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Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Urban Visibility Impact Assessment

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Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
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Office of Air and Radiation
Office of Air Quality Planning and Standards
Health and Environmental Impacts Division
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LIST OF ACRONYMS/ABBREVIATIONS

AQI	Air Quality Index
AQS	EPA's Air Quality System
ASOS	Automated Surface Observing System
Ca	Calcium
CAA	Clean Air Act
CAIR	Clean Air Interstate Rule
CASAC	Clean Air Scientific Advisory Committee
CBSA	Consolidated Business Statistical Area
CCN	Cloud Condensation Nuclei
CCSP	US Climate Change Science Program
Cd	Cadmium
CMAQ	Community Multiscale Air Quality
CONUS	CMAQ simulations covering continental US
CSA	Consolidated Statistical Area
CTM	Chemical Transport Model
Cu	Copper
DRE	Direct Radiative Effects
EPA	United States Environmental Protection Agency
FEM	Federal Equivalent Method
FRM	Federal Reference Method
GEOS	Global Scale Air Circulation Model
GI	Group Interviews
Hg	Mercury
ICR	Information Collection Request
IFG	Investigative Focus Groups
IMPROVE	Interagency Monitoring of Protected Visual Environment
IPCC	Intergovernmental Panel on Climate Change
ISA	Integrated Science Assessment
Km	Kilometer
N	Nitrogen
NAAQS	National Ambient Air Quality Standards
NCEA	National Center for Environmental Assessment
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen oxides
NPS	National Park Service
NRC	National Research Council
NWS	National Weather Service
OAQPS	Office of Air Quality Planning and Standards
OAR	Office of Air and Radiation
OMB	Office of Management and Budget
ORD	Office of Research and Development
PM	Particulate Matter

$PM_{2.5}$	Particles with a 50% upper cut-point of 2.5 µm aerodynamic diameter and a penetration curve as specified in the Code of Federal Regulations.
PM_{10}	Particles with a 50% upper cut-point of 10± 0.5 µm aerodynamic diameter and a penetration curve as specified in the Code of Federal Regulations.
$PM_{10\text{-}2.5}$	Particles with a 50% upper cut-point of 10 µm aerodynamic diameter and a lower 50% cut-point of 2.5 µm aerodynamic diameter.
Pb	Lead
PRB	Policy Relevant Background
REA	Risk and Exposure Assessment
RF	Radiative Forcing
RH	Relative Humidity
SEARCH	Southeastern Aerosol Research and Characterization Study
S	Sulfur
SO_2	Sulfur Dioxide
SO_x	Sulfur Oxides
STP	Standard Temperature and Pressure
TOA	Top-of-atmosphere
UVA	Urban Visibility Impact Assessment
VAQ	Visual Air Quality
Zn	Zinc

1 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is presently conducting a review of the particulate matter (PM) national ambient air quality standards (NAAQS). EPA's overall plan and schedule for this PM NAAQS review presented in the *Integrated Review for the National Ambient Air Quality Standard for Particulate Matter* (US EPA, 2008a). That plan outlines the Clean Air Act (CAA) requirements related to the establishment and reviews of the NAAQS, the process and schedule for conducting the current PM NAAQS review, and two key components in the NAAQS review process: an Integrated Science Assessment (ISA) and a Risk and Exposure Assessment (REA). It also lays out the key policy-relevant issues to be addressed in this review as a series of policy-relevant questions that will frame our approach to determining whether the current primary and secondary NAAQS for PM should be retained or revised.

The ISA prepared by EPA's Office of Research and Development (ORD), National Center for Environmental Assessment (NCEA) provides critical assessment of the latest available policy-relevant scientific information upon which the NAAQS are to be based. The ISA will critically evaluate and integrate scientific information on the health and welfare effects associated with exposure to PM in the ambient air. The REA, prepared by EPA's Office of Air and Radiation (OAR), Office of Air Quality Planning and Standards (OAQPS) will be developed in two parts addressing: (1) human health risk and exposure assessment and (2) quantitative assessments of urban visibility impairment and qualitative assessments of other welfare-related effects. This document describes the scope and methods planned to conduct the quantitative urban visibility assessment (UVA) to support the review of the secondary (welfare-based) PM NAAQS (U.S. EPA, 2009b). The UVA will draw from the information assessed in the ISA, and will include, as appropriate, quantitative estimates of urban visibility conditions and public preferences associated with recent ambient levels of PM, with levels simulated to just meet the current standards, and with levels simulated to just meet possible alternative standards. A separate document describes the scope and methods planned to conduct quantitative assessments to support the review of the primary (health-based) PM NAAQS (U.S. EPA, 2009). Preparation of these two planning documents coincides with the development of the first draft PM ISA (U.S. EPA, 2008b) to facilitate the integration of policy-relevant science into all three documents.

This planning document is intended to provide enough specificity to facilitate consultation with CASAC, as well as for public review, in order to obtain advice on the overall scope, approaches, and key issues in advance of conducting the UVA and presentation of results in the first draft of the UVA. NCEA has compiled and assessed the latest available policy-relevant science available to produce a first draft of the ISA and related Annexes (US EPA, 2008b), which we have reviewed and used in the development of the approaches described below. This includes information on atmospheric chemistry, source emissions, air quality, urban visibility conditions, public perception/preference studies and other PM-related welfare effects. CASAC consultation on this planning document coincides with its review of the first draft ISA. CASAC and public comments on this document will be taken into consideration in the development of the first draft UVA, the preparation of which will coincide and draw from the second draft ISA. The second draft UVA will draw on the final ISA and will reflect consideration of CASAC and public comments on the first draft UVA. The final UVA will reflect consideration of CASAC and public comments on the second draft UVA.

OAQPS will prepare a policy assessment that will discuss the policy implications of the key studies and scientific information contained in the final ISA and the quantitative analyses contained in the final UVA. The policy assessment is intended to "bridge the gap" between the scientific review and the judgments required of the EPA Administrator in determining whether, and if so, how, it is appropriate to revise the secondary NAAQS for PM. The policy assessment will present various policy options for standard setting together with a discussion of how the underlying interpretations of the urban visibility impact assessments and evidence-based information regarding other non-visibility welfare effects inform consideration of the adequacy of the current standards, and the appropriateness of alternative secondary standards that could be considered by the EPA Administrator. The policy assessment will focus on the basic elements of the PM air quality standards: indicators, averaging times, forms[1], and levels. These elements, which serve to define each secondary PM NAAQS, will be considered collectively in evaluating the public welfare protection afforded by the standards.

[1] 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.

This introductory chapter includes background on the current PM standards and the quantitative assessments conducted for the last review; the key issues related to designing the quantitative assessments in this review, building upon the lessons learned in the last review; and an overview introducing the planned assessments that are described in more detail in later chapters. The planned assessments are designed to estimate ranges of urban visual air quality impairment that are associated with recent ambient levels, with ambient levels simulated to just meet the current standards, and with ambient levels simulated to just meet alternative standards that may be considered. The major components of the assessments briefly outlined in the Integrated Review Plan (U.S., 2008a, Section 6), are conceptually presented in Figure 1-1, and are described in more detail below in Chapters 2, and 3, respectively. The schedule for completing these assessments is presented in Chapter 4.

1.1 BACKGROUND ON LAST PM NAAQS

As a first step in developing this planning document, we considered the work completed in the most recent review of the PM standards, completed in 2006 (71 FR 61144, October 17, 2006)[2], and in particular, the quantitative assessments conducted in support of that review. At that time, public welfare effects were addressed under/divided into two main categories: visibility impacts and other welfare effects. Regarding visibility impacts, EPA took into account that the Regional Haze Program[3], implemented under sections 169A and 169B of the CAA, is providing ongoing protection against visibility impairment in Class I areas. The 2006 PM NAAQS review therefore focused on evaluating the levels of visibility impairment occurring in urban areas and on assessing available information on public preferences regarding at what point PM-related urban visibility impairment becomes unacceptable to the individual. At that time, EPA's focus continued to remain on particle mass and EPA determined that size-fractionated particle mass, rather than particle composition, remained the most appropriate approach for addressing PM-related urban visibility effects. EPA conducted a quantitative assessment to provide additional information and insights that could help inform decisions on the standards. These assessments

[2] See also http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_index.html

[3] See http://www.epa.gov/air/visibility/program.html for more information on EPA's Regional Haze Program.

and the resulting recommendations regarding an appropriately protective secondary standard for urban visibility impacts are described in section 1.1.1 below.

With respect to the other welfare effects category, it was recognized that the chemical composition of the particle was more relevant to associated ecosystem effects than was particle mass or size. The chemical and physical properties of PM can vary greatly with time, region, meteorology, and source categories, thus complicating the assessment of potential welfare impacts. In particular, the last review concluded that the nitrate and sulfate components of PM have the most widespread ecological relevance when deposited. However, because of the difficulty in determining the particulate matter contribution to the total load of N and S in sensitive ecosystems, an appropriate secondary PM standard to address these effects remained elusive. As a result, EPA did not conduct any quantitative assessments for these N and S effects, nor for the other non-visibility PM-related public welfare effects (e.g., materials damage, climate) due to a paucity of relevant current information.

The rationale for the 2006 final decision on the appropriate revisions to the secondary PM NAAQS included consideration of: (1) the latest scientific information on visibility effects associated with PM; (2) insights gained from assessments of correlations between ambient $PM_{2.5}$ and visibility impairment prepared by EPA; and (3) specific conclusions regarding the need for revisions to the current standards (i.e., indicator, averaging time, form, and level) that, taken together, would be requisite to protect the public welfare from adverse effects on visual air quality.

EPA proposed to revise the secondary standards to provide additional protection against PM-related public welfare effects including urban visibility impairment, effects on vegetation and ecosystems, and materials damage and soiling, by making them identical in all respects to the suite of proposed primary standards for fine and coarse particles. EPA also solicited comment on adding a new sub-daily $PM_{2.5}$ secondary standard to address visibility impairment in urban areas. CASAC provided advice to EPA in several letters to the Administrator stating support for the sub-daily standard. On September 21, 2006, EPA announced its final decisions to revise the secondary NAAQS for PM to provide increased protection of public welfare by making them identical to the revised primary standards (71 FR 61144, October 17, 2006).

Specifically, EPA revised the level of the 24-hour $PM_{2.5}$ standard to 35 µg/m^3, retained the level of the annual $PM_{2.5}$ annual standard at 15 µg/m^3, and revised the form of the annual $PM_{2.5}$ standard by narrowing the constraints on the optional use of spatial averaging. With regard to the standards for coarse particles, EPA retained PM_{10} as the indicator for purposes of regulating the coarse fraction of PM_{10} (referred to as thoracic coarse particles or coarse-fraction particles; generally including particles with a nominal mean aerodynamic diameter greater than 2.5 µm and less than or equal to 10 µm, or $PM_{10-2.5}$). EPA retained the 24-hour PM_{10} standard at 150 µg/m^3 and revoked the annual PM_{10} standard because available evidence generally did not suggest a link between long-term exposure to current ambient levels of coarse particles and health or welfare effects.

1.1.1 Overview of Visibility Impairment Assessment in the Last Review

In the last PM NAAQS review key information was developed in both the Criteria Document and Staff Paper on: (a) the nature of PM-related visibility impairment, including trends in visual air quality; (b) the characterization of current visibility conditions and the quantitative relationships between ambient PM and visibility; (c) the impacts of visibility impairment on public welfare; and (d) approaches to evaluating public perceptions and attitudes about visibility impairment. The assessments conducted by EPA associated with this information are described briefly below.

Nature of PM-related Visibility Impairment

The science of PM-related visibility impairment was already well understood at the time of the last review. The relevant aspects of this science are briefly described here. Visibility, which can be defined as the degree to which the atmosphere is transparent to visible light, is determined by the scattering and absorption of light by particles and gases, from both natural and anthropogenic sources. Fine particles are more efficient per unit mass at scattering light than coarse particles. The classes of fine particles principally responsible for visibility impairment are sulfates, nitrates, organic matter, elemental carbon, and soil dust. The scattering efficiency of certain classes of fine particles, such as sulfates, nitrates, and some organics, increases as relative humidity rises because these particles can absorb water and grow to sizes comparable to the wavelength of visible light. In addition to limiting the distance that one can see, the scattering and absorption of light caused by air pollution can also degrade the color, clarity, and contrast of scenes. Visibility conditions are often described in terms of visual range (in distance units), light extinction (in inverse distance units), or haziness (in deciviews units).

