spent in each location, as well as the exertion level of the activity performed, will

populations, modeling is the preferred approach to estimating exposures to O_3. Additional information on APEX can be found at: https://www.epa.gov/fera/human-exposure-modeling-air-pollutants-exposure-model.

[90] An exposure event occurs when a simulated individual inhabits a microenvironment for a specified time, while engaged at a constant exertion level and experiencing a particular pollutant concentration. If the microenvironmental concentration and/or activity/activity level changes, a new exposure event occurs (McCurdy and Graham, 2003).

[91] The CHAD is comprised of data from several surveys that collected activity pattern data at city, state, and national levels. Included are personal attributes of survey participants (e.g., age, sex), the locations visited and activities performed by survey participants throughout a day, and the time-of-day activities occurred and their duration. Additional information is available at: https://www.epa.gov/healthresearch/consolidated-human-activity-database-chad-use-human-exposure-and-health-studies-and

influence an individual's exposure to O_3 from ambient air and potential for adverse health effects. Activity patterns vary both among and within individuals, resulting in corresponding variations in exposure across a population and over time (2013 ISA, section 4.4.1). For each exposure event, APEX tracks activity, ventilation rate, exposure concentration, and duration. The time-series of exposure events serve as the basis for exposure metrics of interest, such as the daily maximum 8-hour exposure. Development of the two exposure-based metrics derived for the 2014 HREA (comparison to benchmarks and lung function risk) is summarized in the subsections below.

5.1.1.1.1 Benchmark Comparison

In the comparison-to-benchmarks analysis for the last review, the percent and number of individuals in the study area populations expected to experience one or more days with an exposure at or above benchmark concentrations, while at specified exertion levels, were estimated (2014 HREA, chapter 5). As summarized in section 3.1 above, the benchmark concentrations for this analysis (60, 70, and 80 ppb O_3) were established based on a set of controlled human exposure studies of healthy adults engaged in moderate or greater exertion, while exposed to those concentrations (2013 ISA, section 6.2; 2014 PA, section 3.1.2.1). These studies employed a 6.6-hour quasi-continuous exposure during which subjects participated in five 50-minute exercise periods, each followed by 10-minute rest periods, with a 35-minute lunch period after the third hour (e.g., Folinsbee et al., 1988 and Schelegle et al., 2009). The lowest benchmark, 60 ppb, represents the lowest O_3 exposure concentration, as a time-weighted average, for which these controlled human exposure studies have reported respiratory effects. At this concentration, there is evidence of a statistically significant decrease in lung function and increase in airway inflammation (Brown et al., 2008; Adams, 2006). Exposure to approximately 70 ppb[92] averaged over a similar time resulted in larger lung function decrements (and greater prevalence of decrements) than was observed for 60 ppb, as well as an increase in prevalence of respiratory symptoms. In such studies, exposures of 80 ppb O_3, as a time-weighted average, resulted in larger lung function decrements than following exposures to 60 or 70 ppb, in addition to an increase in airway inflammation, increased respiratory symptoms, increased airway responsiveness, and decreased resistance to other respiratory effects (section 3.1.2.1, above).

For the 2014 REA, population exposures were estimated for four study groups: all school-age children (ages 5 to 18), school-age children with asthma, adults with asthma (ages 19 to 95), and all older adults (ages 65 to 95) in each of the 15 urban study areas (2014 HREA, section 5.2.5). The results given primary attention in the review were those for school-age

[92] The study on which the 70 ppb benchmark concentration is based, Schelegle et al. (2009), reported that the actual mean exposure concentration was 72 ppb.

children (ages 5-18), including school-age children with asthma,[93] both of which were identified as key at-risk populations in the ISA (2014 PA, section 3.1.5). The percentages of children estimated to experience exposures at or above benchmarks are considerably larger than the percentages estimated for adult populations (2014 HREA, section 5.3.2 and Figures 5-5 to 5-8). The larger benchmark exposure estimates for children are due primarily to the larger percentage of children estimated to spend an extended period of time being physically active outdoors during times of day when O_3 concentrations are highest compared to other population study groups (2014 HREA, sections 5.3.2 and 5.4.1).

In estimating the exposures used for comparison to benchmark concentrations, the APEX model averages exposures over a duration of interest. In addition, the model averages the ventilation rate ($\dot{V}_E$) for the exposed individual (based on the activities performed) over that exact same period. This can be done because APEX simultaneously estimates $\dot{V}_E$ and exposure concentration for every individual's time-series of exposure events. For the exposure duration of interest (e.g., 5 minutes, 1 hour, or 8 hours), the model then derives and outputs the daily maximum average $\dot{V}_E$ (and hence an equivalent ventilation rate or EVR)[94] and exposure concentration for the specified duration for each simulated individual. The model produces summary tables based on comparison to the specified benchmark concentrations. The averaging time and EVR used in the 2014 HREA – 8-hour average and 13 L/min-m^2 – reflect parameter values for the exposure assessments performed for the last three O_3 NAAQs reviews (2014 HREA; U.S. EPA, 2007; Whitfield, 1996). Additional details on this analysis are provided in Chapter 5 and the associated appendices of the 2014 HREA.

5.1.1.1.2 Lung Function Risk Assessment

In the 2014 HREA, risk of lung function decrements in terms of FEV_1 reductions of at least 10%, 15% and 20% was estimated using two different approaches.[95] The primary estimates were based on a new approach that estimates FEV_1 responses for simulated individuals associated with short-term exposures to O_3 (McDonnell, Stewart, and Smith, 2007, 2010;

[93] In terms of the percentage of the exposed population experiencing days at or above the benchmark concentrations, the estimates for all children and children with asthma are virtually indistinguishable (2014 HREA, Chapter 5). This is because HREA analyses indicate that activity data (i.e., time spent outdoors, exertion level) for people with asthma are generally similar to people not having asthma (2014 HREA, Appendix 5G, Tables 5G-2 to 5G-5).

[94] To reasonably extrapolate the ventilation rate of the controlled human study subjects (i.e., adults having a specified body size and related lung capacity), who were engaging in quasi-continuous exercise during the study period, to individuals having varying body sizes (e.g., children with smaller size and related lung capacity), an equivalent ventilation rate (EVR) was calculated by normalizing the ventilation rate (L/min) by body surface area (m^2).

[95] Both approaches to estimating lung function risk have been implemented in the air pollution exposure model APEX (U.S. EPA, 2012a,b).

McDonnell et al., 2012). This approach (termed here, the McDonnell-Stewart-Smith [MSS]-FEV_1 model) uses the time-series of O_3 exposure, corresponding ventilation rates, and a few other influential personal attributes (e.g., age, body surface area) for each APEX simulated individual to estimate their personal time-series of ambient air O_3-related FEV_1 reductions, effectively utilizing an individual-based approach to estimate lung function risk. When selecting for the daily maximum FEV_1 reduction for each person and aggregating across individuals, APEX estimates the percent and number of people at risk, i.e., those experiencing FEV_1 reductions of at least 10%, 15% and 20%, in a study area.

The 2014 HREA also provided lung function risk estimates following the methodology used in the previous reviews which employs a simpler, population-based E-R function approach to estimate the percent and number of people at risk in a study area (Whitfield et al, 1996; U.S. EPA, 2007; U.S. EPA, 2014).[96] This approach uses a Bayesian Markov Chain Monte Carlo approach to develop probabilistic E-R functions to estimate the probability of O_3-related lung function decrements (U.S. EPA, 2007). These E-R functions were then combined with the APEX estimated population distribution of 8-hr maximum exposures for people at or above moderate exertion ($\geq$ 13 L/min-m^2 body surface area) to estimate the number of people expected to experience lung function decrements. A key difference between the population-based E-R function approach and the MSS-FEV_1 model is that the previous method estimates a population distribution of FEV_1 reductions by using the population-based distribution of daily maximum 8-hour average exposures while at moderate or greater exertion, where the MSS-FEV_1 model estimates maximum FEV_1 reductions at the individual level using their continuous time-series of exposures and concomitant breathing rates. The lung function risk estimates from the MSS-FEV_1 model for simulated individuals are then aggregated to a population level (2014 HREA, section 6.2.2).

The MSS-FEV_1 model was used in the 2014 HREA to estimate exposure-based lung function risk for three population groups: school-age children (5-18 years), young adults (19-35 years), and adults (aged 36-55 years) in all 15 urban study areas (2014 HREA, section 6.3). This model (along with an age adjustment term) was developed based on data from controlled human exposure study subjects aged 18 to 35 years and was used in the 2014 HREA to estimate lung function risk for individuals as young as 5 years and as old as 55 years based on the 2013 ISA's

[96] The 2014 HREA referred to this approach as the "population E-R model", the same general form of which was used in the previous reviews.

interpretation of the available information for these age groups (2014 HREA, section 6.2.4 and Appendix 6E). [97,98]

Additional details on this analysis are provided in Chapter 6 and the associated appendices of the 2014 HREA.

5.1.1.2 Air Quality Epidemiologic Study-based Risk Analyses

Ozone-associated risk of various respiratory health outcomes and mortality were estimated in twelve urban study areas using concentration-response (C-R) functions drawn from the epidemiologic studies and "area-wide" average O_3 concentrations, primarily in terms of several daily air quality metrics (HREA, Table 7-2, Appendix 7A).[99]

The health outcomes for which O_3-associated risk was estimated using the daily air quality metrics were: hospital admissions (HAs) for any respiratory outcome (Katsouyanni et al., 2009; Linn et al., 2000); HAs for chronic lung disease, except asthma (Medina-Ramon et al., 2006); emergency department (ED) visits for any respiratory outcome (Strickland et al., 2010, Tolbert et al., 2017, Darrow et al., 2011); ED visits for asthma (Ito et al., 2007), incidence of

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[97] Assumptions made for extending the MSS-FEV_1 model to children younger than 18 years old were in part based on a McDonnell et al. (1985) study of children aged 8 to 11 years old who experienced FEV_1 responses similar to those observed in adults aged 18 to 35 years old when both groups were exposed to 120 ppb O_3 at an EVR of 32-35 L/min/m^2. In addition, summer camp studies of school-aged children exposed outdoors in the Northeast also showed O_3-induced lung function changes similar in magnitude to those observed in controlled human exposure studies using adults (e.g., Spektor et al., 1988; Spektor and Lippmann, 1991; see ISA section 6.2.1.2). Thus, for children younger than 18 years old, we set the MSS-FEV_1 model age term to its highest value, the value used for age 18.

[98] Assumptions made for extending the MSS-FEV_1 model to adults older than 35 years old were based on evidence indicating lung function responses to O_3 exposure for adults older than 18 decrease with age until around age 55, when responses are minimal. "Children, adolescents, and young adults appear, on average, to have nearly equivalent spirometric responses to O_3, but have greater responses than middle-aged and older adults when similarly exposed to O_3" (2013 ISA p. 6-21). "In healthy individuals, the fastest rate of decline in O_3 responsiveness appears between the ages of 18 and 35 years (Passannante et al., 1998; Seal et al., 1996), more so for females than males (Hazucha et al., 2003). During the middle age period (35-55 years), O_3 sensitivity continues to decline, but at a much lower rate. Beyond this age (>55 years), acute O_3 exposure elicits minimal spirometric changes" (2013 ISA p. 6-23). Based on the effect age has on responses observed for middle aged adults, the model was set with a linearly decreasing response with increasing age for individuals between ages 36 to 55. For adults older than 55 years, the MSS-FEV_1 model age term was nullified (2014 HREA, sections 6.2.3.1 and 6.2.4; 2013 ISA, pp. 6-21 and 6-23). Simulations were still performed for adults older than 55 years; however, there was minimal O_3-induced lung function risk estimated for any of the air quality scenarios (HREA, section 6.6).

[99] The air quality metrics analyzed in the epidemiologic studies from which concentration-response functions were taken are daily maximum 1-hour, daily maximum 8-hour average and daily 24-hour average concentrations, each averaged across multiple monitors within study areas (2014 HREA, Appendix 7A, Table 7-2). The epidemiologic studies use these ambient air quality metrics as surrogates for the spatial and temporal patterns of exposures in study populations. Accordingly, the HREA applied the C-R functions obtained from the epidemiologic studies to O_3 concentrations in terms of these same ambient air metrics, as averaged across ambient air monitor locations in each study area (2014 HREA, section 4.3.2.2). In the last review, we referred to these area-averaged concentrations as "composite monitor" or "area-wide" O_3 concentrations (e.g., 2014 PA, section 3.1.4; 2014 HREA, section 4.3.2.2).

asthma exacerbation-related chest tightness, shortness of breath or wheeze (Gent et al., 2003); and mortality (Smith et al., 2009; Zanobetti and Schwartz, 2008; Jerrett et al., 2009[100]). Risk estimates were derived for each health outcome for 12 urban study areas,[101] or a subset thereof, depending on the array of study areas included in the epidemiologic studies from which each C-R function was drawn (HREA, Table 3-1).

These risk estimates were derived for air quality scenarios involving unadjusted air quality from five years encompassing two 3-year periods (2006-2008, 2008-2010), model-adjusted air quality just meeting the then-current standard (75 ppb), and three potential alternative standards with alternative levels of 70, 65 and 60 ppb (2014 HREA, section 7.1.1). The risk estimates were derived using the EPA's Environmental Benefits Mapping and Analysis Program (BenMAP, version 4.0)[102] for the specified health outcomes and locations with the C-R function information from the studies cited for those outcomes and other relevant information for the analysis. In presenting the results for the two 3-year periods assessed for each air quality scenario, the HREA presented the annual risk estimates for one year with generally higher O_3 concentrations (2007) and one year with generally lower O_3 concentrations (2009). Additional detail on these analyses is provided in section 3.7, Chapter 7 and the associated appendices of the 2014 HREA.

[100] The C-R functions from Jerrett et al. (2009) related O_3-associated respiratory mortality to seasonal averages of daily max 1-hour O_3.

