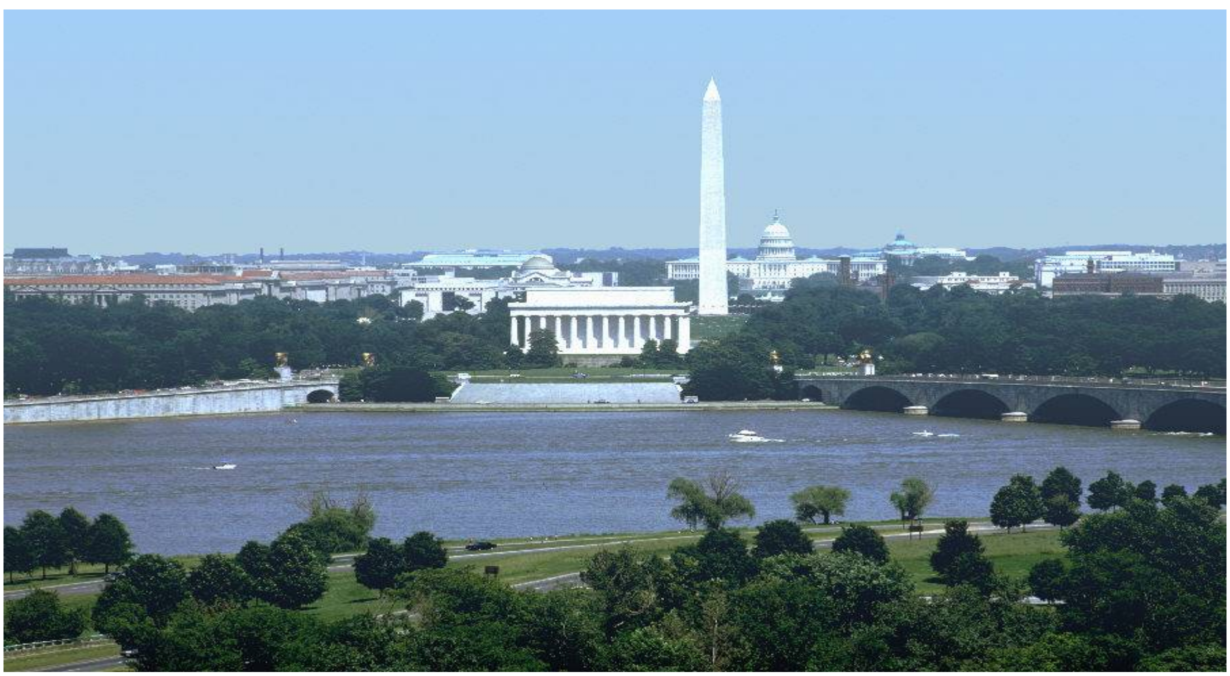
Particulate Matter
Urban-Focused Visibility Assessment

External Review Draft

September 2009



DISCLAIMER

This draft document has been prepared by staff from the Ambient Standards Group, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. Any opinions, findings, conclusions, or recommendations are those of the authors and do not necessarily reflect the views of the EPA. This document is being circulated to obtain review and comment from the Clean Air Scientific Advisory Committee (CASAC) and the general public. Comments on this draft document should be addressed to Vicki Sandiford, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, C504-06, Research Triangle Park, North Carolina 27711 (email: sandiford.vicki@epa.gov).

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U.S. Environmental Protection Agency
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Office of Air Quality Planning and Standards
Health and Environmental Impacts Division
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AQS	EPA's Air Quality System
BAM	Beta Attenuation Mass Monitor
BC	British Columbia
CAA	Clean Air Act
CAIR	Clean Air Interstate Rule
CASAC	Clean Air Scientific Advisory Committee
CBSA	Consolidated Business Statistical Area
CCN	Cloud Condensation Nuclei
CDPHE	Colorado Department of Public Health and Environment
CMAQ	Community Multiscale Air Quality
CONUS	CMAQ simulations covering continental US
CPL	Candidate Protection Level
CRA	Charles River Associates
CSA	Consolidated Statistical Area
CSN	Chemical Speciation Network
CTM	Chemical Transport Model
CTS	CMAQ model run
DRE	Direct Radiative Effects
dv	deciview
EPA	United States Environmental Protection Agency
FEM	Federal Equivalent Method
FRM	Federal Reference Method
GEOS	Global Scale Air Circulation Model
IMPROVE	Interagency Monitoring of Protected Visual Environment
ISA	Integrated Science Assessment
Km	Kilometer
LCD	Liquid Crystal Display
LOESS	Locally weighted Scatter Plot Smoothing
Mm	Megameter
MSA	Metropolitan Statistical Area
N	Nitrogen
NAAQS	National Ambient Air Quality Standards
NARSTO	North American Research Strategy for Tropospheric Ozone

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
PA	Policy Assessment
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.
$PM_{10-2.5}$	Particles with a 50% upper cut-point of 10 µm aerodynamic diameter and a lower 50% cut-point of 2.5 µm aerodynamic diameter.
PRB	Policy Relevant Background
REA	Risk and Exposure Assessment
RF	Radiative Forcing
RH	Relative Humidity
SANDWICH	Sulfate, Adjusted Nitrate, Derived Water, Inferred Carbonaceous mass approach
SEARCH	Southeastern Aerosol Research and Characterization Study
SMOKE	Sparse Matrix Operator Kernal Emissions
S	Sulfur
SO_2	Sulfur Dioxide
SO_x	Sulfur Oxides
STP	Standard Temperature and Pressure
TEOM	Tapered Element Oscillating Microbalance
UBC	University of British Columbia
UFVA	Urban-Focused Visibility Impact Assessment
VAQ	Visual Air Quality

1 INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is presently conducting a review of the national ambient air quality standards (NAAQS) for particulate matter (PM). Sections 108 and 109 of the Clean Air Act (Act) govern the establishment and periodic review of the NAAQS. The NAAQS are to be based on air quality criteria, which are to accurately reflect the latest scientific knowledge useful in indicating the kind and extent of identifiable effects on public health or welfare that may be expected from the presence of the pollutant in ambient air. The EPA Administrator is to promulgate and periodically review, at no later than five-year intervals, "primary" (health-based) and "secondary" (welfare-based) NAAQS for such pollutants. Based on periodic reviews of the air quality criteria and standards, the Administrator is to make revisions in the air quality criteria and standards, and to promulgate any new standards, as may be appropriate. The Act also requires that an independent scientific review committee advise the Administrator as part of this NAAQS review process, a function performed by the Clean Air Scientific Advisory Committee (CASAC).

The current NAAQS for PM include a suite of standards to provide protection from health and welfare effects related to fine and coarse particles, using $PM_{2.5}$ and PM_{10} as indicators, respectively (71 FR 61144, October 17, 2006). With regard to the primary and secondary standards for fine particles, in 2006 EPA revised the level of the 24-hour $PM_{2.5}$ standard to 35 $\mu g/m^3$ (calculated as a 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor), retained the level of the annual $PM_{2.5}$ annual standard at 15 $\mu g/m^3$ (calculated as the 3-year average of the weighted annual mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors), and revised the form of the annual $PM_{2.5}$ standard by narrowing the constraints on the optional use of spatial averaging[1]. With regard to the primary and secondary standards for PM_{10}, EPA retained the 24-hour PM_{10} standard at 150 $\mu g/m^3$ (not to be exceeded more than once per year on average over 3 years) and revoked the annual 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. The 2006 primary standards were based primarily on a large body of epidemiological evidence relating ambient PM concentrations to various adverse health outcomes. The 2006 secondary standards for $PM_{2.5}$ and PM_{10} were revised to be identical to the primary standards, on the basis that in the Administrator's judgment these standards, in conjunction with the regional haze

[1] In the revisions to the PM NAAQS finalized in 2006, EPA tightened the constraints on the spatial averaging option limiting the conditions under which some areas may average measurements from multiple community-oriented monitors to determine compliance (see 71 FR 61165-61167, October 17, 2006).

program , will provide appropriate protection to address PM-related welfare effects, including visibility impairment, effects on vegetation and ecosystems, materials damage and soiling, and effects on climate change.

The next periodic review of the PM NAAQS is now underway.[2] In the *Integrated Review Plan for the National Ambient Air Quality Standards for Particulate Matter,* March 2008 (US EPA, 2008a), EPA outlined the science policy questions that will frame this review, outlined the process and schedule that the review will follow, and provided more complete descriptions of the purpose, contents, and approach for developing the key documents that will be developed in the review.[3] EPA is currently completing the process of assessing the latest available policy-relevant scientific information to inform the review of the PM standards. The latest draft of this assessment is contained in the second external review draft of the Integrated Science Assessment for Particulate Matter (ISA, US EPA, 2009a) which was released in July 2009 for review by CASAC and for public comments. The 2009 second draft PM ISA includes a summary of the scientific evidence for the relationship of PM to visibility effects, remote area and urban haze conditions, the PM components responsible for visibility impacts, and studies of public preference with respect to urban visibility conditions.

Building upon the visibility effects evidence presented in the second draft PM ISA, as well as CASAC advice (Samet, 2009) and public comments on a planning document (US EPA, 2009b), EPA's Office of Air Quality Planning and Standards (OAQPS) has developed this draft Urban-Focused Visibility Assessment (UFVA) describing the quantitative assessments being conducted by the Agency to support the review of the secondary PM standards. This draft document is a concise presentation of the methods, key results, observations, and related uncertainties associated with the quantitative analyses performed. Revisions to this draft UFVA will draw upon the final ISA and will reflect consideration of CASAC and public comments on this draft UFVA.

The final ISA and final UFVA will inform the policy assessment and rulemaking steps that will lead to final decisions on the secondary PM NAAQS. A Policy Assessment (PA) is now being prepared by OAQPS staff to provide a transparent staff analysis of the scientific basis for alternative policy options for consideration by senior EPA management prior to rulemaking.

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[2] See http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_index.html for more information on the current and previous PM NAAQS reviews.

[3] On November 30, 2007, EPA held a consultation with the Clean Air Scientific Advisory Committee (CASAC) on the draft IRP (Henderson, 2008). Public comments were also requested on the draft plan and presented at that CASAC teleconference. The final IRP incorporated comments received from CASAC and the general public on the draft plan as well as input from senior Agency managers. CASAC is an independent scientific advisory committee established to meet the requirements of section 109(d)(2) of the Clean Air Act. See http://yosemite.epa.gov/sab/sabpeople.nsf/WebCommittees/CASAC for more information, and, in particular, information on the CASAC PM Review Panel activities.

The PA is intended to help "bridge the gap" between the Agency's scientific assessments, presented in the ISA and UFVA, and the judgments required of the Administrator in determining whether it is appropriate to retain or revise the secondary PM standards. The PA will integrate and interpret information from the ISA and the UFVA to frame policy options and to facilitate CASAC's advice to the Agency and recommendations on any new standards or revisions to existing standards as may be appropriate, as provided for in the Clean Air Act. A very preliminary draft PA is planned for release in September 2009 to facilitate discussion on the overall structure, areas of focus, and level of detail to be included in an external review draft of the document, which EPA plans to release for CASAC review and public comment later this year. A discussion of the preliminary draft PA with CASAC will be held in conjunction with CASAC review and public comment of the second draft ISA, this draft UFVA, and a draft assessment document that will inform the review of the primary PM standards - *Risk Assessment to Support the Review of the PM Primary National Ambient Air Quality Standards - External Review Draft* (US EPA, 2009c).

1.1 PM NAAQS BACKGROUND

In the review of the secondary PM NAAQS completed in 2006, EPA took into account that the Regional Haze Program[4], implemented under sections 169A and 169B of the CAA, was established to address all human-caused visibility impairment in Class I areas. Recognizing that efforts were underway under that program, EPA focused the 2006 PM NAAQS review on visibility impairment primarily in urban areas. The EPA evaluated the levels of visibility impairment occurring in urban areas and assessed available information on public preferences regarding acceptability of PM-related urban visibility impairment. At that time, EPA's focus continued to remain on particle size and mass and EPA staff determined that $PM_{2.5}$ size and particle mass, rather than particle composition, remained the most appropriate approach for addressing PM-related urban visibility effects. EPA recognized that PM composition and relative humidity are important factors in the relationship between light extinction (a measure of visibility) and PM mass concentration. The EPA's assessment of PM and meteorological data from 161 cities showed that the least variation in the relationship of light extinction to $PM_{2.5}$ mass concentration was for afternoon periods when low relative humidity conditions generally prevail (EPA, 2005).

The EPA proposed to revise the secondary standards by making them identical to the suite of proposed primary standards for fine and coarse particles, providing protection against PM-related public welfare effects including visibility impairment, effects on vegetation and

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

ecosystems, and materials damage and soiling (71 FR 2620). The EPA also solicited comment on adding a new sub-daily $PM_{2.5}$ secondary standard to address visibility impairment in urban areas. CASAC provided additional advice to EPA in a letter to the Administrator requesting reconsideration of CASAC's recommendations for both the primary and secondary $PM_{2.5}$ standards as well as standards for thoracic coarse particles (Henderson, 2006). With regard to the secondary standard, CASAC reaffirmed "… the recommendation of Agency staff regarding a separate secondary fine particle standard to protect visibility….. The CASAC wishes to emphasize that continuing to rely on primary standards to protect against all PM-related adverse environmental and welfare effects assures neglect, and will allow substantial continued degradation, of visual air quality over large areas of the country" (Henderson, 2006).

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). This was designed to address both visibility and other non-visibility welfare related effects. Specifically, with regard to the secondary standards for fine particles, EPA revised the level of the 24-hour $PM_{2.5}$ standard to 35 $\mu g/m^3$, retained the level of the annual $PM_{2.5}$ annual standard at 15 $\mu g/m^3$, 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 secondary 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 $\mu g/m^3$ and revoked the annual PM_{10} standard.

Several parties filed petitions for review following promulgation of the revised PM NAAQS in 2006. These petitions addressed a number of issues, including the decision to set the secondary $PM_{2.5}$ standards identical to the primary standards. On judicial review the court remanded the secondary $PM_{2.5}$ NAAQS to EPA because the Agency failed to adequately explain why setting the standards equal to the primary $PM_{2.5}$ standards provided the required protection from visibility impairment. In particular, the Agency failed to identify a target level of visibility impairment that would be requisite to protect the public welfare, and improperly relied on a comparison of the number of counties which would be in nonattainment for the revised primary NAAQS compared to various alternative secondary standards. Among other things, this equivalence analysis failed to address the issue of regional differences in humidity-related effects on visibility *American Farm Bureau Federation v. EPA*, 559 F. 3d 512 (D.C. Cir. 2009)

1.2 SCOPE OF URBAN-FOCUSED VISIBILITY ASSESSMENT

This chapter provides an overview of the scope and key design elements of the UFVA conducted for this review, including the process that has been followed to design the analyses. Following initiation of the current PM NAAQS review, we began the design of this assessment by reviewing the analyses completed during the previous PM NAAQS review (Abt Associates Inc., 2001; US EPA, 2005, chapter 6) with an emphasis on considering key limitations and sources of uncertainty recognized in that analysis. Furthermore, as an initial step in the overall PM NAAQS review, EPA invited a wide range of external experts as well as EPA staff, representing a variety of areas of expertise to participate in a workshop titled, "Workshop to Discuss Policy-Relevant Science to Inform EPA's Integrated Plan for the Review of the Secondary PM NAAQS" (72 FR 34005, June 20, 2007). This workshop provided an opportunity for the participants to broadly discuss the key policy-relevant issues around which EPA would structure the PM NAAQS review and to discuss the most meaningful new science that would be available to inform our understanding of these issues. One session of this workshop was centered around issues related to visibility impacts associated with ambient PM. Specifically, the discussions focused on the extent to which new research and/or improved methodologies were available to inform how EPA evaluated visibility impairment in this review.

Based in part on these workshop discussions, EPA developed a draft IRP outlining the schedule, the process, and the key policy-relevant science issues that would guide the evaluation of the air quality criteria for PM and the review of the primary and secondary PM NAAQS including initial thoughts for conducting quantitative assessments (US EPA, 2007, chapter 6). On November 30, 2007, CASAC held a teleconference with EPA to provide its comments on the draft IRP (72 FR 63177, November 8, 2007). Public comments were also presented at that teleconference. A final IRP incorporating comments received from CASAC and the general public on the draft plan was issued in March 2008 (US EPA, 2008a).

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.[5]

As a next step in the design of the quantitative assessments, EPA developed a planning document outlining the initial design for the PM NAAQS visibility assessment - *Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Urban Visibility Impact Assessment,* henceforth Scope and Methods Plan (US EPA, 2009b). This planning document was released for CASAC consultation and public review in February 2009. Based on consideration of CASAC and public comments on that Scope and Methods Plan, along with ongoing review of the latest PM-related literature, we made modifications to the scope and design of the visibility assessment and completed our initial analyses. These modifications, as well as the current scope of the UFVA and the rationale supporting it, are described in this section below.

The EPA staff continues to believe that a focus on urban area visibility is appropriate. In articulating a rationale for this conclusion, we have reviewed the information contained in the second draft ISA and find the following information compelling: 1) PM levels in urban areas are often in excess of those of the surrounding region since urban haze typically includes both regional and local contributions (US EPA, 2009a; sections 9.2.3.3 and 9.2.3.4), suggesting the potential for higher levels of PM-induced visibility impairment in urban areas; 2) the existence of numerous urban visibility protection programs and goals demonstrates that urban VAQ is noticed and an important value to urban residents (US EPA, 2009a; section 9.2.4), and 3) the existence of large urban populations suggests that potentially more people are routinely affected by poor VAQ than in rural areas. One aspect of the urban visibility conditions assessment, as depicted in Figure 1-1 of section 1.3 of the Scope and Methods document (US EPA, 2009b), has been modified. Taking into account the nature of urban versus more remote area PM composition, and input received at the April 2, 2009 CASAC meeting, EPA staff has concluded that it is unnecessary to develop a new urban-optimized algorithm at this time and that it remains appropriate in the context of this assessment to use the original IMPROVE algorithm to relate urban PM to local haze (PM light extinction).

With regard to the urban visual air quality preference assessment described in the Scope and Methods document (US EPA, 2009b, section 1.3), more significant modifications have occurred. EPA staff has decided to conduct a reanalysis of the urban visibility preference studies available at the time of the 2006 PM NAAQS review, rather than conduct new public preference studies, as it has become apparent that the results of these studies would be unlikely to be completed in time to inform this review. Recognition that the initial plans described in the Scope

[5] To view the complete report from the October 2008 urban visibility workshop, see: http://vista.cira.colostate.edu/improve/Publications/GrayLit/gray_literature.h tm

and Methods document were possibly overly ambitious was also shared by members of CASAC (see individual member comments; Samet, 2009). This analysis, therefore, relies on existing, rather than new, urban visibility preference studies and is designed to explore the similarities and differences (comparability) between these studies and assess what information can be drawn from these results to inform the selection of VAQ candidate protection levels (CPLs) to be used in subsequent impact assessments. Further, information presented during the public comment phase of the April 2, 2009 CASAC meeting and later provided to EPA staff, led to the inclusion of a recent study by Smith and Howell (2009) for Washington, D.C. in the reanalysis.

As described in the Scope and Methods document (US EPA, 2009b), EPA staff is continuing to focus assessments in this document in terms of an alternative indicator for PM visibility impairment, i.e. PM light extinction, instead of the traditional $PM_{2.5}$ mass concentration. The 2005 Staff Paper discussed the use of a four-hour afternoon $PM_{2.5}$ standard, where the underlying rational was that the generally lower afternoon relative humidity tended to produce a more uniform relationship between light extinction and $PM_{2.5}$ mass concentration throughout the country, therefore providing a more uniform level of visibility protection nationwide. However, this more uniform level of visibility protection was limited to the afternoon hours of the day when relative humidity and visibility impairment are typically the lowest. However, visibility conditions can be the poorest when relative humidity levels are the highest. Thus, from a public welfare perspective, greater protection from visibility impairment is needed during the times when humidity is high. In that regard, morning relative humidity conditions, which are often generally higher in the Eastern US and coastal areas than in the West, causes the same PM concentrations to produce much higher PM-related visibility impairment in those regions than in areas with lower morning relative humidity resulting in unequal visibility impairment at the national scale. Unlike PM mass concentration, which is determined by removing the liquid water from the PM prior to measuring it, PM light extinction can be measured at ambient humidity conditions so that it includes the enhanced light extinction resulting from the liquid water that is associated with the hygroscopic PM components in the atmosphere. PM light extinction, like PM mass concentration, is a measurable physical characteristic of ambient PM. Thus, EPA believes that use of PM light extinction as the indictor for a secondary PM NAAQS is a more appropriate target and more directly related to the welfare effect of interest.

1.3 VISIBILITY EFFECTS SCIENCE OVERVIEW

Light extinction is the optical characteristic of the atmosphere that best determines the impact potential of PM on perceived visibility. Light extinction is the loss of light per unit of distance and occurs when light is either scattered or absorbed. Particulate matter and gases can both scatter and absorb light. Light scattering by gases (e.g., nitrogen, oxygen, etc.) that comprise the atmosphere (also known as Rayleigh or clean-air scattering) is related to the density of the air, which is sufficiently constant with elevation that it can be considered a known constant value for any location. NO_2 is the only atmospheric pollutant gas that absorbs light appreciably and its effects are generally small (i.e. less than 5%) compared to PM light extinction, so its contribution to ambient visibility impacts is often ignored (as is done here). By this assumption, light extinction is approximated as the sum of PM light extinction (including both scattering and absorption) plus Rayleigh scattering, where the former characterizes the PM contribution to visibility impacts, and the latter is taken to be a time invariant constant depending only on elevation above sea level. In the same way PM light extinction is a good measure of the degree of visibility impairment.

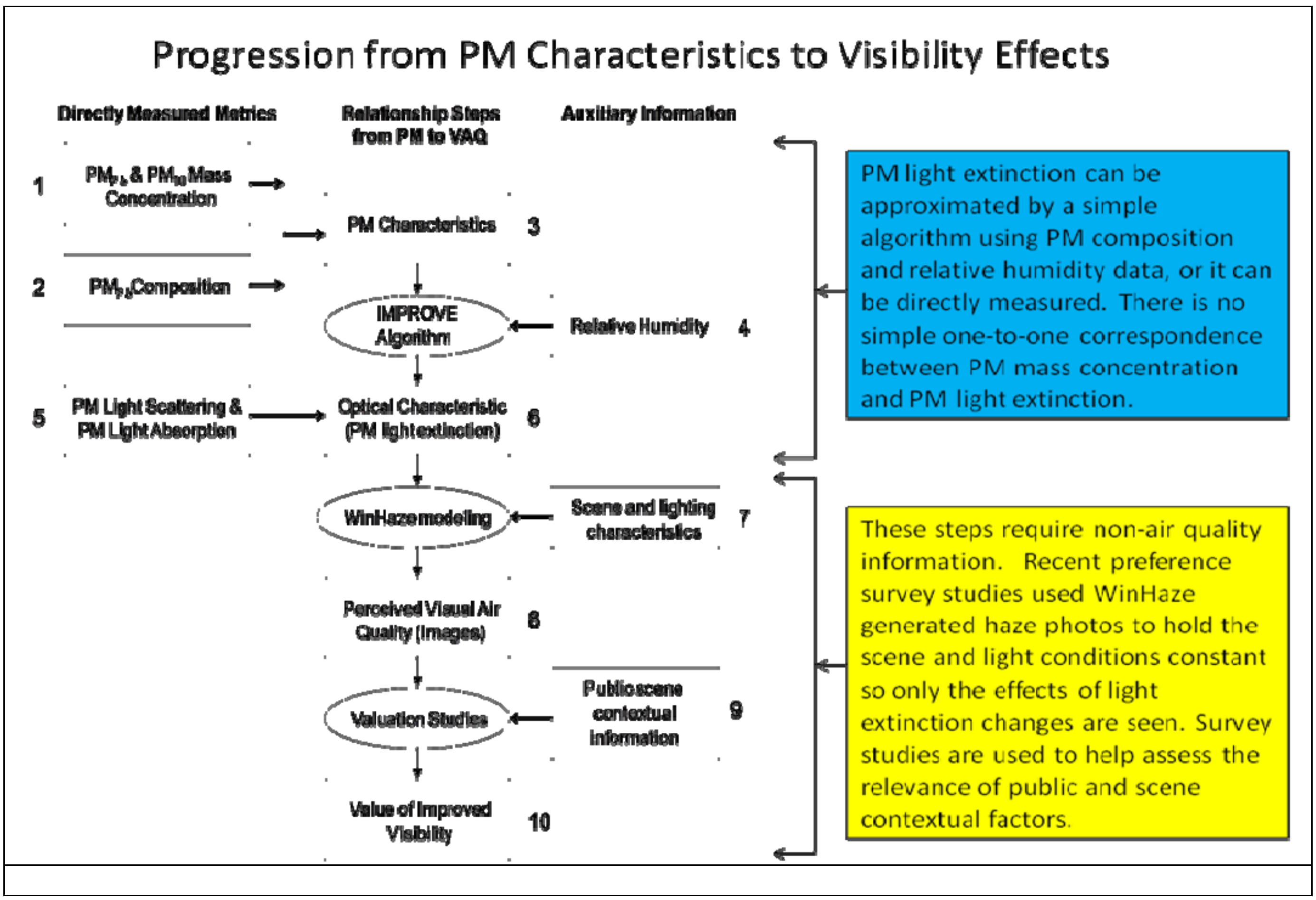
Visual air quality is defined as the visibility effect caused solely by air quality conditions and excluding those associated with meteorological conditions like fog and precipitation. It is commonly measured as either light extinction (in terms of inverse megameters, Mm^{-1}) or the deciview (dv) metric (Pitchford and Malm, 1993), which is a logarithmic function of extinction. Extinction and deciviews are physical measures of the amount of visibility impairment (e.g., the amount of "haze"), with both extinction and deciview increasing as the amount of haze increases. A haziness index measured in deciview units was developed for use in visibility perception studies because it has a more linear relationship to perceived changes in haze compared with light extinction. The haziness index in deciviews (dv) is defined as ten times the natural logarithmic of one tenth of the light extinction in inverse megameter units (Mm^{-1}) (Pitchford and Malm, 1993).

There is no simple one-to-one correspondence between PM concentration and PM light extinction. However, as shown in Figure 1-1, the PM light extinction can be estimated from PM composition and relative humidity data, using an algorithm with assumed light extinction efficiencies for each of the major PM species and water growth factors for the hygroscopic species. Though PM light extinction can be accurately determined by direct measurements, there is only limited existing urban PM light extinction data. As a result, the assessment below will principally use monitored and modeled PM mass, species estimates, and relative humidity measurements.

The extent to which any amount of light extinction affects a person's ability to view a scene depends on both scene and light characteristics. For example the appearance of a nearby object (i.e. a building) is generally less sensitive to a change in light extinction than the appearance of a similar object at a greater distance. For a scene with known characteristics, the amount of degradation in the scene associated with a change in light extinction can be determined and the change in appearance can be realistically displayed on a digital photograph of the scene using the WinHaze system.

Survey studies have used sets of photographs depicting a range of visibility conditions on urban scenes to assess the public's opinion on the acceptability of conditions. For the specific scenes used in such studies there is a known/predetermined one-to-one correspondence between the percieved haze in the photographs and the amount of PM light extinction. For visibility preference studies, visibility levels are generally characterized using the haze index in units of deciview (similar to the decibel scale for sound).

Figure 1-1. Diagram showing the relationship steps between ambient PM and visibility impairment.



1.4 GOALS AND APPROACH

The principal goal of the current UFVA is to characterize current levels of visibility impairment, with a focus on urban areas, both in terms of the current secondary PM standards, as well as in terms of alternative standards, including indicators and forms that may better reflect the relationship between PM and visibility impairment. In particular, this UFVA focuses on the effectiveness of a light extinction-based indicator for a possible secondary PM NAAQS (see Figure 1-1). This is done by comparing estimates of hourly light extinction in 15 major U.S. urban areas over the three-year period 2005-2007 to the CPLs, which are a range of light extinction values beyond which half of the participants in assessed urban visibility preference studies indicated the haze conditions were unacceptable (see discussion in chapter 2 below and Stratus Consulting Inc., 2009). In addition, the UFVA will include additional characterizations of the effectiveness of a sub-daily $PM_{2.5}$ mass concentration indicator, which was explored in the 2005 PM staff paper and which was considered a viable option by EPA staff and CASAC in the 2006 review. These latter assessments will be summarized in Appendix A.

The previous PM NAAQS review used the results of visibility preference survey studies conducted in Denver (1990), Phoenix (2003), and British Columbia (1993) as the basis for suggesting that a standard set to protect visibility conditions to a level within a visual range from between about 40 km to about 60 km (corresponding to light extinction from ~100 Mm^{-1} to ~67 Mm^{-1}) could represent an appropriate degree of welfare protection from PM. With the exception of a small pilot study conducted in Washington, D.C. in 2001 (9 participants; Abt Associates Inc., 2001), and a replicate study also conducted for Washington, D.C. in 2009 (26 participants; Smith and Howell, 2009), there have been no additional visibility preference survey studies upon which to base the selection of CPLs. The EPA staff, with contractor support, has conducted a more detailed, in-depth assessment of the results from these studies, including the two recent Washington, D.C. studies. This assessment includes an analysis that combines data from across all studies to examine the consistency of the results between the surveys (Stratus Consulting Inc., 2009). Based on the results of this analysis, we have been able to refine the range of visibility conditions that could represent an appropriate degree of public welfare visibility protection that was put forth in the 2006 review, and to determine a central tendency value for the CPLs. These analyses and results are described below in chapter 2.

In the previous PM NAAQS review, the characterization of urban visibility conditions were based on IMPROVE algorithm estimates using the 2001 to 2003 $PM_{2.5}$ mass and speciation data by assuming a constant composition for every hour of the day equal to the 24-hour measured composition and by using either actual or monthly average (10-year mean) hour of the day relative humidity for 161 urban area. Statistical relationships between hourly light extinction estimates and concurrent hourly $PM_{2.5}$ mass concentrations were used to show that daytime and especially afternoon relationships are relatively strong with a similar linear relationship for both eastern and western urban areas (i.e. R^2>0.6, slope ~6 m^2/g). Relationships that included the non-daylight hours were not as strong and differed more between eastern and western urban areas.

The current assessment of urban visibility conditions (as described in chapter 3) is similar in its development of an algorithm to estimate hourly light extinction using $PM_{2.5}$ mass and speciation data with measured relative humidity. However, it differs in that instead of assuming constant composition for $PM_{2.5}$, composition is made to vary during the day using urban-specific monthly mean diurnal variations of species concentrations determined from regional air quality model results, while constraining the means of the hourly species concentration for each day to closely match the 24-hour duration measured species concentrations. The current assessment examines 15 urban areas using 2005 to 2007 data sets (i.e. the same cities as used in the current assessment for the primary standard).

1.5 ORGANIZATION OF DOCUMENT

The remainder of this document is organized as follows: Chapter 2 includes an analysis of the urban visibility preference studies with a discussion of similarities and differences regarding the approaches and methods used and results obtained for each study. This chapter also includes a summary discussion of the results of a composite assessment of the combined four city results and use of these results in the selection of the alternative levels evaluated in the remainder of the assessment. Chapter 3 describes the analytical approach, methods, and data used in conducting the assessment of recent urban visibility conditions, both in terms of $PM_{2.5}$ and light extinction indicators for the set of urban case studies included in this analysis. Selected results are presented in chapter 3, with additional results found in the Appendices. Chapter 4 presents estimates of $PM_{2.5}$ and light extinction conditions generated for the urban case studies for six alternative $PM_{2.5}$ and light extinction scenarios. Additional information regarding approaches and results for both chapters 3 and 4 are presented in Appendices A-F).

2 URBAN VISIBILITY PREFERENCE STUDIES

The purpose of this chapter is to present the reanalysis of the methods and results of existing studies of preferences for urban visibility that EPA staff conducted (with contractor support) in order to provide information useful in selecting a range of CPLs in terms of light extinction values for subsequent use in the UFVA assessments of current and alternative VAQ conditions. To date, available urban visibility preference studies have examined individuals' desire for good VAQ by investigating the basic question, "What level of visibility degradation is acceptable?" Preference studies have used a similar group interview type of survey to investigate the level of visibility impairment that participants described as "acceptable." The specific definition of acceptable is largely left to each individual survey participant, allowing each to identify their own preferences.

The reanalysis effort included three completed urban visibility preference survey studies plus a pair of smaller focus studies designed to explore and further develop urban visibility survey instruments. The first urban visibility study conducted was in Denver, Colorado (Ely et al., 1991), which developed the basic survey method used in all the subsequent studies. The two other western studies included one in the lower Fraser River valley near Vancouver, British Columbia (BC), Canada (Pryor, 1996), and one in Phoenix, Arizona (BBC Research & Consulting, 2003). A pilot focus group study was also conducted for Washington, DC (Abt Associates Inc., 2001). In response to an EPA request for public comment on the Scope and Methods Plan (74 FR 11580, March 18, 200), Dr. Anne Smith provided comments (Smith, 2009) about the results of a new Washington, D.C., focus group study that had been conducted using methods and approaches similar to the method and approach employed in the EPA pilot study (Smith and Howell, 2009). In total, 852 individuals participated in these studies in four cities, with each individual responding to a series of questions answered while viewing a set of images of various urban VAQ conditions.

2.1 METHODS USED IN PREVIOUS STUDIES

One direct physical measure of VAQ used in many visibility analyses is light extinction. Light extinction is the loss of light per unit of distance, and measures the ability of particles and gases in the atmosphere to scatter and absorb light traveling between an object and a person (or camera). Extinction and haziness are physical measures of the amount of visibility impairment (e.g., the amount of "haze"), with both extinction and haziness increasing as the amount of haze increases.

In all but one[6] of the visibility preference studies reviewed in this paper, participants were shown a series of different VAQ conditions projected on a large screen using a slide projector. In the earliest two studies (the Denver and lower Frazer River Valley studies) a range of VAQ conditions were presented by projecting photographs (slides) of actual VAQ conditions. The photographs were taken on different days from the same location, and presented the same scene. Photographs were selected to avoid depicting significant weather events (e.g., rain, snow, or fog), and where measured extinction data were available from the time the photograph was taken.

The Phoenix study, as well as the subsequent Washington, D.C. survey instrument, development projects, used photographic-quality images generated by a computer to present different VAQ conditions. The images were developed from an original photograph using the WinHaze software program, which is based on a technique described in Molenar et al. (1994). The Phoenix study and the 2001 Washington, DC project projected slides of digital images prepared by WinHaze. The 2009 Washington, DC project presented images directly from the desktop version of WinHaze using either a liquid crystal display (LCD) projector or a computer monitor.

WinHaze analysis synthetically superimposes a uniform haze on a digitized, near-pristine actual photograph. The WinHaze computer algorithm calculates how a given extinction level would impair the appearance of each individual portion of the photograph. A major advantage of presenting WinHaze-generated images is that they provide viewers depictions of alternative VAQ levels, with each image containing exactly the same scene, with identical light angle, time of day properties, weather conditions, and specific scene content details (e.g., the amount of traffic in a intersection). Additional details about WinHaze, and a discussion of the applicability of WinHaze images for regulatory purposes, is in the 2004 PM Criteria Document (U.S. EPA, 2004). The desktop version of WinHaze is available online (Air Resources Specialists, 2008).

The first urban visibility preference study was conducted in Denver, Colorado (Ely et al., 1991), and developed the basic survey method used in all the subsequent studies. Although there are variations in specific details in each study, all the studies use a similar overall approach (key variations are discussed in the section on each study later in this paper).

Visibility preference studies consist of a series of group interview sessions, where the participants are shown a set of photographs or images of alternative VAQ conditions and asked a series of questions. The group interview sessions are conducted multiple times with different

[6] Smith and Howell (2009) used digital projection technology not available at the time of the other studies to present the series of VAQ conditions. Some of the participants in the Smith and Howell study were shown images using a LCD projector connected to a laptop computer. In other sessions, participants in the Smith and Howell study were shown images on a computer monitor connected to the computer.

participants. Ideally the participants will be a representative sample of the residents of the metropolitan area. While all studies agree that this is the preferred approach, due to the high cost of organizing and conducting a series of in-person group interviews with a large, statistically representative sample, only the Phoenix study was able to fully meet this objective.

During a group interview session, the participants were instructed to consider whether the VAQ in each photograph or image would meet an urban visibility standard, according to their own preferences and considering three factors:

1. The standard would be for their own urban area, not a pristine national park area where the standards might be more strict
2. The level of an urban visibility standard violation should be set at a VAQ level considered to be unreasonable, objectionable, and unacceptable visually
3. Judgments of standards violations should be based on visibility only, not on health effects.

The photographs (images) are not shown in order of ascending or descending VAQ conditions; the VAQ conditions are shown in a randomized order (with the same order used in each group interview session). In order to check on the consistency of each individual's answers, the full set of photographs (images) shown during the group interview included duplicates with the identical VAQ conditions.

The participants were initially given a set of "warm up" exercises to familiarize them with how the scene in the photographs or image appears under different VAQ conditions. The participants next were shown 25 randomly ordered photographs (images), and asked to rate each one based on a scale of 1 (poor) to 7 (excellent). They were then shown the same photographs or images again (in the same order), and asked to judge whether each of the photographs (images) would violate what they would consider to be an appropriate urban visibility standard (i.e., whether the level of impairment was "acceptable" or "unacceptable").

2.2 DENVER, COLORADO

The Denver urban visibility preference study (Ely et al., 1991) was conducted on behalf of the Colorado Department of Public Health and Environment (CDPHE). The study consisted of a series of focus group sessions conducted in 1989 with participants from 16 civic associations, community groups, and employees of state and local government organizations.[7]

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[7] No preference data were collected at a 17^{th} focus group session due to a slide projector malfunction.

The participants were not selected to be a fully representative sample of the Denver metropolitan population but were instead selected to take advantage of previously scheduled meetings.

During the 16 focus group sessions, a total of 214 individuals were asked to rate photographs of varying visibility conditions in Denver. The photographs were taken November 1987 through January 1988 by a camera in Thornton, Colorado. Thornton is suburb of Denver, located approximately six miles north of downtown Denver. The photographs were taken as part of a CDPHE study of Denver's air quality. The scene in the photographs was toward the south from Thornton and included a broad view of downtown Denver and the mountains to the south. Each group was shown one of two sets of 20 randomly ordered unique photographs (13 of the sessions included 5 duplicate slides, for a total of 25 photographs, to evaluate consistency of responses). The two sets of different slides were used to investigate whether the responses between the two sets of photographs were different (no differences were found). Approximately 100 participants viewed each photograph. Projected color slides were used to present the photographs to focus group participants, and were projected on a large screen

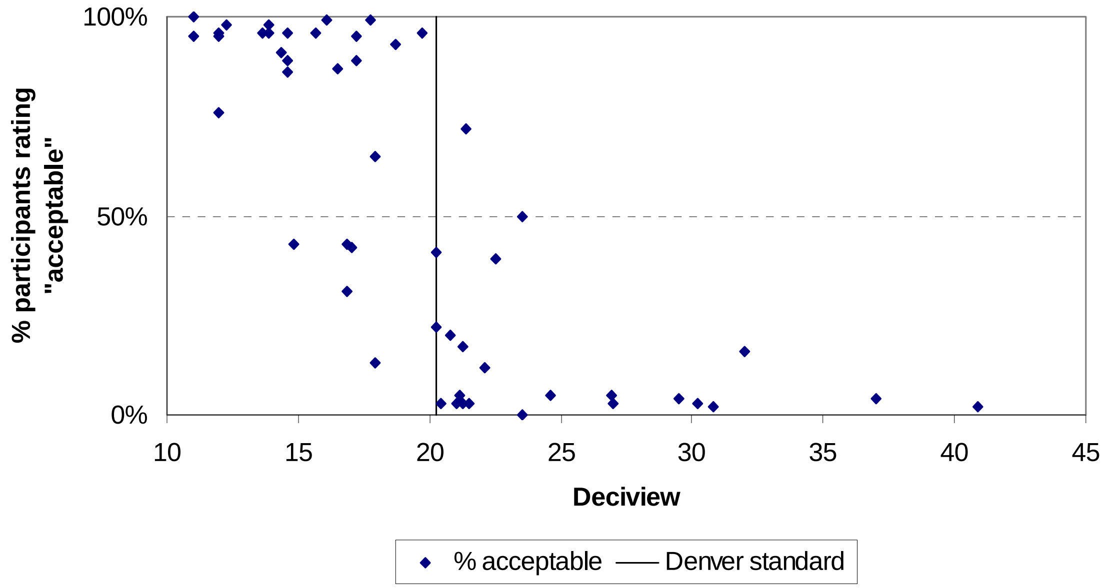
The VAQ conditions in each Denver photograph were recorded when the photograph was taken and measured by a transmissometer yielding hourly average light extinction, b_{ext}. The transmissometer was located in downtown Denver, approximately eight miles from the camera and in the middle of the camera's view path. Ely et al. (1991) provide the time of day and measured extinction level for each photograph. The extinction levels presented in the Denver photographs ranged from 30 to 596 Mm^{-1}. This corresponds to 11dv to 41dv, approximating the 10^{th} to 90^{th} percentile of wintertime visibility conditions in Denver in the late 1980s.

The participants first rated the VAQ in each photograph on a 1 to 7 scale, and subsequently were asked if each photograph would violate an urban visibility standard. The individual's rating on the 1 to 7 scale and whether the photograph violated a visibility standard were highly correlated (Pearson correlation coefficient greater than 80%).

The percent of participants who found a photograph acceptable to them (i.e., would meet an appropriate urban visibility standard) was calculated for each photograph. Figure 2-1 shows the results of the Denver participants' responses, with VAQ measured in deciviews.

Ely et al. (1991) introduce a "50% acceptability" criteria analysis of the Denver preference study results. The 50% acceptability criteria is designed to identify the VAQ level that best divides the photographs into two groups: those with a VAQ rated as acceptable by the majority of the participants, and those rated not acceptable by the majority of participants. While no single VAQ level creates a perfect separation between the two groups, the CDPHE identified a VAQ of 20.3 dv as the point that best separates the Denver study responses into "acceptable" and "not acceptable" groups. Based in part on the findings of the Denver visibility preference study, the CDPHE established a Denver visibility standard at b_{ext} = 76 Mm^{-1} (dv = 20.3).

Figure 2-1. Percent of Denver participants who consider VAQ in each photograph "acceptable."



Using 20.3 dv as a 50% acceptability criteria led to six photographs being inconsistently rated by the majority of the viewers. A photograph was inconsistently rated for two possible reasons; either the photograph's VAQ was at least 1 dv better than the Denver standard (i.e., dv < 19.3) but was judged to be "unacceptable" by a majority of the participants rating that photograph, or the VAQ was at least 1 dv worse than the standard (> 21.3 dv) but found to be acceptable by the majority of the participants. This definition of inconsistent rating helps evaluate the robustness of the study results to support the selection of the Denver urban visibility standard at 76 Mm^{-1} (20.3 dv) by identifying photographs with VAQ a minimum of 1 dv above or below the standard and ignoring "near misses" involving photographs within 1 dv of the standard. A change of 1 or 2 dv in uniform haze under many viewing conditions will be seen as a small but noticeable change in the appearance of a scene, regardless of the initial haze condition (U.S. EPA, 2004).

Table 2-1 presents information about the six photographs that were inconsistently rated. All six of the inconsistently rated photographs were taken at 9:00 a.m. The five inconsistently rated photographs with a VAQ better than the Denver standard have a VAQ at least 2 dv below the standard. The VAQ in the only inconsistently rated photograph with air quality worse than the standard (Photograph #6) is 1.1 dv above the standard. The study used 18 photographs from 9:00 a.m., so a third of the 9:00 a.m. photographs were inconsistently rated. Conversely, none of the 32 photographs taken at noon or 3:00 p.m. were inconsistently rated.

Table 2-1. VAQ of Denver photos substantively misclassified by majority of participants

Photograph #	VAQ in photograph in extinction (Mm^{-1})	VAQ in photograph (dv)	% of participants who rated the photo "acceptable"	Time of day of photograph
14	44	13.8	43%	9:00 a.m.
18	54	16.9	43%	9:00 a.m.
19	54	16.9	31%	9:00 a.m.
20	55	17.0	42%	9:00 a.m.
24	60	17.9	13%	9:00 a.m.
36	85	21.4	72%	9:00 a.m.

Figure 2-2 shows the same data results about percent of participants who rated each photograph acceptable as in Figure 2-1, but with the time of day of each photograph indicated by different colors. The time of day colors clearly indicate how inconsistently participants rated some of the 9:00 a.m. photographs.

Eliminating the 9:00 a.m. photographs creates a "hole" in the range of remaining photographs; there are no photographs with a VAQ between 17.7 dv and 20.3 dv. As seen in Figure 2-2, this is a critical range in evaluating the responses. All of the photographs with a VAQ equal to or better (i.e., a lower dv value) than 17.7 dv are rated acceptable by the majority of the participants, and all photographs with a VAQ at or above 20.3 dv are rated not acceptable. After eliminating the 9:00 a.m. photographs, any VAQ level between 17.7dv and 20.3 dv would completely divide the photographs into two groups with no inconsistent ratings.

A modestly broader range of VAQ conditions provides an even more unambiguous interpretation of the Denver study results. Every photograph with a VAQ of 17.7 dv or lower was rated acceptable by 89% or more of the participants, and every photograph with a VAQ of 24.6 or higher was rated not acceptable by 84% or more of the participants. The 17.7 dv to 24.6 dv range separating the results is shown in Figure 2-3, which also eliminates the 9:00 a.m. results.

Figure 2-2. Photograph time of day information for the percent of participants who consider VAQ in each photograph "acceptable."

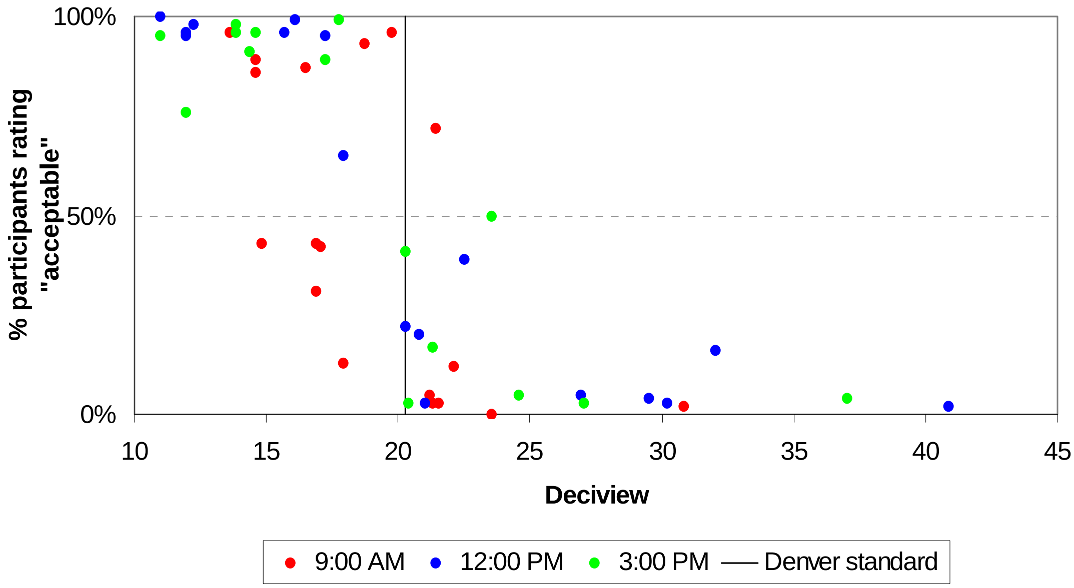
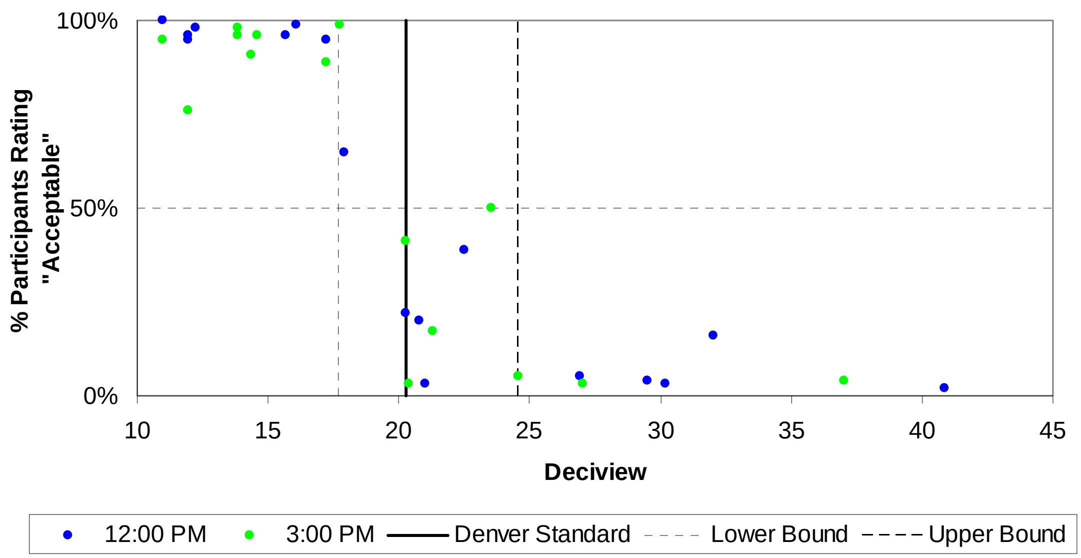


Figure 2-3. Denver photograph time of day results (9:00 a.m. photographs eliminated), with the broader range (17.7 dv and 24.6 dv) of the 50% acceptability criteria shown.