Direct relationships exist between ambient pollutant species and their contributions to light extinction and thus to visibility impairment. EPA's guidance for tracking progress under the regional haze program specifies an algorithm for calculating total or "reconstructed" light extinction by multiplying the concentrations of each major fine particle constituent by its extinction efficiency (EPA, 2005a, section 2.8.1). Because certain fine particle constituent, extinction efficiencies increase significantly with increases in relative humidity, a measure of un-speciated $PM_{2.5}$ mass concentration is not as precise a metric as the light extinction. Nonetheless, by using historic averages, regional estimates, or actual day-specific measurements of the component-specific percentage of total mass, one can develop reasonable estimates of light extinction from PM mass concentrations. In the last review, EPA concluded that fine particle mass concentrations could be used as a general surrogate for visibility impairment (EPA, 2005a, p. 2–74).

Due to regional differences in typical relative humidities and PM pollutant mixes, visibility levels between the eastern and western U.S. are significant, especially in non-urban areas. For example, in Class I areas, visibility levels on the 20 percent haziest days in the West are about equal to levels on the 20 percent best days in the East. For example, the average visual ranges on the 20 percent haziest days in eastern and western urban areas are approximately 20 km and 27 km, respectively (Schmidt et al., 2005). By contrast, visibility levels in urban areas show far less difference between eastern and western regions. (See discussions below).

Characterization of Current Conditions and Correlations Between Urban Visibility and $PM_{2.5}$ Mass

As mentioned above, the assessment of visibility impairment in the last review was primarily focused on visibility impairment in urban areas. Data available indicate that urban areas generally have higher loadings of $PM_{2.5}$ and, thus, higher visibility impairment than monitored Class I areas. In an effort to better characterize urban visibility, EPA analyzed the extensive newly available data on $PM_{2.5}$ ambient air concentrations primarily in urban areas. The

$PM_{2.5}$ Federal Reference Method (FRM) monitoring network and national data base of $PM_{2.5}$ ambient air concentrations had expanded greatly since the 1997 $PM_{2.5}$ NAAQS had been promulgated and included 24-hour measurements of total $PM_{2.5}$ mass, continuous measurements of hourly (total) $PM_{2.5}$ mass, and 24-hour duration $PM_{2.5}$ chemical speciation (component) measurements. These federal reference method (FRM) measurements of $PM_{2.5}$ mass data allowed for analyses that explored factors that had historically complicated efforts to address visibility impairment nationally, including regional differences related to levels of primarily fine particles and to relative humidity. The analyses showed a consistently high correlation between visibility, in terms of reconstructed light extinction, and $PM_{2.5}$ concentrations (daily, hourly, and block hourly) for urban areas in a number of regions across the U.S. and, more generally, in the eastern and western U.S. The correlations in urban areas were generally similar in the East and West, in sharp contrast to the East/West differences observed in rural areas.

While the average daily relative humidity levels are generally higher in the East than in the West, in both regions relative humidity levels are appreciably lower during daylight as compared to nighttime hours. By focusing on the daylight time period with lower relative humidity levels, visibility impacts related to East/West differences in average relative humidity were minimized. Both 24-hour and shorter-term daylight hour averaging periods were considered in evaluations of correlations between $PM_{2.5}$ concentrations in urban areas and visibility in eastern and western areas, as well as nationwide. Clear and similarly strong correlations were found between visibility and 24-hour average $PM_{2.5}$ in eastern, western, and all urban areas (U.S. EPA, 2005a, Figure 6-3). Somewhat stronger correlations were observed between visibility and $PM_{2.5}$ concentrations averaged over certain sub-daily (e.g., a 4-hour) time periods (U.S. EPA, 2005a, Figure 6-5), principally because the relative humidity, which effects the extinction efficiency of much of the PM, varies less during any of the sub-daily time periods than over entire days. During the 12-4 pm time period, the average visual ranges on the 20 percent haziest days in eastern and western urban areas were approximately 26 km and 31 km, respectively (Schmidt et al., 2005).

The correlations between visibility and $PM_{2.5}$ concentrations during daylight hours, which tend to have the lowest relative humidity levels, were relatively more reflective of $PM_{2.5}$

mass rather than relative humidity effects and aerosol composition, in comparison to correlations based on a 24-hour averaging time. Another rationale for considering the use of daylight sub-daily time-periods was the expected greater importance of visibility during hours when most people are awake and most scenes are better illuminated.

Impacts of Urban Visibility Impairment on Public Welfare

Congress and the EPA have long recognized that impairment of visibility is an important effect of PM on public welfare, and that visibility impairment is experienced throughout the U.S. in urban areas as well as in remote Class I areas, as discussed above. Visibility conditions directly impact people's enjoyment of daily activities in all parts of the country. Individuals value good visibility for the sense of well-being it provides them directly, both in places where they live and work, and in places where they enjoy recreational opportunities. Survey research on public awareness of VAQ using direct questioning typically reveals that 80 percent or more of the respondents are aware of poor visual air quality (Cohen et al., 1986).

The importance of VAQ to public welfare across the country has also been demonstrated by the establishment of a number of other programs, goals, standards, and planning efforts in the U.S. and abroad to address visibility concerns in urban and non-urban areas. Several state and local governments have developed programs to improve visual air quality in specific urban areas, including Denver, CO; Phoenix, AZ; and, Lake Tahoe, CA. At least two states have established statewide standards to protect visibility. In addition, interest in visibility protection in other countries, including Canada, Australia, and New Zealand has resulted in various studies, surveys, and programs. Methods developed in conjunction with these regulatory and planning activities are discussed below in the next section. A number of studies have also been designed to quantify the benefits (or willingness to pay) associated with potential improvements in visibility both in national parks and in urban areas (Chestnut and Dennis, 1997; Chestnut and Rowe, 1991). .

In the last review, EPA conducted a pilot study in Washington D.C. in order to test both the session design and survey questions that could potentially be used in a broader focus group effort. This small pilot study was briefly discussed in the preliminary draft Staff Paper (US EPA, 2001) and in the technical report (Abt Associates, 2001) to elicit CASAC and public comment on the use of this type of approach to help inform EPA's review of the secondary PM NAAQS, and, more specifically, to elicit comments on various aspects of the survey methodology used in the pilot project. The project was premised on the view that public perceptions of and judgments about the acceptability of visibility impairment in urban areas are relevant factors in assessing what constitutes an adverse level of visibility impairment in the context of this NAAQS review. EPA received general support for the use of this type of approach, and also received advice from members of CASAC as to how the survey methodology could be improved.

Approaches to Evaluating Public Perceptions and Attitudes

Survey methods and tools have been applied and evaluated in various studies, such as those done in Denver, Phoenix, and the Lower Fraser Valley in British Columbia. One such tool, a sophisticated visual air quality simulation technique, known as the WinHaze program developed by Air Resources Specialists, Inc. (Molenar et al.,1994) produces images that standardize non-pollution related effects on visibility so that perceptions of these images are not biased due to these other factors. The studies in Phoenix and British Columbia, and the pilot study in Washington, DC used survey approaches based on that used in Denver. This approach involved conducting a series of meetings with civic and community groups to elicit individual ratings of a number of images of well-known local vistas having varying levels of visual air quality. Even with variations in each study's approach the public perception survey methods used in these studies produced reasonably consistent results from location to location, with each study indicating that a majority of participants find visual ranges within about 40 to 60 km to be acceptable. These public perception studies use images of urban and distant scenic views under different visibility conditions together with survey techniques designed to elicit judgments from members of the public about the acceptability of differing levels of visual air quality. The fact that each of the U.S. public perception and preference studies occurred in western cities with similar scenic vistas of distant mountains was viewed as a limitation in the evidence available in the last review regarding establishing an appropriate level of protection for urban visibility at the national level. It remained an open question as to whether public preferences for given levels of VAQ would be consistent in different regions of the country and looking at different types of urban scenes.

1.1.2 Overview of Qualitative Assessments of Other Welfare Effects in the Last Review

Other non-visibility PM-related effects qualitatively assessed in the last review included impacts on vegetation and ecosystems, materials damage and soiling, and climate. Because PM size classes used in human health risk assessment do not necessarily have relevance for vegetation or ecosystem effects, a conclusion of the last review was that an ecologically-relevant indicator for PM should be based on constituents of greatest and most widespread environmental significance. The CD and Staff Paper, therefore, focused on the effects of deposited nitrates and sulfates on receiving ecosystems. Reactive nitrogen, nitrogen saturation, nitrogen inputs to aquatic habitats and acidifying deposition were considered for the purpose of assessing impacts of deposited PM to ecosystems. The Staff Paper identified a group of ecosystems known to be sensitive to excess N and S inputs. A list of characteristics that could be used to predict or locate other potentially sensitive ecosystems was also developed as a component of the last review.

In materials damage and soiling attributed to PM components, both fine and course particles were recognized as contributors, however, there was not sufficient data to support a distinct secondary standard based on deposition to material surfaces.

In the last review, information available regarding atmospheric and suspended PM effects on climate change processes and in altering the penetration of solar UV-B radiation focused generally on global- and regional- scale processes and provided an insufficient basis for characterizing how differing levels of ambient PM in areas across the U.S. would contribute to these larger scale effects. Limitations to using PM effects on climate as a basis for the secondary standard included the lack of information on how PM alters cloud properties and disrupts hydrological cycles, as well as the lack of data on PM speciation.

In considering the available evidence on each of these types of PM-related welfare effects, EPA noted that there was much information linking ambient PM to potentially adverse effects on materials and ecosystems and vegetation, and on characterizing the role of atmospheric particles in climatic and radiative processes. However, given the substantial limitations in the evidence, especially the lack of evidence linking various effects to specific levels of ambient PM, the Administrator concluded that the available evidence did not provide a sufficient basis for establishing a separate and distinct secondary standard for PM based on any of these effects alone. The Administrator further concluded that sufficient information was not available at that time to consider either an ecologically based indicator or an indicator based distinctly on soiling and materials damage, in terms of specific chemical components of PM. Further, consistent with the rationale and recommendations in the Staff Paper, the Administrator agreed that it was appropriate to continue control of ambient fine and coarse fraction particles, especially long-term deposition of particles such as particulate nitrates and sulfates that contribute to adverse impacts on vegetation and ecosystems and/or to materials damage and soiling.

In selecting an appropriate level of protection for these effects, the Administrator believed that any standards should be considered in conjunction with the protection afforded by other programs intended to address various aspects of air pollution effects on ecosystems and vegetation, such as the Acid Deposition Program and other regional approaches to reducing pollutants linked to nitrate or acidic deposition. Based on these considerations, and taking into account the information and recommendations of CASAC and staff, the Administrator, as previously noted, revised the then current secondary $PM_{2.5}$ and PM_{10} standards by making them identical in all respects to the proposed suite of primary $PM_{2.5}$ and $PM_{10-2.5}$ standards.

1.2 GOALS OF ASSESSMENTS IN THE CURRENT REVIEW

A critical step in designing the quantitative assessments associated with an evaluation of urban visibility impacts is to clearly identify the policy-relevant questions to be addressed by these assessments. As identified above, the Integrated Review Plan presents a series of key policy questions (U.S. EPA, 2008a, Section 3). To answer these questions, EPA will integrate information from assessments of urban PM air quality, visibility conditions, and public preferences as we evaluate both evidence- and assessment-based considerations.

More specifically, to focus the UVA, we have identified the following goals: 1) to characterize PM impacts on Visual Air Quality (VAQ) for hourly, sub-daily, and 24-hour averaging times for various urban areas in order to determine current VAQ levels, as a basis for estimating levels of VAQ associated with "just meeting" current and potential alternative standards, and to characterize the PM levels and components responsible for VAQ; (2) to develop information beyond what was available in the last review regarding public preferences for urban VAQ in geographically diverse urban areas to help inform judgments by the Administrator regarding establishment of a secondary PM NAAQS that would provide the requisite degree of public welfare protection from adverse levels of PM-related urban visibility impairment.