[101] The 12 urban areas were Atlanta, Baltimore, Boston, Cleveland, Denver, Detroit, Houston, Los Angeles, New York, Philadelphia, Sacramento, and St. Louis.

[102] BenMAP is a GIS-based computer program that draws upon a database of population, baseline incidence/prevalence rates and effect coefficients to automate the calculation of health impacts (2014 HREA, Chapter 7; U.S. EPA, 2013b). Additional information available at: https://www.epa.gov/benmap.

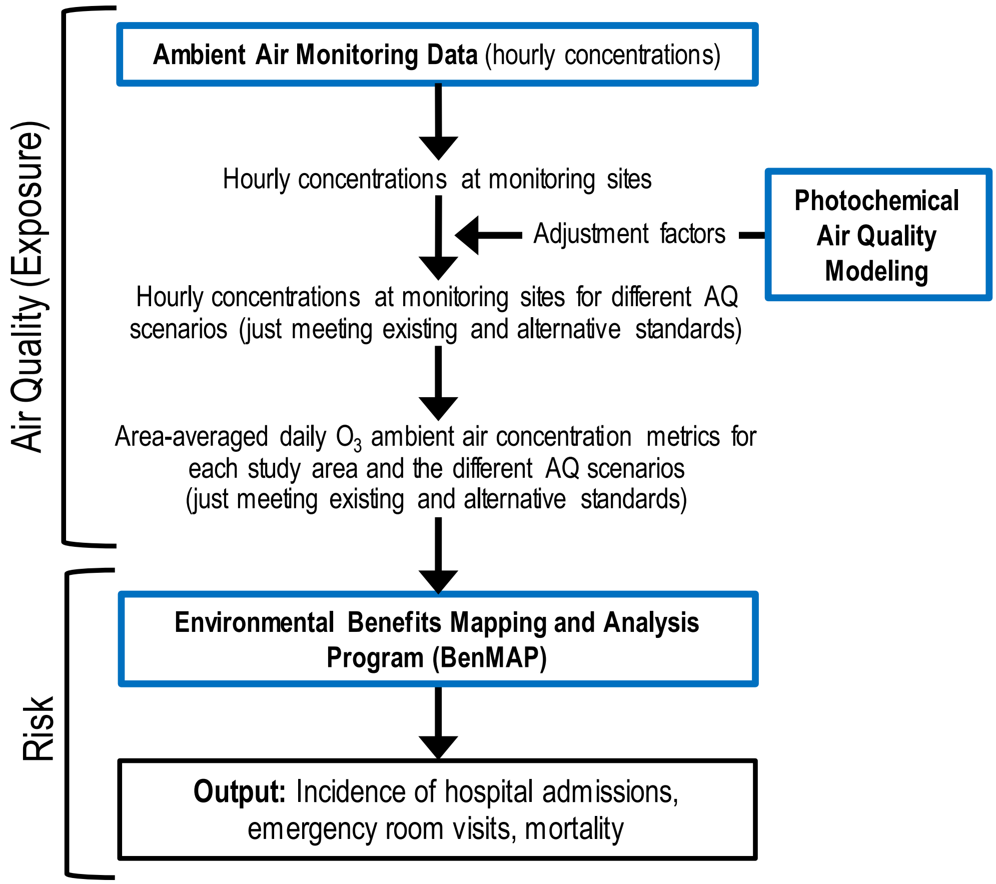

Figure 5-4. Analytical approach for epidemiologic-based analyses.

5.1.2 Assessments for this Review

In the preceding section we have briefly summarized air quality, exposure and risk analyses developed in the last review, noting key uncertainties or limitations associated with the various assessments. The two sections below briefly summary key considerations in our planning for assessments in the current review and our initial plans for such analyses.

5.1.2.1 Key Considerations

Our planning for assessments in this review will consider the uncertainties and limitations that were highlighted during the last review to direct new analyses (if any) toward reducing such uncertainties. This approach could potentially improve the utility of risk estimates in informing the current review. As a first step, we consolidated the previously identified and characterized uncertainties in the 2014 HREA,[103] along with integrating any related discussions found in the

[103] The 2014 HREA (sections 5.5, 6.5.7, and 7.4.2) included a characterization of uncertainty in which elements were judged regarding the potential for associated uncertainty to influence the risk estimates, with attention given to those elements described to have the potential for a "moderate" or greater influence on risk estimates.

2014 PA, the proposed and final rulemaking notices in the last review and consideration of public comments in the 2015 response to comments document. Then, as in any review, we considered the availability of new information, models, and tools since completion of the prior assessment that have potential to better characterize key areas of uncertainty. Further, we identified model/assessment aspects for which updates may reduce uncertainty or address limitations, thus improving appropriateness of model outputs for their intended purposes. And finally, following the review of this information, consideration was also given to new uncertainties and limitations relevant for this review that were not explicitly identified in the prior review documents. Detailed results of this characterization are given in Appendix 5A and are summarized below.

Regarding the exposure-based analyses (as summarized in section 5.1.1.1 above), several important uncertainties were identified in the last review, largely related to estimating ambient air concentrations, estimating exposure concentrations (and concomitant exertion levels), and modeling lung function decrements. In this review, there are newly available ambient air quality data that better reflect concentrations at or near the current standard, updated emissions data and air quality models, and updates to the exposure model to better estimate exposure-based risk (Appendix 5A). Regarding the epidemiologic-based risk approach (as summarized in section 5.1.1.2 above), there were also several important uncertainties identified in the 2014 HREA. However, it is expected that, for most if not all the recognized uncertainties except for those related to the estimation of ambient air quality, there is unlikely to be newly available information, models, or tools that would result in substantially improved risk estimates with appreciably less uncertainty than those in the 2014 HREA (Appendix 5A).[104]

5.1.2.2 Initial Plans for the Current Review

Based upon the findings presented in Appendix 5A, we expect that any new quantitative analyses in this review would focus on exposure-based analyses that can benefit from updated information, models, and tools, ensuring that the new exposure and risk estimates are both improved and appropriately targeted. Estimates from the exposure-based analyses, particularly the comparison of maximum exposures to benchmark concentrations, were most informative to the Administrator's decision in the last review (as summarized in section 3.1.2 above). This largely reflected the EPA conclusion that "controlled human exposure studies provide the most

[104] There are several important uncertainties associated with aspects of the O_3 epidemiologic study-based approach used in the last review for which information available in this review is not expected to appreciably affect, such that they are expected to still have a moderate or greater impact on risk estimates. Such uncertainties include those involving the correlation of population O_3 exposures and ambient air monitor concentrations (including the use of area wide average O_3 concentrations) and uncertainties in the derived concentration-response functions (e.g., the shape of concentration response curves at the lowest O_3 concentrations). See Appendix 5A for details.

certain evidence indicating the occurrence of health effects in humans following specific O_3 exposures," and recognition that "effects reported in controlled human exposure studies are due solely to O_3 exposures, and interpretation of study results is not complicated by the presence of co-occurring pollutants or pollutant mixtures (as is the case in epidemiologic studies)" (80 FR 65343, October 26, 2015). In the last review, the Administrator placed relatively less weight on the air quality epidemiologic-based risk estimates, in recognition of an array of uncertainties, including, for example, those related to exposure measurement error (80 FR 65346, October 26, 2015).

Therefore, based on preliminary consideration of the information cited here, including consideration of the complex and extensive exposure and risk analyses performed for the 2014 REA, and given the expedited nature of this review, we are planning to focus new analyses in this review on exposure-based risk analyses. This would reflect the emphasis given to these types of analyses and the characterization of their uncertainties in the last review, along with the expectation of having newly available information, models, and tools that could address such uncertainties (Appendix 5A). Briefly, updates to these new analyses would build upon the combined ambient monitor data, air quality modeling, and exposure/risk modeling approach used in the last review, as follows.

Air quality updates

- Use recent ambient air monitoring data (e.g., 2015-2017) from US EPA's Air Quality System (AQS) having unadjusted concentrations at or near the current standard. The prior assessment used 2006-2010 air quality conditions, that in many study areas, had unadjusted ambient monitor design values that were well above (>10 ppb) the then-existing standard (HREA 2014, section 4.3.1.1, Table 4-1)
- Use photochemical modeling (CAMx version 6.5)[105] to adjust ambient air concentrations to just meet the air quality scenarios to be assessed
  - Most recent CAMx model contains updated chemical mechanisms reflecting understanding of important chemical pathways for ozone formation and destruction
  - Use recent year modeling inputs that reflect emissions, meteorology and international transport (e.g., 2016). For example, on-road/non-road emissions estimates have been substantially improved via use of the recent MOVES model (2014) versus that previously used (MOBILE6)[106]

APEX exposure modeling updates

- Model input data

[105] CAMx is the Comprehensive Air Quality Model with Extensions. Additional information and model download can be found at http://www.camx.com/.

[106] MOVES is the Motor Vehicle Emissions Simulator (see http://www.epa.gov/otaq/models/moves/index.htm) and MOBILE6 is the Mobile Source Emission Factor Model, version 6 (see http://www.epa.gov/otaq/m6.htm)

- Use most recent U.S. Census demographics and commuting data (i.e., 2010).
- Use meteorological data to reflect the assessment years studied (e.g., 2015-2017).
- Update estimated asthma prevalence for all census tracts in all study areas (e.g., 2014-2017). Compared to prevalence used in the prior review (2006-2010), asthma prevalence shows an increasing trend for children aged 10-17 years (Akinbami et al., 2016) and adults through 2013-2014 (CDC, 2016)[107]

- Model algorithms, tools, and approaches
  - Updated equations to estimate resting metabolic rate (RMR) and associated ventilation rate ($\dot{V}_E$). Compared to the equations previously used, the overall statistical model fit and predictability has been improved (U.S. EPA, 2018 Appendix H)
  - Improve matching of controlled human exposure study duration (6.6-hour) and target $\dot{V}_E$ (EVR) to that estimated for simulated individuals and used for benchmark comparisons and population-based E-R lung function risk estimates (2014 HREA, section 5.2.8). Addressing this limitation would more appropriately identify when simulated individuals experience benchmark concentrations of interest.
  - Use a probit link to fit the population-based E-R function used to estimate lung function risk (rather than the combined logistic/linear model fit used previously). Note that using logistic fit in E-R functions may overestimate the contribution of risk attributed to low O_3 exposure levels (U.S. EPA, 2018, section 4.6.2)
  - Use new MSS-FEV_1 model (McDonnell et al., 2013) to estimate individual-based lung function risk. In comparison to their previous model (McDonnell et al. 2012) that was used in the prior review, McDonnell et al (2013) indicates that when accounting for intra-subject variability in their new model yields an improved model fit, however it is uncertain as to how that new model might affect risk estimates.

Given the rapid timeline for this review, we would expect to focus on a streamlined set of study areas and air quality scenarios compared to the expansive set assessed in the last review. As in prior NAAQS reviews, a collection of study areas will be used to estimate population exposures and risks, primarily considering those areas having ambient air O_3 concentrations at or near the current standard and comprising a large population (e.g., consolidated statistical areas that include urban and suburban populations). In addition to consideration of the above assessment updates, we plan to also update our characterization of uncertainties in the exposure-based risk analyses (2014 HREA sections 5.4, 5.5, 6.4, and 6.5), largely informed by input data evaluations, sensitivity analyses, and model performance evaluations, where possible.

We expect to consider in the PA other types of analyses from the last review that we do not update in this review but that remain informative to this review when viewed in the context

[107] https://www.cdc.gov/nchs/products/databriefs/db239.htm

of the currently available evidence as characterized in the ISA and of updated air quality and other analyses performed for this review. Accordingly, the PA for this review will describe and discuss in detail, all risk and exposure analyses considered informative to this review. This would include risk and exposure analyses newly developed in this review, as well as analyses performed for the last review for which updated analyses were not performed. The draft PA will be released for public comment and provided to the CASAC for their review. Advice and comments received on this information will be considered in completing any updated risk and exposure analyses and drawing on them in the policy evaluations presented in the final PA.

5.2 ASSESSMENTS INFORMING REVIEW OF THE SECONDARY STANDARD

In reviews of secondary standards, quantitative exposure and risk assessments for welfare effects are generally intended to inform consideration of key policy relevant questions (see section 3.2), such as the following:

- What are the nature and magnitude of exposure- and risk-related estimates for welfare effects associated with air quality conditions just meeting the current standard?
- To what extent are the estimates of exposures and risks associated with air quality conditions just meeting the current standard reasonably judged important from a public welfare perspective?

In considering exposure and risk estimates in this context, an accompanying important consideration is:

- What are the important uncertainties associated with any risk/exposure estimates?

The types of analyses performed generally reflect the nature and strength of the evidence in various aspects. For example, for the welfare effects pertaining to exposures associated with the presence of the pollutant in ambient air, the availability of concentration-response, exposure-response, or dose-response data from the welfare or ecological effects literature influences the types of exposure and risk assessments that are performed. The assessments focus on exposure metrics that are appropriate for effects of concern for the subject pollutant, with available measurements and model estimates, where appropriate, used to generate estimates of exposure.

Several different exposure and risk analyses were conducted in the last review of the secondary O_3 standard. They included extensive air quality-based analyses, E-R function-based risk analyses and some monitoring-based analyses in the 2014 WREA, as well as monitoring-based analyses in the 2014 PA and in technical memoranda developed for the rulemaking notices. Some types of these quantitative analyses were more informative to the 2015 decision on the standard than others. Regarding the key policy-relevant questions above, the uncertainties associated with results for some analyses limited their use in the Administrator's decision-making, while uncertainties regarding public welfare significance of the findings for other analyses also limited such use of those analyses. In general, decision-making in the last review placed greatest weight on estimates of cumulative exposures to vegetation based on ambient air monitoring data and consideration of those estimates in light of E-R relationships for O_3-related reduction in tree growth (summarized in section 3.2 above). These analyses supported the Administrator's consideration of the potential for O_3 effects on tree growth and productivity, as well as its associated impacts on a range of ecosystem services, including forest ecosystem productivity and community composition (80 FR 65292, October 26, 2015).

