Particulate Matter Urban-Focused Visibility Assessment

Final Document

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

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
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 2006 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 suite of secondary standards for $PM_{2.5}$ and PM_{10} were set in 2006 to be identical to the primary standards, on the basis that these standards would, in conjunction with the Regional Haze Program[1], 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 (71 FR 61144, October 17, 2006). At that time, the EPA revised the level of the 24-hour $PM_{2.5}$ primary standard to 35 $\mu g/m^3$ (calculated as a 3-year average of the 98^{th} percentile of 24-hour concentrations at each population-oriented monitor), retained the level of the $PM_{2.5}$ annual primary 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 $PM_{2.5}$ primary standard by narrowing the constraints on the optional use of spatial averaging[2]. With regard to the primary 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 effects. The 2006 primary standards were based primarily on a large body of

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

[2] 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).

epidemiological evidence relating ambient PM concentrations to various adverse health outcomes. (As noted below, portions of the 2006 decision were reversed and remanded by the Court of Appeals for the District of Columbia Circuit.)

In the *Integrated Review Plan for the National Ambient Air Quality Standards for Particulate Matter,* March 2008 (US EPA, 2008a), developed early in the current review of the PM NAAQS,[3] the EPA outlined the science policy questions that frame this review, outlined the process and schedule for the review, and provided descriptions of the purpose, contents, and approach for developing the key documents that will be developed in the review.[4] EPA has completed the process of assessing the latest available policy-relevant scientific information to inform the review of the PM standards. The final assessment is contained in the final Integrated Science Assessment for Particulate Matter (ISA, US EPA, 2009a) which was released in December 2009. The final 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 PM ISA, as well as CASAC advice (Samet, 2009a and b) and public comments on the plan for and first draft of the Urban-Focused Visibility Assessment (UFVA) (US EPA, 2009b, c), EPA's Office of Air Quality Planning and Standards (OAQPS) developed a second draft UFVA (US EPA, 2010a) which described the quantitative assessments conducted by the Agency to support the review of the secondary PM standards. This second draft document presented the methods, key results, observations, and related uncertainties associated with the quantitative analyses performed and was reviewed and discussed by CASAC and the public at a March 10-11 meeting. Based on input received at the March 2010 meeting and in a subsequent letter (Samet, 2010a), this final UFVA document includes the following changes: 1) inclusion of the complete logit memo in Appendix J and streamlining of logit discussion in chapter 2 to reduce redundancy and reflect this addition; 2) Figure 3-13 and associated text was modified to provide a more consistent comparison of speciated PM mass for the top 10% and 2% of maximum daylight hours and all daylight hours, respectively; 3) addition of footnotes and caveats in the text to acknowledge that

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

[4] 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 St. Louis data is now considered unrealistically high and is not carried forward into the second draft PA[5]; 4) modification of Table 3-6 to correctly omit non-daylight hours which were inadvertently included in the second draft UFVA, report results for four study areas for which results were missing in the second draft UFVA, and separate “mist” from “smoke/haze” to reflect that “mist” is a natural condition while “smoke/haze” is not always a natural condition; and 5) addition of an integrative summary (chapter 5).

In addition, a preliminary draft PA (US EPA, 2009d) was released in September 2009 for informational purposes and to facilitate discussion with CASAC at the October 5-6, 2009 meeting on the overall structure, areas of focus, and level of detail to be included in the PA. This preliminary draft PA was discussed in conjunction with CASAC review of and public comment on the second draft ISA, first draft UFVA, and first draft health risk assessment documents produced in support of this PM NAAQS rulemaking. CASAC comments on the preliminary draft PA were considered in developing the first external review draft PA (US EPA, 2010b). The first draft PA, which built upon the information presented in the final ISA and second draft UFVA, was released for CASAC review and public comment in February of 2010 (US EPA, 2010b). EPA presented an overview of the first draft PA at the CASAC meeting on March 10, 2010. CASAC and public review of the first draft PA was discussed during public teleconferences on April 8-9, 2010 (75 FR 8062, February 23, 2010) and May 7, 2010 (75 FR 19971, April 16, 2010). CASAC (Samet, 2010b) and public comments on the first draft PA were considered in developing the second draft PA which will be reviewed by CASAC at an upcoming meeting scheduled for July 26-27, 2010 (75 FR 32763), June 9, 2010).

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 is intended to provide a transparent staff analysis of the scientific basis for alternative policy options for consideration by senior EPA management prior to rulemaking by integrating and interpreting 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 second draft PA (US EPA, 2010c) has been released in conjunction with this final UFVA document.

[5] Comments concerning unrealistically high $PM_{10-2.5}$ values for St. Louis are viewed as credible, but were received too late in the review process to permit reanalysis using an alternate data set or to remove St. Louis from all portions of this document. However, the text has been revised to caution readers with respect to the St. Louis results, and they are not included in the visibility effects discussion in the second draft PM Policy Assessment document. Some graphics have been updated to exclude St. Louis results in this final UFVA.

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, authorized under sections 169A and 169B of the CAA, was established to address all human-caused visibility impairment in federal Class I areas. The national goal of this program is to prevent any future, and remedy any existing, impairment of visibility in mandatory class I Federal areas (Class I areas) which results from manmade air pollution. This program also mandates that states develop SIPs to ensure that reasonable progress is made towards meeting those goals. Because Congress explicitly targeted Class I areas for this pristine level of protection, it can be concluded that Congress did not envision such a stringent goal in non-Class I areas. See American Trucking Ass'n v. Browner, 175 F. 3d 1027, 1056-57 (D. C. Cir. 2002) (upholding this position). However, Congress recognized that visibility impairment can and often does occur in areas outside federal Class I areas, including urban areas and judged that protection from visibility impairment was important in those areas as well. In this regard, Congress included visibility effects in the definition of public welfare effects that should be protected under the national ambient air quality standards (NAAQS) program authorized in sections 108 and 109 of the CAA. As a result, EPA may establish secondary standards addressing visibility impairment notwithstanding existence of the Regional Haze Program. Under the NAAQS program, it is up to the Administrator to judge the requisite level of public welfare visibility protection.

Recognizing that efforts were underway to provide increased protection to Class I areas under the Regional Haze Program, EPA focused the 2006 PM NAAQS review on visibility impairment in non-Class I areas. Because most of the available non-Class I PM data came from PM monitoring sites located primarily in urban areas, the assessments took on an urban focus. In addition, EPA considered available information on people's preferences for different levels of visual air quality which came from studies conducted in urban areas and information regarding existing urban visibility programs and goals.

In an effort to minimize the factors that historically had complicated efforts to address visibility impairment nationally, (i.e., the substantial East/West differences in factors contributing to impairment in Class I areas), EPA staff noted that with respect to fine particles, East/West differences in urban areas are substantially smaller than in rural areas. Further, relative humidity levels, though generally higher in eastern than western areas, are appreciably lower in both regions during daylight, as compared to nighttime, hours. The $PM_{2.5}$ data available at that time in urban areas were obtained using a filter –based Federal Reference Method (FRM) which captures ambient $PM_{2.5}$ on a filter and then dries it to get the dry $PM_{2.5}$ mass concentration. By drying the sample, most water and to some extent other labile PM compounds evaporate so that the original characteristics (e.g., particle size and composition) of the ambient

PM are altered. Using PM and meteorological data from 161 cities, EPA staff assessed the correlations between $PM_{2.5}$ levels and reconstructed (RE) (i.e., calculated) light extinction during daylight hours for different regions of the country. This assessment showed that the strongest correlation in the relationship of ambient PM light extinction to dry $PM_{2.5}$ mass concentration was during afternoon periods when lower relative humidity conditions generally prevailed in all regions of the country and ambient PM was drier (Staff Paper, US EPA, 2005). While EPA recognized that the effect of ambient PM on visibility results from the ambient particle characteristics of size, concentration, and composition (including associated water) present in the air in the sight path of the observer, given the data availability at the time, EPA viewed the FRM altered $PM_{2.5}$ mass concentration as an acceptable indicator for addressing ambient PM-related visibility effects at the national scale during afternoon hours. Thus, the 2005 Staff Paper chose to address the issue of regional differences in terms of averaging time rather than indicator, discussing the use of a sub-daily afternoon dry $PM_{2.5}$ standard, because the generally lower afternoon relative humidity tended to produce a more uniform relationship between light extinction and dry $PM_{2.5}$ mass concentration throughout the country, therefore providing a more uniform level of visibility protection nationwide. This more uniform level of visibility protection, however, was limited to the afternoon hours of the day when relative humidity and visibility impairment tend to be the lowest.

Based on the above, in the 2005 PM Staff Paper, EPA staff recommended a separate sub-daily secondary standard to address visibility impairment using dried $PM_{2.5}$ mass concentration as the indicator, a recommendation endorsed by CASAC. In the 2006 proposal notice, however**,** EPA proposed to revise the secondary standards by making them identical to the suite of proposed primary standards for fine and coarse particles, to provide protection against PM-related public welfare effects including visibility impairment, effects on vegetation and ecosystems, materials damage and soiling, and climate, while soliciting comment on adding a new sub-daily $PM_{2.5}$ secondary standard to address visibility impairment primarily in urban areas (71 FR 2620). 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 provide increased protection of public welfare by making the secondary NAAQS identical to the revised primary standards (71 FR 61144, October 17, 2006). This suite of secondary standards was designed to address both visibility and other non-visibility welfare related effects. Specifically, with regard to the secondary welfare effect of visibility impairment, the Administrator believed that revising both the 24-hour and annual $PM_{2.5}$ secondary standards to be identical to the revised suite of $PM_{2.5}$ primary standards was a reasonable policy approach to address visibility impairment primarily in urban areas. With regard to the other non-visibility PM-related welfare effects such as vegetation and ecosystems, materials damage and soiling, and climate, the Administrator concluded that it was appropriate to address these effects by revising the current suite of $PM_{2.5}$ secondary standards, making them identical in all respects to the suite of primary $PM_{2.5}$ standards, while retaining the current 24-hour PM_{10} secondary standard and revoking the current annual PM_{10} secondary standard. In particular for coarse particles, EPA retained PM_{10} as the indicator for purposes of regulating the coarse fraction of PM_{10} and retained the 24-hour secondary PM_{10} standard at 150 $\mu g/m^3$ and revoked the annual secondary 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 $PM_{2.5}$ secondary 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 misleading comparison of the number of counties which would be in nonattainment for the revised primary NAAQS compared to one alternative secondary standard under consideration. 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, 530-31 (D.C. Cir. 2009).

The analyses developed for and described in this document reflect consideration of the issues raised by the court. In particular, a) the reanalysis of public preference studies (described in Chapter 2) provides information useful for the selection of "target levels" for urban visibility protection; b) the analyses of the factors contributing to visibility impairment for selected urban areas, including PM species component contributions and variations in relative humidity, provide information useful for better characterization of regional differences important for development of a national standard (Chapter 3); and c) the analyses of alternative standards (Chapter 4) using different combinations of indicator, averaging times, levels and forms provide information useful in understanding the degree of visibility protection provided by alternative standards.

1.2 VISIBILITY EFFECTS SCIENCE OVERVIEW

Light extinction is the loss of light per unit of distance and occurs when light is scattered and/or absorbed. Particulate matter and gases can both scatter and absorb light. Light scattering by gases (e.g., nitrogen, oxygen, etc.) that comprise the pollutant free or clean 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 taken to be a time invariant constant that depends principally on elevation above sea level. 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. Hereinafter the phrase "PM light extinction" indicates that the Rayleigh contribution to light extinction (nominally considered 10 Mm^{-1}) has been subtracted out and the NO_2 contribution is considered negligible or is simply excluded due to the measurement approach used. By contrast, the term "light extinction" or "total light extinction" is meant to include both the Rayleigh and NO_2 contributions.

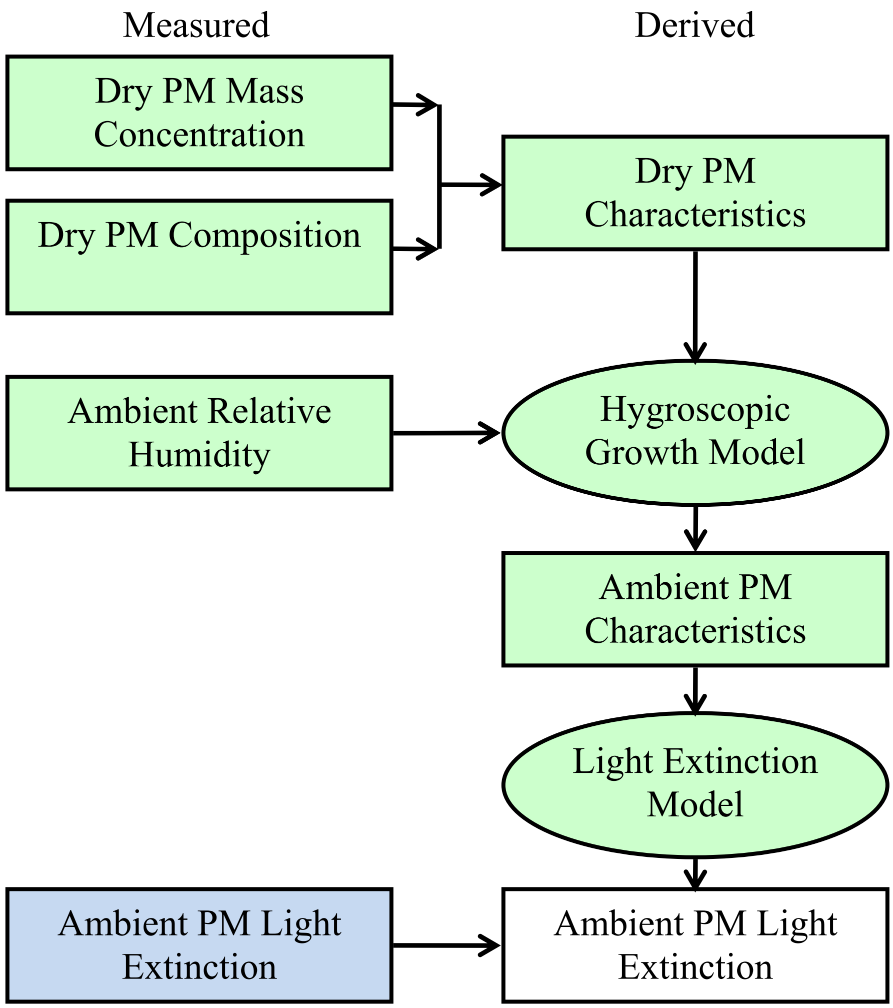
Visual air quality (VAQ) is defined as the visibility effect caused solely by air quality conditions and excluding those associated with meteorological conditions like fog and precipitation. It is commonly measured as either light extinction (in terms of inverse megameters, Mm^{-1}) or the haziness index (in terms of deciview, dv) (Pitchford and Malm, 1993). The 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. It 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). Light extinction and haziness are physical measures of the amount of visibility impairment (e.g., the amount of "haze"), with both increasing as the amount of haze increases. Visual range, defined as the greatest distance that a large dark object can be seen, was developed for military and transportation safety use. Under conditions that meet certain standard assumptions, visual range is inversely related to light extinction (Pitchford and Malm, 1993).

PM is a heterogeneous mixture of particles of different sizes and chemical compositions. While visibility impairment has been associated most often with $PM_{2.5}$, larger particles such as those found in PM_{10} may be a significant contributor in some areas. Thus, the UFVA considers the visibility impairment caused by all particles 10 microns or smaller. As stated above, the degree of visibility impairment caused by a given mass of PM depends in large part on the size, density and chemical composition of the PM. If the ambient PM has a large number of hygroscopic particles (i.e., particles that readily absorb moisture from the atmosphere), and also occurs when the relative humidity of the air is higher, those particles will grow larger in size and have a larger haze effect than if those same particles occurred in ambient air with lower relative humidity.

Ambient PM light extinction is most accurately determined by direct measurements. However, as shown in Figure 1-1, the ambient PM light extinction can also be estimated from dry PM mass and composition data and relative humidity using an algorithm. One well established algorithm, known as the IMPROVE algorithm[6], accounts for water present in hygroscopic PM components and uses assumed light extinction efficiencies for each of the major PM species. Because there is limited ambient PM light extinction data available in urban areas, the assessments below will principally use monitored and modeled dry PM mass and species estimates, along with relative humidity measurements as input to the IMPROVE algorithm for estimating ambient PM light extinction.

[6] Malm, et al., 1994 and DeBell, 2006. (See also ISA, section 9.2.2.2, pgs. 9-7 and 9-8.)

Figure 1-1. Progression from PM Characteristics to PM Light Extinction That Shows the Modeling Approach (shaded light green) as well as the Use of Direct Measurements (shaded blue) as Alternative Ways to Estimate PM Light Extinction

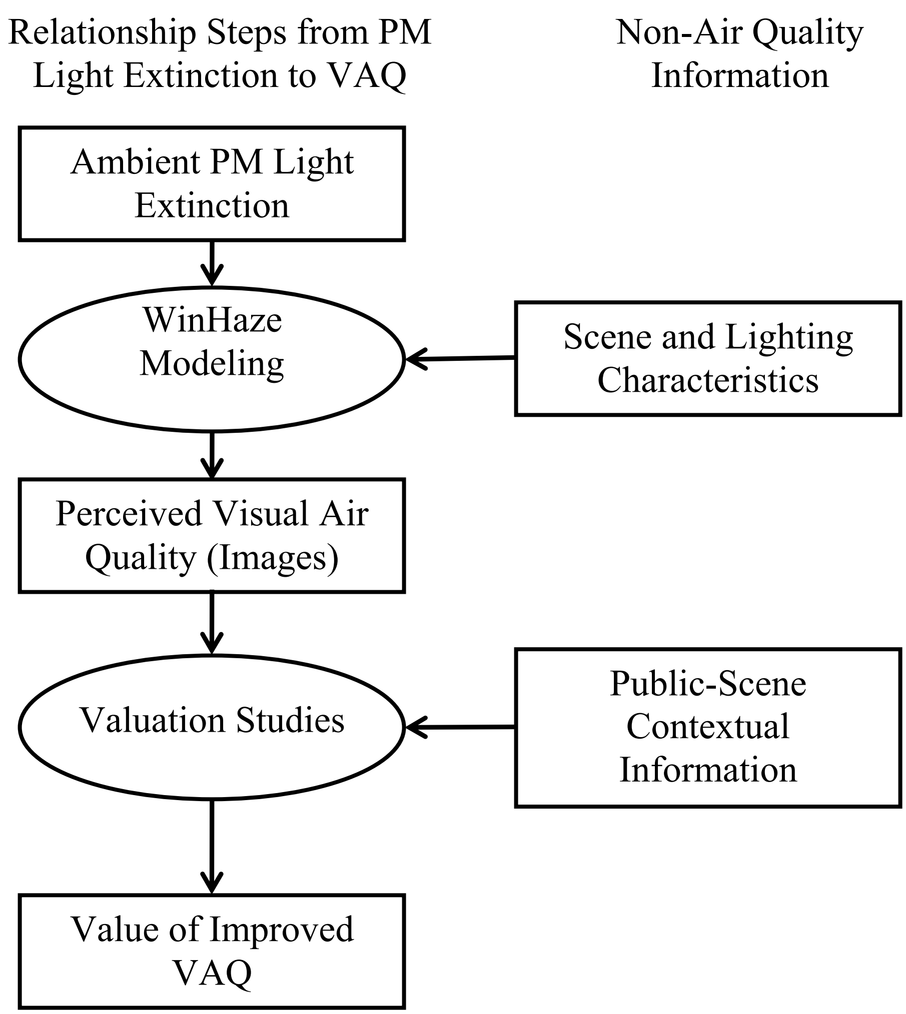


The extent to which any amount of light extinction affects a person's ability to view a scene depends on both scene and light characteristics. For example the appearance of a nearby object (i.e., a building) is generally less sensitive to a change in light extinction than the appearance of a similar object at a greater distance. For a scene with known characteristics, the degradation in the scene associated with a change in light extinction can be determined and the resulting appearance can be realistically displayed on a digital photograph of the scene using the WinHaze system[7]. Figure 1-2 below shows the progression from PM light extinction to perceived visual air quality impacts to the valuation of those perceived impacts.

[7] Molenar, et al., 1994

Survey studies have used sets of photographs or computer simulated images developed from a base photo depicting a range of visibility conditions on urban scenes to assess the individual's opinion on the acceptability of those VAQ conditions. For the specific scenes used in such studies there is a known or predetermined one-to-one correspondence between the amount of ambient or computer generated haze captured in the photographs or images, respectively, and the associated amount of ambient 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 1-2. Progression from PM Light Extinction to Value of Improved Visual Air Quality (VAQ)



1.3 GOALS AND APPROACH

The goal of the UFVA is to characterize visibility impairment in 15 selected urban areas under recent air quality conditions, "just meet" air quality scenarios for both current secondary $PM_{2.5}$ standards, and under scenarios using various alternative standards which utilize different indicators, averaging times, forms and levels to identify those that better reflect the relationship between ambient PM and visibility impairment. In particular, the UFVA focuses on the use of a PM_{10} light extinction-based indicator for a possible secondary PM NAAQS (see Figure 1-1 and 1-2). This is done by comparing estimates of hourly PM_{10} light extinction in 15 major U.S. urban areas over a three-year period (2005-2007) to a range of light extinction values, i.e., candidate protection levels (CPLs), beyond which half of the participants in assessed urban visibility preference studies indicated the haze conditions were unacceptable (see discussion in chapter 2 below, Stratus Consulting Inc., 2009 and Appendix J). In addition, the UFVA includes additional characterizations of the effectiveness of the current and an alternative suite of PM2.5 secondary standards[8].

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[9]. With the exception of a small pilot study conducted in Washington, DC in 2001 (9 participants; Abt Associates Inc., 2001), and a replicate study also conducted for Washington, DC in 2009 (26 participants; Smith and Howell, 2009), there are 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 Washington, DC studies. This assessment includes an analysis that combines data from across all studies using graphical and logit model analysis to examine the consistency of the results between the surveys (Stratus Consulting Inc., 2009 and Appendix J). Based on the results of this analysis, we have been able to refine the range of visibility conditions put forth in the 2006 review, that could represent an appropriate degree of public welfare visibility protection, and to determine a central tendency value for the CPLs. These analyses and results are described below in chapter 2.

[8] EPA also included an assessment of the 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 are summarized in Appendix D.

[9] Light extinction is inversely related to visual range.

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 from 161 urban areas 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. 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).

The current assessment of urban visibility conditions (as described in chapter 3) uses a modeling approach to estimate hourly light extinction using $PM_{2.5}$ mass and speciation data with measured relative humidity. However, it differs by replacing the unrealistic assumption of constant composition for $PM_{2.5}$, with composition that 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.

1.4 SCOPE OF URBAN-FOCUSED VISIBILITY ASSESSMENT

This section provides an overview of the scope and key design elements of the UFVA, including the process that has been followed to design the analyses. Following initiation of this PM NAAQS review in 2007, we began the design of the assessments in the UFVA by revisiting 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 review.

1.4.1 Background

As an initial step in this 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 centered on 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).

In articulating a rationale for the urban focus of this assessment, we reviewed the available information and found 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 demonstrating that urban VAQ is noticed and considered an important value to urban residents (US EPA, 2009a; section 9.2.4); and 3) the existence of large urban populations means that potentially more people are routinely affected by poor VAQ than in rural areas. These features of urban areas have led EPA staff to conclude that urban dwellers represent a susceptible population group for adverse PM-related effects on visibility. However, this conclusion is not meant to imply that there are not other susceptible populations or individuals living in other non-urban and non-Class I areas that are currently adversely impacted by ambient PM-related visibility conditions. Unfortunately, visibility preferences and PM levels in these areas have not been well characterized. Although this visibility assessment focuses only on selected urban areas, a new secondary PM standard would apply to all non-Class I areas of the country.

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 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), National Park Service, academia, regional and state air pollution planning agencies, and consulting firms.[10] The information discussed at this Workshop was useful in informing subsequent steps in the process.

1.4.2 Selection of Alternative Scenarios for First Draft Assessments

In designing the quantitative assessments to include in the first draft UFVA, EPA staff 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 the Scope and Methods Plan, along with ongoing review of the latest PM-related literature, several aspects of the original scope 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), were modified in the first draft UFVA (US EPA, 2009c). 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 concluded that it was unnecessary to develop a new urban-optimized algorithm at this time and that it remained appropriate in the context of this assessment to use the original IMPROVE algorithm to relate urban PM to local haze (PM light extinction). One of the primary reasons for initially considering an urban-optimized algorithm was a concern that the organic components of PM in urban areas, being generally nearer their emission sources, would have a lower ratio to the measured organic carbon mass than the ratio of organic component mass to measured organic carbon mass currently used for the more aged PM organic components found in remote areas. As described below in chapter 3, this concern has been addressed by using the SANDWICH mass balance approach to estimate the PM organic component mass, which negates the need to estimate organic component mass from measured organic carbon mass.

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 occurred. EPA staff 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 and Methods document were possibly overly ambitious was also shared by members of CASAC (see individual member comments; Samet, 2009a). The analysis, therefore, relied on existing, rather than new, urban visibility preference studies and was designed to explore the similarities and

[10] 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

differences (comparability) among these studies. Information drawn from these results informed the selection of VAQ CPLs (described in chapter 2 below) 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, DC in the reanalysis.

1.4.3 Selection of Alternative Scenarios for Second Draft Assessments

The first draft UFVA was reviewed at an October 2009 CASAC meeting, and a CASAC letter providing its advice and recommendations was submitted to the Administrator in November 2009 (Samet, 2009b). In its letter, the CASAC indicated support for EPA staff's approach to evaluating the nature and degree of PM-related visibility impairment, including EPA's focus on non-Class I areas, including in particular, urban areas as an "effective complement" to the Regional Haze Rule. In this regard, CASAC expressed support for consideration of a new PM light extinction indicator, a one hour averaging time, and for the range of selected candidate protection levels.

- Indicator: PM_{10} Light Extinction

There are a number of different ways to measure ambient PM: particle counts, surface area, volume, mass concentrations, and concentration of components. Each of these different characteristic of ambient PM can be important in the context of different effects. For example, particle count may be important from the perspective of cloud formation or to characterize the abundance of ultrafine PM, which is of interest for health effects. In a similar way PM light extinction measures the characteristic of ambient PM most relevant and directly related to the effect of PM visibility impairment. Thus, as described in the Scope and Methods document (US EPA, 2009b) and first and second drafts of the UFVA, EPA staff has continued to focus assessments in this final document in terms of ambient PM_{10} light extinction as the indicator for PM visibility impairment, instead of the traditional $PM_{2.5}$ mass concentration. Unlike the current FRM measurement method for PM mass concentration, which generally changes the composition and size of the particles by driving off most of the water, direct measurement of ambient PM light extinction captures the PM-induced visibility impairment of the particles as they exist in the atmosphere. PM light extinction, like conventional PM mass concentration, is a measurable physical characteristic of atmospheric PM. PM light extinction can also be calculated using a simple algorithm such as the IMPROVE algorithm[11]

Section 109 (b) (2) of the CAA states that "Any national secondary ambient air quality standard prescribed under subsection (a) of this section shall specify a level of air quality the

[11] Malm, et al., 1994 and DeBell, 2006. (See also ISA, section 9.2.2.2, pgs. 9-7 and 9-8.)

attainment and maintenance of which … is requisite to protect the public welfare from any known or anticipated adverse ***effects associated with the presence of such air pollutant in the ambient air….”*** *(emphasis added).* In addition, section 108 (a) (2) states that the air quality criteria “for an air pollutant shall accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of such pollutant in the ambient air, in varying quantities. The criteria … shall include information on (A) ***those variable factors (including atmospheric conditions) which of themselves or in combination with other factors may alter the effects*** on public health or welfare of such air pollutant;…” (*emphasis added*). Thus, EPA staff believes that the visibility effects of PM important to the public welfare are precisely the visibility effects of PM occurring in the ambient air, which necessarily entails association with ambient atmospheric conditions that affect the nature or magnitude of the PM visibility effect. These ambient conditions lead to constant changes in the size and composition of particles as these particles come in contact with other pollutants or natural components, become oxidized/age as they are transported great distances, and shrink or grow in the absence or presence of water vapor, or other atmospheric gases. The combined effect of all these interactions of ambient PM with real time atmospheric conditions and chemistry on the public welfare effect of visibility impairment depends on factors other than dry PM mass concentration alone. Use of PM_{10} light extinction as the indicator for a secondary PM NAAQS is thus a more direct measure of the relationship between ambient PM and the public welfare effect of visibility impairment than any dry PM mass concentration (either $PM_{2.5}$ or any other dry mass fraction).

- Averaging times: Daylight Daily Max. 1 Hour or All Daylight Hours

It is necessary to also identify an averaging time to apply along with the CPLs in the assessments described in chapters 3 and 4. Because the nature of visibility impairment and its impact on the public welfare is sufficiently different and less well understood at night, this assessment only considers visibility conditions that occur during daylight hours. Though not directly supported by preference or other studies, EPA staff believes that a short averaging time (e.g. an hour) may be more appropriate than longer time periods (e.g. multiple hours) since VAQ impacts are instantaneously perceived. This is also consistent with staff’s belief that most individuals in an urban setting experience urban VAQ in relatively short-term incidental and intermittent periods when they have the opportunity to be outdoors (e.g. during commutes to work, school, shopping, etc.). Since this 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 to 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. There is uncertainty associated with predicting the duration of the effect associated with such brief periods of exposures, i.e., it is not known how long the person remembers the poor VAQ conditions once he/she goes indoors and is removed from the sight.

Alternately, a complementary fraction of the public may have multiple or continuing opportunities to experience visibility throughout the day. People in this situation can experience a variety of conditions ranging from improvement, maintenance, or diminished VAQ throughout the day. For them, a day with several hours that exceed acceptable VAQ levels may represents a greater impact on their wellbeing than on a day with only one such hour. To assess impacts more related to this portion of the population, in which the degree of impact depends upon the conditions present across multiple hours of exposure, EPA staff has also considered all daylight hours which have light extinction levels beyond the three CPLs, as well as the 1-hour daily maximum light extinction in the assessments described in chapters 3 and 4.

- Level: Candidate Protection Levels (CPLs)

In order to identify a range of light extinction levels associated with acceptable VAQ to compare to current and projected conditions in the assessment in chapters 3 and 4 of this document, CPLs have been selected in a range from 20 dv to 30 dv (74 Mm^{-1} to 201 Mm^{-1}) based on the composite results and the effective range of 50th percentile acceptability across the four urban preference study areas shown in Figure 2-16. 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 define daylight hours with urban haze conditions that have been judged unacceptable by the participants of these preference studies. As discussed in greater detail in section 1.2 above, PM light extinction is taken to be light extinction minus the Rayleigh scatter (i.e. light scattering by atmospheric gases is about 10 Mm^{-1}) and NO_2 contribution (assumed to be negligible), so the PM light extinction levels that correspond to low, middle and high CPLs are about 64 Mm^{-1}, 112 Mm^{-1} and 191 Mm^{-1}, respectively.

- Forms: Percentiles and Relative Humidity Constraints

In considering an appropriate range of forms to consider in the analyses of alternative PM light extinction visibility standards analyzed in chapter 4 of this final UFVA, staff considered what frequency of conditions at or below the CPLs should 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. In the first draft UFVA, staff selected the 90th and 95th percentiles to assess. In the CASAC letter following the review of the first draft UFVA, CASAC recommended that other percentiles be considered, up to and including the 98th percentile used for the current 24-hour primary and secondary standards. EPA staff has therefore considered the 90th, 95th and 98th percentiles per year in the second and final iterations of this document. Due to inter-annual variability in meteorology and other circumstances that affect air quality, EPA staff is recommending using a three year average form of the standard for purposes of consistency and stability**,** as is the current 24-hour primary $PM_{2.5}$ standard. By considering all of the combinations of the two hourly forms (i.e. each daylight hour and daylight 1-hour daily maximum), the three CPLs and the three frequencies, a total of 18 separate alternative secondary PM NAAQS scenarios were generated for use in the assessments described below in chapters 3 and 4 (See table 4-1). An additional CASAC recommendation, that the relative humidity (RH) limit be lowered from 95% to 90% and used as a screen (i.e., hours above it should be discarded) rather than as a cap, to more clearly exclude weather events like fog or precipitation and to minimize effects of measurement error and spatial variability, was also incorporated into the second and final iterations of this document.