1.3 OVERVIEW OF ASSESSMENTS IN CURRENT REVIEW

This plan outlines the scope and approaches as well as highlights key issues associated with our plans to focus our quantitative assessments on the urban visibility impacts associated with the mixture of fine particle and aerosol compounds found in ambient air, including particulate nitrates and sulfates. A discussion of our initial qualitative approach to considering the information with respect to other PM-related welfare effects is provided below in Appendix A. Both the quantitative and qualitative assessments will draw on the detailed description of the recent state of the science provided in first and second draft ISAs (EPA, 2008b). As described in the Integrated Review Plan (EPA, 2008a) the evaluation of the depositional effects associated with particulate nitrates and sulfates on sensitive ecosystems is being addressed in the joint NOx/SOx secondary NAAQS review that is underway.[4]

In order to evaluate the adequacy of the current suite of secondary standards to provide adequate protection against adverse levels of urban visibility impairment, we envision two areas of quantitative assessments in this review. Figure 1-1 shows the activities associated with each assessment and how information flows among the activities. The following two subsections provide an overview of these planned quantitative assessments, with the components associated

[4] See http://www.epa.gov/ttn/naaqs/standards/no2so2sec/index.html for more information on the NO_2/SO_2 secondary NAAQS review

with the assessment of urban visibility conditions and those associated with the assessment of urban VAQ, discussed in greater detail in chapters 2 and 3, respectively, below.

1.3.1 Urban Visibility Conditions Assessment

The first area of assessment (Boxes1a-f) is characterization of urban VAQ conditions.

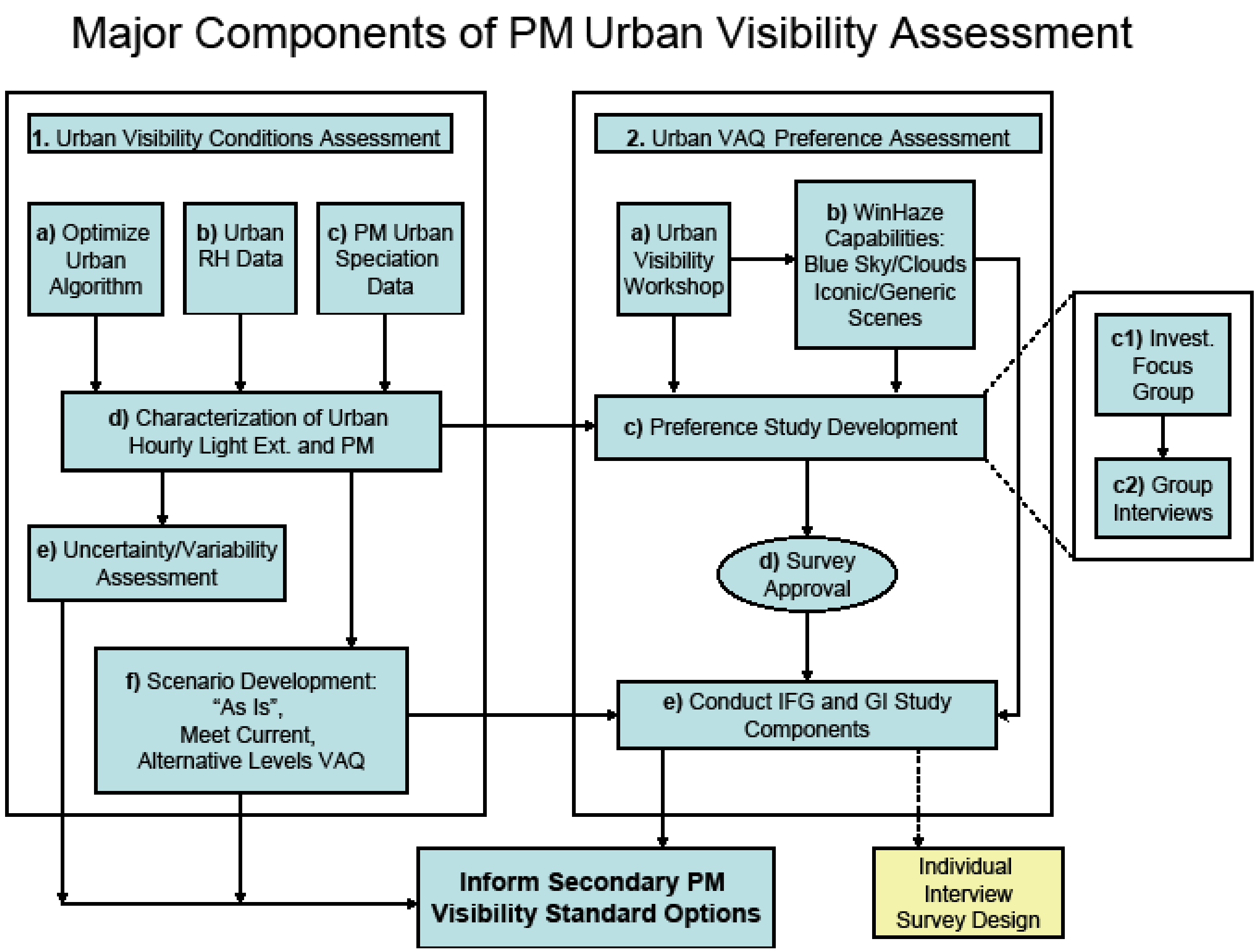

Figure 1-1 Major Components of the PM Urban Visibility Assessment

Air Quality Analyses

Characterizing urban visibility impacts for the current review of the secondary NAAQS for PM will include conducting air quality analyses to support quantitative assessments in specific locations as well as potentially putting the results into a broader public welfare perspective. These assessments will be designed to characterize current visibility conditions and the potential impacts that are associated with recent ambient levels, with ambient levels simulated to just meet the current standards, and with ambient levels simulated to just meet alternative standards that may be considered. As part of such analyses, explicit and, where possible, quantitative characterizations of the uncertainties associated with the air quality analyses, as well as impact assessments will be developed. Air quality will be characterized in urban areas along with the associated potential of adverse visibility impairment effects for hourly, sub-daily, and 24-hour averaging times. The characterization of urban visibility conditions will generate ambient concentrations and metrics that are most relevant for addressing concerns about characterizing the impacts on VAQ associated with PM exposures.

The current review has access to more and better speciated ambient PM data from urban areas than were available for previous reviews, allowing EPA to plan for a more comprehensive and robust assessment of $PM_{2.5}$ characteristics (i.e., concentrations and compositions) in urban areas and their effects on visibility (see Chapter 2 and Table B.1 in Appendix B). In addition, we plan to characterize visibility impairment in terms of an optical metric (light extinction) that is closely related to the adverse public welfare effect of perceived VAQ (see section 1.3.3 and Figure 1.2 below).

We plan to estimate and summarize hourly visibility in a number of urban assessment locations under several air quality scenarios: recent conditions (defined as conditions during 2005-2007), "just meeting" the current secondary PM NAAQS, and "just meeting" one or more alternative secondary NAAQS. The objectives of this area of the assessment are to determine the current range, time of day, and PM concentration and composition associated with maximum daylight hourly light extinction, taking into account the influence of humidity. This information will help identify the PM species that are most responsible for current haze levels, and the visibility improvements that might be achieved by meeting the current secondary PM NAAQS, the regions of the country that might not meet alternative secondary NAAQS under consideration, and the visibility improvements that might be achieved by meeting alternative secondary PM NAAQS. This type of information may also be useful in informing the second area of assessment described in the following paragraphs.

1.3.2 Urban VAQ Preference Assessment

The second area of assessment (Boxes 2a-e; Figure 1.1) is that of urban visual air quality preferences. In order to help inform what levels of urban VAQ could be judged adverse to the public welfare, we plan to conduct an expanded assessment of the preferences for and value of urban visibility by building on the information available in the last review from public preference studies, including the EPA sponsored pilot study conducted in Washington, D.C., and by conducting additional public preference studies in urban areas, utilizing ongoing refinements to the WinHaze model.

As an initial step, EPA sponsored a workshop on October 6-8, 2008 in Denver, Colorado to brainstorm possible approaches and next steps for developing additional information on public preferences for VAQ in urban areas to inform the current PM Secondary NAAQS review. Many useful ideas and suggestions came out of that workshop and have been incorporated in the planned assessment described below in chapter 3.0. For additional details regarding the workshop, see the attached workshop summary in Appendix C.

Participants at the workshop identified three different study approaches/methods that could be employed to gather relevant information. These include 1) investigative focus groups (IFG); 2) group interviews (GI); and 3) individual interviews (II) or surveys. In addition, workshop participants identified 13 issues that they felt could be subjects for further investigation. One issue discussed at the workshop was the uncertainty regarding a concern that current urban visibility preference information may not be representative of urban preferences nationwide, since to date, all of the public preference studies have been conducted in western areas using scenes that featured distant mountain backdrops. The limited nature of the preference study information was clearly seen as a critical uncertainty in the last review.

Therefore, the second phase of the urban visibility impact assessment includes a plan to conduct both IFG and GI studies to address important issues. First, we are developing plans to conduct an IFG study to address the issue of how to improve communication with study participants through a) selection of appropriate word choices in order to clearly communicate concepts of preferences (e.g., acceptable, unacceptable, adverse), and b) determination of the appropriate amount, type, depth/detail and wording of introductory materials. This IFG study would be conducted in one location but include several iterations in order to allow responses from one session to inform/refine the wording and introductory materials used in subsequent sessions. Second, we are planning to conduct a GI study to assess whether concern for PM-related urban visibility impairment varies by region or is a consistent value nationwide. We plan to select at least three non-western urban areas which do not have distant mountain backdrops, and one western city (e.g., Denver, CO or Phoenix, AZ), that was the site of an earlier urban visibility survey, as GI study areas. If at all possible, these urban areas will also be areas selected for assessment in the primary public health risk and exposure assessments. The techniques employed for the IFG and GI studies will be similar to those already successfully employed in earlier public preference surveys. Additional information and detail are provided below in Chapter 3.

Prior to beginning these discussions, however, it is important to explain in more detail an alternate standard structure that we are considering to characterize current urban visibility conditions and to measure changes in urban visibility impairment associated with possible revised secondary PM NAAQS. The discussion of the basis for our rationale is provided in 1.3.3.

1.3.3 Discussion of Alternative Secondary Standard Structure

In order to select the most appropriate and technically based indicator(s), averaging time(s), form(s) and level(s) for a secondary standard to provide appropriate protection for urban visual air quality, it is important to understand the relatively complex relationship that exists between ambient $PM_{2.5}/PM_{10-2.5}$ mass concentrations and visibility effects on the public welfare (e.g., impairment of VAQ) (see Figure 1.2). This complexity is introduced at several points by different suites of variable factors that modify this relationship over time and space. When examining Figure 1-2, it is important to realize that visibility is an instantaneous process – air quality and relatively humidity at each moment determines the visibility at that moment. However, human valuations of visibility may reflect average visibility over longer periods than an instant. For simplicity, and because of the at-best hourly temporal scale of most existing air quality data and relative humidity data, the discussion here considers averaging periods no shorter than one hour.

The first set of factors that modify this relationship includes the composition of the atmospheric particles in these size fractions, and the co-occurring level of relative humidity. These two factors alter the atmospheric optical characteristics so that a wide range of optical visibility conditions (also termed haze or light extinction) can occur for a given concentration of $PM_{2.5}/PM_{10\text{-}2.5}$ mass. This is due to the differential impacts of various component species in PM on light scattering and/or absorption, and the role relative humidity plays in changing the optical characteristics of some hygroscopic particles. It is important to note that the same level of ambient haze can be obtained with different combinations of PM component concentrations and relative humidity.