In the first section below (section 5.2.1), we provide an overview of the set of assessments performed in the 2015 review. In the subsequent section (section 5.2.2), the relative roles of the analyses in judgments made and conclusions reached in the 2015 review are indicated, along with some key uncertainties and limitations of the analyses. In this section we additionally consider information, methods or tools that may be newly available in this review and that may address these uncertainties or limitations and thus provide for the development of appreciably improved analyses that might be considered in this review, in combination with the comprehensive analyses developed in the last review that remain informative to this review.

5.2.1 Overview of Assessments in Last Review

Quantitative analyses performed in the last review included both the extensive analyses presented in the 2014 WREA and a smaller set of additional analyses, which were presented in the 2014 PA or in technical memoranda to the rulemaking docket and that were described in the notices of proposed and final rulemaking for the 2015 decision.

The full set of analyses presented in the 2014 WREA were generally related to two types of effects on vegetation: (1) reduced growth in both trees (relative biomass loss or RBL) and agricultural crops (relative yield loss or RYL), and (2) visible foliar injury (2014 PA; 2014 WREA; 80 FR 65374-65376, October 26, 2015; 79 FR 75324-75329, December 17, 2014). Estimates of O_3-related reduced growth in native trees and crops were based on combining E-R functions described in the 2013 ISA for a set of tree and crop species with estimates of O_3 exposures. These risk estimates were developed nationally, as well as in a small set of study areas. The foliar injury related analyses were based on information from the U.S. Forest Service (USFS) that included estimates of W126-based cumulative exposure[108] and foliar injury scores at

[108] The W126 index is described above in section 3.2.2.

established biosites[109] in 41 states in the contiguous U.S.[110] Analyses of reduced growth, in both trees and agricultural crops, are described in section 5.2.1.1 and assessments regarding visible foliar injury are described in section 5.2.1.2.[111] The additional analyses, which, in combination with E-R functions described in the 2014 WREA and summarized in the 2014 PA, proved to be more informative to the 2015 decision than the WREA analyses, are summarized in section 5.2.1.3 (2014 WREA, section 6.2; 2014 PA, section 5.2.1; 80 FR 65382-65410, October 26, 2015).

5.2.1.1 Growth-related Assessments

The growth-related assessments performed in the WREA included national-scale analyses of tree growth (in terms of RBL) and crop yield (in terms of RYL), and also estimation, at national or smaller scales, of associated changes in related ecosystem services, including pollution removal, carbon sequestration or storage, and hydrology, as well as impacts on the forestry and agriculture sectors of the economy. These assessments were conducted for several air quality scenarios developed by adjusting air quality data using factors derived from regional photochemical modeling to achieve reduced concentrations of O_3 that just met the different scenario objectives.

The air quality scenarios included one in which the then-current standard was just met and additional scenarios in which the maximum 3-year W126-based exposure equaled 15, 11, and 7 ppm-hrs.[112] These scenarios were developed from ambient air monitoring data for 2006 to 2008 and adjustments based on model-predicted relationships between the response of O_3 concentrations at each monitor location to reductions in NO_X emissions for the associated NOAA climate region. The adjustments were applied independently for each of the nine NOAA climate regions in the U.S., such that the highest monitor in the region was adjusted to just meet the

[109] Sampling sites in the National Forest Service's Forest Inventory and Analysis Forest Health Monitoring O_3 biomonitoring program, called "biosites", are plots of land on which data are collected regarding the incidence and severity of visible foliar injury on a variety of O_3-sensitive plant species. Biosite index scores are derived from these data (2014 WREA, section 7.2.1).

[110] Data were not available for several western states (Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, Oklahoma, and portions of Texas).

[111] The 2014 WREA also presented several more descriptive exposure analyses where W126-based cumulative O_3 exposure was estimated for different modeled air quality scenarios in areas of high fire or beetle infestation threat (2014 WREA, sections 5.2.3 and 5.4).

[112] The target for each scenario was judged to have been met when the O_3 concentrations at the monitor location with the highest concentrations equaled the target. For example, for the then-current standard scenario, the highest monitor location had a fourth highest daily maximum 8-hour O_3 concentration averaged over three years equal to 75 ppb. For the W126 scenario of 15 ppm-hrs, the target was met when the 3-year average W126 index value at the monitor with the highest 3-year W126 value equaled 15 ppm-hrs. The development of the air quality scenarios is further summarized in the final decision notice (80 FR 65374-65375, October 26, 2015) and Table 5-4 of the 2014 PA, and described in detail in Chapter 4 and Appendix 4A of the 2014 WREA.

target for the air quality scenario, and other monitor sites not already at/below the target for the scenario were adjusted by the same factor.[113] Based on the adjusted concentrations at all monitor sites, concentrations were derived for each 12 km by 12 km grid cell in a national-scale spatial surface by applying the Voronoi Neighbor Averaging (VNA) spatial interpolation technique to the monitor-location values. This step resulted in further reduction of the highest values in each modeling region.[114]

Because the W126 estimates generated for the different air quality scenarios assessed are inputs to the vegetation risk analyses for tree biomass and crop yield loss, and also used in some components of the visible foliar injury assessments, limitations and uncertainties in the air quality analyses, which are discussed in detail in the WREA and some of which are mentioned here, were propagated into those analyses (2014 WREA, chapters 4 and 8, including section 8.5, and Table 4-5). An important uncertainty in the analyses is the application of adjustments at the regional-scale based on modeled emissions reductions in NO_X that characterize only one potential distribution of air quality across a region for situations when all monitor locations in a region meet the then-current standard or the W126 cumulative exposure targets (2014 WREA, section 4.3.4.2). The impact of the approach's broad regional reductions on O_3 concentrations at monitor locations that were already well below the target indicated an uncertainty with regard to air quality expected from specific control strategies that might be implemented to meet a particular target level (80 FR 65375, October 26, 2015).

An additional uncertainty related to the W126 index estimates in the national surfaces for each air quality scenario, and to the estimates for the single-year surfaces used in the visible foliar injury cumulative analysis, is associated with the creation of the national-scale spatial surfaces of grid cells from the monitor-location O_3 data.[115] In general, spatial interpolation techniques perform better in areas where the O_3 monitoring network is denser. Therefore, the

[113] The adjustment was based on the minimum percentage reduction in NO_X emissions necessary to reduce O_3 concentrations at all monitors within a region sufficiently to meet the target. This adjustment results in broad regional reductions in O_3 and includes reductions in O_3 at some monitors that were already at or below the target level (2014 WREA, sections 4.3.4.2 and 4.4).

[114] This is seen when comparing the W126 index values from before and after the application of the VNA approach to the then-existing standard scenario. After the adjustment of the monitor location concentrations such that the highest location in each NOAA region just met the then-existing standard (using the model-based relationships), the maximum 3-year average W126 values in the nine regions ranged from 18.9 ppm-hrs in the West region to 2.6 ppm-hrs in the Northeast region (2014 WREA, Table 4-3). After application of the VNA technique, however, the highest 3-year average W126 values across the national surface grid cells, which were in the Southwest region, were below 15 ppm-hrs (2014 WREA, Figure 4-7). Thus, using VNA interpolated W126 index values at the centroid of every 12 km x 12 km grid cell compared to using W126 index values only at each monitor location results in a lowering of the highest values in each region (80 FR 65374, October 26, 2018).

[115] Some uncertainty is inherent in any approach to characterizing O_3 air quality over broad geographic areas based on concentrations at monitor locations.

W126 index values estimated using this technique in those rural areas within the West, Northwest, Southwest, and West North Central regions where there are few or no monitors (2014 WREA, Figure 2-1) are more uncertain than those estimated for areas with denser monitoring. Further, as noted above, this interpolation method may underpredict the highest W126 exposure index values in a region. Due to the important influence of higher exposures in determining risks to plants and the potential for the interpolation step to dampen peak W126 index values, some risk underestimation could have resulted.

The assessments related to tree growth relied on the species-specific E-R functions referenced in section 3.2.2 above. For the air quality scenarios assessed, the species-specific E-R functions were used to develop estimates of O_3-related RBL and associated effects on productivity, carbon storage and associated ecosystem services (2014 WREA, Chapter 6). More specifically, the WREA derived species-specific and weighted RBL estimates for grid cells across the continental U.S. and summarized the estimates by counties, regions and Class I areas and national parks (2014 WREA, section 6.2.1 and 6.8). Potential impacts on commercial timber were also estimated (2014 WREA, section 6.3). Additional case study analyses estimated impacts on carbon removal and pollutant removal in selected urban areas (2014 WREA, sections 6.6.2 and 6.7).

Relative biomass loss nationally (across all air quality surface grid cells) was estimated for each of eleven studied species[116] using the composite E-R functions for each species and information on the distribution of those species across the U.S. (2014 WREA, section 6.2.1.3 and Appendix 6A). These analyses provided estimates of per-species RBL, as well as median and total RBL across resident species in the different air quality scenarios. The WREA also used the E-R functions to estimate RBL across tree lifespans and the resulting changes in consumer and producer/farmer economic surplus in the forestry and agriculture sectors of the economy. Case studies in five urban areas provided comparisons across air quality scenarios of estimates for urban tree pollutant removal and carbon storage or sequestration (2014 WREA, sections 6.6.2 and 6.7). The array of uncertainties associated with estimates from these tree RBL analyses, including those associated with the air quality adjustment approach which contributed to a potential for the air quality scenarios to underestimate the higher W126 index values and the associated implications for the RBL estimates, are summarized in section 5.2.2 below.

The assessments of O_3 impacts on agricultural crops relied on the robust E-R functions established prior to the last review. For the different air quality scenarios, the WREA applied the

[116] In consideration of CASAC advice regarding uncertainties associated with the E-R function derived for a twelfth species, the eastern cottonwood, the WREA derived RBL and weighted RBL estimates separately, both with and without the eastern cottonwood, with primary focus given to analyses that excluded cottonwood (Frey, 2014c, p. 10; 2014 WREA; 2014 PA; 79 FR 75234, December 17, 2014; 80 FR 65292, October 26, 2015).

species-specific E-R functions to develop estimates of O_3 impacts related to crop yield, including annual yield losses, for 10 commodity crops grown in the U.S. and estimates of how these losses might be expected to affect producer and consumer economic surpluses (2014 WREA, sections 6.2 and 6.5). The WREA derived estimates of crop RYL nationally and in a county-specific analysis, relying on information regarding crop distribution (2014 WREA, section 6.5). As with the tree analyses described above, the county analysis included estimates based on the median O_3 response across the studied crop species (2014 WREA, section 6.5.1, Appendix 6B).

Overall effects on agricultural yields and producer and consumer surplus depend on the ability of producers/farmers to substitute other crops that are less O_3 sensitive, and the responsiveness, or elasticity, of supply and demand (2014 WREA, section 6.5). The WREA discusses multiple areas of uncertainty associated with the crop RYL estimates, including those associated with the model-based adjustment methodology as well as those associated with the projection of yield loss using the Forest and Agriculture Sector Optimization Model (with greenhouse gases) at the estimated O_3 concentrations (2014 WREA, Table 6-27, section 8.5) and the lack of a role in the assessment for agricultural crop management practices which have substantial influence on crop yield. Because the W126 index estimates generated in the air quality scenarios are inputs to the vegetation risk analyses for crop yield loss, any uncertainties in the air quality scenario estimation of W126 index values are propagated into those analyses (2014 WREA, Table 6-27, section 8.5). Therefore, the air quality scenarios in the crop yield analyses have the same uncertainties and limitations as in the biomass loss analyses (summarized above), including those associated with the model-based adjustment approach (2014 WREA, section 8.5).

5.2.1.2 Foliar Injury Assessments

The foliar injury assessments involved analysis of W126 cumulative exposure estimates and foliar injury scores at USFS biosites for five years (2006-2010), and consideration of the implications of the analysis with regard to risk of O_3-related foliar injury in nationally protected areas such as national parks (2014 WREA, Chapter 7; Smith and Murphy, 2015; 80 FR 65376, 65395-65396, October 26, 2015). In the biosite data analysis, the WREA used the biomonitoring site data from the USFS FHM/FIA Network (USFS, 2011), associated soil moisture data during the sample years, and national surfaces of ambient air O_3 concentrations based on spatial interpolation of monitoring data from 2006 to 2010[117] in a cumulative analysis of the proportion of biosite records with any visible foliar injury, as indicated by a nonzero biosite index score

[117] Estimates of W126 were drawn from national-scale spatial surfaces of single-year, unadjusted W126 index values created for each year from 2006 through 2010 using the VNA interpolation technique applied to the monitor location index values for these years (2014 WREA, section 4.3.2, Appendix 4A).

(2014 WREA, section 7.2). This analysis was done for all records together, and also for subsets based on soil moisture conditions (normal, wet or dry).

In each cumulative analysis, the biosite records were ordered by W126 index and then, moving from low to high W126 index, the records were cumulated into a progressively larger dataset. With the addition of each new data point (composed of biosite index score and W126 index value for a biosite and year combination) to the cumulative dataset, the percentage of sites with a nonzero biosite index score was derived and plotted versus the W126 index estimate for the just added data point. This analysis was found to be appreciably affected by the larger representation within the subset of the lower W126 conditions which are associated with a lower occurrence or extent of foliar injury.[118] Nearly two thirds of the dataset included records for which the W126 index estimates are at or below 11 ppm-hrs (Smith and Murphy, 2015, Table 1).