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 results from the four urban areas (Denver, Phoenix, British Columbia, and Washington, DC, an accompanying logit (statistical) analysis, and use of these results in the selection of the alternative levels evaluated in the remainder of the assessment. The complete description of the logit analyses is found in Appendix J. Chapter 3 describes the analytical approach, methods, and data used in conducting the assessment of recent urban visibility conditions, both in terms of PM mass concentration and PM light extinction 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 mass concentration and PM_{10} light extinction conditions generated for the urban case studies for two alternative $PM_{2.5}$ mass concentration levels and for the three light extinction CPLs. Additional information regarding approaches, results, method validation studies and uncertainty assessments for both chapters 3 and 4 are presented in Appendices A-J).

2 URBAN VISIBILITY PREFERENCE STUDIES

The purpose of this chapter is to describe the reanalysis of available urban visibility preference studies conducted by EPA staff with contractor support. The reanalysis covered the 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 three completed survey studies (all in the west) included Denver, Colorado (Ely et al., 1991), one in the lower Fraser River valley near Vancouver, British Columbia (BC), Canada (Pryor, 1996), and one in Phoenix, Arizona (BBC Research & Consulting, 2003). The first pilot focus group study was conducted in Washington, DC on behalf of EPA to inform the 2006 PM NAAQS review (Abt Associates Inc., 2001). In response to an EPA request for public comment on the Scope and Methods Plan (74 FR 11580, March 18, 2009) for the current review, Dr. Anne Smith provided comments (Smith, 2009) about the results of a new Washington, DC 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). When taken together, these studies from the four different urban areas included a total of 852 individuals, with each individual responding to a series of questions answered while viewing a set of images of various urban VAQ conditions. The apparent similarity in the methods used across the studies made it appear initially that the studies were comparable.

However, in order to ensure that our basis for selecting an appropriate range of CPLs was sound, we, along with contractor support, undertook a detailed reanalysis to determine the robustness of the survey study results, the appropriateness of comparing each study's results to the others, and the key uncertainties relevant to data interpretation. This reanalysis included a statistical analysis using a logit regression model to assess the comparability of different datasets. Limited discussion of logit model results occurs in the body of this chapter when pertinent to informing staff judgments regarding comparability of study results. A detailed description of the logit assessment is provided in the contractor memo included as Appendix J of this document. The following sections (sections 2.1 to 2.5) examine in detail the study methods used and results obtained from each of the available studies.

2.1 METHODS USED IN VISIBILITY PREFERENCE STUDIES

In all but one[1] of the visibility preference studies assessed in this document, 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 British Columbia studies) the 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 and the Washington, DC projects used computer generated photographic-quality images to present different VAQ conditions. Using an original near-pristine base photograph, additional images representing a range of VAQ conditions were generated 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, 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, 2003).

The first urban visibility preference study (Denver, CO; Ely et al., 1991) 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 chapter). This approach consisted of conducting a series of group interview sessions, where the participants were shown a set of photographs or images of alternative VAQ conditions and asked a series of questions.

[1] Smith and Howell (2009) used digital projection technology not used by 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.

The group interview sessions were conducted multiple times with different 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 the group interview sessions, 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 stricter.
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) were not shown in order of ascending or descending VAQ conditions; the VAQ conditions were 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 photograph 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"). While the studies all asked the basic question, "What level of visibility degradation is acceptable?", the term "acceptable" was not defined, so that each person's response was based on his/her own values and preferences for VAQ.

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.[2] 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

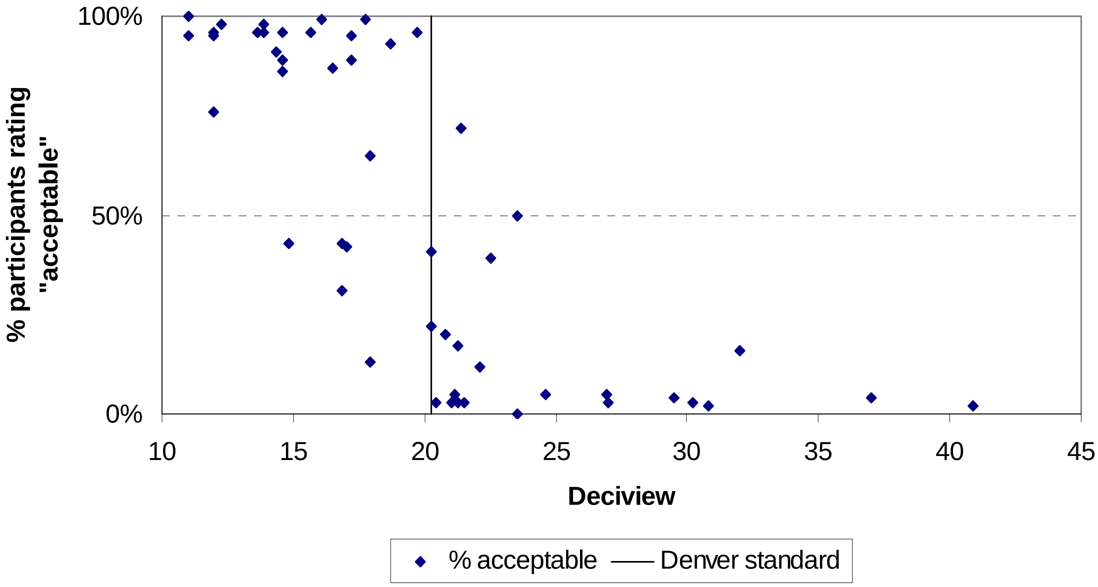
The VAQ conditions in each Denver photograph were recorded when the photograph was taken and measured by a transmissometer yielding hourly average light extinction, b_{ext}. The transmissometer was located in downtown Denver, approximately eight miles from the camera and in the middle of the camera's 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.

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

Figure 2-1. Percent of Denver Participants Who Considered VAQ in Each Photograph "Acceptable"



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).

Using 20.3 dv as the 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.

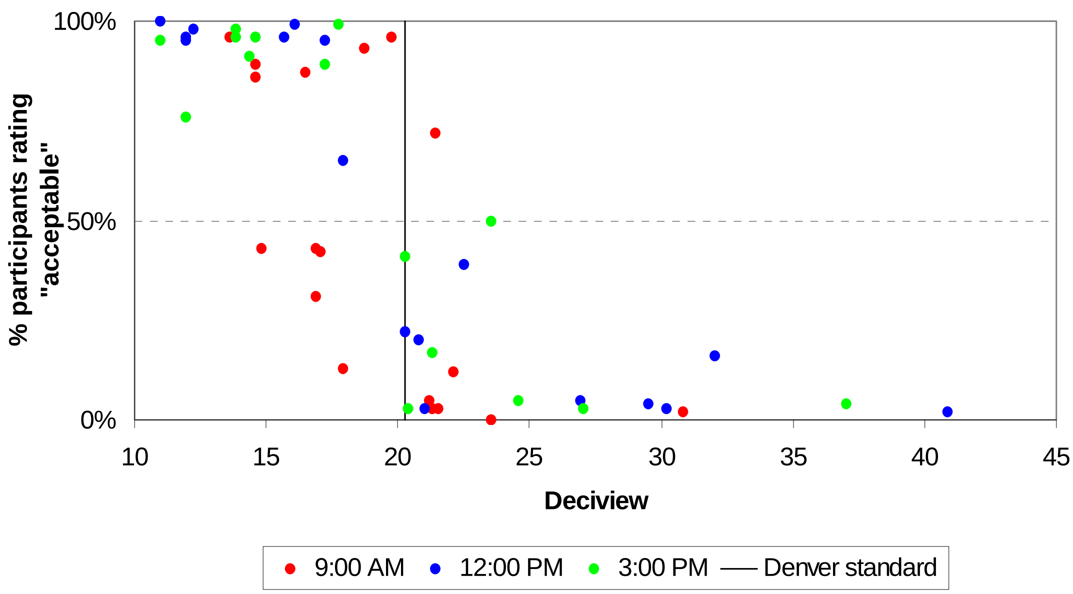
Table 2-1. VAQ of Denver Photos Substantively Misclassified by Majority of Participants

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.

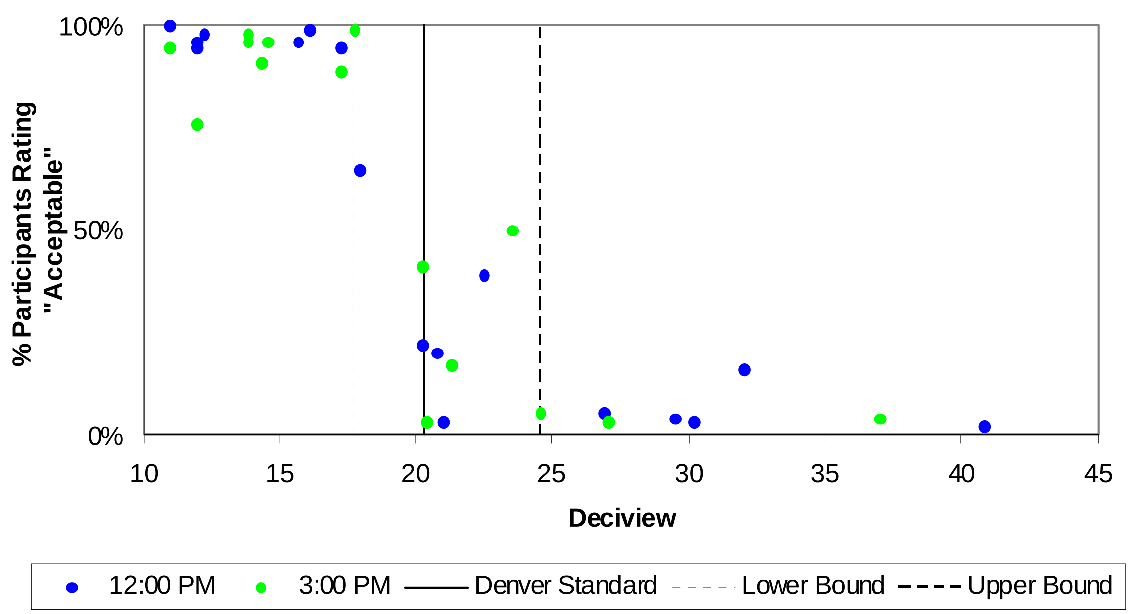
Eliminating the 9:00 a.m. photographs creates a "hole" in the range of remaining photographs; there are no photographs with a VAQ between 17.7 dv and 20.3 dv. As seen in Figure 2-3, this is a critical range in evaluating the responses. All of the photographs with a VAQ equal to or better (i.e., a lower 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.

Figure 2-2. Photograph Time of Day Information



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 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 2-3. 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.

Figure 2-4. Composite Chilliwack, BC Photograph Shows VAQ of 14.1 dv and 34 dv

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 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.

As explained in section 1.3, 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-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 more than 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.

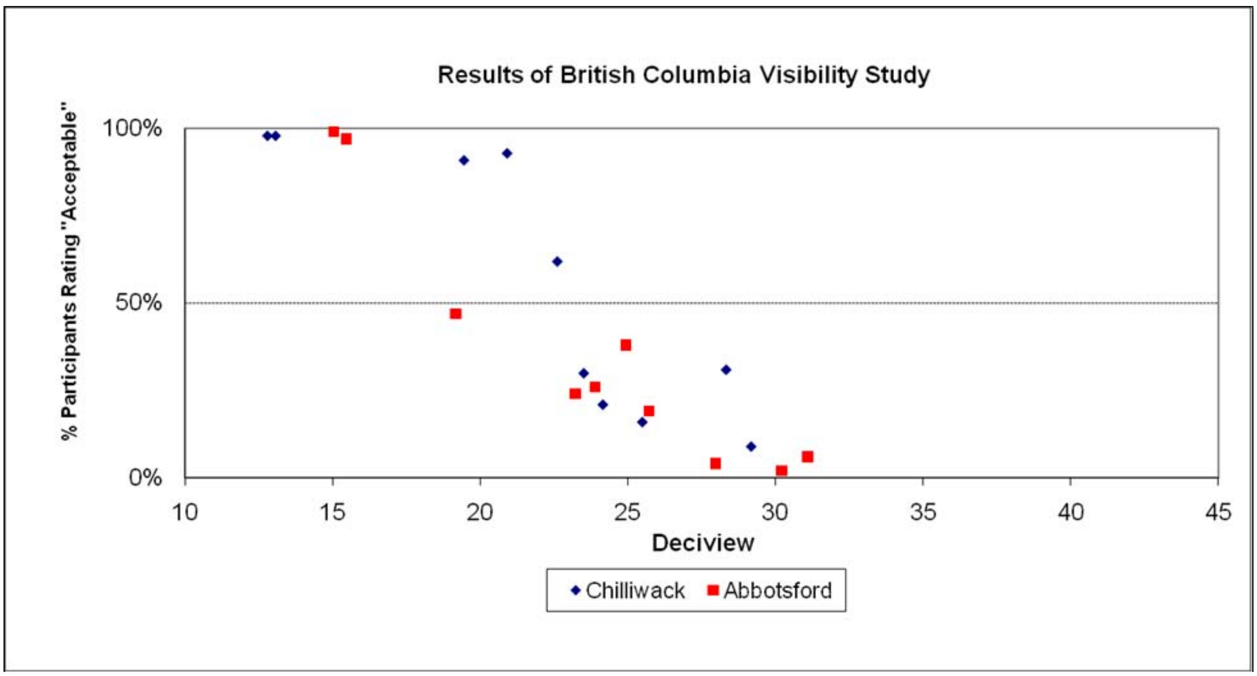
Table 2-2. Summary of Photographs Used in British Columbia Study

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 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.

Figure 2-5. Percent of BC Participants Who Consider VAQ in Each Photograph "Acceptable"



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, 2003), 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, 2003). 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).

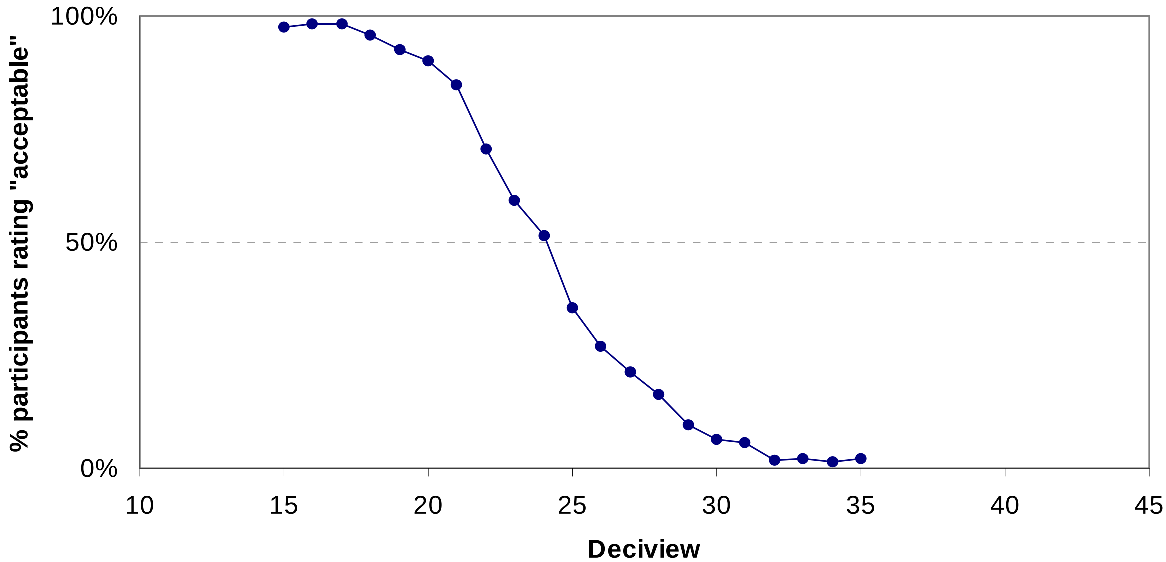
Figure 2-6 Reproduction of Image with the Best VAQ (15 dv) Used in the Phoenix Study

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 so that 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 the same VAQ scale of 1 to 7. 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"



Ninety percent 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, DC

One of the Washington, DC 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 pilot study (Abt Associates Inc., 2001). 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, DC 2001

The EPA's Washington, DC 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[3] in Washington, DC provides substantially shorter maximum sight distances.

The Washington, DC 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 western studies.

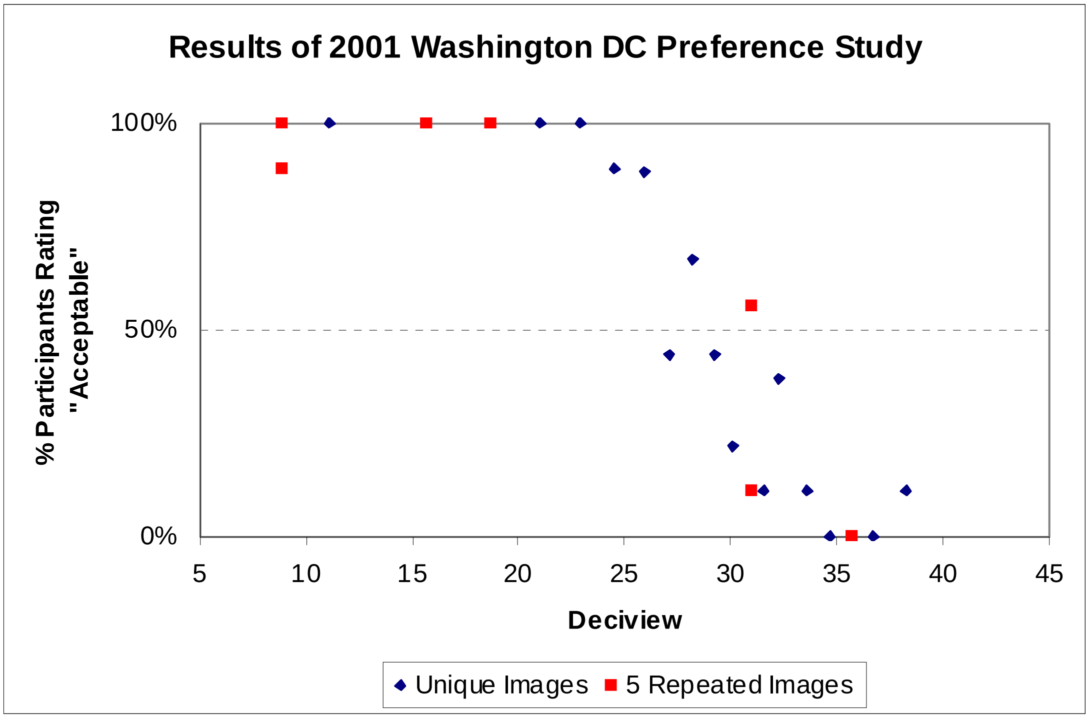
A single scene of a panoramic photograph taken from Arlington National Cemetery in Virginia was used, and included an iconic view of the Potomac River, the National Mall, and downtown Washington, DC. All of the distinct buildings in the scene are less than four miles from the camera, and the higher elevations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

[3]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, DC Study

The Washington, DC 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 VAQ in the images ranged from 8.8 to 38.3 dv 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 Considered VAQ Acceptable in Each Image



In the 2001 Washington, DC 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, DC 2009

The Smith and Howell (2009) study conducted additional focus group sessions based on the methods and materials used in the 2001 Washington, DC study. Smith and Howell recreated the WinHaze images used in the 2001 Washington, DC 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, DC and Houston, Texas offices (44 and 20 participants, respectively). The Houston participants were included to explore whether familiarity with Washington, DC 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.

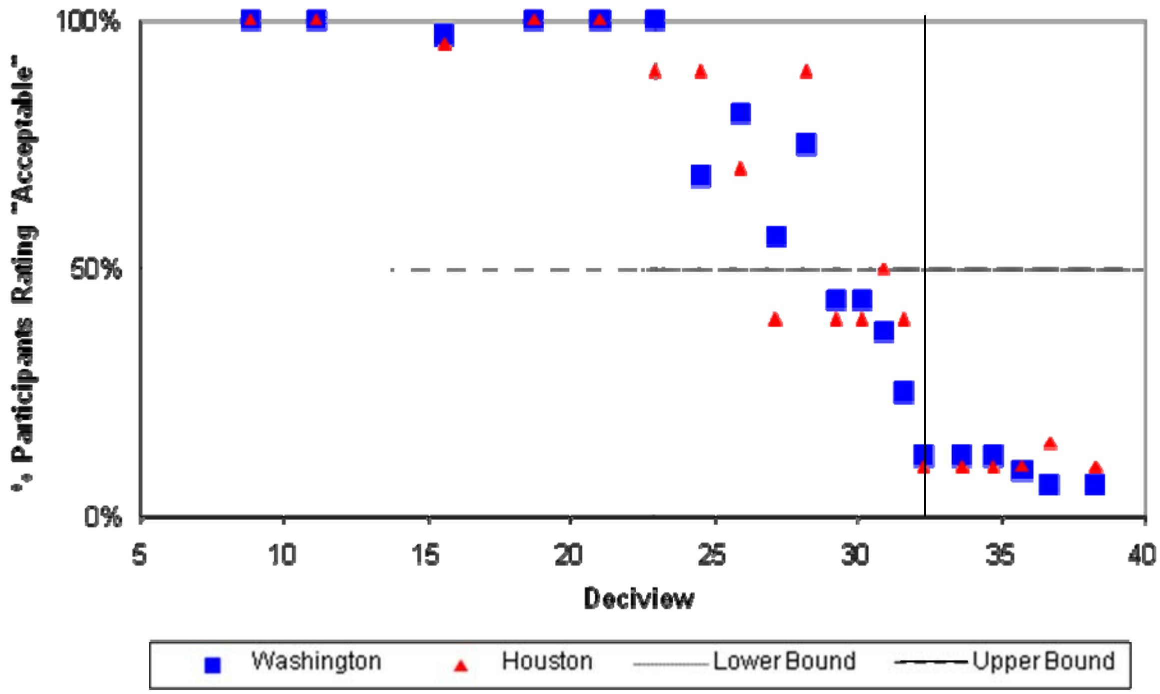
Eight of the Washington-based participants and all of the Houston participants viewed the WinHaze images on a desktop computer monitor. The remaining Washington participants viewed the images projected on a screen.

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, DC 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, DC, 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, DC, which may influence the similarity of responses by residents of the two cities.

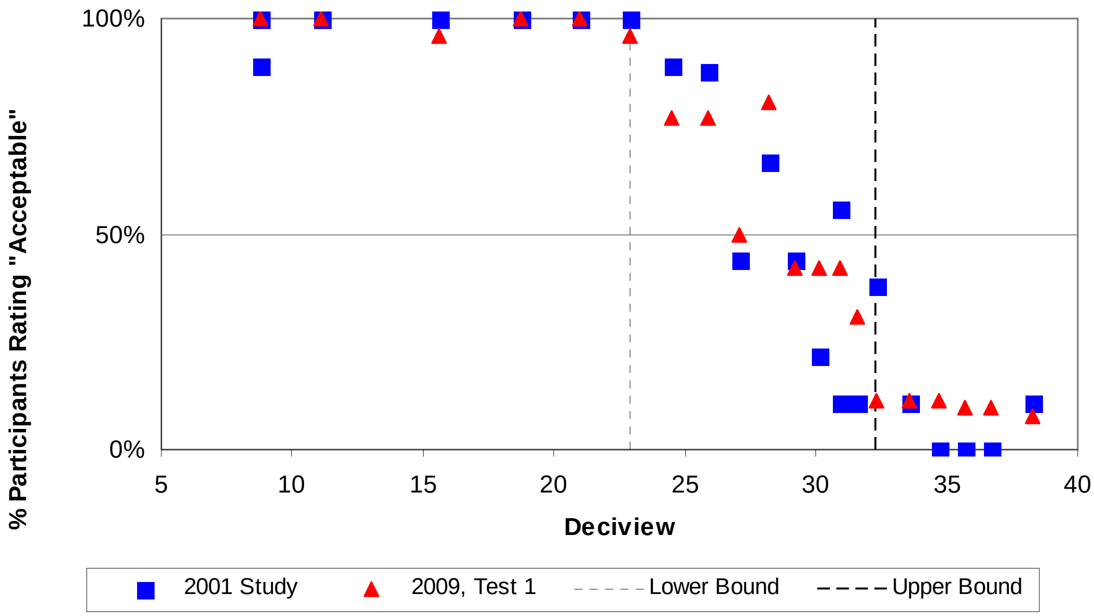
Figure 2-10. Percent of 2009 Test 1 Study Participants Who Considered VAQ Acceptable in Each Image, Showing the Range of the Lower and Upper Bound of 50% Acceptability Criteria



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 2-11 presents the Abt Associates Inc., 2001 study and Smith and Howell 2009 (Test 1) study 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 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 indicates that the results from the 2009 study (Test 1) are not appreciably different than the results of the 2001 Washington study. This observation of similar results is confirmed by a logit regression analysis of the 2001 and 2009 Test 1 data that includes estimates of the 50% criteria deciview values with confidence intervals and hypothesis testing of the similarity of the values, as described in Appendix J (see Tables 6, 7 & 8 and Figure 3).

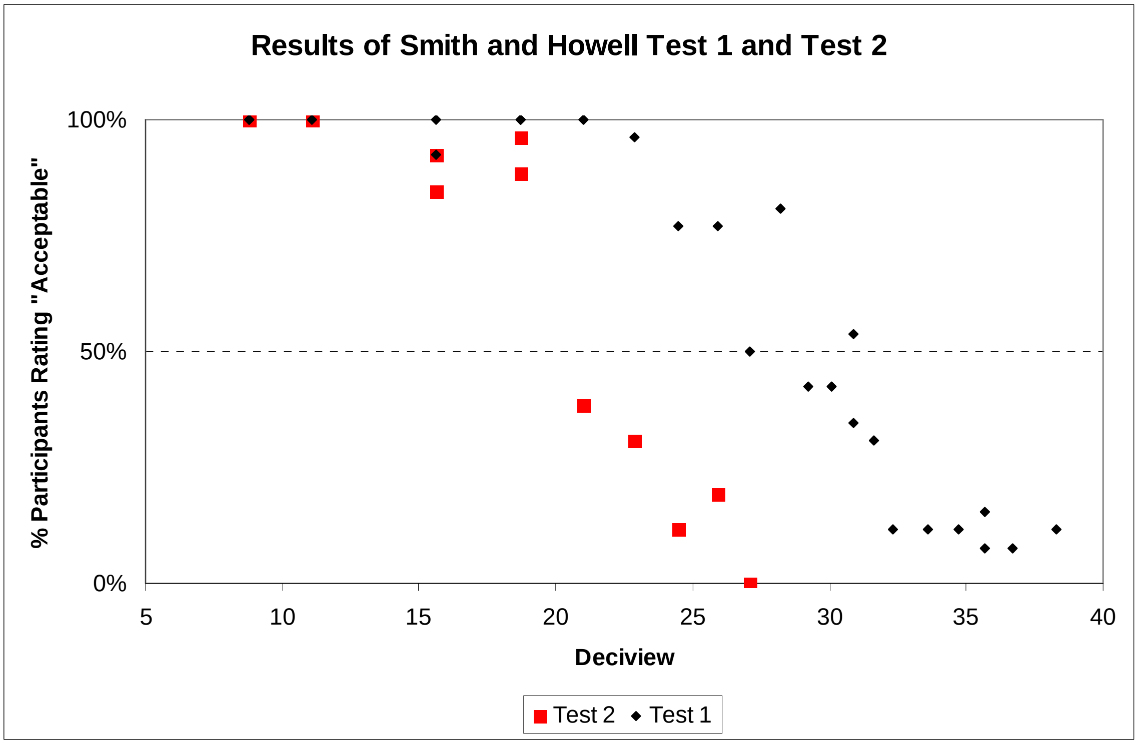
Figure 2-11. Combined Results of Washington, DC 2001 and 2009 Test 1 (showing 50% Acceptability Criteria from 2009, Test 1)



In Test 2, Smith and Howell reduced the range of VAQ images to images with a VAQ of 27.1 dv or less. The 26 participants in the Test 2 study 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, along with 3 duplicates for a total of 12 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 the VAQ range by 11.2 dv.

Figure 2-12 presents the Test 1 and Test 2 results. Test 2 found a substantial shift in the responses regarding which VAQ levels are considered acceptable. The smaller number of images used in Test 2 made 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 VAQ levels identified as acceptable in an urban visibility preference study conducted using the general approach previously used in the all the studies may be influenced by the range of VAQ images presented.

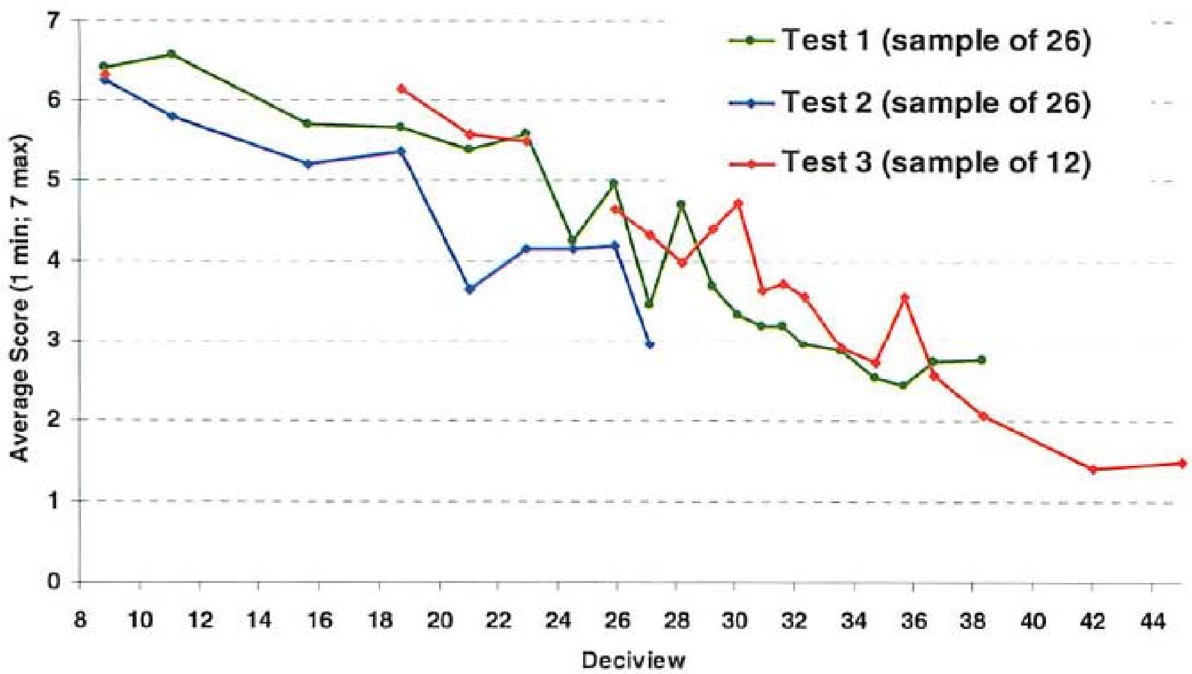
Figure 2-12. Comparison of Results from Test 1 and Test 2 (Smith and Howell, 2009)



In order for the range of images shown to be able to influence the acceptability ratings, participants would need to be aware of the upper and lower bounds of the range prior to the judging acceptability. However, since they were shown images randomly with respect to the VAQ levels, asked to rate each one before going to the next image, and were not given a chance to revise their acceptability ratings, this was not possible during the acceptability exercise itself. The only other opportunity participants could have to learn the VAQ range is during the VAQ rating exercise done just prior to the acceptability rating. However, in the VAQ rating exercise where the participants were asked to rate the quality of visibility for the shown images on a scale from 1 to 7, the images were also shown in a random order, participants were not aware how many photographs would be shown or the range of conditions, they were asked to rate each one using a value from 1 to 7 before going on to the next image and they did not have the opportunity to revise the ratings of earlier viewed images.

Figure 2-13 shows the average visibility rating on the 1 to 7 scale for each image used in each of the three tests conducted by Smith and Howell (2009). The consistency observed in the relationship between VAQ deciview levels and the average scores assigned across the three tests demonstrates that the participants come to the survey with the capability to consistently rate the haze levels shown in the images, regardless of the breadth of the range used or the order or number of slides shown, and that they are aware of a full range of conditions, even when, as was the case in Test 2, they were not shown the worst haze images.

Figure 2-13. Average Visibility Ratings for the Washington, DC WinHaze Images by Participants in Tests 1-3 Conducted by Smith and Howell (2009).