2.3 VANCOUVER, BRITISH COLUMBIA, CANADA

The BC urban visibility preference study (Pryor, 1996) was conducted on behalf of the BC Ministry of Environment following the methods used in the Denver study. Participants were students at the University of British Columbia, who were in one of four focus group sessions with between 7 and 95 participants. A total of 180 participants completed the surveys (29 did not complete the survey).

The BC study used photographs (projected as slides) depicting various VAQ conditions in two cities (Chilliwack and Abbotsford) in the lower Fraser River valley in southwestern BC. Abbotsford is located approximately 75 miles east of Vancouver, BC, and had a 2006 population of 159,000 (Statistics Canada, 2009a). Abbotsford has a diverse and successful economy, with approximately 25% of the labor force working in the Vancouver metropolitan area. Chilliwack is adjacent to Abbotsford to the east. Both cities have experienced rapid population growth, growing faster than the Vancouver metropolitan area, and are considered suburbs (or exurbs) of Vancouver.

The survey was conducted at the University of British Columbia (UBC) in 1994. The participants were 206 undergraduate and graduate students enrolled in classes in UBC's Department of Geography. Information about student demographics and where they lived prior to enrolling at UBC (which potentially influences their knowledge of, and preferences for, Vancouver area visibility) is not available.

The BC survey showed 20 unique photographs to the participants in random order. Ten photographs were from Chilliwack, and 10 were from Abbotsford. The Chilliwack photographs were taken at the Chilliwack Hospital, and the scene includes a complex foreground with downtown buildings, with mountains in the background up to 40 miles away. Figure 2-4 is a composite of two of the Chilliwack photographs used in the preference study, showing the scene with a good visibility day (14.1 dv) in the middle and a significantly impaired day (34 dv) around the border (Jacques Whitford AXYS, 2007). The Abbotsford photographs were taken at the Abbotsford Airport. The Abbotsford scene includes fewer man-made objects in the foreground and is primarily a more rural scene with the mountains in the background up to 36 miles away.

The photographs were taken in July and August 1993 as part of a VAQ and fine particulate monitoring project sponsored by the BC Ministry of Environment, Lands and Parks (REVEAL, the Regional Visibility Experimental Assessment in the Lower Fraser Valley). All of the photographs were taken at either 12:00 p.m. or 3:00 p.m. VAQ data were available for each photograph from visibility monitors near the location of each camera. The types of VAQ measurement data available from the two locations were not identical. The Chilliwack location used both an open-chamber nephelometer and a long path transmissometer and collected hourly average data on both aerosol light scattering (b_{sp}) and total extinction (b_{ext}), respectively. The visibility monitoring at the Abbotsford location had only a nephelometer and collected only b_{sp} data.

Figure 2-4. Composite Chilliwack, BC photograph showing VAQ of 14.1 dv and 34 dv.

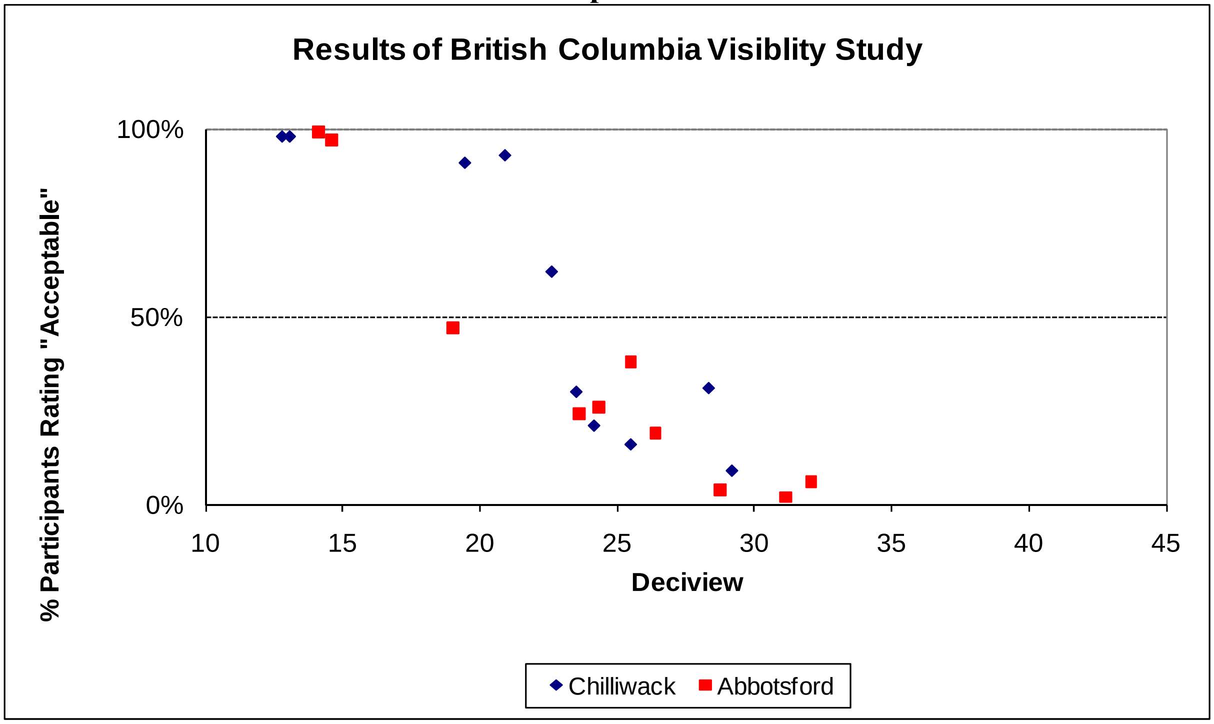
Total light extinction is the sum of scattering by gases (b_{sg}) and particles (b_{sp}) plus light absorption by gases (b_{ag}) and particles (b_{ap}). In order to present the preference results from the BC study in comparable terms, b_{ext} for the Abbotsford photographs is estimated by assuming that the average of the ratios of PM light extinction (i.e., $b_{ap} + b_{sp}$) to PM light scattering (b_{sp}) for all ten of the Chilliwack photographs can be multiplied by the Abbotsford nephelometer determined b_{sp} values corresponding to each of its photographs to estimate its PM light extinction value. By assuming that absorption by gases (b_{ag}) is zero, total light extinction is equal to the PM light extinction (i.e., $b_{ap} + b_{sp}$) plus particle scattering by gases (i.e., b_{sg} that is approximately equal to $10 Mm^{-1}$). Table 2-2 presents the data from the photographs used in the BC study, including the estimated b_{ext} for the Abbotsford photographs.

There are two caveats to be noted about the extinction data for the photographs reported in Pryor, 1996. First, in Table 2 of the original article, two of the Abbotsford photographs are listed with the same date and time (12:00 p.m., 7/26/1993). There is no information provided for a 3:00 p.m., 7/26/1993 Abbotsford photograph, although there is a Chilliwack photograph from that time. The preference and VAQ data are presumed to be correct for both photographs and one of the two identical date/time labels is assumed to be a typographic error. The second caveat is that b_{sp} levels from the same date and time can differ substantially between Abbotsford and Chilliwack, and the relative levels can change rapidly, even though the two cities are only 25 miles apart . For example, at 12:00 p.m. on 8/19/1993, the b_{sp} level in Chilliwack was about one-

Table 2-2. Summary of photographs used in British Columbia study

Date	Time	b_{sp}	b_{ext}	Ratio $(b_{ext}-b_{sg})/b_{sp}$	Estimated b_{ext}	Deciview
Chilliwack						
7/26/93	12:00 p.m.	86	128	1.372	NA	25.49
7/26/93	3:00 p.m.	67	112	1.522	NA	24.16
7/27/93	12:00 p.m.	63	105	1.508	NA	23.51
7/27/93	3:00 p.m.	119	185	1.471	NA	29.18
8/2/93	12:00 p.m.	18	37	1.5	NA	13.08
8/2/93	3:00 p.m.	20	36	1.3	NA	12.81
8/5/93	12:00 p.m.	45	70	1.333	NA	19.46
8/5/93	3:00 p.m.	51	96	1.686	NA	22.62
8/19/93	12:00 p.m.	46	81	1.543	NA	20.92
8/19/93	3:00 p.m.	105	170	1.524	NA	28.33
Average		***62***	***102***	***1.476***		***21.96***
Abbotsford						
7/26/93	12:00 p.m.	39	NA	NA	68	19.17
7/26/93	12:00 p.m.	82	NA	NA	131	25.73
7/27/93	12:00 p.m.	104	NA	NA	205	30.20
7/27/93	3:00 p.m.	132	NA	NA	164	27.97
8/2/93	12:00 p.m.	24	NA	NA	45	15.04
8/2/93	3:00 p.m.	25	NA	NA	47	15.48
8/5/93	12:00 p.m.	62	NA	NA	121	24.93
8/5/93	3:00 p.m.	75	NA	NA	102	23.22
8/19/93	12:00 p.m.	67	NA	NA	224	31.09
8/19/93	3:00 p.m.	145	NA	NA	109	23.89
Average		***76***			***122***	***23.67***

Figure 2-5. Percent of BC participants who consider VAQ in each photograph "acceptable."



third of the Abbotsford b_{sp} level. By 3:00 p.m. the situation was reversed, with the Chilliwack b_{sp} level 50% higher than Abbotsford. In those three hours the Chilliwack b_{sp} level had over doubled (from 46 Mm^{-1} to 105 Mm^{-1}), and the Abbotsford level had fallen by over half (from 145 Mm^{-1} to 67 Mm^{-1}). Such substantial changes in measured b_{sp} levels occurring across a relatively short period of time and short distance, may reflect an inherent uncertainty introduced by using a single measure of light extinction from a portion of visual scene (where the nephelometer or transmissometer was operating) to assess visibility conditions throughout an actual photographs of a complex scene. Spatial and temporal non-uniformity of visibility conditions within a scene are an atmospheric condition known to occur on some days, and may contribute to the variability in participant responses in preference studies utilizing actual photographs.

Figure 2-5 presents the results of the BC study. The division corresponding to the Denver "50% acceptable" criteria occurs between 22.6 dv and 23.2 dv. All of the photographs with a VAQ better than 22.6 dv were rated acceptable by the majority of the participants with one exception (47% of the participants judged the 19.2 dv photograph to be acceptable). All photographs with a VAQ better than 19.2 dv were rated acceptable by over 90% of the participants. All photographs with a VAQ worse than 22.6 dv were rated not acceptable by the majority of the participants, and all photographs with a VAQ worse than 28.3 dv were rated not acceptable by over 90% of the participants.

Figure 2-5 also suggests that there may be some difference between the preferences expressed for the Chilliwack scene and those for the Abbotsford scene. All photographs were rated by the same individuals (students at UBC), but the summary of the responses indicate that the participants may have rated as acceptable a worse level of impaired VAQ impairment (e.g., higher dv levels) in photographs showing more of a downtown area (Chilliwack) than in less congested scenes (Abbotsford). The strongest evidence for this hypothesis, however, is the preference for a single photograph (the 19.0 dv photograph from Abbotsford, rated as acceptable by 47%), previously identified as an outlier observation.

The BC Ministry of the Environment is considering the BC urban visibility preference study as part of establishing urban and wilderness visibility goals in BC.

2.4 PHOENIX, ARIZONA

The Phoenix urban visibility preference study (BBC Research & Consulting, 2002), which was conducted on behalf of the Arizona Department of Environmental Quality, used group interviews based on the methods used in the Denver study, with two major exceptions: (1) the focus group participants were selected as a representative sample of the Phoenix area population, and (2) the pictures presented in the focus groups were computer-generated images to depict specific uniform haze conditions.

The Phoenix study included 385 participants in 27 separate focus group sessions. Participants were recruited using random digit dialing to obtain a sample group designed to be demographically representative of the larger Phoenix population. During July 2002, group interview sessions took place at six neighborhood locations throughout the metropolitan area to improve the participation rate. Participants received $50 as an inducement to participate.

Three sessions were held in Spanish in one region of the city with a large Hispanic population (25%), although the final overall participation of native Spanish speakers (18%) in the study was below the targeted level. The age distribution of the participants corresponded reasonably well to the overall age distribution in the 2000 U.S. Census for the Phoenix area (BBC Research & Consulting, 2002). Participants slightly over-represented the middle-income range ($50,000 to $74,999), compared with 2000 Census data, and slightly under-represented very low-income ranges (under $24,999). The distribution of participant education levels was fairly consistent with the education distribution in the 2000 Census.

Photographic-quality slides of the images were developed using the WinHaze software (Molenar et al., 1994). The scene used in the Phoenix study images was taken at a water treatment plant. The view is toward the southwest, including downtown Phoenix, with the Sierra

Estrella Mountains in the background at a distance of 25 miles. Figure 2-6 shows the image with the best VAQ (15 dv).

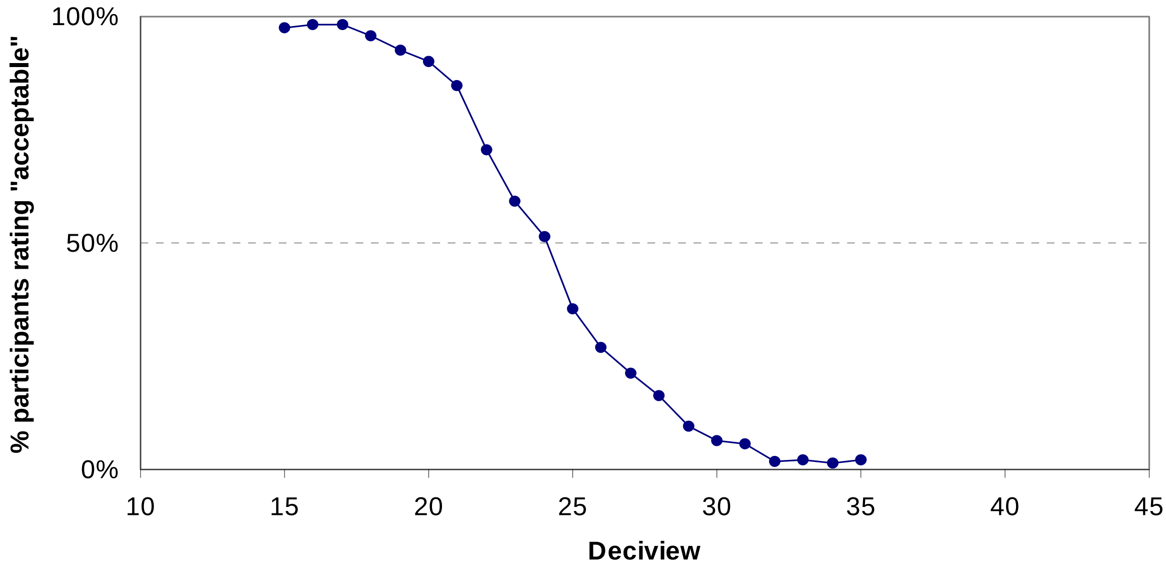
Figure 2-6. Reproduction of the image with the best VAQ (15 dv) used in the Phoenix study.

The study used a total of 21 unique WinHaze images. Four of the 21 unique images were randomly selected and used twice to evaluate consistency; participants viewed a total of 25 images. The 25 images were randomly ordered, with all participants viewing the images in the same order. The WinHaze images used in the Phoenix study do not include layered haze, a frequent and widely recognized form of visibility impairment in the Phoenix area.

The VAQ levels in the 21 unique images ranged from 15 dv to 35 dv (the extinction coefficient b_{ext} ranged from 45 Mm^{-1} to 330 Mm^{-1}). As in the Denver study, participants first individually rated the randomly shown slides on a VAQ scale of 1 (unacceptable) to 7 (excellent). Participants were instructed to rate the photographs solely on visibility and to not base their decisions on either health concerns or what it would cost to have better visibility. Next, the participants individually rated the randomly ordered slides as “acceptable” or “not acceptable,” defined as whether the visibility in the slide is unreasonable or objectionable.

Figure 2-7 presents the percent acceptability results from the Phoenix study. The combination of the use of WinHaze images and the larger number of participants than in the Denver study may account for the “smoother” backwards S-shaped pattern of preferences.

Figure 2-7. Percent of Phoenix participants who consider VAQ in each image "acceptable."



90% or more of the participants rated a VAQ of 20 dv or better as acceptable, and 70% rated a VAQ of 22 dv or better as acceptable. The "50% acceptable criteria" was met at approximately 24.3 dv (with 51.3% of the participants rating that image as acceptable). The percent acceptability declines rapidly as VAQ worsens; only 27% of the participants rated a 26 DV image as acceptable, and fewer than 10% rated a 29 dv image as acceptable.

The Phoenix urban visibility study formed the basis of the decision of the Phoenix Visibility Index Oversight Committee for a visibility index for the Phoenix metropolitan area (Arizona Department of Environmental Quality, 2003). The Phoenix Visibility Index establishes an indexed system with 5 categories of visibility conditions, ranging from "Excellent" (14 dv or less, which was a better VAQ than any of the images used in the Phoenix study) to "Very Poor" (29 dv or greater, which less than 10% of the study participants rated as acceptable). The "Good" range is 15 dv to 20 dv (more than 90% of the participants rated images in this VAQ range as acceptable). The environmental goal of the Phoenix urban visibility program is to achieve continued progress through 2018 by moving the number of days in poorer quality categories into better quality categories.

2.5 WASHINGTON, D.C.

One of the Washington, D.C. urban visibility pilot studies was conducted on behalf of EPA (Abt Associates Inc., 2001). It was designed to be a pilot focus group study, an initial developmental trial run of a larger study. The intent of the pilot study was to refine both focus group method design and potential survey questions. Due to funding limitations, only a single focus group session took place, consisting of one extended session with nine participants. No further urban visibility focus group sessions were held in Washington, DC, on behalf of EPA.

In March 2009, Dr. Anne Smith conducted a separate study of Washington urban visibility, using the same photographs and similar approach as the 2001 study (Smith and Howell, 2009). On behalf of the Utility Air Regulatory Group, Dr. Smith presented comments (Smith, 2009) to the CASAC at a public meeting held on April 2, 2009 to review EPA's plan (US EPA, 2009b) for conducting further urban visibility studies in support of PM NAAQS reviews. Dr. Smith submitted the Smith and Howell (2009) report to the CASAC as part of the public comment process. The Smith and Howell study conducted three study variations of a Washington, DC, preference study, including one experiment involving 26 participants designed to replicate the EPA 2001 preference study.

Both the Abt Associates Inc. (2001) study results and the results of the Smith and Howell (2009) study are discussed below.

2.5.1 Washington, D.C. 2001

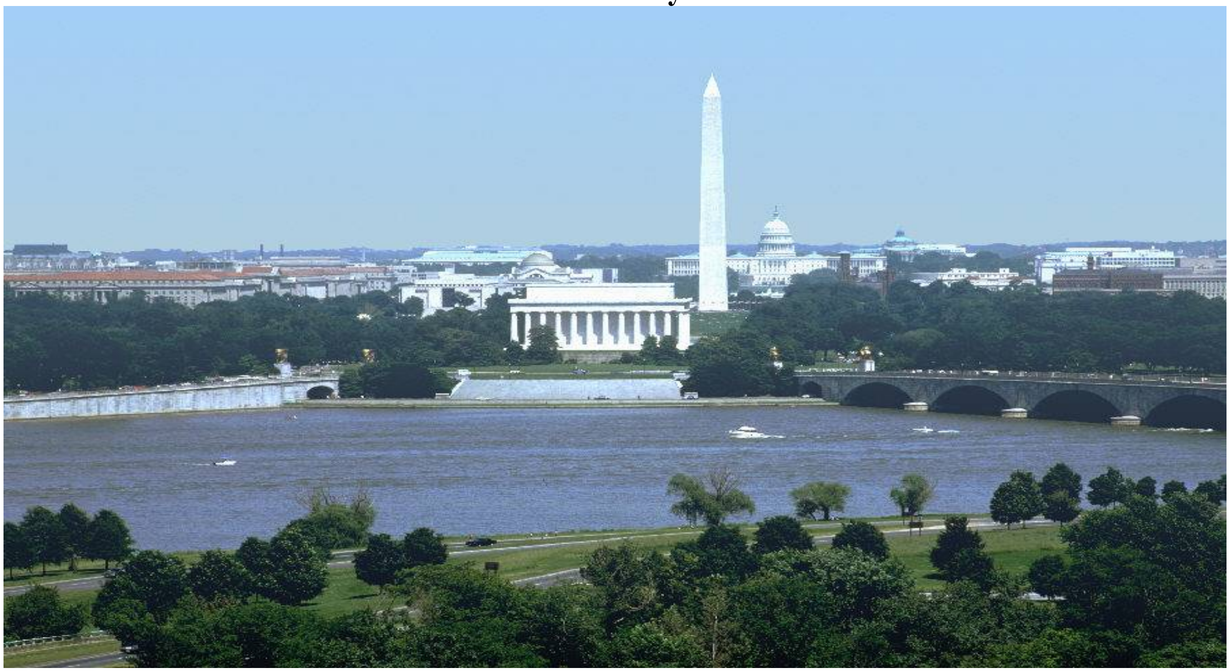
The EPA's Washington, D.C. study (Abt Associates Inc., 2001) adopted the general study methods used in the Denver, BC, and Phoenix studies, modifying them appropriately to be applicable in an eastern urban setting. Washington's (and the entire East's) current visibility conditions are typically substantially worse than western cities and have different characteristics. Washington's visibility impairment is primarily a uniform whitish haze dominated by sulfates, and the relative humidity levels are higher compared with the western study areas. In addition, the relatively low-lying terrain[8] in Washington, D.C., provides substantially shorter maximum sight distances. Many residents are not well informed that anthropogenic emissions impair visibility on hazy days.

The Washington, D.C. focus group session included questions on valuation, as well as on preferences. The focus group content dealing with preferences for an urban visibility standard was similar to the focus group sessions in the Denver, BC, and Phoenix studies.

A single scene of a panoramic photograph taken from Arlington National Cemetery in Virginia was used, and included an iconic view of the Potomac River, the National Mall, and downtown Washington, D.C. All of the distinct buildings in the scene are less than four miles from the camera, and the higher elevations in the background are less than 10 miles from the camera. Figure 2-8 presents the photograph used in the study.

[8]The maximum elevation in Washington, DC is 409 feet.

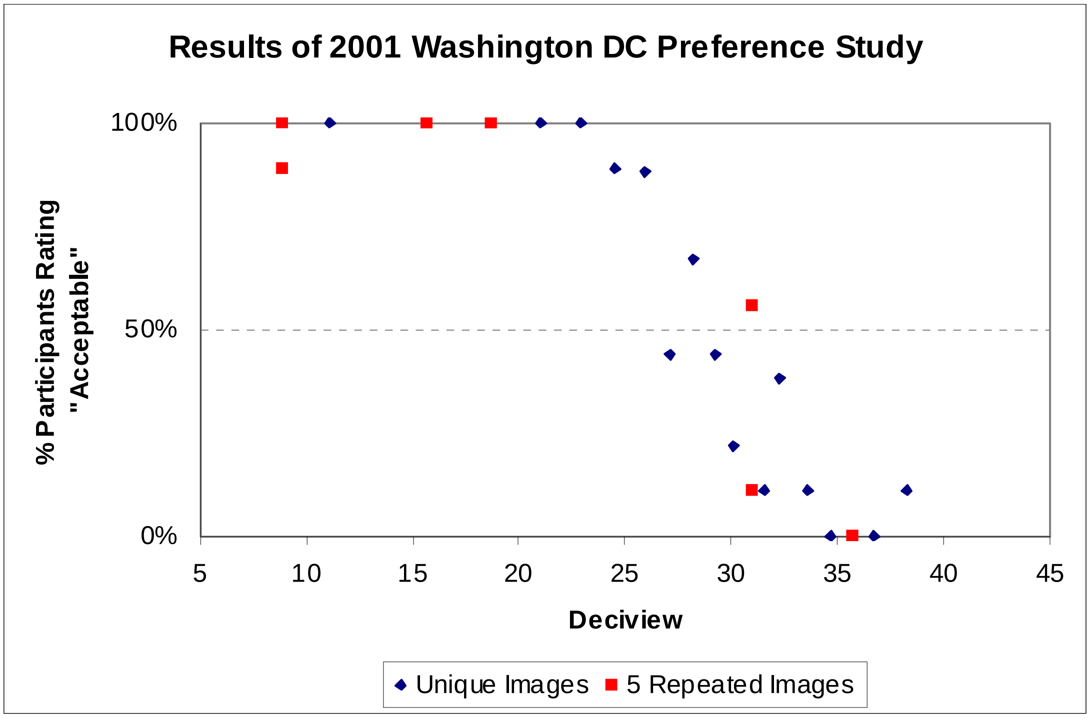
Figure 2-8. Reproduction of the image with the best VAQ (8.8 dv) used in the Washington, D.C. study.



The Washington, D.C. study used 20 unique images generated by WinHaze, each prepared from the same original photograph. Humidity and gaseous light scattering was held constant in preparing the WinHaze images, as was the relative chemical mix of aerosol particulates in the photos (i.e., only the aerosol concentrations were increased to create the images with worse VAQ). Five of the images were repeated as a consistency check, so participants viewed a total of 25 slides. The range of VAQ in the images ranged from 8.8 to 38.3 dv, which is approximately the 10^{th} to the 90^{th} percentile of the annual distribution of hourly VAQ conditions in Washington.

Figure 2-9 presents the percent acceptability results from the 2001 Washington study. Because only nine participants were involved in the study, the possible values of "percent acceptable" are limited to multiples of 1/9. Figure 2-9 also shows an anomalous result involving one of the five repeated images. Three of the repeat images had the same ranking each time they were presented (i.e., all nine participants rated them acceptable or not acceptable both times they rated that slide). One of the images (the image with 8.8 dv, the best VAQ image used in the study) was rated acceptable by all nine participants the first time it was used, but the repeat of that slide was rated not acceptable by one participant. Another image, however, had a substantially different result. The 30.9 dv image was rated acceptable by five of the nine participants the first time it was presented, but the repeat of the slide was only rated acceptable by one of the nine participants. The responses for all five pairs of repeated images are shown in red on Figure 2-9, including the images which were identically rated both times they were presented.

Figure 2-9. Percent of 2001 Washington participants who consider VAQ acceptable in each image.



In the 2001 Washington, D.C. study, all images with a VAQ below 25.9 dv were rated acceptable by the majority of the participants, and all images with a VAQ below 29.2 dv were rated acceptable by at least four of the nine (44%) participants. All images with a VAQ above 30.9 dv were rated not acceptable. The "50% acceptability criteria" division occurs in the range of 25.9 dv to 30.9 dv, with the anomalous result of the inconsistent responses to the repeated image with 30.9 dv effectively broadening this range and adding uncertainty to identifying a clear division.

2.5.2 Washington, D.C., 2009

The Smith and Howell (2009) study conducted additional focus group sessions based on the methods and materials used in the 2001 Washington, D.C. study. Smith and Howell recreated the WinHaze images used in the 2001 Washington, D.C. urban visibility preference study, using the description in the report on the 2001 study (Abt Associates Inc., 2001), and created images using currently available desktop computer version of WinHaze (Version 2.9.0). Smith and Howell used a shortened version of the same question protocol as the 2001 study. The WinHaze images were presented to a total of 64 participants who were all employees of Charles River Associates (CRA International, Inc). (Smith and Howell also are CRA International employees). The CRA employees were based at the firm's Washington, D.C. and Houston, Texas offices (44 and 20 participants, respectively). The Houston participants were included to explore whether familiarity with Washington, D.C. VAQ conditions developed from currently living in the Washington region noticeably influenced the responses. As noted by Smith and Howell, the participants were not a representative sample of either metropolitan area's population; all participants were employed, and the participant group included a higher proportion of college educated individuals and higher household incomes than the general population.

Eight of the Washington-based participants and all of the Houston participants viewed the WinHaze images on a desktop computer monitor. The remaining Washington participants viewed the images projected on a screen.

The stated purpose of the Smith and Howell study was to explore the robustness of the 2001 results. To investigate this issue, Smith and Howell conducted three different tests concerning urban visibility preferences. Each participant was involved with only one test. The three tests were:

- **Test 1** - replicated the Abt Associates Inc. (2001) study
- **Test 2** - reduced the upper end of the range of VAQ by eliminating the 11 images used in Test 1 with a VAQ above 27.1 dv
- **Test 3** - increased the upper end of the range of VAQ by including two new images of worse VAQ; the two new images had a VAQ of 42 dv and 45 dv

Sixteen employees from the Washington, D.C. office and 10 participants from the Houston office took Test 1 (a total of 26 participants). All the participants viewed the same unique 20 Washington, DC WinHaze images as the 2001 study (plus repeated images for a total of 25 images shown to participants). Images were presented in the same random order as in the 2001 study. Figure 2-10 presents the results of Test 1. The results for the 16 Washington participants are indicated in blue and results for the 10 Houston participants in red. Although all images used in the study were of Washington, D.C., the results suggest that there is not a significant difference in the preferences of participants based in the two offices. The scene in the images is an immediately recognizable iconic view of the National Mall and downtown Washington, D.C., which may influence the similarity of responses by residents of the two cities.

Using the combined Test 1 results from the two CRA offices (26 total participants), the majority of participants in the 2009 study rated all VAQ images with 25.9 dv or less as acceptable and all VAQ images with 29.2 dv or greater as not acceptable. The image of 27.1 dv was rated as acceptable by 50% of the total participants (56% of the Washington-based and 40%

of the Houston-based participants). All images with a VAQ less than 22.9 dv were rated acceptable by at least 90% of the participants, and all images with a VAQ greater than 32.3 dv were rated not acceptable by 88% of the participants.

Figure 2-10. Percent of 2009 Test 1 study participants who consider VAQ acceptable in each image, showing the range of the lower and upper bound of 50% acceptability criteria.

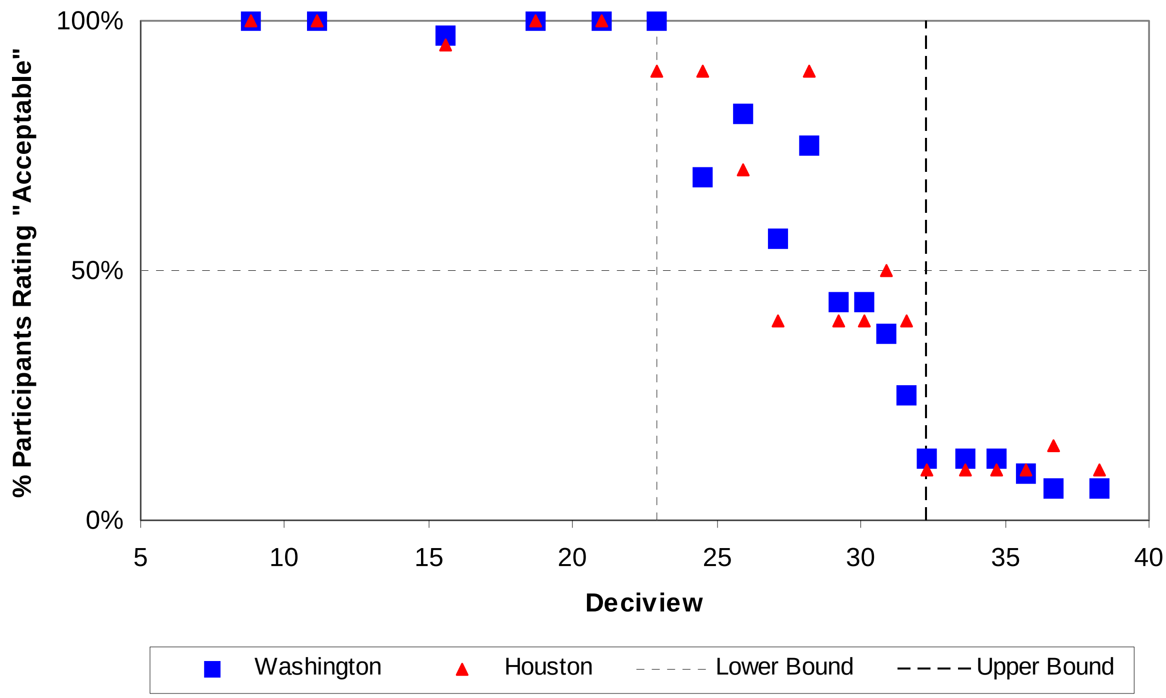


Figure 2-11 presents the 2001 and 2009 study (Test 1) results on a single graph, representing the results of 35 total participants of preferences for urban visibility in Washington, DC. The results from the 2009 study on Figure 2-11 combine the Test 1 responses from the two CRA offices. Figure 2-11 also shows the 50% acceptability criteria range (22.9 dv to 32.3 dv) from the 2009 study, Test 1. In comparison, the 2001 study 50% acceptability range was 25.9 dv to 30.9 dv. Inspection of the points in Figure 2-11 indicate that the results from the 2009 study (Test 1) are not appreciably different than the results of the 2001 Washington study.

In Test 2, Smith and Howell reduced the range of VAQ images presented to 26 participants to images with a VAQ of 27.1 dv or less. The 26 participants were different people than the Test 1 participants. Test 2 presented only the nine unique clearest WinHaze images from the full Test 1 set of 20 images. This constricted the VAQ levels presented to the range that the majority of participants in the 2001 study rated as acceptable and reduced the upper end of

Figure 2-11. Combined results of two Washington preference studies (showing 50% acceptability criteria from 2009, Test 1).

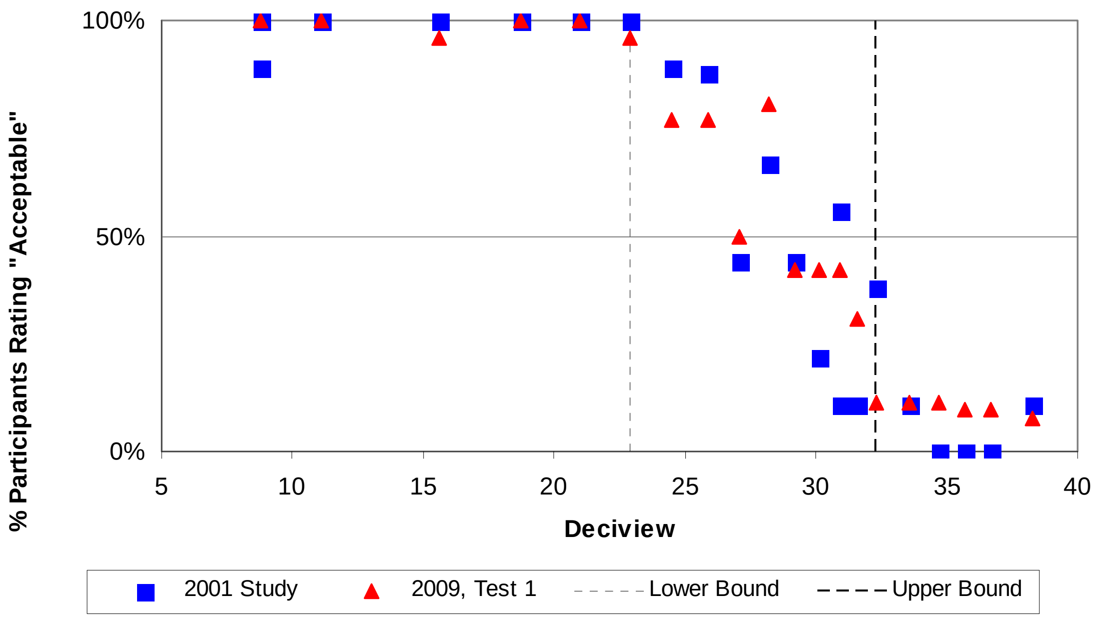
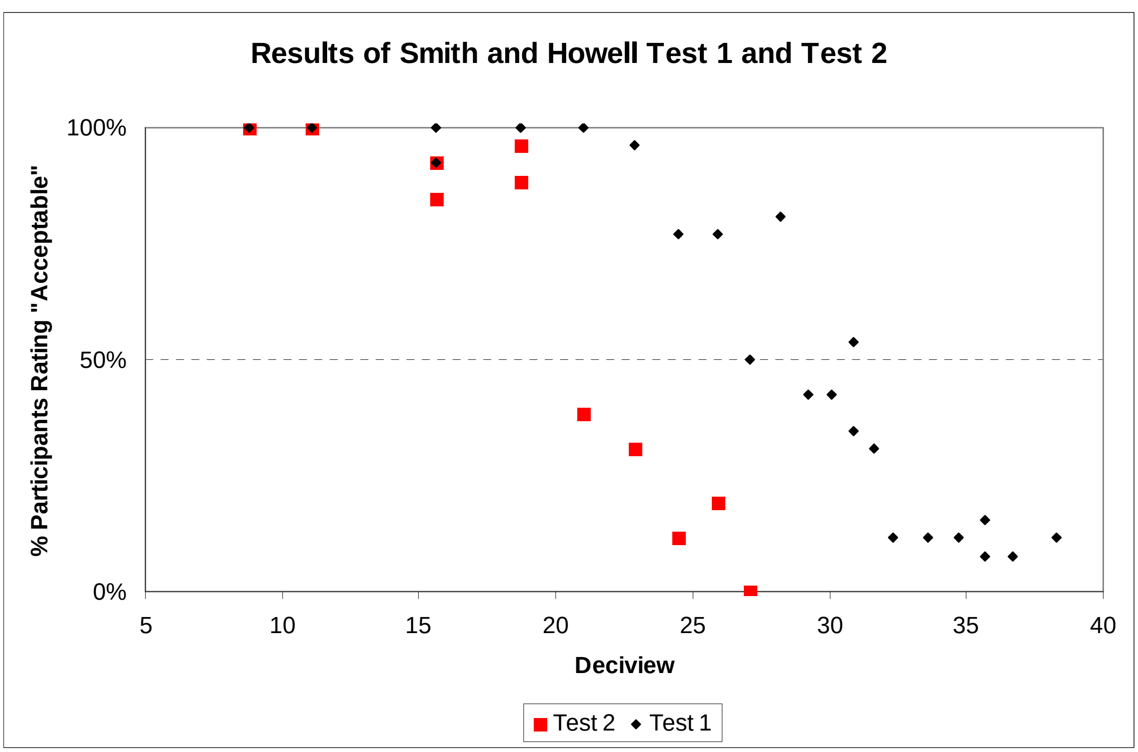


Figure 2-12. Comparison of results from Test 1 and Test 2 (Smith and Howell, 2009).



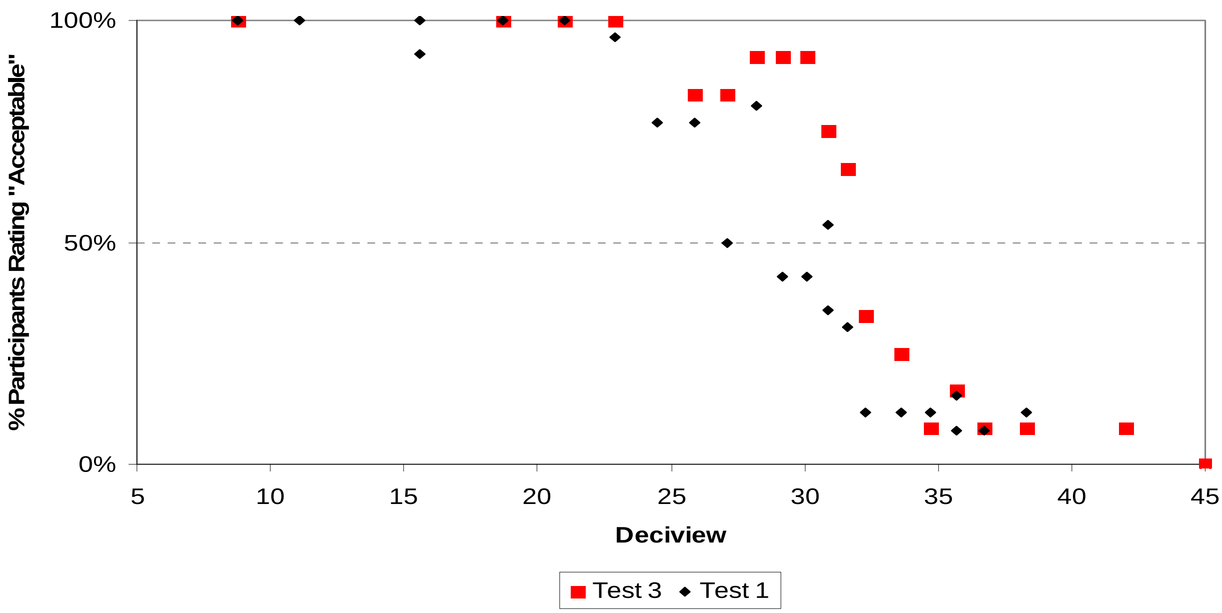
the VAQ range by 11.2 dv. Nine unique WinHaze images were used in Test 2, with three duplicates included, so Test 2 participants were shown 12 images. Figure 2-12 presents the Test 1 and Test 2 results. Test 2 found a substantial shift in the responses about which VAQ level is considered acceptable. The smaller number of images used in Test 2 makes identifying the range of the 50% acceptability criteria more difficult than in Test 1. The lower bound of the range occurs between 15.6 and 18.7 dv, and the upper bound occurs between 24.5 and 27.1 dv. Smith and Howell conclude that the shift in the acceptability responses between Test 1 and Test 2 suggests that the acceptable responses in an urban visibility preference study conducted using the general approach used in the all the studies may be susceptible to the range of VAQ images presented.

One hypothesis (not raised by Smith and Howell) suggested by the Test 2 results is that the 50% acceptability criteria occurs near the middle of the range of images shown to participants. This might be the result of the participants consciously or subconsciously identifying approximately the middle of the VAQ range presented to them. Participants (in all the studies reviewed in this paper) were shown all the images as part of "warm up" exercises and a separate initial rating exercise (ranking the VAQ in each image on a scale of 1 to 7). These initial reviews of the images allow participants to become familiar with the range of VAQ and may consciously or subconsciously calibrate their subsequent responses to the VAQ range they were presented.

In Test 3, Smith and Howell expanded the VAQ range of WinHaze images shown to the participants, including two new images with a worse VAQ. The new images had a VAQ of 42 dv and 45 dv, raising the upper end of the VAQ range by 6.7 dv. Test 3 reduced the total number of images shown to participants to 19 images by eliminating the use of the five repeat images in Test 1, and also eliminated three additional images in order to reduce the participants' time burden. The three deleted images had a VAQ of 11.1, 15.6, and 24.5 dv. The best VAQ image shown to Test 3 participants was 8.8 dv (same as the best VAQ image in Tests 1 and 2). However, in Test 3 there were no images with VAQ between 8.8 dv and 18.7 dv, creating a significant "hole" in the distribution of VAQ conditions presented to the Test 3 participants. Test 3 was conducted with 12 participants from the CRA Washington office (none of whom participated in Test 1 or Test 2). No Houston participants were involved with Test 3. The results of Test 3 are shown in Figure 2-13, along with the results of Test 1.

Increasing the upper end of the VAQ range in Test 3 resulted in an overall increase in the percent of respondents rating as acceptable the VAQ images used in both tests. In Test 3 all images with a VAQ below 22.9 dv were rated acceptable by 100% of the participants (similar to the Test 1 results), implying there was no general change in the acceptability of the images with good VAQ. However, for all VAQ images (that were used in both studies) between 25.9 dv and

Figure 2-13. Comparison of results from the Smith and Howell (2009) Test 1 and Test 3.



33.6 dv, a noticeably larger percentage of the participants in Test 3 rated the image as acceptable than in Test 1. At VAQ levels worse than 33.6 dv, the majority of the participants found the VAQ level not acceptable in both tests.

While not as dramatic as the impact in Test 2 (which substantially reduced the VAQ range), the impact on the Test 3 results of increasing the VAQ range is consistent with Smith and Howell's conclusion that changing the range of VAQ presented to the participants affects the responses about whether a particular VAQ is acceptable. The results of Test 3 also are consistent with the hypothesis that the "dividing line" for the 50% criteria occurs near the middle of the range of VAQ presented, and that changing the range of VAQ images changes the 50% criteria "dividing line," with the "dividing line" remaining in roughly the middle of the VAQ range.

The VAQ ranges that Smith and Howell used in Tests 2 and 3 did not span the range of actual VAQ conditions that occur in Washington, DC, and Smith and Howell provided no information about the range of actual conditions in Washington in any of their tests. The images used in the 2001 Washington, DC study (and Test 1) were deliberately selected to present the range of VAQ conditions in Washington, DC. In the 2001 study, participants were shown an image of annual average VAQ in Washington at the time, as well as an image of conditions on a hazy day (the 20th percentile day in the annual distribution). The Denver, Phoenix, and BC studies also provided participants with information that the range of VAQ conditions they would be seeing included the actual annual range of VAQ conditions in their city. It is not known whether the participants in the Smith and Howell Tests 2 and 3 recognized (based on their own knowledge and experience) that the range of VAQ images presented did not represent the actual annual range, or if they believed the range did depict the annual distribution.

2.6 SUMMARY OF PREFERENCE STUDIES AND SELECTION OF CANDIDATE PROTECTION LEVELS

Each of the studies reviewed in this assessment investigates the common question, "What level of visibility degradation is acceptable?" The approaches used in the four studies are similar and are all derived from the method first developed for the Denver urban visibility study. The specific materials and methods used in each study vary, however, making direct comparison of the study results challenging. Key differences between the studies include:

- use of WinHaze (a significant technical advance in the method of presenting VAQ conditions),
- number of participants in each study,
- representativeness of participants for the general population of the relevant metropolitan area, and
- specific wording used to frame the questions used in the group interview process.

Although the differences between the methods used in the urban visibility preference studies are significant, it is possible to examine the results of the studies to identify overall trends in the study findings. Figure 2-14 present a graphical summary of the results of the studies in the four cities. Figure 2-14 draws on results previously presented in Figures 2-3, 2-5, 2-7 and 2-11. For clarity in Figure 2-14, the Denver results omit the 9:00 a.m. photograph results, the Chilliwack and Abbotsford photographs appear as a single set of data for the BC study, and the results from 2001 and 2009 (Test 1) studies of VAQ preferences in Washington, D.C. are presented as a single combined set of data. The results from the 2009 Washington, D.C. study Tests 2 and 3 are not included on Figure 2-14; those tests are not comparable studies because they did not present the actual range of VAQ conditions in the study city.

Figure 2-14 also contains lines at 20dv and 30 dv that effectively and pragmatically identifies a range where the 50% acceptance criteria occurs across all four of the urban preference studies. Out of the 114 data points shown in Figure 2-14, only one photograph (or image) with a VAQ below 20 dv was rated as acceptable by less than 50% of the participants who rated that photograph.[9] Similarly, only one image with a VAQ above 30 dv was rated acceptable by more than 50% of the participants who viewed it.[10]

Figure 2-14. Summary of results of urban visibility studies in four North American cities, showing the identified range of the 50% acceptance criteria.

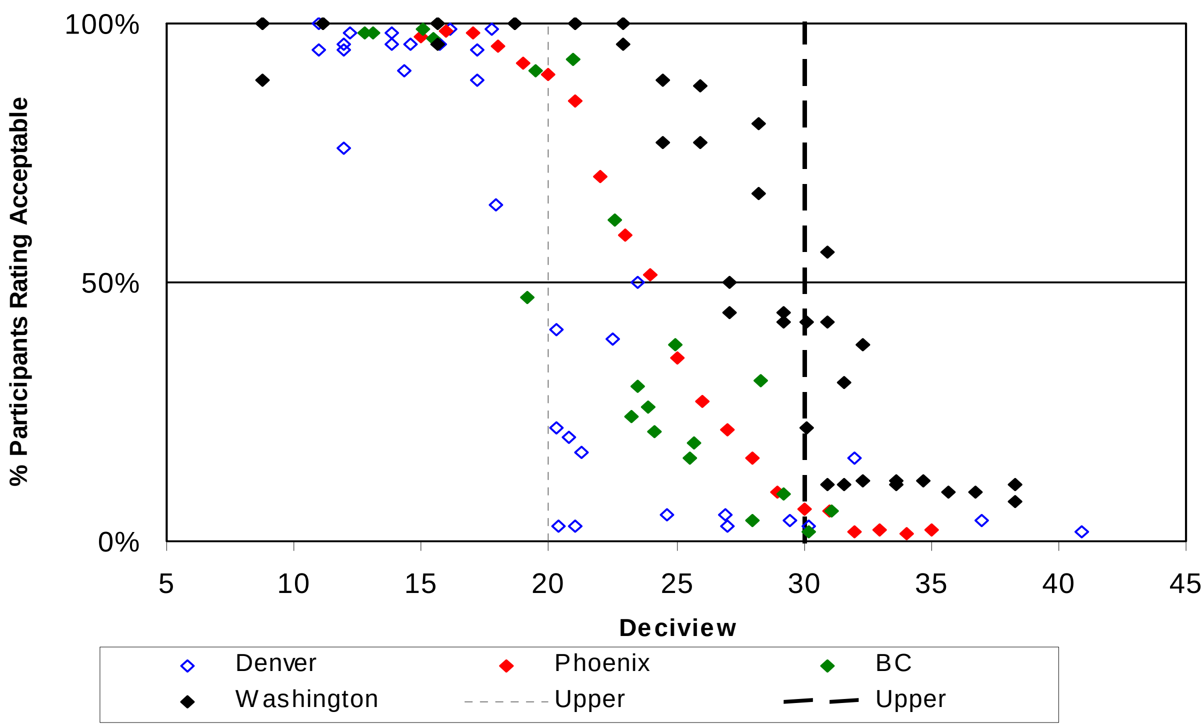


Figure 2-14 shows that while there is a high degree of similarity between the preferences found in each study, there may be important differences in VAQ preferences in the four cities as well. For example, the Denver study identified preferences for a relatively good level of VAQ; the 50% criteria occur between 17.7 dv and 20.3 dv. In Washington, D.C., however, the 50% criteria separation occurs at a substantially worse level of VAQ, between 27 dv and 31 dv.