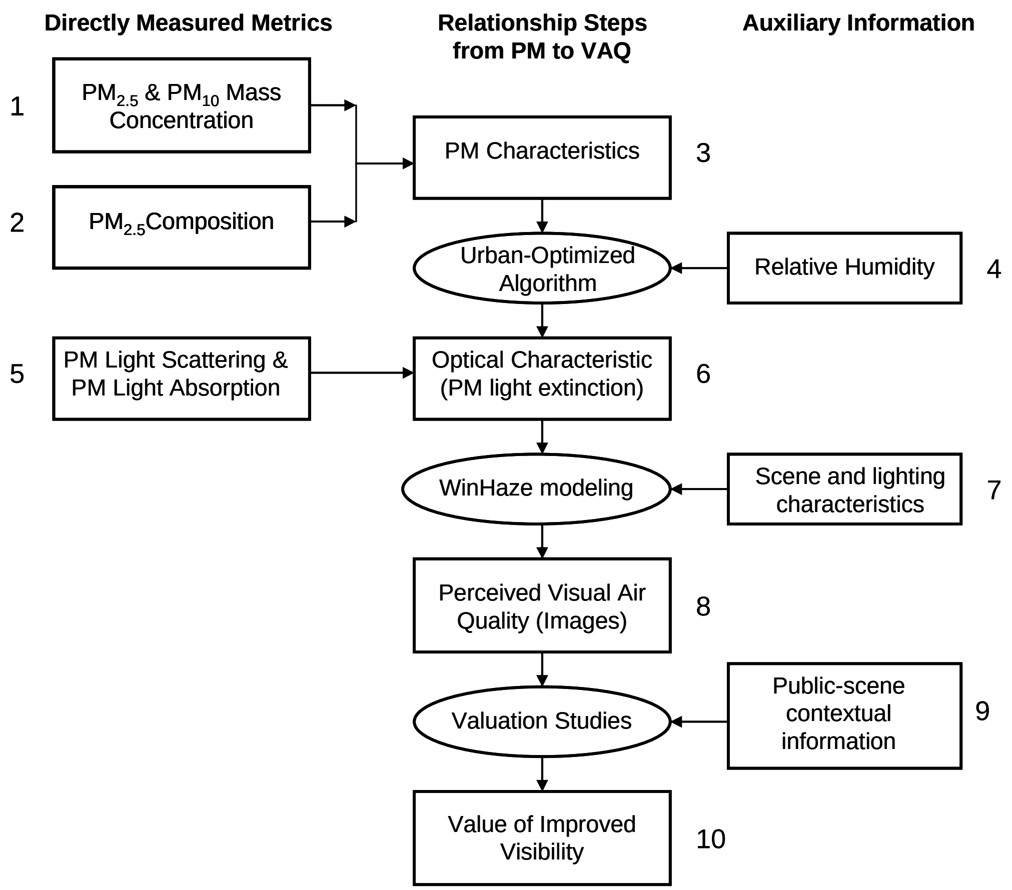

Figure 1-2 Progression from PM Characteristics to Visibility Effects

A second set of complicating factors occur in moving from a given level of haze (light extinction) to public perception of VAQ (boxes 7-10). Thus, the same level of light extinction can be associated with differing levels of protection of the public welfare effect of concern, (i.e., perceived visual air quality), depending on the sensitivity of the scenes involved. This phase in the progression represent a dramatic increase in data needs and complexity, requiring the incorporation of scene and lighting characteristics that influence whether and to what extent a specific change in light extinction can be perceived, and public judgments concerning the importance/value of that perceived change in VAQ for a particular setting. These latter judgments, while related to the perceived degree, frequency, and timing of haziness, could also be influenced by the unique site specific features of the scene (e.g., public/scene contextual factors, apparent intrinsic scenic value), as well as individual preferences and potentially local or regional expectations that are currently not well understood. Because the use of a perceptual or visibility valuation metric would require incorporating the effects of urban-specific scene sensitivity and public/scene contextual information for every applicable urban area, we conclude its selection as a metric would be impractical in the context of setting a national standard.

The influence of this latter set of factors can be minimized, however, if scene and lighting characteristics are selected to be similarly sensitive to small incremental changes in haze levels. In public perception surveys these factors are held constant for each scene, so that there is a one to one correspondence between perceived VAQ and the light extinction level associated with it in the pictures selected. Preference or valuation studies can also be conducted to determine the benefits associated with maintaining an acceptable level of this environmental good or service (e.g., VAQ).

There is a possible mismatch between the averaging periods for the current PM secondary standards (24-hour and annual averaging times), and those most appropriate for visibility impairment. The current averaging times were selected to protect for acute and chronic health exposures, respectively, not daytime visibility impairment. For example, a 24-hour average also incorporates nighttime PM levels, and while visibility impairment by PM occurs both during the day and at night, the physical and physiological/perceptual aspects of the daytime and nighttime PM-visibility relationships are very different. Because nighttime visibility effects are less well understood, we continue to believe that it remains appropriate to focus solely on daytime PM-related visibility conditions for purposes of quantifying visibility-related welfare impacts.

In the last review, EPA developed the sub-daily afternoon 4-hour average approach in order to reduce, relative to a 24-hour approach, the variability in protection levels afforded by a national standard by limiting the contribution of relative humidity, which is generally lowest in the afternoon compared to other periods of the day. This approach has technical merit and remains under consideration in this review. In addition we are considering use of a more integrated structure that incorporates these two important sources of variability (e.g., PM species composition and relative humidity) directly.

A standard with this structure could include a nationally uniform level (with associtated form and averaging time) of PM light extinction that would be determined by the Administrator to represent an appropriate level of protection for urban VAQ. The ambient standard would then be specified as the level of ambient PM such that the calculated or measured PM light extinction level meets the level of protection of public welfare set by the Administrator. Compliance could be determined by measuring PM mass concentrations at a given site. Using the algorithm to incorporate known relationships between PM mass and speciated components at that site, in combination with local or regional relative humidity data, one could then calculate the level of PM light extinction associated with that concentration of PM mass. Alternatively, it would also be possible and likely less costly to directly measure the PM contributions to PM light extinction using a nephelometer to measure the PM light scattering and an aethalometer to measure the PM light absorption. The estimated or measured PM light extinction would then be compared to the level of PM light extinction set by the Administrator, including averaging time and form. Thus, whether a certain ambient concentration of PM would attain the standard would depend in part on the species and relative humidity, which vary geographically and temporally.

This alternative standard structure approach is distinct from the current 24-hour $PM_{2.5}$ secondary and afternoon sub-daily 4-hour approaches in several ways. First, it could be used to provide a consistent level of VAQ protection, regardless of urban-specific PM species mix and relative humidity levels that vary throughout the day. Second, this approach could allow one to more directly relate ambient PM mass concentrations to an atmospheric optical metric, such as PM light extinction, which is more directly associated with the public welfare effect of concern (e.g., visibility impairment). Third, it could accommodate measured or estimated PM light extinction information for an even shorter integration time (e.g. hourly), which would allow consideration of the instantaneous nature of visibility impacts. PM light extinction levels can be calculated in terms of measured or modeled ambient PM species concentrations at any relative humidity. Thus, EPA believes it is appropriate to explore this alternative approach, with an aim of setting a national standard that provides sufficient, but not more than necessary protection throughout the United States by taking into account the recognized sources of variability from relevant ambient factors.

2 ASSESSMENT OF URBAN VISIBILITY CONDITIONS

2.1 OVERVIEW

Box 1 at the top of the Figure 1.2 represents information on mass concentrations of $PM_{2.5}$ and PM_{10}. Mass concentration data are currently collected to determine compliance with the primary and secondary NAAQS for $PM_{2.5}$ and PM_{10}. Currently, such compliance monitoring for $PM_{2.5}$ is based on 24-hour filters, rather than hourly measurements. Thus, additional data from the somewhat smaller network of non-compliance monitors is needed to establish hourly $PM_{2.5}$ mass concentration values. PM_{10} compliance monitoring makes use of both 24-hour filters and continuous instruments providing hourly concentration values. We will estimate PM light extinction from measured or estimated $PM_{2.5}$ and PM_{10} mass, composition, and relative humidity using a refined urban-optimized linear algorithm. For urban areas it is usually the case that the ambient concentrations of $PM_{2.5}$ (in combination with humidity growth effects) contribute more to PM light extinction than do ambient concentrations of the $PM_{10-2.5}$. Therefore, special attention to the contribution of $PM_{2.5}$ to light extinction is merited. The summary of the visibility estimates will be based on statistics such as the numbers of hours with PM light extinction greater than selected benchmarks, (e.g., 98^{th} percentile daily maximum daylight 1-hour light extinction values).

In the last review, practical $PM_{2.5}$ measurement considerations argued (at least implicitly) for an averaging period of at least several hours, because accurate measurements of 1-hour $PM_{2.5}$ concentrations were problematic and little research had been completed and assessed on a Federal Reference Method for such measurements. Since that time, however, more continuous $PM_{2.5}$ data has become available and we have a better understanding of its quality from site-to-site. In addition, high time resolution (e.g., hourly) PM light extinction values can be directly measured today (box 5, Figure 2.2) using either a transmissometer or a combination of nephelometer (light scattering) and aethalometer (light absorption) instruments.[5] Currently there

[5] A transmissometer can directly measure the total light extinction over a long open path, using a widely spaced light source and light detector; it inherently captures the effect of relative humidity, but also measures the light extinction by fog and precipitation, which would require data processing to remove. Additionally, transmissometers require extensive efforts to calibrate. An ambient temperature nephelometer measures light scattering over a short closed path (internal to the instrument) and also inherently captures the effect of relative humidity provided the path is not

is no Federal Reference Method for PM light extinction based on one or both of these instrumental approaches, but a reference method could be developed if needed or useful.[6] Therefore, we plan to explore the appropriateness of an hourly averaging time, which on the surface appears more compatible with the instantaneous nature of visibility impact. However, the framework for the quantitative analysis will also allow consideration of 4-hour and longer averaging periods.

2.1.1 Policy Relevant Background PM Light Extinction

There are several methods for characterizing PRB concentrations of PM within the United States. As described in the ISA (US EPA, 2008b), some methods rely upon analyses of measured PM concentrations at remote rural locations while other methods utilize air quality chemical transport models (CTMs) to estimate PRB. In the last review, PRB for $PM_{2.5}$ on a 24-hour average basis was characterized by summarizing the non-sulfate portion of $PM_{2.5}$ measured at Interagency Monitoring of Protected Visual Environment (IMPROVE) sites in remote areas between 1990 and 2002. Sulfate was omitted because it is attributable almost entirely to anthropogenic emissions. It was noted that this method likely results in an underestimate of PRB. In the last Staff Paper, the range of mid-day 4- to 8-hour average $PM_{2.5}$ mass levels described for consideration as a possible secondary $PM_{2.5}$ standard were compared to percentile points in the estimated distributon of 24-hour average $PM_{2.5}$ PRB. Also, the previous Staff Paper referenced estimates of annual average PRB for light extinction made by the National Acid Precipitation Assessment Program in 1991 (NAPAP, 1991).

In this review, we plan to consider applying the CTM modeling being done to estimate PRB for $PM_{2.5}$ for health risk assessment purposes to the visibility risk assessment. The CTM-based approach is based on a "zero-out" model simulation in which anthropogenic emissions inside the U.S., Canada, and Mexico are set to zero while all biogenic emissions for these areas

heated or dehydrated. An aethalometer collects PM on a filter and continuously measures the resulting light absorption, for which humidity is not a factor in either the atmonsphere or the instrument. The sum of the light scattering from a nephelometer and light absorption from an aethalometer is PM light extinction in inverse distance units

[6] There is a conceptual distinction between using a transmissometer versus a nephelometer/aethalometer combination as the Reference Method for a secondary PM NAAQS. The former instrument's measurement of light extinction would include a very small effect of light extinction due to gases, while the latter instrument would report only extinction effects due to PM.

and biogenic and anthropogenic emissions from elsewhere in the world are not altered. This approach can provide more spatial and temporal resolution for estimating PRB compared to the use of measurements given the sparse nature of remote measurement sites and the concern that even remote sites are affected by non-local anthropogenic sources.

For this assessment, we are planning to rely upon a CTM-based approach which involves coupling the global-scale circulation model GEOS-Chem (Fiore, et al, 2003) with the regional scale air quality model CMAQ (Byum, et. al., 2006 and Byum, et. al, 1999). The GEOS-Chem model is run on a global scale and is used to provide estimates of transported pollutant from emissions of natural and anthropogenic sources outside the U.S., Canada, and Mexico. These transported pollutant concentrations are used to provide the "boundary condition" concentrations for two CMAQ simulations covering the continental US and adjacent portions of Canada and Mexico (CONUS), one simulation with all emissions to evaluate model performance and one to estimate PRB. In the CMAQ simulation to estimate PRB, only natural emissions in the U.S., Canada, and Mexico are considered. The details of this modeling approach, including the input data sets and model chemistry are described in Chapter 3 of the ISA. The following is a brief summary.