Why then did Test 2 participants in the subsequent part of the survey rate images of haze levels as unacceptable that were rated acceptable by participants in the other tests and the earlier Washington, DC pilot study? In a three sentence script[4] that constituted the only instructions read prior to the acceptability rating, the participants were told that they would see the same set of slides that they had just rated (i.e., on the 1 to 7 scale), and they were asked to rate them according to whether the VAQ depicted were acceptable or unacceptable to them. Apparently by directing then to rate the same images for acceptability, the participants understood that their choices of visibility conditions were restricted to a range of conditions shown in the 1 to 7 ratings that they had just completed. For participants in Test 2 this would mean that by their own 1 to 7 ratings the range was restricted to include no poor visibility conditions (i.e. only scenes rated from 3 to 7).

Smith and Howell (2009) concluded that the effects of a changed range on the acceptability ratings results demonstrates that VAQ preference studies results are not robust and

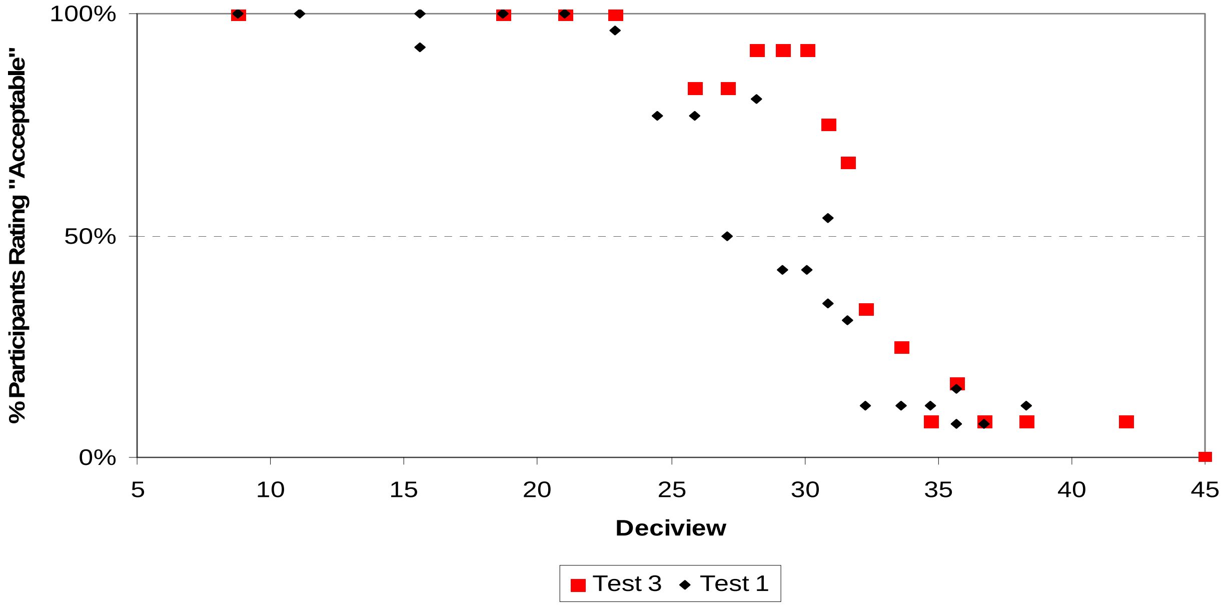
[4] The complete script for the acceptability/unacceptability part of the study is as follows. *"Now you will be shown the same set of slides that you just rated. Again each image will illustrate the effects of a different level of visibility. This time, rate the slides according to whether the visibility is acceptable or unacceptable to you."*

do not reflect an enduring view on the “unacceptability” of different levels of VAQ degradation. However, there is an alternative explanation. It seems more likely that the use of such a severely truncated range of VAQ conditions in Test 2, which did not include any of the images of VAQ that previous studies identified as unacceptable, in effect fundamentally changed the implied instructions for the participants. Instead of conveying that they were to identify VAQ levels that they found acceptable among a full range of VAQ conditions from very poor to very good, the implied message was that they should identify the VAQ levels that they found acceptable among a curtailed range of VAQ conditions that only included average to very good VAQ. By this reasoning, it would be inappropriate to include Test 2 results with those of the other tests as a measure of VAQ preference for Washington, DC.

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 also 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. Figure 2-13 shows that the Test 3 average ratings from 1 to 7 during the VAQ rating exercise increased the average participant rating by about 1 at the low end of the scale (very poor VAQ). The results of Test 3 are shown in Figure 2-14, along with the results of Test 1.

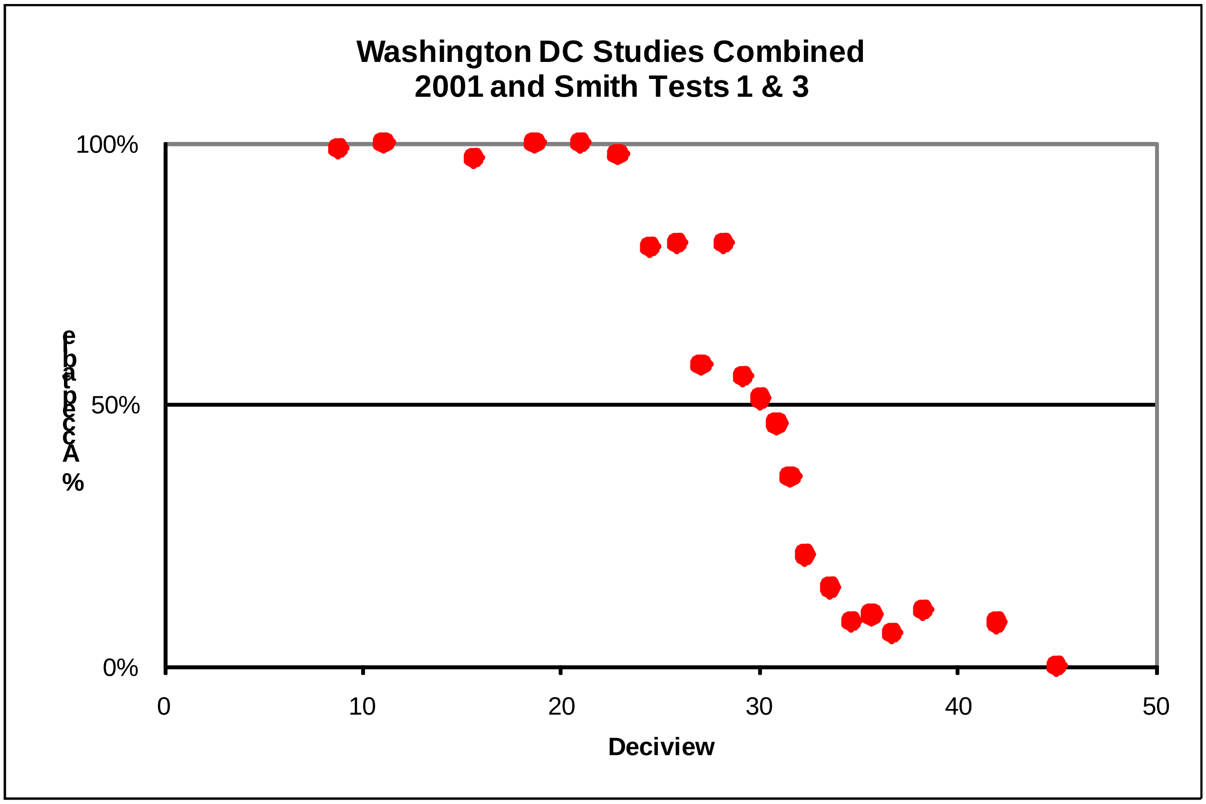
Test 3 resulted in an overall increase in the percent of respondents rating as acceptable the VAQ images used in both tests. In Test 3 all images with a VAQ below 22.9 dv were rated acceptable by 100% of the participants (similar to the Test 1 results), implying there was no general change in the acceptability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

Figure 2-14. Comparison of Results from the Smith and Howell (2009) Test 1 and Test 3



Given that most of the same images of VAQ conditions were used in all of the tests, composite acceptability ratings (i.e., from the original pilot study (2001) and from Tests 1 and 3) of each image were initially developed to evaluate whether increasing the number of participant ratings for each image influenced the 50% acceptability value. Figure 2-15 shows composite results from the combination of these three groups (total of 47 participants). The 50% acceptability criteria value for this composite dataset lies unambiguously between the 30.1 dv (at 51.1%) and the 30.9 dv points (at 46.3%),

Figure 2-15. Composite Results from Smith and Howell (2009) Tests 1 and 3, and Abt (2001) Washington, DC Pilot Study



To determine whether it would be appropriate to combine all of the results from the Washington, DC studies, in order to increase the number of data points for Washington, DC, we considered several factors. First, while the range limitations identified with Test 2 (i.e. an overly restrictive range) that resulted in its results being eliminated from consideration in the selection of appropriate CPLs do not apply to Test 3 results due to its somewhat more complete coverage of the 1 to 7 rating range in the VAQ rating exercise, the number of participants in Test 3 (i.e., 12) is small enough that the statistical uncertainty of the results may be an issue if used alone. Second, it was not clear whether the significant "hole" in the Test 3 VAQ distribution between 8.8 dv and 18.7 dv potentially had an effect on participant acceptability responses. Finally, the logit regression analysis which was applied to each of the individual Smith and Howell (2009) tests as well as subsets of some of these tests to investigate differences in the preference curves and 50% criteria deciview levels (Appendix J) concluded in part that Test 2 and Test 3 response curves and 50% criteria values are statistically dissimilar from those of the 2001 and Test 1 Washington, DC studies. In contrast, the logit analysis concluded that the 2001 and Test 1 results have 50% criteria values that are statistically indistinguishable. These findings provided support for combining the 2001 and Test 1 data sets and for excluding the dissimilar results of Test 2 and Test 3.

2.6 SUMMARY OF PREFERENCE STUDIES AND SELECTION OF CANDIDATE PROTECTION LEVELS

As described above, because each of the studies reviewed in this assessment investigates a common question and use similar approaches that are all derived from the method first developed for the Denver urban visibility study, we concluded that it is reasonable to compare the results from all four urban areas to identify overall trends in the study findings and that this comparison can usefully inform the selection of CPLs for use in further analyses. However, because variations in the specific materials and methods used in each study introduce uncertainties, direct comparison of the study results should take these factors into account. Key differences between the studies include:

- Image presentation methods (e.g., projected slides of actual photos, projected images generated using WinHaze (a significant technical advance in the method of presenting VAQ conditions), use of computer monitor screen
- Number of participants in each study,
- Participant representativeness of the general population of the relevant metropolitan area, and
- Specific wording used to frame the questions used in the group interview process.

Figure 2-16 presents a graphical summary of the results of the studies in the four cities and draws on results previously presented in Figures 2-3, 2-5, 2-7 and 2-11. As described in the separate discussions for each urban area above, the data and curves depicted in Figure 2-16 include the following modifications: 1) the Denver results omit the 9:00 a.m. photograph results; 2) the Chilliwack and Abbotsford results appear as a single set of data for the BC study; 3) the results from 2001 and 2009 (Test 1) studies of VAQ preferences in Washington, DC are presented as a single combined set of data; 4) the results from the 2009 Washington, DC study Tests 2 and 3 are not included.

Figure 2-16. Summary of Results of Urban Visibility Studies in Four Cities, Showing the Identified Range of the 50% Acceptance Criteria[5]

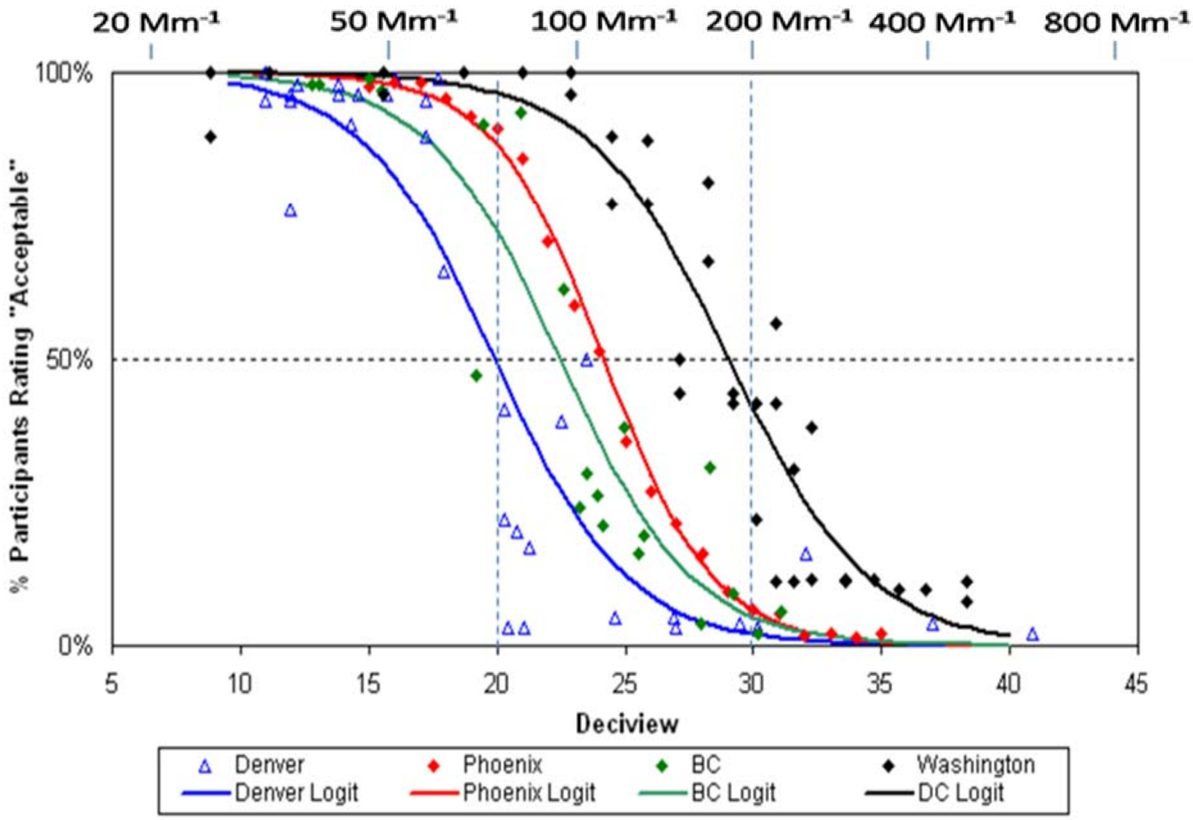


Figure 2-16 shows the results of a logistical regression analysis using a logit model of the greater than 19,000 ratings of haze images as acceptable or unacceptable. The logit model is a generalized linear model used for binomial regression analysis which fits explanatory data about binary outcomes (in this case, a person rating a VAQ image as acceptable or not) to a logistic function curve. A more complete description of the logit model application to these data is contained in Appendix J. The results shown in Figure 2-16 are from the more generalized of the two logit assessment models (i.e. model 2) in which both the shape and displacement of the curves for the four cities are permitted to vary independently.

The logit analysis city intercept coefficients (Appendix J, Table 3) are all positive and statistically significant, indicating that the response functions for different cities shifted right relative to the function for Denver. However, only the Phoenix interaction term is insignificant,

[5] Top scale shows light extinction in inverse megameter units; bottom scale in deciviews. Logit analysis estimated response functions are shown as the color-coded curved lines for each of the four urban areas.

indicating that the Phoenix response function has a different shape that is steeper than the other three cities, as can be seen in Figure 2-16. Figure 2-16 also shows the Washington, DC function is modestly less steep than the others, but the decrease in the slope is not statistically significant. The model results can be used to estimate the VAQ deciview values where the estimated response functions cross the 50% acceptability level, as well as any alternative criteria levels. Selected examples of these are shown in Table 2-3. A t-test of these 50% acceptance deciview values for the four cities shows each to be significantly different from the others (Appendix J, Table 5).

Table 2-3. Logit Model Estimated VAQ Values Corresponding to Various Percent Acceptability Values for the Four Cities

	Denver	British Columbia	Phoenix	Washington, DC
90% Acceptability criteria	14.21	16.80	24.15	23.03
75% Acceptability criteria	17.05	19.63	21.80	26.03
50% Acceptability criteria	**19.90**	**22.45**	**24.15**	**29.03**
25% Acceptability criteria	22.74	25.28	26.51	32.03
10% Acceptability criteria	25.59	28.10	28.87	35.03

Figure 2-16 also contains lines at 20 dv and 30 dv that effectively and pragmatically identify a range where the 50% acceptance criteria occur across all four of the urban preference studies. Out of the 114 data points shown in Figure 2-16, 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.[6] Similarly, only one image with a VAQ above 30 dv was rated acceptable by more than 50% of the participants who viewed it.[7] These upper and lower range values are also supported by the logit model data which estimates 50th percentile acceptability values near 20 dv for Denver and near 30 dv for Washington, DC (see Table 2-4).

There are several hypotheses that may explain why the VAQ acceptability response curves for the four cities are different and why some study results have greater variability than

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

[7] 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).

others.[8] First, as mentioned, the use of photographs (Denver and BC surveys) versus WinHaze-generated images (Phoenix and Washington, DC surveys) may play a significant role in preference studies, perhaps introducing bias (such as suggested by the responses to the 9:00 a.m. Denver photographs) as well as variability. Further, the use of photographs from different days and times of day that rely on associated ambient measurements of light extinction to characterize their VAQ level can introduce two other 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, DC 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 put forward by Smith and Howell (2009) is that the range of VAQ images presented in the survey may influence the results. As discussed above, a more plausible explanation it that the range of haze images shown to participants in the VAQ 1 to 7 rating exercise was interpreted by participants as a restriction on acceptability rating exercise to confine their rating to the range VAQ conditions shown, which for Test 2 was curtailed to only average to good VAQ conditions. When other evidence is taken into account, the Smith and Howell hypothesis seems an even more 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. Also**,** inspection of the average VAQ 1 to 7 ratings for the Phoenix and Denver studies showed that they spanned the full ratings range of values similar to those for the Smith and Howell Test 1 and 3, so the participants in those studies were not presented with a restricted range within which to select acceptable VAQ conditions, suggesting that the range itself was not an important factor

[8] Variability here refers to the degree of scatter of the average acceptability ratings for each image around the logit curve for that city.

influencing their results. Values for the British Columbia 1 to 7 VAQ rating exercise were not readily available.

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, DC 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 most prominent and picturesque feature of the cityscape of Denver is the clearly visible snow-covered mountains in the distance, while the prominent and picturesque features of the Washington, DC cityscape are buildings relatively nearby without prominent and/or valued scenic features that are more distant.

Finally, and perhaps of significant importance is that the sensitivity of individual scenes to perceived changes in VAQ under changing light extinction levels 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 of about 20 dv, while the Washington, DC study scene, with much shorter sight paths yielded a 50% criteria VAQ value at a substantially worse level of about 30 dv. The distinction between the last two hypotheses are that the earlier one speaks to the desirability of seeing distant mountains versus this hypothesis which concerns the ability to perceive changes in haze at lower light extinction levels. Additional studies, including directly comparable studies using similar methods in diverse cities, would be useful 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 2-16, 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 chapters of the UFVA to provisionally define daylight hours with urban haze conditions that have been judged unacceptable by the participants of these preference studies. As discussed earlier (section 1.2), PM light extinction is taken to be light extinction minus the Rayleigh scatter (i.e. light scattering by atmospheric gases is about 10 Mm^{-1}), so the low, middle and high CPL levels correspond to PM light extinction levels of about 64 Mm^{-1}, 112 Mm^{-1} and 191 Mm^{-1}.

3 ESTIMATION OF RECENT PM MASS AND SPECIES CONCENTRATIONS AND PM_{10} LIGHT EXTINCTION

This chapter characterizes hourly PM conditions in terms of both $PM_{2.5}$ mass concentration and PM_{10} light extinction in a set of urban study areas during 2005-2007. This characterization supports the following goals: (1) to improve understanding of the levels, patterns, and causes of PM-related impairment of urban visibility during daylight hours; (2) to create the basis for projections of $PM_{2.5}$ mass and PM_{10} light extinction levels under "what if" scenarios; and (3) to examine the correlation between PM_{10} light extinction and potential alternative indicator(s) based on $PM_{2.5}$ mass concentration. These goals are addressed in chapters 3, 4 and Appendix D, respectively. A number of other appendices address related topics of particular interest in more detail.

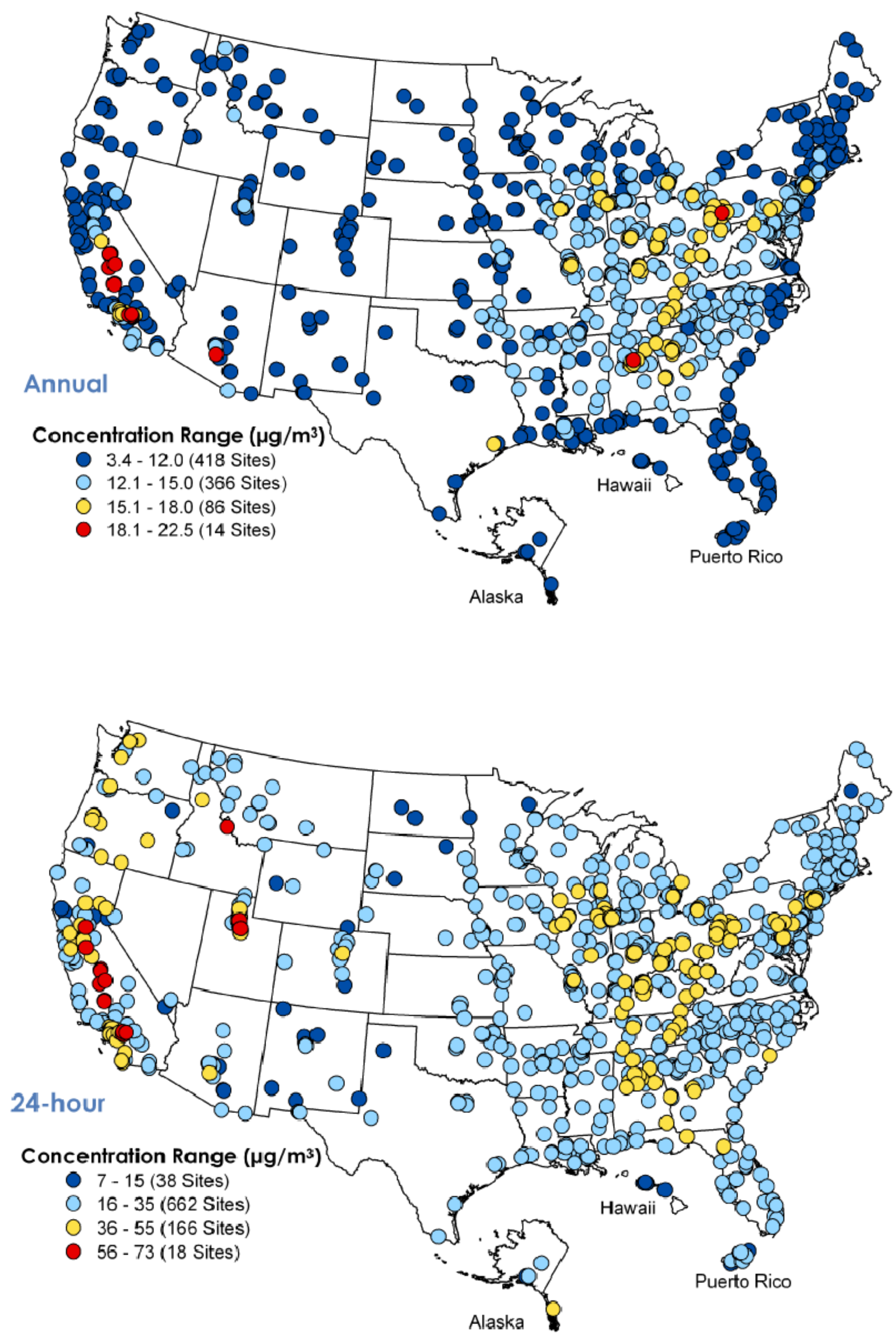
3.1 SUMMARY OF PREVIOUS CHARACTERIZATIONS OF PM CONCENTRATIONS AND LIGHT EXTINCTION

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

Chapter 2 of the 2005 Staff Paper (US EPA, 2005) from the previous review and chapters 3 (especially section 3.5) and 9 (especially section 9.2.3) and Annex A of the final 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.

Using 2005-2007 air quality data, 38 urban areas violated the annual $PM_{2.5}$ NAAQS set at a level of 15µg/m^3 in 1997 and retained in the last review completed in 2006. Seventy-six areas violated the 2006 24-hour NAAQS level of 35µg/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 µg/m³, 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. Areas in the upper Midwest and to a lesser extent upper East have notable nitrate concentrations in winter but not in summer, while southeastern areas generally have lower nitrate concentrations even in winter. Many western urban areas have large nitrate concentrations 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 fraction 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 final 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 final 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 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 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 the 15 selected 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 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 PM_{10} Light Extinction

While total light extinction is directly measurable using a transmissometer and PM_{10} light extinction can be measured with other instruments, there are very few regularly operating monitoring sites measuring either form of light extinction in urban areas, and generally those that do operate do not submit data to AQS.[1] Consequently, any characterization of PM_{10} 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 measure light scattering, operate that equipment in a heated mode for purposes of tracking “dry” $PM_{2.5}$ mass concentrations, and actual light scattering due to ambient PM 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 PM light extinction, so these data alone are not a good indicator of overall PM_{10} light extinction in

[1] EPA is aware of routine, long-term direct measurement of light extinction using transmissometers only in the Phoenix, AZ, Denver, CO, and Washington, DC urban areas, none of which submit data to AQS, although the site in Washington submits data to the IMPROVE program data system. Also, 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 final PM ISA discusses these monitors in section 9.2.2.3.

urban areas. Also, there are unresolved issues of data corrections and comparability for the light absorption data from these instruments now residing in AQS.

PM_{10} light extinction can be "reconstructed" from measurements of $PM_{2.5}$ mass components and $PM_{10-2.5}$ concentrations, in combination with relative humidity values, using either of two versions of the formula known as the IMPROVE algorithm but excluding its term for Rayleigh scattering by gases in clean air. (Section 9.2.2.2 of the ISA gives an overview of the algorithm and its basis. Section 3.2.3 of this document discusses the application of the original version of the IMPROVE algorithm in this assessment. $PM_{2.5}$ component measurements are generally available only on a 24-hour average basis, so it generally is possible to estimate only 24-hour average PM_{10} light extinction, unless additional information on hourly patterns is brought to bear.[2] 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 PM_{10} 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 ISA summarize this literature. Section 9.2.3.3 of the ISA contrasts concentrations of $PM_{2.5}$ and $PM_{2.5}$ 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 PM_{10} 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.[3] 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

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[2] When the IMPROVE algorithm is used to estimate 24-hour PM_{10} 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 PM_{10} light extinction, including the strongly non-linear effect of relative humidity, are then averaged to get the 24-hour PM_{10} light extinction estimate.

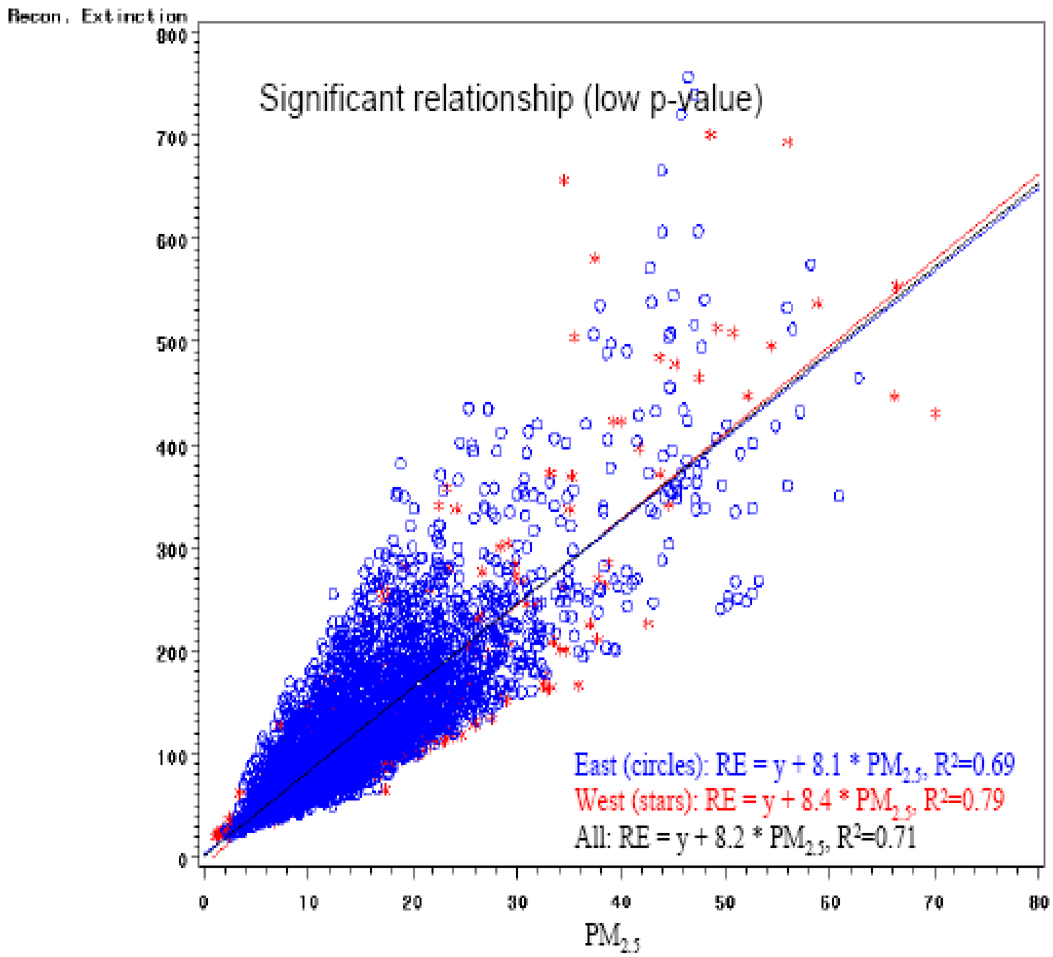
[3] Estimates of light extinction in the 2005 Staff Paper include Rayleigh scattering of 10 Mm^{-1} and thus represent "total" light extinction (excluding NO_2 absorption). Adjustment for consistency must be made before any close comparisons to PM_{10} light extinction values in this document.