In a technical memorandum prepared subsequent to the WREA, the same dataset was re-presented in a different format to more directly consider what the data indicate with regard to a relationship between O_3 exposure in terms of W126 and foliar injury. This presentation indicated the reduction in the occurrence (and severity) of visible foliar injury with decreasing exposures across a range that extended from above 19 ppm-hrs to below 7 ppm-hrs (Smith and Murphy, 2015, Table 2).[119]

5.2.1.3 Additional Air Quality/Exposure and E-R Analyses

Additional analyses developed in the last review included two air quality and exposure analyses, summarized below, and a separate tabular presentation involving tree and crop E-R functions. The tabular presentation was based on the robust established E-R functions for growth effects on tree seedlings and crops was developed for the 2014 PA (2014 PA, Appendix 5C).

[118] The cumulative analysis for all sites indicated that (1) as the cumulative set of sites grows with addition of sites with progressively higher W126 index values, the proportion of the dataset for which no foliar injury was recorded changes (increases) noticeably prior to about 10 ppm-hrs, and (2) as the cumulative dataset grows still larger with the addition of records for higher W126 index estimates, the proportion of the cumulative dataset with no foliar injury remains relatively constant (2014 WREA, Figure 7-10). This "leveling off" (e.g., observed above ~10 ppm-hrs in the "all sites" analysis) likely reflects the counterbalancing of visible foliar injury occurrence at the relatively fewer higher O_3 sites by the larger representation within the subset of the lower W126 conditions associated with which there is lower occurrence or extent of foliar injury (Smith and Murphy, 2015).

[119] Criteria derived from the WREA cumulative analyses were used in two additional WREA analyses. The national-scale screening-level assessment compared W126 index values estimated within 214 national parks using the VNA technique described above for the individual years from 2006 to 2010 with benchmark criteria developed from the biosite data analysis (2014 WREA, Appendix 7A and section 7.3). Separate case study analyses described visits, as well as visitor uses and expenditures for three national parks, and the 3-year W126 index estimates in those parks for the four air quality scenarios (2014 WREA, section 7.4). Uncertainties associated with these analyses, included those associated with the W126 index estimates, are discussed in the WREA, sections 7.5 and 8.5.3, and in WREA Table 7-24, and also summarized in the PA (2014 PA, section 6.3).

This analysis presented the estimates of RBL[120] (and RYL) at a range of W126-based exposure levels for 11 tree species and 10 crop species, respectively (2014 PA, Tables 5C-1 and 5C-2). Additionally, the median tree species RBL (or crop RYL) was presented for each W126 level (2014 PA, Table 5C-3; 80 FR 65391 [Table 4], October 26, 2015). As summarized in section 3.2.2 above, the 2015 decision on the secondary standard included a focus on O_3-related RBL in tree seedlings as a surrogate or proxy for the broader array of vegetation-related effects of potential public welfare significance, which include effects on growth of individual sensitive species and extend to ecosystem-level effects, such as community composition in natural forests, particularly in protected public lands, as well as forest productivity (80 FR 65406, October 26, 2015).

The first of the two sets of air quality/exposure analyses included the development of W126-based cumulative exposure estimates in Class I areas during 3-year periods that met the then-current standard (75 ppb, in terms of the 3-year average of consecutive year fourth highest daily maximum 8-hour averages). The second set of air quality/exposure analyses investigated the W126-based cumulative exposure estimates for locations and time periods that met the then-current and several potential alternative standards, in terms of 3-year averages of the fourth highest daily maximum 8-hour average concentration. The former analysis was particularly informative to the decision regarding the need to revise the then-current standard of 75 ppb (80 FR 65389-65390, October 26, 2015), while the second set of analyses informed the Administrator's decision on the appropriate revision (80 FR 65403-65410, October 26, 2015).

The first set of air quality/exposure analyses, as presented and relied upon in the final decision, was an update of an analysis initially presented in the 2014 PA (2014 PA, pp. 5-27 to 5-29). Based on air quality data for the period from 1998 to 2013, the analysis focused consideration on 17 Class I areas,[121] in which during one or more three-year periods the air quality met the current standard and the three-year average W126 index value was at or above 15 ppm-hrs. The analysis that informed the 2015 decision was restricted to data for monitors sited in or within 15 kilometers of a Class I area.[122]

[120] These functions for RBL estimate the reduction in a year's growth as a percentage of that expected in the absence of O_3 (2013 ISA, section 9.6.2; 2014 WREA, section 6.2). In specifically evaluating exposure levels, in terms of the W126 index the 2014 PA focused particularly on RBL estimates for the median across the 11 tree seedling species for which robust E-R functions are available (80 FR 65391-65392 [Table 4], October 26, 2015; 2014 WREA, Appendix 5C, Table 5C-3).

[121] For the four modeled air quality scenarios in the WREA, the WREA also derived detailed estimates of 3-year W126-based exposures in a screening-level national park assessment and in three individual national parks. (2014 WREA, section 4.3.2, Appendix 4A). Limitations and uncertainties associated with the WREA air quality adjustment approach limited their usefulness in the EPA's final decision-making.

[122] The 15 km distance was selected as a natural breakpoint in distance of O_3 monitoring sites from Class I areas and as still providing similar surroundings to those occurring in the Class I area. We note that given the strict

This analysis considered cumulative exposure estimates in Class I areas during times that met the then-current standard in the context of such estimates associated with varying RBL values for the median tree species derived using the robust E-R functions for RBL in seedlings of 11 tree species. The analysis gave particular weight to the W126 index values at or above 19 ppm-hrs, which were associated with a 6% median RBL, described as "unacceptably high" by the CASAC (80 FR 65391-92, October 26, 2015; Frey, 2014c). In the analysis, the numbers of areas, states and NOAA climatic regions, for which the 3-year W126 exposure index values ranged at or above 19 ppm-hrs were tallied and characterized as to magnitude and variation across the three years.

The second set of air quality/exposure analyses were focused on air quality monitoring for O_3 monitoring sites with complete data for the most recent 3-year period and also for periods extending back to 2001.[123] This set was comprised of several analyses of air quality that considered relationships between 3-year W126 index based exposure estimates and the design value for the then current standard (referred to as the "fourth-high" metric) (2014 PA, Chapter 2, Appendix 2B and section 6.4; Wells, 2015). These analyses indicated that, depending on the level, a standard of the then-current averaging time and form could be expected to control cumulative seasonal O_3 exposures to such that they may meet specific 3-year average W126 index values. The fourth-high and W126 metrics, and changes in the two metrics over the past decade, were found to be highly correlated (2014 PA, section 6.4 and Appendix 2B; Wells, 2015).

These analyses were performed for two recent periods (2009-2011 and 2011-2013), as well as extending back to 2001 (2014 PA, section 6.4; Wells, 2015). All NOAA climatic regions in the contiguous U.S. were represented. These analyses illustrated the extent and magnitude of W126-based exposures at monitoring sites meeting the then existing standard and alternate standards, including the now-current standard of 70 ppb (2014 PA, section 6.4 and Appendix 2B; Wells, 2015).

5.2.2 Assessments for this Review

In the preceding section we have briefly summarized air quality, exposure and risk analyses developed in the last review, noting key uncertainties or limitations associated with the

restrictions on structures and access within some of these areas, it is common for monitors intended to collect data pertaining to air quality in these types of areas to be sited outside their boundaries.

[123] These analyses are summarized and discussed in sections IV.C.1.c, IV.C.2.d and IV.C.3 of the 2015 decision notice and presented in detail in a technical memorandum to the rulemaking docket (80 FR 65292, 65400-65401, 65408-65409, October 26, 2015; Wells, 2015).

various assessments. The two sections below briefly summary key considerations in our planning for assessments in the current review and our initial plans for such analyses.

5.2.2.1 Key Considerations

In identifying the types of assessments to be developed or updated in this review, we give particular attention to those types of analyses that formed the main foundation for conclusions in the last review due to their relatively lesser uncertainty and fewer limitations. In so doing, we consider the availability at this time of any new information that may address limitations or uncertainties in any of the analyses from the last review. In this regard, we consider both the analyses based on regional air quality modeling scenarios (e.g., as summarized in section 5.2.1.1) and environmental exposure analyses based on air quality monitoring data (summarized in sections 5.2.1.3).

As in any review, key considerations in planning risk and exposure analyses that may be appropriate in this review include:

- Availability of new information (including more recent air quality patterns), models and tools since completion of the prior assessment that have potential to address key areas of uncertainty;
- Identification of model/assessment aspects for which updates are available and feasible within the constraints of the timeline for the review that may reduce uncertainty or address limitations, thus improving appropriateness of model outputs for their intended purposes.

The analyses developed in the last review, along with key limitations and uncertainties, and also the availability of relevant more recent information or updates, are briefly summarized in Appendix 5B.

It is the analyses with relatively lesser uncertainty or fewer limitations regarding their interpretation, which include those most informative in the last review, that we plan to emphasize in considering analyses that may be appropriate to conduct for the current review. In so doing, our objective is to focus on analyses for which there are updated models, tools, or data that would have the potential to substantially improve the utility of risk estimates in informing the current review. The matrix in Appendix 5B has informed these considerations. Based on this approach, we expect to focus any new quantitative analyses in this review on the types of analyses that can benefit from updated information or methods, with the goal of ensuring that the exposure and risk estimates for this review reflect consideration of newly available information or methods. Accordingly, we expect that in this new review we will develop updated analyses for types of assessments for which new/updated information, methods or tools provide a basis for producing appreciably improved or more targeted exposure and risk information. Thus, we do not expect to develop updated analyses for types of assessments for which associated uncertainties limited their usefulness in the 2015 decision and are unlikely to be addressed by information available in this review.

5.2.2.2 Initial Plans for the Current Review

Based on the considerations identified above, including consideration of the array of complex and extensive exposure and risk analyses performed in the last review, and given the expedited nature of this review, we are preliminarily planning that any new analyses in this review include the two exposure-based analyses based on air quality monitoring data, summarized in section 5.2.1.3 above. These analyses both include updates to the derivation of cumulative exposure estimates at monitoring sites nationwide, providing for the assessment of such exposures under air quality conditions that meet the current standard or any potential alternatives for consideration. These two sets of analyses are (1) the analysis of O_3 concentrations and derivation of W126 index values for Class I areas and (2) the similar analysis for monitoring sites nationally. A decision to update these analyses would reflect the relatively lesser uncertainty associated with these types of analyses as compared to the analyses based on the regional air quality modeling approach; that lesser uncertainty contributed to the air quality monitoring-based analyses being more informative in the last review.

Updates to these analyses can reflect the more recent, now available, air quality monitoring data. These analyses are expected to inform our understanding of current patterns of air quality and their impact on vegetation exposures under conditions just meeting the now-current standard. Given the array of monitoring sites for which recent design values indicate conditions just meeting the current standard, such a focus on monitoring data is expected to again be accompanied by reduced uncertainty compared to the regional modeling approach described in the 2014 WREA. Preliminary consideration of such analyses based on model-adjusted air quality scenarios does not indicate a potential for appreciably addressing key uncertainties, such that we expect that those analyses would not be updated, but the results from the last review may be considered as relevant in the current review (e.g., with regard to exposure/risk considerations in the PA).[124]

Interpretation of the cumulative exposure estimates in the two types of air quality and exposure analyses will be informed by the consideration of the currently available evidence on relationships of cumulative O_3 exposure with tree seedling growth and visible foliar injury. Such information is expected to include up-to-date tree seedling E-R functions for RBL based on the

[124] Note that the approach for the WREA differed from that used in the HREA, with the latter focused on urban areas (as summarized in section 5.1 above) as compared to the large regions that were the focus of the adjustment approach in the WREA (2014 WREA, section 4.3; 2014 HREA, section 2.2).

currently available evidence, as well as currently available information on relationships between cumulative O_3 exposures and visible foliar injury, building on the information available in the last review (e.g., Smith and Murphy, 2015). As indicated in Chapter 4, the ISA for this review will consider and assess the currently available evidence on the role of O_3 in effects on vegetation growth, and in visible foliar injury. Quantitative exposure-based analyses performed for the PA will be interpreted considering this current evidence as presented in the ISA.

All of the analyses developed in this review will be described in the PA, with details documented in appendices or accompanying volumes, as appropriate. We expect to also consider in the PA any other types of analyses from the last review that we do not update in this review but that are still informative to this review when viewed in the context of the currently available evidence as characterized in the ISA and of updated air quality and other analyses performed for this review. Accordingly, the PA will include description and discussion of all risk and exposure analyses being considered in this review, both those newly performed in this review as well as analyses performed for the last review for which an updated assessment was not performed but that are still informative for this review. The draft PA will be released for public comment and provided to the CASAC for its review. Advice and comments received will be considered in completing the final version of the risk and exposure analyses and drawing on all of the analyses considered in the policy evaluations presented in the final PA.

6 POLICY ASSESSMENT

As described in section 1.2 above, the PA is a document that provides an evaluation of the currently available information with regard to the adequacy of the current standards and potential alternatives, if any are appropriate to consider in the current review. The PA integrates and interprets the information from the ISA and available information from quantitative exposure/risk analyses to frame policy options for consideration by the Administrator. This evaluation of policy implications is intended to "bridge the gap" between the Agency's scientific assessments and the judgments required of the EPA Administrator in determining whether it is appropriate to retain or revise the NAAQS.

The discussion in the O_3 PA in this review will be framed by consideration of a series of the policy-relevant questions drawn from those outlined in chapter 3, including the fundamental questions associated with the adequacy of the current standards and, as appropriate, consideration of alternative standards that involve revision to any of the specific elements of the standards: indicator, averaging time, level, and form. The PA conclusions will be based on the assessment of the scientific information contained in the ISA, any updated exposure/risk assessments or other additional evaluations and assessments discussed in the PA. Thus, the PA will address the implications of the science and quantitative assessments for the adequacy of the current standards, and, as appropriate, for any potential alternative standards. To the extent it is concluded to be appropriate to consider potential alternative standards, the PA will also describe a range of policy options for such revisions that is supported by the available information. In so doing, the PA will describe the underlying interpretations of the scientific evidence, risk/exposure information and any other quantitative analyses that might support such alternative policy options and that could be considered by the Administrator in making decisions for the O_3 standards. Additionally, the PA will identify key uncertainties in this policy evaluation and areas for future research and data collection.