There are several major hypotheses that may explain why the results of these studies may be indicating potentially important differences between the preferences for VAQ in different cities. As mentioned, the use of photographs versus WinHaze-generated images may play a significant role in preference studies, perhaps introducing bias (such as suggested by the

[9] Only 47% of the BC participants rated a 19.2 dv photograph as acceptable.

[10] In the 2001 Washington, D.C. study, a 30.9 dv image was used as a repeated slide. The first time it was shown 56% of the participants rated it as acceptable, and 11% rated it as acceptable the second time it was shown. The same VAQ level was rated as acceptable by 42% of the participants in the 2009 study (Test 1).

responses to the 9:00 a.m. Denver photographs) as well as variability. Use of photographs from different days and times of day that rely on associated ambient measurements of light extinction to characterize their VAQ level introduces two types of uncertainty. The intrinsic appearance of the scene can change due to the changing shadow pattern and cloud conditions, and spatial variations in air quality can result in ambient light extinction measurements not being representative of the sight-path-averaged light extinction. WinHaze has neither of these sources of uncertainty because the same base photograph is used (i.e. no intrinsic change in scene appearance) and the modeled haze that is displayed in the photograph is determined based on uniform light extinction throughout the scene.

Second, variation in the degree of representativeness of the participants and the sizes of the participant samples involved may also be important factors. The small sample size and fairly uniform population of respondents is a plausible explanation for the noisiness of the combined Washington, D.C. results (35 participants, including 26 from a single consulting firm and 10 of those from a different city) compared with the larger and more representative population of responders from Phoenix (385 participants, carefully selected to be representative of the Phoenix population).

A third hypothesis explored by Smith and Howell (2009) is that the range of VAQ images presented in the survey may influence the results. Though this hypothesis appears to be borne out by Smith and Howell's results for Washington, D.C., it seems an unlikely explanation for the differences in results between the four urban preference studies. For example the Denver study included photographs with the haziest conditions among the four studies, but resulted in the lowest haze condition for the 50th percentile preference ratings among the four, not the highest as might be expected if the range of haze levels were a significant factor influencing the results of preference studies.

A fourth major hypothesis is that urban visibility preferences may differ by location, and the differences may arise from inherent differences in the cityscape scene used in each city. The key evidence to suggest this hypothesis is that the apparent differences between the Denver results (which found the 50% acceptance criteria occurred in the best VAQ levels among the four cities) and the Washington, D.C. results (which found the 50% acceptance criteria occurred at the worst VAQ levels among the four cities). This hypothesis suggests that these results may occur because the cityscape of Denver includes clearly visible snow-covered mountains in the distance, while the prominent features of the Washington, D.C. cityscape are buildings relatively nearby with only modest changes in elevation.

Finally, perhaps of significant importance is that the perceived sensitivity of individual scenes to changes in light extinction can be quite different. As in the fourth hypothesis, this may in part explain why the Denver study scene, with its long distance to the mountain backdrop, resulted a preference for the best VAQ level with a 50% criteria value between 17.7 and 20.3 dv, while in Washington, D.C., the 50% criteria separation occurs at a substantially worse level of VAQ, between 27 and 31 dv from Abt Associates Inc. (2001) and Smith and Howell (2009) Test 1. The distinction between the last two hypotheses are that the earlier one speaks to the desirability of seeing distant mountains versus this hypothesis where its ability to perceive haze at lower light extinction levels. Additional studies, including directly comparable studies using similar methods in diverse cities, are necessary to gain further understanding of preferences for urban visibility.

Based on the composite results and the effective range of 50th percentile acceptability across the four urban preference studies shown in Figure 2-14, CPLs have been selected in a range from 20 dv to 30 dv (74 Mm^{-1} to 201 Mm^{-1}) for the purpose of comparing to current and projected conditions in the assessment in chapters 3 and 4 of this document. A midpoint of 25 dv (122 Mm^{-1}) was also selected for use in the assessment. These three values provide a low, middle, and high set of light extinction conditions that are used in subsequent sections of the UFVA to provisionally define daylight hours with urban haze conditions that have been judged unacceptable by the participants of these preference studies.

Though not directly supported by preference or other studies, it is necessary to also identify an averaging time and form to apply along with the CPLs in the assessments described in chapters 3 and 4. For this assessment only daylight hour visibility is being considered. VAQ impacts are instantaneously perceived, suggesting that a short averaging time (e.g. an hour) may be more appropriate than longer time periods (e.g. multiple hours). This is also consistent with the belief that most individuals experience urban VAQ as relatively short-term incidental and intermittent opportunities to be outdoors (e.g. during commutes to work, school, shopping, etc.). Given that some fraction of the public may experience poor VAQ during a relatively small time period and not have the opportunity to see it improve later during the same day, it seems appropriate by EPA staff to consider assessing the current and projected conditions in chapters 3 and 4 by comparing the 1-hour daily maximum light extinction to each of the three CPLs supported by the preference studies. Another characteristic that needs to be set for the assessment is the frequency of conditions that should be at or below the CPLs to be considered acceptable. Again, none of the preference studies provided insight into this aspect of acceptability. Because the nature of the public welfare effect is one of aesthetics and/or on feelings of wellbeing and not directly related to a physical health outcome, EPA staff believes that it is not necessary to eliminate all such exposures and that some number of hours/days with poor VAQ can reasonably be tolerated. EPA staff is therefore considering the 90th and 95th percentiles per year averaged over a three year period as a reasonable range of frequencies for meeting the range of PM light extinction CPLs and has incorporated them in this assessment.

3 ESTIMATION OF CURRENT PM CONCENTRATIONS AND LIGHT EXTINCTION

The goals of the "current conditions" portion of this urban-focused visibility impact assessment are to characterize hourly light extinction conditions in a set of urban study areas in 2005-2007, in order (1) to improve understanding of the levels, patterns, and causes of daylight hours light extinction given that essentially no direct measurements are available to inform that understanding, (2) to provide the starting point for projections of light extinction levels under "what if" scenarios in each of which it is assumed that each study area complies with a certain secondary NAAQS based either on a measurement-based light extinction indicator or on annual and 24-hour average $PM_{2.5}$, and (3) to examine the correlation between light extinction and potential alternative indicator(s) based on $PM_{2.5}$ concentration. This chapter addresses the first goal. Chapter 4 addresses the second goal regarding "what if" scenarios. Appendix D addresses the third goal.

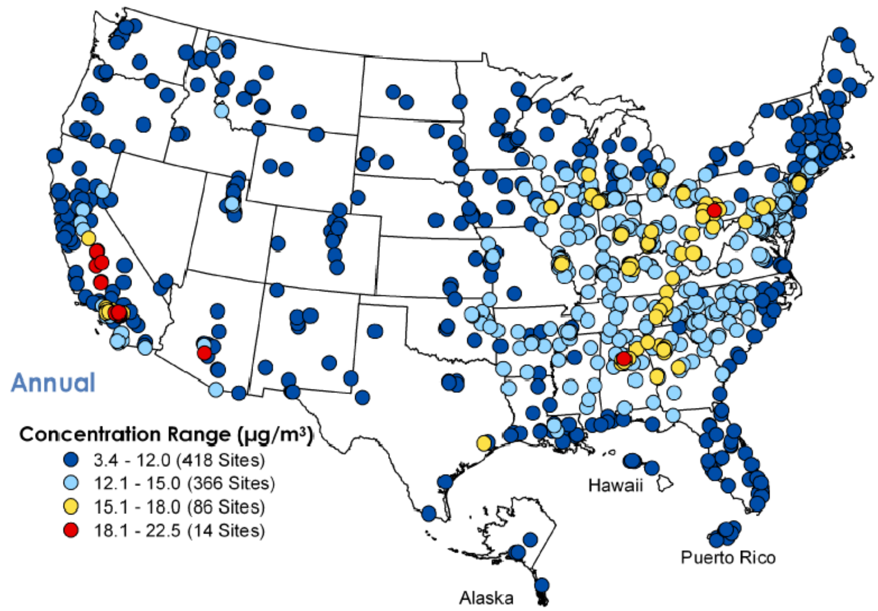
3.1 GENERAL CHARACTERIZATION

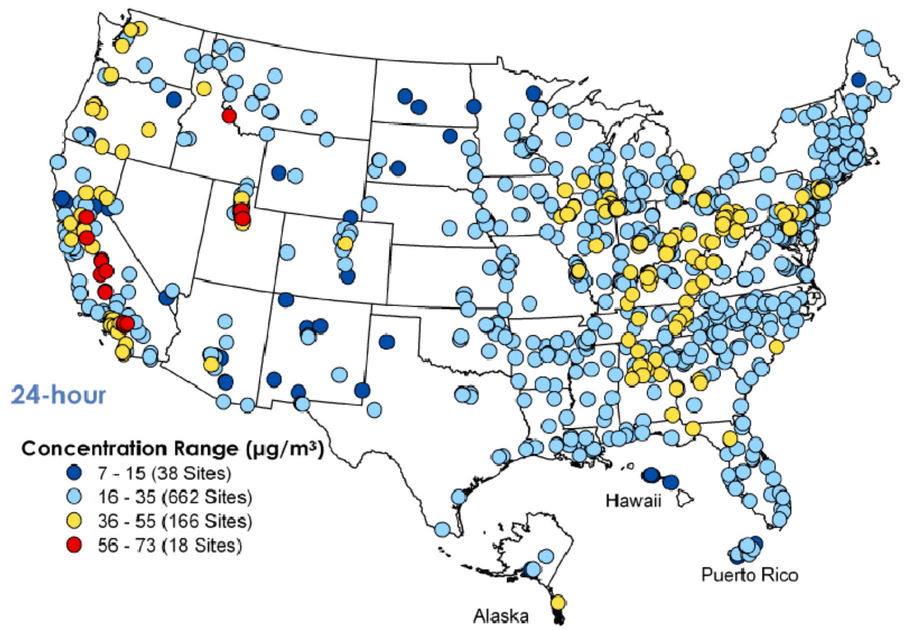
3.1.1 $PM_{2.5}$ and $PM_{10-2.5}$

Chapter 2 of the 2005 Staff Paper from the previous review and chapters 3 (especially section 3.5) and 9 (especially section 9.2.3) and Annex A of the second draft ISA (US EPA, 2009a) from the current review present extensive characterizations of the levels, composition, and temporal and spatial patterns of $PM_{2.5}$ in U.S. urban areas. Both documents present data summaries based on the approximately 1000 $PM_{2.5}$ monitoring sites in the U.S. The characterizations in the 2005 Staff Paper were based on 2001-2003 data. The characterizations in the ISA are based on 2005-2007 data, which is the same time period used in this visibility assessment. While there generally have been reductions in the concentrations of $PM_{2.5}$ in many areas as a result of emission reductions of $PM_{2.5}$ and its precursors, the general patterns, and the diversity of patterns across areas, noted in the 2005 Staff Paper still prevailed in the 2005-2007 period.

In 2005-2007, 38 urban areas violated the annual $PM_{2.5}$ NAAQS of 15 $\mu g/m^3$, adopted in 1997 and retained in the last review completed in 2006. Seventy-six areas violated the revised 24-hour NAAQS of 35 $\mu g/m^3$. There is considerable but not complete overlap in the areas not meeting the two NAAQS. It should be noted that in many parts of the U.S., $PM_{2.5}$ concentrations in 2005 were high relative to the next three years. Figure 3-1 illustrates $PM_{2.5}$ air quality in 2007 by representing each monitor by a symbol whose color reflects the annual mean of the concentration at that site or the 98th percentile 24-hour concentration, in both cases in that one year.

Figure 3-1. Annual average and 24-hour (98th percentile 24-hour concentrations) $PM_{2.5}$ concentrations in $\mu g/m^3$, 2007.





Each urban area exhibits its own detailed patterns of observed concentration levels, temporal and spatial variation, and composition. These differences are due to differences in local and transported emissions and in meteorology. Because of differences in the placement of $PM_{2.5}$ monitoring sites in each urban area, the actual levels and spatial pattern of $PM_{2.5}$ and $PM_{2.5}$ species concentrations may not be consistently discernable in all areas. This variability and limited monitoring network make it difficult to offer concise generalizations, although some broad similarities can be drawn among areas.

Midwestern, southeastern, and eastern urban areas have much higher sulfate levels than do more western areas, attributable to the much higher emissions of SO_2 in and upwind of them. Upper midwestern areas and to a lesser extent upper eastern areas have notable nitrate concentrations in winter but not in summer, while southeastern areas generally lack notable nitrate even in winter. Many western urban areas have notable nitrate year round. In all areas, carbonaceous material is an important component of $PM_{2.5}$ and is attributable to many emission sources of organic material in PM form and of organic PM precursor gases; in some areas with high local use of wood for residential heating carbonaceous material is dominant during the heating season. $PM_{2.5}$ derived from crustal sources is generally a small faction of total mass, except during local high wind events or due to brief periods of intercontinental transport of dust from Africa or Asia.

Comparison of $PM_{2.5}$ species concentrations within and outside urban areas leads to the conclusion that, in the eastern areas with high sulfate concentrations, the large majority of the sulfate affecting any given urban area originates outside that area. Inward transport and local generation of nitrate and carbonaceous material are more evenly balanced in eastern areas, with some differences among areas. In western areas, local sources dominate for carbonaceous material and nitrate, with the origins of the small sulfate component being more balanced. See Figure 9-24 of the second draft ISA (US EPA, 2009a).

Southeastern areas have their highest $PM_{2.5}$ concentrations in the summer, when conditions are most conducive to sulfate formation. More northern areas, being affected by a more balanced mix of contributors, tend not to have such a strongly seasonal pattern. The seasonal patterns in western areas are individual and varied, related to differences in local sources and formation and dispersion conditions. In all areas, inversion conditions with low wind speeds are conducive to high concentrations due to the trapping of emissions from local sources. Some western areas, especially those with valley or bowl-like topography, are especially affected.

There is at present no systematic monitoring network in place for $PM_{10-2.5}$, as states have until January 1, 2011, to implement required monitoring sites for $PM_{10-2.5}$. Consequently, estimates of $PM_{10-2.5}$ must be developed using data from $PM_{2.5}$ and PM_{10} monitoring sites and equipment, which are not always collocated and consistent. The 2005 Staff Paper presented such estimates in section 2.4.3. The second draft ISA presents such estimates in Figure 3-10 and Table 3-9 of section 3.5.1.1. The 2005 Staff Paper used a data-inclusive approach in which the best available data on $PM_{2.5}$ and PM_{10} concentrations – in some cases not very robust data – were used to estimate 2001-2003 $PM_{10-2.5}$ concentrations for 351 metropolitan area counties. For these counties, the annual mean $PM_{10-2.5}$ concentrations were generally estimated to be below 40 $\mu g/m^3$, with one maximum value as high as 64 $\mu g/m^3$ and a median of about 10-11 $\mu g/m^3$. The second draft ISA used a much more data-restrictive approach based only on paired (collocated) low-volume filter-based samplers for both PM_{10} and $PM_{2.5}$, the most accurate method of measuring $PM_{10-2.5}$. The second draft ISA reports that only 40 counties have such paired samplers. Using these available co-located PM measurements from 2005-2007, the mean 24-hr $PM_{10-2.5}$ concentration in these 40 counties was 13 $\mu g/m^3$. This urban visibility assessment has used a data-inclusive approach to estimating $PM_{10-2.5}$ concentrations, similar to that used for the 2005 Staff Paper, where needed to obtain hourly $PM_{10-2.5}$ estimates for 15 study areas, which are reported below in section 3.3.2.

Additional detail on $PM_{2.5}$, PM_{10}, and $PM_{10-2.5}$ concentrations, composition, and patterns appears in section 3.5.1.1 of the second draft ISA. Also, chapter 6 of the 2004 PM Assessment by NARSTO contains more detailed characterizations of PM in different parts of the U.S.

3.1.2 Light extinction

While light extinction is directly measurable, there are very few regularly operating monitoring sites measuring light extinction in urban areas, and generally those that do operate do not submit data to AQS.[11] Consequently, any characterization of light extinction conditions based on actual measurements is necessarily less comprehensive than for $PM_{2.5}$ and $PM_{10-2.5}$. Many monitoring sites that employ nephelometers, which do measure light scattering, operate that equipment in a heated mode for purposes of tracking "dry" $PM_{2.5}$ mass concentrations, and actual ambient light extinction is not reportable. There are many more filter-based Aethalometers® and similar instruments for measuring light absorption in operation and reporting to AQS, but light absorption is typically a small fraction of total light extinction, so these data alone are not a good indicator of light extinction in urban areas. Also, there are unresolved issues of data corrections and comparability for the light absorption data from these instruments now residing in AQS.

[11] There is a large network of "visual range" monitors in operation at U.S. airports, aimed at providing information to determine landing and takeoff safety. Due to their locations and to the lack of data resolution (values of visual range above the level needed for unlimited airport operations are not individually reported) the data from these monitors are not suitable for use in this assessment. The second draft ISA discusses these monitors in section 9.2.2.3.

Light extinction can be "reconstructed" from measurements of $PM_{2.5}$ mass components and $PM_{10-2.5}$ concentrations, along with relative humidity, using the formula known as the IMPROVE algorithm. (Section 9.2.2.2 of the second draft ISA gives an overview of the algorithm and its basis.) $PM_{2.5}$ component measurements are generally available only on a 24-hour average basis, so it generally is possible to estimate only 24-hour average light extinction, unless additional information on hourly patterns is brought to bear.[12] Because EPA's Regional Haze Rule (RHR) currently requires states to address visibility problems in Class I visibility protection areas, which are nearly all rural and remote, there is a large body of literature characterizing light extinction in remote rural areas, based on data from the IMPROVE network's 24-hour samplers and on special studies. Sections 9.2.3.2 and 9.2.3.4 of the second draft ISA summarizes this literature. Section 9.2.3.3 of the ISA contrasts concentrations of PM and PM components between rural and urban areas using data from the rural IMPROVE network and the urban Chemical Speciation Network (CSN), but does not present estimates of light extinction in urban areas.

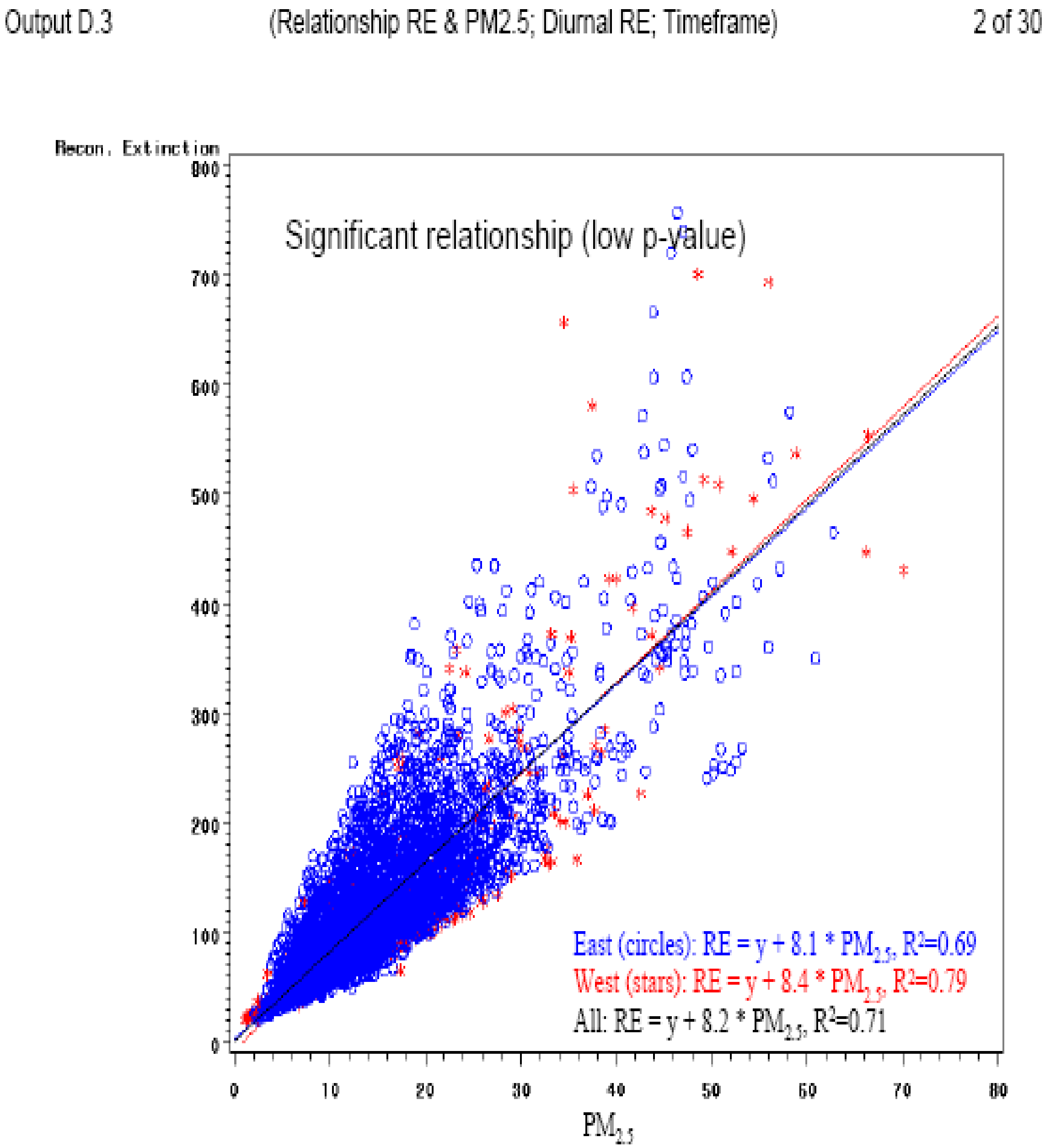
The CSN network provides 24-hour $PM_{2.5}$ species measurements at about 200 urban sites, from which mass components can be derived. These sites have a mix of daily, one day in three, and one day in six sampling schedules. The 2005 Staff Paper (and its references) may be the only readily available prior assessment to use these urban $PM_{2.5}$ speciation monitoring data, along with estimates of $PM_{10-2.5}$ concentrations and data on relative humidity, to reconstruct daily 24-hour average light extinction in urban areas, for the year 2003. One presentation of the results was in the form of a scatter plot of daily 24-hour reconstructed light extinction versus 24-hour $PM_{2.5}$ concentration. This graphic appears here as Figure 3-2. (For the immediate purpose of this section, it is the distribution of the data points along the y-axis that is of interest, not the relationship between light extinction and $PM_{2.5}$ concentrations; the latter subject is addressed in Appendix D.) Generally, most days have light extinction below 200 inverse megameters (Mm^{-1}), but a small percentage of values were as high as about 750 Mm^{-1}.[13]

In addition to this scatter plot, a table developed for the previous PM NAAQS review presented the annual average of estimates of 24-hour reconstructed light extinction values, averaged across 161 urban areas grouped into seven regions (Schmidt, et al., 2005). Table 3-1 reproduces these estimates. For regions excluding Southern California, annual average 24-hour light extinction

[12] When the IMPROVE algorithm is used to estimate 24-hour light extinction from 24-hour $PM_{2.5}$ species and $PM_{10-2.5}$ concentrations, an assumption is made that every hour has the same PM concentrations but its own relative humidity value. Hourly estimates of light extinction, including the strongly non-linear effect of relative humidity, are then averaged to get the 24-hour light extinction estimate.
[13] Unfortunately, the file of paired data used to create this scatter plot is no longer available, so the actual distribution of light extinction values cannot be described more specifically.

Figure 3-2. Reconstructed 24-hour light extinction in U.S. urban areas in 2003

Source: Schmidt et al., 2005

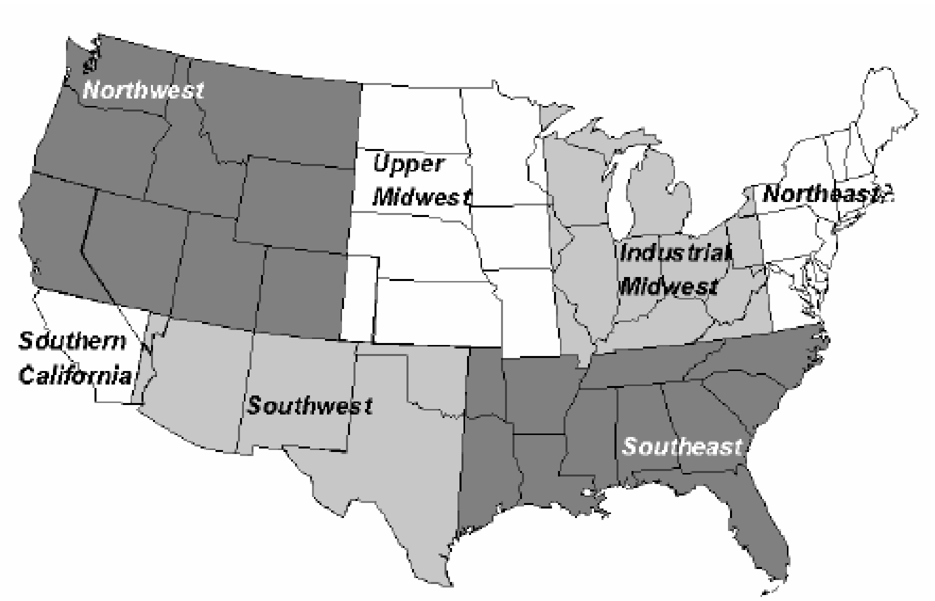


Relationship between reconstructed light extinction (RE) and 24-hour average $PM_{2.5}$, 2003. Using actual *f(RH)*

ranged from 73 to 118 Mm^{-1}. The estimate of the annual average 24-hour light extinction for Southern California was 168 Mm^{-1}. These estimates were based on 10-year average 1-hour relative humidity values and 2003 PM monitoring data.

Table 3-1. Annual Mean Reconstructed 24-hour Light Extinction Estimates by Region (Mm^{-1})

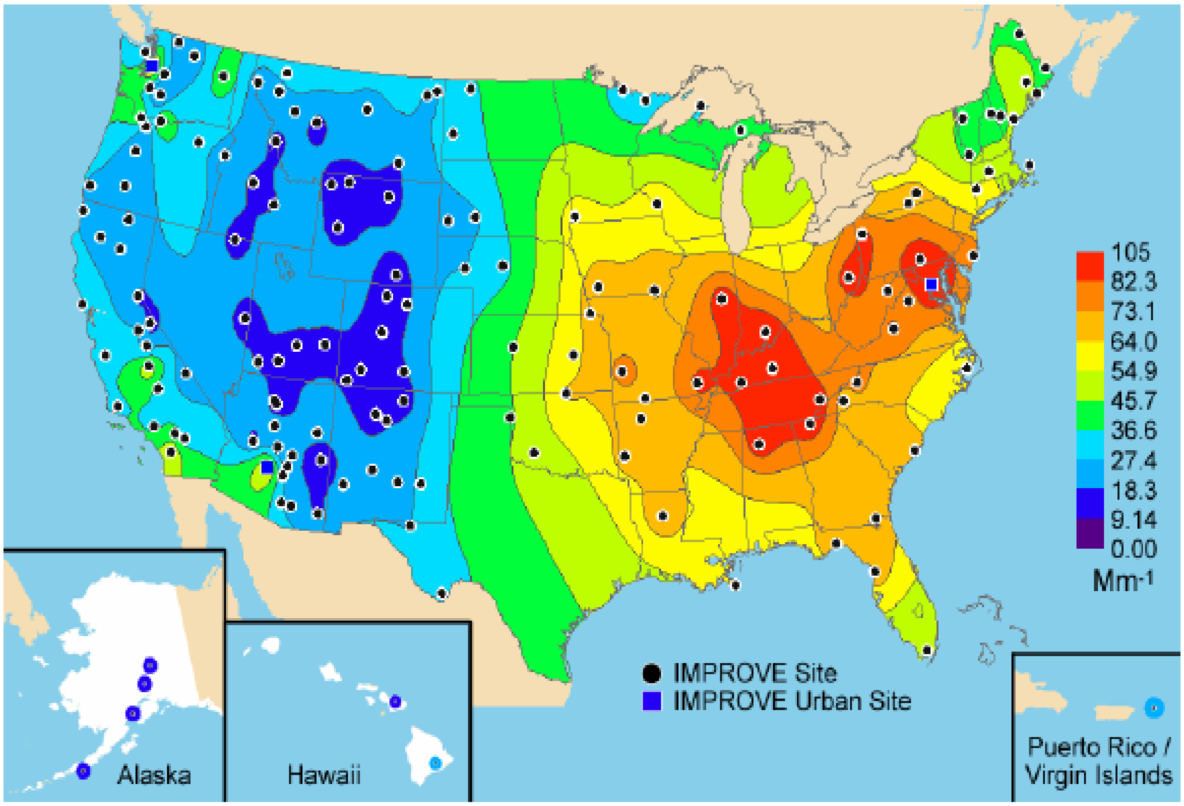
Region	Reconstructed 24-hour Light Extinction in 2003
Northeast	108
Southeast	98
Industrial Midwest	118
Upper Midwest	80
Southwest	73
Northwest	76
Southern California	168



Source: Output D.3, Schmidt et al., 2005. We note these regions were used to summarize $PM_{2.5}$ patterns for the PM NAAQS review 1997 (US EPA, 1996).

Figure 3-3 is a contour map of annual average reconstructed 24-hour light extinction based on IMPROVE monitoring sites in 2000-2004, nearly all of which are remote and rural (the three urban sites in Phoenix, AZ, Washington, D.C., and Puget Sound, WA are indicated by square symbols). Comparing the mean urban light extinction levels by region listed in Table 3-1, estimated based on CSN data, with this map of rural light extinction based on IMPROVE data indicates that remote rural light extinction levels are notably lower than in urban areas in most parts of the U.S., with the northeast and the southeast regions having the most similarity between rural and urban light extinction levels. This is consistent with observations of an "urban excess"

Figure 3-3. Isopleth map of annual total reconstructed particulate extinction based on IMPROVE data.



(Source: Spatial and Seasonal Patterns and Temporal Variability of Haze and its Constituents in the United States Report IV, November 2006.)

of $PM_{2.5}$ and $PM_{10-2.5}$ and with the known high regional concentrations of sulfate in these eastern areas.

One-hour light extinction values of course vary above and below the 24-hour average, due to diurnal variations in $PM_{2.5}$ component concentrations, $PM_{10-2.5}$ concentrations, and relative humidity. Because low wind speeds, inversion conditions, and lower temperatures are more prevalent in the night and early morning hours, light extinction generally is higher at those times, with morning daylight hours being when poor visibility will most often be most observable. Although light extinction was formally reconstructed on an hourly basis in the 2005 Staff Paper analysis for the last review cited above, the actual full strength of the diurnal pattern could not be discerned in that analysis because component mix was assumed not to vary from hour to hour. Under the unverified assumption of constant component mix and using actual hourly relative humidity data, the daily maximum daylight 1-hour light extinction values were roughly 50 percent higher than the 24-hour average light extinction values.[14] The new analysis presented in this document includes a closer look at diurnal patterns, for 15 study areas.

3.2 OVERVIEW OF APPROACH AND DATA SOURCES FOR URBAN STUDY ANALYSIS

As explained above, there are limited data from direct measurements of light extinction in urban areas. Consequently, this assessment has reconstructed hourly light extinction levels from values of hourly $PM_{2.5}$ components, $PM_{10-2.5}$, and relative humidity. Hourly monitoring data for these parameters are also lacking, so the estimates of these parameters necessarily in turn have been developed from a combination of other available ambient monitoring data and air quality modeling results from a chemical transport model (CTM) run. Specifically, the ambient monitoring data starting points are 24-hour $PM_{2.5}$ mass measured by filter-based Federal Reference Method (FRM) or Federal Equivalent Method (FEM) monitors[15], 24-hour $PM_{2.5}$ components measured by the filter-based monitors of the Chemical Speciation Network, and hourly $PM_{2.5}$ mass measured by continuous instruments (Tapered Element Oscillating Microbalance (TEOM), beta attenuation monitors (BAMs), and nephelometers were used at different sites). The CTS-based diurnal profiles for individual components, in conjunction with hourly $PM_{2.5}$ measurements, are used to adjust and allocate the 24-hour $PM_{2.5}$ components measurements to individual hours of each day, as described in detail below. In addition, levels of hourly $PM_{10-2.5}$ mass are calculated from separate measurements of hourly PM_{10} and hourly $PM_{2.5}$ if both are available and by applying $PM_{10-2.5}$ to $PM_{2.5}$ ratios to hourly $PM_{2.5}$ data if both types of hourly measurements are not available. The ambient data are from 2005-2007 and were all obtained from AQS in the first half of 2009.

The CTM run was the "actual emissions" run of the 2004 CMAQ modeling platform with boundary conditions provided by GEOS-Chem global scale CTM.[16] The primary use of the CTM modeling is to provide realistic diurnal variations for each of the major $PM_{2.5}$ components used to estimate light extinction, anchored to site-specific, day-specific measurements of 24-hour concentrations. That is, monthly averaged diurnal profiles for the five major components were generated using the CTM results which were then used to generate realistic hourly concentration variations for each of the 24-hour CSN sample days during the 2005-2007 period.

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[14] These observations on diurnal patterns come from examination of "Output D.3 (Relationship RE & $PM_{2.5}$; Diurnal RE; Timeframe) 8 of 30" and "Output D.3 (Relationship RE & $PM_{2.5}$; Diurnal RE; Timeframe) 17 of 30", Analyses of Particulate Matter (PM) Data for the PM NAAQS Review, Schmidt et al., 2005.

[15] Filter-based Federal Reference Method samplers and filter-based Federal Equivalent Method samplers will both be referred to as FRM samplers in the remainder of this document.

[16] GEOS-Chem is the NASA Goddard Earth Observing System-CHEMistry (global 3-D CTM for atmospheric composition). This modeling platform, with an appropriately different emissions scenario, is also the basis for the estimates of policy relevant background concentrations of $PM_{2.5}$ presented in section 3.6 of the second draft ISA (US EPA, 2009a).

3.2.1 Study Period, Study Areas, Monitoring Sites, and Sources of Ambient PM Data

As of the time this assessment began, the ambient monitoring data from 2005-2007, but not from 2008, had been certified as accurate and complete by the state/local monitoring agencies that collected them, and the data had been extensively summarized and presented in the first draft ISA. The EPA staff aimed to develop estimates of daylight hours light extinction for a reasonably representative number of days in each year of 2005-2007, to allow the application of statistical forms based on three years of data. However, as explained in more detail below, in several study areas the limited availability of starting data for these estimates resulted in estimate sets that do not cover all three years. Also, even in areas with some data in all three years, the number of days with valid estimates differs by year and is in some cases not large by typical standards of monitoring data completeness.

For efficiency in the analysis, this visibility assessment uses the same 15 urban study areas selected for the health risk assessment. These areas are listed in Table 3-2, along with the area-wide FRM-based 2005-2007 annual and 24-hour $PM_{2.5}$ design values for each study area. (See below for an explanation of the "site-specific" columns in Table 3-2.)

Table 3-2. Urban Visibility Assessment Study Areas

Study Area	Area-wide 2005-2007 Annual Design Value	Area-wide 2005-2007 24-hour Design Value	Site-specific 2005-2007 Annual Design Value	Site-specific 2005-2007 24-hour Design Value	Region
Tacoma	10.2	43	Same	Same	Northwest
Fresno	17.4	63	Same	Same	Southern California
Los Angeles-South Coast Air Basin	19.6	55	Same	Same	Southern California
Phoenix	12.6	32	7.9	15	Southwest
Salt Lake City	11.6	55	10.7	48	Northwest
Dallas	12.8	26	11.5	25	Southeast
Houston	15.8	31	13.1	25	Southeast
St. Louis	16.5	39	14.5	34	Midwest
Birmingham	18.7	44	Same	Same	Southeast
Atlanta	16.2	35	15.7	33	Southeast
Detroit-Ann Arbor	17.2	43	Same	Same	Midwest
Pittsburgh	16.5	43	15.0	40	Industrial Midwest
Baltimore	15.6	37	14.5	35	Northeast
Philadelphia-Wilmington	15.0	38	14.7	37	Northeast
New York-N. New Jersey-Long Island	15.9	42	14.4	42	Northeast

For time reasons and because it was anticipated that some study areas would not contain more than one suitable study site, EPA staff sought to identify the single best study site in each area. In identifying the single best study site in each study area consideration was given to the availability of collocated 24-hour data on $PM_{2.5}$ and its components, because the contribution of $PM_{2.5}$ components to total light extinction will typically dominate the contribution from $PM_{10-2.5}$. Ideally, within each study area the three types of $PM_{2.5}$ data (FRM $PM_{2.5}$, CSN $PM_{2.5}$ components, continuous $PM_{2.5}$) would be available at a common site, and that site would be located in a manner consistent with reliance on it to characterize visibility as it would be perceived by a large number of area residents and visitors. Shown in Table 3-2 for convenient comparison are the site-specific FRM-based design values for the monitoring site in each study area from which FRM $PM_{2.5}$ data were taken for the purposes of this assessment, where not the same as the site providing the area-wide design values.[17] As can be seen in Table 3-2, in most of the study areas the site providing FRM data for this assessment is not the area-wide design value site, because the area-wide design value site did not have collocated CSN and/or continuous $PM_{2.5}$ data.

Appendix A provides details on the site(s) identified and used in each study area, including information on the type of monitoring that provided the data and other information that may help interpret the results of the analysis. A portion of this table for a single site – Tacoma – is presented here as Table 3-3 as an example. When viewing this document electronically, the site IDs in these tables are active links and can be used to view the location of the site via GoogleMaps.[18]

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[17] 2005-2007 $PM_{2.5}$ design values were taken from the information posted at http://www.epa.gov/airtrends/values.html, and are consistent with the design values used in the health risk assessment to "roll back" current concentrations to represent achievement of alternative annual and 24-hour $PM_{2.5}$ NAAQS. Except in Dallas and Fresno, the area-wide design values are the highest design values of any monitoring site in the designated (1997 NAAQS) nonattainment area that has sufficiently complete data to allow the calculation of a design value according to the provisions of 40 CFR 50 appendix N. For Dallas, the design values come from a site with nearly complete data, and are somewhat higher than the highest values from a site with complete data (see the draft PM Risk Assessment, US EPA, 2009c, section 3.2.3) For Fresno, the area-wide design value is for the Fresno-Madera CSA, which is only a portion of the San Joaquin Valley nonattainment area. Also, note that there are three cases in which the nonattainment area does not include certain areas sometimes thought of as being part of the area named in Table 2; monitors in these non-included areas were not considered in this assessment. (1) The design value shown for Pittsburgh is for the Pittsburgh-Beaver nonattainment area; the Liberty-Clairton nonattainment area is within the Pittsburgh CBSA but is distinct for regulatory purposes, and was not considered in this assessment. (2) Baltimore was treated separately, although part of a CSA with Washington DC. (3) Berks Co., PA is part of the Philadelphia-Camden-Vineland CSA, but not part of the Philadelphia-Wilmington nonattainment area.

[18] Additional meta data on each monitoring site, and access to daily and annual data listings, can be conveniently obtained using GoogleEarth and the $PM_{2.5}$, PM_{10}, and CSN monitoring network KML files that can be downloaded from http://www.epa.gov/airexplorer/monitor_kml.htm.

In 11 of the study areas, the three types of $PM_{2.5}$ data were available at a common site. In the remaining four areas, Phoenix, AZ, Pittsburgh, PA, Baltimore, MD, and St. Louis, MO-IL, two types of data were available at one site, but the remaining type of data had to be taken from another site and treated as being representative of the former site.

The monitoring agencies described all but one of these sites as neighborhood or urban scale, indicating those agencies' opinion that the sites represent concentrations in an area at least 0.5 to 4 km across. An aerial view of the remaining site (in Phoenix) suggests that it may be middle or neighborhood scale. Selected sites are not necessarily the locations of the maximum measured annual or 24-hour $PM_{2.5}$ levels in their urban area.

Hourly $PM_{10-2.5}$ presented more varied challenges. In four areas (Birmingham, Detroit, Baltimore, and Philadelphia) the site that provides the continuous $PM_{2.5}$ data also hosts a continuous FEM PM_{10} monitor, and hourly $PM_{10-2.5}$ could be calculated by difference for most hours. In other areas, this was not the case, and either (1) instruments at two different sites were used in this subtraction (Tacoma, Los Angeles-South Coast Air Basin, Phoenix, St. Louis, Atlanta, and New York-N. New Jersey) or (2) a single regionally applicable $PM_{10-2.5}$ to $PM_{2.5}$ ratio calculated as part of the last review based on 2001-2003 24-hour FRM/FEM PM_{10} and $PM_{2.5}$ samples was applied to 2005-2007 hourly $PM_{2.5}$ data to estimate hourly $PM_{10-2.5}$ (Fresno, Salt Lake City, Dallas, Houston, and Pittsburgh). In the case of Los Angeles-South Coast Air Basin, the continuous PM_{10} and $PM_{2.5}$ sites were quite distant and separated by a range of hills, so the estimates of $PM_{10-2.5}$ and its contribution to total light extinction are more uncertain than if the monitors were clearly within the same air mass. Obviously, for those study areas for which 1-hour $PM_{10-2.5}$ was estimated by application of ratios, $PM_{10-2.5}$ estimates can only represent broad trends, not hour-specific conditions at the particular site. More description of the methods used for estimating hourly $PM_{10-2.5}$ appears in section 3.3.2.

The sampling schedule for CSN $PM_{2.5}$ speciation monitoring was one-in-six days for Tacoma, Phoenix, Houston, Detroit, and Philadelphia, and one-in-three days for the other study areas. Not every scheduled CSN site day in 2005-2007 had data for all three types of $PM_{2.5}$ data, due to missed or invalid samples. Also, for continuous $PM_{2.5}$, values for a small number of hours of an otherwise data-sufficient day were sometimes missing, due to equipment failure or servicing. EPA staff retained only those days in which 75 percent or more of daylight hours had measurements of $PM_{2.5}$ (see section 3.3. for more details). If for isolated hours at a site (or site pair) with collocated measurements, $PM_{10-2.5}$ concentrations could not be estimated because of gaps in the same-hour continuous PM_{10} and/or $PM_{2.5}$ data, EPA staff used the regional ratio approach described above to estimate $PM_{10-2.5}$ for those specific hours. Table 3-4 provides more detailed information on the quarterly distribution of the successfully matched and sufficiently complete data available for use. As described later, for some parts of this assessment EPA staff

Table 3-3. $PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Tacoma Study Area

Study Area	First $PM_{2.5}$ Monitoring Site	Second $PM_{2.5}$ Monitoring Site (if applicable)	PM_{10} data source for $PM_{10-2.5}$
Tacoma	AQS ID 530530029 State: Washington City: Tacoma MSA: Tacoma, WA Local Site Name: TACOMA - L STREET Address: 7802 SOUTH L STREET, TACOMA 0.5 miles east of I-5 2005-2007 annual DV = 10.2 2005-2007 24-hr DV = 43 This is the highest 24-hour PM2.5 DV site in the Seattle-Tacoma-Olympia, WA annual $PM_{2.5}$ nonattainment area Neighborhood Scale Parameters taken from this site: ♦ 24-hour FRM $PM_{2.5}$ mass (AQS parameter 88101; one-in-three sampling schedule) ♦ $PM_{2.5}$ speciation (one-in-six sampling schedule) ♦ 1-hour $PM_{2.5}$ mass (AQS parameter 88502, Acceptable $PM_{2.5}$ AQI & Speciation Mass) Correlated Radiance Research M903 Nephelometry No continuous PM_{10} monitoring at this site, see right hand column.	N/A	AQS ID 530530031 State: Washington City: Tacoma MSA: Tacoma, WA Local Site Name: TACOMA - ALEXANDER AVE Address: 2301 ALEXANDER AVE, TACOMA, WA 6.4 miles NNE of $PM_{2.5}$ site Neighborhood Scale Parameters taken from this site: ♦ 1-hour PM_{10} STP mass (AQS parameter 81102) ♦ Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET ♦ Sample Analysis Method: TEOM-GRAVIMETRIC 7% of $PM_{10-2.5}$ values were determined using regional average $PM_{10-2.5}$:$PM_{2.5}$ ratios from 2005 Staff Paper

Additional Explanation

- In this Table, the 1-hour concentration parameter "88502, Acceptable $PM_{2.5}$ AQI & Speciation Mass" is the same as the ISA refers to as "FRM-like" PM2.5 mass. An entry of "88501, $PM_{2.5}$ Raw Data" indicates that the monitoring agency makes no representation as to the degree of correlation with FRM $PM_{2.5}$ mass. The latter type of continuous PM2.5 data were used only when the former were unavailable.
- Where PM_{10} was reported in STP, it was converted to LC before $PM_{10-2.5}$ was calculated.
- For convenient, continuous $PM_{2.5}$ data was obtained through the AirNow website rather than from AQS, as an initial exploration indicated that not all the desired 1-hour data had been submitted to AQS.

Table 3-4. Number of days per quarter in each study area

		2005				2006				2007			
Study Area	**Total Number of Days**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Tacoma	110	0	0	0	0	13	15	15	14	13	13	14	13
Fresno	324	19	24	27	27	30	29	29	27	26	28	30	28
Los Angeles-South Coast Air Basin	302	28	28	22	28	26	26	27	22	21	26	24	24
Phoenix	86	0	13	11	14	12	13	11	12	0	0	0	0
Salt Lake City	306	27	28	30	26	20	28	31	20	23	25	19	29
Dallas	274	22	24	26	22	23	23	24	24	18	23	24	21
Houston	149	21	20	10	14	14	12	8	12	15	14	9	0
St. Louis	294	27	27	24	27	28	19	27	29	29	25	22	10
Birmingham	350	30	30	29	30	29	29	30	30	30	30	27	26
Atlanta	295	22	25	25	24	28	27	26	27	25	19	26	21
Detroit-Ann Arbor	141	12	12	10	11	12	13	11	15	11	11	12	11
Pittsburgh	284	26	23	25	23	22	25	24	26	22	22	23	23
Baltimore	187	19	17	15	11	15	16	19	18	12	12	17	16
Philadelphia-Wilmington	145	15	11	13	10	9	13	10	13	13	14	12	12
New York-N.New Jersey-Long Island	228	22	23	13	15	23	19	18	21	19	15	19	21

Note: Only days with matched and sufficiently complete data were retained in the assessment.

substituted data for the single missing quarters of data in Phoenix and Houston, to achieve seasonal balance.

3.2.2 Use of CMAQ Model Runs for 2004 to Augment Ambient Data

Because systematic monitoring data are not available on hourly $PM_{2.5}$ component concentrations, EPA staff extracted and applied certain information from the modeling platform for calendar year 2004 described in section 3.7.1.2 of the second draft ISA, in which the global-scale circulation model GEOS-Chem was paired with the regional scale air quality model CMAQ.[19] The main use of this platform in the ISA is to estimate policy-relevant background concentrations of $PM_{2.5}$. For the urban-focused visibility assessment described here, however, we used results from the validation run of the platform, in which emissions for all emission source types and countries are included, to develop realistic diurnal variations of the major $PM_{2.5}$ components.

The EPA staff identified the 36 km-by-36 km CMAQ grid cell corresponding to the location of the CSN monitoring site used in each study area. We then extracted from the detailed model output for this grid cell the day/hour-specific concentrations of sulfate, nitrate, elemental carbon, organic carbon, and "crustal/unspeciated" $PM_{2.5}$ during 2004, and then we averaged across days within the month for each individual hour of the day.[20] Thus, for each species, EPA staff obtained 24 values for a month, for each of the 12 calendar months. We then averaged the 24 hourly values in each monthly set for each component to obtain the 24-hour average concentration for the month. We then divided each hourly value by the 24-hour value, to obtain a normalized diurnal profile for the pollutant, which was taken to represent all days in that month for 2005, 2006, and 2007. In total, this resulted in 5 (components) x 12 (months) x 15 (study areas) = 900 profiles. Visual examination of a number of these showed them to be reasonably smooth and generally to show morning (and sometimes also late afternoon/evening) peaks which are the anticipated effect of higher vehicle traffic and lower mixing heights. The peaks were generally moderate, as would be expected in light of the large grid cells and generally moderate diurnal profiles for SMOKE pre-processing of emissions in the CMAQ modeling platform. Sulfate, as would be expected for a regionally transported pollutant, generally had a flatter diurnal profile than for other components. Hourly nitrate concentrations were low when expected: during warmer months and in warmer areas. Figure 3-4 shows example diurnal profiles

[19] Similar modeling was not available for 2005, 2006, or 2007.