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}.[4]

Figure 3-2. Reconstructed 24-hour Light Extinction in U.S. Urban Areas in 2003

Source: Schmidt et al., 2005

Output D.3 (Relationship RE & PM2.5; Diurnal RE; Timeframe) 2 of 30



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

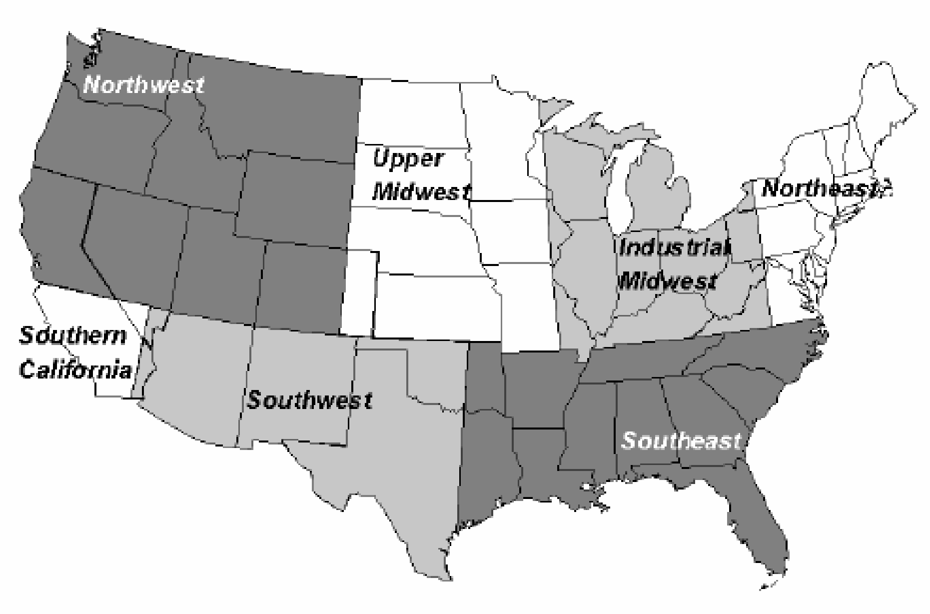
In addition to this scatter plot, a table developed for the previous PM NAAQS review presented the annual average of estimates of 24-hour reconstructed light extinction values, averaged across 161 urban areas grouped into seven regions (Schmidt, et al., 2005). Table 3-1 reproduces these estimates. For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

[4] 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.

light extinction 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})

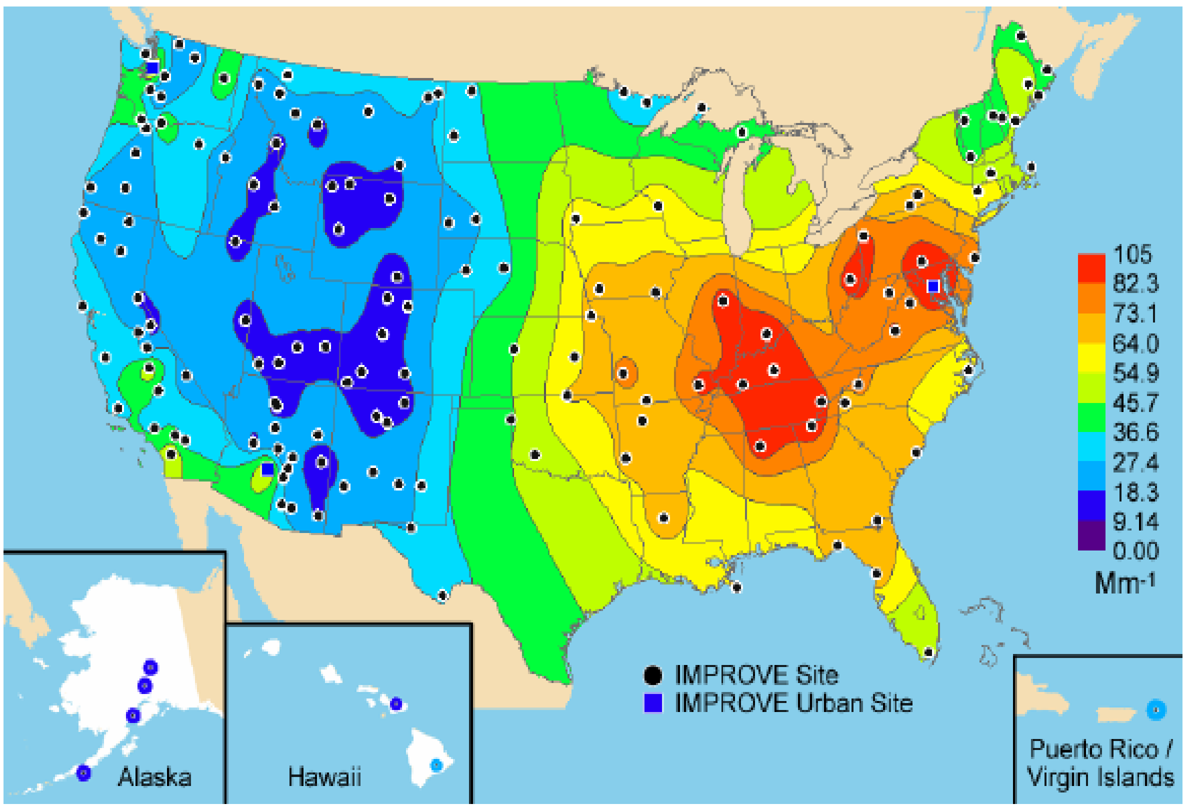
Region	Reconstructed 24-hour Light Extinction in 2003
Northeast	108
Southeast	98
Industrial Midwest	118
Upper Midwest	80
Southwest	73
Northwest	76
Southern California	168



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, 1996b).

Figure 3-3 is a contour map of annual average reconstructed 24-hour PM_{10} 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, DC, and Puget Sound, WA are indicated by square symbols). A comparison of the mean urban light extinction levels by region listed in Table 3-1, with this map of rural light extinction indicates that in most parts of the U.S., light extinction levels in urban areas are notably higher than in the surrounding remote rural area, 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" of $PM_{2.5}$ and

Figure 3-3. Isopleth Map of Annual Total Reconstructed PM_{10} Light Extinction Based on 2000-2004 IMPROVE Data.



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

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

One-hour PM_{10} 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. Although PM_{10} 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 PM_{10} light extinction values were roughly 50 percent higher than the 24-hour average PM_{10} light extinction values.[5] 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 PM_{10} light extinction in urban areas. Consequently, this assessment has reconstructed hourly PM_{10} light extinction levels for daylight hours from values of hourly $PM_{2.5}$ components, $PM_{10-2.5}$, and relative humidity. Hourly monitoring data for $PM_{2.5}$ components and $PM_{10-2.5}$ are also generally lacking, so the estimates of these parameters have necessarily 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[6], 24-hour $PM_{2.5}$ components measured by the filter-based monitors of the CSN, and hourly $PM_{2.5}$ mass measured by continuous instruments such as the Tapered Element Oscillating Microbalance (TEOM), beta attenuation monitors (BAMs), and nephelometers, which were used at different sites. The CTM-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, or 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" or "validation" run of the 2004 CMAQ modeling platform with boundary conditions provided by GEOS-Chem global scale CTM.[7] The CTM modeling is used as one element in the development of realistic diurnal variations for each of the major $PM_{2.5}$ components used to estimate PM_{10} 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

[5] 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.

[6] 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.

[7] 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 ISA (US EPA, 2009a).

combined with hour-specific measurements of $PM_{2.5}$ to generate hourly concentration variations for each of the 24-hour CSN sample days during the 2005-2007 period.

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

At 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 PM_{10} 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 (maximum) FRM-based 2005-2007 annual and 24-hour $PM_{2.5}$ design values for each study area based on the highest-reading monitor in each area, and for the specific site used in this assessment.[8] (See below for an explanation of the "site-specific" columns in Table 3-2.)

[8] 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 PM Risk Assessment, US EPA, 2010e, 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.

Table 3-2. Urban Visibility Assessment Study Areas

Study Area	Area-wide 2005-2007 Annual Design Value ($\mu g/m^3$)	Area-wide 2005-2007 24-hour Design Value ($\mu g/m^3$)	Site-specific 2005-2007 Annual Design Value ($\mu g/m^3$)	Site-specific 2005-2007 24-hour Design Value ($\mu g/m^3$)	2005 Staff Paper Region (See map in Table 3-1)
Tacoma	10.2	43	Same	Same	Northwest
Fresno	17.4	63	Same	Same	Southern California*
Los Angeles	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	17.2	43	Same	Same	Midwest
Pittsburgh	16.5	43	15.0	40	Industrial Midwest
Baltimore	15.6	37	14.5	35	Northeast
Philadelphia	15.0	38	14.7	37	Northeast
New York	15.9	42	14.4	42	Northeast

* While not generally considered to be part of Southern California as the term is commonly used, Fresno lies just south of the line used in the 2005 Staff Paper (US EPA 2005) (based on earlier work by others) to separate the Southern California region from the Northwest region.

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 first 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 PM_{10} 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. As can be seen in Table 3-2, in 10 of the 15 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 equipment 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.[9]

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) which did not have a scale characterization recorded in AQS suggests that it may be middle or neighborhood scale. As already stated, selected sites are not necessarily the locations of the maximum measured annual or 24-hour $PM_{2.5}$ levels in their urban area.

Site days which were missing 1-hour $PM_{2.5}$ concentration data points for more than 25 percent of daylight hours were excluded from the analysis, because such data gaps were judged to result in too much uncertainty in estimates of 1-hour $PM_{2.5}$ components, 1-hour PM_{10} light extinction, and daily maximum PM_{10} light extinction. Days with fewer missing 1-hour $PM_{2.5}$ concentration data points were retained, but no estimate of PM_{10} light extinction was made for hours without 1-hour $PM_{2.5}$ concentration data (see below for more explanation). 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) hourly 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 PM_{10} light extinction are more uncertain than if the monitors were clearly within the same air mass. Comments on the second review draft of this document from those familiar with the monitoring sites in St. Louis indicate that the site selected to provide continuous PM_{10} monitoring, though less than a mile from the site of the $PM_{2.5}$ data is

[9] 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.

not representative of the urban area and resulted in unrealistically large $PM_{10-2.5}$ values.[10] Obviously, for the five 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.

[10] Comments concerning unrealistically high $PM_{10-2.5}$ values for St. Louis are viewed as credible, but were received too late in the review process to permit reanalysis using an alternate data set or to remove St. Louis from all portions of this document. However, the text has been revised to caution readers with respect to the St. Louis results, and they will not be included in the visibility effects discussion in the final PM Policy Assessment document. Some graphics have been updated to exclude St. Louis results.

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 $PM_{2.5}$ 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" $PM_{2.5}$ 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 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.

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 substituted data for the single missing quarters of data in Phoenix and Houston, to achieve seasonal balance. For some sites, two CSN samplers operated on some days for data quality assessment purposes; when this was the case, the results from the two samplers were averaged.

In this assessment, we have not excluded PM concentration data that may have been affected by exceptional events such as wildfires and wind storms. Under EPA's Exceptional Events rule, for existing NAAQS states may request exclusion of such data from regulatory determinations, and accordingly such data are not reflected in design values for existing NAAQS once exclusion is approved by EPA. A similar arrangement presumably would apply to a new or revised secondary PM NAAQS. Design values for PM_{10} light extinction under current conditions (Table 4-2) and percentage reductions to "just meet" alternative secondary NAAQS based on PM_{10} light extinction (Table 4-3), presented below in chapter 4, may thus be overestimates. Overestimation is more likely for the western study sites than for the eastern study sites. However, $PM_{2.5}$ design values shown in Table 3-2, and associated estimates of the reductions needed from 2005-2007 $PM_{2.5}$ level to just meet alternative secondary NAAQS based on $PM_{2.5}$ mass (Table 4-4) do reflect the exclusion of at least some data affected by exceptional events.

Table 3-4. Number of Days per Quarter in Each Study Area

Study Area	Total Number of Days	2005				2006				2007			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Tacoma	109	0	0	0	0	13	15	15	14	12	13	14	13
Fresno	324	19	24	27	27	30	29	29	27	26	28	30	28
Los Angeles	300	26	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	292	26	27	24	27	28	19	27	28	29	25	22	10
Birmingham	350	30	30	29	30	29	29	30	30	30	30	27	26
Atlanta	285	20	25	25	22	26	27	26	24	25	19	26	20
Detroit	141	12	12	10	11	12	13	11	15	11	11	12	11
Pittsburgh	281	25	23	25	21	22	25	24	26	22	22	23	23
Baltimore	186	19	17	15	11	15	16	18	18	12	12	17	16
Philadelphia	145	15	11	13	10	9	13	10	13	13	14	12	12
New York	227	22	23	13	14	23	19	18	21	19	15	19	21

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

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

Because systematic monitoring data on hourly $PM_{2.5}$ component concentrations are not available for most of the 15 study areas, EPA staff extracted and applied certain information from the modeling platform for calendar year 2004 described in section 3.7.1.2 of the ISA, in which the global-scale circulation model GEOS-Chem was paired with the regional scale air quality model CMAQ.[11] 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.

EPA staff identified the one or more 36 km-by-36 km CMAQ grid cells generally corresponding to the urbanized area surrounding each study site, thus omitting grid cells dominated by rural land uses.[12] We then extracted from the detailed model output for these grid

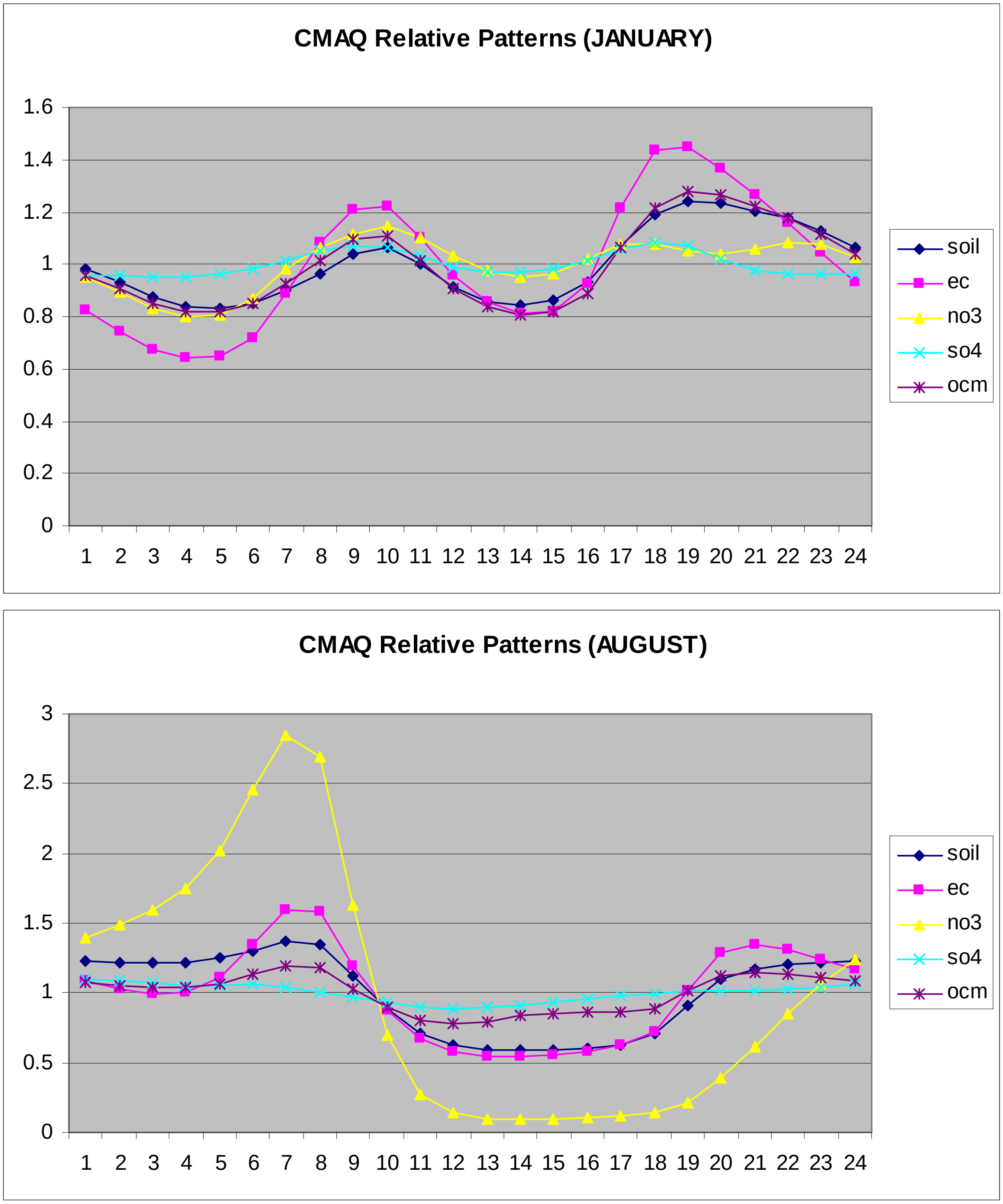
[11] Similar modeling was not available for 2005, 2006, or 2007.

[12] Urbanized area here refers to a specific land area identified by the U.S. Census Bureau based on population density and other factors. Shape files for these areas were compared to the CMAQ grid to identify the grid cells to be used.

cells 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 grid cells and then across days within the month for each individual hour of the day.[13] Thus, for each species, we obtained 24 hour-of-day values for a month, for each of the 12 calendar months. We then averaged the 24 hour-of-day values in each monthly set for each component to obtain the corresponding 24-hour average concentration for the month. We then divided each hour-of-day value by the 24-hour value, to obtain a normalized diurnal profile for the pollutant, which was taken as the initial representation of all days in that month for 2005, 2006, and 2007 (but further adjusted day-by-day in a later step). 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 averaging of predictions for multiple large grid cells, the averaging across days, and the generally moderate diurnal profiles for SMOKE pre-processing of emissions in the CMAQ modeling platform. (Note, however, that as described below a later step in the estimation process reduces the smoothness in the diurnal pattern of PM components.) 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 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.

[13] 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.

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.



3.2.3 Use of Original IMPROVE Algorithm to Estimate PM_{10} 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.[14] To maintain consistency with the form of the candidate protection levels (CPLs) for PM_{10} light extinction identified in chapter 2, EPA staff excluded from the IMPROVE algorithm for total light extinction the term for Rayleigh scattering by gases in clean air. The formula for PM_{10} light extinction using the traditional IMPROVE algorithm but without the Rayleigh scattering term is shown below.

b_{extPM} = 3 x f(RH) x [Sulfate]
+ 3 x f (RH) x [Nitrate]
+ 4 x [Organic Mass]
+10 x [Elemental Carbon]
+ 1 x {Fine Soil]
+ 0.6 x [Coarse Mass]

PM_{10} light extinction (b_{extPM}) is in units of Mm^{-1}, the mass concentrations of the components indicated in brackets are in $\mu g/m^3$, 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 and as retained and measured in the IMPROVE sampling and laboratory methods. Associated water is to be omitted from all bracketed terms since the water absorption effect is reflected in the f(RH) term. The organic mass component is to include the mass of associated elements in addition to 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.

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,

[14] Other differences between the original and revised algorithms include estimates of sea salt contributions which can be important for near-coastal locations, inclusion of site-elevation specific Rayleigh light scattering and provision for calculating NO_2 light absorption when NO_2 data are available. Their exclusion in this assessment is not expected to make any appreciable difference to the results or conclusions.

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 source(s). For example, each 24-hour $PM_{2.5}$ component mass from CSN sampling can be apportioned to hours based on the monthly average 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, sample collection, laboratory analysis, and data reporting, there are differences between the contribution of some PM components to $PM_{2.5}$ mass as reported by a filter-based 24-hour FRM sampler, and the mass of the same components 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 PM_{10} light extinction, the light extinction contribution multipliers per unit of mass concentration of components are not all the same for the five principal components. Consequently, care is required to estimate these components as consistently as possible with the IMPROVE sampling and analytical methods so that particle mass is correctly assigned to the right component.

- **Nitrate:** CSN (and IMPROVE) sampling uses a Nylon filter for purposes of nitrate ion quantification, while FRM sampling uses a Teflon filter for $PM_{2.5}$ mass as a whole. The Nylon filter limits the loss of nitrate in the form of nitric acid vapor which could otherwise occur if the filter temperature rises above the temperature at the time of collection, compared to the Teflon filter. The fine particle nitrate ion collected on nylon and Teflon filters are assumed to be associated with ammonium ions, and for this analysis ammonium is assumed to evaporate at the same rate as nitrate on the FRM filters[15]. Hence, the nitrate ion and calculated ammonium nitrate concentrations 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. On the other hand, FRM sampling may result 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 behaviors regarding retention/loss

[15] EPA staff recognizes that fine particle nitrate may be in the form of calcium or sodium nitrate, but like the IMPROVE program treats nitrate as ammonium nitrate.

of nitrate. In this assessment's approach to estimating actual ambient concentrations and PM_{10} light extinction, the FRM measurement of nitrate is used in the calculation of the concentration of organic carbonaceous material, but not in estimating ambient concentrations of nitrate or PM_{10} light extinction. The CSN-reported nitrate ion concentration and corresponding ammonium nitrate mass is used for the latter purposes.

- **Sulfate:** Unlike nitrate, sulfate is not subject to loss once collected by a filter, so the sulfate ion mass reported by a CSN (or IMPROVE) sampler will be about the same as the contribution of sulfate ion to the mass reported by FRM sampling. In FRM sampling, sulfate ion may not be fully neutralized. When IMPROVE data are used to estimate PM_{10} light extinction, it is assumed that sulfate ion is fully neutralized. Even more important than nitrate, FRM sampling results in water that is associated with sulfate being included in the reported $PM_{2.5}$ mass. While the water associated with the measured sulfate ion is used in the calculation of the concentration of organic carbonaceous material, it is not used in estimating ambient concentrations of sulfate or PM_{10} light extinction.

- **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 assignment of carbon atoms between the reported elemental and organic amounts is dependent on the specifics of the two different thermo-optical analytical methods used in the CSN vs. the IMPROVE network.[16] 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 original 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 adjustments for the same purpose, after reporting of CSN data to AQS. The latter are based on network-wide filter field blanks and are judged as very approximate. For this assessment, the SANDWICH approach to such adjustments (Frank, 2006) is used to estimate the organic mass through a material balance of components 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). None of the instrument types that provided hourly data for this assessment, when averaged over 24 hours, exactly matches either the measurement 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

[16] 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.

vapor, etc. Furthermore, comparability between hourly and 24-hour integrated measurements can only be made on a daily average basis. 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.[17]

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 to assist in understanding these steps.

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 equilibration and weighing), nitrate (including associated ammonium, but not necessarily enough to fully neutralize the sulfate ion, 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. The primary purpose of this SANDWICH step is to estimate organic carbonaceous mass. 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. Therefore, it is not necessary to adjust for organic carbon sampling artifacts or to apply the 1.4 factor commonly used to estimate organic carbonaceous material from IMPROVE measurements of organic carbon. The SANDWICH procedure did not consider sea salt in the material balance, since this is generally a very small mass constituent for the urban areas considered in this analysis. For the same reason, sea salt was also not considered in the aerosol based light extinction algorithm.[18]

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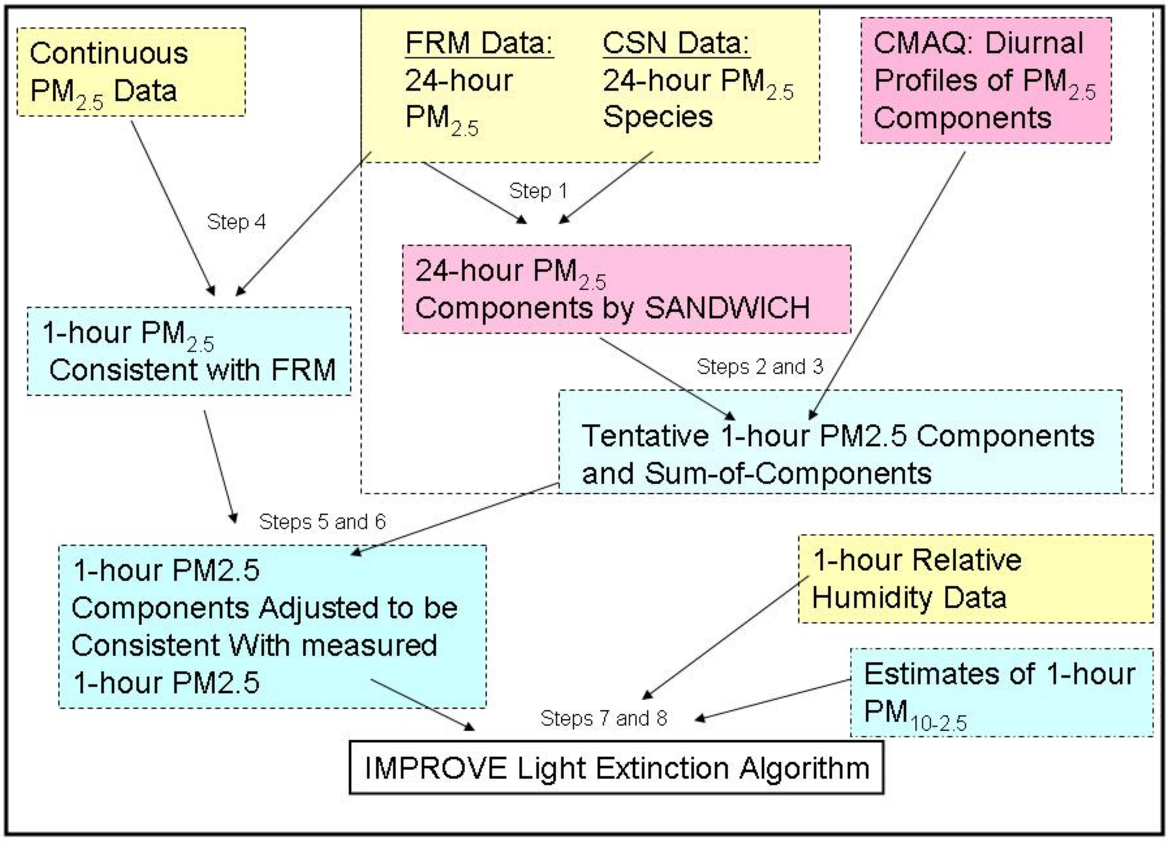
[17] In 2006, EPA developed and promulgated criteria for approval of continuous $PM_{2.5}$ samplers as "federal equivalent methods". These criteria assure a minimum level of correlation between approved continuous instruments and the FRM method, when data from both are expressed as 24-hour average concentrations. However, in 2005-2007 no commercially available instruments were yet approved under those criteria.

[18] After completion of the second draft UFVA, an error in the execution of the SANDWICH method was discovered. The error had the effect of reducing the estimate of nitrate on the FRM filter for some sample days, generally by no more than 3 or 4 $\mu g/m^3$, and increasing the estimate of organic carbon mass on the FRM filter by the same amount. The effect on estimates for PM_{10} light extinction was that light extinction had been overestimated for some hours in some cities. The error has been corrected in this final version. The effect of the correction is in most cases very small and visually imperceptible in graphics such as box plots.

Figure 3-5. Sequence of Steps Used to Estimate Hourly $PM_{2.5}$ Components and PM_{10} Light Extinction



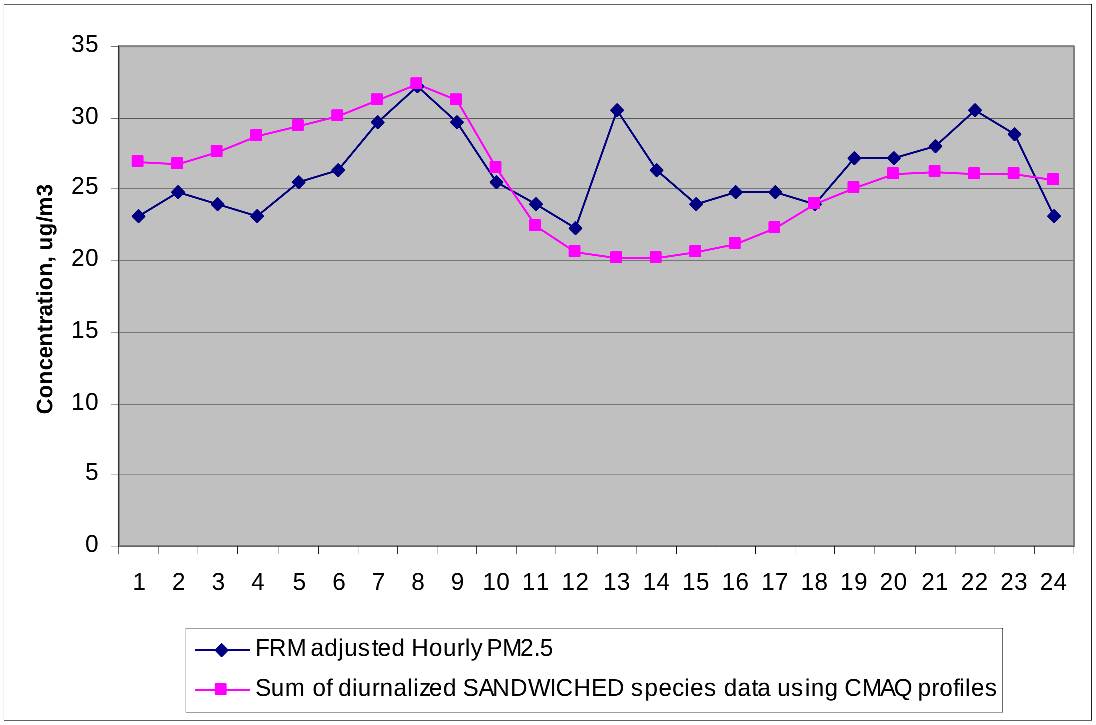
2. The CMAQ-derived monthly diurnal profiles for the sulfate, nitrate, elemental carbon, organic carbon and fine soil/crustal components, like the examples for Detroit in Figure 3-4, were multiplied by the day-specific SANDWICH-based estimates of the 24-hour average concentrations of these five $PM_{2.5}$ 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 preliminary, 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 $PM_{2.5}$ 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 daily average of 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 or water) was multiplied by 1.375 to reflect an assumption of full neutralization of dry sulfate mass.[19]

    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, both reported as fully neutralized sulfate ion.

[19] While it would have been possible to develop a more realistic estimate of partially neutralized sulfate, the assumption of full neutralization was used to maintain consistency with the basis for the f(RH) term in the IMPROVE algorithm.

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 or water) was multiplied by 1.29 to reflect an assumption of full neutralization by ammonia.

   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 A_i 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. 1.375 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.

The net effect of these steps is believed by EPA staff to result in hourly PM_{10} light extinction estimates with the following features with respect to some of the complicating aspects of PM sampling:

- The 24-hour average of the hourly nitrate concentrations used to estimate hourly PM_{10} light extinction agrees closely but not exactly with the 24-hour value provided by the CSN sampling, and generally is higher than the contribution of nitrate to the FRM measure of $PM_{2.5}$ mass. In some mid-day hours in some areas, estimated hourly nitrate is zero which is a more realistic approach than applying a 24-hour species mix to each hour.

- The 24-hour average of the hourly organic carbonaceous material concentrations used to estimate hourly PM_{10} light extinction achieves FRM mass balance closure, taking into account also the difference in nitrate and the possibly partial neutralization of sulfate ion on the FRM filter. Because the Teflon filter used in FRM sampling is less subject to positive artifacts for organic material, this approach sidesteps an area of uncertainty in the IMPROVE sampling method. By relying on mass closure as the driving principle for estimating organic material, it is not necessary to choose a multiplier to relate organic carbon to organic carbonaceous material.[20]

- The 24-hour average of the hourly elemental carbon concentrations used to estimate hourly PM_{10} light extinction agrees closely but not exactly with the 24-hour value provided by the CSN sampling, and with the contribution of elemental carbon to the FRM measure of $PM_{2.5}$ mass. Elemental carbon is generally defined by the thermal optical transmission method used in CSN, rather than the thermal optical reflectance method used by the IMPROVE network.

3.3.2 Hourly $PM_{10-2.5}$ Concentrations

Three different paths were used to estimate hourly $PM_{10-2.5}$ concentrations depending on data availability, 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. This was the approach most often used in Birmingham, Detroit, Baltimore, and Philadelphia. This method should result in reliable estimates of actual $PM_{10-2.5}$ at the study site. (How well the study site represents the study area generally, or the most visibility-impacted portions of the study area, is a separate issue.)

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 or near 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. This was the approach most often used in Los Angeles, Phoenix, St. Louis, Atlanta, and New York. As a result, estimates of $PM_{10-2.5}$ for these areas could be affected by site-to-site differences. In particular, the two sites in Los Angeles were a good distance apart, and the PM_{10} site in Victorville may represent influences from agricultural operations rather than typical urban influences. In St. Louis, the PM_{10} site may also have been influenced by particular local sources. In both cases, very high estimates of hourly $PM_{10-2.5}$ may not represent reality at the $PM_{2.5}$ site, although they may be reasonable estimates for the PM_{10} site.

[20] In other work, EPA staff has observed that when applied to urban sampling data together with CSN network-wide field blanks applied to reported OC measured concentrations, the multipliers that can be back-calculated from the results of the SANDWICH method tend to be nearer to 1.4 than to the higher value used in the new IMPROVE algorithm.

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. This was the approach used for all hours in Tacoma, Fresno, Salt Lake City, Dallas, Houston, and Pittsburgh. With this approach, it is not possible for there to be any particularly high estimates of hourly $PM_{10-2.5}$.

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 compared to the use of paired low-volume filter-based samplers, in most areas and periods the contribution to PM_{10} light extinction from the resulting $PM_{10-2.5}$ concentrations was not large compared to the PM_{10} light extinction contribution from $PM_{2.5}$ 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 Daylight 1-Hour PM_{10} Light Extinction

Because the interest in this analysis is on visibility during daylight hours, EPA staff applied a scheme to denote those hours that would be considered daylight hours. For simplicity, all the days within each "season" in all study areas were considered to have the same daylight hours.[21] Table 3-5 shows the dividing times used to denote 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.

The original IMPROVE algorithm was applied hour-by-hour to estimate PM_{10} light extinction in each study area for each daylight hour. When doing so, we capped the value of the

[21] This simple approach does not account for the effects of the actual date within a three-month season, latitude, or east-west position within a time zone on the actual local hours that are entirely daylight. Appendix I examines the possible impact of this simplification, concluding that it is unlikely to affect later answers to policy relevant questions.

humidity adjustment factor in the IMPROVE algorithm ("f(RH)") at the value of 7.4 that 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 PM_{10} 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.[22] .