With regard to the primary standard, it is recognized that the final decision will be largely a public health policy judgment by the Administrator. A final decision must draw upon scientific information and analyses about health effects and risks, as well as judgments about how to deal with the range of uncertainties that are inherent in the scientific evidence and analyses. Consistent with the Agency's approach across all NAAQS reviews, the approach of the PA to informing these judgments is based on a recognition that the available health effects evidence generally reflects continuums that include ambient air exposures for which scientists generally agree that health effects are likely to occur through lower levels at which the likelihood and magnitude of response become increasingly uncertain. This approach is consistent with the requirements of the NAAQS provisions of the Act and with how the EPA and the courts have historically interpreted the Act. These provisions require the Administrator to establish primary standards that are requisite to protect public health with an adequate margin of safety. In so doing, the Administrator seeks to establish standards that are neither more nor less stringent than necessary for this purpose. The provisions do not require that standards be set at a zero-risk level, but rather at a level that avoids unacceptable risks to public health, including the health of sensitive groups.[125]

With regard to the secondary standard, it is recognized that the final decision will be largely a public policy judgment by the Administrator. A final decision must draw upon scientific evidence and analyses about effects on public welfare, as well as judgments about how to deal with the range of uncertainties that are inherent in the relevant information. This approach is consistent with the requirements of the NAAQS provisions of the Act and with how the EPA and the courts have historically interpreted the Act. These provisions require the Administrator to establish secondary standards that are requisite to protect public welfare from any known or anticipated adverse effects associated with the presence of the pollutant in the ambient air. In so doing, the Administrator seeks to establish standards that are neither more nor less stringent than necessary for this purpose. The provisions do not require that secondary standards be set to eliminate all welfare effects, but rather to protect public welfare from those effects that are judged to be adverse.

The O_3 PA will include pertinent background information, such as information on current air quality as well as the decisions in the last NAAQS review, as well as discussion of the currently available health and welfare effects evidence and exposure/risk information. These discussions will be focused on policy-relevant aspects important for the Agency to consider in reviewing the current standards. With regard to the exposure and risk information, the details of any new analyses will be documented with the PA (e.g., in appendices or associated volumes) and the findings presented and discussed within the main body of the PA.

The draft PA, with associated appendices that fully describe and document updated risk, exposure and other quantitative analyses, will be distributed to the CASAC for its consideration and released to the public for review and comment. Review of the draft PA by the CASAC also facilitates CASAC's advice to the Agency and recommendations to the Administrator on the adequacy of the existing standards or revisions that may be appropriate to consider, as provided

[125] More than one population group may be identified as sensitive or at-risk in a NAAQS review. The decision in the review will reflect consideration of the degree to which protection is provided for these sensitive population groups. To the extent that any particular population group is not among the identified sensitive groups, a decision that provides protection for the sensitive groups would be expected to also provide protection for other population groups.

for in the Clean Air Act. The CASAC will discuss its review of the draft PA at public meetings that will be announced in the *Federal Register*. Based on past practice by the CASAC, the EPA expects that key advice and recommendations for revision of the document would be summarized by the CASAC in a letter to the EPA Administrator. In revising the draft PA document, any such advice and recommendations will be taken into account, and comments received from the public will also be considered. The final document will be made available on an EPA website, with its public availability announced in the *Federal Register*.

7 PROPOSED AND FINAL DECISIONS

Following issuance of the final PA and consideration of analyses and conclusions presented therein, and taking into consideration CASAC advice and recommendations, the Agency will develop a notice of proposed decisions. This notice will convey the Administrator's proposed conclusions, reached in consideration of the analyses and conclusions in the documents developed in the review (e.g., as described in the preceding chapters) and advice and recommendations from the CASAC, regarding the adequacy of the current standards and any revision(s) that may be appropriate. Development of the notice of the proposed (and final) decisions will take into account issues related to the NAAQS process (e.g., Pruitt, 2018), as appropriate in this review. As appropriate, a draft notice of proposed decision will be submitted to the Office of Management and Budget (OMB) for its review and comment. In this interagency review step, the OMB also provides to other federal agencies the opportunity for review and comment. After the completion of interagency review, the notice of proposed action is published in the *Federal Register*.

At the time of publication of the notice of the proposed action, all materials on which the proposal is based are made available in the public docket for the review.[126] Publication of the proposal notice is followed by a public comment period, generally lasting 60 to 90 days, during which the public is invited to submit comments on the proposal to the docket and one or more public hearings may be held. Taking into account comments received on the proposed action, the Agency will then develop a notice of final action, which communicates the Administrator's decisions regarding this review and which may again undergo OMB-coordinated interagency review prior to issuance by the EPA. At the time of the final action, the Agency responds to all significant comments on the proposal.[127] Publication of the notice of the final action in the *Federal Register* will complete the review process.

[126] The docket for the current O_3 NAAQS review is identified as EPA-HQ-OAR-2018-0279. This docket has incorporated the ISA docket (EPA-HQ-ORD-2018-0274) by reference. Both dockets are publicly accessible at www.regulations.gov.

[127] For example, Agency responses to all significant comments on the 2014 notice of proposed rulemaking in the last review were provided in the preamble to the final rule and in a document titled "Response to Significant Comments on the 2014 Proposed Rule on the National Ambient Air Quality Standards for Ozone (December 17, 2014; 79 FR 75234)", which is available at: https://www.epa.gov/naaqs/responses-significant-comments-2014-proposed-rule-national-ambient-air-quality-standards-ozone.

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Appendix 5A

Appendix 5A. Limitations and uncertainties of exposure and risk analyses developed in the last review of the primary standard and consideration of related newly available information and tools. Drawn from the 2014 HREA, Tables 4-7, 5-10, 6-20, 7-4, notice of final decision and response to comments document for the review.

Analysis Element	Limitations/Uncertainty identified in 2014 HREA	2014 Uncertainty Characterization and Newly Available Information for Current Review
Ambient Air Concentrations		
Ambient air monitoring data	The monitoring datasets used for the 2014 HREA were for the period from 2006 through 2010.	Overall, O_3 measurement data are of high quality and have low uncertainty. Newly available are data for more recent 3-year period (2015-2017).
Approach used to derive factors to adjust air quality to just meet then-existing and potential alternate standards	Modeling Platforms and Approaches: Model predictions from the Community Multiscale Air Quality (CMAQ) model, like all deterministic photochemical models, have both parametric and structural uncertainty associated with them. Higher Order Decoupled Direct Method (HDDM) allows for the efficient approximation of O_3 concentrations under alternate emissions scenarios. This approximation is less accurate for larger emissions perturbations, especially under nonlinear chemistry conditions. Application of HDDM sensitivities to ambient data: there is uncertainty in the statistical regressions used to relate O_3 response to emissions perturbations with ambient O_3 concentrations for every season, hour-of-the-day, and monitor location. Further, functional relationships between O_3 response and hourly O_3 concentration were developed based on 8 months of modeling: January and April-October 2007 and applied to ambient data from 2006-2010. Some locations monitor for months not included in this modeling (February, March, November, and December) while others do not. Emissions Reduction Assumptions: In cases where VOC reductions were modeled, equal percentage NO_X and VOC reductions were applied in the adjustment methodology. Assumption of across-the-board emissions reductions: Ozone response is modeled for across-the-board reductions in U.S. anthropogenic NO_X (and VOC). These across-the-board cuts do not reflect actual emissions control strategies.	Low to moderate magnitude of impact on exposure and FEV_1 risk estimates potentially resulting in both under- and over-estimation of ambient concentrations. Updated modeling platforms are available since completion of the 2014 HREA. We could apply HDDM in the CAMxv6.5 photochemical model (somewhat faster approach than HDDM with CMAQ) which includes updated chemical mechanisms reflecting understanding of important chemical pathways for ozone formation and destruction that have been extended since the chemistry available during the last review. We would use modeling inputs that reflect emissions, meteorology and international transport representing a more recent year (2016). Based on results from modeling performed in the 2014 HREA and time constraints for this review, we would focus primarily on NO_X reductions alone. To reduce uncertainty in analyses for this review, we may select a subset of study areas based on consideration of CMAQ/HDDM model performance in different urban areas as well as occurrence of any atypical O_3 episodes during the modeled period.
Approach used to spatially interpolate ambient air monitor concentrations to census tracts	Voronoi Neighbor Averaging (VNA) is a spatial interpolation technique used to estimate O_3 concentrations in unmonitored areas, which has inherent uncertainty. The relative influence on exposure and risk estimates range from low to moderate, with greatest uncertainties when interpolating large distances between monitors.	The uncertainty in this approach could lead to both under- and over-estimation of ambient concentrations. However, the magnitude of impact to exposure and FEV_1 risk estimates was estimated to range between low to

Analysis Element	Limitations/Uncertainty identified in 2014 HREA	2014 Uncertainty Characterization and Newly Available Information for Current Review
		moderate. Several other methods are available, with associated limitations. For this review, preferred study areas could include spatial coverage of ambient air monitors relative to study area dimensions as a study selection criterion.
Exposure Modeling		
APEX general input databases	There are several general databases used including year 2000 population demographics and commuting, CHAD activity diaries, area-specific meteorological data, and 2006-2010 asthma prevalence.	2014 HREA characterization indicated most databases were of high quality and had low impact to estimated exposures. Meteorological and asthma prevalence data could be updated to appropriately correspond with the selected study areas and exposure periods. There are no new activity pattern data however the CHAD activities have been expanded and the associated METs distributions were revised. The demographic data have been updated to reflect the 2010 census. However, a limited sensitivity analysis in the 2014 HREA using the 2010 census indicated a small effect, though consistently yielding lower FEV_1 risk estimates (Table 6-18, 2014 HREA).
APEX anthropometric attributes and physiological processes	There are several databases and algorithms used to estimate body weight (BW), resting metabolic rate (RMR), normalized oxygen consumption rate (nVO_2), metabolic equivalents of work (METS), and ventilation rates (VE) that may contribute to uncertainty in the estimated exposures.	The 2014 HREA characterized these as having between a low to moderate impact on estimated exposures, with two (VE and METS) potentially contributing to overestimates. We have since updated each of these to some extent using either recent data or new algorithms except for the nVO_2.
APEX microenvironmental concentrations	There was uncertainty associated with approaches and factors used to estimate concentrations within indoor, outdoor, and inside vehicle microenvironments including air exchange rates, air conditioning (A/C) prevalence, indoor removal rates, proximity factors to adjust for near road concentrations, and penetration factors.	Because the highest O_3 exposures occur in outdoor environments, these factors were characterized as having low impact to estimated exposures. While some data would be updated (e.g., A/C prevalence), most factors used in 2014 would be reapplied.
Representation of time outdoors considering air quality advisories	Limited availability of data on averting behavior in response to air quality alerts indicates that a small percentage of the population may engage in averting behavior. The lack of representation of this in the exposure modeling may contribute to overestimates of actual exposures in such circumstances (2014 HREA, pp. 5-53 to 5-54; p. 9-11). A sensitivity analysis performed for the 2014 HREA estimated 1-2 percentage point reductions in the percent of simulated children at or above benchmark levels when accounting for averting by a portion of the population and for a particular duration. These results indicate that, depending	While not specifically characterized in the 2014 HREA, simulating the averting of high concentration air pollution events had a moderate impact on the estimated exposures, suggesting the number of people exposed at or above benchmark levels may be overestimated. There may be recent published literature to support the parameters used to develop the averting scenario or to develop a new scenario to better reflect current averting behavior and better characterize the impact to exposures.