[20] For several of the listed components that are not direct CMAQ outputs, concentrations were estimated by post-processing to aggregate the appropriate CMAQ outputs. The "crustal/unspeciated" CMAQ output results from non-reactive dispersion of that portion of the $PM_{2.5}$ emission inputs not assigned during SMOKE processing to a more specific CMAQ species, and is considered in most EPA analyses to represent the same material as the "soil" component reported for IMPROVE sampling.

for the five $PM_{2.5}$ components, for the Detroit study area for the months of January and August. Diurnal profiles like these were applied to 24-hour CSN measurements of component concentrations, as explained in detail below.

3.2.3 Use of Original IMPROVE Algorithm to Estimate Light Extinction

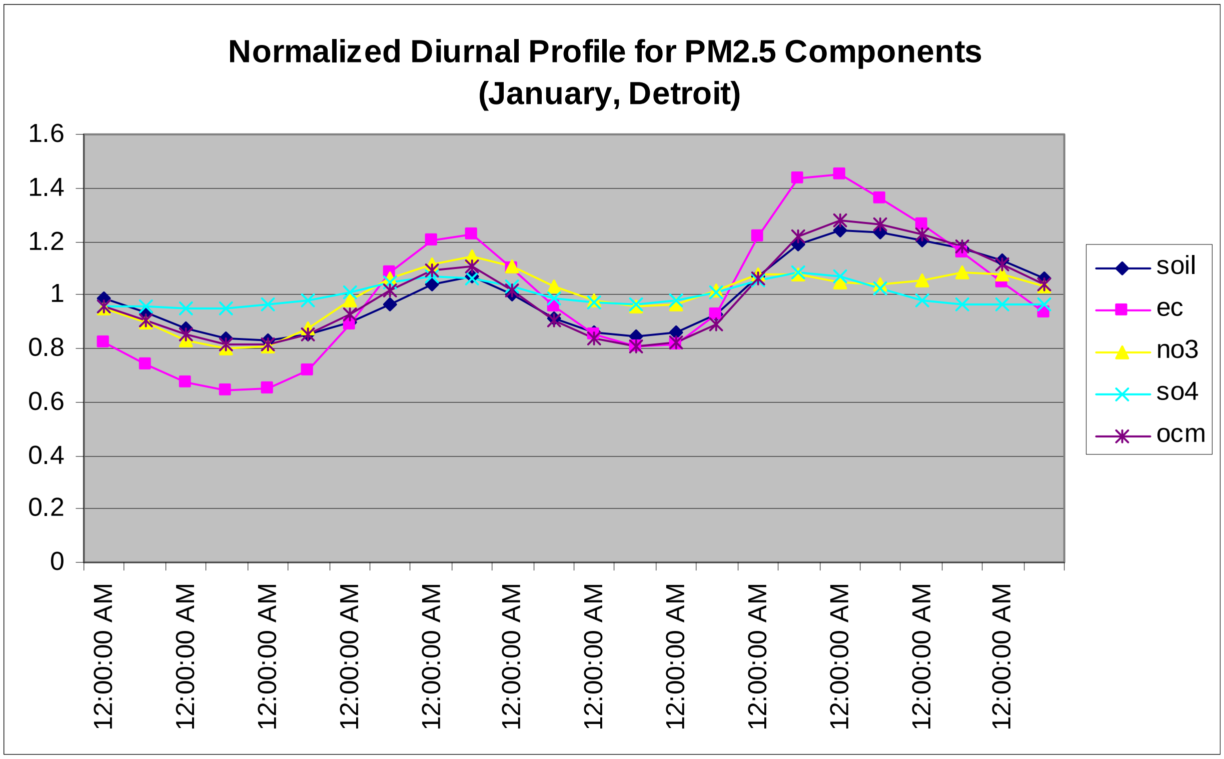
The EPA staff used the original IMPROVE light extinction algorithm, rather than the more recent revised version, because the original version is considered more representative of urban situations, when emissions are still fresh rather than aged as at remote IMPROVE sites. To maintain consistency with the form of the candidate protective levels (CPLs) identified in chapter 2, we staff included a value of 10 Mm^{-1} to represent clear air Rayleigh scattering, and we use the term "total light extinction" to indicate this.[21] No presumption is intended regarding whether a possible secondary NAAQS using measured light extinction as the indicator should include or exclude light extinction due to gases. The formula for total light extinction using the traditional IMPROVE algorithm is shown below.

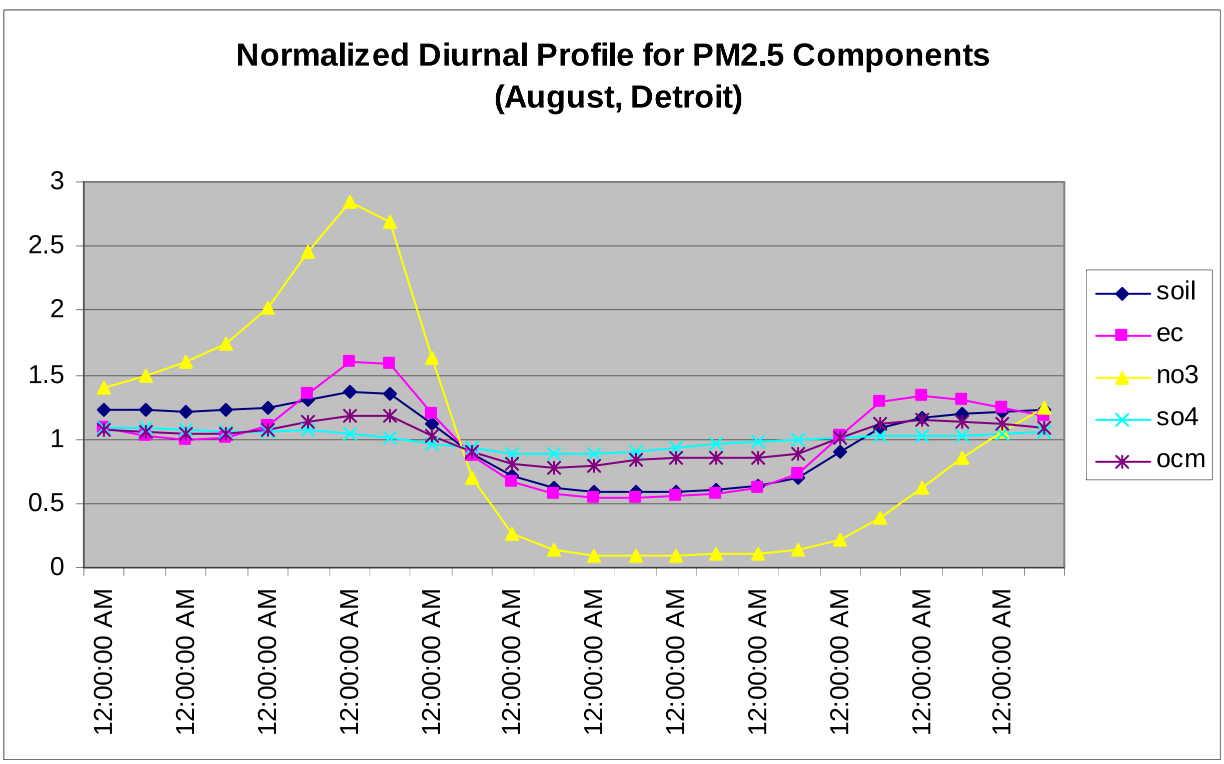
$$\begin{aligned} b_{ext} \approx\ & 3 \times f(RH) \times [Sulfate] \\ & + 3 \times f(RH) \times [Nitrate] \\ & + 4 \times [Organic\ Mass] \\ & + 10 \times [Elemental\ Carbon] \\ & + 1 \times [Fine\ Soil] \\ & + 0.6 \times [Coarse\ Mass] \\ & + 10 \end{aligned}$$

Total light extinction (b_{ext}) is in units of Mm^{-1}, the mass concentrations of the components indicated in brackets are in µg/m3, and f(RH) is the unitless water growth term that depends on relative humidity. We refer to the first five terms in this algorithm as the five $PM_{2.5}$ components. In this algorithm, the sulfate and nitrate components are to be expressed as fully neutralized, without associated water since the water absorption effect is reflected in the f(RH) term. The organic mass component is to include the mass of associated elements other than carbon. As described below, we included steps in our development of estimates of hourly component concentration to ensure consistency with these aspects of the IMPROVE algorithm.

[21] We did not include a term for light absorption by NO_2 or other gases.

Figure 3-4. January and August monthly average diurnal profiles of $PM_{2.5}$ components derived from the 2004 CMAQ modeling platform, for the Detroit study area.





3.3 DETAILED STEPS

3.3.1 Hourly $PM_{2.5}$ Component Concentrations

The task of estimating hourly $PM_{2.5}$ component concentrations is in a sense over-determined, given the four types of available information: 24-hour $PM_{2.5}$ mass by filter-based FRM, 24-hour component concentrations by CSN, hourly $PM_{2.5}$ mass by continuous instrument, and diurnal profiles of components from the 2004 CMAQ run. There are multiple ways in which two or three of these four data sources could be used to estimate hourly $PM_{2.5}$ component concentrations, and the result generally can be expected to be at least somewhat inconsistent with the information in the remaining data sources. For example, each 24-hour $PM_{2.5}$ component mass from CSN sampling can be apportioned to hours based on the diurnal profile developed from the 2004 CMAQ run, but then in general the hourly values of $PM_{2.5}$ mass determined by summing the components in an hour would not exactly match the data from the continuous $PM_{2.5}$ instrument. EPA staff therefore used a sequence of steps which achieves a prioritized compromise among the data sources. In this sequence, we have given greater weight to the 24-hour FRM, CSN, and continuous $PM_{2.5}$ mass data because these are instrument-based and location- and day-specific, than to the CMAQ-based profiles which are CTM-based, averaged to the month, and extrapolated from 2004 to each of 2005, 2006, and 2007.

Because of differences in filter materials, laboratory analysis, and data reporting, there are differences between the contribution of some PM components to $PM_{2.5}$ mass as, reported by filter-based 24-hour FRM sampler or by continuous instruments, and the mass of the same component as reported by CSN (or IMPROVE) sampling. The following summary of these differences may be helpful in understanding the steps used to develop estimates of hourly $PM_{2.5}$ components in this analysis. In the IMPROVE algorithm for reconstructing total light extinction, the light extinction contribution multipliers per unit of mass concentration of components are different for each of the five principle components. Consequently, care is required to estimate these components as consistently as possible with the IMPROVE sampling and analytical methods.

- **<u>Nitrate:</u>** CSN (and IMPROVE) sampling uses a Nylon filter for purposes of nitrate quantification, while FRM sampling uses a Teflon filter for $PM_{2.5}$ as a whole. The Nylon filter limits the loss of nitrate in the form of nitric acid vapor, compared to the Teflon filter. Hence, the nitrate mass reported by CSN (and IMPROVE) sampling typically will be higher than the nitrate contribution to FRM $PM_{2.5}$ mass, particularly under warm ambient conditions. In addition, the IMPROVE program does not measure ammonium ion and hence must make an assumption that nitrate ion is fully neutralized by ammonium ion. In contrast, in FRM sampling ammonium ion is measured and it is possible for nitrate to be found not to be fully neutralized. These two factors tend to make nitrate mass as reported for a CSN or IMPROVE site higher than the nitrate contribution to $PM_{2.5}$ mass reported for a FRM site. On the other hand, FRM sampling results in some water that is associated with nitrate being included in the reported $PM_{2.5}$ mass, while the nitrate mass reported by CSN (or IMPROVE) sampling excludes all water. Continuous $PM_{2.5}$ samplers employ a variety of methods for measuring $PM_{2.5}$ mass, with correspondingly different behavior regarding retention/loss of nitrate. However, it is generally accepted that the continuous $PM_{2.5}$ sampling methods used at the study sites have less nitrate retention than a CSN sampler, and are more like the FRM method in that regard.

- **Sulfate:** Unlike nitrate, sulfate is not subject to loss once collected by a filter, but like nitrate the issues of neutralization and water retention apply. Also, as for nitrate, as a first order approximation, continuous $PM_{2.5}$ instruments can be assumed to be more like FRM samplers in reporting the mass effect of sulfate than like CSN samplers.

- **Elemental and Organic Carbon:** Only the mass of carbon atoms is included in the reported elemental carbon and organic carbon for a CSN (or IMPROVE) sampler. In addition, the distinction between elemental and organic carbon atoms is dependent on the specifics of the two different thermo-optical analytical methods used in the CSN vs. the IMPROVE network.[22] Also, the quartz filter used to quantify carbonaceous material in CSN and IMPROVE sampling both absorbs and loses organic vapors during sampling, while the Teflon filter in a FRM sampler does not absorb organic vapors (although PM on the filter may do so). Therefore, some method other than direct measurement must be used to estimate the total mass concentration of organic carbonaceous material in ambient air. The IMPROVE program adjusts for absorption of vapors by subtracting a monthly average backup filter value, and then applies a standard adjustment factor (1.4 in the "old" IMPROVE method) to the remaining organic carbon measurement to estimate organic carbonaceous material. In contrast, the standard reports from CSN sampling submitted to AQS do not include these two adjustments, but it is routine for EPA staff to apply similar adjustments for the same purpose, after reporting of CSN data to AQS. For this assessment the SANDWICH approach to such adjustments (Frank, 2006) is used to estimate the organic mass through a mass balance of component measured on the CSN and FRM samplers.

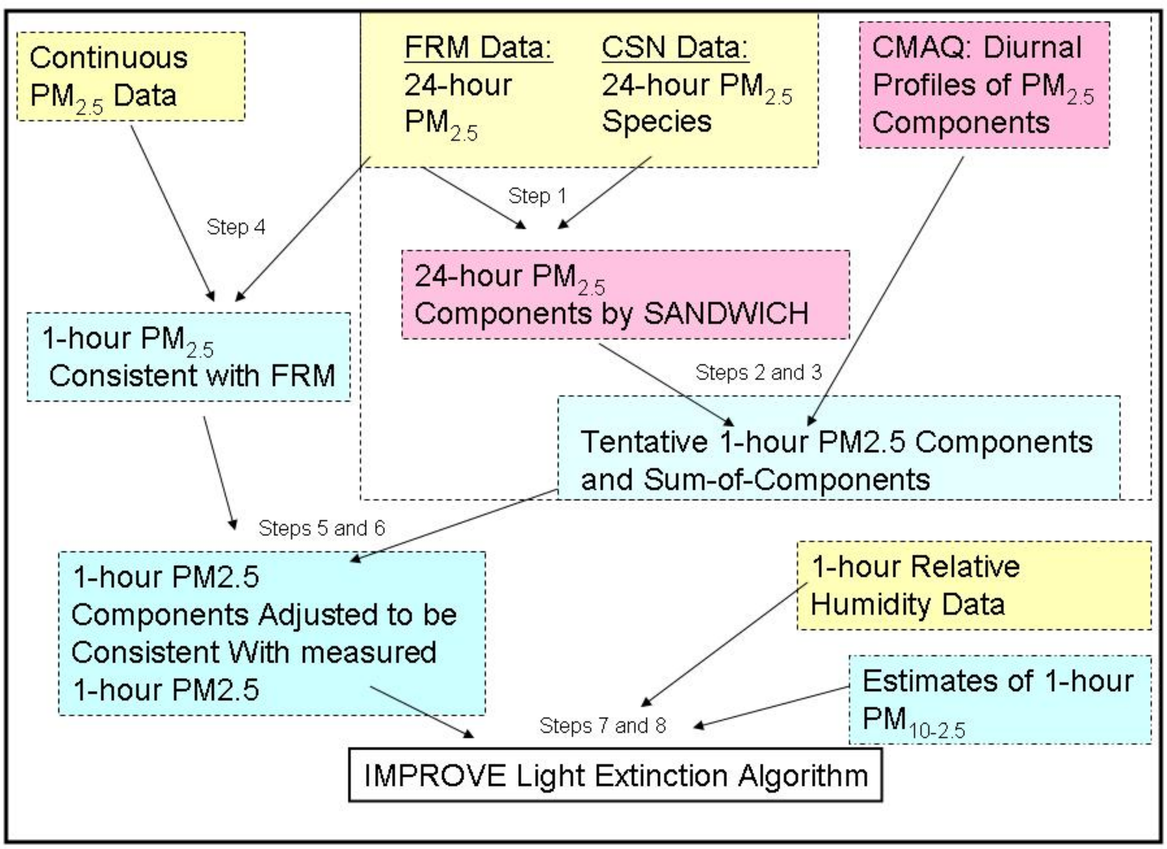
- **Hourly $PM_{2.5}$**: The continuous instruments used for measuring hourly $PM_{2.5}$ mass were different among sites (as listed in Appendix A), and none of the instrument types that provided data for this assessment perfectly measures "true" ambient concentrations. None of them, when averaged over 24 hours, exactly matches either the measurements of $PM_{2.5}$ mass from a FRM sampler or the sum-of-components reportable from CSN sampling. Differences can arise because of differences in water capture and retention, inconsistent absorption and loss of organic vapors and nitric acid vapor, etc. In 2006, EPA developed and promulgated criteria for approval of continuous $PM_{2.5}$ samplers as "federal equivalent methods". These criteria assure a minimum level of correlation between approved continuous instruments and the FRM method, when data from both are

[22] While CSN carbon sampling and analysis methods have recently been harmonized with IMPROVE methods at many CSN sites, it was not until mid-2007 that the first 57 sites were using the harmonized methods. Consequently, most of the elemental and organic carbon data used in this assessment were obtained with the original CSN methods.

expressed as 24-hour average concentrations. However, in 2005-2007 no commercially available instruments were yet approved under those criteria. Consequently, the continuous instruments providing data to this assessment can be assumed to have a range of correlation performance versus the FRM. In light of these consistency issues, the hourly data from the continuous instruments were taken to be most indicative of the relative concentrations of $PM_{2.5}$ from hour-to-hour, with less reliance on the absolute accuracy of the continuous instruments.

Taking into consideration the above information, EPA staff combined the four types of available $PM_{2.5}$ data in each study area using the following steps. Figure 3-5 provides a flow chart that may assist in understanding these steps.

Figure 3-5. Sequence of steps used to estimate hourly $PM_{2.5}$ components and total light extinction



1. The SANDWICH method (Frank, 2006) was used to subdivide the 24-hour $PM_{2.5}$ mass reported by the FRM for each day and site into sulfate (including associated ammonium and residual water during filter weighing), nitrate (including associated ammonium and residual water during filter weighing), elemental carbon, organic carbonaceous mass, and fine soil/crustal mass. This is done using information from the CSN measurements, physical models, and day-specific temperatures. Significantly, in the SANDWICH method, the component referred to as organic carbonaceous mass is actually a residual whose value is determined as the difference between the $PM_{2.5}$ mass determined from weighing the FRM filter and the sum of the estimated masses of the other four mass components as listed above.

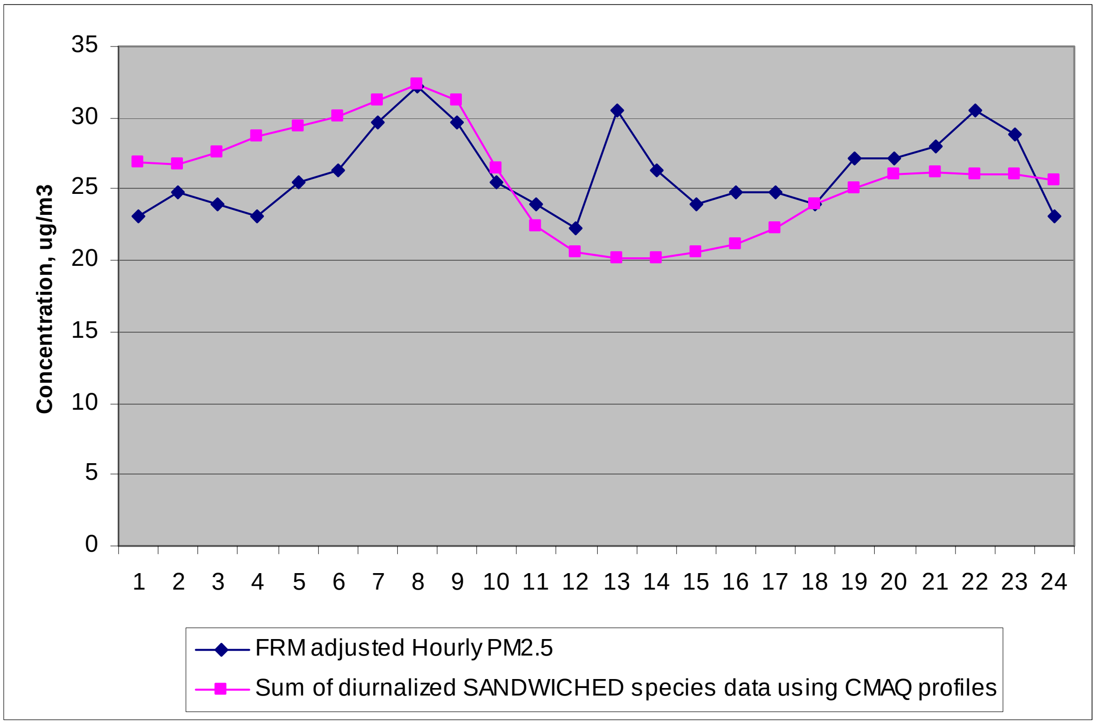
2. The CMAQ-derived monthly diurnal profiles for sulfate, nitrate, elemental carbon, organic carbon and fine soil/crustal, like the examples for Detroit in Figure 3-4, were multiplied by the day-specific SANDWICH-based estimates of the 24-hour average concentrations of these five $PM_{2.5}$ components, to get day-specific hourly estimates of these five components (including ammonium and water associated with sulfate and nitrate ion).

3. The hourly concentrations of these five components (including ammonium and water associated with sulfate and nitrate ion when the filter is weighed) were added together, to get a sum-of-components estimate of hourly $PM_{2.5}$ mass for the day of the FRM sampling.

4. The hourly data from the continuous $PM_{2.5}$ instrument on the day of the FRM sampling were normalized by their 24-hour average, to get a diurnal profile. (Recall that days were not used in this assessment if hourly $PM_{2.5}$ mass data were missing for more than 25 percent of daylight hours.) This profile was applied to the 24-hour $PM_{2.5}$ mass reported by the FRM sampler, to get a second, FRM-consistent estimate of hourly $PM_{2.5}$ mass for the day of the FRM sampling. This is straightforward when all 24 values of 1-hour $PM_{2.5}$ mass were available for the day. However, for some (but not many) days, some values for continuously measured hourly $PM_{2.5}$ mass were missing. In such cases, EPA staff used only the hours with valid 1-hour $PM_{2.5}$ mass values to develop the diurnal profile and then applied the profile to the FRM value as just described. This keeps the average of the valid 1-hour PM2.5 values equal to the 24-hour value from the FRM sampler.

5. The two estimates of hourly $PM_{2.5}$ mass from steps 3 and 4 were compared, hour-by-hour. By virtue of the way they were derived, the averages of these estimates across all 24 hours of the day will necessarily be the same (and will be equal to the 24-hour FRM measurement). However, while the diurnal pattern of these two estimates of the same physical parameter should also be generally similar, it can be expected (and it is observed) that the hourly measurements from the continuous $PM_{2.5}$ instruments (after adjustment to be consistent with the FRM data) have more hour-to-hour variability. Figure 3-6 gives an example of this comparison, for one day for the Detroit study area.

Figure 3-6. Example from Detroit study area.



Example comparison from the Detroit study area of hourly $PM_{2.5}$ mass on March 24, 2006 as estimated by applying CMAQ-based diurnal profiles to SANDWICH estimates of 24-hour component concentrations versus applying a diurnal profile derived from continuous $PM_{2.5}$ measurements to FRM $PM_{2.5}$ mass.

6. Given that the continuous instrument is reacting to hour-specific local conditions that can vary from hour-to-hour due to real variations in local emissions and dispersion/transport conditions, while the CMAQ-based estimates contain much less specific information, the diurnal pattern of $PM_{2.5}$ mass observed by the continuous instrument (adjusted to be consistent with the FRM value for 24-hour average $PM_{2.5}$) was taken as more reliable. Within each hour, the estimates of all five components from step 2 were increased or decreased by a common percentage (referred to below as A_i where the subscript i indicates the hour) so that the sum of the five components after this adjustment was equal to the estimate of the hourly $PM_{2.5}$ mass from step 4. The adjustment percentage varied from hour-to-hour. Necessarily, in some hours the adjustment is an increase in the concentrations of all components, and in other hours it is a decrease. While this adjustment preserves the consistency between the 24 values of hourly $PM_{2.5}$ mass and the 24-hour FRM mass, it can disturb the consistency between the hourly estimates of $PM_{2.5}$ components and the SANDWICH-based estimates of 24-hour average component concentrations. This disturbance was generally small, because the adjustments necessarily go in one direction for some hours and the other direction for other hours. For example, for the particular day in Detroit used for illustration purposes in Figure 6, the effect of this step was to cause a discrepancy of 3 percent between the SANDWICH-based values of 24-hour sulfate concentration and the average of the 24 estimates of 1-

hour sulfate concentrations (the positive percent indicates a higher concentration in the result of this step than the SANDWICH-based value). The discrepancies were 1, 1, 2, and 2 percent for nitrate, elemental carbon, organic carbon, and fine soil/crustal, respectively.

7. Each hourly estimate of sulfate concentration from step 6 (which includes estimates of associated ammonium and particle bound water) was adjusted so that it excludes water and reflects full neutralization and therefore is consistent with the reporting practices of the IMPROVE program and the IMPROVE algorithm. This was done via these sub-steps:

    a. The 24-hour CSN value for the dry mass of sulfate ion (not SANDWICHed, no ammonium) was multiplied by 1.375 to reflect an assumption of full neutralization.

    b. The ratio of this fully neutralized 24-hour sulfate mass to the SANDWICH-based 24-hour sulfate value was calculated.

    c. This ratio was applied to each individual hour's sulfate concentration from step 6.

    As in Step 6, it is possible for the 24 final hourly sulfate estimates to no longer be exactly consistent with the 24-hour CSN sulfate measurement.

8. A similar adjustment as in step 7 (for sulfate) was made to each hour's nitrate concentration from step 6, so that the estimate of hourly nitrate would reflect actual atmospheric conditions and be consistent with the IMPROVE algorithm. However, the ratio approach used in step 7(b) for sulfate could not be applied for nitrate, so this adjustment had to be more complicated. Because in warm weather the FRM Teflon filter does not retain nitrate, the initial FRM-consistent nitrate estimate derived by applying the SANDWICH method to the FRM and CSN data can be zero. Such a zero value makes it impossible to use the ratio approach in 7(b). Instead, the adjustment was made as follows:

    a. The 24-hour CSN value for nitrate ion (not SANDWICHed, no ammonium) was multiplied by 1.29 to reflect an assumption of full neutralization.

    b. This 24-hour value was then diurnalized using the CMAQ-based profile, similar to step 2.

    c. Each resulting hourly value of nitrate was further multiplied by the Ai factor from step 6.

    d. This new estimate of hourly nitrate was used to replace the initial nitrate value that had resulted from step 6.

For cooler areas and days in which the 24-hour SANDWICH results include some nitrate, the effect of these steps for nitrate are exactly the same as the effects of step 7 for sulfate (except for the 1.29 vs. 1.37 neutralization factor). For warmer areas and days in which the 24-hour

SANDWICH results did not include any nitrate even though nitrate was measured on the CSN Nylon filter, the effect of these steps is to assign the CSN nitrate to each hour using a combination of the information in the CMAQ-based profiles and the information provided by the continuous $PM_{2.5}$ sampler. As in Step 6, it is possible for the 24 final hourly nitrate estimates to no longer be exactly consistent with the 24-hour CSN nitrate measurement.

3.3.2 Hourly $PM_{10-2.5}$ Concentrations

Three different paths were used to estimate hourly $PM_{10-2.5}$ concentrations, in the following order of preference:

1. When hourly data from a collocated PM_{10} instruments were available at the continuous $PM_{2.5}$ site in a study area, $PM_{2.5}$ was subtracted hour-by-hour from PM_{10}. Negative values were reset to zero.

2. When collocated continuous PM_{10} data were not available at the continuous $PM_{2.5}$ site in a study area, but continuous PM_{10} data were available at another site in the same study area, $PM_{10-2.5}$ was estimated by subtraction, implicitly assuming that the latter site was also representative of PM_{10} at the former site.

3. If neither of the first two methods was possible, a regional average ratio of $PM_{10-2.5}$ to $PM_{2.5}$ determined from an analysis of 24-hour data for the 2005 Staff Paper was applied to hourly $PM_{2.5}$ from the continuous instrument associated with the study area.

The estimation of $PM_{10-2.5}$ was further complicated because some types of data were missing for isolated hours in the 2005-2007 period. As result, even for a single study area more than one method sometimes had to be used to estimate hourly $PM_{10-2.5}$. Appendix A gives more specifics about the estimation of hourly $PM_{10-2.5}$ in each study area.

The three-path approach described here is similar to that used for the visibility analysis reported in the 2005 Staff Paper. While the second and third paths involve the use of data and assumptions that are not robust compared to the use of paired, collocated, same-method continuous instruments or to the use of paired low-volume filter-based samplers, in most areas and periods the contribution to total light extinction from the resulting $PM_{10-2.5}$ concentrations was not large compared to the light extinction due to $PM_{2.5}$ components.

3.3.3 Hourly Relative Humidity Data

Hourly relative humidity (RH) data for each study area's primary monitoring site were obtained hour-by-hour from the closest available non-missing relative humidity measurement, as reported by either an air monitoring station reporting such data to AQS or a National Weather Service (NWS) station. For the AQS RH data, parameter 62201 values were utilized. RH data from both sources are expressed as percentages.

3.3.4 Calculation of Hourly and Daily Maximum 1-Hour Total Light Extinction

The original IMPROVE algorithm was applied hour-by-hour to estimate total light extinction in each study area.

Because the interest in this analysis is on visibility during daylight hours, EPA staff applied an hour-of-day filter to identify those hours that were daylight hours. The actual times of local sunset and sunrise for each day and area were taken from tables of sunrise and sunset available from the US Naval Observatory for each of the 15 urban areas. Daylight hours were defined as any hour (e.g., 8:00 AM to 8:59 AM) containing no minutes before sunrise or after sunset. For simplicity, these were generalized, so that all the days within each "season" in all study areas were considered to have the same daylight hours.[23] Table 3-5 shows the resulting definition of daylight hours for the study areas. Unless otherwise stated, all subsequent discussion of the results refers only to the values of parameters during these daylight hours.

Table 3-5. Assumed daylight hours by season (Local Standard Time)

	November-January	February-April	May-July	August-October
First hour that is entirely daylight	8:00-9:00 AM	7:00-8:00 AM	5:00-6:00 AM	6:00-7:00 AM
Last hour that is entirely daylight	3:00-4:00 PM	5:00-6:00 PM	6:00-7:00 PM	5:00-6:00 PM
Number of daylight hours	8	11	14	12

Daily maximum 1-hour total light extinction is the statistic of most interest in this assessment, as briefly discussed in section 2.6. Days were set aside and not used to determine this statistic if the hourly $PM_{2.5}$ mass value was missing (or reported to be less than zero) for more than 25 percent of daylight hours. Two or three missing daylight hours were allowed, depending on season.

In this assessment, we capped the value of the humidity adjustment factor in the IMPROVE algorithm ("f(RH)") at the value it has for a relative humidity of 95 percent. The effect of measurement errors in relative humidity at values above 95 percent on the value of f(RH) and thus on reconstructed total light extinction is considerable because of the highly nonlinear form of the function in that range. This creates uncertainty as to the representativeness of the extinction values calculated with high values of relative humidity. In addition, very high values of relative humidity may be due to ongoing or very recent precipitation or fog. Persons

[23] This simplification may be eliminated for the final version of this assessment.

may not expect or value clear visibility during such conditions. Later, consideration will be given to the interpretation of these results and the appropriate treatment of days with very high relative humidity in the statistical form of possible secondary PM NAAQS aimed at protection of visibility in urban areas.

3.4 SUMMARY OF RESULTS FOR CURRENT CONDITIONS

3.4.1 Levels of Estimated $PM_{2.5}$, $PM_{2.5}$ Components, $PM_{10-2.5}$, and Relative Humidity

Figure 3-7 presents box-and-whisker plots to illustrate the distributions in each study area of the estimates of 1-hour $PM_{2.5}$ (the diurnalized FRM value, resulting from step 4 in section 3.4.1), $PM_{10-2.5}$, and relative humidity over the entire 2005-2007 study period. In the plot for each parameter, areas are ordered by longitude, to make it easier to see east-versus-west regional differences. For these three parameters, the distributions are given for all the daylight 1-hour estimates. Similar plots of the daily maximum daylight 1-hour values of $PM_{2.5}$, $PM_{10-2.5}$, and relative humidity concentration are available in Appendix B, as are plots of all daylight 1-hour values for each of the $PM_{2.5}$ component species.

From these plots we see that the distributions of $PM_{2.5}$ generally trend toward higher concentrations from west to east except for the two California urban locations which have $PM_{2.5}$ concentrations more typical of eastern areas. The lowest median $PM_{2.5}$ concentrations are in Tacoma, WA, and Phoenix, AZ. Median $PM_{10-2.5}$ concentrations are highest in St. Louis, MO, and Phoenix, AZ, and lower elsewhere. The highest outlier $PM_{10-2.5}$ concentrations are in St. Louis, MO, and Los Angeles, CA. Relative humidity is lowest for the western urban areas except for Tacoma, WA, which is similar to the northeastern urban locations with respect to humidity. These hourly daylight PM concentration and relative humidity box and whisker plots are consistent with our expectations based on regional 24-hour PM concentration values and humidity climatology.

3.4.2 Levels of Estimated Total Light Extinction

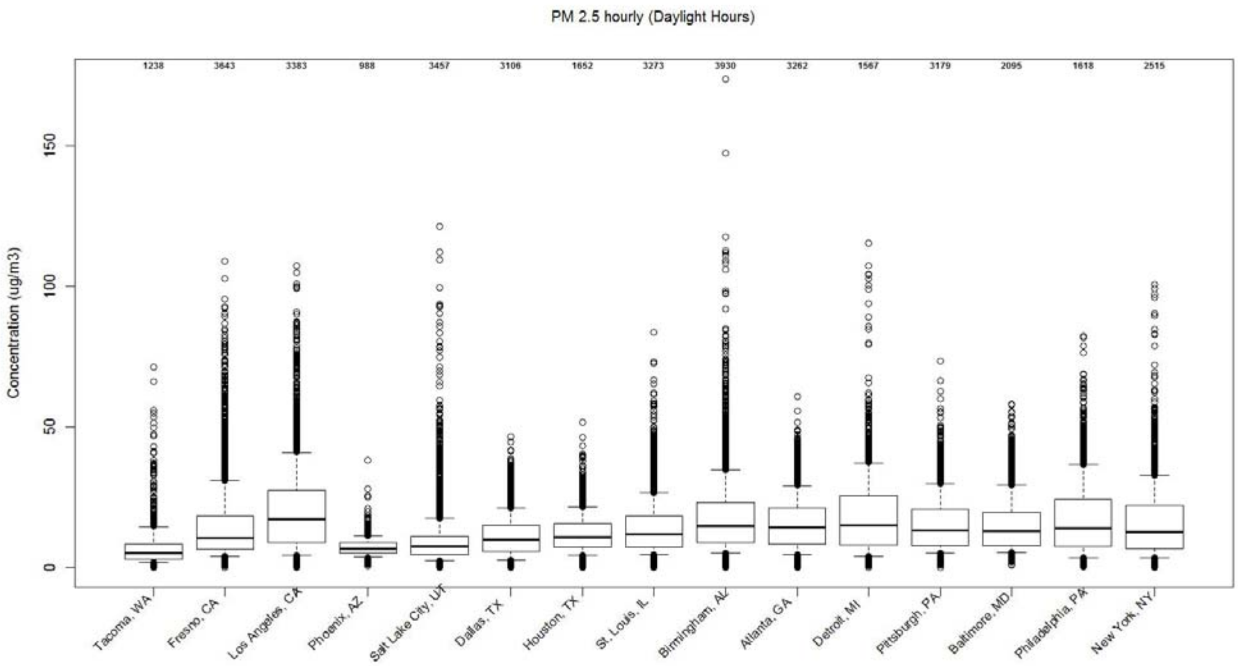
Figure 3-8 presents box-and-whisker plots to illustrate the distributions of the estimates of daylight 1-hour reconstructed total light extinction levels in each area in each year. The distribution of the individual 1-hour values (8a) and the daily maximum 1-hour values (8b) are both shown. The horizontal dashed lines in the plots represent the low, middle, and high candidate protective levels (CPL) as discussed in section 2.6. These benchmarks for total light extinction are 74, 122, and 201 Mm^{-1}, corresponding to the benchmark VAQ values of 20 dv, 25 dv and 30 dv. Table 3-6 provides the percentages of days (across all of 2005-2007, unweighted) in which the daily maximum daylight 1-hour total light extinction level was greater than each of the three candidate protective levels.

As was also seen in the comparable $PM_{2.5}$ box and whisker plots in Figure 3-7, the hourly total light extinction values in Figure 3-8 tend to be higher in the eastern urban areas and lower in the non-California western urban areas. The distributions of maximum daily total light extinction values are higher (Figure 3-8b), as expected, than for all hours (Figure 3-8a). Both Figure 3-8 and Table 3-6 indicate that all 15 urban areas have daily maximum hourly total light extinctions that exceed even the highest of the CPL some of the time. Again, the non-California western urban locations have the lowest frequency of maximum hourly total light extinction with values in excess of the high CPL less than 10% of the time. Except for the two Texas and the non-California western urban areas, all of the other urban areas exceed that high CPL about one-quarter to one-half the time. Based on these estimated maximum hourly total light extinction estimates, all 15 of the urban areas exceed the low CPL for about 60% to 100% of the days. As noted in section 3.2.1, in most of the study areas the study site used in this assessment is not the site in the study area with the highest concentrations of $PM_{2.5}$.

In the last review of the secondary PM NAAQS, the pattern of light extinction during the day was of particular interest. To illustrate the distributions of 1-hour total light extinction levels in specific daylight hours, Figure 3-9 shows the distributions of 1-hour total light extinction across the entire three-year study period, individually for the study areas. (Appendix E provides additional graphics related to temporal/spatial patterns of light extinction.) These plots show that high total light extinction can occur during any of the daylight hours, though for most of these urban areas the early morning hours have the highest total light extinction. Urban areas without a prominent preference for early morning high total light extinction include Phoenix, AZ; Salt Lake City, UT; Tacoma, WA; Fresno, CA; and Philadelphia, PA.

Figure 3-7. Distribution of PM parameters and relative humidity across the 2005-2007 period, by study area

(a) Estimates of 1-hour $PM_{2.5}$ mass, based on applying continuous instrument-based diurnal profiles to 24-hour FRM $PM_{2.5}$ mass



(b) Estimates of 1-hour $PM_{10-2.5}$

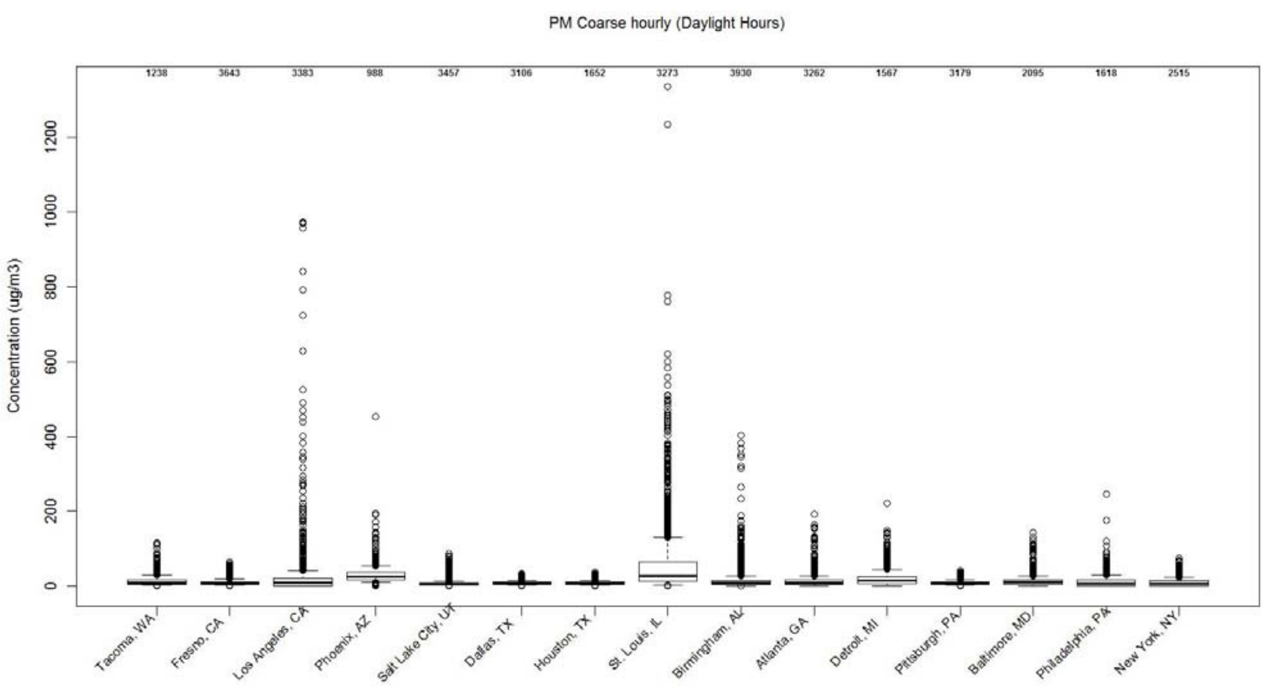


Figure 3-7. (cont.). Distribution of PM parameters and relative humidity across the 2005-2007 period, by study area

(c) 1-hour relative humidity

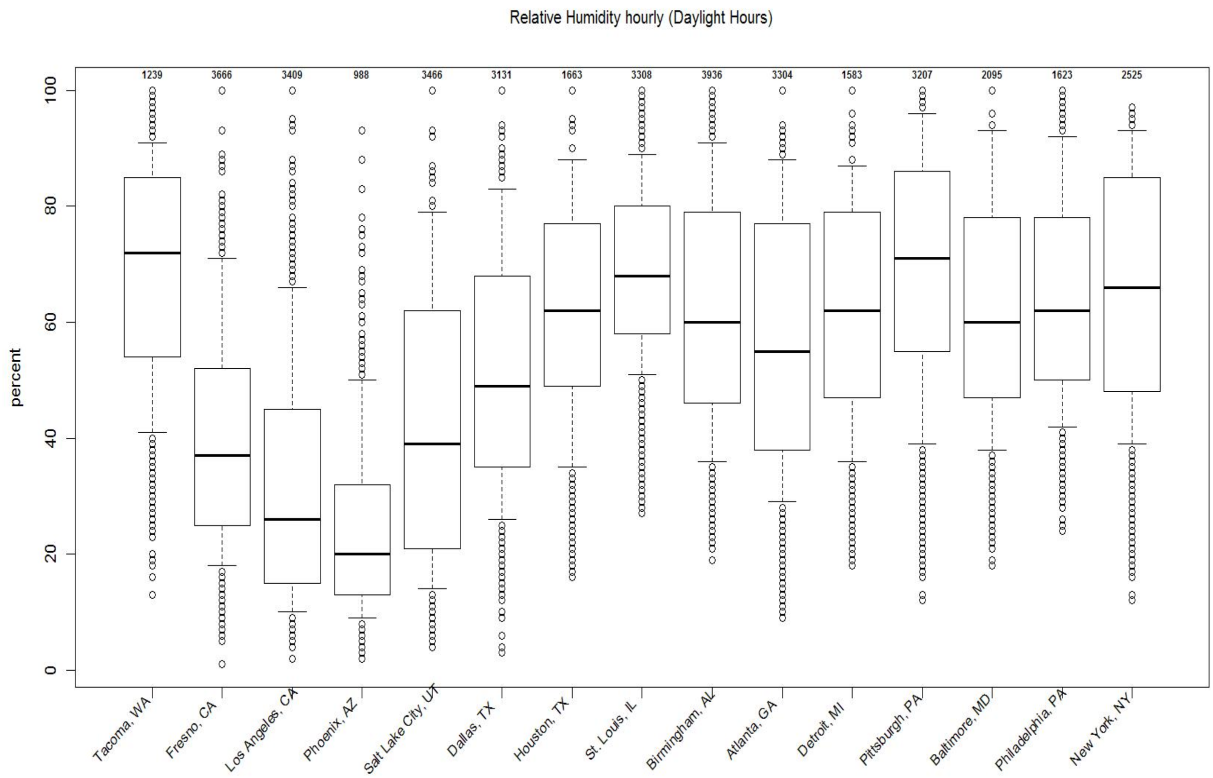
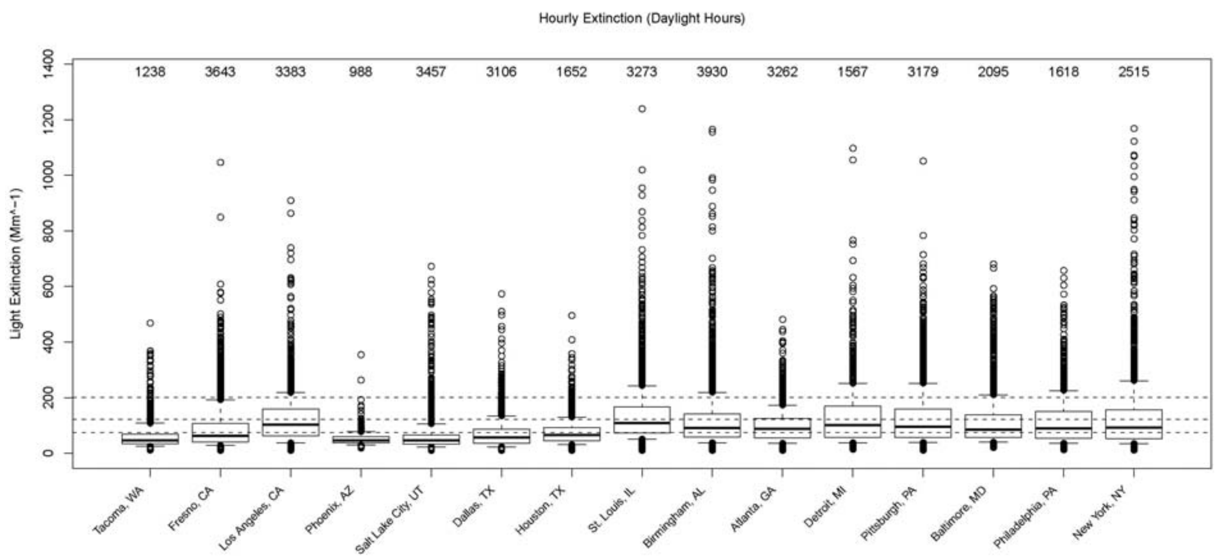


Figure 3-8. Distributions of estimated daylight 1-hour total light extinction and maximum daily daylight 1-hour total light extinction across the 2005-2007 period, by study area.