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

3.3.5 Exclusion of Hours with Relative Humidity Greater than 90 Percent from PM_{10} Light Extinction NAAQS Scenarios and Most Results

As advised by CASAC as part of its comments on the first public review draft of this assessment, EPA staff considered whether to structure the PM_{10} light extinction NAAQS scenarios so that ambient data obtained during daylight hours in which relative humidity was greater than 90 percent would play no role in the form of the NAAQS, i.e., so that those data would not enter into the calculation of the design value. EPA staff obtained hourly meteorological parameters from NWS monitoring sites near the 15 study sites (usually a major airport), for 2005 through 2007, for all days in this period including days for which PM observations to support estimates of PM_{10} light extinction are not available. Using these data, EPA staff compared the occurrence of liquid precipitation, hail, other frozen precipitation, fog, mist, and smoke/haze during daylight hours with humidity greater than 90 percent and during all other daylight hours.[23] The first five of these conditions are generally considered natural causes

[22] The IMPROVE program also caps the value of f(RH) at its value for a relative humidity of 95% when reporting visibility in deciviews.

[23] The "smoke/haze" category is not an original NWS reporting category. It is a combination of two original NWS weather categories: smoke and haze. The explanation of these categories in the NWS documentation does not allow EPA staff to be confident that these terms have distinct and clear meanings that are uniformly applied across observation sites, so they have been combined in this presentation. As best EPA staff can determine, the combined category reflects some mix of smoke from burning biomass, smoke from industrial processes, dust from

of reduced visibility. Table 3-6 presents this comparison.[24] The percentages of hours with each of these five conditions individually are shown for the two sets of daylight hours.

wind storms, volcanic ash, and general urban haze. Also, the reported conditions may be at some distance from the observation site.

[24] Compared to the version of this table in the second external review draft, this version correctly omits non-daylight hours which were inadvertently included in the earlier version, reports results for four study areas for which results were missing in the earlier version, and separates "mist" from "smoke/haze" to reflect that "mist" is a natural condition while "smoke/haze" is not always a natural condition.

Table 3-6. Comparison of Meteorological Parameters for Daylight Hours with Relative Humidity Greater than 90 Percent and Other Daylight Hours, During 2005 -2007

Study Area	Daylight Hours with Relative Humidity <= 90%								Daylight Hours with Relative Humidity > 90%							
	Number of Hours	Percentage of Hours with Weather or Other Condition							Number of Hours	Percentage of Hours with Weather or Other Condition						
		Liquid Precip.	Hail	Other Frozen Precip.	Fog	Mist	Smoke/ Haze	Any		Liquid Precip.	Hail	Other Frozen Precip.	Fog	Mist	Smoke/ Haze	Any
Tacoma	10,326	12%	0%	0%	0%	0%	4%	14%	1,756	36%	0%	1%	10%	0%	43%	63%
Fresno	11,758	3%	0%	0%	1%	0%	15%	17%	342	25%	0%	1%	60%	0%	65%	93%
Los Angeles	11,419	2%	0%	0%	0%	0%	8%	9%	713	25%	0%	0%	12%	0%	52%	73%
Phoenix	12,123	1%	0%	0%	0%	0%	0%	1%	43	67%	0%	0%	30%	0%	40%	74%
Salt Lake City	11,810	4%	0%	2%	1%	0%	4%	8%	304	28%	0%	40%	42%	0%	69%	85%
Dallas	11,827	4%	0%	0%	1%	0%	5%	8%	223	68%	0%	2%	20%	0%	82%	91%
Houston	11,525	6%	0%	0%	1%	0%	6%	9%	645	42%	0%	0%	25%	0%	64%	75%
St. Louis	11,590	5%	0%	1%	1%	0%	10%	14%	583	56%	0%	8%	48%	0%	82%	91%
Birmingham	11,590	5%	0%	0%	1%	0%	9%	11%	486	56%	0%	0%	41%	0%	79%	86%
Atlanta	11,337	5%	0%	0%	1%	0%	10%	13%	867	50%	0%	0%	45%	0%	81%	88%
Detroit	11,484	5%	0%	3%	1%	0%	9%	14%	676	51%	0%	16%	39%	0%	76%	92%
Pittsburgh	10,603	5%	0%	3%	1%	0%	9%	14%	1,261	46%	0%	9%	12%	0%	72%	85%
Baltimore	11,321	4%	0%	1%	2%	0%	12%	14%	858	53%	0%	5%	38%	0%	80%	90%
Philadelphia	11,125	4%	0%	1%	1%	0%	8%	11%	878	47%	0%	3%	33%	0%	64%	84%
New York	11,799	7%	0%	1%	1%	0%	10%	14%	397	66%	0%	8%	48%	0%	86%	96%
Average	**11,442**	**5%**	**0%**	**1%**	**1%**	**0%**	**8%**	**11%**	**669**	**48%**	**0%**	**6%**	**34%**	**0%**	**69%**	**84%**

NWS observations of these conditions are instantaneous, and are generally made about 50 minutes after the hour. The relative humidity observations are made at the same time. It should be noted that this analysis of the co-occurrence of high relative humidity and these five conditions uses data from NWS sites other than the AQS sites that provided the data used to estimate PM_{10} light extinction. AQS sites could not be used for this analysis because they generally do not report similar weather condition data.

The comparison for the 15 sites shows that in the set of hours with relative humidity above 90 percent, the frequencies of liquid precipitation (rain), other frozen precipitation (snow and sleet), or fog ranged as high as 68 percent, and were considerably higher for the same condition than in the set of hours with lower relative humidity. The frequencies of hail and mist were all less than 0.5 percent and thus too low for meaningful comparisons. Moreover, except in Tacoma, the frequency of rain or fog at the observation moments during the hours with relative humidity less than or equal to 90 percent was less than 8 percent. Also, a separate analysis (not shown) indicated that rainy hours with lower relative humidity experience considerably less accumulation than rainy hours with higher relative humidity. Based on this assessment, the 90% relative humidity cutoff criteria is effective in that on average less than 6 percent of the daylight hours are removed from consideration, yet those hours have on average about 10 times the likelihood of rain, 6 times the likelihood of snow/sleet, and 34 times the likelihood of fog compared to hours with 90% or less relative humidity.

Rain, snow/sleet, and fog cause a natural reduction in visibility, independent of PM concentrations. To reduce the likelihood that a design value for a secondary PM NAAQS could be affected by measurements made under natural weather conditions that reduce visibility, for this assessment EPA staff eliminated from the design value definition any contribution from PM_{10} light extinction values that come from any daylight hours with relative humidity above 90 percent.[25] Also, because PM_{10} light extinction during such hours is not as likely to be the primary cause of adverse effects on the public, all figures and tables in the body of this document and in Appendices that present PM_{10} light extinction values or statistics exclude values for such hours (unless explicitly stated to include them), so that the patterns of PM_{10} light extinction during the remaining daylight hours can be seen clearly. Figures and tables that present PM component concentrations and relative humidity values are based on all daylight hours, however.

More information on this topic can be found in Appendix G, which reports by study area the percentages of daylight hours that were excluded from design values, the distribution of the excluded hours by time of day, and the percentage of days that had one or more daylight hours

[25] Another consideration is that instruments used to measure light extinction could be adversely affected if allowed to operate without heating or other protective method (such as diffusion drying of incoming air) when relative humidity is very high. If protected, however, the measured light scattering would not reflect actual ambient conditions.

eliminated. Appendix G also contains box plots which contrast the distributions of daylight 1-hour PM_{10} light extinction values (and maximum daily daylight 1-hour PM_{10} light extinction, see section 3.3.6) before and after this elimination step. The tile plots in Figure 3-12 also present additional detailed information on the specific hours that had relative humidity values above 90 percent, and on the PM_{10} light extinction values during those and other daylight hours.

3.3.6 Calculation of Daily Maximum 1-Hour PM_{10} Light Extinction

Daily maximum 1-hour PM_{10} light extinction is a statistic of interest in this assessment, as briefly discussed in section 1.4.3. The daylight hour with the maximum value of PM_{10} light extinction and the corresponding PM_{10} light extinction value were identified for each day for each study area. As mentioned in section 3.2.1, days which were missing 1-hour $PM_{2.5}$ values for more than 25 percent of daylight hours were not used in this analysis. No further completeness requirement for 1-hour data during a day was applied when selecting the daylight hour with the maximum value of PM_{10} light extinction.

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, including hours with relative humidity greater than 90 percent. Similar plots of the daily maximum daylight 1-hour values of $PM_{2.5}$ and $PM_{10-2.5}$ concentrations and relative humidity are available in Appendix B, as are plots of all daylight 1-hour values for each of the $PM_{2.5}$ component species.[26]

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

[26] In all box-and-whisker plots in this document, the box represents the 25^{th} to 75^{th} percentile range and the whiskers represent the 10^{th} and 90^{th} percentile points of the data; individual data points below the 10^{th} percentile and above the 90^{th} percentile are graphed as small circles (which may not all be visible because they may lie on top of one another as is the case for relative humidity in Figure 3-7(c) because relative humidity is reported as an integer).

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

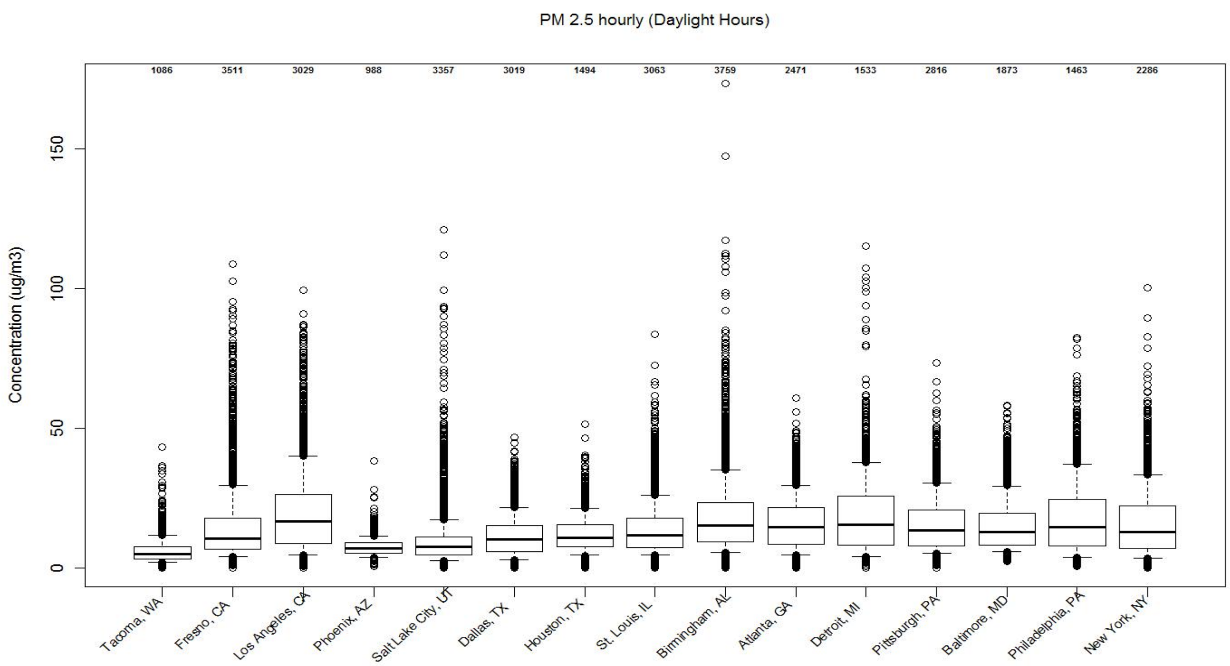


Figure 3-7. Distribution of PM Parameters and Relative Humidity Across the 2005-2007 Period, by Study Area, continued

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

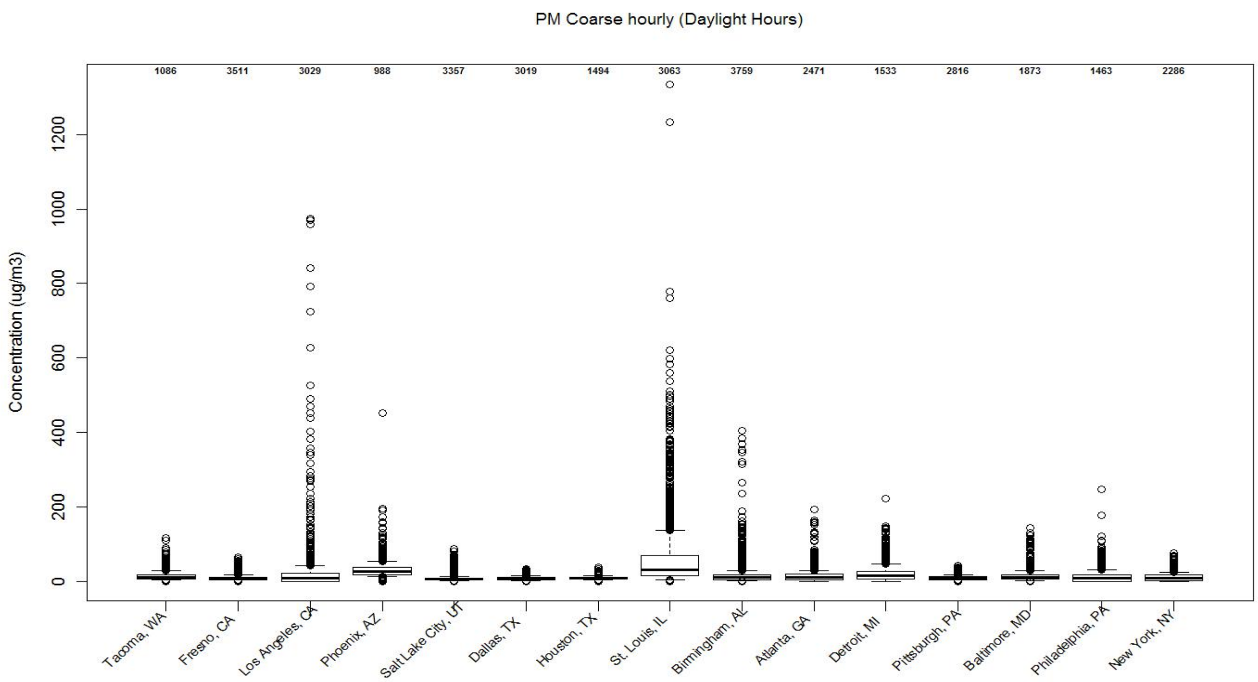
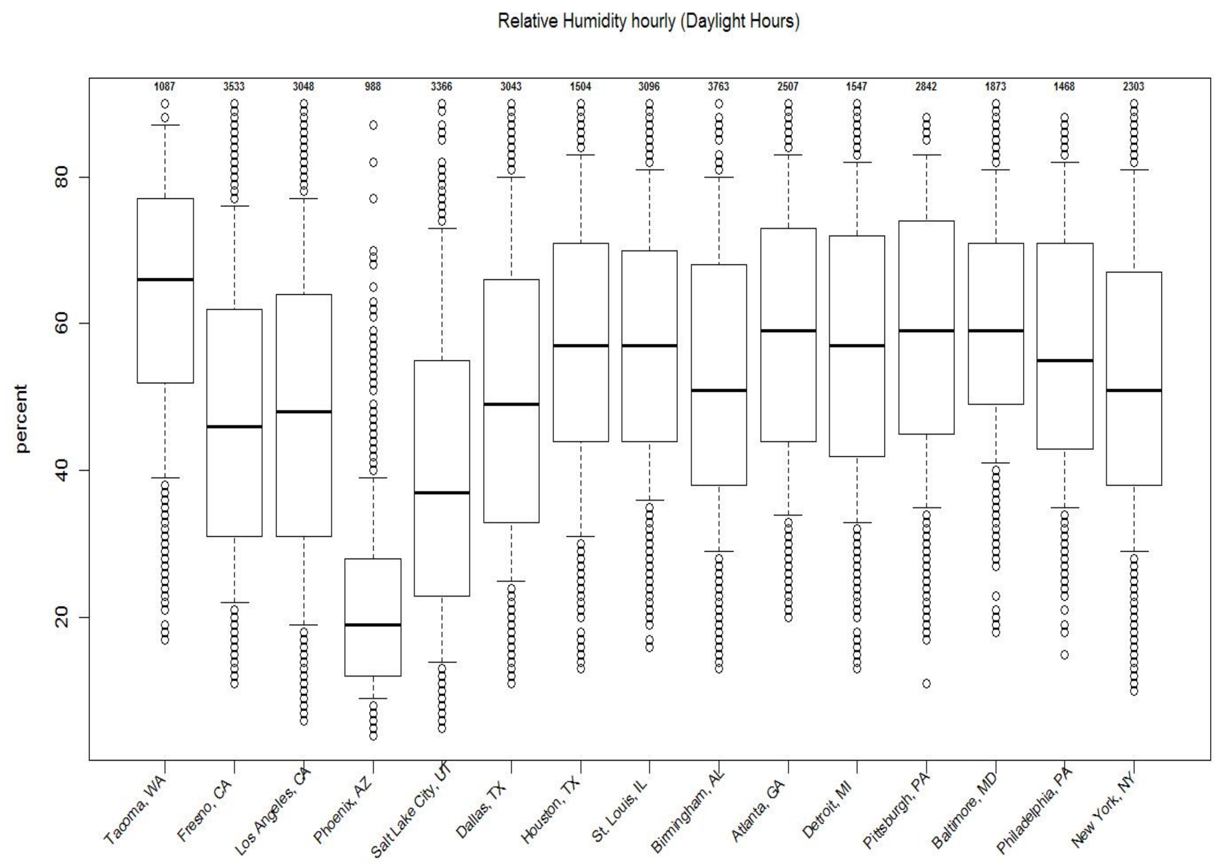


Figure 3-7. Distribution of PM Parameters and Relative Humidity Across the 2005-2007 Period, by Study Area, continued

(c) 1-Hour Relative Humidity



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 PM_{10} Light Extinction

Figure 3-8 presents box-and-whisker plots to illustrate the distributions of the estimates of daylight 1-hour reconstructed PM_{10} light extinction levels in each area in each year (excluding hours with relative humidity greater than 90 percent). The distribution of (a) the daily maximum 1-hour values and (b) the individual 1-hour values are both shown. The horizontal dashed lines in the plots represent the low, middle, and high CPLs for PM_{10} light extinction as discussed in section 2.6. These benchmarks for PM_{10} light extinction are 64, 112, and 191 Mm^{-1}, corresponding to the benchmark VAQ values of 20 dv, 25 dv and 30 dv. Table 3-7 provides (a) the percentages of days (across all of 2005-2007, unweighted) in which the daily maximum daylight 1-hour PM_{10} light extinction level was greater than each of the three CPLs (excluding hours with relative humidity greater than 90 percent), and (b) the similar percentage based on all daylight hours (with the same exclusion).

As was also seen in the comparable $PM_{2.5}$ concentration box and whisker plots in Figure 3-7, the high percentile hourly PM_{10} 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 PM_{10} light extinction values are higher (Figure 3-8a), as expected, than for all hours (Figure 3-8b). Both Figure 3-8 and Table 3-7 indicate that all 15 urban areas have daily maximum hourly PM_{10} light extinctions that exceed even the highest of the CPLs some of the time. Again, the non-California western urban locations have the lowest frequency of maximum hourly PM_{10} light extinction with values in excess of the high CPL for 8 percent or fewer of the days. Except for the two Texas and the non-California western urban areas, all of the other urban areas exceed that high CPL from about 20 percent to over 60 percent of the days. Based on these estimated maximum hourly PM_{10} light extinction estimates, all 15 of the urban areas exceed the low CPL for about 40 percent to over 90 percent of the days. As noted in section 3.2.1, in 10 of the 15 study areas the study site used in this assessment is not the site in the study area with the highest concentrations of $PM_{2.5}$. Thus, these estimates may not characterize visibility in the worst-visibility portion of each study area.

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 PM_{10} light extinction levels in specific daylight hours, Figure 3-9 shows the distributions of 1-hour PM_{10} light extinction across the entire three-year study period, individually for the study areas (excluding hours with relative humidity greater than 90 percent). (Appendix E provides additional graphics related to temporal/spatial patterns of light extinction.) These plots show that high PM_{10} light extinction can occur during any of the daylight hours, though for most of these urban areas the morning hours have somewhat higher PM_{10} light extinction than in the afternoon.[27] Urban areas without a pronounced preference for morning high PM_{10} light extinction include Phoenix, AZ; Salt Lake City, UT; Tacoma, WA; Fresno, CA; and Philadelphia, PA.

[27] If hours with relative humidity greater than 90 percent were not eliminated, the tendency for higher PM_{10} light extinction in the morning hours would be stronger.

Figure 3-8. Distributions of Estimated Daylight 1-Hour PM_{10} Light Extinction and Maximum Daily Daylight 1-Hour PM_{10} Light Extinction (in Mm^{-1} units) Across the 2005-2007 Period, by Study Area (Excluding Hours with Relative Humidity Greater Than 90 Percent).

(a) Maximum Daily Values

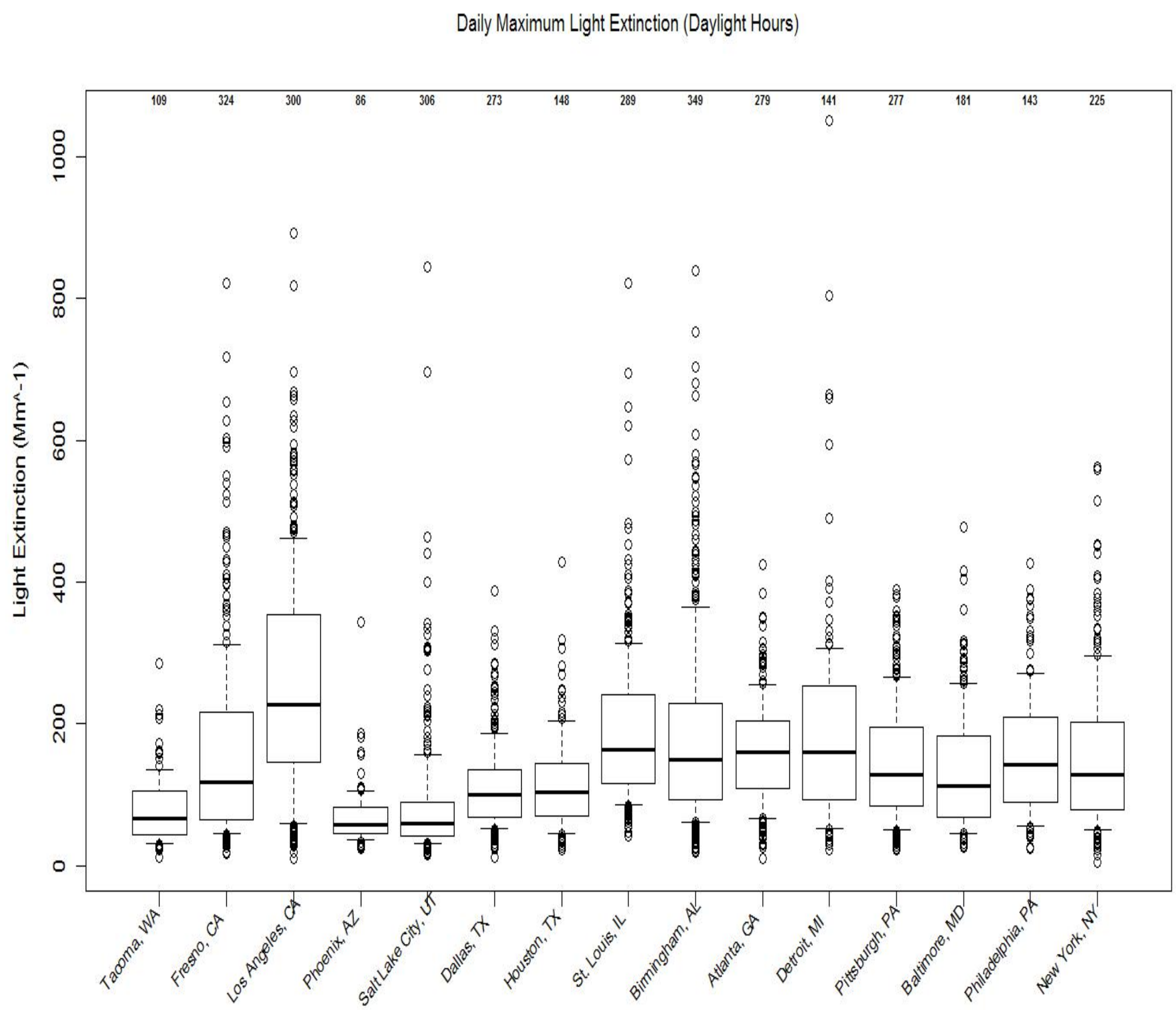


Figure 3-8. Distributions of Estimated Daylight 1-Hour PM_{10} Light Extinction and Maximum Daily Daylight 1-Hour PM_{10} Light Extinction (in Mm^{-1} units) Across the 2005-2007 Period, by Study Area (Excluding Hours with Relative Humidity Greater Than 90 Percent), continued.

(b) Individual 1-Hour Values

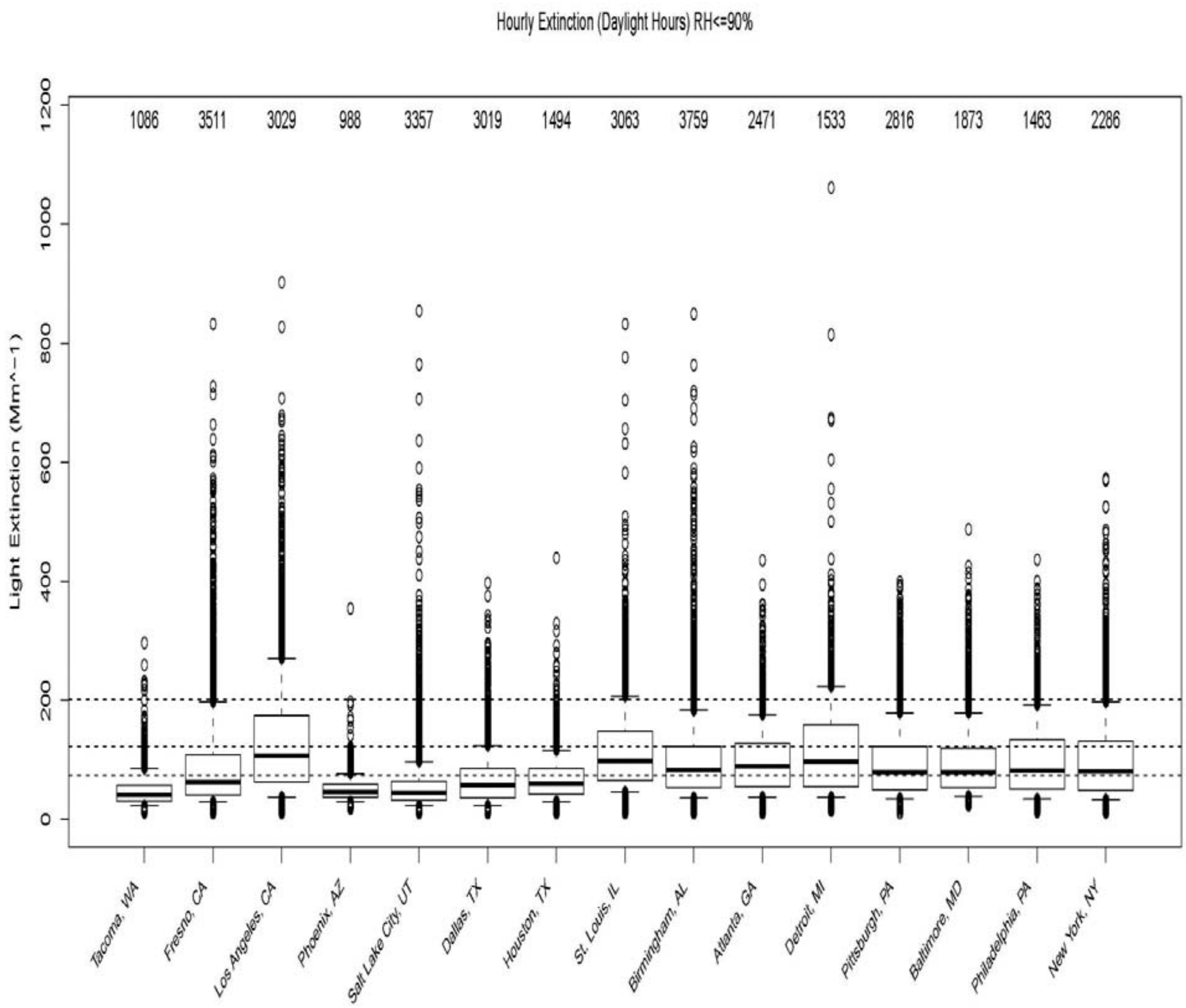
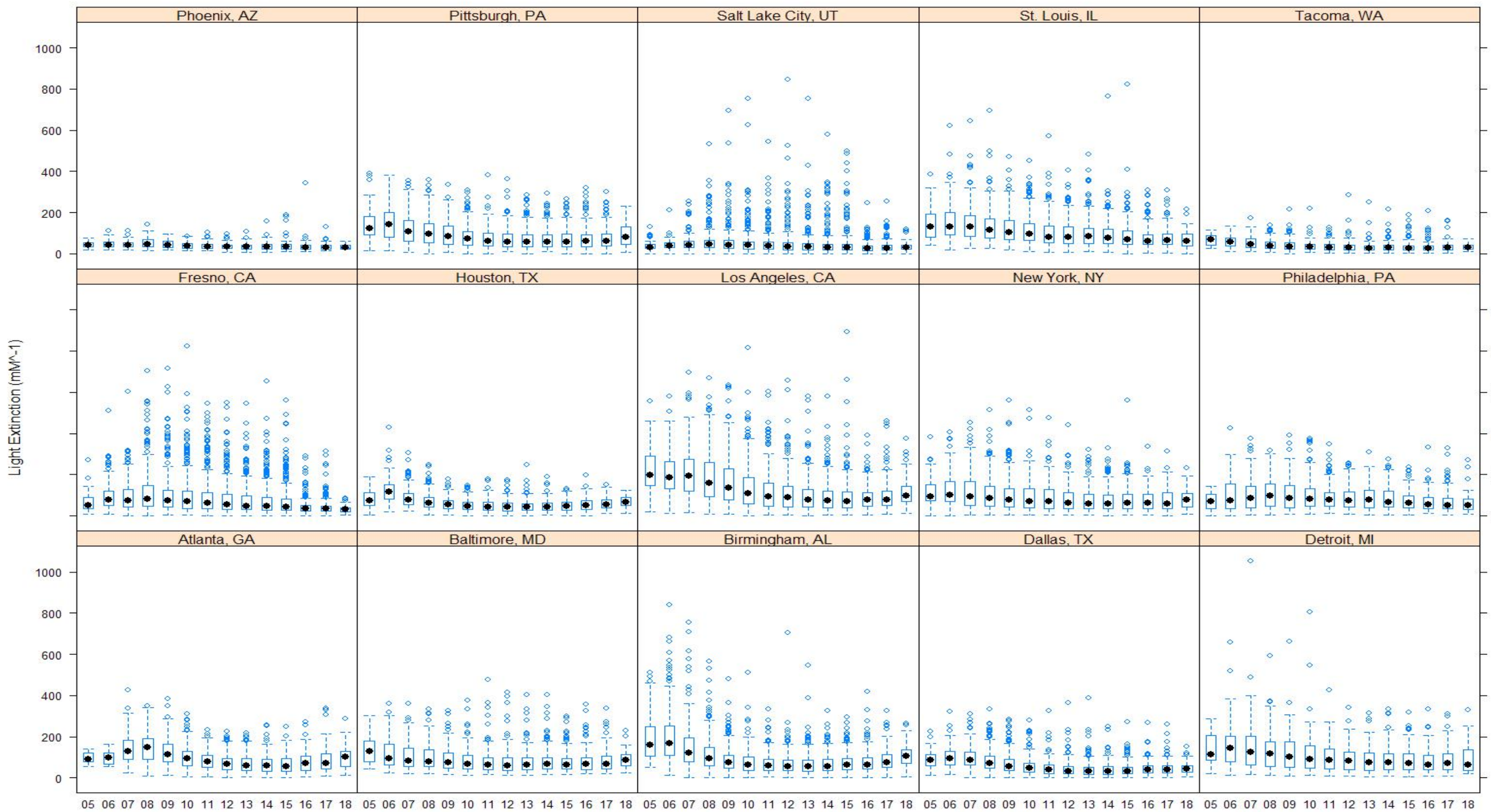


Table 3-7. Percentage of Daily Maximum Hourly Values and Individual Hourly Values of Daylight PM_{10} Light Extinction Exceeding CPLs (Excluding Hours with Relative Humidity Greater Than 90 Percent).