Analysis Element	Limitations/Uncertainty identified in 2014 HREA	2014 Uncertainty Characterization and Newly Available Information for Current Review
	on benchmark levels, averting could lead to 20% or greater reductions in the number of people experiencing exposures of interest.	
Estimating repeated exposures for select at-risk populations	The limited availability of longitudinal activity diary data and the general population modeling approach used may underestimate the correlation in activity patterns for certain potentially at-risk populations (e.g., outdoor workers or the subset of children with systematically high outdoor activity levels). Accordingly, the results may underestimate how often there are repeated exposures to exposures above benchmarks and we are limited in our ability to identify the percent of the population with unusually high numbers of multiple exposures (2014 HREA, section 9.5.2). The simulated scenarios were highly dependent on existing activity pattern data and several assumptions made to characterize a particular at-risk population.	While not specifically characterized in the 2014 HREA, simulating potentially at-risk populations having repeated exposure to high air pollution events had a moderate impact on the estimated exposures, suggesting the number of people exposed at or above benchmark levels may have been underestimated. Unclear as to whether new data are available to enhance the approach used.
Comparison of Simulated Exposures to Benchmarks		
Cut point for moderate or greater ventilation	An equivalent ventilation rate (EVR in L/min-m^2) served as a cut point for selecting simulated individuals performing moderate or greater exertion activities. The EVR was used to allow for extrapolation of information obtained from adults to children. The value used (13 L/min-m^2) was a lower bound based on approximating the 5th percentile of the distribution of targeted ventilation rates maintained by the study subjects (Whitfield et al., 1996). There is uncertainty in the extrapolation of adult data to simulated children and the use of a lower bound value.	The 2014 HREA recognized that the simulated number of people achieving this level of exertion could be moderatelyoverestimated, affecting the results for comparison to benchmarks and the population-based E-R approach used to estimate lung function risk. A new approach to identifying when individuals may be at moderate or greater exertion could be explored using available exposure study data. Consideration will also be given to the total time-averaged ventilation rate in calculating the EVR of study subjects (see exposure duration below), rather than using the exercise ventilation rate alone to calculate EVR (as was done in prior reviews).
Exposure duration	The exposure duration for the studies from which the benchmark concentrations are drawn is 6.6 hours (6 x 50 min exercise periods separated by 10-minute rest periods, and with a 35-minute lunch after 3rd hour). Simulated exposures relied on a daily maximum 8-hour averaging time. Therefore, health responses observed at a 6.6-hour concentration would directly relate to a lower 8-hour average concentration. Further, there is some indication that the pattern of the exposure may be important to generating the adverse health response (2013 ISA, section 6.2.1.1, pp. 6-10 to 6-11). The approach used to define the exposure benchmark considered average concentration over the exposure period without consideration of exposure pattern or peak concentrations within the exposure averaging time.	The simulated number of people with exposures at or above benchmarks and those expected to experience lung function decrements via the population-based E-R approach could have been 1) underestimated when considering the different averaging periods, and 2) underestimated or overestimated when ignoring the pattern of exposure within the averaging period. New benchmarks that better reflect the averaging time used in the controlled human exposure study data could be used (e.g., 6 or 7 hours)
Benchmark concentrations	An important uncertainty is that there is only very limited evidence from controlled human exposure studies of population groups potentially at greater risk. Compared to the healthy young adults included in the controlled human exposure	Although not directly characterized in the 2014 HREA, the benchmark levels derived from the controlled human exposure studies may not be entirely representative of

Analysis Element	Limitations/Uncertainty identified in 2014 HREA	2014 Uncertainty Characterization and Newly Available Information for Current Review
	studies, members of some populations (e.g., children with asthma) are considered more likely to experience adverse effects following exposures to lower O_3 concentrations (80 FR 65322, 65346, October 26, 2015; Frey 2014a, p. 7).	effects likely to be exhibited by the simulated population and could underestimate the size of the population at risk and/or the magnitude of adverse effects.
Exposure to O_3 alone vs. O_3 plus all related oxidants in ambient air	The controlled human exposure studies evaluated the adverse health effects resulting from O_3 exposure only. Exposure and risk estimated for simulated individuals also considers O_3 exposures alone (as is appropriate given the E-R functions that are derived from the O_3-only exposure studies). However, O_3 serves as a surrogate for all oxidants that exist in ambient air and, as such, it is possible that individuals could be exposed to these pollutants in addition to O_3. Adverse health effects (if any) resulting from oxidants other than O_3 are not accounted for when using the current O_3-only exposure approach.	This element was not characterized in the 2014 HREA. We are unaware of any controlled human exposure studies that evaluated health effects resulting from exposure to a mixture of O_3 and other oxidants. Therefore, it is largely unknown how health effects might be altered following exposure to oxidants other than O_3 and as such, it is uncertain as to how this may relate to the estimated risk in the assessment.
MSS FEV1 Lung Function Risk Assessment		
The McDonnell-Stewart-Smith (MSS) FEV_1 model for ages 18 to 35	While there is a good conceptual foundation for the structure of the MSS model, the variability in measurements of FEV_1 and estimated parameters of the model introduce uncertainty into estimates of FEV_1 reductions. For instance, some of the estimated parameters have wide confidence intervals (2014 HREA, Table 6-14). Sensitivity analyses in the 2014 HREA additionally addressed how the general pattern of exercise/ventilation of study subjects affects estimated risks, however there were no evaluations of how exposure patterns of study subjects or changes in other influential attributes may affect risk estimates.	A new MSS model (McDonnell et al., 2013) is available for use in this review.
Representation of inter-individual variability	There is uncertainty in the degree to which the MSS model represents inter-personal variability in FEV_1 reductions (i.e., via the MSS model variable Var(U)). This is the result of having very few exposure studies with repeated clinical trials using the same individuals, likely yielding an underestimate in the Var(U) parameters. In addition, the method used for adjusting for filtered air (FA) exposures in the data used to fit the MSS model does not use the subject-specific adjustments, rather the mean FA response across a study is used to adjust the O_3 responses of each subject in the study. Furthermore, there are few clinical data for population with diseased lungs (i.e., asthma), thus the MSS model may not account for the increase in inter-individual variability that would result from inclusion of exposure-response (E-R) data from such individuals. A higher Var(U) indicates greater between-individual variability and less within-individual variability, therefore more responsive individuals are more likely to see repeated occurrences of high ΔFEV_1 (and thus less responsive individuals are more likely to see no occurrences of high ΔFEV_1).	The 2014 HREA concluded that the number of people experiencing FEV_1 decrements could be moderately overestimated given underestimates in the MSS FEV_1 model Var(U) parameter (absent the influence by other sources of uncertainty).
Representation of intra-individual variability	There is uncertainty in the degree to which the MSS model represents intra-personal variability in FEV_1 reductions (i.e., via the MSS model variable Var(ε)). The Var(ε) term is assumed to have a Gaussian distribution {mean=0, standard	Sensitivity analyses conducted in the 2014 HREA indicated that how the MSS FEV_1 model Var(ε) parameters are bounded has a moderate or greater influence in predicting

Analysis Element	Limitations/Uncertainty identified in 2014 HREA	2014 Uncertainty Characterization and Newly Available Information for Current Review
	deviation=4.14} and for our purposes in estimating risk was bounded at ±2 standard deviations (i.e., ±8.3). Extending or restricting these bounds will result in either greater or fewer simulated individuals experiencing lung function decrements, respectively. The assumption that the distribution of this term is Gaussian is convenient for fitting the data but may not be accurate.	the proportions of the population with FEV_1 decrements ≥ 10 and 15%. It is not clear how potential misspecification of the Var(ε) distribution shape affects its parameters and that of other variables in the MSS model, and how these changes may affect risk estimates.
Extrapolation of MSS variable parameters estimated for adults (18-35) to children (ages 5 to 18)	There are virtually no controlled human exposure data for children (i.e., the youngest age for which controlled human exposure data are generally available is 18 years old). Thus, the 2014 HREA essentially applied the same lung function response following O_3 exposures to children as was applied for adults (2014 HREA, section 6.5.3). This assumption is justified in part by the findings of McDonnell et al. (1985), who reported that children (8-11 years old) experienced FEV1 responses similar to those observed in adults (18-35 years old) (2014 HREA, p. 3-10) and from summer camp studies of school-aged children reported O_3-induced lung function decrements similar in magnitude to those observed in controlled human exposure studies using adults (2013 ISA, section 6.2.1). To estimate health risk for children, a constant value was used for the MSS model age variable (and derived from 18-year olds, and as a maximum value). There is uncertainty in this approach, depending on how this age term influences overall risk estimates for children compared to adults in controlled human exposure studies (2014 HREA, section 6.5.3).	The 2014 HREA concluded that the extrapolation approach could result in moderate over- or underestimates of O_3-induced lung function decrements in simulated children.
Extrapolation of exposure-response data from healthy subjects to simulated people with asthma	There is uncertainty associated with using E-R functions derived from healthy subjects in the controlled exposure studies to estimate O_3-induced lung function risk in simulated individuals with asthma (2014 HREA, section 6.5.4). Although the evidence is mixed (2013 ISA, section 6.2.1.1), several studies have reported statistically larger, or a tendency toward larger, O_3-induced lung function decrements in asthmatics than in non-asthmatics (Kreit et al., 1989; Horstman et al., 1995; Jorres et al., 1996; Alexis et al., 2000). On this issue, CASAC noted that "[a]sthmatic subjects appear to be at least as sensitive, if not more sensitive, than non-asthmatic subjects in manifesting O_3-induced pulmonary function decrements" (Frey, 2014c, p. 4). Furthermore, the response could depend on a variety of factors that have not been well-evaluated, including the severity of asthma and the prevalence of medication use. For instance, responses to O_3 increase with severity of asthma (Horstman et al., 1995) and corticosteroid usage does not prevent O_3-induced lung function decrements or respiratory symptoms in people with asthma (Vagaggini et al., 2001, 2007).	The 2014 HREA indicated that if asthmatics experience larger O_3-induced lung function decrements than the healthy adults used to develop E-R functions, the impacts of O_3 exposures on lung function in asthmatics, including asthmatic children, could be underestimated, albeit to an unknown extent.
Population-based Exposure-Response model		

Analysis Element	Limitations/Uncertainty identified in 2014 HREA	2014 Uncertainty Characterization and Newly Available Information for Current Review
Cut point for moderate or greater ventilation	See entry for this element under Comparison to Benchmarks section. The approach used could overestimate the number of individuals at moderate or greater exertion.	While not directly characterized in the 2014 HREA, the reported number and percent of individuals estimated to experience a lung function decrement would likely be greater than that estimated using a higher, alternative EVR value to estimate elevated exertion.
Exposure duration	See entry for this element under Comparison to Benchmarks section. The duration used results in fewer simulated individuals identified as having the exposure of interest than expected for the E-R function.	While not directly characterized in the 2014 HREA, the reported number and percent of individuals estimated to experience a lung function decrement would be underestimated given the difference in exposure durations.
E-R function shape	In both the 2007 O_3 Staff Paper and 2014 HREA, an E-R function was derived using a combination of two functions (90% logistic fit and 10% linear-threshold). The selection of this parameterization was based largely on 1) linearity of E-R function for exposures between 0.08 – 0.12 ppm (and used in the 1997 O_3 risk assessment), a "very good" logistic model fit (2007 Staff Paper), and CASAC advice noting a linear model cannot entirely be ruled out given the are limited data at the two lowest exposure levels (Henderson, 2006). Sensitivity analyses of three different logistic/linear-threshold forms (90/10, 80/20, 50/50) indicated differences in the estimated risks, most notably lower risks estimated with increasing proportion of the linear threshold form and when considering the air quality adjusted to the lowest standard level of 64 ppb (2007 Staff Paper). A key issue of concern regarding each of these model fits is how responses are estimated at concentrations below which we have controlled human exposure study data (i.e., <40 ppb).	While not directly characterized in the 2014 HREA, the reported number and percent of individuals estimated to experience a lung function decrement may be greater when using primarily a logit fit than when using a probit fit. Based on the 2009 and 2018 SO_X REAs, the use of a probit form of a logistic model is more appropriate than using a logit form. This is based on assumptions regarding the distribution of individual thresholds for response supporting the use of a probit function, which is based on the inverse of the cumulative standard normal distribution function, rather than a logistic function which assumes a logistic distribution, for estimating risk (U.S. EPA, 2009, 2018e). It is possible the combined 90% logistic/10% linear may be more similar to a probit form (i.e., have lower response at lowest concentrations), the impact to risk estimates remains uncertain.
Ambient AQ (epidemiologic study)-based risk		
Ambient air concentrations	<u>Relationship between population exposures and ambient air monitor concentrations</u>: One of the assumptions in the use of ambient air concentration-response functions drawn from epidemiological studies to estimate risk associated with a pollutant for a modeled air quality scenario and population is that the relationship between ambient air monitor concentrations (usually represented in the studies by an area-wide average) and the exposure of the population is the same in the modeled air quality scenario and population as what existed in the epidemiologic study situation. Listed below are several aspects of that relationship. <u>*Use of areawide average concentrations*</u>*:* The use of areawide averages can miss important patterns of exposure within urban study areas introducing uncertainty	It is difficult to quantitatively characterize the direction and magnitude the uncertainty in monitor averaging might have on risk estimates. The issue could be a greater concern in large urban areas which may exhibit greater variation in O_3 levels compared to small urban areas due to diverse sources, topography, and patterns of commuting. In addition, populations living near heavily-trafficked roadways may experience different patterns of exposure relative to more generalized urban populations (both for O_3 and co-pollutants such as $PM_{2.5}$). Further, while there is increased uncertainty in the response at lower concentration levels, it remains difficult to characterize

Analysis Element	Limitations/Uncertainty identified in 2014 HREA	2014 Uncertainty Characterization and Newly Available Information for Current Review
	into the epi study effect estimates and accordingly into the C-R functions applied in the HREA. *<u>Monitor locations used for area wide averages</u>:* For some of the HREA analyses, the locations of the ambient air monitors used to characterize air quality in the HREA urban study areas do not necessarily match directly with the locations of monitors used in the original epidemiological study. This may be due to differences in the monitors operating during and used in the study and those for which data are available in the years included in the HREA. This may additionally occur due to the use of CBSAs for the HREA study area, given that CBSAs are generally larger areas than the epi study areas. *<u>Population Residence and Activity</u>:* Differences in the residences and activity patterns of the simulated population and the epi study population can contribute uncertainty to risk estimates given the relationships between individual activity and exposure to pollutants in ambient air are not accounted for in an epi study. For instance, in one HREA study area, the O_3 C-R functions were based on an epidemiological study in a region (northern Connecticut and Springfield) that did not encompass the actual urban study area assessed for risk (Boston). Another area of uncertainty relates to the location of exposure events vs location of the ambient air monitors and the relationship of the associated ME concentrations vs ambient air monitors. All of these can contribute to differences between the HREA and the epidemiologic studies in the relationship between ambient air monitor concentration and population exposure, which can contribute uncertainty to the risk estimates.	whether there are known and quantifiable biases in these low concentrations. Regardless, we expect there to be similar uncertainties in appropriately and accurately representing hypothetical ambient air conditions used in concert with C-R functions previously used and any functions derived from newly available epidemiologic studies identified in the current review. Differences in population representation in the risk assessment compared with the population in O_3 epidemiologic studies could have low to moderate magnitude of impact on the estimated risks and potentially lead to instances of over and underestimations (HREA, Table 7-4). We expect there to be similar uncertainties in population representation when using any newly available information for the current review.
Population baseline incidence of health outcome being assessed	<u>At-risk populations</u>: To some extent, differences in risk factors for the outcomes being quantified are accounted for by using baseline incidence rates. Uncertainty can be introduced into the characterization of baseline incidence in varying ways (e.g., error in reporting incidence for specific endpoints, mismatch between the spatial scale in which the baseline data were captured and the level of the risk assessment).	We would anticipate that sources of uncertainty related to baseline incidence (e.g., potential mismatch between the spatial scale of reporting in epidemiology studies versus risk modeling) would still apply if an updated analysis were completed.
Concentration-Response (C-R) functions	<u>Use of effect estimates obtained from epidemiology studies as the basis for C-R functions</u>: Exposure measurement error combined with other factors (e.g., magnitude of the effect, sample size, controls for confounding variables,	The HREA recognized that the uncertainty in these features associated with the O_3 C-R functions could have a moderate impact on risk estimates and, in some instances,