The two models were applied to simulate one year of air quality data for 2004. The base case CMAQ run for 2004 includes meteorology and all the anthropogenic and natural sources both within and outside of the U.S., Canada and Mexico. This run was performed to provide a comparison of model predictions with measurements. The ISA characterizes the CMAQ performance for the annual average concentrations and most of the seasonal averages of $PM_{2.5}$ at remote sites as "very good" in the East and Midwest. In the West, predictions at remote sites are "generally too low in all seasons". The ISA notes that degraded performance in the West is not unexpected because the grid resolution in the CMAQ model simulation (36 km for this application) will smooth out significant variations in terrain that influence measured concentrations, particularly concentrations attributable to anthropogenic emissions which in the West are often concentrated in basin settings where local meteorological conditions coupled with local emissions of primary particles may dominate $PM_{2.5}$ concentrations. However, looking across the U.S., the model does correctly reproduce broad geospatial differences in that predicted

$PM_{2.5}$ concentrations are lower at western locations than they are in the East consistent with measured data. Also, natural emissions in the West are less concentrated in basin settings, and western terrain may therefore have less effect on model performance when estimating PRB.

In addition to the "base case" run which includes all anthropogenic and biogenic emissions, CMAQ was also run for a second scenario to estimate PRB, with the same boundary conditions but with only natural emissions from within the U.S., Canada, and Mexico. The hourly outputs from this second CMAQ run were used to calculate seasonal and annual average estimates of PRB within seven regions of the U.S. These data are provided in Table 3-26 of the ISA. For the purposes of the visibility risk assessment, it would be desirable to extract and summarize the distribution of hourly $PM_{2.5}$ mass and $PM_{2.5}$ species concentration estimates from the PRB CMAQ run, and to estimate PRB for light extinction from these concentration estimates. An alternative and less time consuming approach would be to develop PRB levels of hourly light extinction using other information sources, such as the PRB estimates for $PM_{2.5}$ mass and information about background levels developed in the previous review.

2.1.2 Recent Conditions

In assessing recent levels of PM-related visibility impairment in urban areas, we plan to develop a set of hourly light extinction estimates for the years 2005 through 2007 for a set of urban assessment locations. The planned approach is to start with 24-hour measurements of $PM_{2.5}$ mass, develop and apply diurnal profiles to estimate hourly mass concentrations, develop and apply hourly speciation factors to estimate hourly concentration of each species affecting visibility, and hourly relative humidity. These hourly data will be converted into hourly PM light extinction levels, using an urban-optimized algorithm. The range of hourly and sub-daily PM light extinction values is expected to vary considerably among urban areas, seasonally, and regionally.

We also plan to assess whether and how to include $PM_{10-2.5}$ data in the estimates of PM light extinction. $PM_{10-2.5}$ is only a significant contributor to PM light extinction when its concentrations are comparable or greater than the $PM_{2.5}$ concentration. For urban areas without collocated $PM_{2.5}$ and PM_{10} monitoring, the $PM_{2.5}$ crustal component determined using speciation monitoring may be scaled up to estimate the $PM_{10-2.5}$ concentration. Urban areas in the arid regions of the southwestern U.S. are likely the only ones where $PM_{10-2.5}$ will be a significant component of PM light extinction. While we have not yet selected the urban assessment locations, where feasible, we plan to select from among the set of urban locations used for the PM health risk assessment, to leverage the planning and analytical work addressing those areas.

These estimates of hourly PM light extinction over three years for a set of assessment locations will help inform selection of an appropriate range of haze conditions to be used in public perception focus group studies (see 3.0 below). The combination of these two areas of quantitative analysis is intended to provide information regarding how often unacceptable visibility conditions occur under current levels of PM urban air quality.

2.1.3 "Just Meeting" the Current and Potential Alternative Secondary PM NAAQS

Some urban assessment locations will not meet the current or potential alternative secondary PM NAAQS under recent air quality conditions. To assess urban visibility conditions under a scenario of "just meeting" the current or potential alternative secondary PM NAAQS in each study area individually, we will develop a method of adjusting hourly PM concentrations so that in each area the highest concentration monitor just meets the more stringent of the annual and 24-hour secondary NAAQS. That monitor will have a design value for the other averaging period below the NAAQS, and other monitors will have design values for both averaging periods that are less than the NAAQS. At this time we plan to use the corresponding adjustment method(s) being employed in the PM health risk assessment work, wholly or in part. One difference is that we plan to include hourly concentration results in our analyses for the secondary NAAQS, while the health risk assessment work focuses on annual average and 24-hour average concentrations. Thus, it may be necessary to assume that each hour in a day experiences the same adjustment (possibly by species) as does the day as a whole.

The alternative secondary PM standards to be analyzed in this review have not been selected, but we expect that one or more of them could be based on achieving a range of hourly PM light extinction levels as may be informed by the available public preference information. Several alternative standards based on different combinations of form and level will be studied, and we expect that a standard which incorporates the urban optimized linear algorithm structure will be among the alternative standard options considered, including one based on the three-year average of the 98th percentile daily maximum 1-hour light extinction level. Other percentiles and forms structured in other ways (e.g., an allowed number of exceedances per year) may be considered also. Initially, we will assume a three-year evaluation period.

2.2 DATA SOURCES, TYPES, AVAILABILITY, AND APPLICATION

Table B-1 (in Appendix B) shows the types, availability, time period, and intended applications of data that will be used to create a characterization of recent urban visibility conditions. We do not anticipate using ASOS visibility monitoring data in this urban visibility assessment.[7] Because urban visibility has never been regulated using hourly PM data or light extinction measures, there is no extensive state/local or EPA monitoring program which would provide the most relevant data for a large number of monitoring sites of interest. We plan to use only air quality data that are available in the Air Quality System, plus any well organized, significant data sets that are in-hand by April 15, 2009. At the present time, we anticipate that the Southeastern Aerosol Research and Characterization Study (SEARCH) monitoring program will be a source of relevant data that will be used; some SEARCH data are available on the internet, while more data on additional air quality parameters reportedly exist but would have to be obtained via personal contact with the SEARCH researchers.

Some but not all $PM_{2.5}$ monitoring stations have submitted hourly relative humidity data to AQS. These data will be used where they are sufficiently complete on a site-year basis. If a site-year of such data is not sufficiently complete, all estimates for the year will be drawn from the National Weather Service (NWS) database. It will be necessary to identify the NWS site most representative of each monitoring site in each assessment location.

While we intend to use continuous $PM_{2.5}$ speciation data, nephelometer, aethalometer, and transmissometer data contained in AQS, it should be noted that these data are not used in the NAAQS regulatory program and so EPA does not provide guidance to monitoring agencies on the operation of these types of monitors or on data validation procedures, nor does EPA

[7]The utility of airport visual range measurements that are made with open path instruments that include fog and precipitation is severely limited for characterizing current urban PM visibility conditions. In addition, most

systematically review or audit the operation of these types of monitors. Nevertheless, we believe that using these data will provide Administrator with a more informative quantitative analysis than would ignoring these data.

Another consideration is the selection of appropriate monitors to analyze for urban areas with a variety of monitoring sites. For the purposes of an urban visibility assessment, data from micro-scale and middle-scale sites (as recorded in AQS) will not be used, as these may not be representative of air quality over the distance range relevant to visual air quality.

2.3 DEVELOPMENT OF AN URBAN OPTIMIZED LINEAR ALGORITHM

The IMPROVE algorithm, an example of a linear algorithm, was developed and recently refined to use IMPROVE network PM speciation data and climatological relative humidity data to estimate PM light extinction in remote areas. This algorithm's principal use is to generate the Regional Haze Rule metric so it was optimized for remote area sites typical of the visibility-protected federal Class I areas. Thus, the algorithm's treatment of the contribution of organic PM to light extinction is consistent with the aged aerosol that is expected for remote areas, but may not be appropriate for the abundance of freshly produced organic aerosol associated with urban areas. Coarse particle mass (i.e. $PM_{10-2.5}$) data are also used in the IMPROVE algorithm to estimate the contribution of the coarse fraction to PM light extinction. Many urban monitoring sites do not measure coarse mass, which if substantial, would need to be accounted for in some way to reduce a possible bias in urban PM light extinction estimates.

An analysis of the IMPROVE algorithm's performance in predicting urban light extinction will be conducted and changes made as necessary to create a new urban optimized linear algorithm for use in this assessment with FRM/FEM $PM_{2.5}$ mass data and the Chemical Speciation Trend network data that are available in many urban areas. It will also be evaluated for use with high time resolution speciation and optical measurement to the extent possible for the limited available datasets. Light extinction estimates from the resulting urban-optimized linear algorithm will be used to generate estimates of daylight hourly PM light extinction.

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available airport visual range data are collected and archived in coarse ranges of conditions (e.g. VR≥10 miles), restricting its utility in quantitative analysis.

2.4 DEVELOPMENT OF RELATIONSHIPS BETWEEN PM LIGHT EXTINCTION AND $PM_{2.5}$ MASS CONCENTRATIONS IN URBAN AREAS

The Staff Paper in the previous review of the PM NAAQS contained an analysis in which scatter plots and regressions were used to explore the relationship between historical 24-hour light extinction (calculated from 24-hour PM mass and species measurements and both actual and 10-year average 24-hour average relative humidity values, using the IMPROVE algorithm available at the time, and 24-hour $PM_{2.5}$ mass. This analysis underscored the sensitivity of PM light extinction to PM species mix and humidity, and how a secondary PM standard using a 24-hour $PM_{2.5}$ mass indicator would allow a wide range of 24-hour PM light extinction in complying areas. We do not plan to update this analysis for this review as it is not reasonable to expect an updated analysis of historical data to provide any new insights regarding 24-hour average light extinction given that mass concentrations of $PM_{2.5}$ air pollution has not greatly changed since the last review. However, in the scenario of just meeting the current $PM_{2.5}$ secondary standard, the composition of $PM_{2.5}$ air quality may be substantially different than historical air quality. For example, sulfate and nitrate levels may be considerably lower. Such differences may change the conclusions reached in the last review, because with lower sulfate and nitrate present in the air, light extinction would be less sensitive to relative humidity. It will be possible to use the simulated hourly air quality and light extinction values from this scenario to feed an analysis similar to that in the previous Staff Paper, and we are considering whether such an analysis is warranted. However, we will not use 10-year average relative humidity data, which were used in a sensitivity study in the last Staff Paper. Use of such averages clearly would obscure actual variability in the relationship and make a standard based on a $PM_{2.5}$ mass indicator appear to be capable of achieving a more uniform and constant level of protection for urban visibility than it actually would provide.

The previous Staff Paper also reported the results of an analysis of the correlation between 4-hour, mid-day average $PM_{2.5}$ concentrations and 4-hour average PM light extinction, which showed that there was more correlation within the eastern and western U.S. regions than for the 24-hour case, and more similarity in the slope of the regression relationship between eastern and western regions. This analysis led staff to consider an indicator based on mid-day

$PM_{2.5}$ mass suitable for a revised secondary standard. However, that analysis used the assumption that the 24 hourly species profiles during the day were the same as the 24-hour species profile for purposes of estimating PM light extinction averaged over several hours, an assumption that tends to make the correlation between PM light extinction and $PM_{2.5}$ mass appear better than it might be. For the current analysis, we plan to re-examine this assumption. If a different approach to hourly speciation is chosen, we will consider repeating this element of the previous Staff Paper. We plan also to consider conducting the same analysis for the "just meeting" current standards scenario, for the same reasons explained in the previous paragraph, even if the same approach is taken to hourly speciation.