Study Area	Number of Days with Estimates	Candidate Protection Level		
		$64 Mm^{-1}$	$112\ Mm^{-1}$	$191\ Mm^{-1}$
		(a) Percentage of Daily Maximum Hourly Values Exceeding CPL		
Tacoma	109	52	22	4
Fresno	324	76	52	29
Los Angeles	300	90	83	61
Phoenix	86	42	7	1
Salt Lake City	306	44	17	8
Dallas	273	80	41	10
Houston	148	79	45	11
St. Louis	289	98	78	40
Birmingham	349	89	64	34
Atlanta	279	91	75	31
Detroit	141	87	68	43
Pittsburgh	277	85	57	26
Baltimore	181	80	50	23
Philadelphia	143	86	63	31
New York	225	83	59	28
Average	***229***	***77***	***52***	***25***
	Number of Daylight Hours with Estimates	**(b) Percentage of Individual Daylight Hours Exceeding CPL**		
Tacoma	1087	14	4	1
Fresno	3533	41	20	10
Los Angeles	3048	68	42	19
Phoenix	988	11	1	0
Salt Lake City	3366	17	7	3
Dallas	3043	33	10	2
Houston	1504	35	8	1
St. Louis	3096	66	36	11
Birmingham	3763	57	25	8
Atlanta	2507	60	28	5
Detroit	1547	62	36	14
Pittsburgh	2842	53	25	7
Baltimore	1873	55	24	7
Philadelphia	1468	55	28	9
New York	2296	53	28	9
Average	***2398***	***45***	***21***	***7***

Figure 3-9. Distributions of 1-Hour PM_{10} Light Extinction Levels by Daylight Hour Across the 2005-2007 Period, by Study Area (Excluding Hours with Relative Humidity Greater Than 90 Percent).



3.4.3 Patterns of Relative Humidity and Relationship between Relative Humidity and PM_{10} Light Extinction

Figure 3-9 shows the distribution of relative humidity values at each daylight hour, for each study area across 2005-2007 (excluding hours with relative humidity greater than 90 percent).[28] 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 the early afternoon, 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 the relationship between PM_{10} light extinction values and relative humidity values, Figure 3-10 is a scatter plot of actual 1-hour relative humidity and 1-hour reconstructed PM_{10} light extinction (excluding hours with relative humidity greater than 90 percent). Horizontal lines are included in each of the individual plots corresponding to the three benchmarks for PM_{10} light extinction and a vertical line in each for the 90 percent relative humidity cutoff. There are many instances with PM_{10} light extinction greater than the CPLs when relative humidity is 90 percent or lower. Notice that in Figure 3-10 there also are plenty of high humidity conditions for each urban area that correspond to low PM_{10} 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 3-10 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.)

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[28] Similar information on diurnal patterns but broken out by season is given in Appendix E.

Figure 3-10. Distributions of 1-Hour Relative Humidity Levels by Daylight Hour (X-axis) Across the 2005-2007 Period, by Study Area (Excluding Hours with Relative Humidity Greater Than 90 Percent).

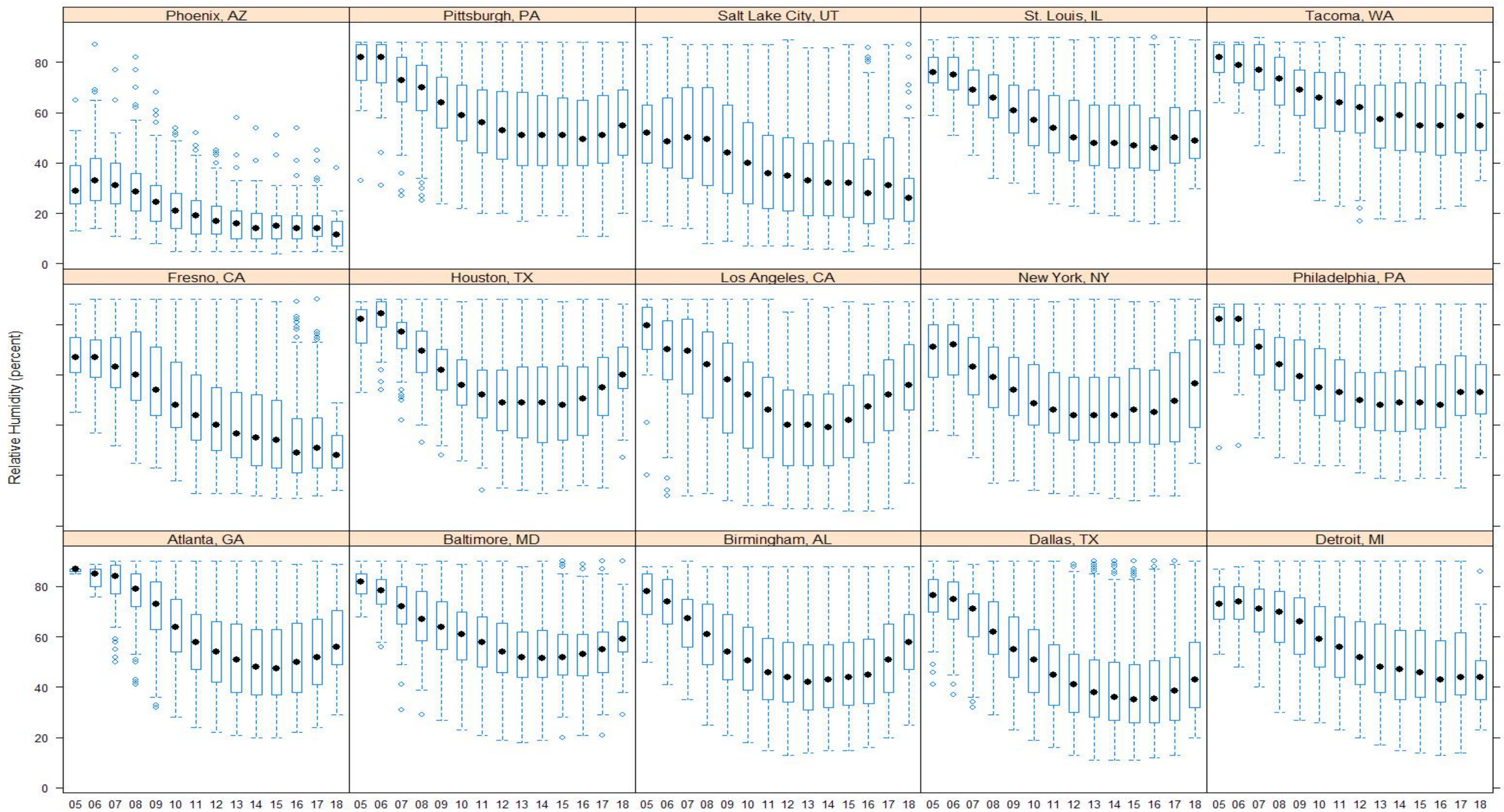
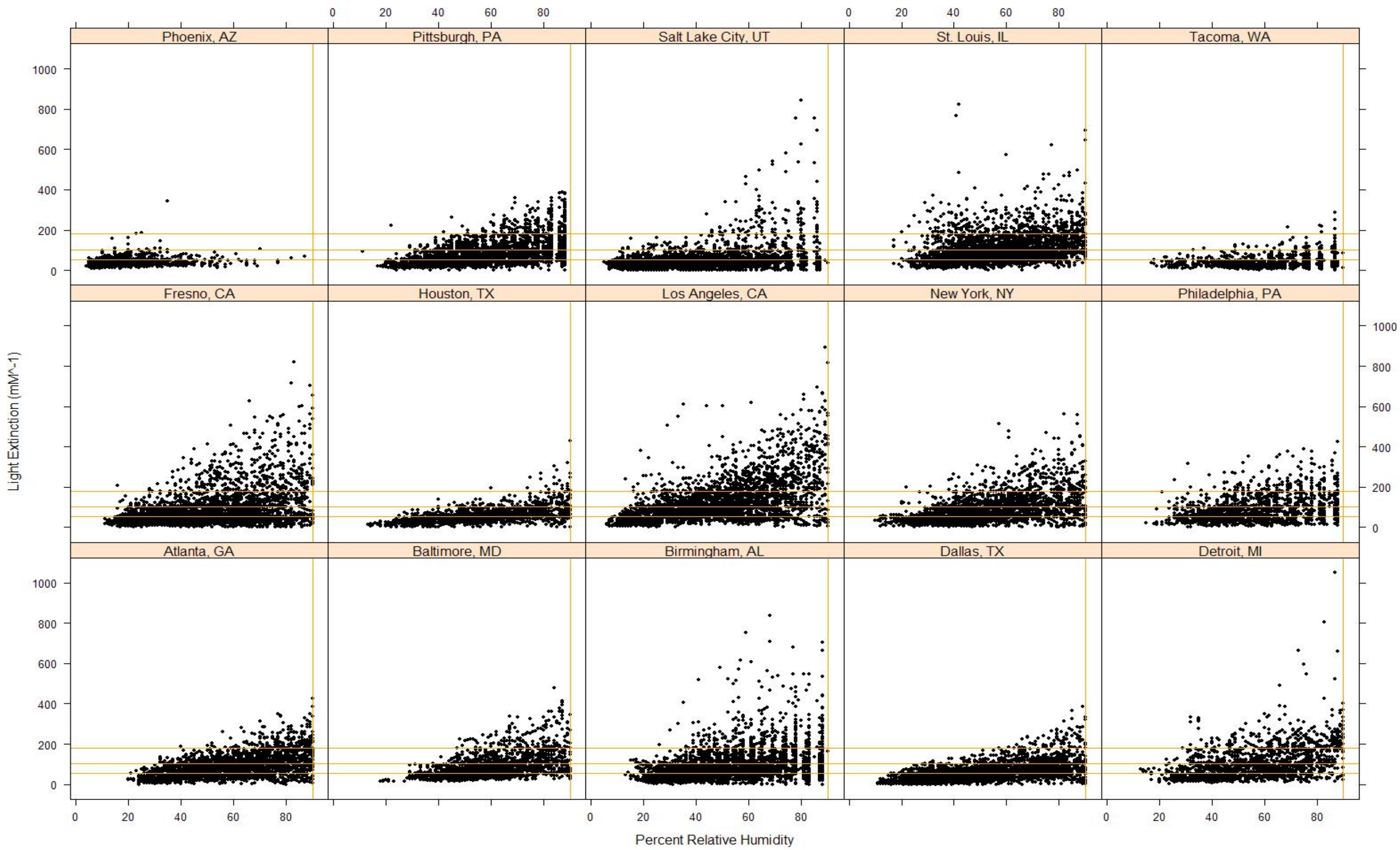


Figure 3-11. Scatter Plot of Daylight 1-Hour Relative Humidity (Percent) vs. Reconstructed PM_{10} Light Extinction (Mm^{-1}) Across the 2005-2007 Period, by Study Area (Excluding Hours with Relative Humidity Greater Than 90 Percent).



3.4.4 Tile Plots of Hourly PM_{10} Light Extinction

Figure 3-12 consists of "tile plots" that show the estimated levels of 1-hour PM_{10} light extinction for each daylight hour for each study area. These plots assist in understanding the times of the year and hours of the day in which high relative humidity and high PM_{10} light extinction occur, both separately and together.

Time runs horizontally with each row of tiles representing a single day from midnight (left site) to midnight (right side), and vertically from January (top) to December (bottom). Each tile represents one hour of the year for which data to estimate PM_{10} light extinction were sufficient. Sites with 1:3 speciation sampling have more (and smaller) tiles than sites with 1:6 speciation sampling. The tick marks on the vertical axis identify the first available sample day of each month identified by its month number.

PM_{10} light extinction is presented in terms of four ranges or bins defined by the two intervals between the three CPLs, a bin above the high CPL, and a bin below the low CPL. For the hours with relative humidity of 90 percent and below (referred to as "Low RH bext" in the figure legend), shades of green are used to indicate the CPL range. Contrasting blue color scales are used for the tiles representing hours with relative humidity greater than 90 percent (referred to as "High RH bext" in the shading legend), so that the hours excluded from the PM NAAQS scenarios (see section 3.3.5 and Chapter 4) can be distinguished. Hours with missing $PM_{2.5}$ data from the continuous instrument have no estimates of PM_{10} light extinction and are white. Such cases are rare, following the prior complete exclusion of days in which more than 25 percent of daylight hours were missing such data.

Note that for Tacoma and Phoenix there are plots for only two years because the third year did not have suitable data, and for Phoenix and Houston only 9 months are shown for one of the available years because suitable data were not available for the remaining quarter (the available 9 months of results are stretched over the same vertical distance as the 12 months in the other cases).

One observation that can be made in looking at these tile plots is that in very many cases, days which have one or more hours with high PM_{10} light extinction excluded because of high relative humidity have other hours with high PM_{10} light extinction which are not excluded.

Although none of the PM_{10} light extinction NAAQS scenarios considered in Chapter 4 are based on averaging periods longer than one hour, these tile plots can be used to get a rough sense of whether hours with high PM_{10} light extinction tend to be isolated, such that average values over several hours would be considerably lower, or tend to occur together, such that a longer averaging period would produce roughly the same design value. A number of the eastern urban areas have numerous day-long haze episodes throughout the year (e.g. St. Louis, Detroit, Pittsburgh, Philadelphia and New York) or seasonally (e.g. Fresno and Salt Lake City, in the winter, and Los Angeles and Atlanta in the summer). Some of the urban areas have morning haze levels that diminish later in the day on a year-around basis (e.g. Dallas) or seasonally (e.g. Los Angeles, Birmingham and Atlanta in winter and Tacoma, Fresno, and St. Louis in the summer). This type of information may be useful in this regard during the subsequent preparation of the final Policy Assessment Document.

Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction

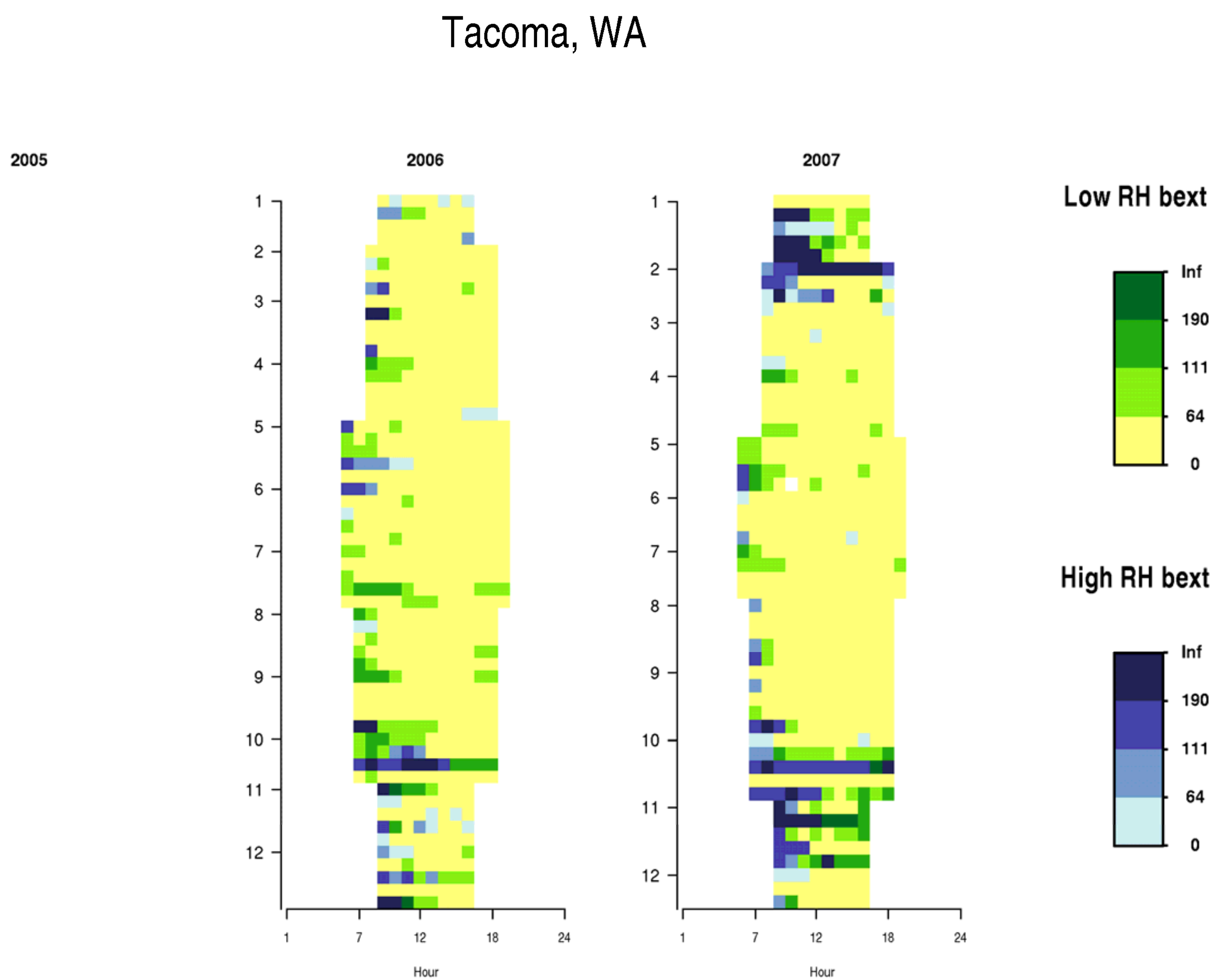


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

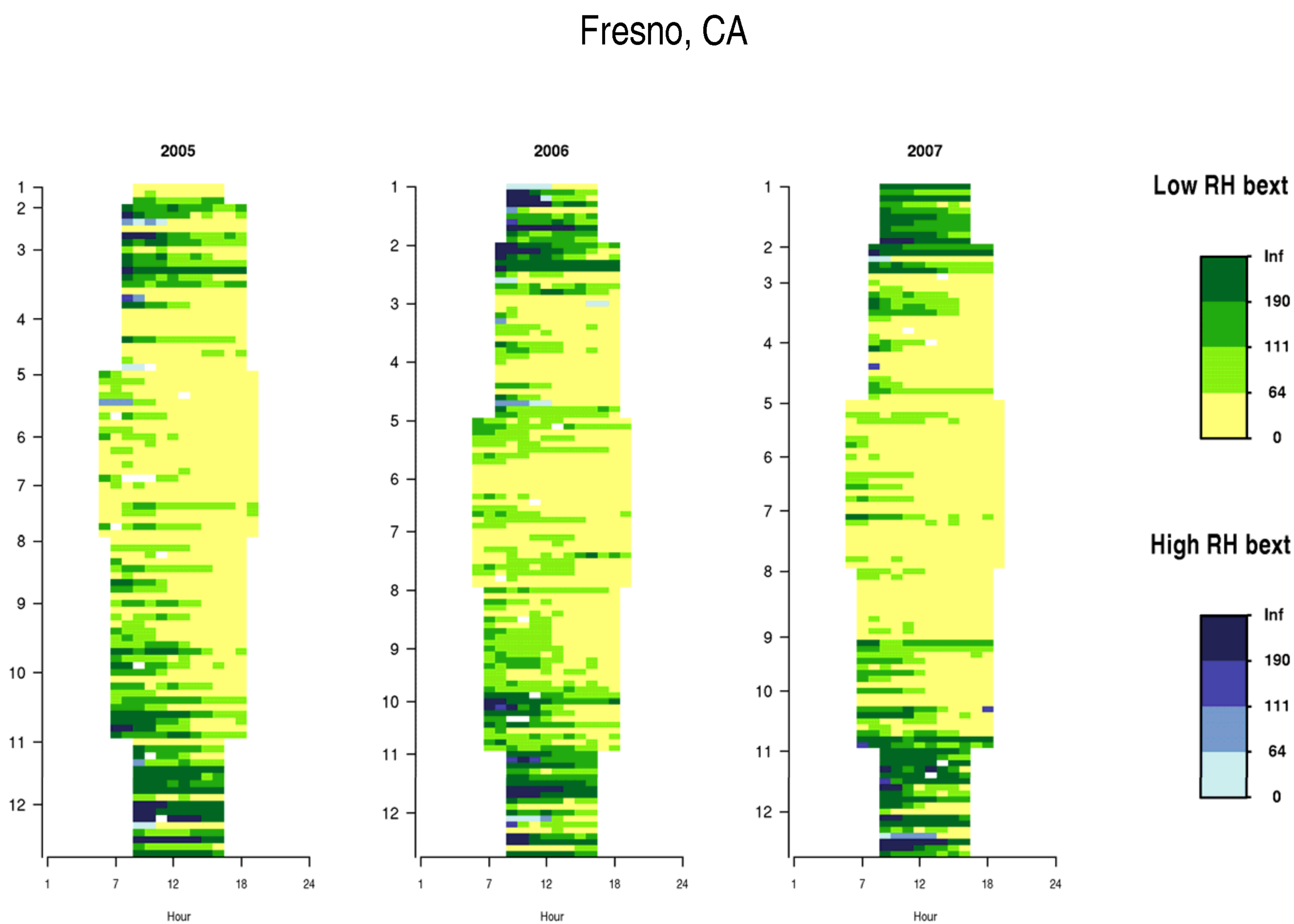


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

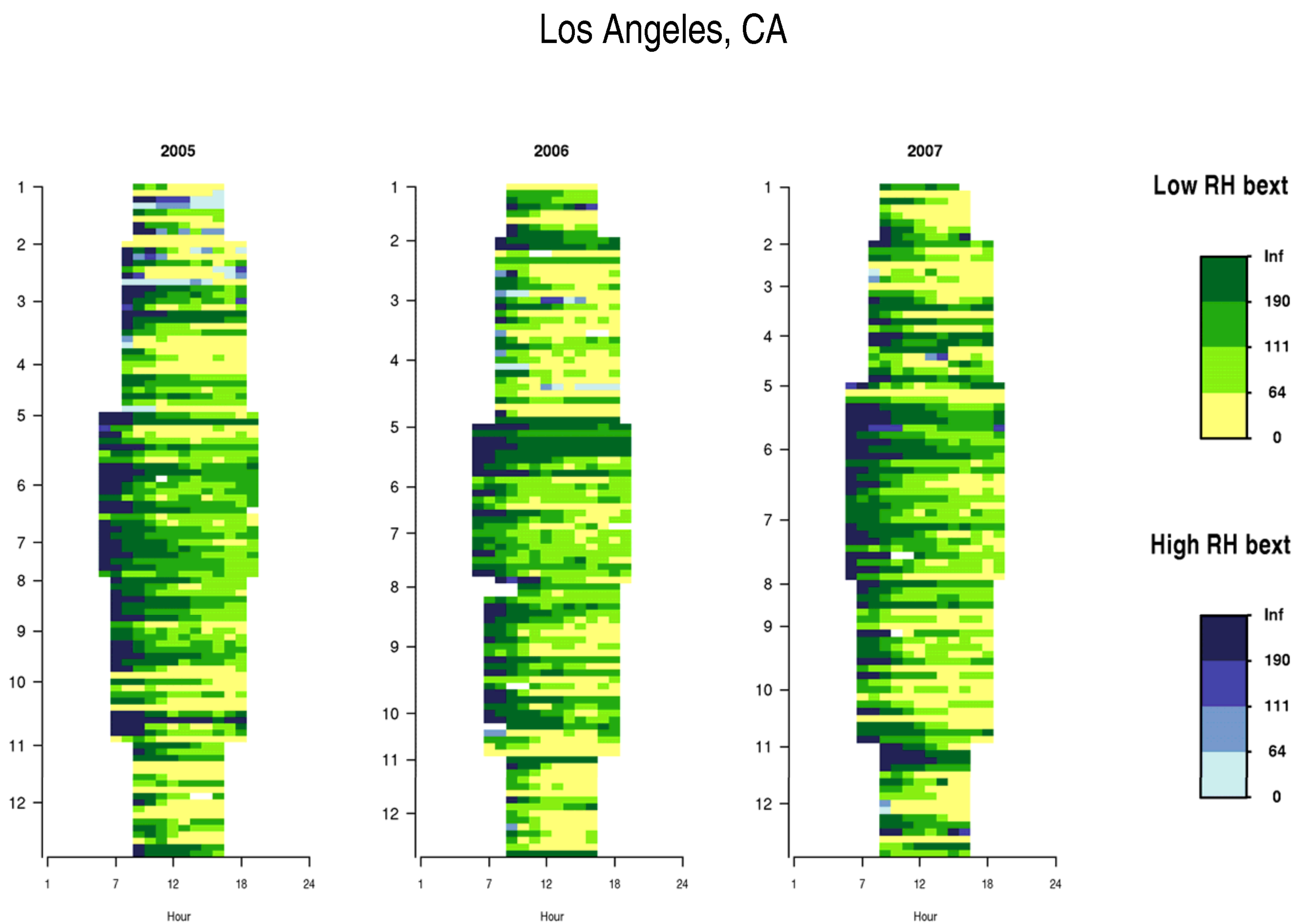


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

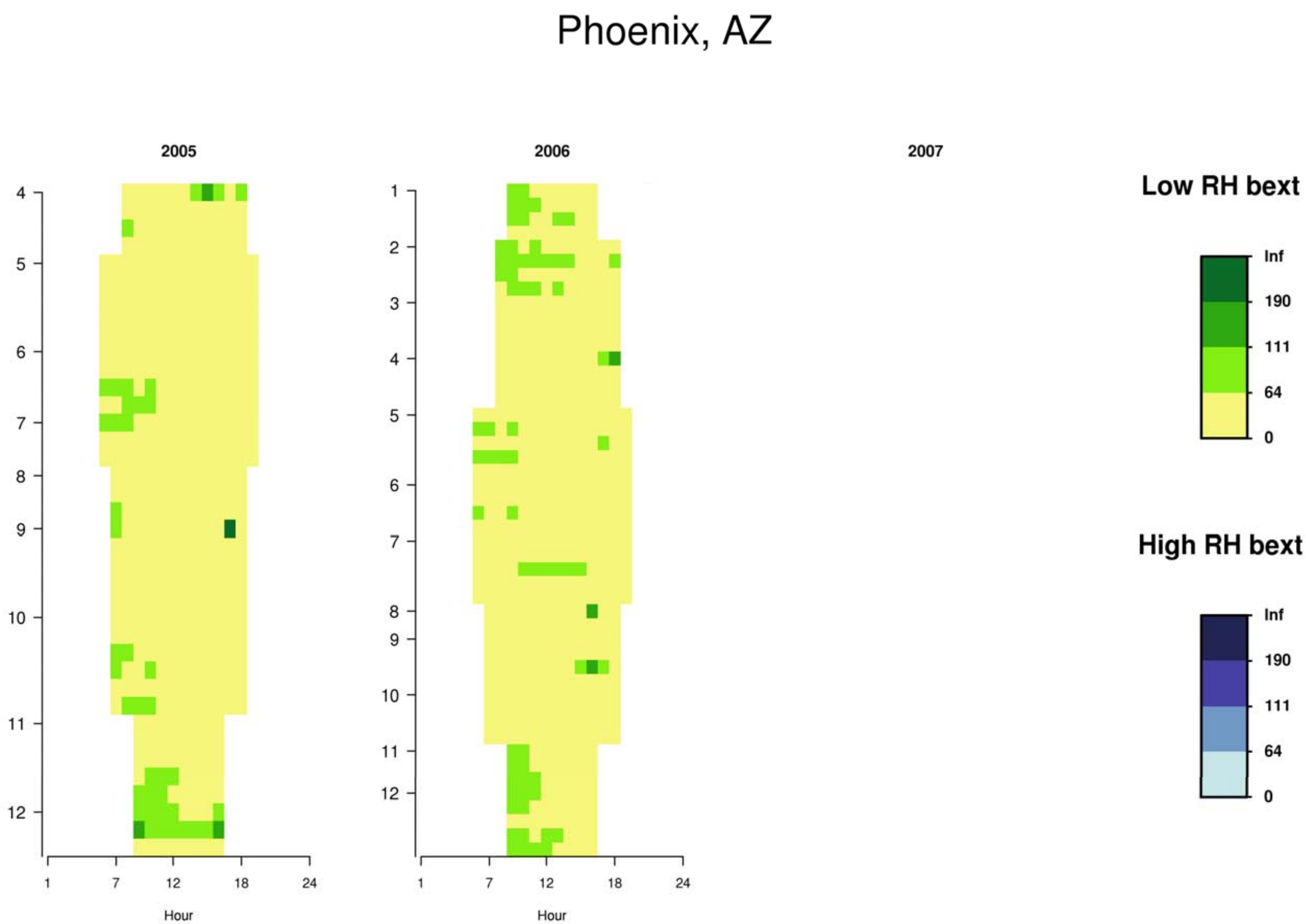


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

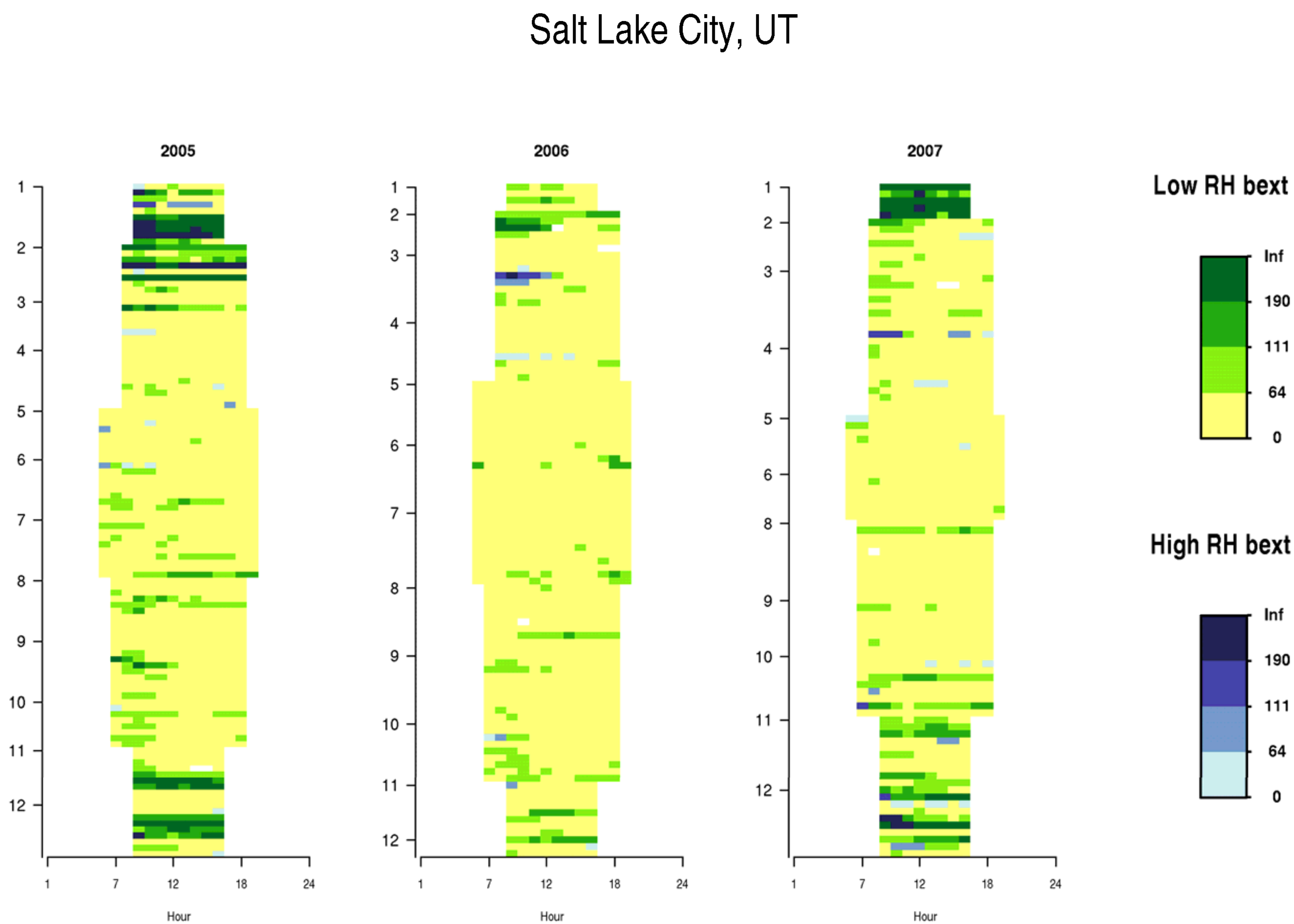


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

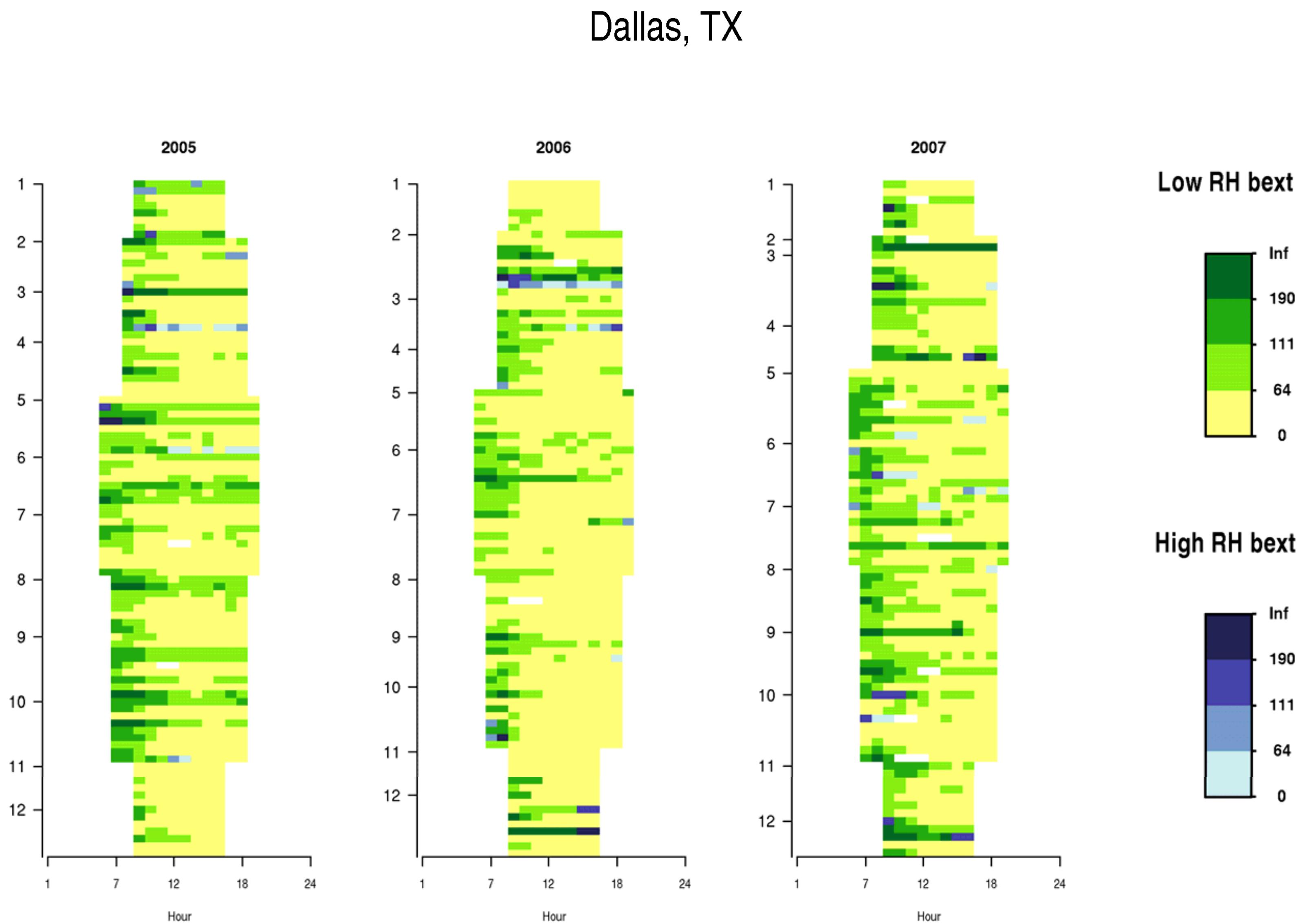


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

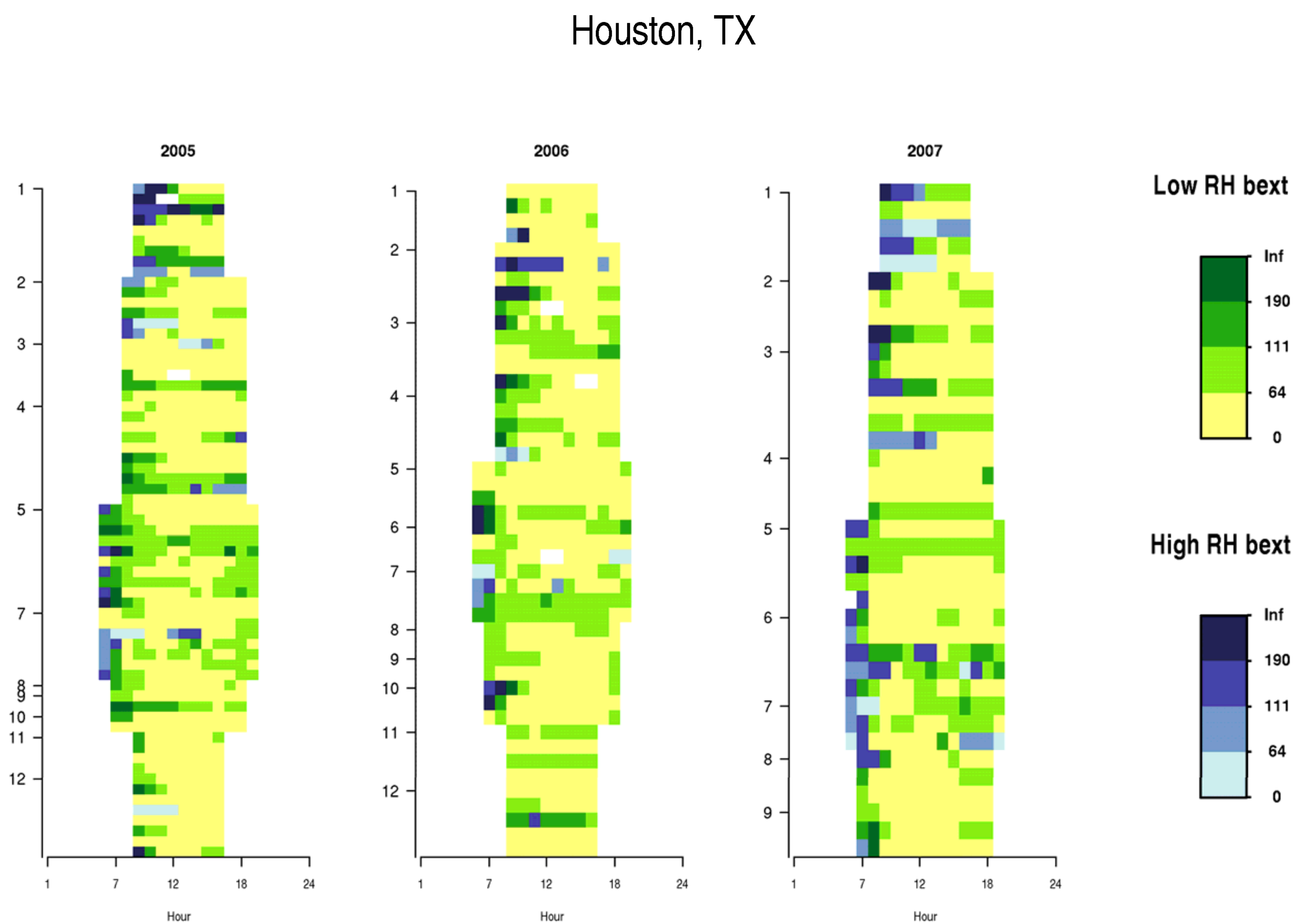


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

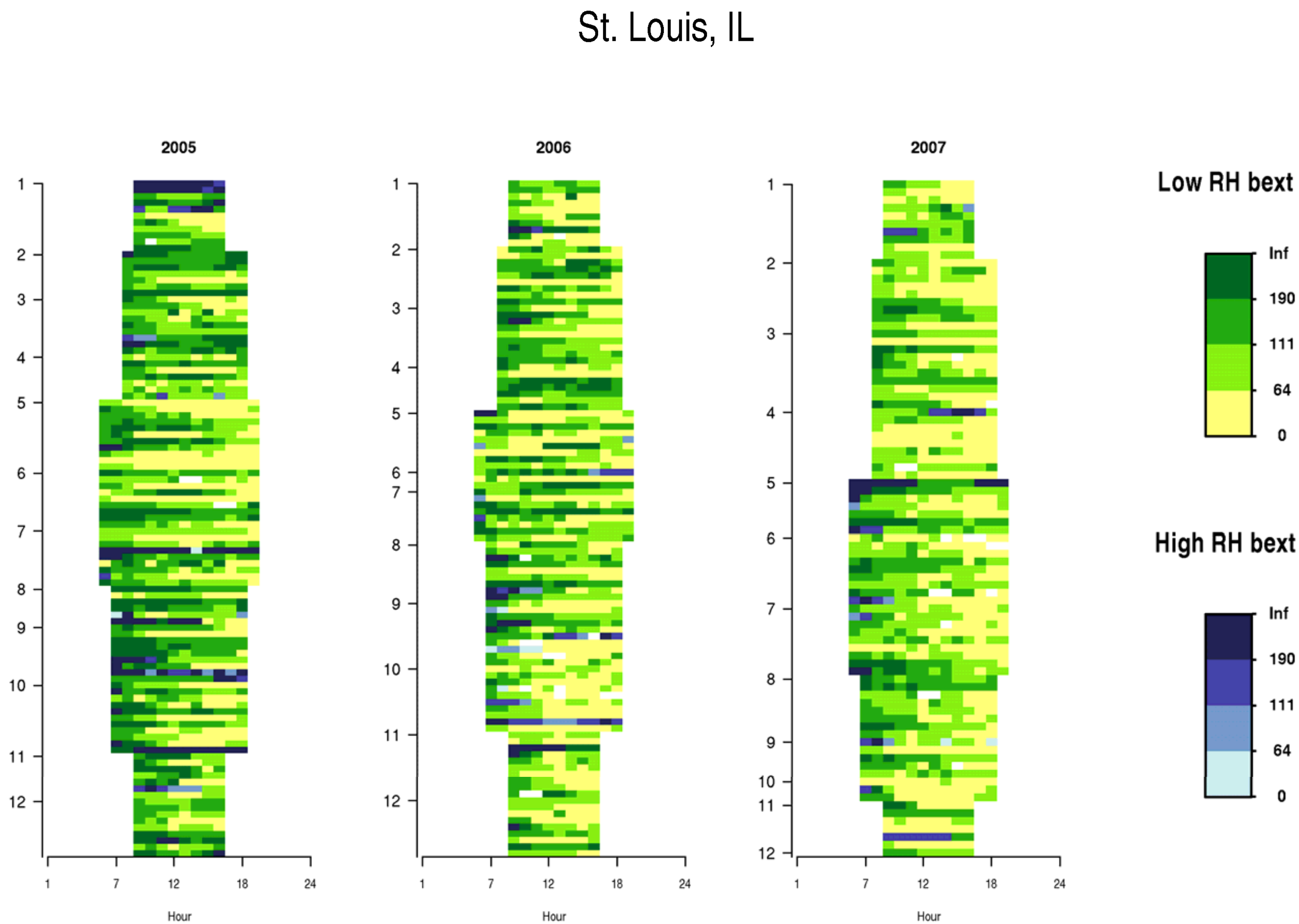


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

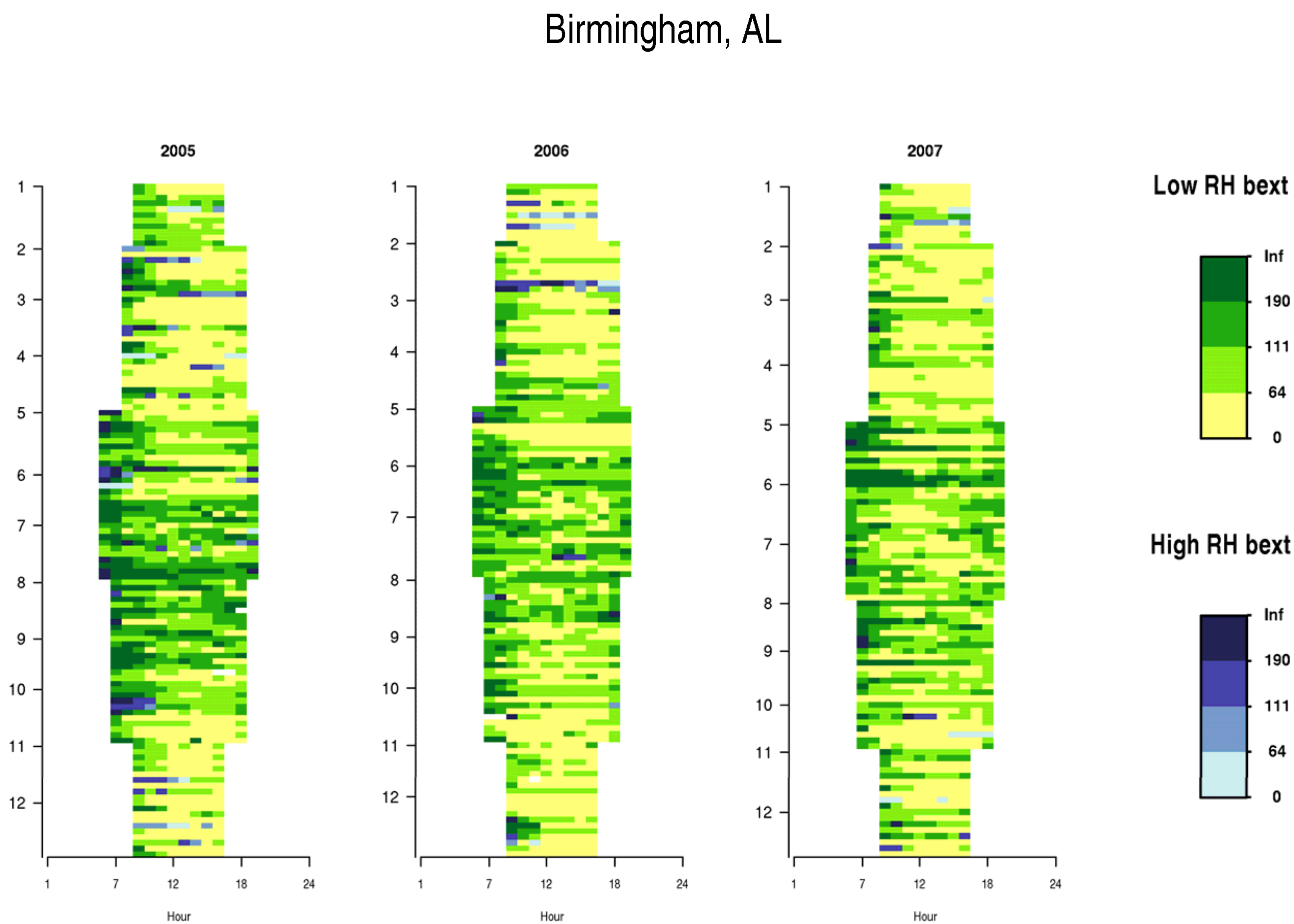


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

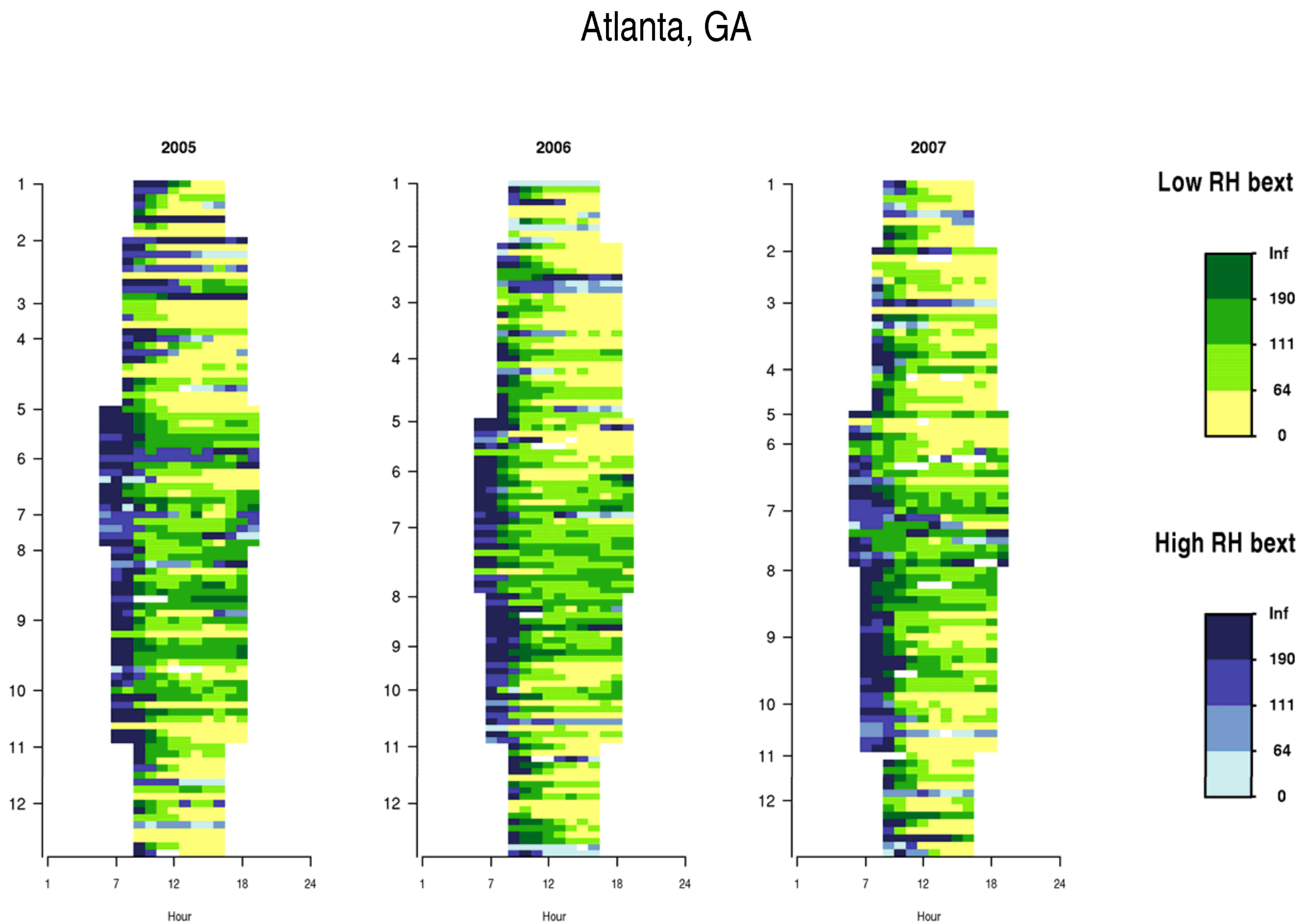


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

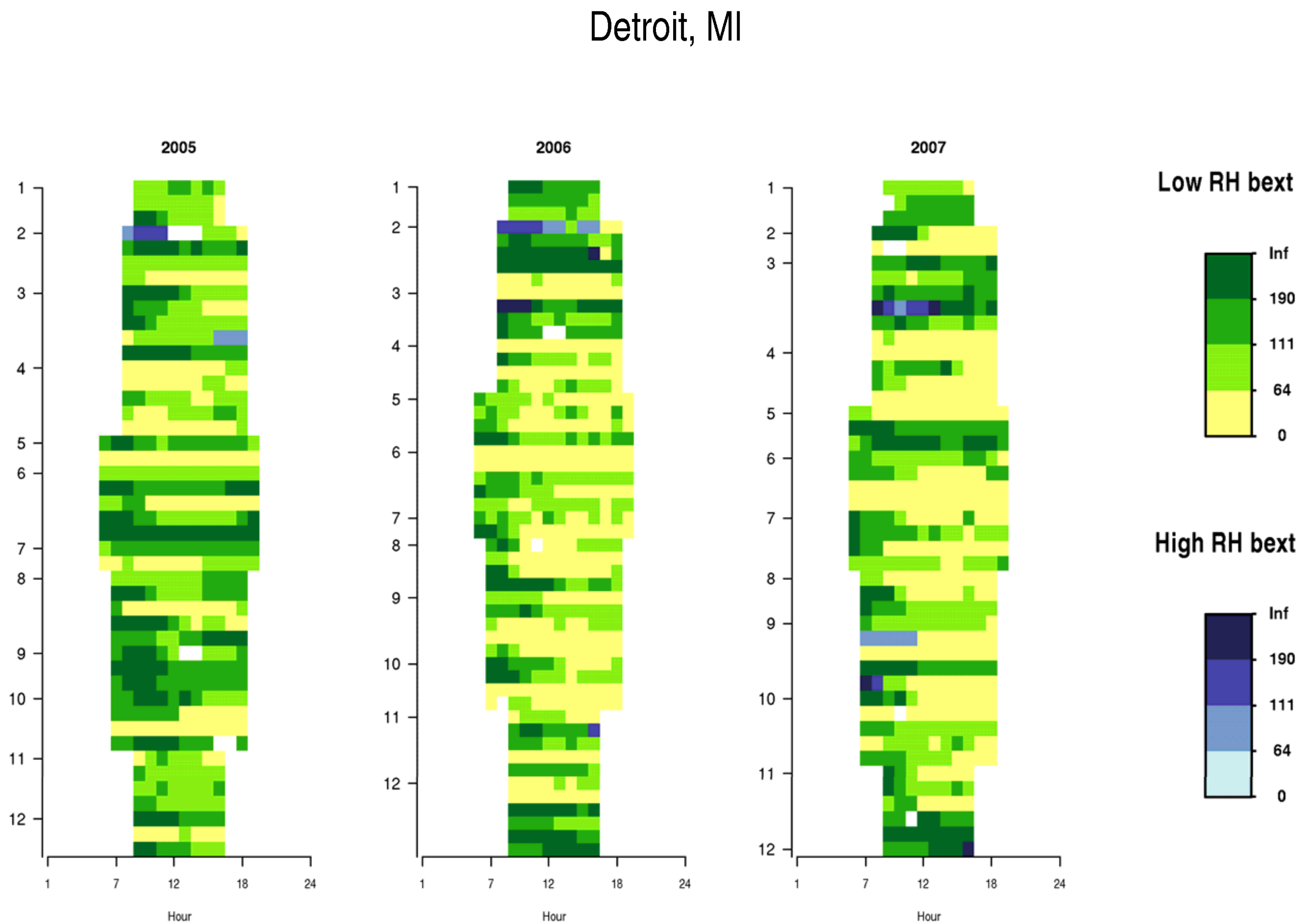


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

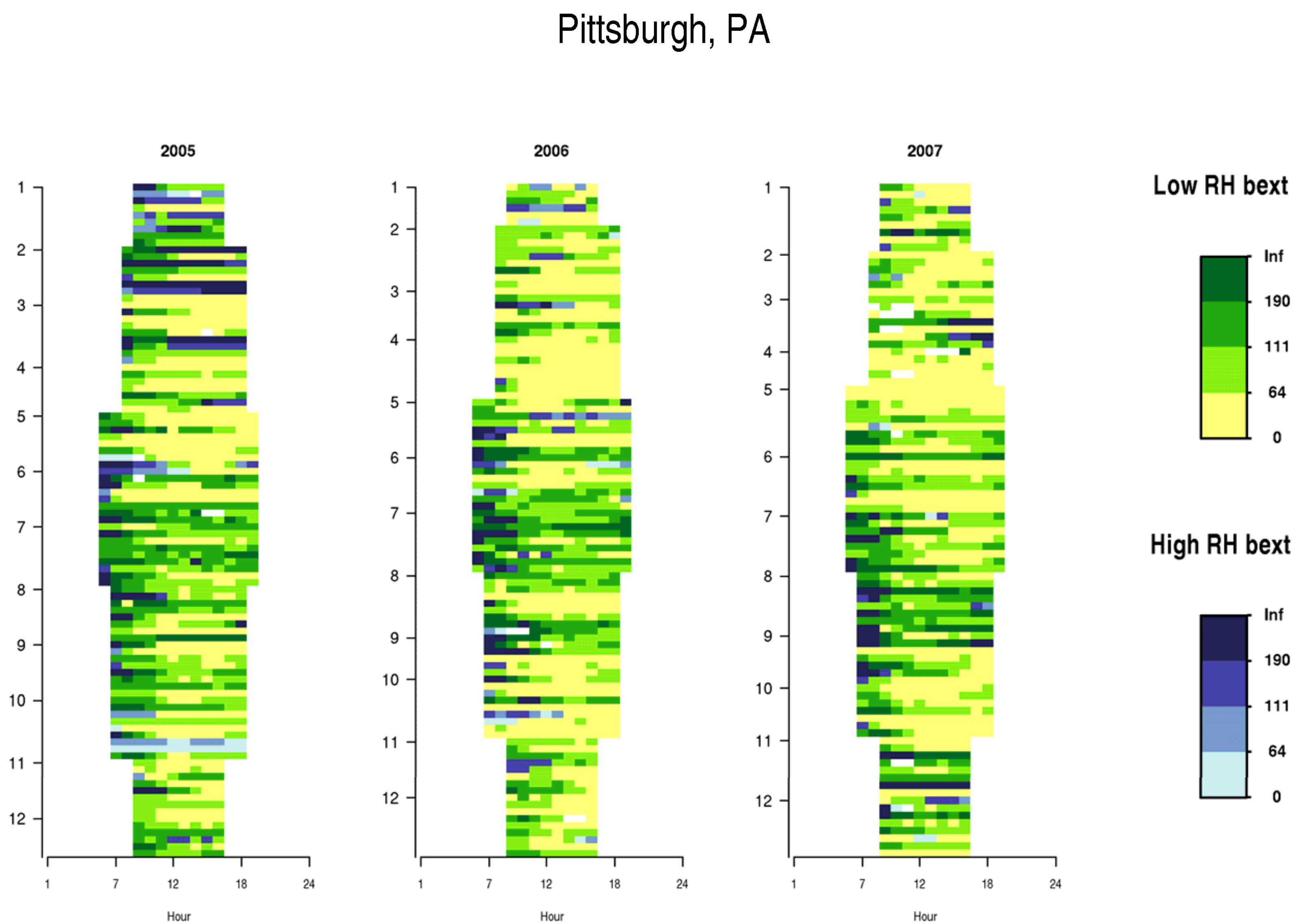


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

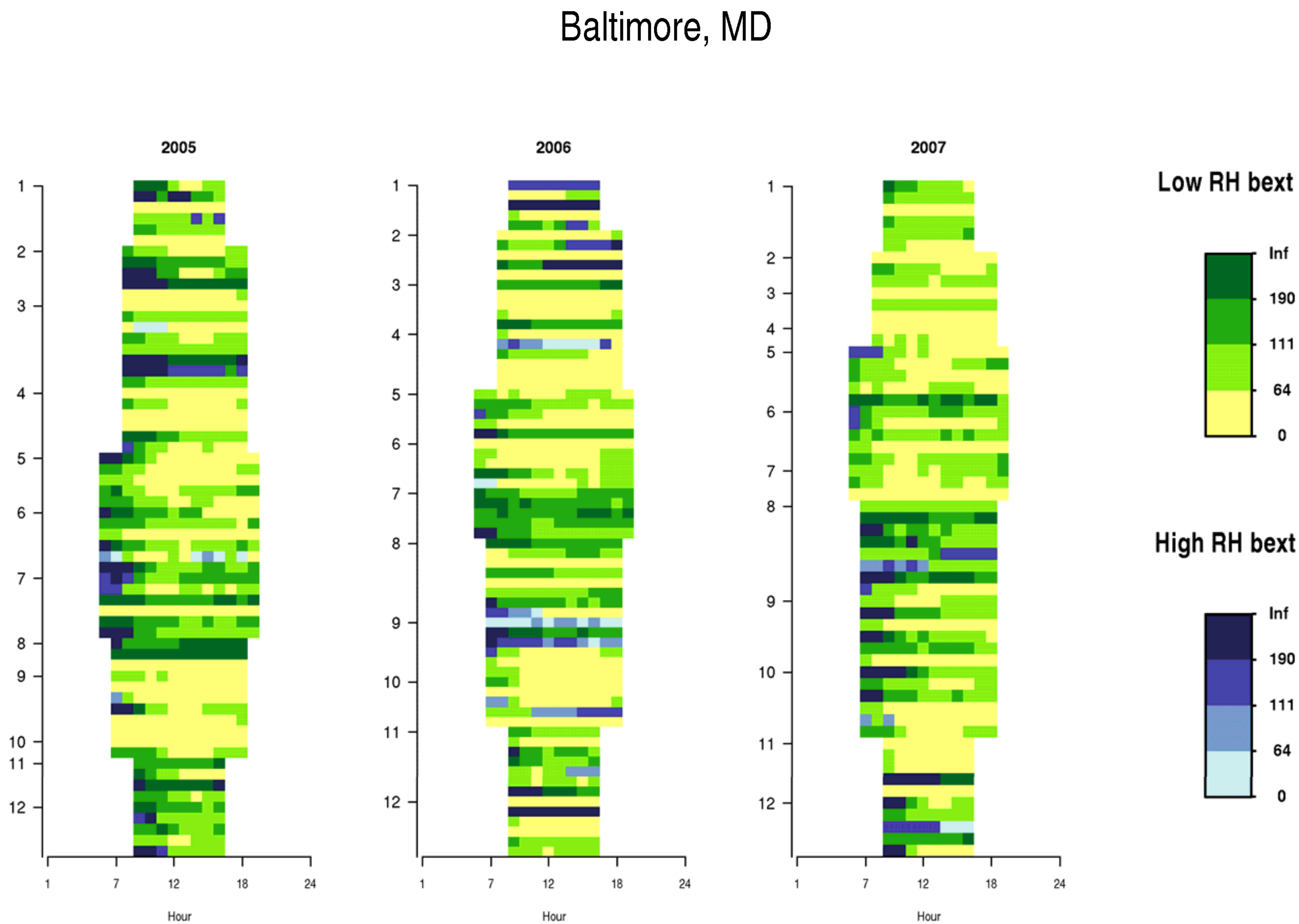


Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

Figure 3-12. Tile Plots of Hourly PM_{10} Light Extinction, continued

3.4.5 Extinction Budgets for High PM_{10} Light Extinction Conditions

An extinction budget for a single period shows the contribution that each PM component makes to PM_{10} 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 pollutants cause poor urban visibility and what emission reduction approach may be most effective in reducing PM_{10} light extinction.

Figure 3-13 presents (a) day-specific maximum daylight 1-hour PM_{10} light extinction budgets for the 10 percent of the days in each study area that have the highest daily maximum 1-hour PM_{10} light extinction levels (excluding hours with relative humidity greater than 90 percent), and (b) light extinction budgets for the greatest 2 percent of all individual daylight hours with the same relative humidity restrictions. The day and hour of each hourly budget are indicated on the horizontal axis, and the hours are arranged chronologically. Note that the vertical scale differs from city-to-city, to accommodate the wide variation in PM_{10} light extinction values.

Since there is an annual average of about 10 daylight hours per day [29], there are approximately twice the number of hours (i.e., bars in the plots) included in the top 2% of all daylight hours form compared to the number of hours in the top 10% of the daily maximum 1-hour form. The rationale for pairing the top 10% of the maximum daily 1-hour PM_{10} light extinction form with the top 2% of all hours PM_{10} light extinction form was the similarity of the design values for the 90th and 98th percentiles for each form, respectively,, as discussed in Chapter 4 (see Table 4-2 and Figure 4-1). In each of these plots the height of the shortest bar is the PM_{10} light extinction design value associated with the selected form (e.g., the smallest value in the top 2% of all hours corresponds to the design value of the 98th percentile of all hours form). The largest light extinction value in each pair of plots is identical, representing the single largest daylight hour value for the city. As a result, the ranges of bar heights for each city's pair of plots are approximately the same.