Analysis Element	Limitations/Uncertainty identified in 2014 HREA	2014 Uncertainty Characterization and Newly Available Information for Current Review
	consideration for effect modification) can affect the statistical models and associated effect estimates obtained from O_3 epidemiological studies. Uncertainty in effect estimates due to these influential factors contributes to uncertainty in the O_3 C-R functions used to estimate risk. Consequently, this introduces uncertainty to the epidemiological-based risk estimates. See discussion in 2014 HREA (p. 7-43) regarding statistical fit of the O_3 C-R functions. <u>Shape of the C-R curve at lower concentrations</u>: The shape of the curve at the most prevalent ambient air concentrations can have an important influence impact on the risk estimates. Most of the population will experience relatively low ambient air concentrations compared with a lesser proportion of the population experiencing concentrations having a high level of risk. The 2013 ISA indicates reduced certainty in the shape of O_3 C-R functions at lower ambient air concentrations due to lesser prevalence of these concentrations in the epidemiological studies (2014 HREA, pp. 7-43 to 7-44; 2013 ISA, section 2.5.4.4). As a result, the HREA provides estimates of epidemiology-based mortality risks using the entire distribution of ambient O_3, as well as providing estimates of mortality associated with specific ambient O_3 concentrations. <u>Specifying lag structure (short-term exposure studies):</u> There is uncertainty associated with specifying the exact lag structure to use in modeling short-term O_3-attributable mortality and respiratory-related morbidity. Most studies examining different lag models suggest that O_3 effects occur within a few days of exposure (see O_3 ISA, section 2.5.4.3). While the nature of an ideal lag model remains uncertain, we consider this uncertainty to be relatively small in magnitude compared with other the identified uncertainties. <u>C-R function for long-term (seasonal average 1-hr daily max) mortality</u>: There is also uncertainty about the extent to which mortality estimates based on the long-term metric in Jerrett et al. (2009) (i.e., seasonal average of 1-hour daily maximum concentrations) reflects associations with long-term average O_3 versus repeated occurrences of elevated short-term concentrations. For example, the CASAC concluded that "[i]n light of the potential nonlinearity of the C-R function for long-term exposure reflecting a threshold of the mortality response, the estimated number of premature deaths avoidable for long-term exposure reductions for several levels need to be viewed with caution" (Frey, 2014a, p. 3).	could result in either over- or underestimation of health risks. Of greatest importance is the uncertainty in risks estimates for low ambient O_3 concentrations. The PA recognizes a greater public health concern for the risk of adverse O_3-attributable effects at higher ambient O_3 concentrations (which drive higher exposure concentrations, section 3.2.2 of the 2014 PA), compared to risks associated with lower concentrations. This suggests that application of the C-R function at the lowest ambient O_3 concentrations, combined with instances of increased low concentrations resulting from the air quality adjustment approach (see above), could potentially contribute to over-estimation of risks. A broader impact of this uncertainty that is discussed in the last review is associated with the public health importance of the increases in relatively low O_3 concentrations following air quality adjustment (80 FR 65316-17, October 26, 2015). To the extent adverse O_3-attributable effects are more strongly supported for higher ambient concentrations, the impacts on risk estimates of increasing low O_3 concentrations (an impact of reductions in some O_3 precursors) reflect an important source of uncertainty in the AQ epidemiologic risk estimates (80 FR 65316-17, October 26, 2015). While it is possible that different C-R relationship shapes could be considered in addition to the previously used approach of apportioning the contribution of particular levels to the risk estimates, we expect there to be similar uncertainties in the O_3 C-R functions when using any newly available information, approaches, or tools identified for the current review.

Analysis Element	Limitations/Uncertainty identified in 2014 HREA	2014 Uncertainty Characterization and Newly Available Information for Current Review
	Lack of C-R functions that have addressed potential for influence of co-pollutants: The inclusion or exclusion of co-pollutants in epidemiologic study models may confound, or in other ways, impact the O_3 effect estimates reported in the epi studies in those instances where other pollutants are causally associated with the endpoint of interest. Regarding PM as one copollutant, the O_3 ISA notes that across studies where its role was assessed, the potential impact of co-pollutants such as PM on O_3-mortality risk estimates tended to be much smaller than the variation in O_3-mortality risk estimates across epi study cities.	

Appendix 5B

Appendix 5B. Limitations and uncertainties of the air quality, exposure and risk analyses developed in the last review of secondary standard, and consideration of related newly available information and tools. Drawn from the 2014 WREA, 2014 PA; notices of proposed and final decisions; and, response to comments document for the review.

Analysis Element	Limitations/Uncertainty Identified in Last Review	Conclusions from Last Review and Newly Available Information for Current Review
***[Section 5.2.1.3*]** **W126-based Cumulative Exposure Estimates for Class I Areas (based on Air Monitoring Data)**		
Ambient air monitoring data for O_3	The monitoring dataset used was for the period from 1998 through 2013 (80 FR 65385, October 26, 2018). The data set included SLAMS monitors as well as CASTNET monitors, thus providing extended representation in rural areas. The monitoring season varies across states in length from May to September to year-round, with duration intended to capture the highest concentration periods, thus including highest 3-month period needed for derivation of W126 index values.	Overall O_3 measurements are of high quality and have low uncertainty (2014 WREA, Section 4.4). Ambient air monitoring data are now available for more recent years, e.g., through the 2017 monitoring year.
Class I area representation by monitoring sites	This analysis focused on monitors sited in or within 15 km of a Class I area for which any of the years in the time period had a W126 index value above 15 ppm-hrs (80 FR 65385, October 26, 2015). The 15 km distance was selected as a natural breakpoint in distance of O_3 monitoring sites from Class I areas and as still providing similar surroundings to those occurring in the Class I area. We note that given the strict restrictions on structures and access within some of these areas, it is common for monitors intended to collect data pertaining to air quality in these types of areas to be sited outside their boundaries. The analysis focused on those sites for which at least one 3-year period between 1998 and 2013 included a 3-year W126 value at/above 15 ppm-hrs (80 FR 65385, October 26, 2015).	The 17 locations in this analysis represent nearly 25% of the approximately 70 Class I areas for which there are ambient air monitors within 15 km, and approximately 10% of the approximately 160 Class I areas in the U.S. (80 FR 65385, October 26, 2015). There is an O_3 monitor within approximately 24 of Class I areas (somewhat less than 15%), and a monitor in or within 15 km of approximately 70 of them (somewhat fewer than half) (80 FR 65385, October 26, 2015). More recent monitoring data may include additional sites.
[Section 5.2.1.3] W126-based Cumulative Exposure Estimates for O_3 Monitoring Sites across the U.S. with Design Values at/below 75, 70, 65 and 60 ppb		
Ambient air monitoring data for O_3	The monitoring dataset used was for the period from 1998 through 2013 (80 FR 65400, October 26, 2015; Wells, 2015). The data set included SLAMS monitors, which are largely focused in urban and suburban areas, as well as CASTNET monitors, which are located in rural areas, thus providing extended representation in rural areas (as summarized in section 2.2 above). The monitoring network in some areas of the Western U.S. is much less dense than in the eastern portions of the U.S. and the west coast states (Wells, 2015, Figures 1 and 2). The monitoring season varies across states in length from May to September to year-round, with duration intended to capture the highest concentration periods, thus including highest 3-month period needed for derivation of W126 index.	Overall O_3 measurements are of high quality and have low uncertainty (2014 WREA, Section 4.4). Data are now available through the more recent 2017 monitoring year, e.g., four more 3-year periods extending through the 2015-2017 time period are now available. Data are also available now for a few additional sites in Montana and Wyoming (Figure 2-3 above).
Nationwide representation by monitoring sites	The analysis included 1,430 monitoring sites with sufficient data to derive valid air quality metrics for at least one 3-year period from 2001 to 2013 (Wells, 2015). During the then-most recent 3-year period (2011-2013), there were more than 500 monitoring sites that would meet the now-current standard of 70 ppb. These monitors were	Given the reductions in O_3 concentrations that have occurred since then (see section 2.3 above), it is likely there are more sites that meet the now-current

Analysis Element	Limitations/Uncertainty Identified in Last Review	Conclusions from Last Review and Newly Available Information for Current Review
	distributed across all nine NOAA climatic regions and 46 of the 50 states. Across all 11 3-year periods of data over the complete time period, there were nearly 4,000 site-time period instances for which the now-current standard of 70 ppb would have been met.	standard in an update of such an analysis for the four more recent 3-year periods now available.
***[Section 5.2.1.1]* National and Regional/Urban Estimates of O_3-attributable Impacts for Model-adjusted O_3 Concentrations in Nine NOAA Regions**		
Ambient Air Concentrations		
Ambient air monitoring data	The monitoring dataset used was for the 3-year period from 2006 through 2008 (WREA, Table 4-5).	Overall O_3 measurements are of high quality and have low uncertainty (2014 WREA, section 4.4). Data are now available for the period 2015-2017.
Approach used to derive factors to adjust air quality to just meet then-existing standard	Modeling Platforms and Approaches: Model predictions from the Community Multiscale Air Quality (CMAQ) model, like all deterministic photochemical models, have both parametric and structural uncertainty associated with them. Higher Order Decoupled Direct Method (HDDM) allows for the efficient approximation of O_3 concentrations under alternate emissions scenarios. This approximation is less accurate for larger emissions perturbations, especially under nonlinear chemistry conditions (WREA, Table 4-5).	Medium magnitude of impact potentially resulting from both under- and over-estimation of ambient concentrations. Updated modeling platforms are available since the 2014 WREA, e.g., the CAMxv6.5 photochemical model includes updated chemical mechanisms for O_3 formation and destruction pathways. Somewhat more recent emissions, meteorology and international transport information is available (e.g., for 2016).
	Application of HDDM sensitivities to ambient data: there is uncertainty in the statistical regressions used to relate O_3 response to emissions perturbations with ambient O_3 concentrations for every season, hour-of-the-day, and monitor location (WREA, Table 4-5).	
	Emissions Reduction Assumptions: Assumption of across-the-board emissions reductions: Ozone response is modeled for across-the-board reductions in U.S. anthropogenic NO_X. These across-the-board cuts do not reflect actual emissions control strategies. The form, locations, and timing of emissions reductions that would be undertaken to meet various levels of the O_3 standard are unknown. The across-the-board emissions reductions bring levels down uniformly across time and space to show how O_3 would respond to changes in ambient levels of precursor species but do not reflect spatial and temporal heterogeneity that may occur in local and regional emissions reductions (WREA, Table 4-5).	As the adjustment is applied to all monitor locations in each region, the adjustment results in broad regional reductions in O_3, including at some monitors that were already meeting or below the target level. Thus, the adjustments performed to develop a scenario meeting a target level at the highest monitor in each region resulted in substantial reduction below the target level in some areas of the region. This result at the monitors already well below the target indicates an uncertainty with regard to air quality expected from specific control strategies that might be implemented to meet a particular target level (80 FR 65375, October 26, 2015). Adjustments made across smaller areas might reduce this uncertainty.
	Concentration Adjustment: Adjustments were applied independently for each of the nine NOAA climate regions in continental U.S. such that the highest monitor location in each region just met the then-existing standard (WREA, Table 4-5). In regions where the air quality adjustment was applied, it was based on emissions reductions determined necessary for the highest monitor in that region to just equal the existing standard or the W126 target for the scenario. Concentrations at all other monitor locations in the region were also adjusted based on the same emissions reductions assumptions.	

Analysis Element	Limitations/Uncertainty Identified in Last Review	Conclusions from Last Review and Newly Available Information for Current Review
Approach used to derive factors to adjust air quality to just meet the 3-year W126 targets (15, 11, and 7 ppm-hr)	Model-based adjustments: Beginning with concentrations at monitor locations that had been adjusted to just meet the then-existing standard, further adjustments were made at all sites in each NOAA region in which at least one site was not already at/below the target W126 value for that scenario (2014 WREA, section 4.3.4.1). In such regions, the adjustment made at all sites was that determined necessary for the highest monitor in that region to just equal the W126 target.	See above.
Approach used to spatially interpolate ambient monitor concentrations to grid cells	Spatial interpolation technique: Voronoi Neighbor Averaging (VNA) was used to estimate O_3 concentrations in unmonitored areas (as summarized in section 5.2.1.1 above). The uncertainty tends to increase with greater distance from the monitoring sites as the VNA estimates are weighted based on distance from neighboring monitoring sites. Thus, there is less uncertainty in the VNA estimates near urban areas with more dense monitoring networks, and more uncertainty in sparsely populated areas where monitors are further apart, such as in the Western U.S. (2014 WREA, Table 4-5).	The uncertainty in this approach could lead to both under- and over-estimation of ambient concentrations. However, the magnitude of potential impact to exposure and risk estimates ranges from low to moderate, with greatest uncertainties when interpolating large distances between monitors (2014 WREA, Table 4-5). Several other methods are available, with associated limitations.
Impacts on Tree Growth at Species- and Ecosystem-level		
Response estimates for controlled exposures	Robust and well-established E–R functions for RBL are available for eleven tree species in the seedling growth stage: black cherry, Douglas fir, loblolly pine, ponderosa pine, quaking aspen, red alder, red maple, sugar maple, tulip poplar, Virginia pine, and white pine (2013 ISA; 2014 PA; 80 FR 65371-73, 65383-65384, 75393-65395, October 26, 2015). The data for these species come from extensive controlled studies in open top chambers (OTCs), with most species studied multiple times under a wide range of exposure and/or growing conditions	New field-based studies available in the last review qualitatively strengthened support for and confidence in the evidence from the OTC studies providing additional evidence that O_3-induced tree seedling biomass loss effects observed in chambers also occurs in the field (2014 PA, pg. 1-29 to 1-30).
Species-specific E-R functions	Robust composite species-specific E-R functions were developed for each of the 11 tree species (above) based on the separate E-R functions for each combination of species, exposure condition and growing condition scenario (2013 ISA, section 9.6.1). The species-specific composite E-R functions have been successfully used to predict the biomass loss response from tree seedling species over a range of cumulative exposure conditions (2013 ISA, section 9.6.2). A 12^{th} species-specific E-R function was considered but not given the same emphasis as the other eleven, as it lacked the robust basis of the others given that its underlying data were from a single gradient study that did not control for O_3 and climatic conditions, as contrasted with the more well controlled OTC exposure studies (Frey, 2014c, p. 10, 80 FR 65372, October 26, 2015). Shape of E-R function: Relative biomass loss estimates are highly sensitive to the parameters in the E-R function. Some species are represented by one study, other species by many studies (WREA, Table 6-27).	Sensitivity analyses showed high intraspecific and interspecific variability. Among the species for which robust E-R functions are available are a few very sensitive species and several with little or no O_3 sensitivity. It is unknown how well this reflects the larger suite of tree species in the U.S. Potential influence on risk estimates estimated to have high magnitude (WREA, Table 6-27).