If either of the above two types of analysis is undertaken, relationships between both same-period and maximum daylight hourly light extinction levels and 24-hour and/or mid-day $PM_{2.5}$ concentrations would be assessed by season and individual urban area. This will include generation of scatter plots of PM light extinction versus $PM_{2.5}$ concentration. Particulate matter light extinction budgets (i.e., the fraction of light extinction by each of the major species) will be estimated using the urban optimized linear algorithm for estimating light extinction from PM species.

2.5 UNCERTAINTY AND VARIABILITY

Uncertainty associated with the use of the urban optimized linear algorithm relating PM and relative humidity to light extinction will be characterized as part of the revision process. Uncertainty associated with the use of available data and the techniques and assumption that may be employed to generate the required information used in this assessment will also be described. Specific methods to characterize or document the magnitude of any bias and uncertainty associated with these assessments have not yet been developed, but we will do so as an integral part of the assessment.

3 QUANTITATIVE VISUAL AIR QUALITY IMPACT ASSESSMENT

3.1 OVERVIEW AND PURPOSE

As was described in Chapter 1 above, a lack of information regarding public preferences for urban visual air quality was considered one of the key limitations cited by the Administrator (71 FR 2681, January 17, 2006) in the proposal notice regarding the establishment of a separate, sub-daily secondary PM NAAQS to protect urban visibility. Specifically, "the Administrator took into account the results of the public perception and attitude surveys in the U.S. and Canada, State and local visibility standards within the U.S., and visual inspection of photographic representations of several urban areas across the U.S. summarized in section IV.A.1 of the proposal. In the Administrator's judgment, these sources provide useful but still quite limited information on the range of levels appropriate for consideration in setting a national visibility standard primarily for urban areas, given the generally subjective nature of the public welfare effect involved…" and "…attitudes with regard to the acceptability of various degrees of visibility impairment in urban areas across the country." (71 FR 61206/8). Similarly, some CASAC Panel members "…recognized that developing a more specific (and more protective) level in future reviews would require updated and refined public visibility valuation studies, which CASAC strongly encouraged the Agency to support prior to the next review." (71 FR 61207, October 17, 2006).

The primary objective of this assessment, therefore, is to develop information beyond what was available in the last review to help inform judgments by the Administrator regarding establishment of a secondary PM NAAQS that would provide the requisite degree of public welfare protection from adverse levels of PM-related urban visibility impairment. This chapter describes a series of activities (see Figure 2.1 above), some of which have already occurred, are underway, or are planned for this review, while others fall outside the resource and time constraints of this current review. Nonetheless, each activity completed in this review is expected to contribute to and help lay the groundwork for the development of subsequent steps, in particular, public perception/valuation survey designs or methods that could be employed in future studies or NAAQS reviews.

3.2 METHODS, APPROACHES, AND TOOLS

On October 6-8, 2008 the EPA sponsored an urban visibility workshop in Denver, Colorado to identify and discuss methods and materials that could be used in “next step” projects to develop additional information about people’s preferences for reducing existing impairment of urban visibility, and about the value of improving urban visibility. Invited individuals came from a broad array of relevant technical and policy backgrounds, including visual air quality (VAQ) science, sociology, psychology, survey research methods, economics, and EPA’s process of setting NAAQS. The 23 people who attended the workshop (including one via teleconference line) came from EPA, the National Oceanic and Atmospheric Administration (NOAA), NPS[8] academia, regional and state air pollution planning agencies, and consulting firms. For a complete summary of the workshop, see the Workshop Summary Report in Appendix C.

Participants at the workshop identified three different study approaches/methods that could be employed to gather relevant information. These include 1) investigative focus groups; 2) group interviews; and 3) individual interviews. Each type of study requires different degrees of sophistication and statistical rigor. Investigative focus groups (IFG) are often used as the first stage of survey development and are intended to explore what people are thinking and understanding about the topics they are being asked about -- these are very interactive sessions, with a greater focus on understanding what people are thinking than on the answers they provide. Focus groups can use participants from either convenience groups (e.g., students, civic clubs, church groups) or individuals selected from the general population (known as a random recruitment process). Group interviews (GI), on the other hand, are used to test a survey instrument. Background material may be shown to the group without a group discussion. Individual responses to survey questions are then collected with relatively little feedback or discussion. The moderator may answer questions to clarify what is meant by a question, or the directions on how to complete the survey. After the survey instrument questions are answered, an interactive session can be held to help improve the survey instrument. The final study type is the

[8]NPS is currently conducting a study designed to estimate the benefits of visibility improvement in national parks and wilderness areas that are expected as a result of the Regional Haze Rule. While the results of this work are not expected to be directly applicable to the issue of urban visibility preference/valuation, the experience of their team in conducting this similar study was deemed an important source of information to include in the urban workshop.

individual interview (II), or survey. This final survey component is used to determine respondents' preferences and/or valuation responses. Individual interviews can be held in group sessions for efficiency (such as to show slides to a large group of people simultaneously), but the responses are collected from each individual. In person interviews, or surveys completed at home, can also be used as an individual interview. The design of a survey project must consider both the reliability and validity of the responses. Workshop participants identified 13 issues that they felt could usefully be subjects for further investigation (see pages 15/16 of the Workshop Summary Report, http://vista.cira.colostate.edu/improve/Publications/GrayLit/gray_literature.htm)

3.2.1 Planned Assessments

Based on this revised issue list, we are developing plans to conduct an IFG study to address the first two topics regarding the improvement of communication with study participants through a) selection of appropriate word choices in order to clearly communicate concepts of preferences (e.g., acceptable, unacceptable, adverse), and b) determination of the appropriate amount, type, depth/detail and wording of introductory materials. This IFG study would be conducted in one location but include several iterations in order to allow responses from one session to inform/refine the wording and introductory materials used in subsequent sessions.

Another key issue discussed at the workshop was the uncertainty regarding a concern that current urban visibility preference information may not be representative of urban preferences nationwide, since to date, all of the public preference studies have been conducted in western areas using scenes that featured distant mountain backdrops. This was clearly seen as a critical uncertainty in the information available in the last review. Therefore, the second phase of this assessment includes a plan to conduct a GI study to address whether concern for PM-related urban visibility impairment varies by region or is a consistent value nationwide. We plan to conduct GIs in at least three non-western urban areas which do not have distant mountain backdrops, and one GI in a western city (e.g., Denver, CO or Phoenix, AZ), that was the site of an earlier urban visibility survey, for comparison.

Scene Selection

Selection of appropriate scenes for use in urban visibility studies is an important step in study design, as not all scenes are equally sensitive to changes in haze levels. In general, long-distance views are more sensitive to changes in perceived haze level as a function of changed light extinction compared to those with short-distance views. In order to be comparable to the western studies which used scenes where distant mountains were the backdrop of the scenic photographs, it will be important to try to select other urban scenes that have a long sight path. Since most urban areas in other regions of the country do not have distant mountains as a backdrop for urban scenes, alternative views such as from the edge of some urban areas of the skyline may be of sufficient distance to constitute sensitive scenes. In situations where there are no distant scenic elements, the color of the sky near the horizon or the presence of white clouds may be among the most sensitive indicators of visibility impacts. Workshop participants considered the use of clouds in a blue sky as a distant scenic element a topic for an IFG. We have decided to review a series of WinHaze photos currently being developed with skycolor/cloud conditions to determine in-house whether these scenes appear similarly sensitive to previously developed western scenes. If we determine that they are sufficiently sensitive, they will be used in the study design. All scenes for use in assessment studies will be carefully selected to have sensitive scenic elements.

Another topic identified as usefully investigated with a focus group study is whether a single set of generic scenes could be successfully used in cities across the U.S. We have decided to show at least two types of scenes in each urban area that is used for a study. One view will be an "iconic" scene (i.e. one that is recognizable to area residents and having acknowledged intrinsic value), while the other scene will be a "generic" scene selected because it is a familiar type of urban scene with no obvious clues that would indicate the urban area or region it was from (e.g. an urban park). The exact same generic scene would be used in all study locations. The purpose in having the iconic scene is to identify acceptable visibility levels for a valuable view in each urban area, while the purpose of the generic scene is to present viewers in each of the study locations with the identical combination of scene and haze characteristics to test for the consistency of public response across differing regions in determining acceptable urban visibility levels. The degree of consistency of the preference level in response to the generic urban scene versus the responses to iconic city views may shed some light as to the importance of haze protection by type of scene shown and regional differences in expectations and preferences.

Assessment Scenarios

Study participants would be shown iconic and generic scenic photos having a range of light extinction level conditions superimposed on them using WinHaze technology designed for this purpose. The upper end of the light extinction range could be selected to correspond to the typical daytime maximum hourly light extinction value under the current $PM_{2.5}$ secondary NAAQS level (i.e. 35µg/m^3) for typical urban PM compositions and high relative humidity conditions (e.g. RH=90%), and the lower end of the range could correspond to daytime maximum hourly light extinction conditions for days with mean regional natural background light extinction levels due to naturally occurring levels and composition of PM under low relative humidity (RH<50%) conditions.

Recognizing that urban haze conditions vary over time to form a distribution of conditions, studies would be designed to elicit information on the haze level thought to be unacceptable if it occurs more often than some number of days per year. For example, the current daily $PM_{2.5}$ NAAQS control level (i.e. 35µg/m^3) applies to the 98 percentile, so it can be exceeded up to 7 days out of 365 days in a year without violating the standard. Studies could be designed to specify a range of both the frequency and level of daily maximum light extinction that could be acceptable in urban areas. Alternately, for consistency, the frequency could be set to the same as the current daily $PM_{2.5}$ NAAQS and the survey used to assess the maximum daily haze level that should not be exceeded 98% of the time. It is expected that a standard number of scenes depicting roughly equally spaced haze conditions through the full range would be generated for use in the studies.

Visual Display Methods

There are a number of methods available for presenting images to study participants. These were discussed at length at the workshop. The traditional approach would be to use a standard number of photos/images depicting roughly equally spaced haze levels through the full range of conditions. An alternate approach that was suggested in the workshop was to provide participants with high quality computer monitors equipped with a “dial in” capability where participants could adjust haze levels in a continuous manner through the full range of conditions to select desired and undesirable ranges. It is not clear at this time whether such an approach would be advantageous or feasible. We plan to explore this in house prior to finalizing study design.

Valuation Studies

A final group of topics identified by workshop participants were related to using investigative focus groups to assess various approaches (e.g., willingness to pay, conjoint analysis) available to determine how the public values improvements in urban visual air quality. While we recognize the usefulness and desirability of such information, adding studies to address these topics/issues will greatly increase study design complexity and require additional time and resources that may not be available in this review.

3.3 CHARACTERIZATION OF UNCERTAINTY/PLANNED SENSITIVITY ANALYSIS

The factors that contribute to uncertainty of the results from geographic focus groups include those related to the design of the focus groups and those that are inherent to differences among the participants. Variations in participants’ ability to perceive visual haze differences are expected to be relatively small since participants will be screened for normal corrected vision and exclude colorblind individuals. However, participants’ judgments of the unacceptable level of haze will likely vary more than their perceptual capabilities. Inclusion of sufficient numbers of participants that are representative of the general population should provide mean responses that represent the public. Focus groups would include features to test for participant consistency of results as a way to detect such problems.

Study responses will be assessed separately for each scene and urban areas and by participant subgroups (e.g., age, education, etc.) to determine the sensitivity of urban haze levels judged to be unacceptable by such groupings. The use of different iconic scenes to show various haze levels to the participants of the four urban areas selected for survey studies may result in different mean responses across the different urban study sites. Despite efforts to use scenes selected to be similarly sensitive to perceived haze changes associated with various changed light extinction levels, the scenes are unlikely to be identically sensitive. Also these iconic scenes may have different intrinsic value to the residents of each of the urban areas. These concerns would not be an issue for responses to the same generic scenes used for all studies. Results from the generic scenes should help in the interpretation of the reasons for difference in response to the iconic scenes among the four urban study sites. If significantly different responses are obtained among the different urban areas to the generic scenes, they would likely be attributed to regional differences in the public's valuation of haze levels.

3.4 BROADER CHARACTERIZATIONS

Haze levels judged to be unacceptable on the basis of study responses will be used to more broadly characterize a range of unacceptable haze levels for urban areas across the country. This assessment would estimate the frequency, seasonality and regional patterns of urban haze levels that could reasonably be judged to be unacceptable, as well as help identify the PM species and humidity levels that are principally responsible for various candidate unacceptable haze levels. The sensitivity of these results to reasonable variations of levels judged to be unacceptable would also be tested.