(a) Individual 1-hour values



(b) Maximum daily values

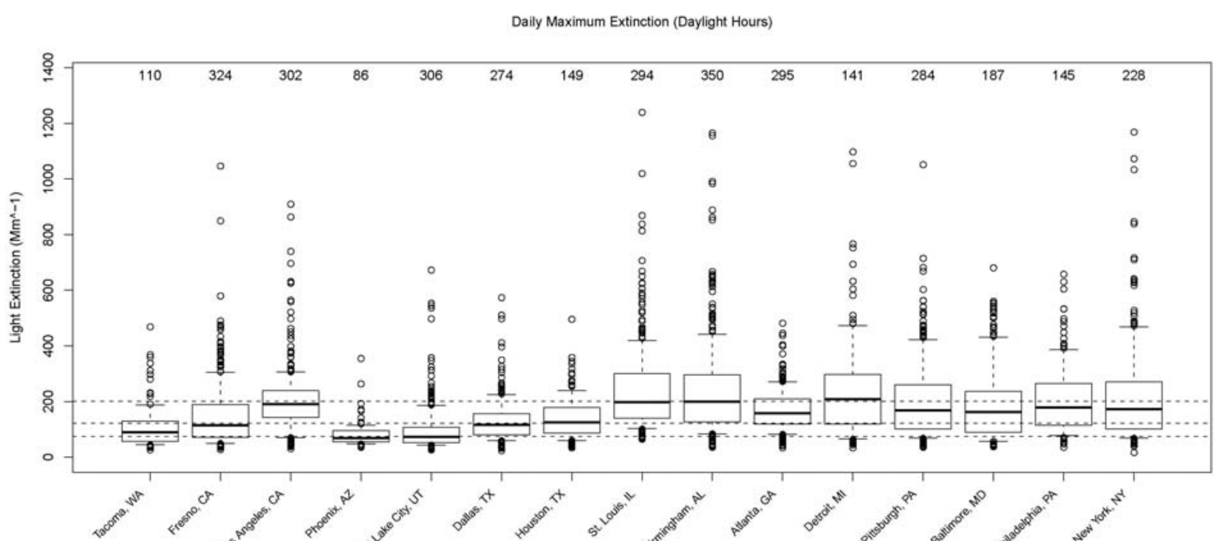
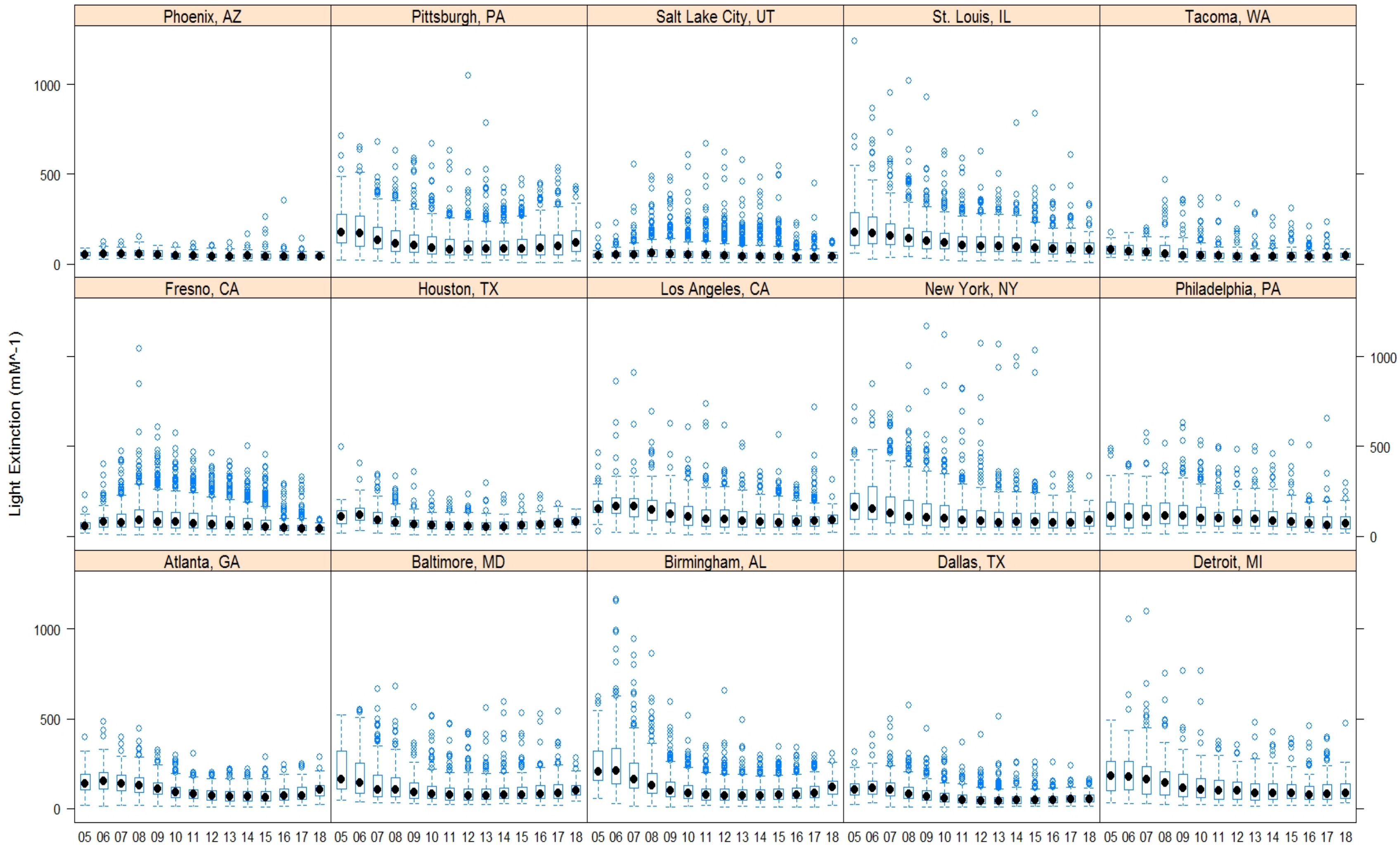


Table 3-6. Percentage of days in which daily maximum daylight 1-hour total light extinction exceeded three candidate protective levels across the 2005-2007 period, by study area

Study Area	Number of Days with Estimates	Candidate Protective Level		
		74 Mm^{-1}	122 Mm^{-1}	201 Mm^{-1}
		Percentage of days		
Tacoma	110	68	36	9
Fresno	324	80	51	24
Los Angeles-South Coast Air Basin	302	92	80	49
Phoenix	86	59	13	3
Salt Lake City	306	61	24	9
Dallas	274	86	53	14
Houston	149	89	58	21
St. Louis	294	100	86	55
Birmingham	350	96	80	52
Atlanta	295	95	80	34
Detroit-Ann Arbor	141	91	79	57
Pittsburgh	284	93	70	43
Baltimore	187	88	65	38
Philadelphia-Wilmington	145	95	76	46
New York-N. New Jersey-Long Island	228	91	70	46
Average	***232***	***86***	***61***	***33***

Figure 3-9. Distributions of 1-hour total light extinction levels by daylight hour across the 2005-2007 period, by study area



3.4.3 Patterns of Relative Humidity and Relationship between Relative Humidity and Total Light Extinction

Figure 3-10 shows the distribution of relative humidity values at each daylight hour, for each study area across 2005-2007 (Seasonal patterns are shown in Appendix E). As expected, in every area relative humidity is lowest in the early afternoon, typically the warmest part of the day. Relative humidity is most similar across areas in this time period, as observed in the 2005 Staff Paper. However, even in this period there are notable differences among areas. This variation was not as evident in the information presented in the 2005 Staff Paper because only regionally averaged information was presented. In all areas, there is considerable variation in hour-specific relative humidity during the three-year period.

To allow closer inspection of estimated total light extinction values that have been calculated using high relative humidity values, Figure 3-11 is a scatter plot of actual (uncapped) 1-hour relative humidity and 1-hour reconstructed total light extinction. Horizontal lines are included in each of the individual plots corresponding to the three benchmarks for total light extinction and a vertical line in each for 90 percent relative humidity. As stated above, f(RH) was capped at its value when relative humidity is 95 percent. While some of the highest values of total light extinction occur when relative humidity is above 90 percent, the majority of the instances with total light extinction greater than the candidate protective levels occur when relative humidity is 90 percent or lower. Notice that in Figure 3-11 there are plenty of high humidity conditions for each urban area that correspond to low total light extinction values. This is because humid air does not by itself contribute to light extinction. Particles composed of material that absorbs water in high relative humidity conditions (e.g., sulfate and nitrate PM) swell to larger solution droplets that scatter more light than their smaller dry particle counterparts in a less humid environment. The magnitude of the relative humidity effect on light extinction depends directly on the concentration of these hygroscopic PM components. (Figure 3-11 reveals skips in reported relative humidity values for some but not all the study areas. This is a result of calculations of relative humidity from dry and wet bulb temperatures reported to the nearest whole Celsius degree.)

Figure 3-10. Distributions of 1-hour relative humidity levels by daylight hour across the 2005-2007 period, by study area

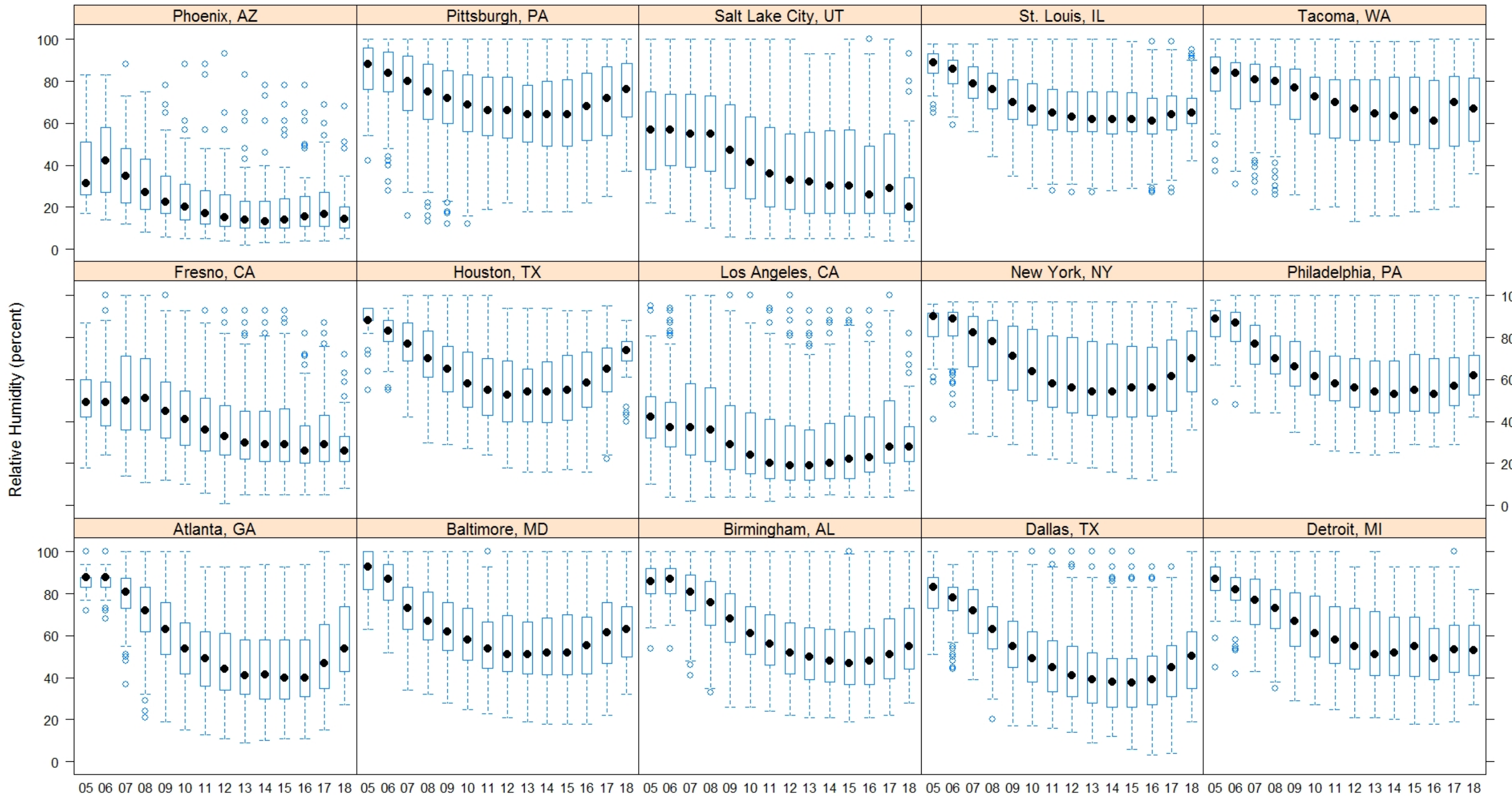
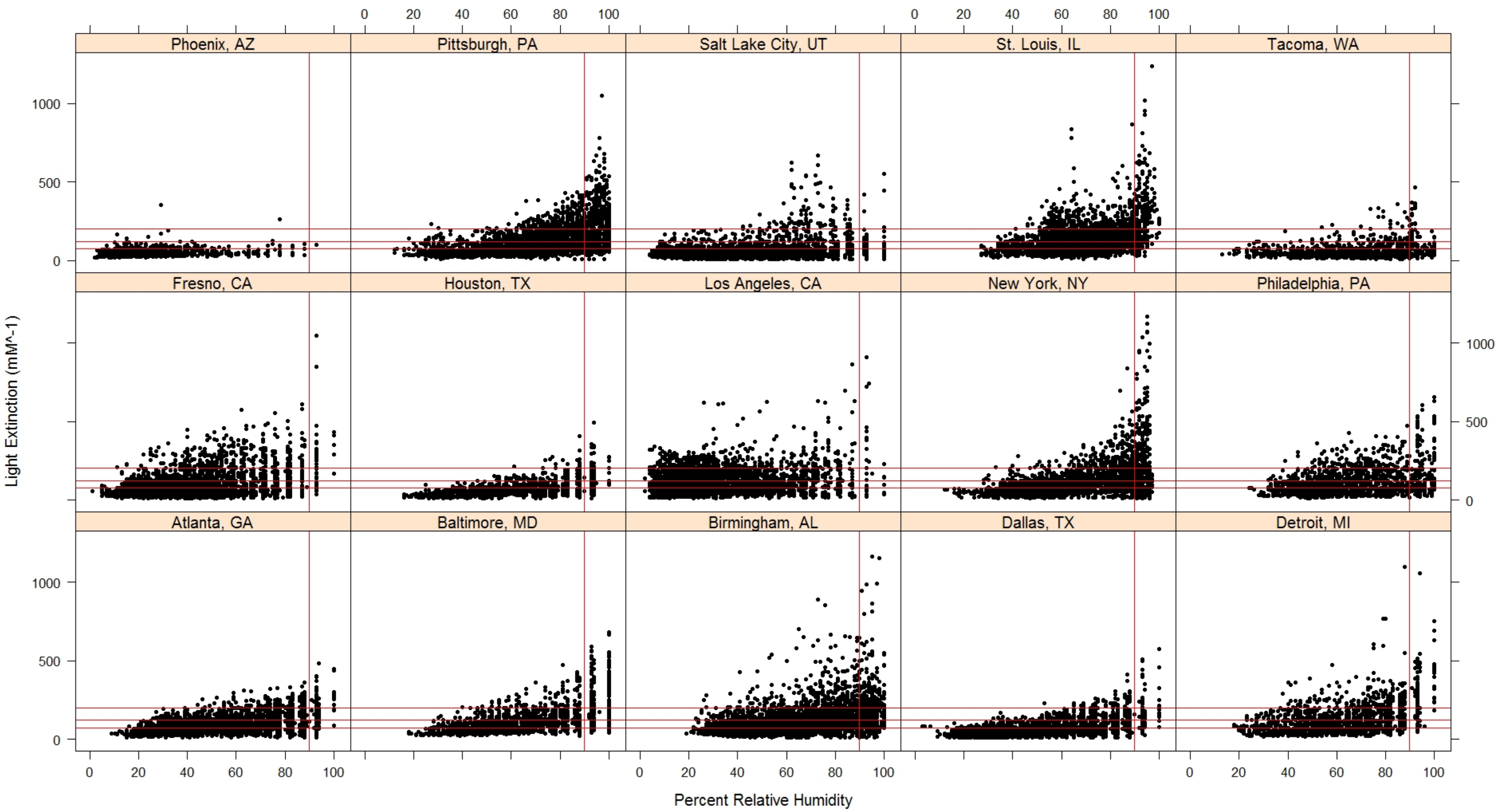


Figure 3-11. Scatter plot of daylight 1-hour relative humidity (percent) vs. reconstructed total light extinction (Mm^{-1}) across the 2005-2007 period, by study area



3.4.4 Extinction Budgets for High Total Light Extinction Conditions

An extinction budget for a single period shows the contribution that each PM component makes to total light extinction via the additive terms of the IMPROVE algorithm. It can be expected that the pattern in the extinction budgets will vary by time of year and by study area. Examination of extinction budgets allows initial insights into what emission reduction approach may be most effective in reducing total light extinction.

Figures 3-12 through 3-19 present day-specific maximum daylight 1-hour light extinction budgets for the 10% of the days in each study area that have the highest daily maximum 1-hour light extinction levels. (These figures show PM light extinction, not total light extinction. The Rayleigh scattering term of 10 Mm^{-1} is not shown in Figures 3-12 through 3-19.) The pattern of results shown in Figures 3-12 through 3-19 is generally as expected in light of emissions and climate differences among study areas. Except for the $PM_{2.5}$ soil component, each of the components of total light extinction is a major contributor to extreme light extinction events at some time and location. In the West, carbonaceous $PM_{2.5}$ (i.e., organic mass and elemental carbon), nitrate, and/or coarse mass (especially in Phoenix) tend to be most responsible for these high haze hours. In the East it tends to be sulfate, nitrate, and the carbonaceous $PM_{2.5}$ components that are the large contributors to total light extinction. From the sample period dates we can determine the seasonal variations in major components. Nitrate and carbonaceous $PM_{2.5}$ contribute more to the extreme light extinction periods during winter, while sulfate contributes more in the summer. In many of the more northerly eastern urban areas, a combination of sulfate and nitrate contributes to high light extinction year-round.

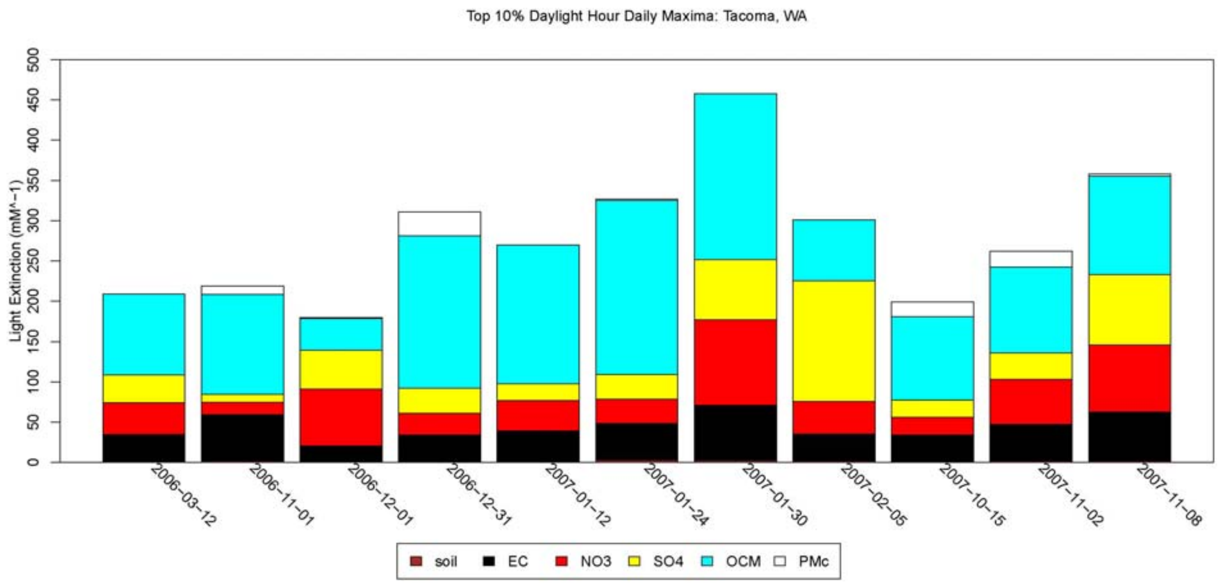
Looking at individual urban areas, Tacoma has its highest light extinction hours in the colder months and primarily due to carbonaceous $PM_{2.5}$ components. Extreme haze hours in the two California urban areas are primarily caused by high nitrate $PM_{2.5}$, though Los Angeles has several extreme hours associated with coarse PM. Phoenix is unique among the 15 urban areas in having most of its extreme light extinction caused by coarse PM, though there are a few top-10-percent days where the maximum hourly haze is dominated by carbonaceous, sulfate, and nitrate $PM_{2.5}$. Salt Lake City has extreme haze hours caused mostly by nitrate in the winter with some periods with carbonaceous $PM_{2.5}$ being the major contributor. Dallas and Houston have high contributions to total light extinction by sulfate $PM_{2.5}$, but Dallas includes winter nitrate and carbonaceous-caused extreme hours in the winter while Houston seems to have less contribution by nitrate. Sulfate in the summer and nitrate in the fall and winter are responsible for most of the extreme light extinction at St. Louis, though there are several maximum hourly periods where coarse PM is a major component. Birmingham and Atlanta are similar in having sulfate year-round and winter carbonaceous $PM_{2.5}$ as major contributors to their extreme light extinction periods. Detroit has frequent large light extinction contributions from nitrate $PM_{2.5}$, mostly in the winter, as well as some contributions from sulfate $PM_{2.5}$ year-round and one winter period with high contributions from carbonaceous $PM_{2.5}$. The remaining four urban locations (i.e., Pittsburgh, Baltimore, Philadelphia, and New York) are similar in that most of their extreme light extinction is from year-round combinations of sulfate and nitrate. New York also has some winter carbonaceous contributions to its extreme light extinction.

3.5 POLICY RELEVANT BACKGROUND

Policy relevant background levels of total light extinction have been estimated for this assessment by relying on outputs for the 2004 CMAQ run in which anthropogenic emissions in the U.S., Canada, and Mexico were omitted, as described in the second draft ISA. Estimates of PRB for total light extinction were calculated from modeled concentrations of $PM_{2.5}$ components using the IMPROVE algorithm. The necessary component concentrations were extracted from the CMAQ output files, as they were not summarized in the second draft ISA. More detail is provided in Appendix C.

It is also necessary to have estimates of PRB for $PM_{10-2.5}$, as input to the IMPROVE algorithm. The second draft ISA for this review does not present any new information on this subject. The approach used in the two previous reviews was to present the historical range of annual means of $PM_{10-2.5}$ concentrations from IMPROVE monitoring sites selected as being least influenced by anthropogenic emissions (US EPA, 2004, Table 3E-1). For this assessment, EPA staff estimated PRB for $PM_{10-2.5}$ using a contour map based on average 2000-2004 $PM_{10-2.5}$ concentrations from all IMPROVE monitoring sites, found in a recent report from the IMPROVE program (DeBell, 2006).

Figure 3-12. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction for 2005-2007 (Tacoma and Fresno)



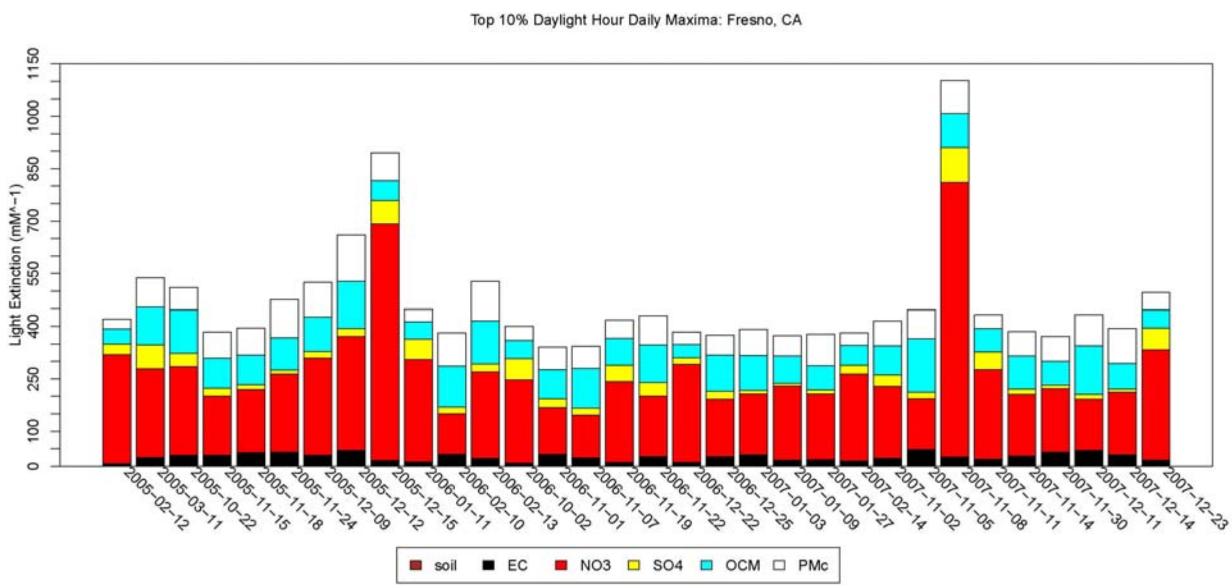
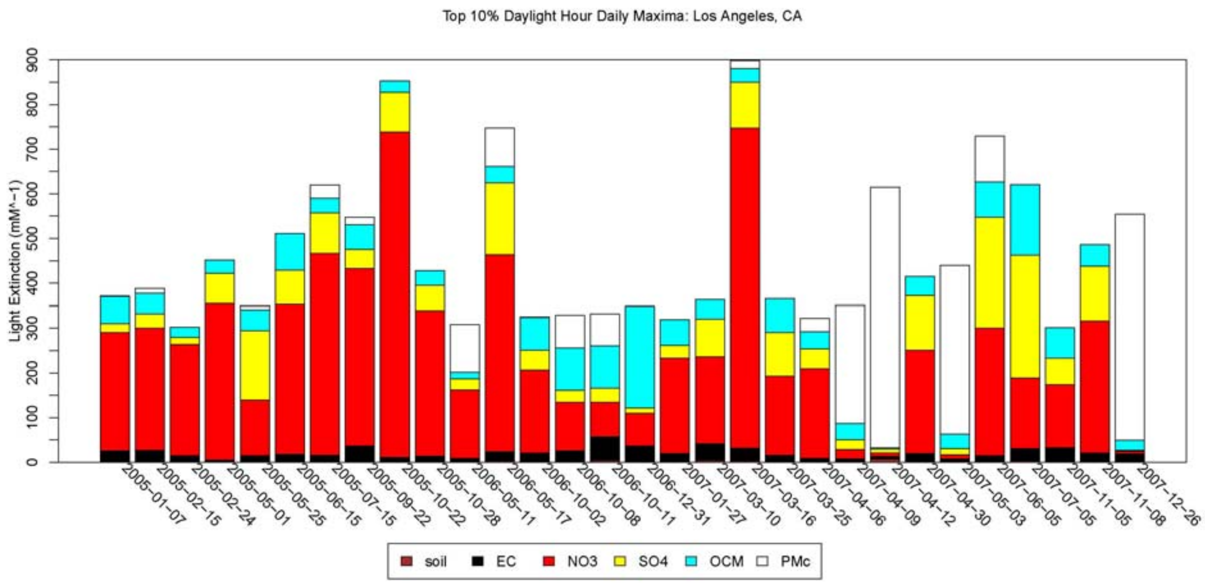


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction for 2005-2007 (Los Angeles and Phoenix)



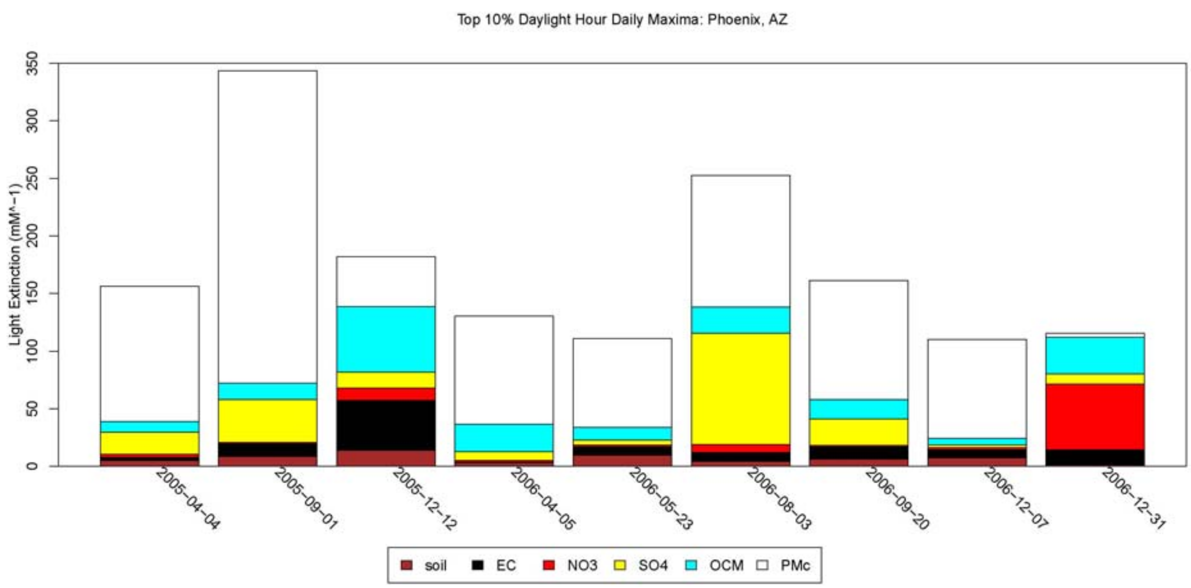
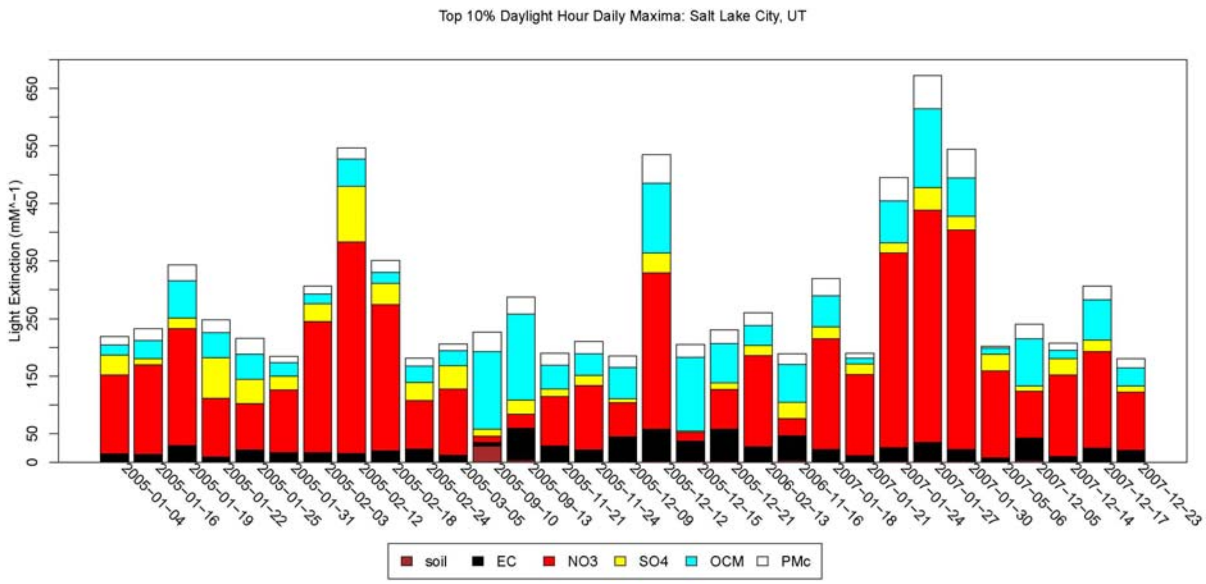


Figure 3-14. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction for 2005-2007 (Salt Lake City and Dallas)



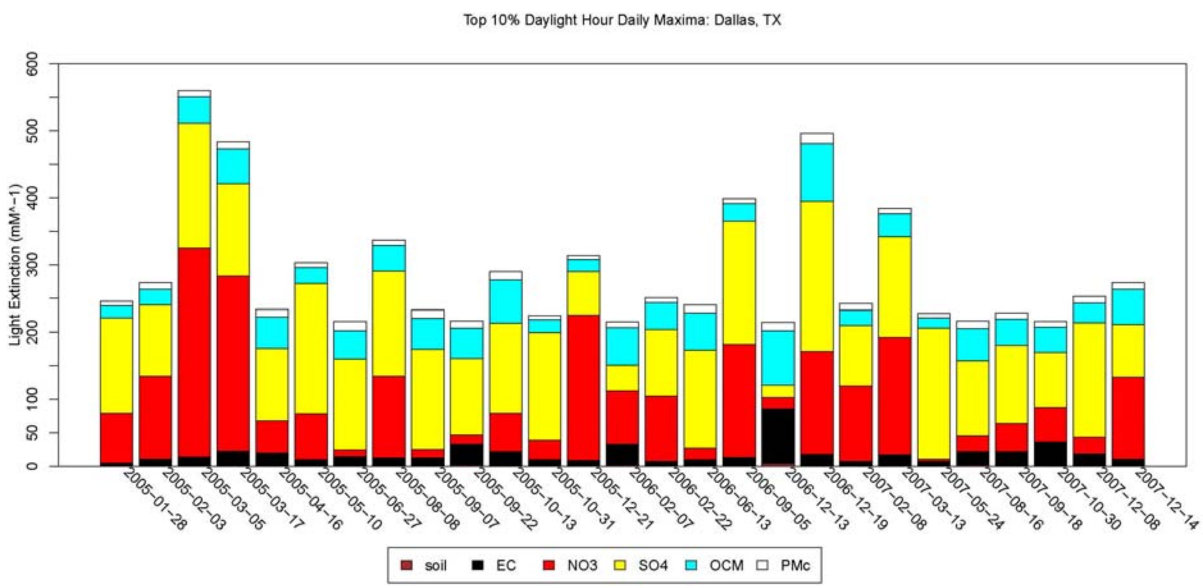
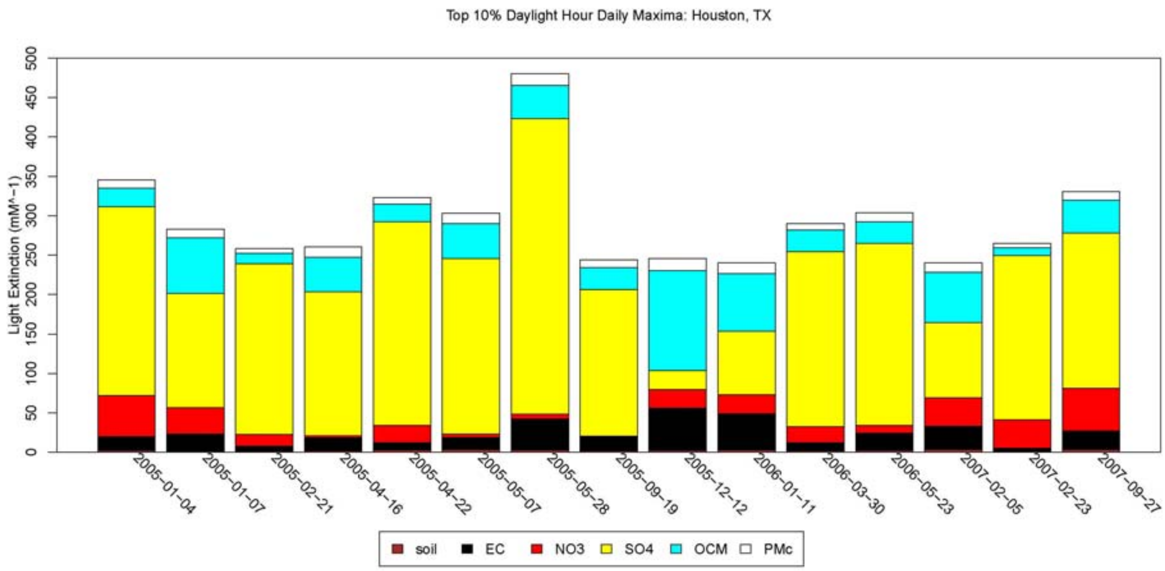


Figure 3-15. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction for 2005-2007 (Houston and St. Louis)



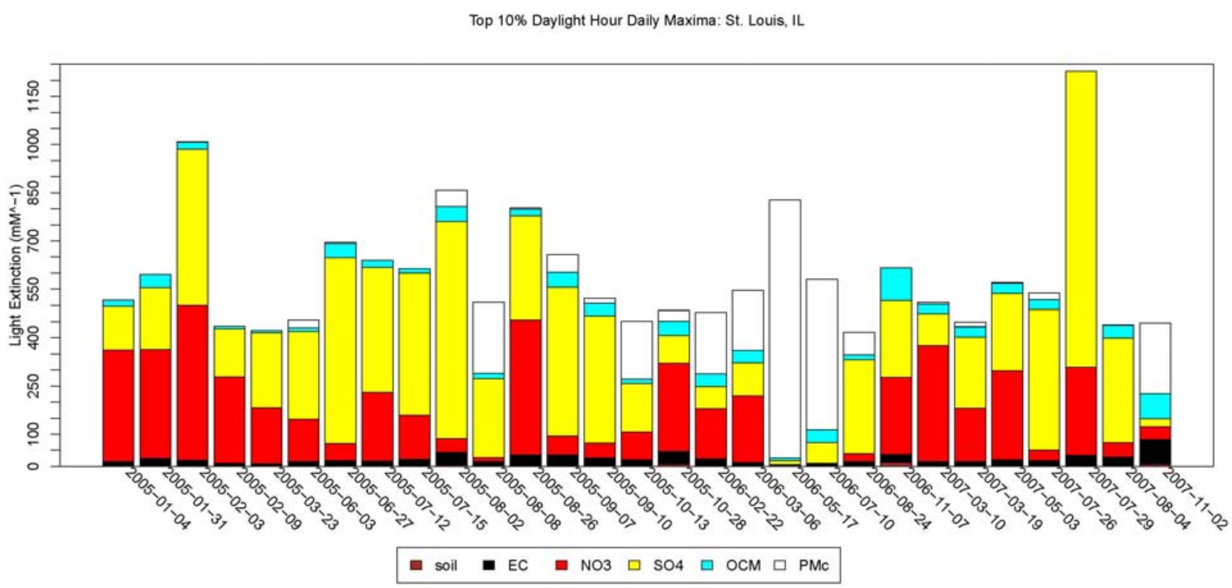
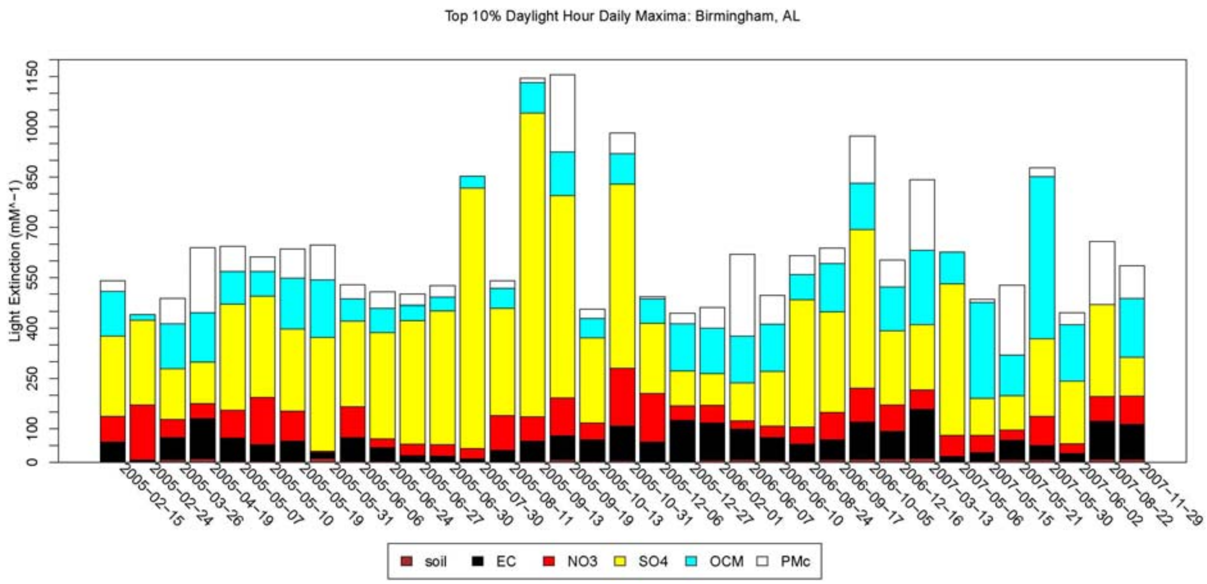


Figure 3-16. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction for 2005-2007 (Birmingham and Atlanta)



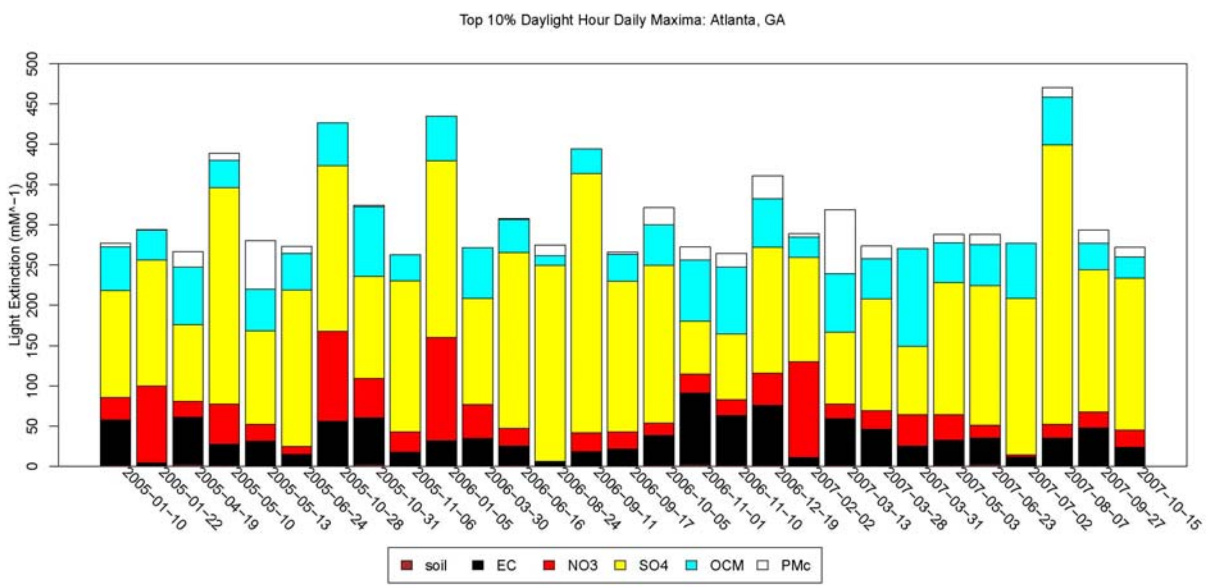
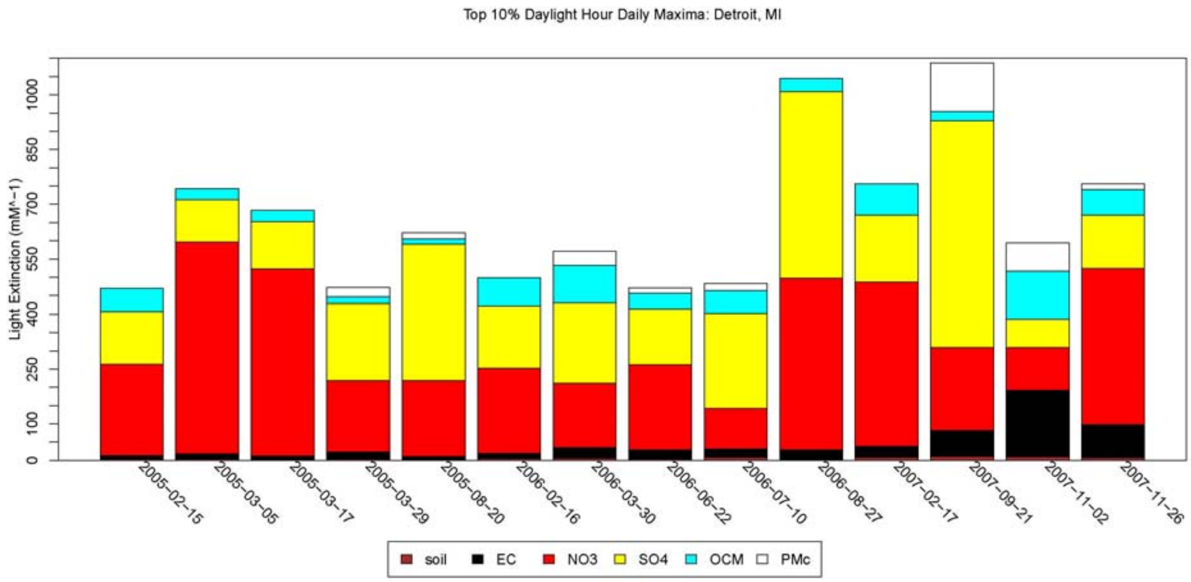


Figure 3-17. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction for 2005-2007 (Detroit and Baltimore)



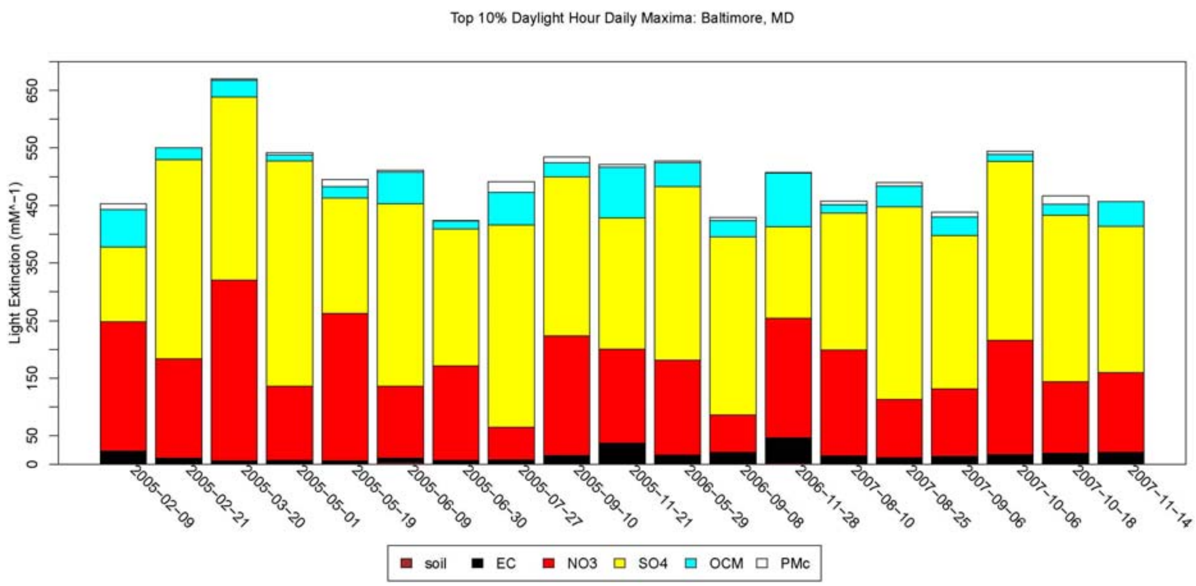
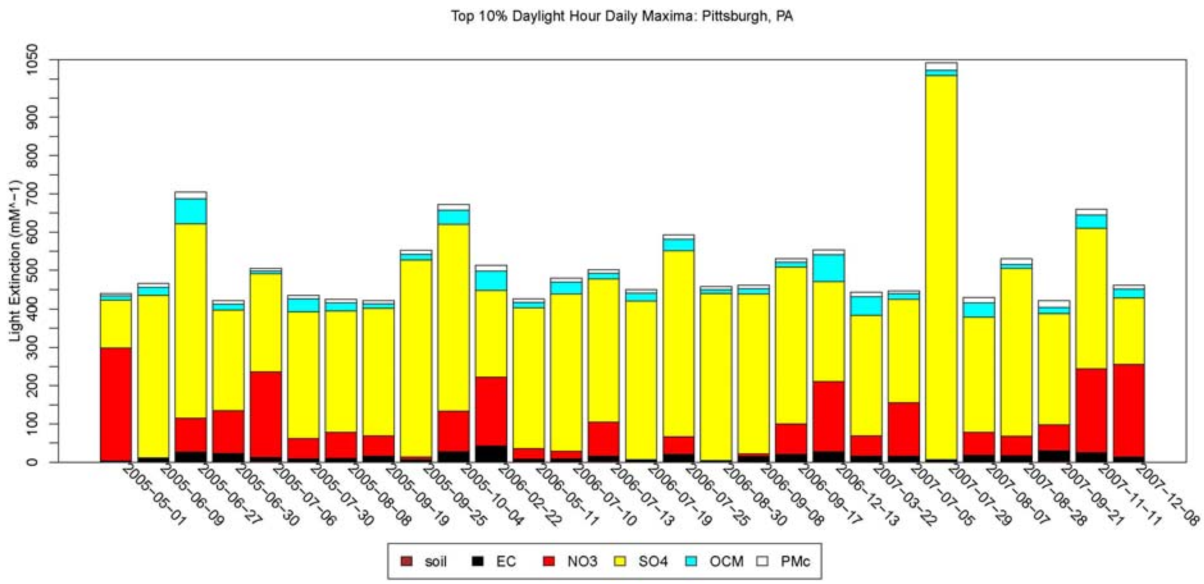


Figure 3-18. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction for 2005-2007 (Pittsburgh and Philadelphia)



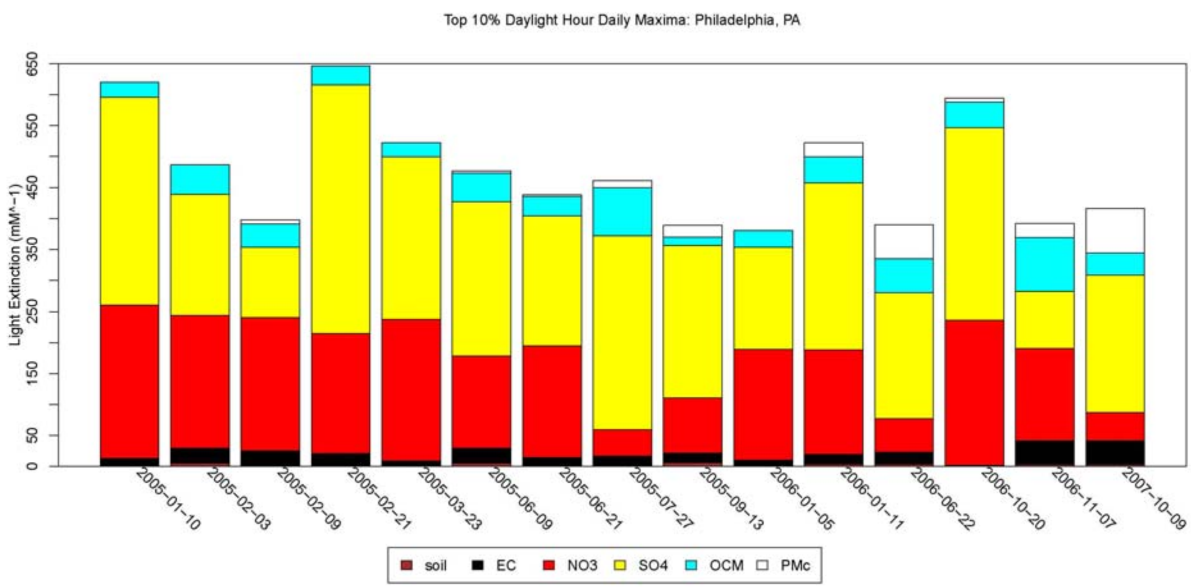
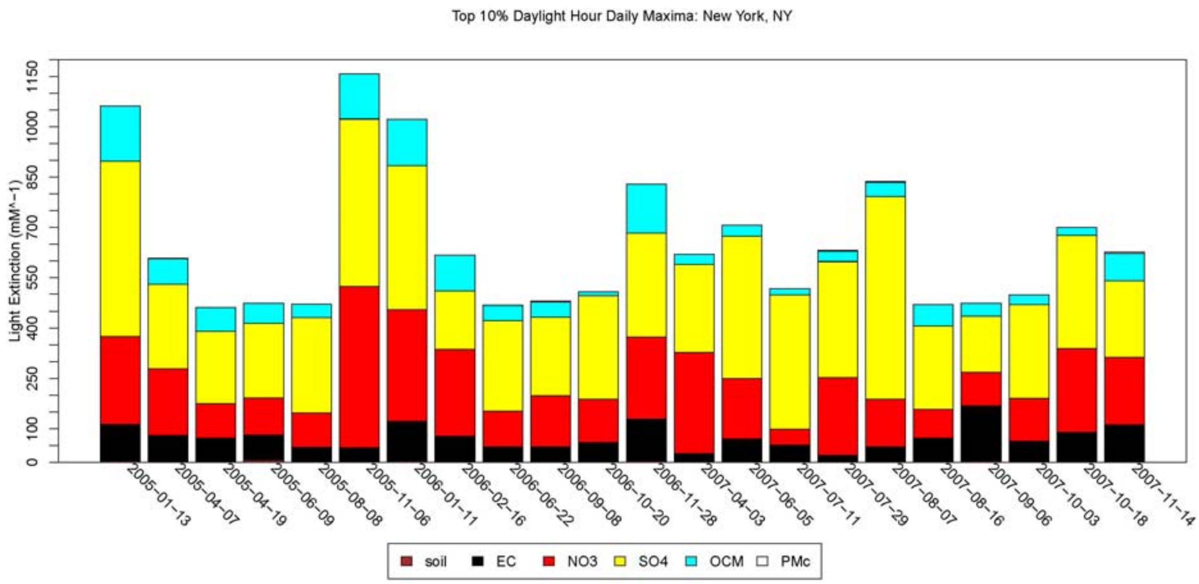


Figure 3-19. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction for 2005-2007 (New York)



4 TOTAL LIGHT EXTINCTION UNDER "WHAT IF" CONDITIONS OF JUST MEETING SPECIFIC ALTERNATIVE SECONDARY NAAQS

4.1 ALTERNATIVE SECONDARY NAAQS BASED ON MEASURED TOTAL LIGHT EXTINCTION AS THE INDICATOR

4.1.1 Indicator and Monitoring Method

As proposed in the Scope and Methods plan, the indicator considered in this section is total light extinction, assumed to be measured by a continuous instrument, or instrument pair, capable of reporting both light scattering and light absorption. For example, the measurement method could be an Aethalometer® or similar instrument for measuring light absorption paired with a nephelometer, with both instruments using a PM_{10} inlet so that total light extinction due to $PM_{2.5}$ and $PM_{10-2.5}$ combined (and gases) would be measured. The measurement would include the effect of Rayleigh scattering by gases, while the alternative NAAQS would be intended to provide protection from the loss in visual air quality due to PM. Therefore, it would be necessary to account for the contribution to measured total light extinction from Rayleigh scattering either when setting the level of the NAAQS (by adding an increment of about 10 Mm^{-1} to the intended permitted level of light extinction caused by PM) or in the data interpretation rule for comparing instrument readings to the NAAQS (by subtracting about 10 Mm^{-1} before comparison to the level of the NAAQS).