Analysis Element	Limitations/Uncertainty Identified in Last Review	Conclusions from Last Review and Newly Available Information for Current Review
	Absence of functions for many sensitive species: Robust E-R functions are not available for the majority of trees in the modeled urban areas and Class I areas, precluding their representation. Study data for other species do not support E-R development (WREA, Table 6-27). Use of seedling functions for adult trees: E-R functions for trees are based on analyses of tree seedlings, but most biomass impacts are from estimated effects to adult trees (WREA, Table 6-27). National distribution of species with E-R functions: While the available robust E-R functions are for species representing only a small fraction (0.8 percent) of the total number of native tree species in the contiguous U.S. (1,497), this small subset includes eastern and western species, deciduous and coniferous species, and species that grow in a variety of ecosystems and represent a range of tolerance to O_3 (2013 ISA, section 9.6.2; 2014 WREA, section 6.2, Figure 6–2, Table 6–1). The range of each species is based on data from USFS and used to specify presence/absence of each species nationally and, in ecosystem-level analysis were used to scale biomass loss by proportional presence of each species (WREA, Table 6-27). Species distribution in urban case study areas and availability of E-R functions: E-R functions are available for only small portion of trees in the urban case study areas. Eighty to 90 percent of the total trees in the urban case study areas are excluded from the analysis as they are species for which we do not have E-R functions; we have some data indicating sensitivity for two of these species.	Additional sensitive species are likely to exist in U.S. Therefore, total tree biomass impacts are likely underestimated, with medium to high potential magnitude of impact (WREA, Table 6-27). It is not known yet if there would be robust E-R functions available for additional tree species in this current review. Generally, RBL estimates in tree seedlings are comparable to adult tree estimates, with a few exceptions such as black cherry. Some E-R functions overestimate and some underestimate RBL in adult trees, with low to medium potential magnitude of impact (2014 WREA, Table 6-27)). The magnitude of the influence is dependent on the community composition in each area. Magnitude of potential influence on national-scale risk estimates estimated to be low to medium, and medium to high for urban case studies (WREA, Table 6-27). It is unclear whether robust E-R functions will be available in this review for additional species.
Species distributions	Tree basal area estimates used to assess larger scale ecosystem effects: Estimates of basal area were modeled by the U.S. Forest Service's Forest Health Technology Enterprise Team (FHTET) at a scale of 240 m^2. These values were aggregated to the 144 (12 x12) km^2 CMAQ grid. Assumption of constant forest composition: Forest and Agriculture Sector Optimization Model with greenhouse gases (FASOMGHG) modeling (used for the urban case study analyses) does not reflect changes in tree species mixes within a forest type made by natural adaptation and adaptive management by landowners due to O_3. Less sensitive tree species may gain relative advantage over more sensitive species. The magnitude of potential influence of associated uncertainties on risk estimates is estimated to be low (WREA, Table 6-27, p. 6-70).	The magnitude of the potential influence of the associated uncertainty on national scale risk estimates is expected to be low to medium (WREA, Table 6-27). While USDA's FHTET has been working on refining its model, the effect of these refinements on risk estimates, though variable, would likely be small (WREA Table 6-27). While updates to FASOM or FASOMGHG models may be available, we do not expect there to be appreciable improvements in scaling up of effects or in incorporation of changes in forest composition.

Analysis Element	Limitations/Uncertainty Identified in Last Review	Conclusions from Last Review and Newly Available Information for Current Review
Crop Yield Impacts		
Response estimates for controlled exposures	Experimental data: There is strong evidence for established E-R functions for 10 crops (barley, field corn, cotton, kidney bean, lettuce, peanut, potato, grain sorghum, soybean and winter wheat). The established E-R functions for relative yield loss (RYL) were developed from OTC-type experiments from the National Crop Loss Assessment Network (NCLAN) (2013 ISA, section 9.6.3; 2014 WREA, section 6.2; 2014 PA, Figure 5–4 and section 6.3; 80 FR 65372, October 26, 2015). These crops were originally selected for study based on their significant role among U.S. commodity crops nationwide (e.g., representing approximately 85% of the commodity crops grown in the U.S. in the 1980s). Data newly available in the 2015 review continued to confirm earlier findings, leading to the ISA conclusion of little new evidence that crops are becoming more tolerant of O_3 (U.S. EPA, 2006a; U.S. EPA 2013).	It is not clear what percentage of the commodity crops grown today the evaluated species represent. Also, it is not clear to what degree crop sensitivities may have changed over time due to genetic modification or change in varieties planted.
Species-specific E-R functions	Shape of E-R function: Crop yield loss estimates are highly sensitive to the parameters in the E-R function. Some functions are based on one study and others on many studies (WREA, Table 6-27).	Sensitivity analyses for 10 crops (in 54 studies) showed high intraspecific and interspecific variability It is unknown how well the set of species with E-R functions reflects the larger suite of crops in the U.S (WREA, Table 6-27).
Agricultural and Timber Market Impacts		
Approach to estimating impacts on agricultural and timber markets	Use of median parameters for crop species E-R functions used to assess national agricultural impacts (in FASOM): In addition to the robust E-R functions developed for the 10 commodity crops above, this modeling used the median E-R function for oranges, rice, and tomatoes, three species for which E-R functions in terms of W126 are not available (2014 WREA, Table 6-27, p. 6-69). Crop proxy and forest type assumptions: Actual impacts may differ from those of the crop proxy or the forest type as the crops/tree species modeled are only a subset of species present in U.S. agriculture and forestry systems. Further, FASOMGHG modeling used a simple average of tree RYLs for all forest types within a region (2014 WREA, Table 6-27). Omission of agriculture/ forestry on public lands: The model used (FASOMGHG) does not include public lands (2014 WREA, Table 6-27). International trade projections in FASOMGHG: FASOMGHG reflects future international trade projections by USDA based on recent O_3 conditions. Soybeans and wheat are major crop exports and have relatively large responses to O_3, which are not reflected in the trade projections (2014 WREA, Table 6-27).	Using alternative E-R functions would result in lower or higher O_3 impacts on crop and tree species biomass productivity, potentially affecting economic equilibrium outcomes (2014 WREA, Table 6-27). The extent to which updates to FASOMGHG address this uncertainty is yet to be examined. Because public lands are not affected within the model, the estimates of changes in consumer and producer surplus would likely be higher if public lands were included (2014 WREA, Table 6-27).

Analysis Element	Limitations/Uncertainty Identified in Last Review	Conclusions from Last Review and Newly Available Information for Current Review
	Overall effects on agricultural yields and producer and consumer surplus depend on the ability of producers/farmers to substitute other crops that are less O_3 sensitive, and the responsiveness, or elasticity, of demand and supply (U.S. EPA, 2014b, section 6.5). The WREA discusses multiple areas of uncertainty associated with the crop yield loss estimates, including those associated with the model-based adjustment methodology as well as those associated with the projection of yield loss using the FASOMGHG at the estimated O_3 concentrations (U.S. EPA, 2014b, Table 6–27, section 8.5). Because the W126 index estimates generated in the air quality scenarios are inputs to the vegetation risk analyses for crop yield loss, any uncertainties in the air quality scenario estimation of W126 index values are propagated into those analyses (U.S. EPA, 2014b, Table 6–27, section 8.5). Therefore, the air quality scenarios in the crop yield analyses have the same uncertainties and limitations as in the biomass loss analyses (summarized above), including those associated with the model-based adjustment methodology (U.S. EPA, 2014b, section 8.5).	While having sufficient crop yields is of high public welfare value, important commodity crops are typically heavily managed to produce optimum yields. Moreover, based on the economic theory of supply and demand, increases in crop yields would be expected to result in lower prices for affected crops and their associated goods, which would primarily benefit consumers. These competing impacts on producers and consumers complicate consideration of these effects in terms of potential adversity to the public welfare (U.S. EPA, 2014c, sections 5.3.2 and 5.7). (80 FR 65379, October 26, 2015).
Carbon Sequestration		
Species-specific estimates	Functions for estimating carbon sequestration: The functions applied in the models to estimate carbon sequestration are uncertain and vary by species. Pollution removal is calculated based on field, pollution concentration, and meteorological data. The pollution removal functions in iTree are from Nowak et al. (2006).	This uncertainty was judged to have medium magnitude of potential influence on risk estimates (2014 WREA, Table 6-27). It is not clear if updates to these models have reduced this uncertainty.
National-scale estimates		
Carbon sequestration estimates in small set of urban areas (using iTree model)	Representation and distribution of trees within assessed urban areas: The base inventory of urban trees, including species and distribution, in iTree has uncertainty. The iTree model estimates are based on tree growth and pollution removal functions that are specific to the forest structure in each urban area, including the species composition, number of trees, and diameter distribution of trees. Of the 11 species with E-R functions, only 2-3 species were in each urban area, comprising at most 18.5% of total tree population (2014 WREA, section 6.6).	The urban tree inventories included in the iTree analyses are based on field counts and measurements of trees in the specific urban areas analyzed. Although such data are generally considered less uncertain than modeled tree inventories, any associated uncertainties are propagated into the estimates of carbon sequestration and pollution removal based on those inventories (2014 WREA, Table 6-27).
Pollutant Removal		
Pollutant removal Estimates in small set urban areas (using iTree model)	Estimation of pollutant removal: The functions applied in iTree to estimate growing trees' removal of some common air pollutants are uncertain and vary by species. Assumption of zero pollutant emissions: Many tree species are biogenic sources of volatile organic compounds (VOC) that contribute to formation of O_3. Additional VOC emissions associated with biomass gains are not addressed.	Magnitude of potential influence of uncertainty on risk estimates estimated to be medium (WREA, Table 6-27). The availability of updated removal functions or functions addressing potential O_3 formation is not yet known.
[Section 5.2.1.2] **Foliar Injury Analyses**		

Analysis Element	Limitations/Uncertainty Identified in Last Review	Conclusions from Last Review and Newly Available Information for Current Review
Associating foliar injury data with CMAQ-generated O_3 exposures by grid cell assignments	Spatial assignment of foliar injury biosite data to 12x12 km grids. Because of privacy laws that require the exact location information of sampling sites to not be made public, the data were assigned to the CMAQ grid by the USFS, except for data in California, Oregon, and Washington which were assigned to the CMAQ grid by EPA staff based on publicly available geographic coordinates, rather than coordinates specific to the sites. Thus, these data have greater uncertainty (2014 WREA, Table 7-24). Availability of biosite sampling data: Because sampling was discontinued in some states prior to this analysis, we did not include data for many western states (Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, New Mexico, Oklahoma, and portions of Texas).	Magnitude of potential influence of this element on risk estimates was estimated to be medium (WREA, Table 6-27).
Categorization of biosites by moisture level	Soil moisture threshold for foliar injury: Low soil moisture reduces the potential for foliar injury, but injury could still occur because plants must open their stomata even during periods of drought (2014 WREA, Table 7-24). Spatial resolution of soil moisture data: Some vegetation such as along riverbanks may experience sufficient soil moisture during periods of drought to exhibit foliar injury. In addition, we did not have soil moisture data for Alaska, Hawaii, Puerto Rico, or Guam (2014 WREA, Table 7-24). Time period for soil moisture data: Short-term estimates of soil moisture are highly variable over time, even from month to month within a single year; yet using averages to address variability contributes to a potential temporal mismatch between soil moisture and injury (2014 WREA, Table 7-24). Drought categories: The soil moisture categories used to derive the foliar injury benchmarks (i.e., wet, normal, and dry) are uncertain (2014 WREA, Table 7-24).	The 2014 WREA estimated this uncertainty to have medium magnitude of impact on risk estimates (2014 WREA, Table 7-24). The 2014 WREA estimated this uncertainty to have medium magnitude of impact on risk estimates (2014 WREA, Table 7-24). More refined spatial data are not known to be available. The 2014 WREA estimated this uncertainty to have low-medium magnitude of impact on risk estimates (2014 WREA, Table 7-24). The 2014 WREA estimated this uncertainty to have unknown magnitude of impact on risk estimates (2014 WREA, Table 7-24).

United States Environmental Protection Agency	Office of Air Quality Planning and Standards Health and Environmental Impacts Division Research Triangle Park, NC	Publication No. EPA-452/R-19-002 August 2019