4 SCHEDULE AND MILESTONES

Table 4-1 lists the key milestones for the Urban Visibility Impact Assessment (UVA) that is planned as part of the current PM NAAQS review. Consultation with the CASAC PM Panel is scheduled for April 1-2, 2009 to obtain review of the first draft Integrated Science Assessment (ISA) and to obtain input on the plans to conduct quantitative assessments. EPA staff will then proceed to develop quantitative assessments of urban visibility conditions and preferences associated with recent PM ambient concentrations and levels representing just meeting the current PM standards. This information will be presented in the first draft PM UVA. CASAC and public comments on this plan will be taken into consideration in the development of the first draft UVA, the preparation of which will coincide and draw from the second draft ISA. The first draft report is scheduled to be released for CASAC and public review in August 2009. EPA will receive comments on this draft document from the CASAC and the general public at a meeting planned for September 2009. The second draft UVA will draw on the final ISA and will reflect consideration of CASAC and public comments on the first draft UVA. The second draft UVA will include assessments for just meeting potential alternative standards. We plan to release the second draft UVA in March 2010 for review by CASAC and the general public at a meeting that is planned for April 2010. Staff will consider these review comments and prepare a final UVA, currently planned to be completed in July 2010. The final UVA will reflect consideration of CASAC and public comments on the second draft UVA. The final ISA and final REA will inform the policy assessment and rulemaking steps that will lead to a final decision of the PM NAAQS. Our current schedule includes plans for issuing a proposed rule in January 2011 and a final rule in October 2011.

Table 4-1 Key Milestones for the Urban Visibility Impact Assessment (UVA) for the PM NAAQS Review

Milestone	Date
Release first draft PM ISA	December 2008
Release draft PM UVA Scope and Methods Plans	February 2009
CASAC/public review and meeting on first draft PM ISA	April 1-2, 2009
CASAC consultation on draft PM UVA Scope and Methods Plans	April 2, 2009
Release second draft PM ISA	July 2009
Release first draft of the PM UVA	August 2009
CASAC/public review and meeting on second draft PM ISA and first draft UVA	September 2009
Final PM ISA	December 2009
Release second draft of the PM UVA	March 2010
CASAC/public review and meeting on second draft of the PM UVA	April 2010
Final PM UVA	July 2010

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APPENDICES

APPENDIX A : QUALITATIVE ASSESSMENT OF OTHER WELFARE EFFECTS

In addition to the well known PM-related effects on visual air quality, other welfare effects are associated with ambient PM. These effects include those associated with deposited particles (e.g., impacts on ecosystems and man-made materials), and those that result from particles that remain suspended in the air (e.g., direct and indirect climate effects). Each of these other welfare effects will be discussed in turn below. As with many PM-related effects, the chemical constituents that make up PM largely determine the nature, degree, and direction of the effects. As a result, the $PM_{2.5}$ and PM_{10} size classes used for human health risk assessment do not necessarily correlate well to other PM welfare effects due to the fact that PM chemistry is often the driving factor, not particle size, through in some cases these two characteristics occur together. With the exception of materials damage, these discussions exclude those effects associated with the deposition of particulate sulfates and nitrates, as those effects are being discussed/assessed under the ongoing NOx/SOx secondary NAAQS review.

ECOLOGICAL EFFECTS OF PARTICULATE ORGANICS AND HEAVY METAL DEPOSITION

Assessment of environmental risk associated with deposited PM is dependent upon 1) elucidation of pathways of exposure, 2) characterization of ecologically important PM components, and 3) identification of ecological receptors that are susceptible to various components in particulate pollution.

Pathways of PM exposure for ecological receptors can include direct deposition to the receptor surface via wet, dry or occult deposition, or transfer from one environmental compartment or organism to another. Depending on the size of the particles and other environmental conditions, deposited PM may have come from local sources or have been transported long distances.

The components that make up a given mass concentration of PM can vary significantly both temporally and spatially. This heterogeneous nature of PM has confounded efforts to evaluate PM-related effects on ecosystem function at the ecosystem, regional, watershed, or national scale. However, second only to the widespread impacts of deposited particulate nitrates and sulfates, particulate heavy metal deposition has also consistently been implicated as toxic to (adversely impacting) a number of ecological receptors on more local scales.

Ecological receptors that have been shown to be sensitive to heavy metal deposition include vegetation, soil microfauna, aquatic biota and terrestrial organisms. With respect to vegetation, Chapter 9 of the ISA details effects of heavy metal contamination on forests. This is not surprising, since forest ecosystems are a significant ecological receptor for PM contaminants. PM dry deposition to leaf surfaces and the inner canopy is well documented. Impacts include growth suppression, toxicity to root colonizing microorganisms, impairment of root development and induction of the phytochelatin intracellular metal-binding peptides. The EPA (2004) demonstrated elevated phytochelatin levels in red spruce stands with high numbers of dead trees and that metal stress increased at higher elevations. Quantitative assessment of PM damage to forests potentially could be conducted by overlaying PM sampling data and elevated phytochelatin levels. However, limited data on phytochelatin levels in other species currently hinders use of this peptide as a biomarker for PM. It may be possible to apply environmental modeling techniques to new data on PM concentrations and tree responses associated with elevational changes to better understand how PM toxicity impacts ecosystem functioning; however, there is currently not sufficient data available for such an analysis.

PM may be deposited directly on the leaf surface and be taken up by the plant or inhibit photosynthesis. Vegetation can also be indirectly impacted by soil-chemistry changes due to PM deposition or alterations in the amount of solar radiation reaching the leaf surface. Increased pollutant levels have led to a decrease in plant diversity at the ecosystem level. Plants vary in sensitivity to PM and susceptible species can be monitored for adverse effects associated with exposure. Lichen and mosses have been deployed as biomonitors for heavy metal deposition with limited success; however, there is insufficient data to evaluate their use as bioindicators. A limitation to incorporating plant data into a qualitative analysis of particulate damage is that toxic effects of some components of PM on plants are not well characterized and it is difficult to isolate these endpoints from other environmental stressors.

With respect to PM effects on soil and soil-associated microfauna, more information has become available since the last review. Heavy metals such as Zinc (Zn), Copper (Cu) and Cadmium (Cd) and some pesticides have been shown to be toxic to soil fungi and bacteria. This topic is covered in greater detail in Chapter 9 of the ISA. Toxicity of deposited particulate matter to soil biota may also have broader implications at the ecosystem level. Many plant species are dependent upon bacteria and fungal associations to obtain nutrients from the rhizosphere. Nutrient and organic matter cycling and carbon utilization may be adversely impacted by shifts in soil microflora populations. Due to the site-specific composition of PM and the ability of soil-associated biota to undergo population shifts in response to ecological stressors and the lack of data, it is not possible to quantify this effect at this time. Long-term atmospheric deposition studies from ice, snow, peat, and lake sediment samples present temporal data on changes in PM that may be applicable to future analyses.

Fauna may also be an ecological receptor for PM components (e.g., heavy metals, PM-associated organics). Chapter 9 of the ISA details limited new data on effects of PM on terrestrial invertebrates, amphibians, birds and mammals. Pathways of PM exposure to fauna include ingestion, absorption, and tropic transfer. PM may also be transferred between aquatic to terrestrial compartments. There is limited evidence for biomagnification of heavy metals up the food chain except for mercury (Hg) which moves readily through environmental compartments. Quantitative assessment of particulate metal toxicity to biota is limited due to the heterogeneous composition of PM, lack of data on the bioavailability of PM components, and uncertainties in cumulative exposure effects. Many of the particulate pollutants demonstrated to have effects on biota are already regulated under the air toxics program.

Adverse effects of particulate matter on ecosystem components including vegetation, soil microfauna, aquatic biota and terrestrial organisms have been demonstrated from point-sources such as coal-fired power plants, quarries, cement, and metal smelting operations. Typically, concentrations of metals and organics associated with particulate matter are highest in proximity to the source and decrease with increasing distance from the operation. Chapter 9 of the PM ISA summarizes the effects of PM originating from point sources on receiving ecosystems. Concentrations of heavy metals and organics associated with point-sources are generally much higher than levels measured away from the site limiting the applicability of point-source data to a national assessment of ambient PM effects.

Non-point sources of PM such as urban areas are significant contributors to particulate loading in the environment. Emissions are generally highest in urban settings where vehicular traffic, industrial processes and home heating contribute PM to the atmosphere. Urban runoff from rooftops, paved areas and buildings may result in transfer of particulate components to different ecological compartments (soil, water, vegetation, or atmosphere). Chapter 9 of the ISA presents evidence for higher PM concentrations in urban areas. Data on the individual components of PM is currently only available for a few urban areas.

Roadway and near-roadway deposition of PM represent chronic non-point sources of heavy metal pollution. Elevated levels of Cd, calcium (Ca), Cu, lead (Pb) and Zn in soils near roadways are attributed to tire wear, road paint and vehicle exhaust. Seasonal differences in PM composition near roadways may be attributed to winter tire use and deicing chemicals. Pollutant concentrations decrease with increased distance from roadways, however, transfer of near roadway PM to other environmental compartments is possible via runoff, plant uptake or tropic transfer. More data on seasonal composition of near roadway PM and tropic transfer of toxic compounds to organisms such as deer, vultures, groundhogs and raccoons that forage on roadsides are needed to quantitatively assess impacts of PM to ecological receptors.

In summary, characterization of PM effects on ecosystem functioning are confounded by the complex composition of particulate pollutants and the geographic heterogeneity of deposition. The potential for ecosystem shifts due to deposition and subsequent movement of PM through pathways of exposure in the environment exists but there is currently insufficient data to quantify the contribution of PM. It is also not possible at this time to quantify ecosystem goods and services that are provided with reductions in PM levels in the atmosphere. Europe and other countries are using the critical load approach to assess pollutant effects at the level of the ecosystem. This type of assessment requires site-specific data and information on individual species responses to PM. The United States currently applies an exposure-based approach to set secondary standards, however, there are efforts underway to use critical load calculations as way to assess ecological risk.

MATERIALS

The effects associated with deposition of atmospheric pollution, including ambient PM, to material surfaces are related to both physical damage and impaired aesthetic qualities. Because the effects of PM are exacerbated by the presence of acidic gases and can be additive or synergistic due to the complex mixture of pollutants in the air and surface characteristics of the material, this discussion will also include those particles and gases that are associated with the presence of ambient NOx and SOx, as well as NH_3 and NHx for completeness. More detailed discussion of these effects on materials can be found in Chapter 9 of the PM ISA and in Chapter 9 of the Annexes to the NOx/SOx secondary ISA.

Materials Damage Effects

Materials damage effects associated with deposited particulate matter (especially sulfates and nitrates) include the corrosion of metals, degradation of painted surfaces, deterioration of building materials such as limestone, concrete and marble and weakening of paper, plastics, elastomers and electronic components. Particles contribute to this damage by adding to the effects of natural weathering processes, and because of their electrolytic, hygroscopic and acidic properties, and their ability to sorb corrosive gases (principally SO_2). Deposited pollutants that damage materials may undergo chemical transformations and are commonly oxidized to acids. Oxides of nitrogen damage textiles, electronics and dyes. Deposition of SO_2 to stone results in a chemical reaction with calcium carbonate to form gypsum. Both wet and dry deposition contributes to particulate accumulation and subsequent damage to surfaces. However, the presence of moisture accelerates some materials damage such as corrosion of metals. In general, SO_2 is more corrosive than NOx although mixtures of NOx , SO_2 and other particulate matter corrode some metals at a faster rate than either pollutant alone. There are significant costs associated with remediation of materials, however, in the most recent ISA there is not sufficient new evidence to conduct a quantitative assessment of damage attributed to PM.