4.1.2 Alternative Secondary NAAQS Scenarios based on Measured Total Light Extinction

Six alternative NAAQS scenarios presented in Table 4-1 are analyzed in this section, each based on daily maximum daylight 1-hour total light extinction. The scenarios are ordered from least to most stringent.

Table 4-1. Alternative Secondary NAAQS Scenarios for Light Extinction

Level (including Rayleigh scattering)	Annual Percentile	Form
201 Mm-1	90	3-year average of percentile value
201 Mm-1	95	3-year average of percentile value
122 Mm-1	90	3-year average of percentile value
122 Mm-1	95	3-year average of percentile value
74 Mm-1	90	3-year average of percentile value
74 Mm-1	95	3-year average of percentile value

It is useful to think ahead to monitor siting aspects of NAAQS implementation, so that the suitability of the monitoring sites used in this assessment for the purpose of this section can be considered.

4.1.3 Monitoring Site Considerations for Alternative Secondary NAAQS Based on Measured Total Light Extinction

It is most likely that instruments that would be used to implement a secondary NAAQS with a measured light extinction indicator will be "closed path" instruments that react only to air quality in their immediate vicinity. However, light paths that matter to perceived visual air quality are likely to be several kilometers long. Therefore, a monitoring site should be at least neighborhood in scale, i.e., its relationship to emission sources and transport should be such that measurements made at the site reasonably reflect concentrations in an area surrounding the site of at least about 0.5 to 4 kilometers in diameter.

It would be logical to require that in any urban area for which light extinction monitoring is deemed a necessary requirement, at least one monitoring site would be placed in an area expected to have the maximum total light extinction conditions, subject to the above scale of representation consideration and possibly also subject to the condition that the site be in an area (or reasonably represent such an area) where scenic vistas are able to be perceived by people. i.e., that the site is "population oriented." Given that site paths of concern will typically be several kilometers long, it is difficult to imagine a neighborhood scale monitoring location within the census-defined urbanized area of an urban area which would not be "population oriented" for purposes of visual air quality, as "neighborhood" size land areas typically would have residents, workers, etc. somewhere within them during daylight hours.

With regard to the monitoring sites used in this assessment, all are reported to be, or appear to be, neighborhood or larger scale, and all are in areas where people are present during daylight hours. The sites in Detroit (Dearborn) and New York-N.New Jersey are, however, rather close to an industrial source and a major interstate highway interchange/turnpike exit, respectively. Significantly, most of the study sites are not the highest PM2.5 concentration site in their urban area, so a "what if" scenario that manipulates the "current conditions" at these sites to "just meet" an alternative secondary NAAQS might implicitly leave other parts of their urban areas with total light extinction above the NAAQS.

4.1.4 Approach to Modeling "What If" Conditions for Alternative Secondary NAAQS based on Measured Total Light Extinction

Before modeling "what if" conditions, EPA staff augmented the data set described in Table 4 so that the sets of study days for Houston and Phoenix were seasonally balanced despite the lack of actual monitoring data for one quarter in each city. For the first quarter of 2005 in

Phoenix, we substituted the available 12 days from the first quarter of 2006. For the fourth quarter of 2007 in Houston, we substituted 13 randomly drawn days from the fourth quarters of 2005 and 2006.

Also, Tacoma (originally) and Phoenix (after this augmentation) each have only two calendar years of suitable data, while the form of the alternative NAAQS scenarios requires the averaging of the 90th or 95th percentile values from three years. In Tacoma and Phoenix, for every step in the analysis at which a design value is used as an input or reported as an output, we averaged the percentile values from the only two available years.

We modeled daily maximum daylight 1-hour total light extinction under each of the "what if" scenarios (in which each study area "just meets" one of the alternative secondary NAAQS listed in section 4.1.2) via the following steps. These steps are essentially the same as the "proportional rollback" steps that have been used in the health risk assessment modeling of "what if" conditions in several previous NAAQS reviews for PM and other criteria pollutants.

1. Identify the appropriate percentile (90^{th} or 95^{th}) daily light extinction value in each year, noting the day and hour each occurred, and average these values across years to calculate the light extinction design value for each site consistent with the percentile form of the NAAQS scenario. The two resulting design values for each area (for the 90^{th} and 95^{th} percentile forms) are shown in Table 4-2. (Note that in a few cases, which are identified by a footnote, the study area meets one or more of the NAAQS scenario under current conditions. In these cases, the "current conditions" total light extinction values are not adjusted, i.e., total light extinction values are never "rolled up.")

2. Using the same days and hours, find the three (or two, in the case of Phoenix and Houston for which there were only two years of suitable data available) corresponding values of PRB total light extinction, and average these values across years to calculate the PRB portion of the design value.

3. Subtract the value from step 2 from the value from step 1, to determine the non-PRB portion of the design value.

4. Calculate the percentage reduction required in non-PRB total light extinction in order to reduce the design value to the total light extinction level that defines the NAAQS scenario, using the following equation:

Percent reduction required = 1 – (NAAQS level – PRB portion of the design value)/(non-PRB portion of the design value)

The percentage reductions determined in this step are shown in Table 4-3.

5. Turning to the entire set of day/hour-specific actual and PRB daylight total light extinction values for the three (or two) year period, determine the non-PRB portion of total light extinction, reduce it by the percentage determined in step 4, and add back in the PRB total light extinction. The result is the "just meets" total light extinction value for that day and hour.

Note that in these steps, it is not necessary to make any explicit or implicit assumption about what PM components would be reduced to allow the area to meet the NAAQS scenario, as the NAAQS scenario's target design value is itself in units of light extinction.

Table 4-2. Current Conditions total light extinction design values for the study areas.

Study Area	Design Value for 90th Percentile Form (Mm^{-1})	Design Value for 95th Percentile Form (Mm^{-1})
Tacoma	228	278
Fresno	308	403
Los Angeles-South Coast Air Basin	323	436
Phoenix	117*	154*
Salt Lake City	184	256
Dallas	213*	262
Houston	235	275
St. Louis	420	512
Birmingham	436	565
Atlanta	269	291
Detroit-Ann Arbor	444	636
Pittsburgh	425	481
Baltimore	441	484
Philadelphia-Wilmington	409	436
New York-N.New Jersey-Long Island	449	538

* This design value meets one or more of the NAAQS scenarios.

Table 4-3. Percentage reductions in non-PRB light extinction required to "just meet" the NAAQS scenarios based on measured light extinction.

	NAAQS Scenarios Based on Maximum Daily 1-hour Daylight Total Light Extinction, Average of Percentile Value Over Three Years					
Total Light Extinction Level (Mm^{-1})	**201**	**201**	**122**	**122**	**74**	**74**
Percentile Form	**90th**	**95th**	**90th**	**95th**	**90th**	**95th**
Area	**Percentage Reduction Required in Non-PRB Total Light Extinction**					
Tacoma	13	29	51	59	74	77
Fresno	38	53	65	73	82	86
Los Angeles	40	56	66	75	82	87
Phoenix	0	0	0	23	43	59
Salt Lake City	0	23	36	56	65	76
Dallas	7	26	49	59	75	79
Houston	16	29	53	60	76	79
St. Louis	55	64	75	80	87	90
Birmingham	56	67	75	82	87	90
Atlanta	28	33	60	63	79	80
Detroit	58	71	77	84	88	91
Pittsburgh	55	61	75	78	87	88
Baltimore	58	61	76	79	88	89
Philadelphia	54	57	74	76	86	88
New York	59	65	77	80	88	90

4.2 ALTERNATIVE SECONDARY $PM_{2.5}$ NAAQS BASED ON ANNUAL AND 24-HOUR $PM_{2.5}$ MASS

4.2.1 Secondary NAAQS Scenarios Based on Annual and 24-hour $PM_{2.5}$ Mass

In this draft version of the assessment, EPA staff have modeled two "what if" scenarios based on the same indicators and averaging periods as define the current secondary $PM_{2.5}$ NAAQS:

- 15 µg/m^3 weighted annual average $PM_{2.5}$ concentration and 35 µg/m^3 24-hour average $PM_{2.5}$ concentration with a 98th percentile form, both averaged over three years. These are the current secondary NAAQS for $PM_{2.5}$.

- 12 µg/m^3 weighted annual average $PM_{2.5}$ concentration and 25 µg/m^3 24-hour average $PM_{2.5}$ concentration with a 98th percentile form, both averaged over three years.

These are the highest and lowest alternative NAAQS scenarios considered in the health risk assessment, and therefore encompass the full range of alternative primary $PM_{2.5}$ NAAQS being analyzed by EPA staff.

4.2.2 Approach to Modeling Conditions If Secondary $PM_{2.5}$ NAAQS Based on Annual and 24-hour $PM_{2.5}$ Mass Were Just Met

Because these NAAQS scenarios are based on $PM_{2.5}$ mass as the indicator, rather than light extinction, the steps needed to model "what if" conditions are somewhat different, and involve explicit consideration of changes in $PM_{2.5}$ components.

1. Apply proportional rollback to all the $PM_{2.5}$ monitoring sites in each study area, taking into account PRB $PM_{2.5}$ mass, to "just meet" the NAAQS scenario for the area as a whole, not just at the visibility assessment study site. The health risk assessment document describes this procedure in detail. The degree of rollback is controlled by the highest annual or 24-hour design value, which in most study areas is from a site other than the site used in this visibility assessment. The relevant result from this analysis is the percentage reduction in non-PRB $PM_{2.5}$ mass need to "just meet" the NAAQS scenario, for each study area. These percentage reductions are shown in Table 4-4. Note that Phoenix and Salt Lake City meet the 15/35 NAAQS scenario under current conditions, and require no reduction. $PM_{2.5}$ levels in these two cities were not "rolled up."

2. For each day and hour for each $PM_{2.5}$ component, subtract the PRB concentration from the current conditions concentration, to determine the non-PRB portion of the current conditions concentration.

3. Apply the percentage reduction from step 1 to the non-PRB portion of each of the five $PM_{2.5}$ components. Add back the PRB portion of the component.

4. Re-apply the IMPROVE algorithm, using the reduced $PM_{2.5}$ component concentrations, the current conditions $PM_{10-2.5}$ concentration for the day and hour, and relative humidity for the day and hour. Include the term for Rayleigh scattering.

Table 4-4. Percentage reductions required in non-PRB $PM_{2.5}$ mass to "just meet" NAAQS scenarios based on annual and 24-hour $PM_{2.5}$ mass

Study Area	Percentage Reduction Required	
	Annual $PM_{2.5}$ NAAQS = 15 µg/m^3 24-hour $PM_{2.5}$ NAAQS = 35 µg/m^3	Annual $PM_{2.5}$ NAAQS = 12 µg/m^3 24-hour $PM_{2.5}$ NAAQS = 25 µg/m^3
Tacoma	19	43
Fresno	45	61
Los Angeles-South Coast Air Basin	37	55
Phoenix	0*	22
Salt Lake City	37	56
Dallas	0*	7
Houston	6	27
St. Louis	10	37
Birmingham	22	45
Atlanta	8	30
Detroit-Ann Arbor	19	43
Pittsburgh	Being recalculated	Being recalculated
Baltimore	6	33
Philadelphia-Wilmington	8	35
New York-N.New Jersey-Long Island	17	41

* These areas meet this NAAQS scenario under current conditions.

4.3 RESULTS FOR "JUST MEETING" ALL ALTERNATIVE SECONDARY NAAQS SCENARIOS

The modeling described in sections 4.1 and 4.2 resulted in estimates of total light extinction for each day and hour in each study area. Four summaries of these conditions are presented here.

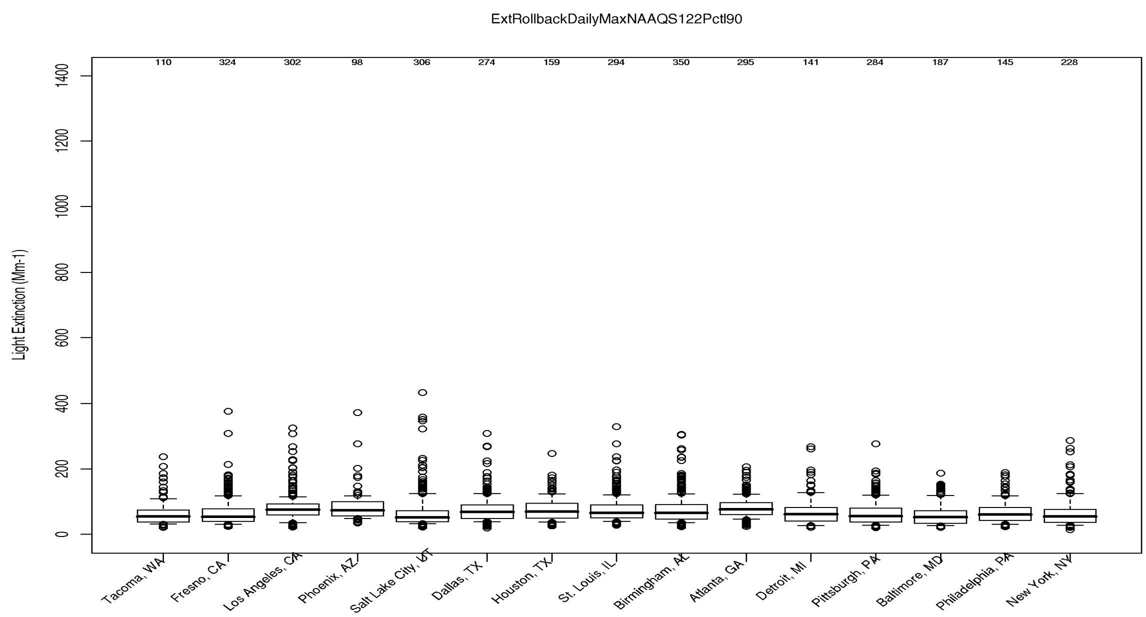
Figure 4-1 shows two box-and-whisker plots of daily maximum daylight 1-hour total light extinction. The top panel (a) is for the single illustrative scenario of a NAAQS based on measured light extinction with a level of 122 Mm^{-1} and a 90th percentile form, which was chosen for this illustration because it is approximately mid-way among the six such scenarios in terms of stringency. Plots for all six scenarios of NAAQS based on measured total light extinction are provided in Appendix F. The bottom panel (b) is for the scenario of meeting the current secondary $PM_{2.5}$ NAAQS of 15 µg/m^3 for the annual average and 35 µg/m^3 for the 98th percentile 24-hour average. A notable feature of this comparison is that in the top panel, all the study areas have a similar distribution of the daily maximum daylight 1-hour total light extinction, while in the bottom panel this is not the case. This is expected, since a NAAQS based on a measured total light extinction indicator will of course result in areas achieving similar total light extinction patterns once each area reaches a "just meets" condition; in areas with generally higher relative humidity conditions, concentrations of $PM_{2.5}$ components and/or $PM_{10-2.5}$ would need to be lower to achieve the "just meet" condition. In contrast, in the NAAQS scenario represented by the bottom panel, concentrations of $PM_{2.5}$ mass will be similar across areas, but concentrations of $PM_{2.5}$ components may not be, and levels of total light extinction will not be similar in areas with dissimilar levels of relative humidity. The specific differences among areas in the bottom panel are generally as expected, with the drier study areas having lower levels of total light extinction.

Tables 4-5 and 4-6 summarize the "just meets" conditions in the eight NAAQS scenarios in terms of the total light extinction design value. Table 4-5 addresses the six scenarios of NAAQS based on measured total light extinction, and the form of the design value given in the Table corresponds to the assumed percentile form of the NAAQS. Table 4-6 addresses the two scenarios of NAAQS based on $PM_{2.5}$ mass, and total light extinction design values in both percentile forms are shown. Note that the design values in Table 4-5 resulting from the rollback steps described in section 4.1.4, in some cases do not exactly equal the assumed level of the NAAQS, although all are quite close. This is a result of hours switching their ranking in the rollback process. This can happen because the level of PRB total light extinction varies with each hour, so a uniform percentage reduction in non-PRB light extinction (step 5) can result in non-uniform percentage reductions in actual total light extinction. In principle, rollback could be iterated to exactly achieve a design value equal to the level of the NAAQS for each scenario. However, the discrepancies indicated in Table 4-5 were judged too small to justify iterative rollback, given other uncertainties in the analysis.

Finally, Table 4-7 summarizes all eight scenarios in terms of the percentage of days (across 2005 to 2007, but after rollback) in which the daily maximum daylight 1-hour total light extinction under "just meeting" conditions exceeds each of the CPLs. Also shown at the bottom of the table in each column representing a NAAQS scenario is the average of these percentages across the 15 study areas. Comparisons of these percentages allows a rough indication of how the two scenarios of a NAAQS based on $PM_{2.5}$ mass compare to the other six scenario in terms of protecting visual air quality. Notice that even the most restrictive of the two NAAQS scenarios based on $PM_{2.5}$ mass would permit projected 1-hour maximum daily light extinction above the least restrictive CPL (201Mm^{-1}) more that 10% of the time for most of the Eastern urban areas (Dallas, Houston and Atlanta have values near 10%), while the percent of maximum hourly days for the Western urban areas are all less than 10%.

Figure 4-1. Distributions of daily maximum daylight 1-hour total light extinction under two "just meeting" secondary NAAQS scenarios

(a) Secondary NAAQS based on measured total light extinction with a level of 122 Mm^{-1} and a 90th percentile form



(b) Secondary NAAQS of 15 $\mu g/m^3$ for the annual average and 35 $\mu g/m^3$ for the 98th percentile 24-hour average

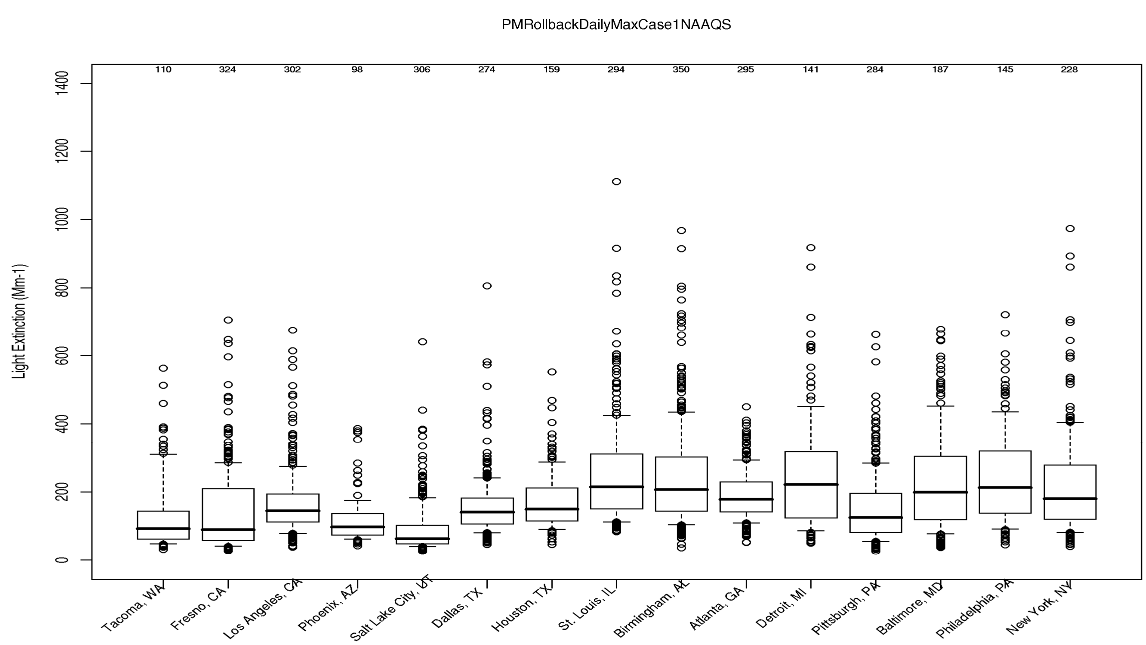


Table 4-5. Total light extinction design values for "just meeting" secondary NAAQS scenarios based on measured total light extinction

	Secondary NAAQS Scenario					
Level (Mm^{-1})	**74**	**74**	**122**	**122**	**201**	**201**
Percentile Form	**90^{th}**	**95^{th}**	**90^{th}**	**95^{th}**	**90^{th}**	**95^{th}**
	Total Light Extinction Design Value (based on same percentile form as the NAAQS scenario)					
Tacoma, WA	74	90	122	126	201	201
Fresno, CA	72	74	121	122	201	201
Los Angeles, CA	74	74	122	122	201	201
Phoenix, AZ	74	74	122	122	201	201
Salt Lake City, UT	75	73	122	122	201	201
Dallas, TX	71	73	120	122	201	201
Houston, TX	78	80	124	124	201	201
St. Louis, IL	75	74	123	122	202	201
Birmingham, AL	77	76	123	122	201	201
Atlanta, GA	73	80	121	127	200	203
Detroit, MI	71	75	121	122	201	201
Pittsburgh, PA	74	76	122	124	200	203
Baltimore, MD	73	75	122	122	202	201
Philadelphia, PA	74	76	122	122	201	201
New York, NY	72	77	121	124	201	202

Table 4-6. Total light extinction design values for "just meeting" secondary NAAQS scenarios based on $PM_{2.5}$ mass

Annual/1-hour $PM_{2.5}$ NAAQS	**15µg/m³ / 35µg/m³**		**12µg/m³ / 25µg/m³**	
City Name	**90^{th} %tile Design Value (Mm^{-1})**	**95^{th} %tile Design Value (Mm^{-1})**	**90^{th} %tile Design Value (Mm^{-1})**	**95^{th} %tile Design Value (Mm^{-1})**
Tacoma, WA	188	228	139	165
Fresno, CA	183	238	139	179
Los Angeles, CA	221	311	175	261
Phoenix, AZ	117*	154*	107	145
Salt Lake City, UT	126	174	98	133
Dallas, TX	213*	262*	200	245
Houston, TX	224	261	182	211
St. Louis, IL	384	477	311	383
Birmingham, AL	355	476	268	369
Atlanta, GA	249	271	197	218
Detroit, MI	364	520	264	376
Pittsburgh, PA	Recalculating	Recalculating	Recalculating	Recalculating
Baltimore, MD	419	459	308	335
Philadelphia, PA	377	403	273	296
New York, NY	377	450	274	325

* Phoenix and Dallas meet 15 µg/m³/35 µg/m³ under current conditions, so these entries are the same as for current conditions.

Table 4-7. Percentage of days across three years (two in the case of Phoenix and Houston) with maximum 1-hour daylight total light extinction above CPLs when "just meeting" the NAAQS scenarios

	Days above 74 Mm^{-1} (Percent)								Days above 122 Mm^{-1} (Percent)								Days above 201 Mm^{-1} (Percent)							
Mm-1 Level	**201**	**201**	**122**	**122**	**74**	**74**			**201**	**201**	**122**	**122**	**74**	**74**			**201**	**201**	122	122	74	74		
Percentile Form	**90**	**95**	**90**	**95**	**90**	**95**			**90**	**95**	**90**	**95**	**90**	**95**			**90**	**95**	90	95	90	95		
Annual/24-hour							**15/35**	**12/25**							**15/35**	**12/25**							**15/35**	**12/25**
Area	**Percentage of days**								**Percentage of days**								**Percentage of days**							
Tacoma	56	46	26	23	11	9	55	39	25	18	8	6	2	1	23	11	8	6	2	0	0	0	6	3
Fresno	54	42	29	21	9	3	48	33	27	19	10	4	1	1	23	14	10	4	1	1	0	0	8	2
Los Angeles	81	74	53	24	8	5	82	76	49	20	8	5	2	1	59	28	8	5	3	1	0	0	12	7
Phoenix	88	66	50	30	9	5	46	42	46	27	9	5	2	1	7	6	9	5	3	2	1	0	2	2
Salt Lake City	54	32	25	14	11	4	26	19	24	13	10	4	3	2	11	6	10	4	3	2	1	0	3	2
Dallas	77	66	43	30	9	4	80	77	42	26	11	4	2	1	46	42	11	5	2	1	0	0	13	11
Houston	75	68	45	32	14	9	81	69	40	30	11	7	1	1	48	31	11	6	1	1	0	0	14	7
St. Louis	75	62	40	28	10	6	98	94	36	25	10	6	2	1	79	66	10	6	2	1	0	0	44	32
Birmingham	67	56	42	26	13	6	90	82	36	22	11	5	2	1	66	52	11	5	2	1	0	0	37	21
Atlanta	86	84	57	50	9	7	91	85	50	42	10	7	0	0	68	49	10	5	0	0	0	0	22	10
Detroit	66	50	40	18	11	5	82	79	36	16	11	5	1	0	70	59	11	5	1	0	0	0	45	22
Pittsburgh	55	52	30	25	10	6	*	*	27	22	10	6	0	0	*	*	10	5	0	0	0	0	*	*
Baltimore	55	50	25	22	10	8	82	71	23	22	10	6	0	0	60	46	9	6	0	0	0	0	34	22
Philadelphia	67	65	33	28	8	6	90	81	29	26	8	6	0	0	70	54	8	6	0	0	0	0	37	21
New York	57	50	27	23	10	6	80	70	26	21	11	6	1	1	60	45	12	5	2	1	0	0	30	19
Average	68	58	38	26	10	6	73	65	34	23	10	5	1	1	49	36	10	5	2	1	0	0	22	13

* EPA is currently recalucating these values.

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APPENDICES

A. $PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas

B. Distributions of Estimated $PM_{2.5}$ Components under Current Conditions

C. Development of PRB Estimates of $PM_{2.5}$ components, $PM_{10-2.5}$, and Total Light Extinction

D. Relationships between PM Mass Concentration and PM Light Extinction under Current Conditions

E. Differences in Daily Patterns of Relative Humidity and Light Extinction between Areas and Seasons

F. Distributions of Maximum Daily Daylight Total Light Extinction under "Just Meets" Conditions

APPENDIX A - $PM_{2.5}$ MONITORING SITES AND MONITORS PROVIDING 2005-2007 DATA FOR THE ANALYSIS OF TOTAL LIGHT EXTINCTION IN THE 15 STUDY AREAS

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First $PM_{2.5}$ Monitoring Site**	**Second $PM_{2.5}$ Monitoring Site (if applicable)**	**PM_{10} data source for $PM_{10-2.5}$**
Tacoma	AQS ID 530530029 State: Washington City: Tacoma MSA: Tacoma, WA Local Site Name: TACOMA - L STREET Address: 7802 SOUTH L STREET, TACOMA 0.5 miles east of I-5 2005-2007 annual DV = 10.2 2005-2007 24-hr DV = 43 This is the highest 24-hour $PM_{2.5}$ DV site in the Seattle-Tacoma-Olympia, WA annual PM2.5 nonattainment area Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; one-in-three sampling schedule) • PM2.5 speciation (one-in-six sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88502, Acceptable PM2.5 AQI & Speciation Mass) Correlated Radiance Research M903 Nephelometry No continuous PM10 monitoring at this site, see right hand column..	NA	AQS ID 530530031 State: Washington City: Tacoma MSA: Tacoma, WA Local Site Name: TACOMA - ALEXANDER AVE Address: 2301 ALEXANDER AVE, TACOMA, WA 6.4 miles NNE of PM2.5 site Neighborhood Scale Parameters taken from this site: • 1-hour PM10 STP mass (AQS parameter 81102) o Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET o Sample Analysis Method: TEOM-GRAVIMETRIC 7% of PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First $PM_{2.5}$ Monitoring Site**	**Second $PM_{2.5}$ Monitoring Site (if applicable)**	**PM_{10} data source for $PM_{10-2.5}$**
Fresno	AQS ID 060190008 State: California City: Fresno MSA: Fresno, CA Local Site Name: None given Address: 3425 N FIRST ST, FRESNO 2.5 miles west of the airport, 3 miles NNE of central Fresno 2005-2007 annual DV = 17.4 2005-2007 24-hr DV = 63 This is not the highest annual or 24-hr PM2.5 DV site in the San Joaquin nonattainment area. Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-three sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88501, PM2.5 Raw Data) Met-One BAM No continuous PM10 monitoring at this site, see right hand column..	NA	PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First $PM_{2.5}$ Monitoring Site**	**Second $PM_{2.5}$ Monitoring Site (if applicable)**	**PM_{10} data source for $PM_{10\text{-}2.5}$**
Los Angeles-South Coast Air Basin	AQS ID 060658001 State: California City: Rubidoux (West Riverside) MSA: Riverside-San Bernardino, CA Local Site Name: None given Address: 5888 MISSION BLVD., RUBIDOUX Eastern SCAB, 0.4 miles from Pomona Freeway. 2005-2007 annual DV = 19.6 2005-2007 24-hr DV = 55 This site is not the highest DV site in the LA-South Coast nonattainment area. Neighborhood scale. Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-three sampling schedule) • 1-hour PM2.5 (AQS parameter 88502, Acceptable PM2.5 AQI & Speciation Mass) [still investigating instrument type] No continuous PM10 monitoring at this site, see right hand column..	NA	AQS ID 060710306 State: California City: Victorville MSA: Riverside-San Bernardino, CA Local Site Name: MOVED FROM 060710014 Address: 14306 PARK AVE., VICTORVILLE, CA 36 miles north of PM2.5 site, on the other side of a range of hills. 0.4 miles from I-15 Measurement Scale not given in AQS, but appears Neighborhood by aerial image. Parameters taken from this site: • 1-hour PM10 STP mass (AQS parameter 81102) o Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET o Sample Analysis Method: TEOM-GRAVIMETRIC 6% of PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First PM$_{2.5}$ Monitoring Site**	**Second PM$_{2.5}$ Monitoring Site (if applicable)**	**PM$_{10}$ data source for PM$_{10-2.5}$**
Phoenix	AQS ID 040137020 (FRM & CSN) State: Arizona City: Scottsdale MSA: Phoenix-Mesa, AZ Local Site Name: Address: 10844 EAST OSBORN ROAD SCOTTSDALE' AZ Reporting Agency: Salt River Pima-Maricopa Indian Community of Salt River Reservation Eastern edge of the metro area, largely surrounded by agricultural fields. 2005-2007 annual DV = 7.9 2005-2007 24-hr DV = 15 This site is not the highest DV site in the Phoenix-Mesa CBSA. Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; one-in-six sampling schedule) • PM2.5 speciation (one-in-three sampling schedule) No continuous PM10 monitoring at this site, see right hand column.	AQS ID 040139998 (Continuous) State: Arizona City: Phoenix MSA: Phoenix-Mesa, AZ Local Site Name: Vehicle Emissions Laboratory Address: 600 N 40th St & Fillmore St Measurement Scale not available; 0.75 miles from intersection of two freeways, 1 mile from Phoenix airport. Parameters taken from this site: • 1-hour PM2.5 mass. Nephelometer.	AQS ID 040133002 State: Arizona City: Phoenix MSA: Phoenix-Mesa, AZ Local Site Name: CENTRAL PHOENIX Address: 1645 E ROOSEVELT ST-CENTRAL PHOENIX STN 1.8 miles NE of central Phoenix Neighborhood Scale Parameters taken from this site: • 1-hour PM10 STP mass (AQS parameter 81102) o Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET o Sample Analysis Method: TEOM-GRAVIMETRIC 2% of PM10-2.5 values were using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First $PM_{2.5}$ Monitoring Site**	**Second $PM_{2.5}$ Monitoring Site (if applicable)**	**PM_{10} data source for $PM_{10-2.5}$**
Salt Lake City	AQS ID490353006 State: Utah City: Salt Lake City MSA: Salt Lake City-Ogden, UT Local Site Name: UTM COORDINATES = PROBE LOCATION Address: 1675 SOUTH 600 EAST, SALT LAKE CITY 2.5 miles SSE of central Salt Lake City 2005-2007 annual DV = 10.7 2005-2007 24-hr DV = 48 This is not the highest DV site in the Salt Lake City CSA. Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-three sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88501, PM2.5 Raw Data) FDMS-Gravimetric No continuous PM10 monitoring at this site, see right hand column.	NA	PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First PM$_{2.5}$ Monitoring Site**	**Second PM$_{2.5}$ Monitoring Site (if applicable)**	**PM$_{10}$ data source for PM$_{10-2.5}$**
Dallas	AQS ID 481130069 State: Texas City: Dallas MSA: Dallas, TX Local Site Name: DALLAS HINTON Address: 1415 HINTON STREET 4.5 miles NE of central Dallas 2005-2007 annual DV = 11.5 2005-2007 24-hr DV = 25 This is not the highest DV site in the Dallas-Ft. Worth CSA. Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-three sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88502, Acceptable PM2.5 AQI & Speciation Mass) TEOM Gravimetric 50 deg C No continuous PM10 monitoring at this site, see right hand column..	NA	PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First $PM_{2.5}$ Monitoring Site**	**Second $PM_{2.5}$ Monitoring Site (if applicable)**	**PM_{10} data source for $PM_{10-2.5}$**
Houston	AQS ID 482010024 State: Texas City: Not in a city MSA: Houston, TX Local Site Name: HOUSTON ALDINE Address: 4510 1/2 ALDINE MAIL RD 10 miles NNE of central Houston 2005-2007 annual DV = 13.1 2005-2007 24-hr DV = 25 This is not the highest DV site in the 'Houston-Baytown-Huntsville, TX CSA. Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; one-in-six day sampling schedule) • PM2.5 speciation (one-in-six sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88502, Acceptable PM2.5 AQI & Speciation Mass) TEOM Gravimetric 50 deg C No continuous PM10 monitoring at this site, see right hand column.	NA	PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First PM$_{2.5}$ Monitoring Site**	**Second PM$_{2.5}$ Monitoring Site (if applicable)**	**PM$_{10}$ data source for PM$_{10\text{-}2.5}$**
St. Louis	AQS ID 295100085 State: Missouri City: St. Louis MSA: St, Louis, MO-IL Local Site Name: BLAIR STREET CATEGORY A CORE SLAM PM2.5. Address: BLAIR S 2 miles north of central St. Louis 2005-2007 annual DV = 14.5 2005-2007 24-hr DV = 34 This is not the highest DV site in the St. Louis nonattainment area. Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-three sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88502, Acceptable PM2.5 AQI & Speciation Mass) TEOM Gravimetric 30 deg C No continuous PM10 monitoring at this site, see right hand column.	NA	AQS ID 295100092 (2005 and 2006 data) State: Missouri City: St. Louis MSA: St, Louis, MO-IL Local Site Name: Address: 3 NORTH MARKET 0.7 miles ESE of PM2.5 site, across the street from the eastern edge of what appears to be a recycling/municipal works yard. Middle Scale Parameters taken from this site: • 1-hour PM10 STP mass (AQS parameter 81102) o Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET o Sample Analysis Method: TEOM-GRAVIMETRIC Site was on the other (western) side of the recycling/municipal works yard as site 295100093, below. 295100093 (2007 data) State: Missouri City: St. Louis MSA: St, Louis, MO-IL Local Site Name: None given Address: Branch Street 0.6 miles ESE of PM2.5 site, across the street from the western edge of what appears to be a recycling/municipal works yard. Middle Scale Parameters taken from this site: • 1-hour PM10 STP mass (AQS parameter 81102) o Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET o Sample Analysis Method: TEOM-GRAVIMETRIC 4% of PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First PM$_{2.5}$ Monitoring Site**	**Second PM$_{2.5}$ Monitoring Site (if applicable)**	**PM$_{10}$ data source for PM$_{10-2.5}$**
Birmingham	AQS ID 010730023 State: Alabama City: Birmingham MSA: Birmingham, AL Local Site Name: Address: NO. B'HAM,SOU R.R., 3009 28TH ST. NO 2.3 miles north of central Birmingham 2005-2007 annual DV = 18.7 2005-2007 24-hr DV = 44 This is the highest DV site in the Birmingham nonattainment area Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-three sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88502, Acceptable PM2.5 AQI & Speciation Mass) TEOM Gravimetric 50 deg C • 1-hour PM10 STP mass (AQS parameter 81102) o Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET o Sample Analysis Method: TEOM-GRAVIMETRIC	NA	Same as PM2.5 site. 0.3% of PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First PM$_{2.5}$ Monitoring Site**	**Second PM$_{2.5}$ Monitoring Site (if applicable)**	**PM$_{10}$ data source for PM$_{10-2.5}$**
Atlanta	AQS ID 130890002 State: Georgia City: Decatur MSA: Atlanta, GA Local Site Name: 2390-B WILDCAT ROAD, DECATUR, GA Address: SOUTH DEKALB About 7 miles SE of central Atlanta 2005-2007 annual DV = 15.7 2005-2007 24-hr DV = 33 This is not the highest DV site in the Atlanta nonattainment area. Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-three sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88502, Acceptable PM2.5 AQI & Speciation Mass) TEOM Gravimetric 30 deg C No continuous PM10 monitoring at this site, see right hand column.	NA	AQS ID 131210048 State: Georgia City: Atlanta MSA: Atlanta, GA Local Site Name: Georgia Tech, Ford Environmental Science and Technology Bldg, roof Address: GA. TECH., Ford ES&T Bldg, 311 Ferst St NW, Atlanta GA 8.6 miles NW of PM2.5 site Neighborhood Scale Parameters taken from this site: • 1-hour PM10 STP mass (AQS parameter 81102) o Sample Collection Method: INSTRUMENT MET ONE 4 MODELS o Sample Analysis Method: BETA ATTENUATION 8% of PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First PM$_{2.5}$ Monitoring Site**	**Second PM$_{2.5}$ Monitoring Site (if applicable)**	**PM$_{10}$ data source for PM$_{10-2.5}$**
Detroit-Ann Arbor	AQS ID 261630033 State: Michigan City: Dearborn MSA: Detroit, MI Local Site Name: PROPERTY OWNED BY DEARBORN PUBLIC SCHOOLS Address: 2842 WYOMING About 0.2 miles from Ford River Rouge auto plant 2005-2007 annual DV = 17.2 2005-2007 24-hr DV = 43 This is the highest annual and 24-hr DV site in the Detroit nonattainment area Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-six sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88501, PM2.5 Raw Data) TEOM Gravimetric 50 deg C • 1-hour PM10 STP mass (AQS parameter 81102) o Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET o Sample Analysis Method: TEOM-GRAVIMETRIC	NA	Same as PM2.5 site. 2% of PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First $PM_{2.5}$ Monitoring Site**	**Second $PM_{2.5}$ Monitoring Site (if applicable)**	**PM_{10} data source for $PM_{10-2.5}$**
Pittsburgh	AQS ID 420030008 State: Pennsylvania City: Pittsburgh MSA: Pittsburgh, PA Local Site Name: None given Address: BAPC 301 39TH STREET BLDG #7 3 miles NE of central Pittsburgh, 0.5 miles from Allegheny River 2005-2007 annual DV = 15.0 2005-2007 24-hr DV = 40 This site is not the highest DV site in the Pittsburgh nonattainment area. Urban Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-three sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88502, Acceptable PM2.5 AQI & Speciation Mass) TEOM Gravimetric 50 deg C No continuous PM10 monitoring at this site, see right hand column.	NA	PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First $PM_{2.5}$ Monitoring Site**	**Second $PM_{2.5}$ Monitoring Site (if applicable)**	**PM_{10} data source for $PM_{10-2.5}$**
Baltimore	AQS ID 240053001 (FRM & CSN) State: Maryland City: Essex MSA: Baltimore, MD Local Site Name: Essex Address: 600 Dorsey Avenue 7 miles east of central Baltimore 2005-2007 annual DV = 14.5 2005-2007 24-hr DV = 35 This is not the highest DV site in the Baltimore nonattainment area. Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-three sampling schedule) • 1-hour PM10 LC mass (AQS parameter 85101	AQS ID 245100040 (Continuous) State: Maryland City: Baltimore MSA: Baltimore, MD Local Site Name: Oldtown Address: Oldtown Fire Station, 1100 Hillen Street 1 mile NNE of Inner Harbor area Middle Scale Parameters taken from this site: • 1-hour PM2.5 mass (AQS parameter 88502, Acceptable PM2.5 AQI & Speciation Mass) TEOM Gravimetric 50 deg C	Same as PM2.5 site. 5% of PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First $PM_{2.5}$ Monitoring Site**	**Second $PM_{2.5}$ Monitoring Site (if applicable)**	**PM_{10} data source for $PM_{10-2.5}$**
Philadelphia-Wilmington	AQS ID100032004 (DE) State: Delaware City: Wilmington MSA: Wilmington-Newark, DE-MD Local Site Name: CORNER OF MLK BLVD AND JUSTISON ST 2.5 miles NE of central Wilimington, 0.25 miles from the Delaware River, 22 miles SW from central Philadelphia 2005-2007 annual DV = 14.7 2005-2007 24-hr DV = 37 This is not the highest DV site in the Philadelphia nonattainment area Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-six sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88501, PM2.5 Raw Data) Beta Attenuation • 1-hour PM10 STP mass (AQS parameter 81102)	NA	Same as PM2.5 site. 3% of PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of Total Light Extinction in the 15 Study Areas			
Study Area	**First PM$_{2.5}$ Monitoring Site**	**Second PM$_{2.5}$ Monitoring Site (if applicable)**	**PM$_{10}$ data source for PM$_{10-2.5}$**
New York-N.New Jersey-Long Island	AQS ID 340390004 (NJ) State: New Jersey City: Elizabeth MSA: Newark, NJ Local Site Name: ELIZABETH LAB Address: NEW JERSEY TURNPIKE INTERCHANGE 13 1.75 miles south of Elizabeth, at the I-95 interchange with I-278 2005-2007 annual DV = 14.4 2005-2007 24-hr DV = 42 This is not the highest DV site in the New York nonattainment area Neighborhood Scale Parameters taken from this site: • 24-hour FRM PM2.5 mass (AQS parameter 88101; every day sampling schedule) • PM2.5 speciation (one-in-three sampling schedule) • 1-hour PM2.5 mass (AQS parameter 88502, Acceptable PM2.5 AQI & Speciation Mass) TEOM Gravimetric 30 deg C No continuous PM10 monitoring at this site, see right hand column.	NA	AQS ID 360610125 State: New York City: New York MSA: New York, NY Local Site Name: PARK ROW Address: 1 PACE PLAZA Near the on-ramp to the Brooklyn Bridge, Manhattan end Measurement scale not stated. Parameters taken from this site: • 1-hour PM10 STP mass (AQS parameter 81102) o Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET o Sample Analysis Method: TEOM-GRAVIMETRIC 2% of PM10-2.5 values were determined using regional average PM10-2.5:PM2.5 ratios from 2005 Staff Paper

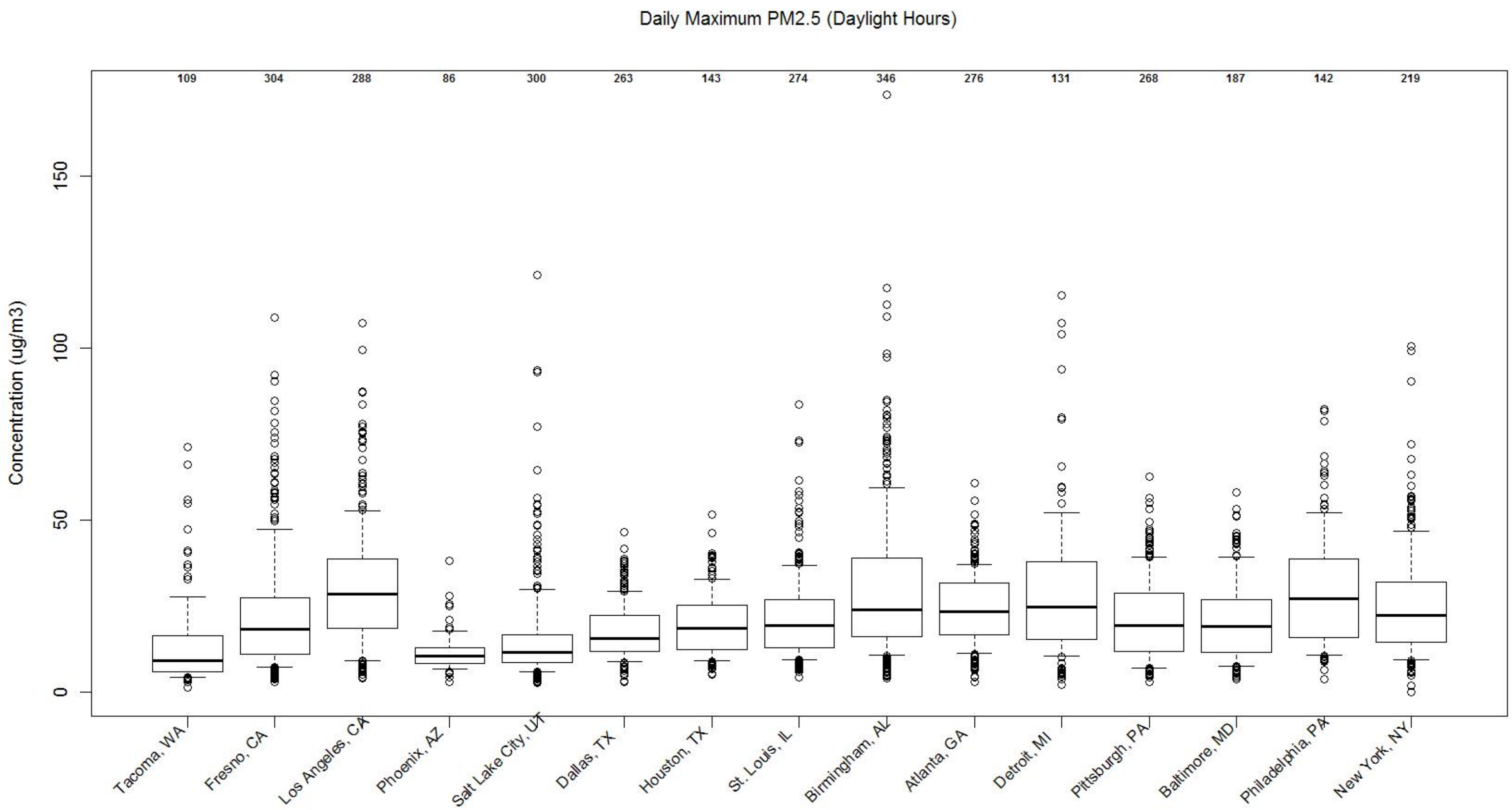
Notes:

- In this Table, the 1-hour concentration parameter "88502, Acceptable PM$_{2.5}$ AQI & Speciation Mass" is the same as the ISA refers to as "FRM-like" PM$_{2.5}$ mass. An entry of "88501, PM$_{2.5}$ Raw Data" indicates that the monitoring agency makes no representation as to the degree of correlation with FRM PM$_{2.5}$ mass. The latter type of continuous PM$_{2.5}$ data were used only when the former were unavailable.
- Where PM$_{10}$ was reported in STP, it was converted to LC before PM$_{10-2.5}$ was calculated.
- For convenience, continuous PM$_{2.5}$ data were obtained through the AirNow website rather than from AQS, as an initial exploration indicated that not all the desired 1-hour data had been submitted to AQS.

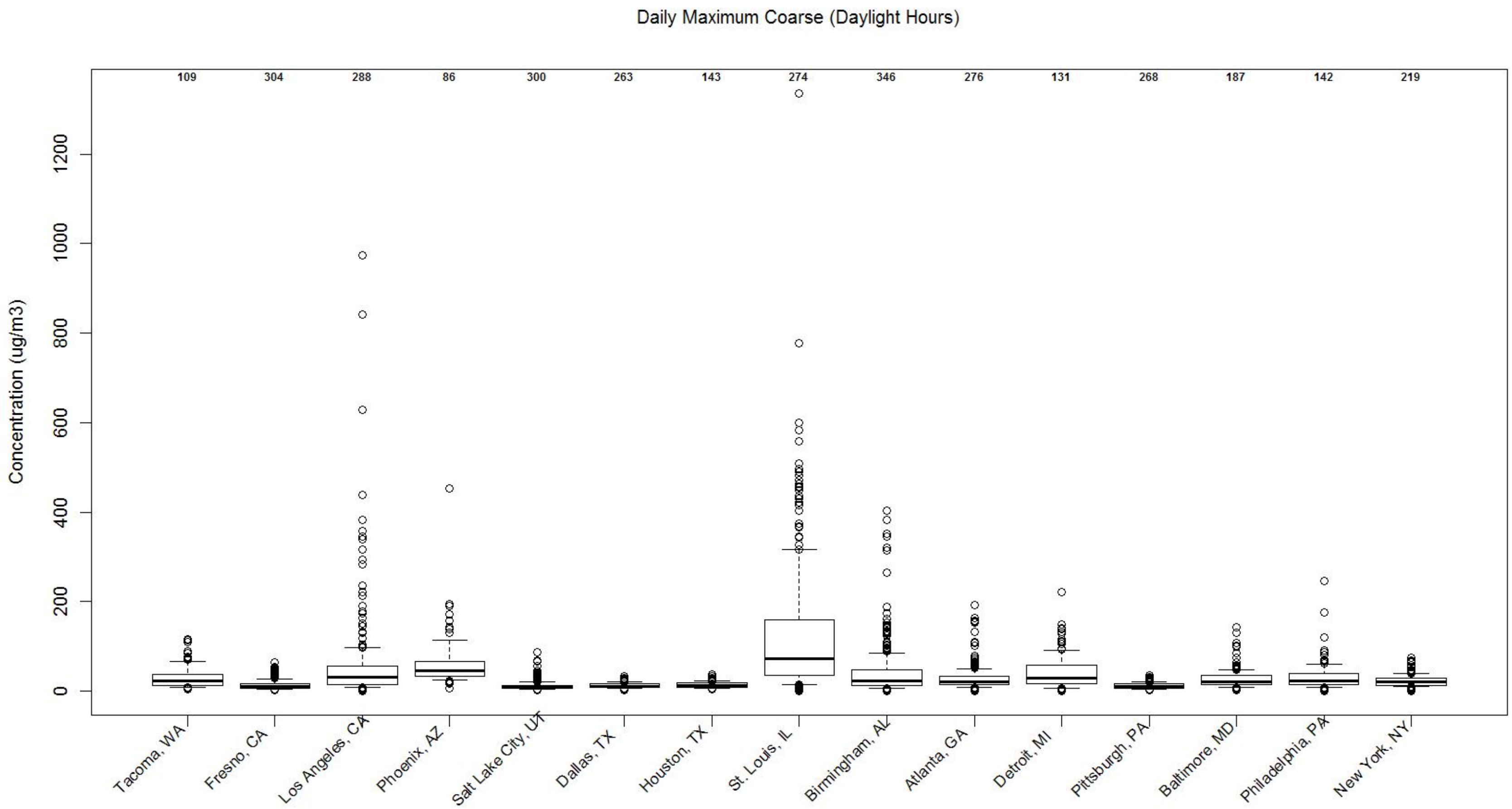
APPENDIX B - DISTRIBUTIONS OF ESTIMATED $PM_{2.5}$ COMPONENTS

Figure B-1 – Distribution of daily maximum $PM_{2.5}$, $PM_{10-2.5}$, and relative humidity across the 2005-2007 period, by study area

(a) Daily maximum daylight $PM_{2.5}$



(b) Daily maximum daylight $PM_{10-2.5}$



(c) Daily maximum daylight relative humidity

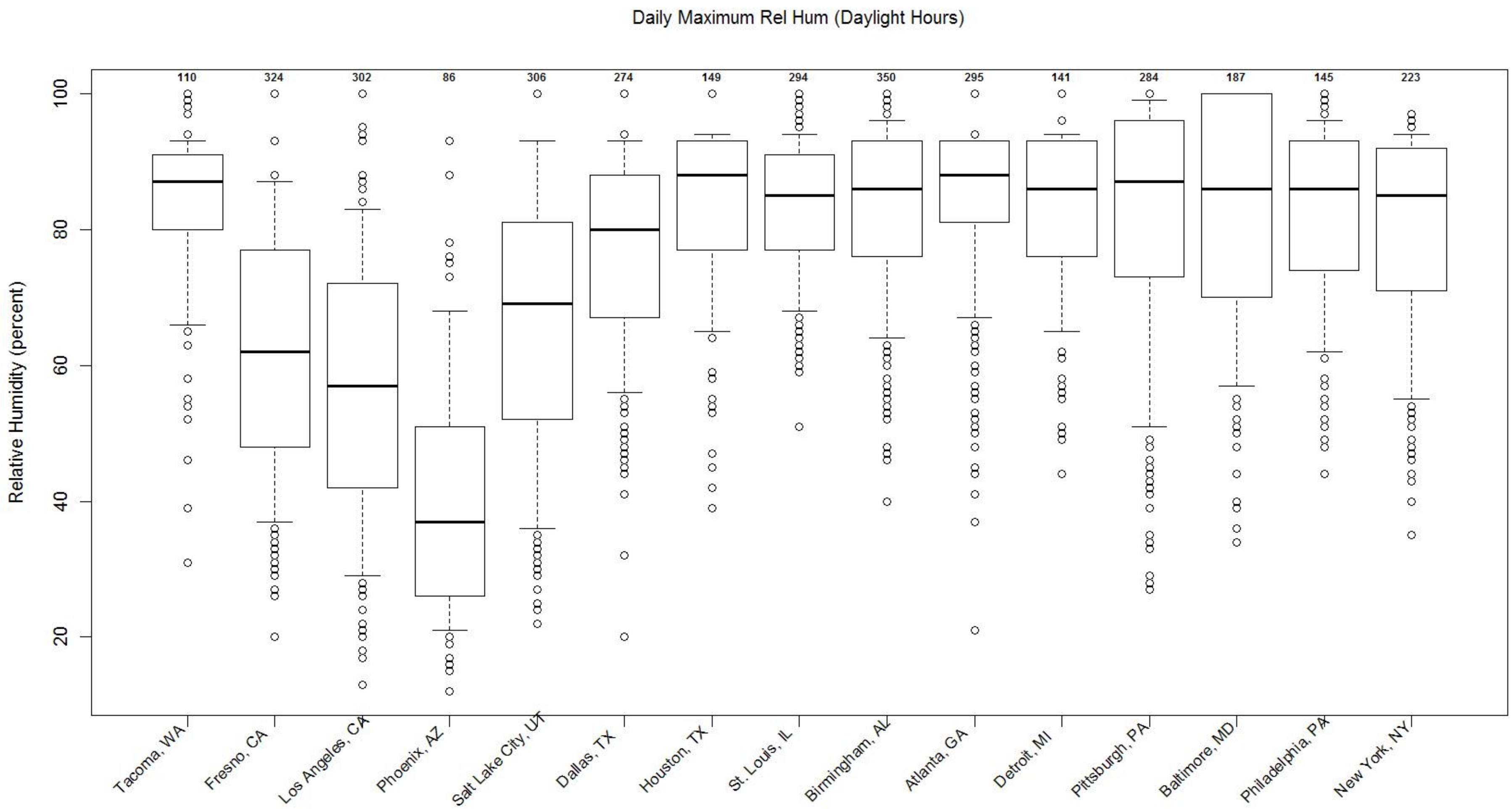


Figure B-2 – Distribution of hourly $PM_{2.5}$ components across the 2005-2007 period, by study area

(a) 1-hour daylight sulfate (dry, fully neutralized)

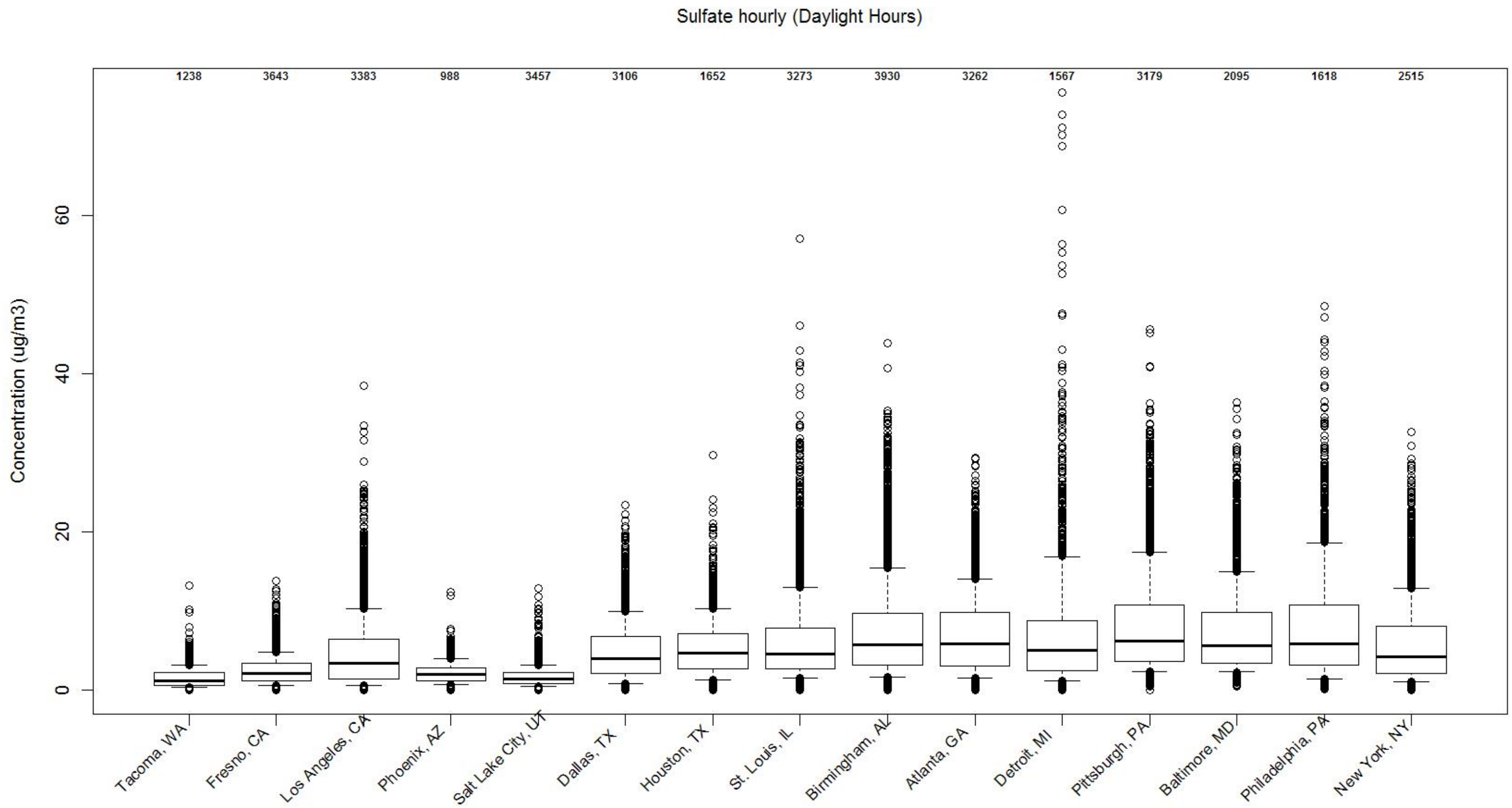


Figure B-2 – Distribution of $PM_{2.5}$ components across the 2005-2007 period, by study area, continued

(b) 1-hour daylight nitrate (dry, fully neutralized, CSN method consistent)

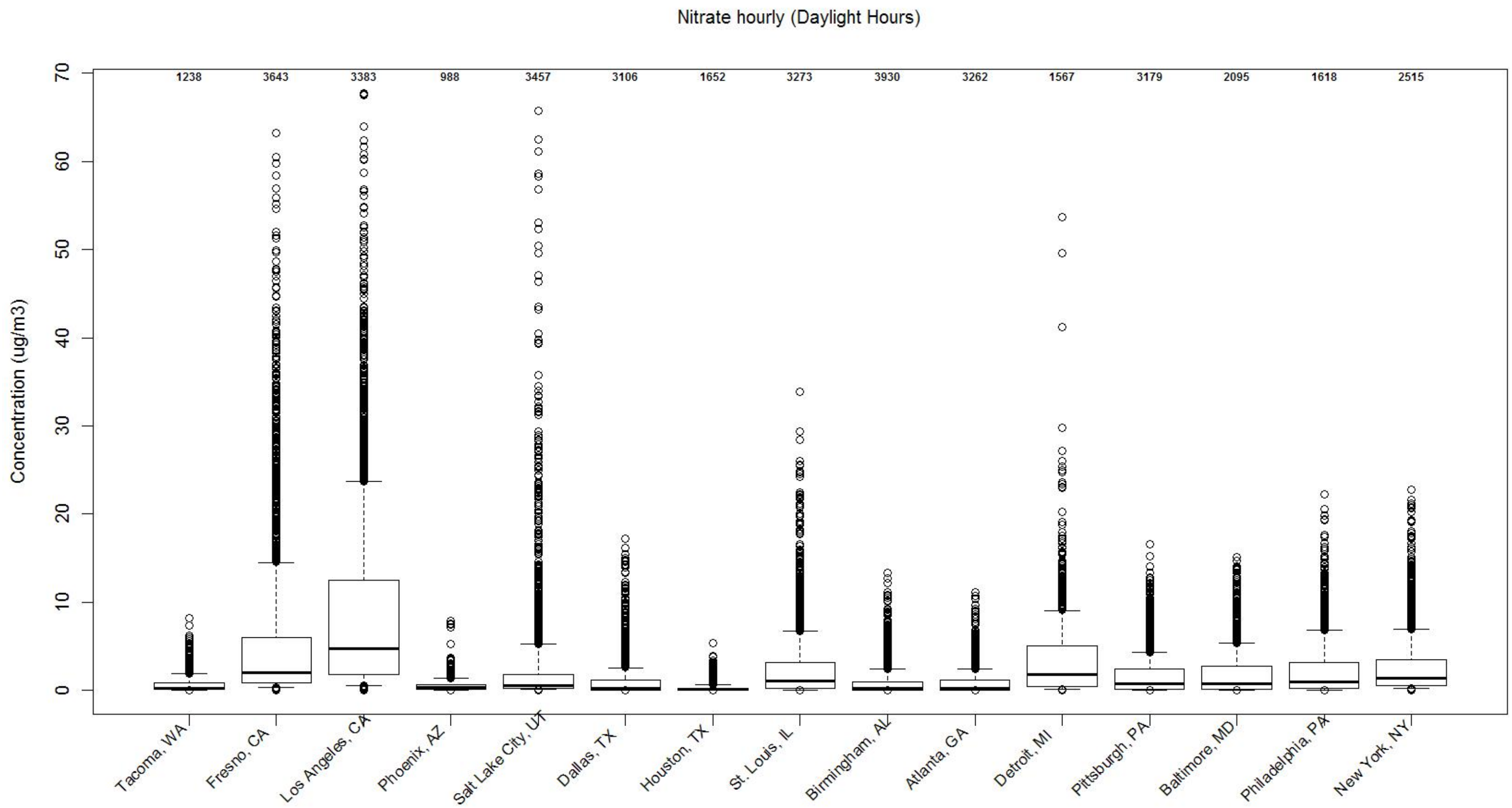


Figure B-2 – Distribution of $PM_{2.5}$ components across the 2005-2007 period, by study area, continued

(c) 1-hour daylight elemental carbon

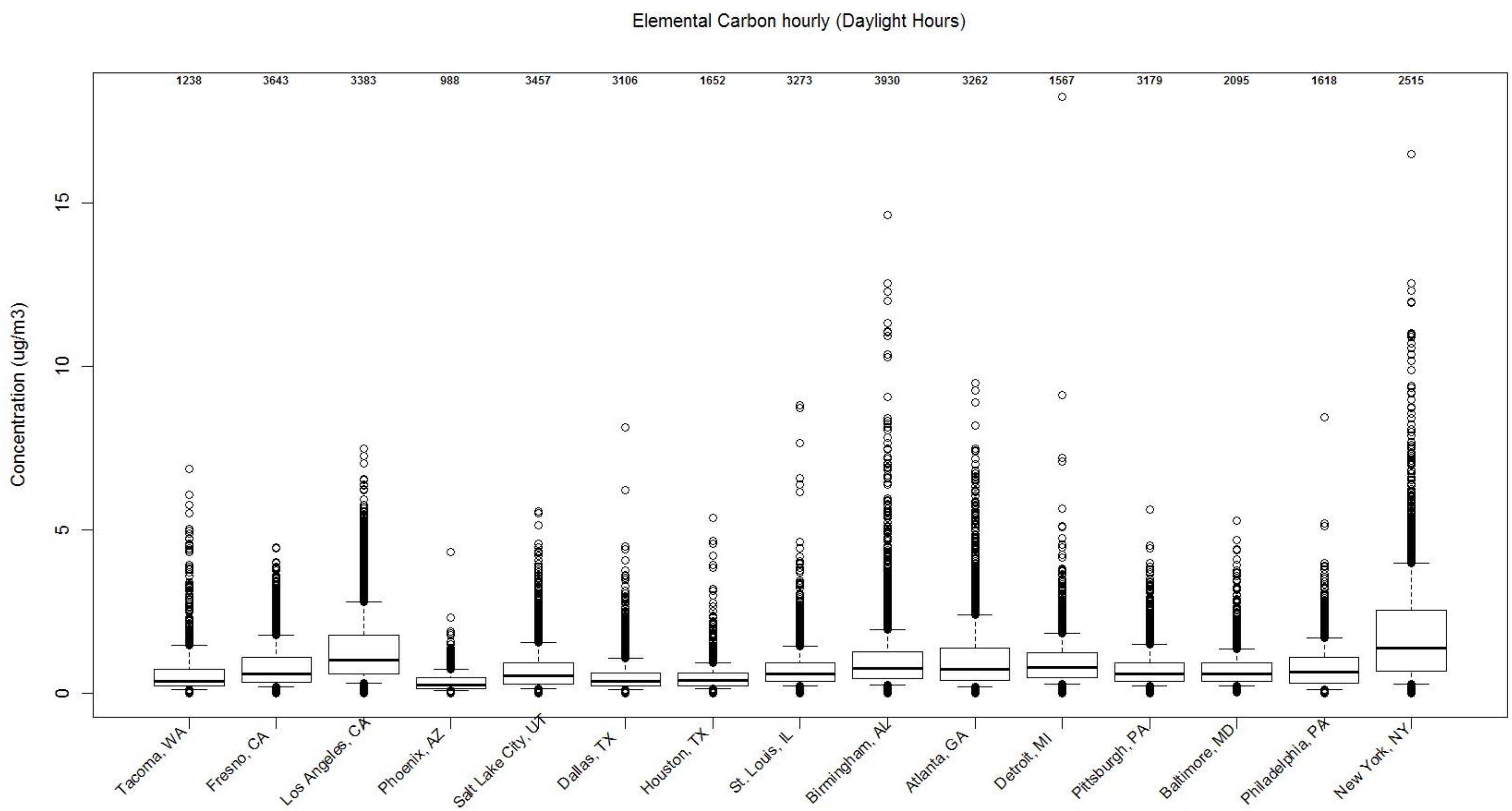


Figure B-2 – Distribution of $PM_{2.5}$ components across the 2005-2007 period, by study area, continued

(d) 1-hour daylight organic carbonaceous material

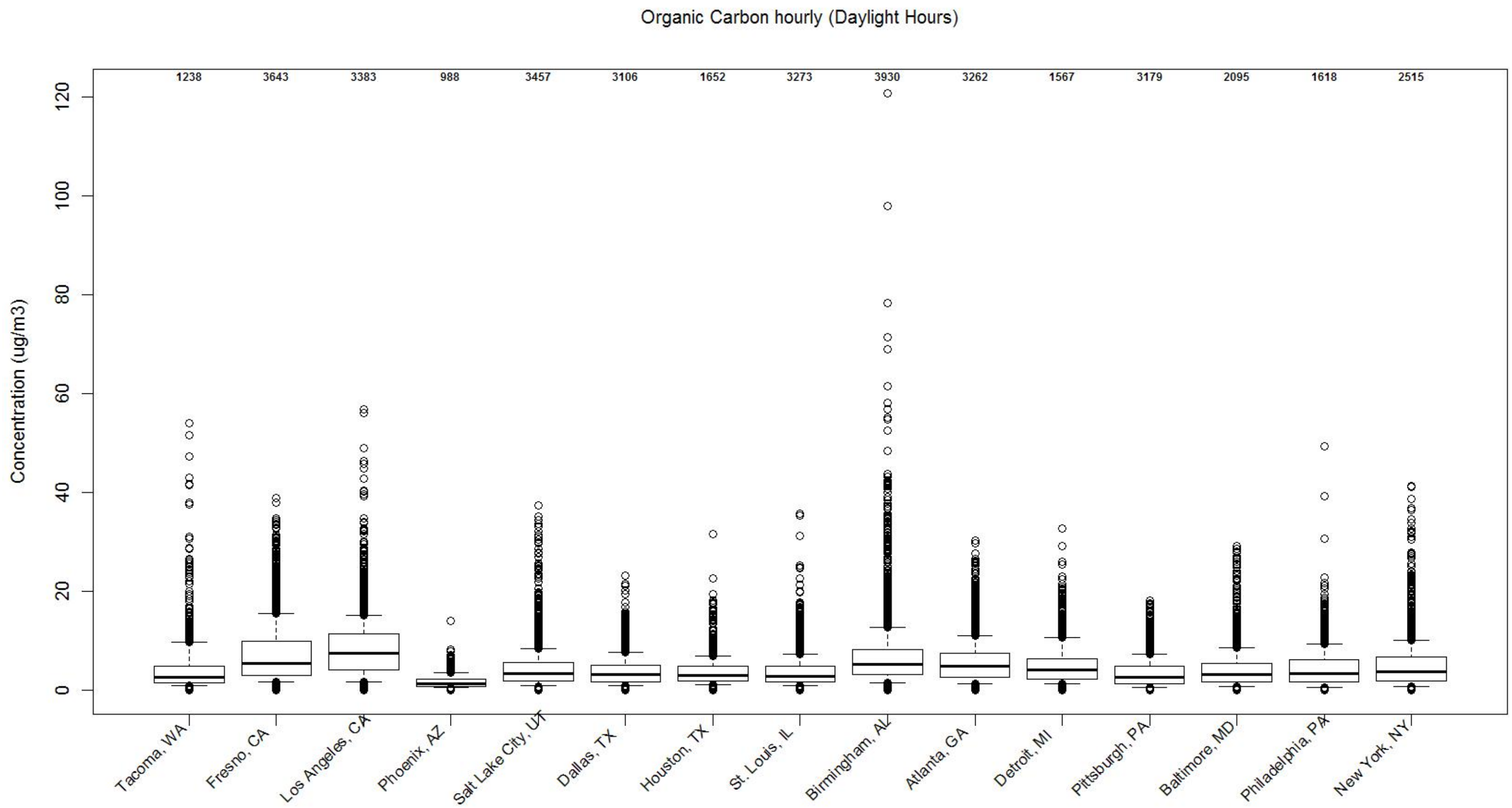
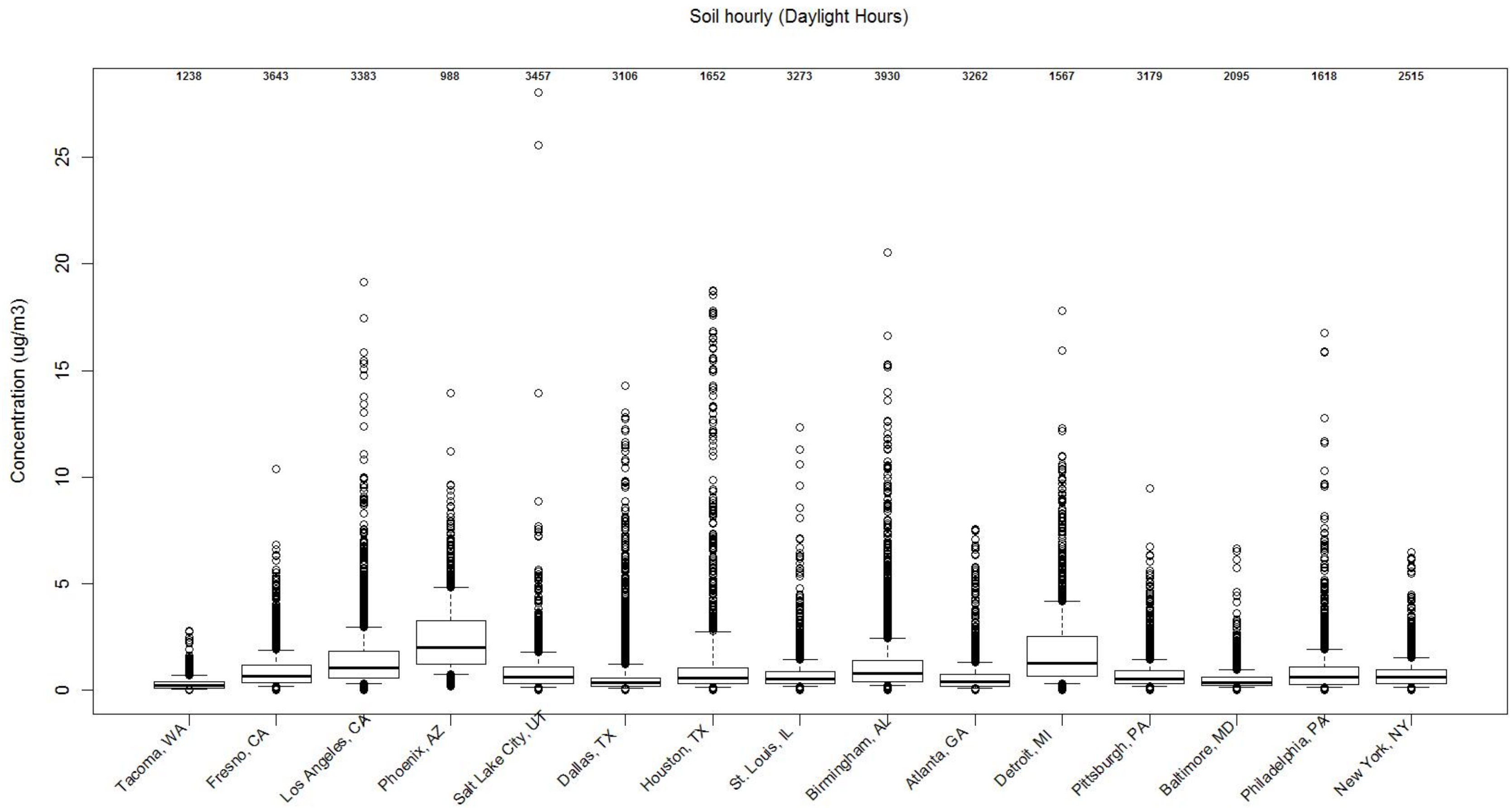


Figure B-2 – Distribution of $PM_{2.5}$ components across the 2005-2007 period, by study area, continued

(e) 1-hour daylight fine soil



APPENDIX C - DEVELOPMENT OF PRB ESTIMATES OF $PM_{2.5}$ COMPONENTS, $PM_{10-2.5}$, AND TOTAL LIGHT EXTINCTION

Policy relevant background levels of total light extinction have been estimated for this assessment by relying on outputs for the 2004 CMAQ run in which anthropogenic emission in the U.S., Canada, and Mexico were omitted, as described in the second draft ISA. Estimates of PRB for total light extinction were calculated from modeled concentrations of $PM_{2.5}$ components using the IMPROVE algorithm. The necessary component concentrations were extracted from the CMAQ output files, as they were not summarized in the second draft ISA.

More specifically, for each study area, EPA staff overlaid CMAQ grid cells over shapes representing the Census-defined urbanized area for each study area, and visually identified the CMAQ grid cells that had a substantial portion of their area coincident with the urbanized area. For each such grid cell, for each of the 12 months of the year, we obtained the 24 values of the hour-specific average concentrations of the five $PM_{2.5}$ components. We then averaged these across the selected grid cells. Thus, a given hour of the day has the same PRB estimate for a component on all days within a month, but months and study areas differ. Table C-1 summarizes these PRB estimates for the $PM_{2.5}$ components (including the specific form assumed for sulfate, nitrate, and organic carbon). The most notable observed feature of the PRB estimates is relatively high values for elemental and organic carbon PRB for the Tacoma study area. This area is often affected by wildfires for extended periods in the autumn months, and such fires were included in the 2004 emissions scenario for the PRB CMAQ run. A cursory review of information on fire events in 2005-2007 confirmed that the fire situation in this part of the country in 2004 was not an anomaly.

Table C-1. Summary of PRB estimates for the five $PM_{2.5}$ components: average 1-hour values across 2005-2007

Study Area	Average 1-Hour PRB Concentration Across 2005-2007 (μg/m^3)				
	Sulfate (dry, no ammonium)	Nitrate (dry, no ammonium)	Elemental Carbon	Organic Carbonaceous Material	Fine Soil/Crustal
Tacoma	0.45	0.026	0.15	1.3	0.31
Fresno	0.4	0.00062	0.08	0.74	0.19
Los Angeles-South	0.36	0.0037	0.028	0.3	0.036
Phoenix	0.31	0.000052	0.02	0.26	0.015
Salt Lake City	0.25	0.00028	0.025	0.26	0.034
Dallas	0.27	0.0022	0.055	0.59	0.092
Houston	0.3	0.0055	0.091	0.86	0.17
St. Louis	0.31	0.0027	0.047	0.53	0.07
Birmingham	0.29	0.007	0.099	1.1	0.19
Atlanta	0.3	0.016	0.1	1.1	0.19
Detroit-Ann Arbor	0.34	0.00062	0.024	0.32	0.018
Pittsburgh	0.3	0.00052	0.029	0.36	0.034
Baltimore	0.34	0.0016	0.039	0.44	0.054
Philadelphia-	0.34	0.00097	0.03	0.36	0.032
New York-N.New Jersey-Long Island	0.36	0.0038	0.026	0.31	0.022

It is also necessary to have estimates of PRB for $PM_{10-2.5}$, to feed into the IMPROVE algorithm. The second draft ISA for this review does not present any new information on this subject. The approach used in the previous two Criteria Documents was to present the historical range of annual means of $PM_{10-2.5}$ concentrations from IMPROVE monitoring sites selected as being least influenced by anthropogenic emissions. See Table 3E-1 of the 2004 Criteria Document. For sites in the lower 48 states, these annual means range from a low of 1.8 $\mu g/m^3$ to a high of 10.8 $\mu g/m^3$. For this assessment, EPA staff estimated PRB for $PM_{10-2.5}$ using a contour map based on average 2000-2004 $PM_{10-2.5}$ concentrations from all IMPROVE monitoring sites, found in a recent report from the IMPROVE program. (Spatial and Seasonal Patterns and Temporal Variability of Haze and its Constituents in the United States: Report IV, November 2006). We located each study area's position on this map, and assigned it the mid-point of the range of concentrations indicated by the contour band for that location. The contour map is reproduced here as Figure C-1. Stars show locations of the 15 study areas. In this reproduction, the midpoints of the contour ranges have been added to the legend.

The results are shown in Table C-2. Lacking any other information, these PRB values are taken to apply to every hour of the year. While the contour map and thus these values are influenced by data from IMPROVE sites that were not considered in the 2004 Criteria Document to be the sites most isolated from the influence of anthropogenic emissions, including three IMPROVE sites in urban areas, these values are generally within the range of values presented in the Criteria Document for such isolated sites. Further, these PRB values are low enough that their exact values will have little effect on the results of "what if" estimation of total light extinction levels under possible secondary PM NAAQS.

Table C-3 presents the resulting 2005-2007 average PRB daylight total light extinction by study area, determined by using each daylight hour's f(RH), the hour-specific PRB $PM_{2.5}$ component estimates summarized as annual averages in Table C-1, the PRB $PM_{10-2.5}$ estimates in Table C-2, and the IMPROVE algorithm. The sulfate and nitrate component values in Table C-1 are multiplied by 1.375 and 1.29 to reflect full neutralization, before being used in the IMPROVE algorithm.

Figure C-1. Selection of PRB values for $PM_{10-2.5}$ based on contoured IMPROVE monitoring data

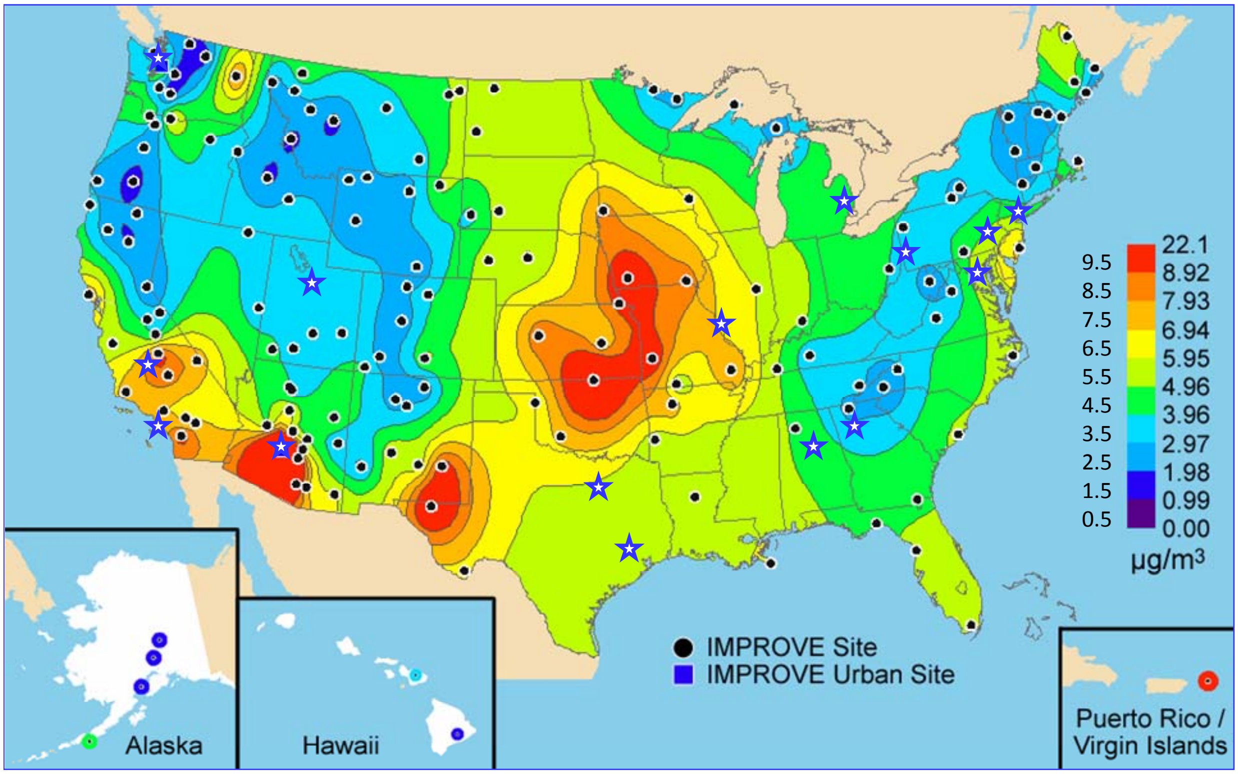


Table C-2. Policy Relevant Background Concentrations of $PM_{10-2.5}$ Used in This Assessment, Based on Measurements at IMPROVE Sites

Study Area	PRB $PM_{10-2.5}$ Mass (µg/m^3)
Tacoma	4.5
Fresno	5.5
Los Angeles-South Coast Air Basin	4.5
Phoenix	5.5
Salt Lake City	4.5
Dallas	8.5
Houston	5.5
St. Louis	7.5
Birmingham	5.5
Atlanta	5.5
Detroit-Ann Arbor	9.5
Pittsburgh	3.5
Baltimore	3.5
Philadelphia-Wilmington	6.5
New York-N.New Jersey-Long Island	3.5

Table C-3. 2005-2007 Average Policy Relevant Background Daylight Total light Extinction

Study Area	2005-2007 Average Policy Relevant Background Daylight Total Light Extinction, Mm^{-1}
Tacoma	22
Fresno	21
Los Angeles-South Coast Air Basin	18
Phoenix	18
Salt Lake City	15
Dallas	18
Houston	20
St. Louis	19
Birmingham	19
Atlanta	19
Detroit-Ann Arbor	17
Pittsburgh	17
Baltimore	19
Philadelphia-Wilmington	18
New York-N.New Jersey-Long Island	18

APPENDIX D RELATIONSHIPS BETWEEN PM MASS CONCENTRATION AND TOTAL LIGHT EXTINCTION UNDER CURRENT CONDITIONS

In the last review, the 2005 Staff Paper examined the correlation between total light extinction and $PM_{2.5}$ mass concentrations, each defined for various consistent time periods. The 2005 Staff Paper analysis assumed that the percentage mix of $PM_{2.5}$ components was the same in all 24 hours of each day, equal to that indicated by 24-hour CSN sampling. The modeling of 1-hour total light extinction in this new assessment allows these correlations to be re-examined, with the more realistic treatment in which the mix of $PM_{2.5}$ components is modeled to vary during the day, based in part of diurnal profiles from CMAQ modeling (see section 3.2.4).

Four figures are presented here, using different time periods for $PM_{2.5}$ mass concentrations and total light extinction, not always matching. In each figure, the solid red line represents a LOESS fit (a form of locally weighted polynomial regression, see http://support.sas.com/rnd/app/papers/loesssugi.pdf) to the data. Table D-1 presents squared correlation coefficients between observed and LOESS model-predicted values for all four figures.

Figure D-1 compares hourly $PM_{2.5}$ mass (as actually measured by the continuous instruments) vs. same-hour daylight total light extinction. As the 2005 Staff Paper explained, the scatter is due to variations in the mix of $PM_{2.5}$ components and in relative humidity across hours. In addition, continuous $PM_{2.5}$ mass instruments do not register the mass of each component consistently with CSN samplers and analysis, which affects the scatter in this figure because the estimates of light extinction are ground truthed to the CSN measurements more strongly than to the continuous $PM_{2.5}$ measurements.

Figure D-2 compares 12-4 pm average $PM_{2.5}$ mass vs. 12-4 pm average total light extinction. Because this time period is generally the time of lowest relative humidity, in most study areas and on average as indicated by the squared correlation coefficients, the scatter in Figure D-2 is less than in Figure D-1.

Figure D-3 compares 12-4 pm average $PM_{2.5}$ mass vs. daily maximum daylight 1-hour total light extinction. The scatter in Figure D-3 is typically more than in Figure D-2, because daily maximum daylight 1-hour total light extinction often occurs earlier in the day than the 12-4 pm period used to average $PM_{2.5}$ mass, when relative humidity is higher.

Figure D-4 compares 8 am-12 pm average $PM_{2.5}$ mass vs. daily maximum daylight 1-hour total light extinction. The scatter in Figure D-4 is typically less than in Figure D-3 and the squared correlation coefficients larger, because this earlier averaging period for $PM_{2.5}$ mass more often encompasses the period of maximum total light extinction.

Table D-1. Squared correlation coefficients between observed and LOESS model-predicted values of total light extinction

	Figure D-1 1-hour $PM_{2.5}$ mass vs. same-hour total light extinction	**Figure D-2 12-4 pm average $PM_{2.5}$ mass vs. 12-4 pm average total light extinction**	**Figure D-3 12-4 pm average $PM_{2.5}$ mass vs. daily maximum daylight 1-hour total light extinction**	**Figure D-4 8 am-12pm** average $PM_{2.5}$ **mass vs. daily maximum daylight 1-hour total light extinction**
Area				
Tacoma	0.82	0.80	0.36	0.73
Fresno	0.79	0.89	0.60	0.69
Los Angeles-South Coast Air Basin	0.58	0.65	0.35	0.46
Phoenix	0.63	0.66	0.16	0.17
Salt Lake City	0.86	0.94	0.70	0.80
Dallas	0.51	0.50	0.15	0.28
Houston	0.52	0.57	0.20	0.31
St. Louis	0.44	0.27	0.25	0.41
Birmingham	0.63	0.60	0.25	0.33
Atlanta	0.62	0.74	0.35	0.58
Detroit-Ann Arbor	0.49	0.58	0.11	0.31
Pittsburgh	0.47	0.51	0.39	0.41
Baltimore	0.43	0.48	0.47	0.49
Philadelphia-Wilmington	0.43	0.36	0.16	0.25
New York-N.New Jersey-Long Island	0.68	0.82	0.49	0.52
AVERAGE	**0.59**	**0.62**	**0.33**	**0.45**

Figure D-1. – Relationship between 1-hour $PM_{2.5}$ mass vs. same-hour total light extinction.

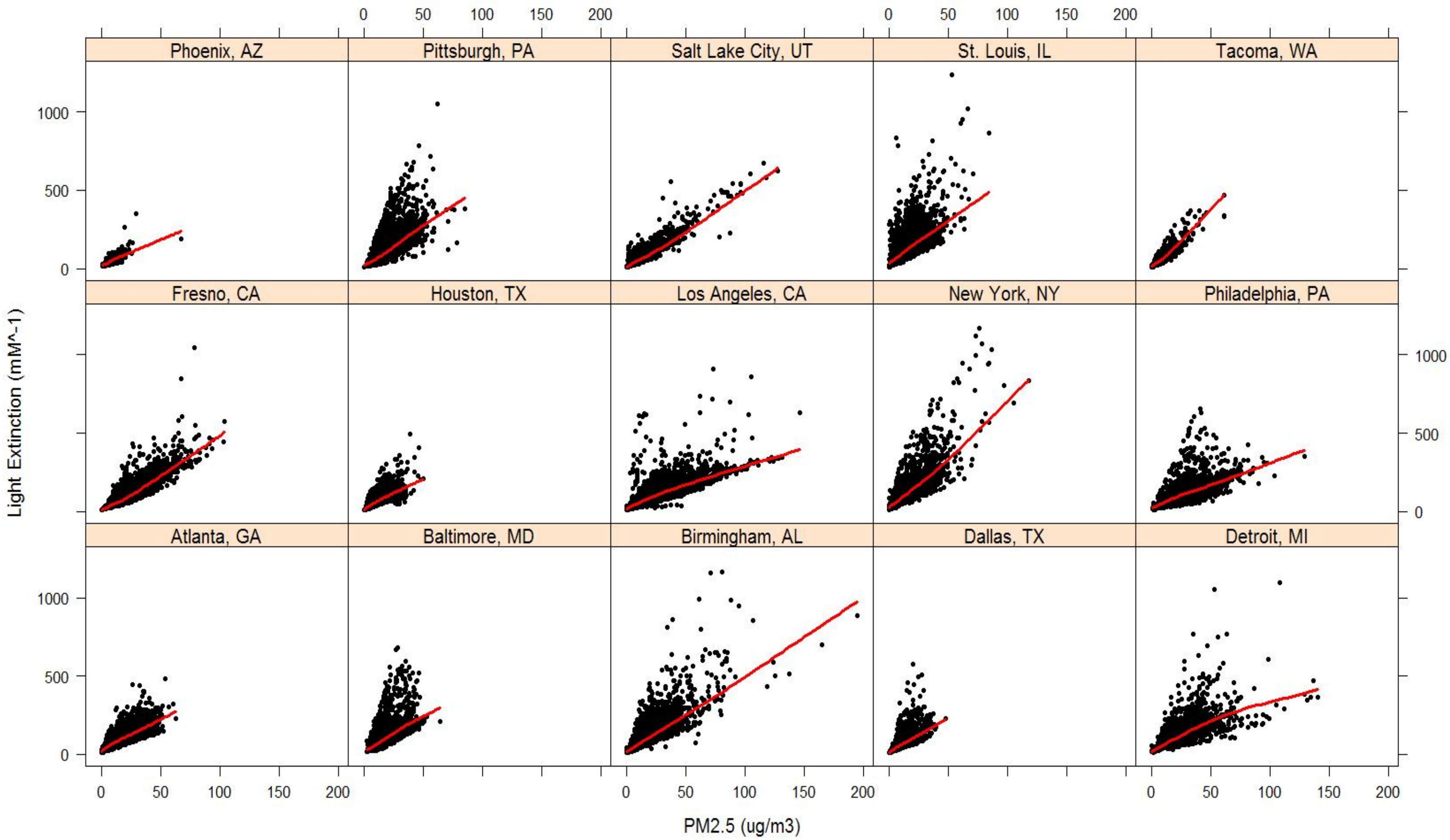


Figure D-2. Relationship between 12-4 pm average $PM_{2.5}$ mass vs. 12-4 pm average total light extinction.