Soiling Effects

PM deposition onto surfaces such as paint, metal, glass and stone can lead to soiling. Soiling results when PM accumulates on an object and alters the optical characteristics (appearance). The reflectivity of a surface may be changed or presence of particulates may alter light transmission. These effects can impact the aesthetic value of a structure or result in reversible or irreversible damage to statues, artwork and architecturally or culturally significant buildings. Formation of black crusts due to carbonaceous compounds and buildup of microbial biofilms results in discoloration of surfaces. Limited new data suggest an increased role for microbial colonizers in contributing to the soiling of buildings. Presence of air pollutants may synergistically enhance microbial biodeterioration processes. Due to soiling of building surfaces by PM, the frequency and duration of cleaning may be increased. There is not sufficient new evidence to conduct a quantitative assessment of materials damage due to soiling.

CLIMATE

Since the last review, new information is available on the role and interactions of atmospheric PM in climate processes. The Intergovernmental Panel on Climate Change (IPCC) published a series of reports in 2007, including information on the effects of PM on climate. The US Climate Change Science Program (CCSP) published a series of reports in 2008 and 2009 some of which address, in part, the effects of PM on climate, including “Atmospheric Aerosol Properties and Climate Impacts” completed in January 2009. There is a considerable ongoing research effort focused on understanding aerosol contributions to fluctuations in global mean temperature and precipitation patterns.

Components of PM are known to have both direct and indirect effects on climate. Aerosols affect the Earth's energy budget by scattering and absorbing radiation (direct effect) and by modifying the cloud amount, lifetime, and microphysical and radiative properties (indirect effects). For example, the presence of SO_4^{2-} and organic carbon particles decrease warming from sunlight by scattering shortwave radiation back into space. Moreover, the direct absorption of radiant energy by PM leads to heating of the troposphere and cooling of the surface, which can change the relative humidity and atmospheric stability thereby influencing the clouds and precipitation (semi-direct effect). The addition of manmade aerosols to the atmosphere may change the radiative fluxes at the top-of-atmosphere (TOA), at the surface, and within the atmospheric column. Such a perturbation of radiative fluxes by anthropogenic aerosols is designated as aerosol climate forcing, which is distinguished from the aerosol radiative effect of the total aerosol (natural plus anthropogenic). The aerosol climate forcing and radiative effect are characterized by large spatial and temporal heterogeneities due to the wide variety of aerosol sources, the spatial non-uniformity and intermittency of these sources, the short atmospheric lifetime of aerosols (relative to that of the gases), and processing (chemical and microphysical) that occurs in the atmosphere.

Improvements in atmospheric measurement and modeling of PM components since the last review have enabled a more detailed understanding of the solar direct radiative effects (DRE) of aerosols. Networks of monitoring instruments including satellite systems, surface-based remote sensing sun-photometers and aerosol-lidar systems are facilitating more advanced analysis of climate parameters. New atmospheric models and improved algorithms reflect the dynamic nature of particulate interactions and have further refined the role of PM components in global climate change. Global estimates of aerosol direct radiative forcing (RF) were recently summarized using a combined model-based estimate (Foster et al. 2007). The overall, model-derived aerosol direct RF was estimated as -0.4 watts per square meter (W/m^2), indicating a net cooling effect in contrast to greenhouse gases which have a warming effect.. Information provided by new instrumentation and modeling has further characterized the complex role of PM in climate processes, however, the uncertainties are still too large to inform policy-making on the adequacy of a secondary PM standard. As described in CCSP SAP

2.3, the influence of aerosols on climate is not yet adequately taken into account in our computer predictions of climate and an improved representation of aerosols in climate models is essential to more accurately predict the climate changes.

Since the last review, more information is available on indirect effects of PM on cloud formation and feedback but the interaction of PM with clouds remains the largest source of uncertainty in climate estimates. Particulates in the atmosphere indirectly affect both cloud albedo and cloud lifetime. Aerosols act as cloud condensation nuclei (CCN). Increased particulates in the atmosphere available as CCN with no change in moisture content of the clouds have resulted in a decrease in the radii and number of cloud droplets in certain clouds. When the size and number of droplets decreases, the albedo of the cloud subsequently increases. Smaller particles slow the onset of precipitation and prolong cloud lifetime. This effect, coupled with changes in cloud albedo, increase the reflection of solar radiation back into space. The interactions of aerosols and linkages between clouds and the overall climate system are complex and limit the feasibility of conducting a quantitative analysis.

The previous OAQPS Staff Paper concluded that available data on PM effects on climate were global and regional in scale and not applicable to quantifying effects at a local level. Since the last review, more data is available on local and regional effects of PM (for example, CCSP SAP 3.2) although the focus continues to be on global-scale processes. It has been previously established that PM can alter precipitation patterns. A series of new studies detailed in the ISA have added to existing evidence that rainfall suppression can occur in local areas where atmospheric aerosol levels are elevated. Increased particulate matter in the atmosphere decrease wind speeds, which, in turn decrease evaporation rates and subsequent precipitation events. Due to insufficient data for many regions of the U.S., local and regional microclimate variations and heterogeneity of cloud formations it is not currently feasible to conduct a quantitative analysis for the purpose of informing revisions to the PM standard in this review.

APPENDIX B : TABLE B.1 DATA TYPES, AVAILABILITY, TIME PERIOD, AND INTENDED APPLICATIONS

Table B.2 Availability of Ambient PM and Light Extinction Related Data for the Assessment.

Measurement Type	Availability	Time Periods	Intended Application
24-hour $PM_{2.5}$ mass by FRM/FEM, local conditions, in units of ug/m3 AQS parameter 88101	Potential assessment locations typically will have several sites, with sampling schedules that may be 1:1, 1:3, or 1:6. Data from micro-scale and middle-scale sites (as recorded in AQS) will not be used, as these may not be representative of air quality over the distance range relevant to visual air quality.	2005-2007	These data will be the common base from which estimates of hourly speciated PM2.5 concentrations will be developed by application of temporal and speciation profiles
24-hour $PM_{2.5}$ speciation data from the urban Chemical Speciation Network	Potential assessment locations typically will have one or two sites, with sampling schedules that may be 1:3 or 1:6. Some but not all PM2.5 mass samplers will have collocated speciation samplers.	2005-2007	These data will be used to speciate the 24-hour PM2.5 mass concentrations. Available speciation data will be spatially interpolated to the location of the FRM/FEM monitors when not collocated.
24-hour PM10 by FRM/FEM, standard temperature and pressure (STP) conditions AQS parameter 81102	Potential assessment locations typically will have one or two sites, with sampling schedules that may be 1:3 or 1:6. Some but not all PM2.5 mass samplers will have collocated speciation samplers. Data from micro-scale and middle-scale sites (as recorded in AQS) will not be used, as these may not be representative of air quality over the distance range relevant to visual air quality.	2005-2007	The IMPROVE algorithm for estimating light extinction includes a term for PM10-2.5. There are very few PM10-2.5 monitoring sites that use the recently established FRM for PM10-2.5. EPA staff has not yet developed a plan for whether and how to use these PM10 data in the algorithm. Difficulties include likely cases of non-collocation and mis-matches of sampling schedules, and the errors than can occur when subtracting PM2.5 concentrations obtain by low-volume samplers from PM10 concentrations obtain from high-volume samplers. Also, PM10 data are submitted based on STP conditions, and in principle should be adjusted to local conditions before PM10-2.5 is calculated by subtraction.
Continuous (hourly) PM2.5 mass, by non-FRM/FEM methods considered to acceptable quality for AQI reporting AQS parameter 88502 Any method code allowed by AQS	Only assessment locations with at least one site with this type of data will be considered.	2005-2007	These data will be used to develop estimates of hourly PM2.5 FRM/FEM mass, via diurnal profiles. Profiles will be expressed as the ratio between concentration in one hour and the 24-hour concentration, with the mean of the 24 1-hour ratios constrained to be 1.0. Some PM2.5 FRM/FEM monitors will have collocated continuous monitors. Others will have to have profiles

Measurement Type	Availability	Time Periods	Intended Application
for use with this parameter code			from other site(s) in the same study area applied.
Continuous (hourly) PM2.5 mass, by recently approved FEM methods AQS parameter 88101	Limited sites are operational	2008	No data is available for 2005-2007, since that was before approval of these FEMs. EPA may consider the 2008 data if it is collocated with light extinction measurements, to help assess the quality of light extinction estimates made from PM2.5 mass and species concentrations, if earlier year collocated data needs to be supplemented.
Continuous (hourly) PM10 mass by FEM methods AQS parameter code 81102 Method codes: 076, 079, 081, 122, 150, 151, 156	A large number of CBSAs and CSA have at least one of these monitors.	2005-2007	EPA staff has not yet developed a plan for whether and how to use these PM10 data. EPA will consider making the presence of one of these monitors a condition of being selected as an assessment location, if hourly PM10-2.5 is judged to make a significant contribution to the light extinction budget.
Hourly PM2.5 Speciation AQS parameters: 88403 (sulfate) 88307 (EC) 88305 (OC) Data only from the following instruments will be used: Thermo sulfate method code 875 Sunset carbon, method code 867 (EPA does not consider any available continuous nitrate data to be suitable for use in the risk assessment.)	Sulfate data are available in AQS for Cedar Rapids, IA; Davenport, IA; Columbia, SC; Anderson, SC; Greenville, SC; Indianapolis, IN; Knoxville, TN; and New York City NY. Carbon data are available in AQS for Chicago, IL; Detroit, MI; New York City, NY; and Seattle, WA. The above data will be used only if collocated with a 24-hour PM2.5 speciation sampler. Staff will request similar data from the SEARCH program.	Any available. For instruments with data from 2005-2007, no older data will be used.	These data will be used to develop diurnal profiles for sulfate, elemental carbon, and organic carbon, which will be applied to 24-hour speciation concentrations. Staff will explore regional differences in the shapes of these profiles, but given the sparsity of the data it can be anticipated that potentially significant uncertainties will be introduced by the need to extrapolate profiles to other locations. Staff will also explore whether profiles need to be segregated by season.
Relative Humidity AQS parameter 62201 (hourly) and 68110 (24-hour average)	Many monitoring sites in AQS report hourly relative humidity from on-site instruments. NWS provides hourly relative humidity at other sites.	2005-2007	Hourly relative humidity data (or estimates) will be used in the IMPROVE algorithm to estimate hourly light extinction.
Nephelometer light scattering.	About 88 nephelometers have operated at	2005-2007	Where possible, these hourly data will be compared to

Measurement Type	Availability	Time Periods	Intended Application
AQS parameter code 11203	some time in 32 CBSAs. Staff will need to investigate further which of these are heated versus unheated.		the estimates of hourly light scattering developed for the same cities and hours using PM2.5 concentrations, as a check on the realism of the method used to create the latter estimates for locations without nephelometers.
Aethalometer light absorption	About 33 aethalometers have operated at some time in 33 CBSAs. These have reported in AQS in units of mass concentration of black carbon. Staff will need to explore whether and how to estimate atmospheric light absorption from these values.	2005-2007	Where possible, these hourly data will be compared to the estimates of hourly light absorption developed for the same cities and hours using PM2.5 concentrations, as a check on the realism of the method used to create the latter estimates for locations without aethalometers.
Transmissometer light extinction, in units of MM^{-1}	Staff are still investigating the availability of this type of data in AQS. It is expected that very few such instruments have been operated by state/local monitoring agencies. Staff are also investigating other sources of data, including the SEARCH program and the PM Supersites studies.		Where possible, these hourly data will be compared to the estimates of hourly light extinction developed for the same cities and hours using PM2.5 concentrations, as a check on the realism of the method used to create the latter estimates for locations without transmissometer.

APPENDIX C : DENVER URBAN VISIBILITY WORKSHOP SUMMARY REPORT

On October 6-8, 2008 the EPA sponsored an urban visibility workshop in Denver, Colorado to identify and discuss methods and materials that could be used in “next step” projects to develop additional information about people’s preferences for reducing existing impairment of urban visibility, and about the value of improving urban visibility. Invited individuals came from a broad array of relevant technical and policy backgrounds, including visual air quality (VAQ) science, sociology, psychology, survey research methods, economics, and EPA’s process of setting NAAQS. The 23 people who attended the workshop (including one via teleconference line) came from EPA, the National Oceanic and Atmospheric Administration (NOAA), NPS, academia, regional and state air pollution planning agencies, and consulting firms. To view the complete report go:

http://vista.cira.colostate.edu/improve/Publications/GrayLit/gray_literature.htm

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