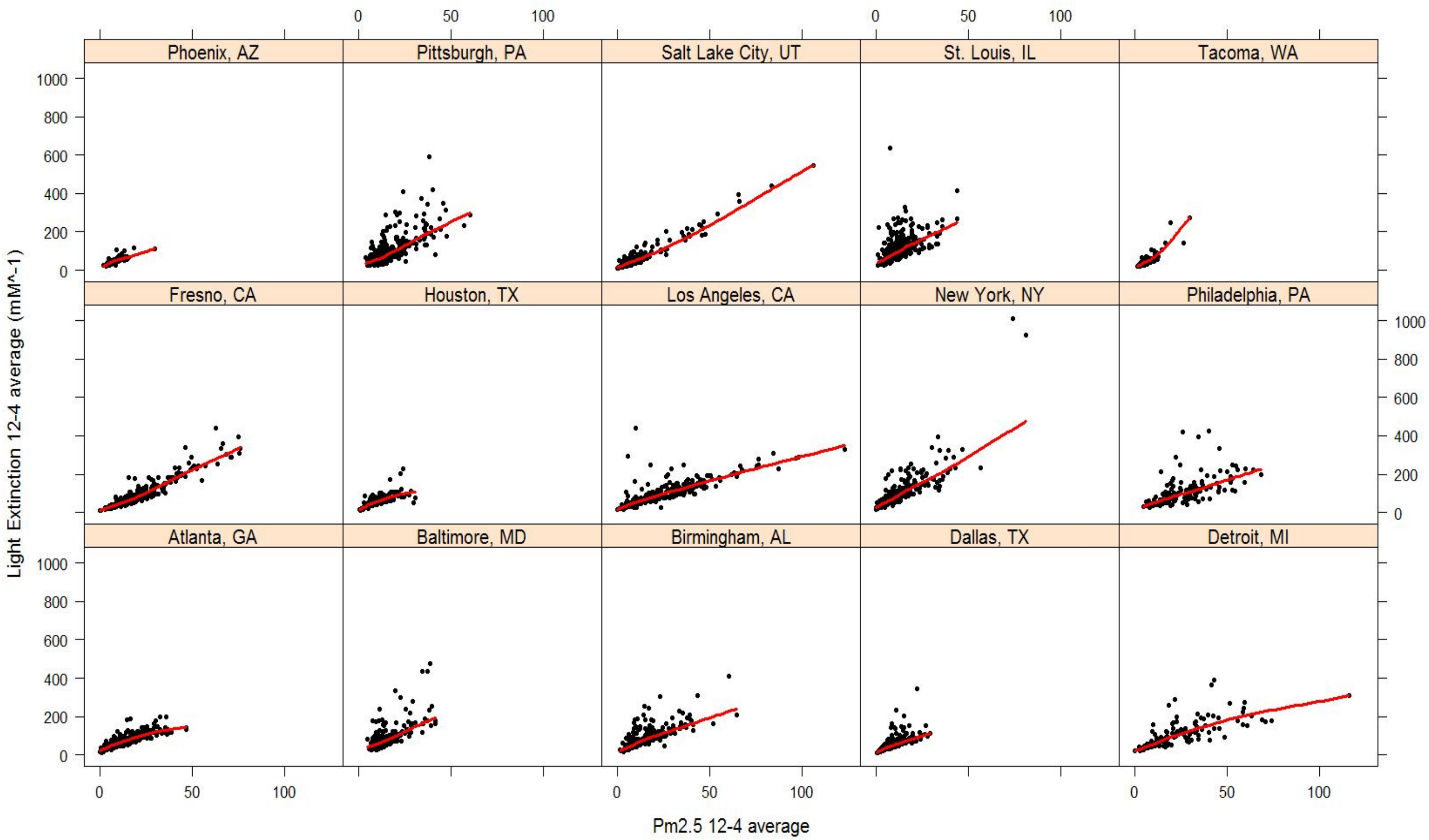


Figure D-3. Relationship between 12-4 pm average $PM_{2.5}$ mass vs. daily maximum daylight 1-hour total light extinction.

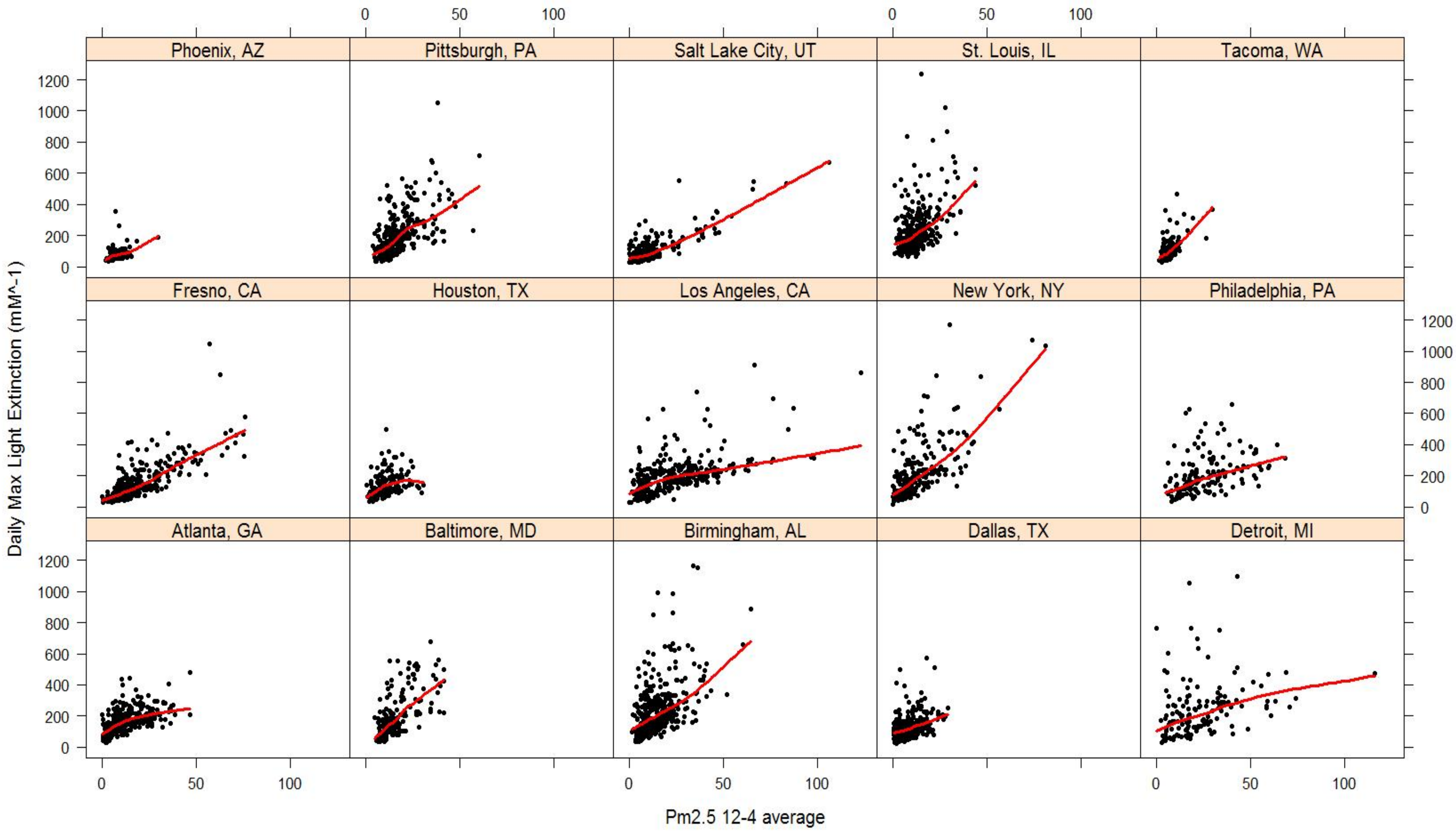
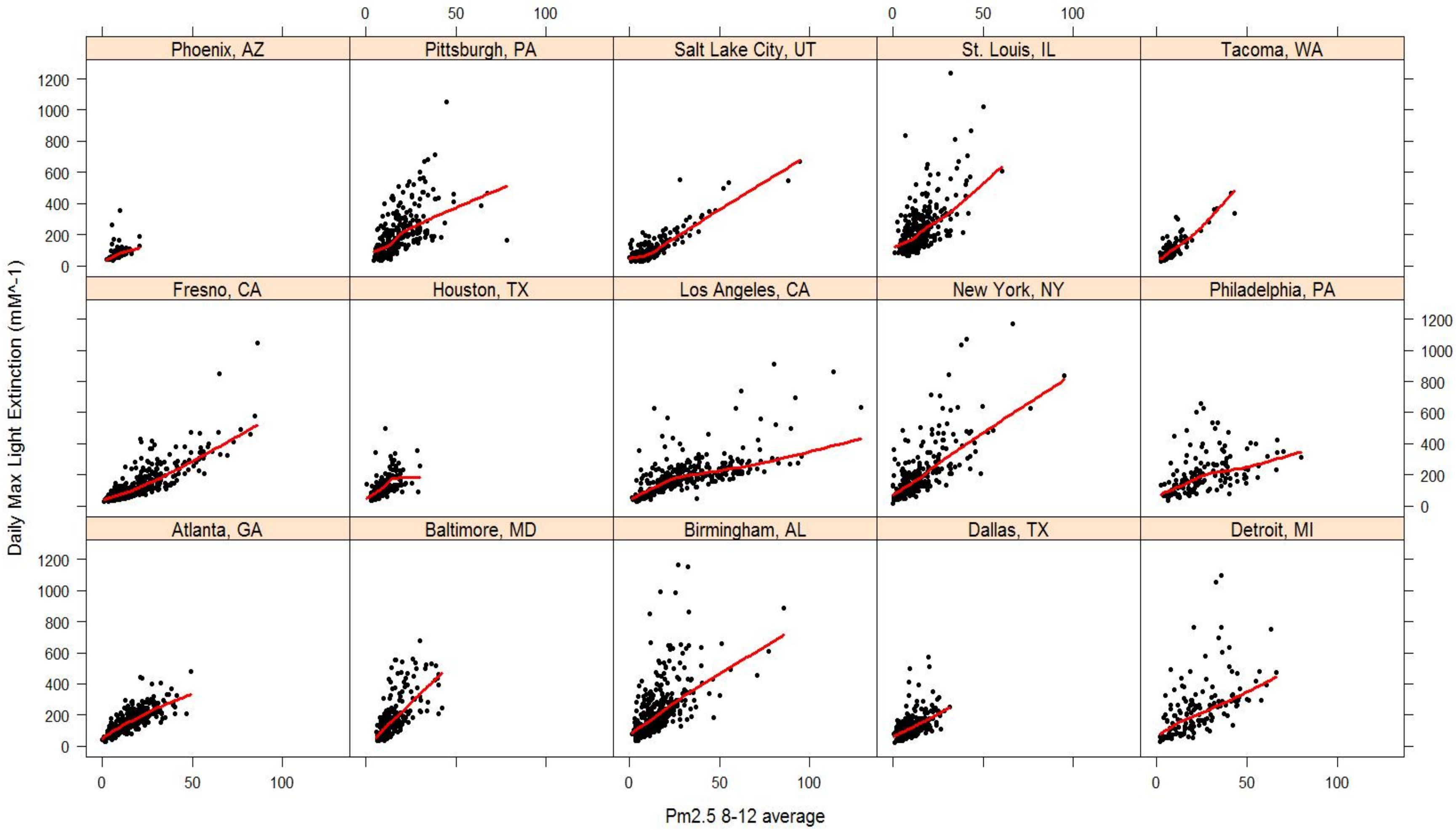


Figure D-4. Relationship between 8 am-12pm average $PM_{2.5}$ mass vs. daily maximum daylight 1-hour total light extinction



APPENDIX E - DIFFERENCES IN DAILY PATTERNS OF RELATIVE HUMIDITY AND TOTAL LIGHT EXTINCTION BETWEEN AREAS AND SEASONS

In the last review of the secondary PM NAAQS, the pattern of total light extinction during the day was of particular interest. It was noted, using estimates of hourly total light extinction based on a simpler approach than described for this analysis, that both (1) mid-day total light extinction and (2) the slope of the relationship between total light extinction and $PM_{2.5}$ concentration varied less among regions of the country that at other times of the day. This was attributed to greater homogeneity of relative humidity across regions in the mid-day period. This is in contrast to the situation in the morning and later afternoon hours, when more eastern areas typically experience higher relative humidity levels than the more arid western and southwestern areas. The current analysis allows these patterns to be re-examined.

Figures E-1 through E-4 show the diurnal pattern of season-average, hour-specific total light extinction and relative humidity for the four "daylight seasons." Light extinction and relative humidity for a given clock hour are averaged across the days in the season, across all three years. Daylight hours (per the simplified schedule of Table 3-5) are indicated by solid circles. Average 1-hour total light extinction generally is highest in the morning, corresponding to higher relatively humidity (mostly due to lower temperature), higher vehicle traffic, and less dispersive conditions than later in the day. As was observed in the last review, there is more variation in average 1-hour total light extinction among areas in the morning than at mid-day.

Figure E-1. Diurnal and seasonal patterns of relative humidity (percent) and total light extinction (Mm^{-1}) for 2005-2007

(a) November-January

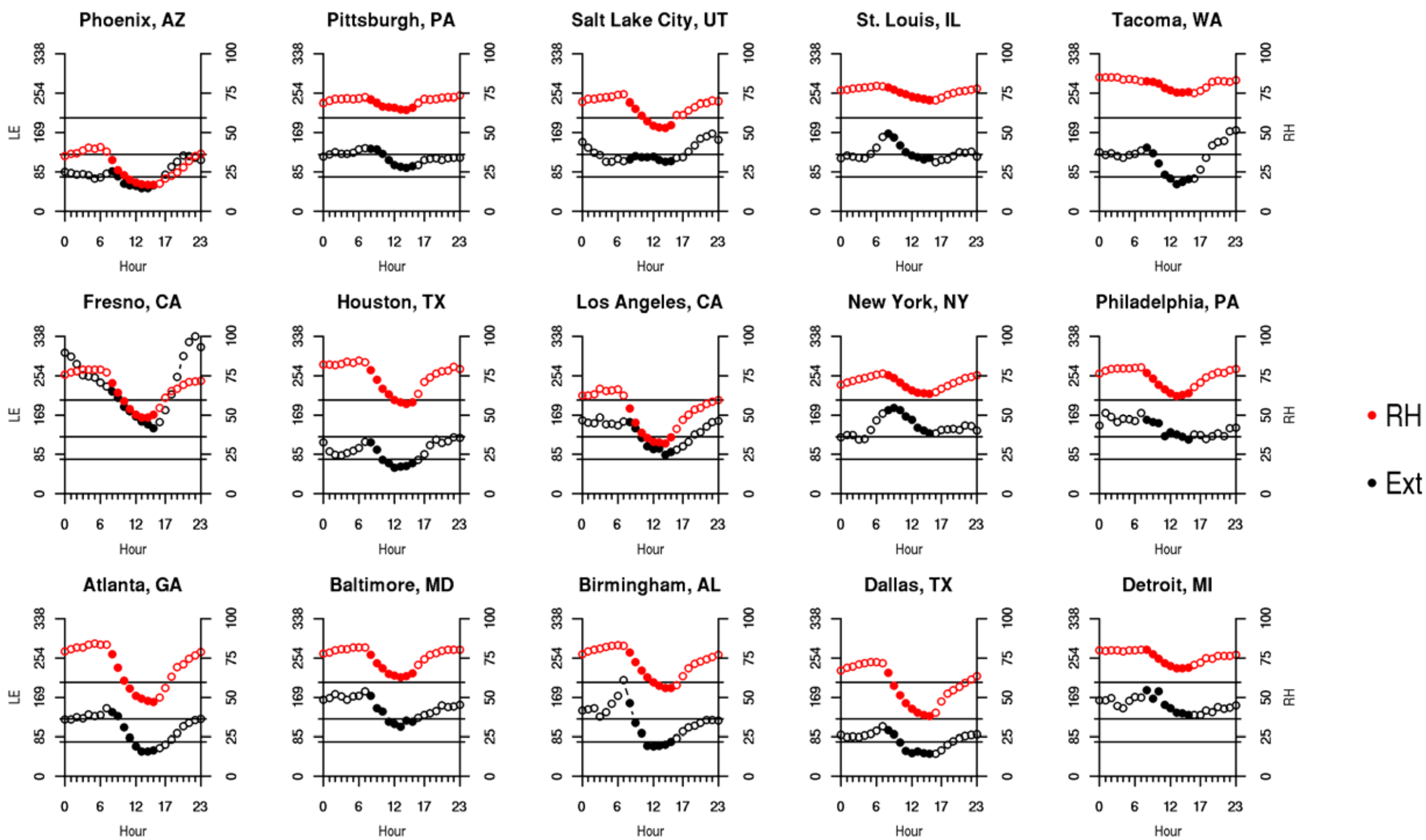


Figure E-2. Diurnal and seasonal patterns of relative humidity (percent) and total light extinction (Mm^{-1}) for 2005-2007, continued

(b) February-April

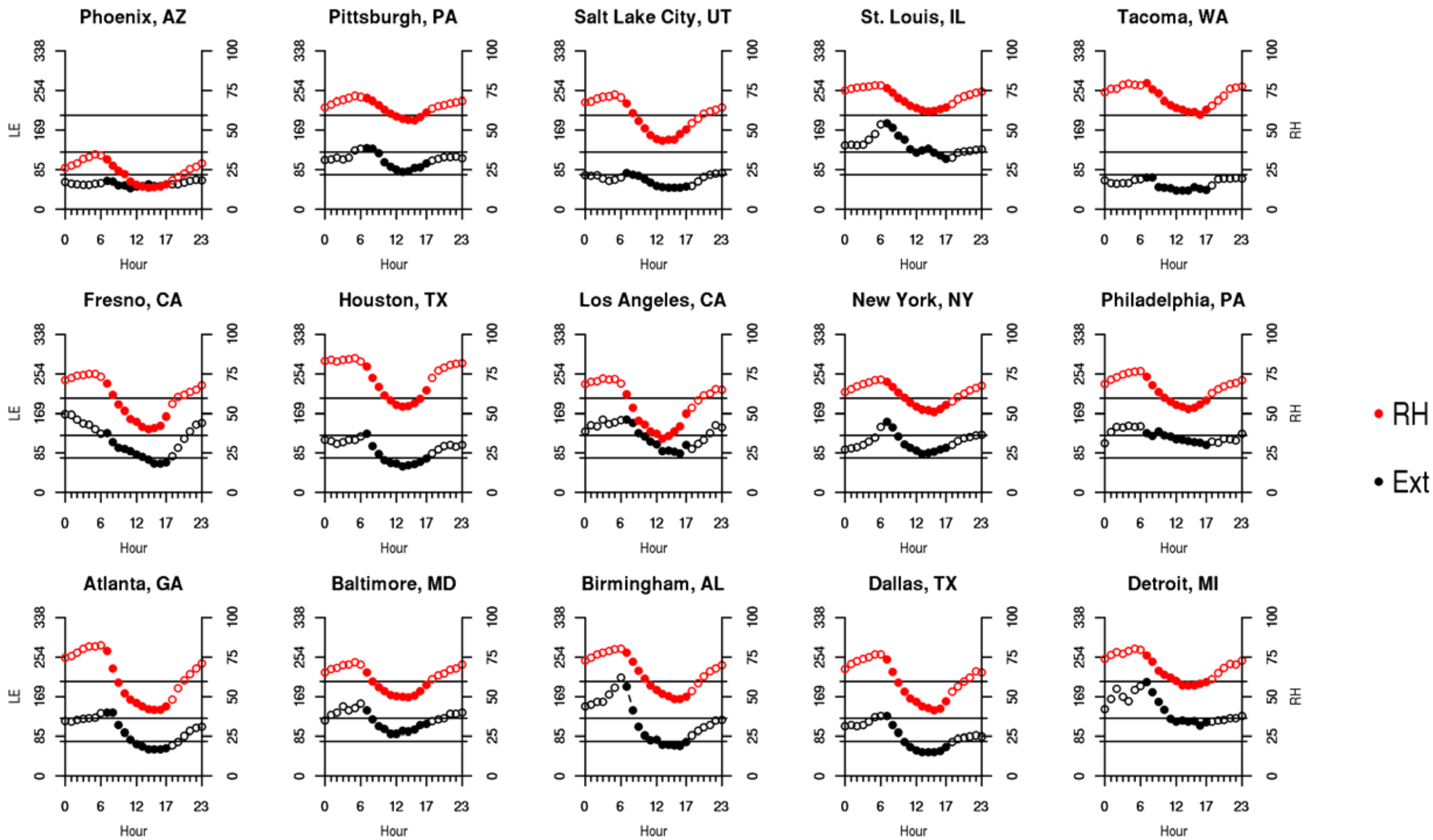


Figure E-3. Diurnal and seasonal patterns of relative humidity (percent) and total light extinction (Mm^{-1}) for 2005-2007, continued

(c) May-July

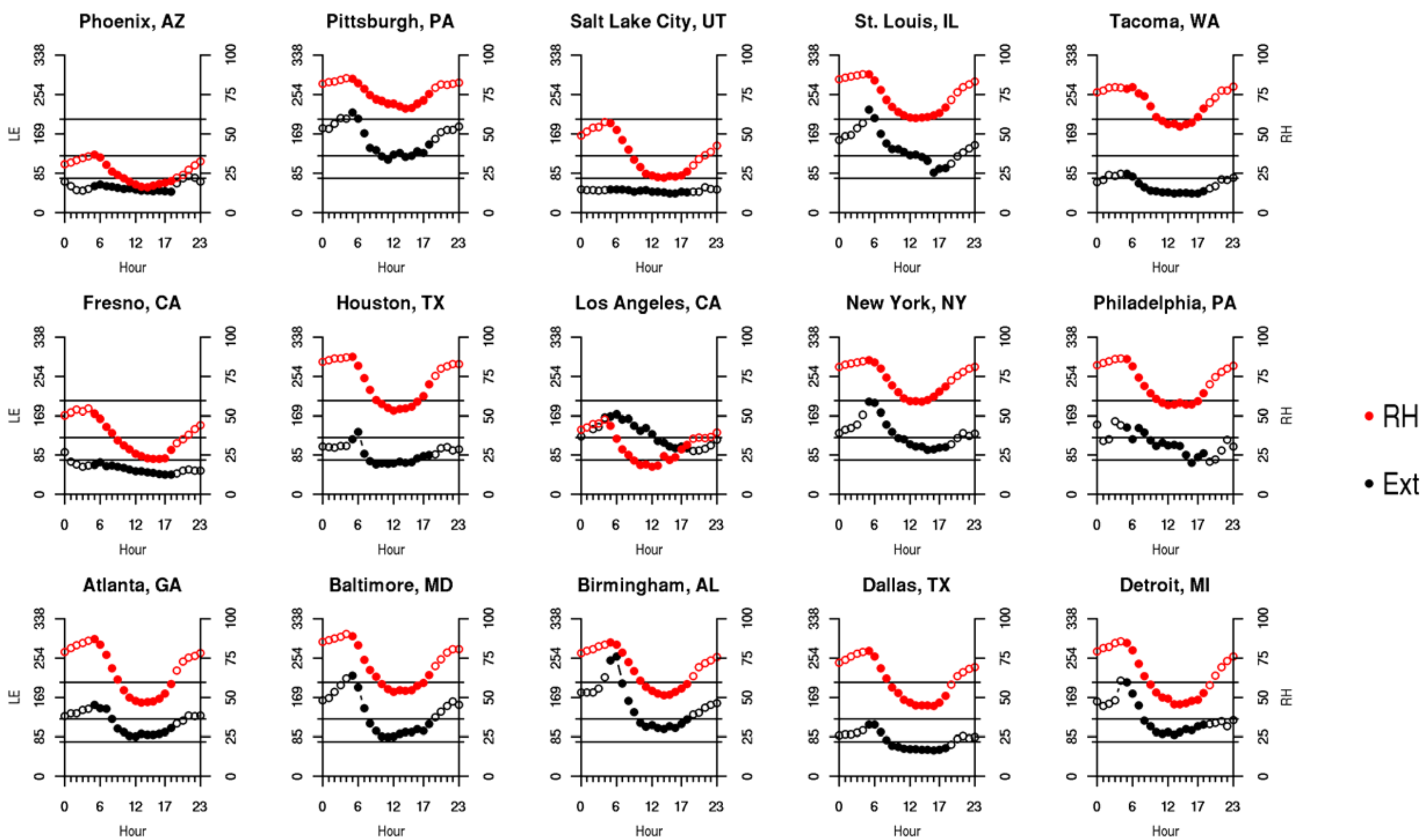
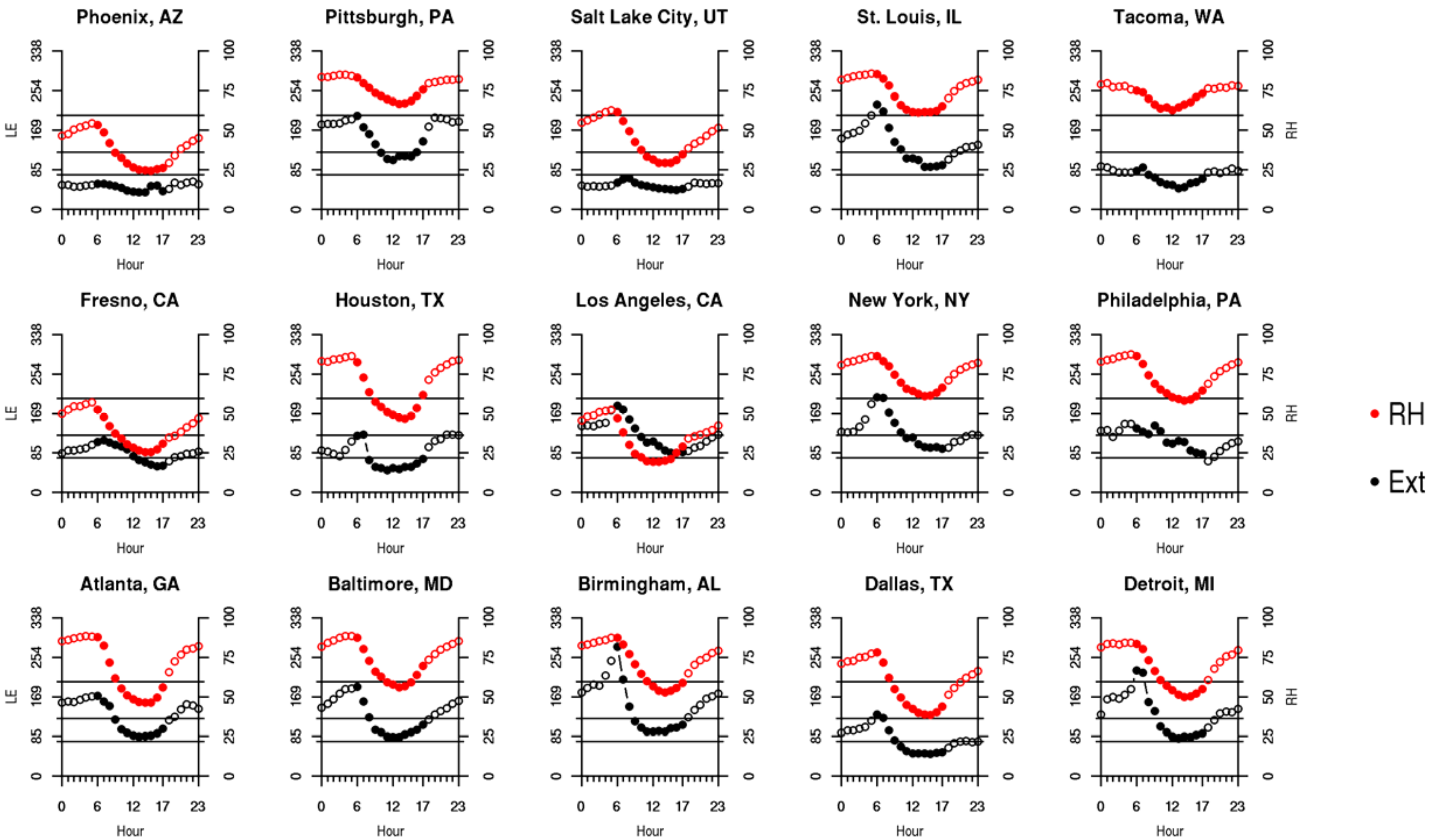


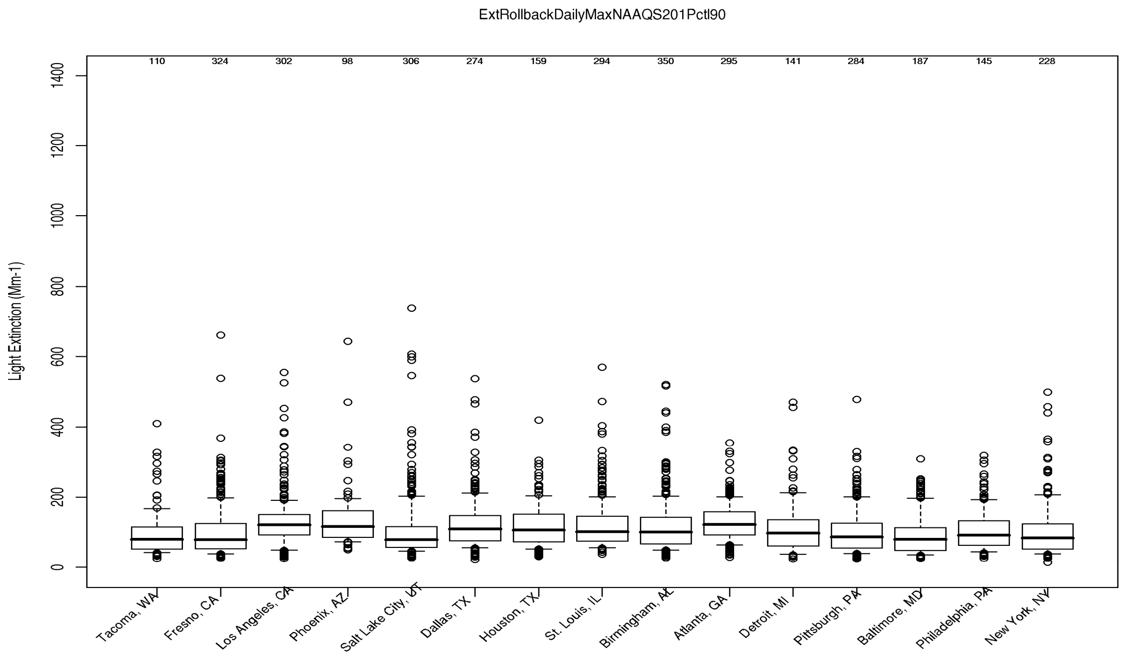
Figure E-4. Diurnal and seasonal patterns of relative humidity (percent) and total light extinction (Mm^{-1}) for 2005-2007, continued

(d) August-October

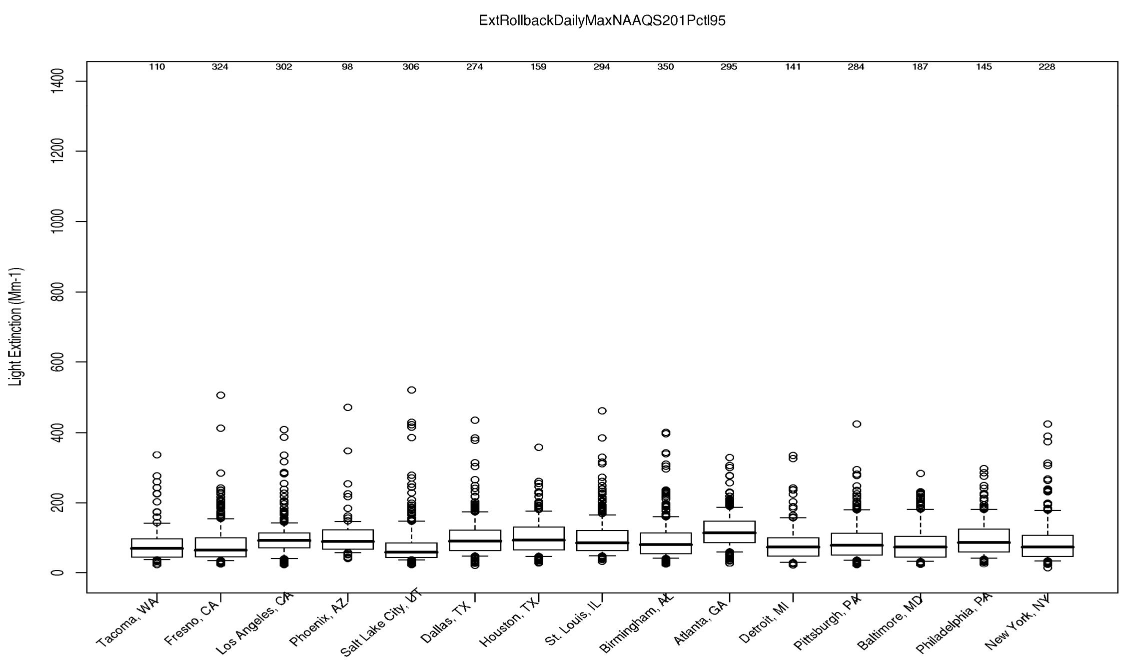


APPENDIX F - DISTRIBUTIONS OF MAXIMUM DAILY DAYLIGHT TOTAL LIGHT EXTINCTION - UNDER "JUST MEET" CONDITIONS

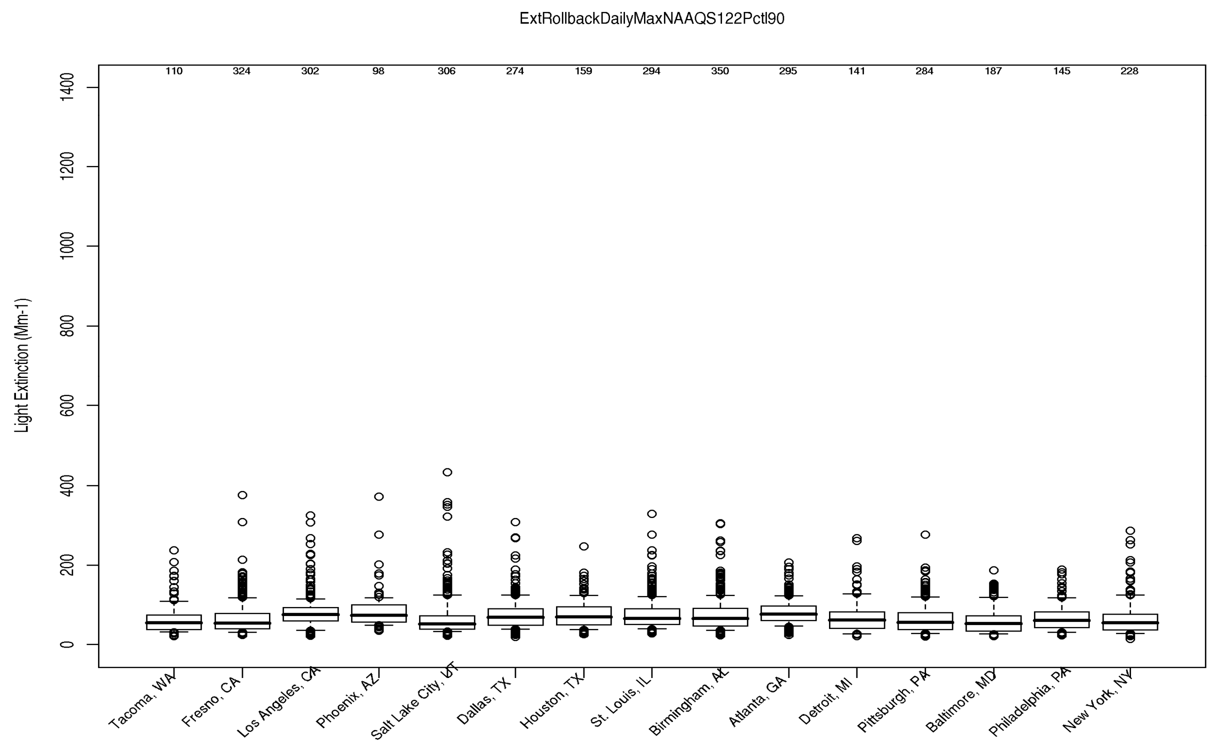
(a) 201 Mm^{-1}, 90^{th} percentile



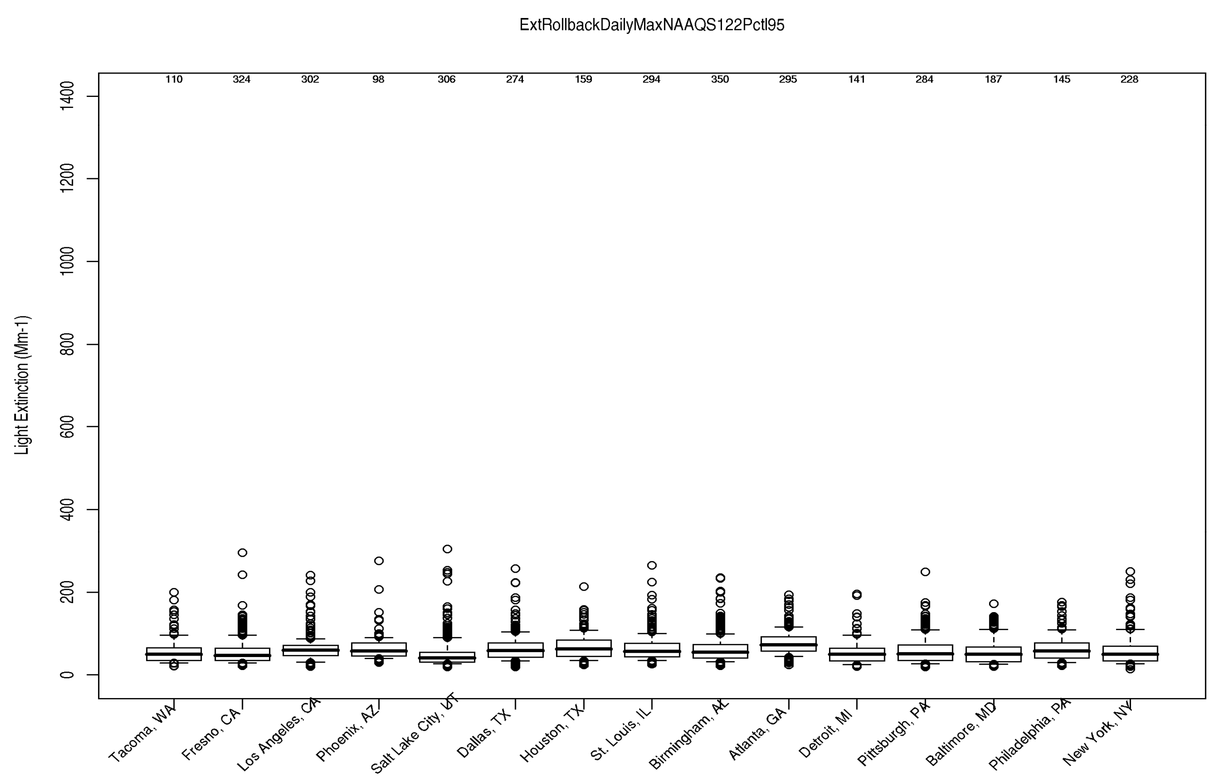
(b) 201 Mm^{-1}, 95^{th} percentile



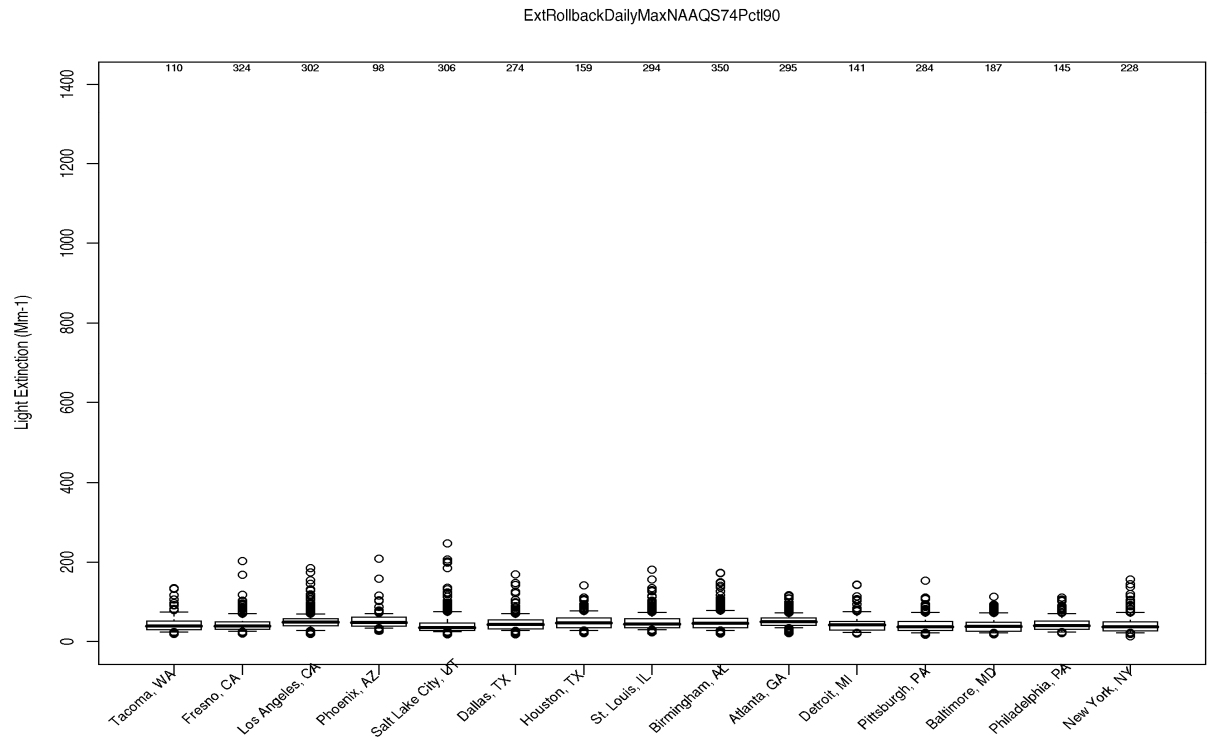
(c) 122 Mm^{-1}, 90th percentile



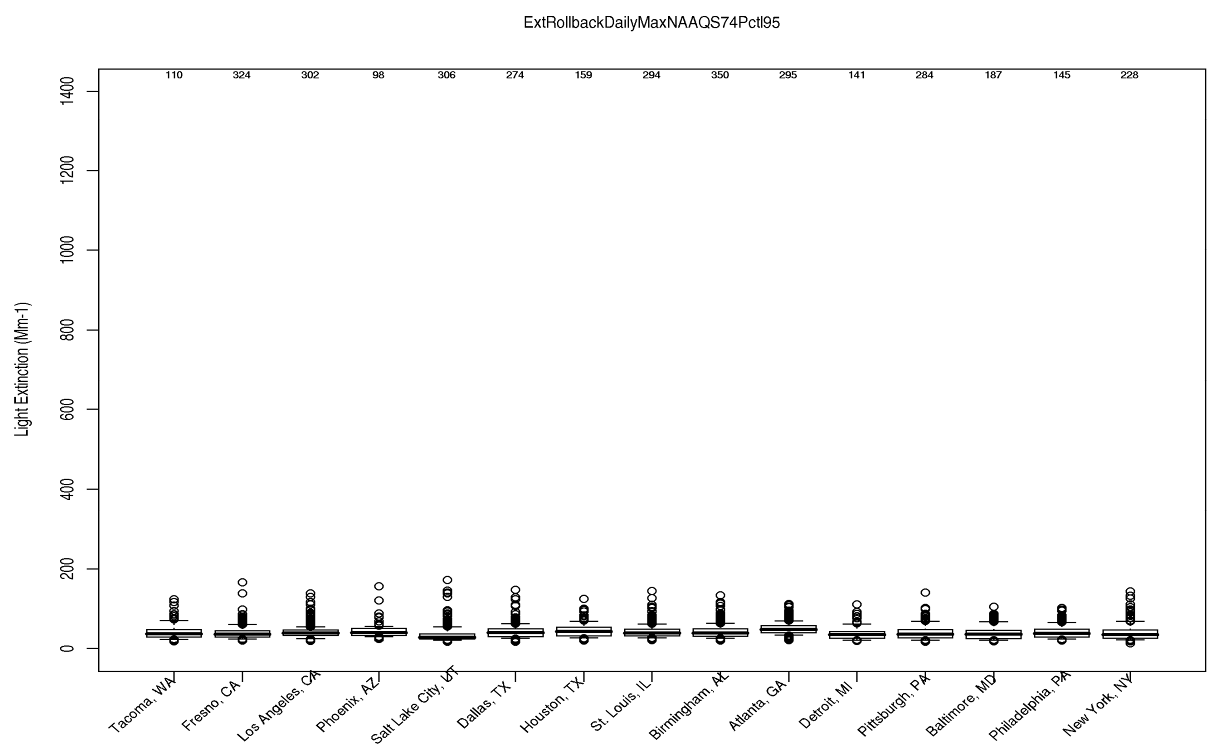
(d) 122 Mm^{-1}, 95th percentile



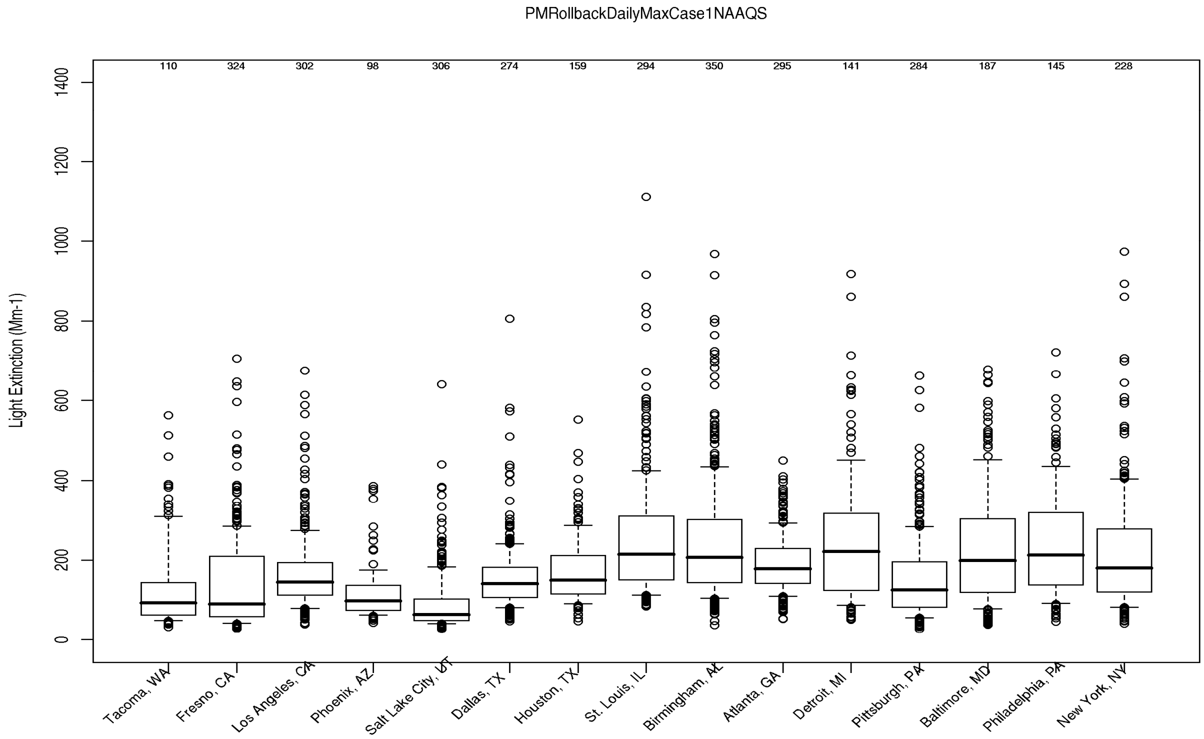
(e) 74 Mm^{-1}, 90^{th} percentile



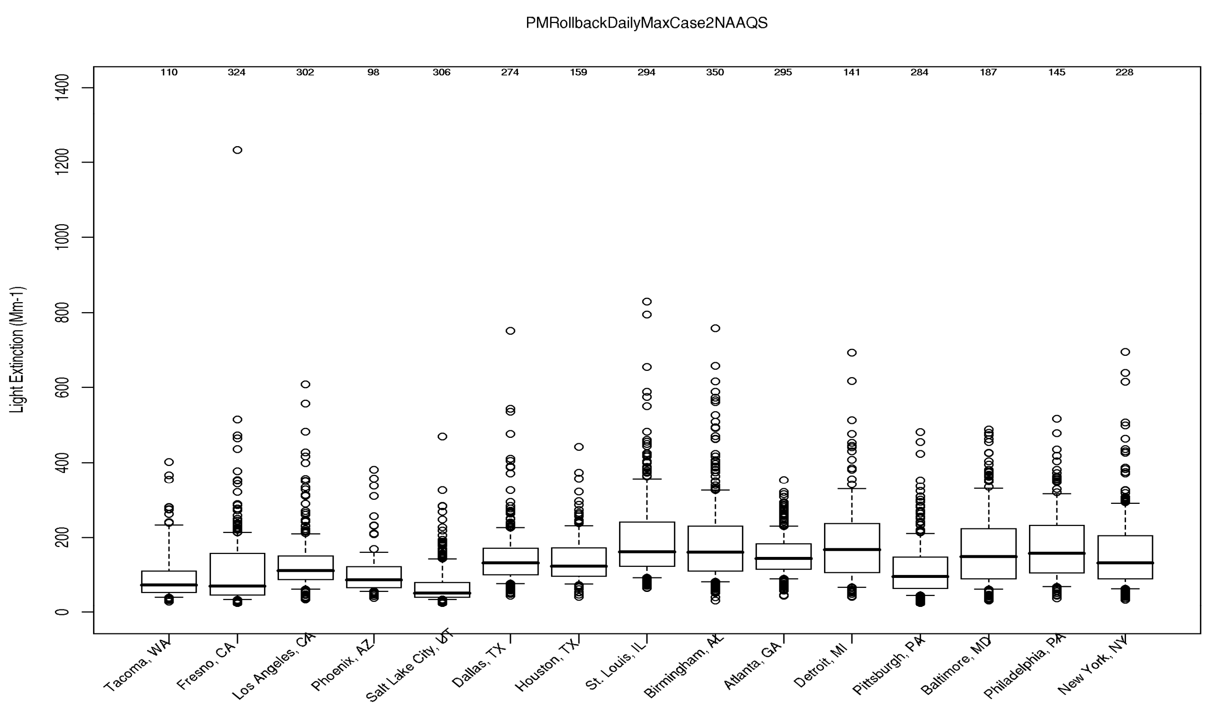
(f) 74 Mm^{-1}, 95^{th} percentile



(g) 15 µg/m^3 annual, 35 µg/m^3 24-hour



(h) 12 µg/m^3 annual, 35 µg/m^3 24-hour



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