The paired extinction budget plots in Figure 3-13 provide a means to examine the similarities and differences between the PM components that contribute to the daylight hours with the greatest PM_{10} light extinction as identified by the two forms. Though for each city there are twice the number of hours selected by the 2% of all hours form compared to the 10% of maximum daily form, the relative component contributions are generally quite similar. Much of the reason for this similarity of the extinction budgets between forms has to do with the selections of the same hours by both forms and having the additional hours for the 2% form

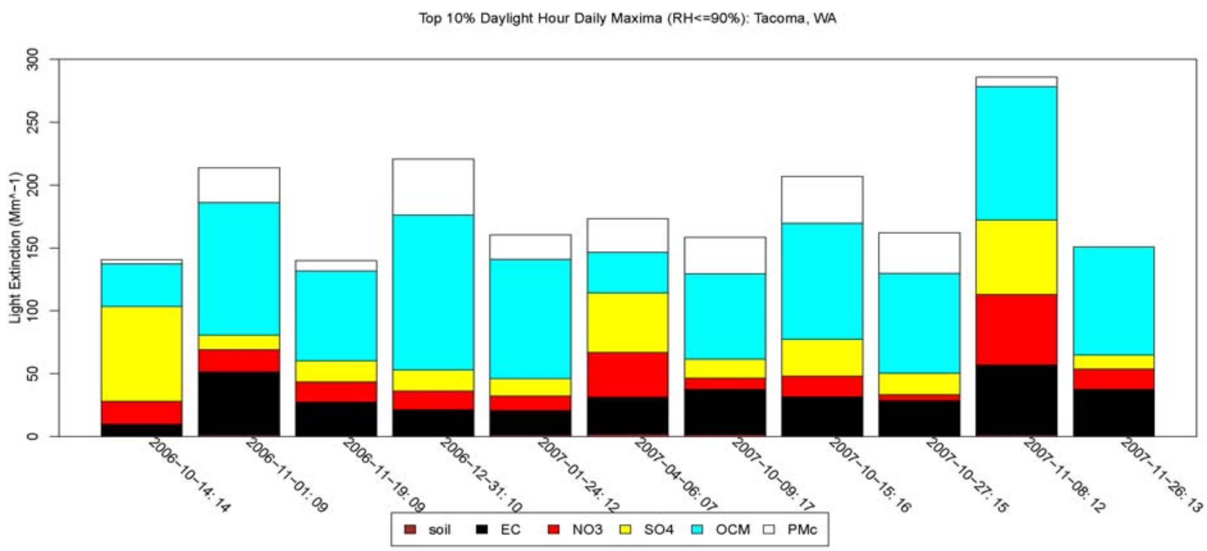
[29] Daylight hours are determined for this assessment as described in section 3.3.4 and Appendix I.

coming as multiple (often consecutive) hours in some of the same days that contained the top 10% maximum daily values. These multiple hours generally have similar relative composition. For example notice that among the Tacoma top 2% of all hours, there are four consecutive hours on November 8, 2007, which includes the largest hourly daylight PM_{10} light extinction in the Tacoma dataset.

Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours

Tacoma

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

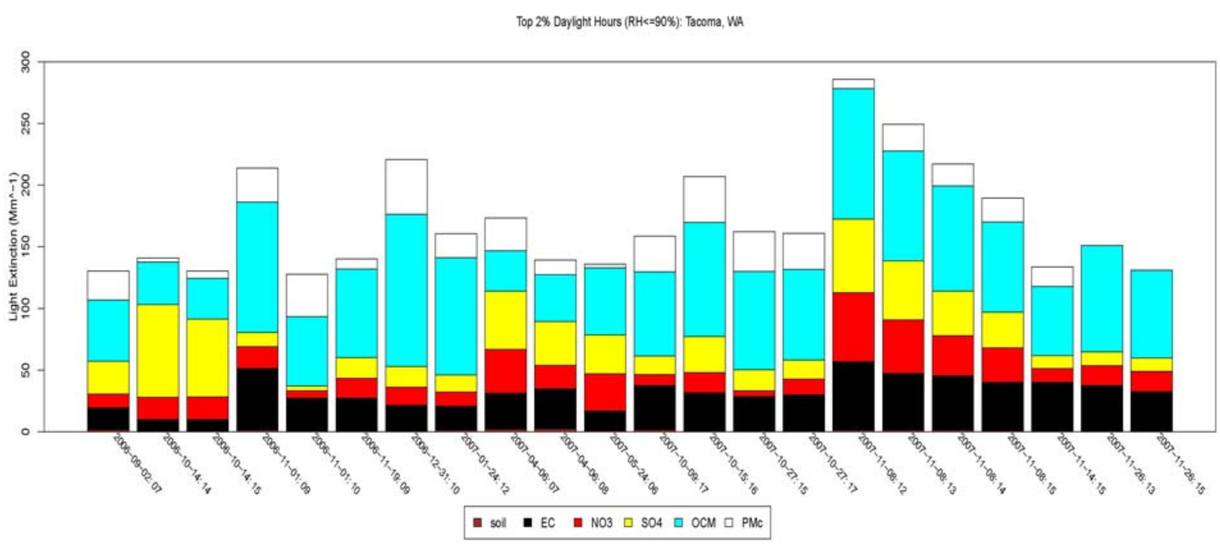
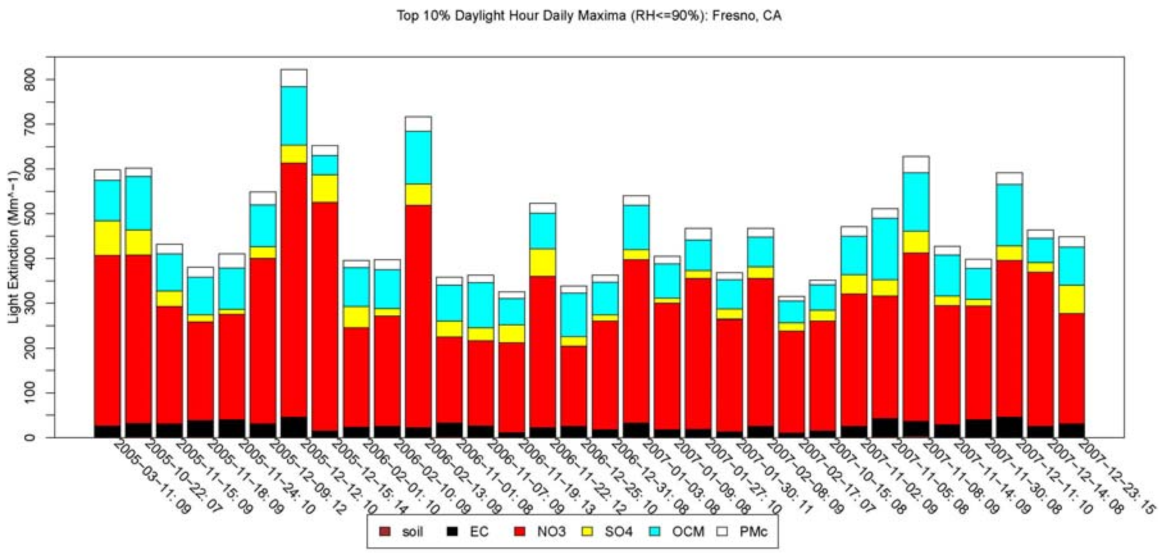


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Fresno

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

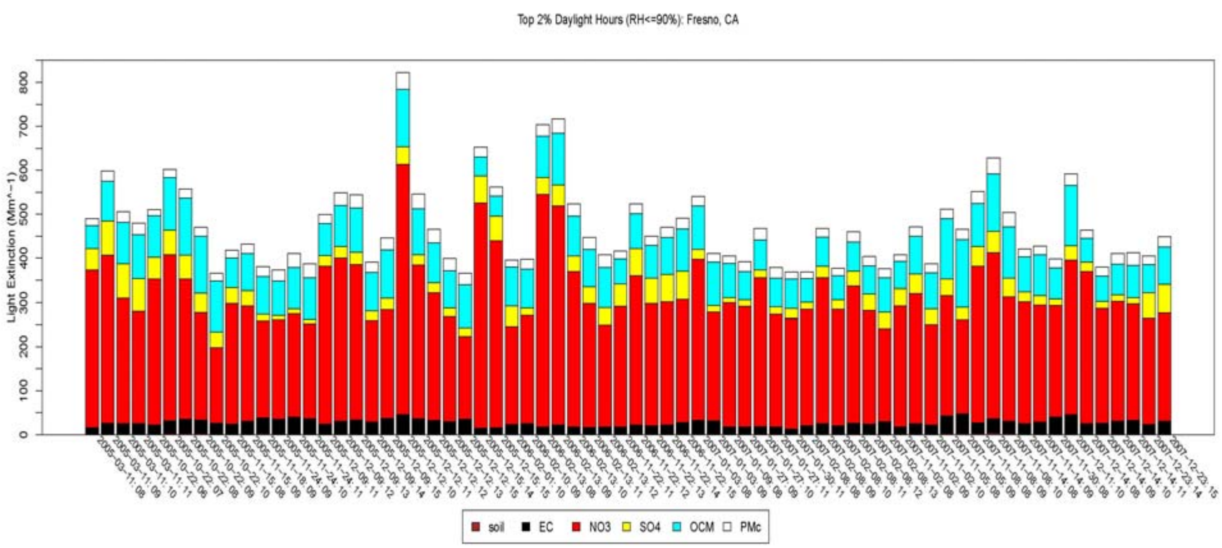
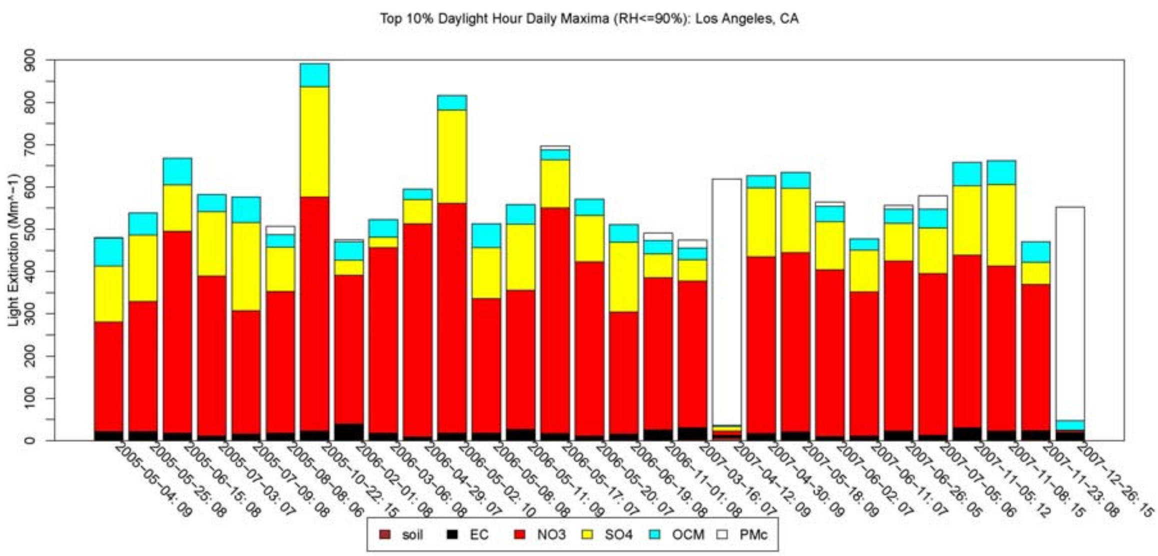


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Los Angeles

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

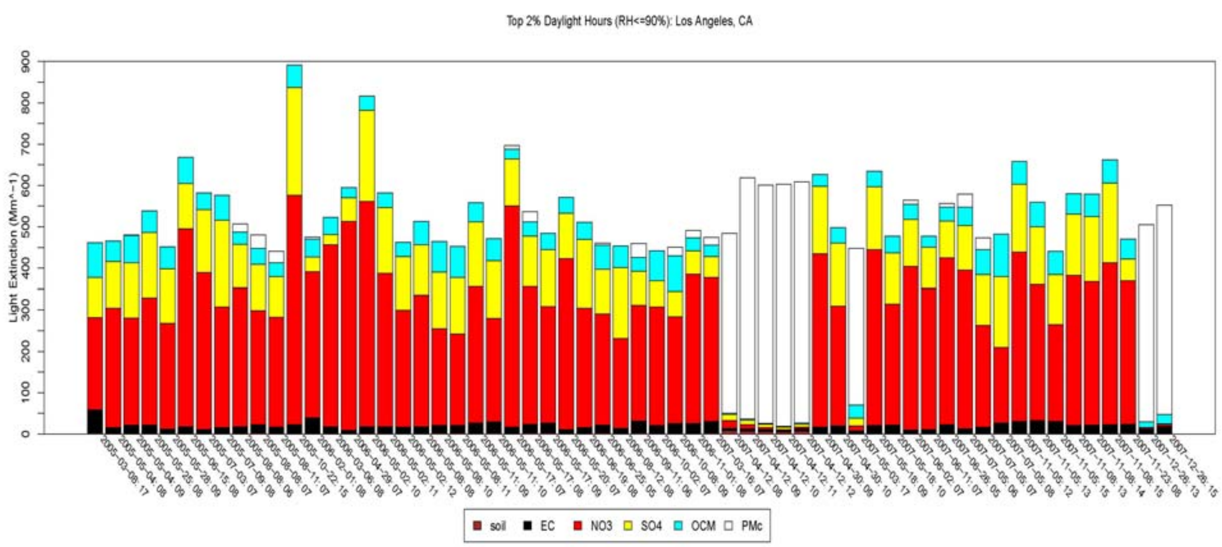
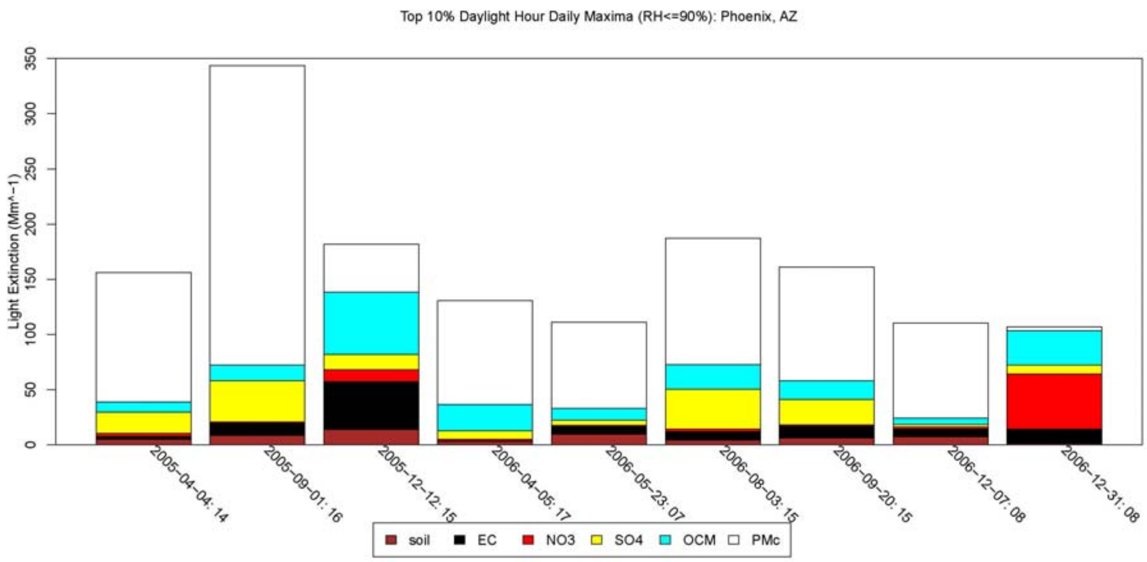


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Phoenix

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

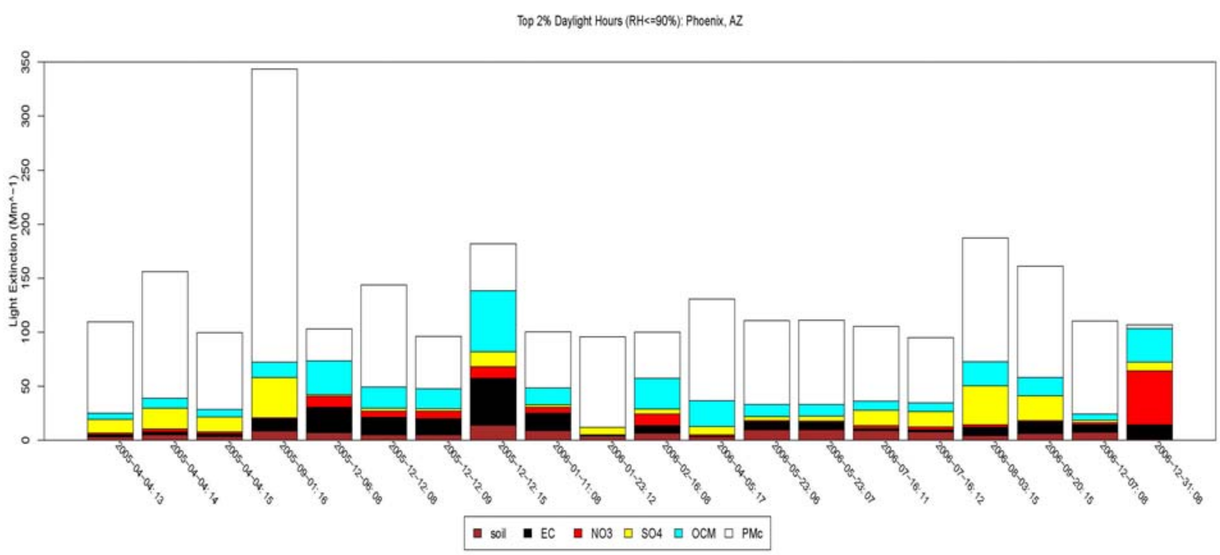
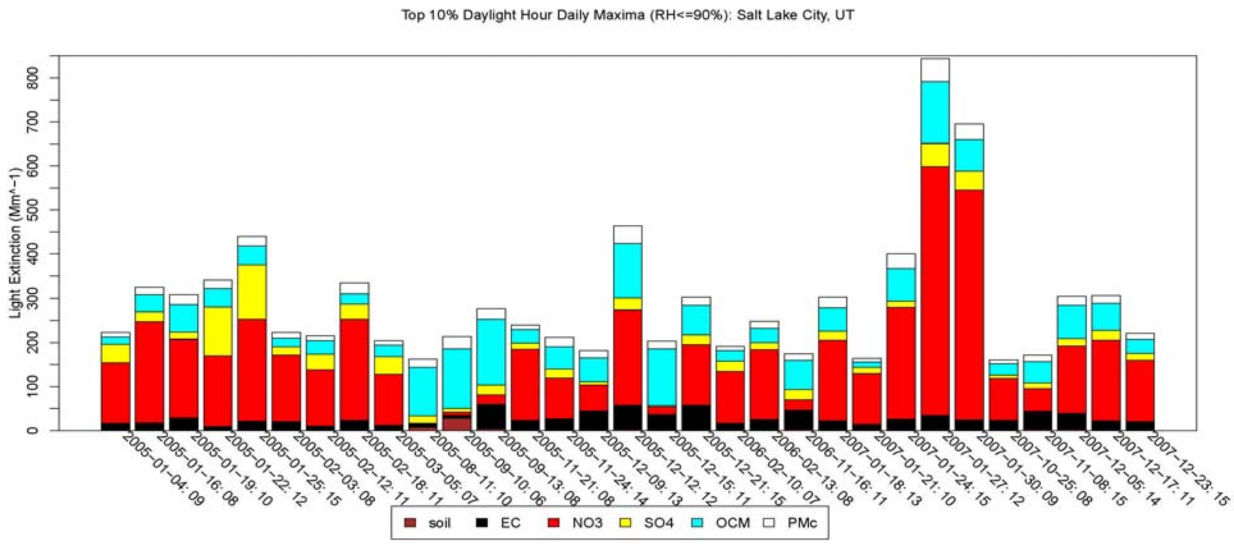


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Salt Lake City

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

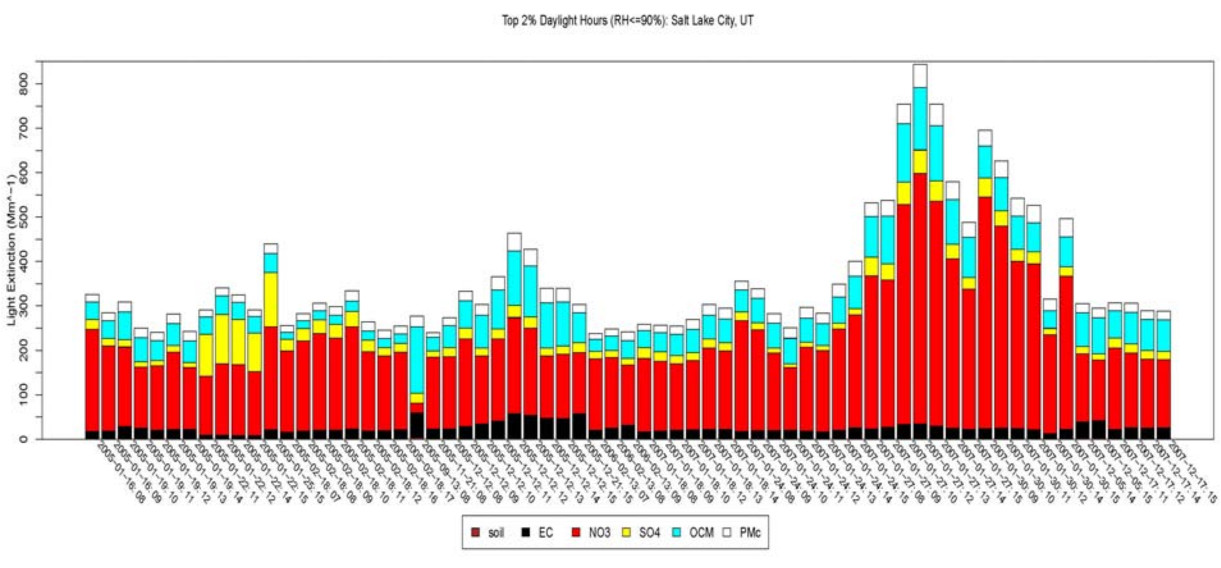
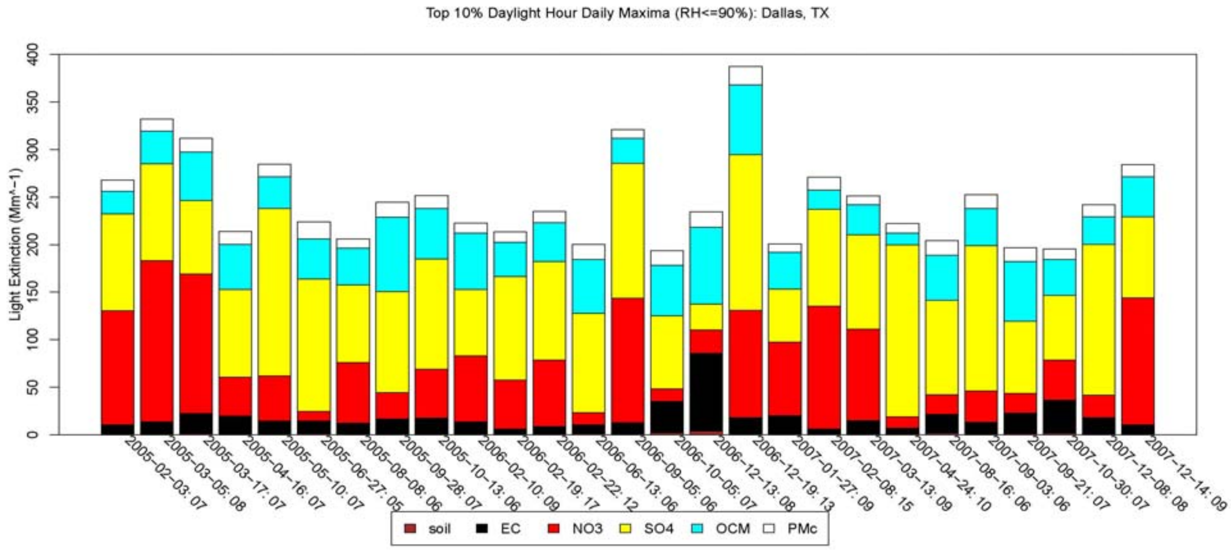


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Dallas

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

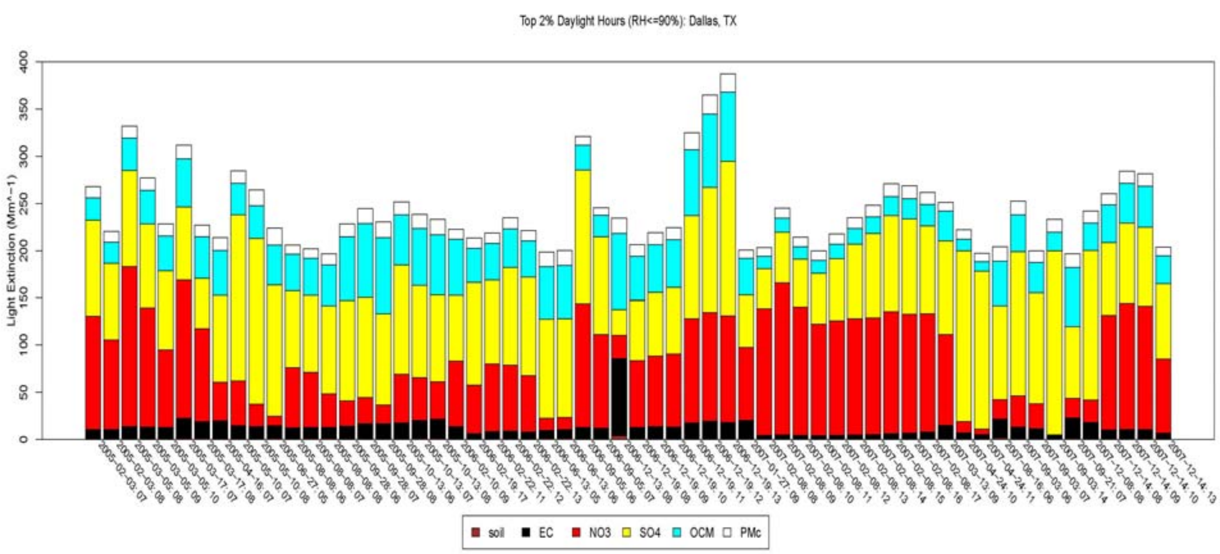
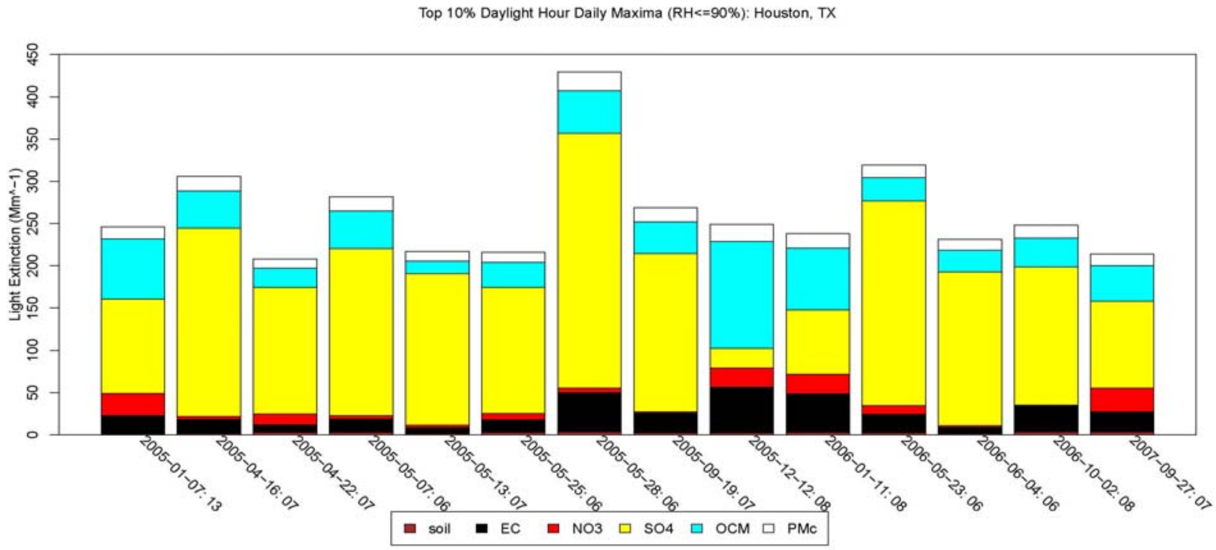


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Houston

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

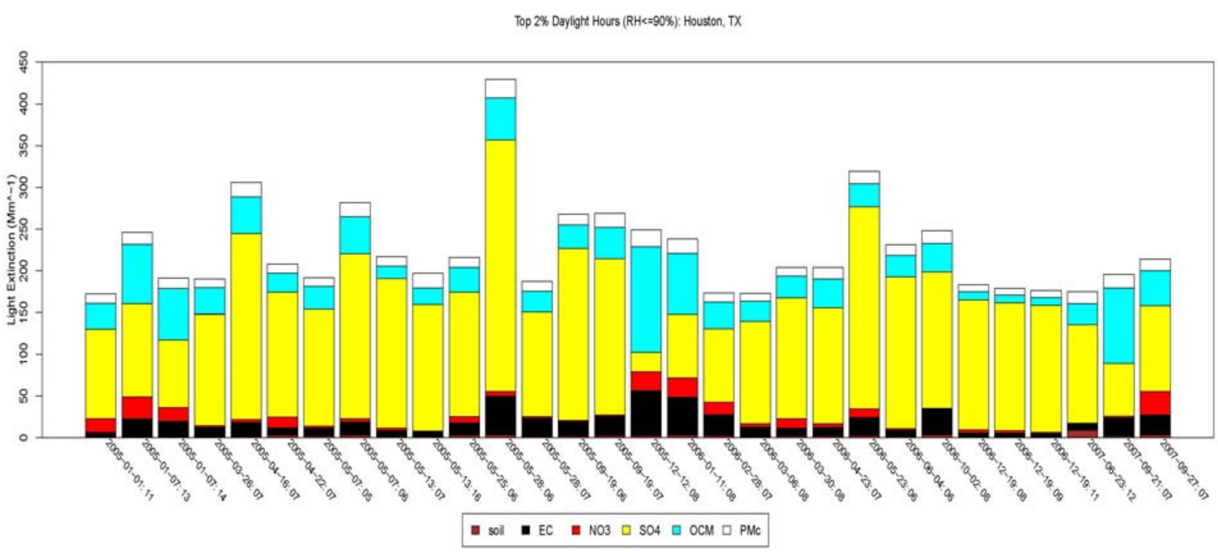
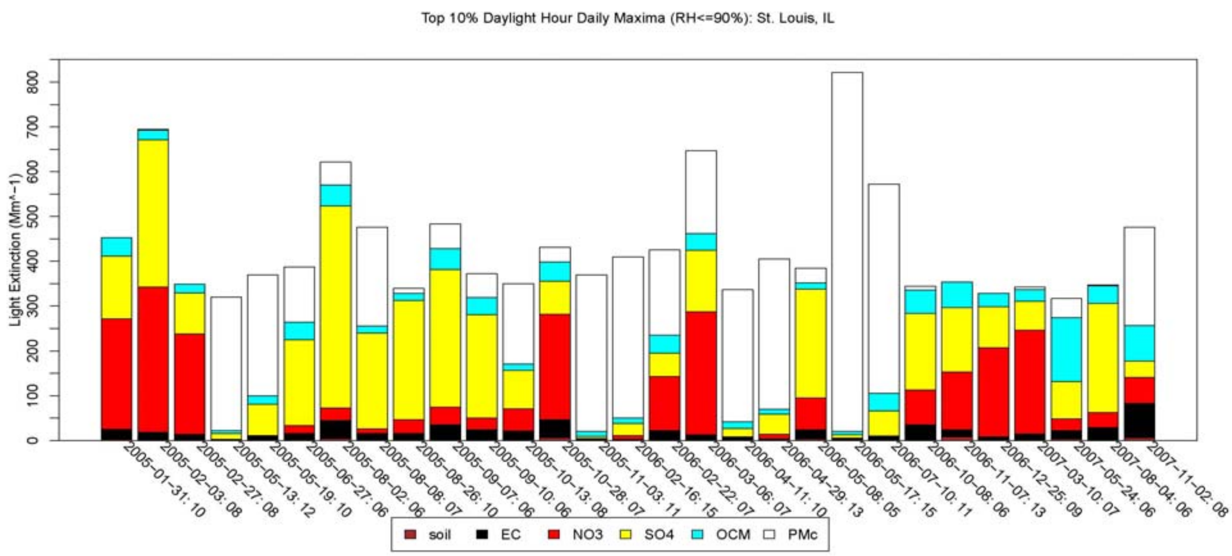


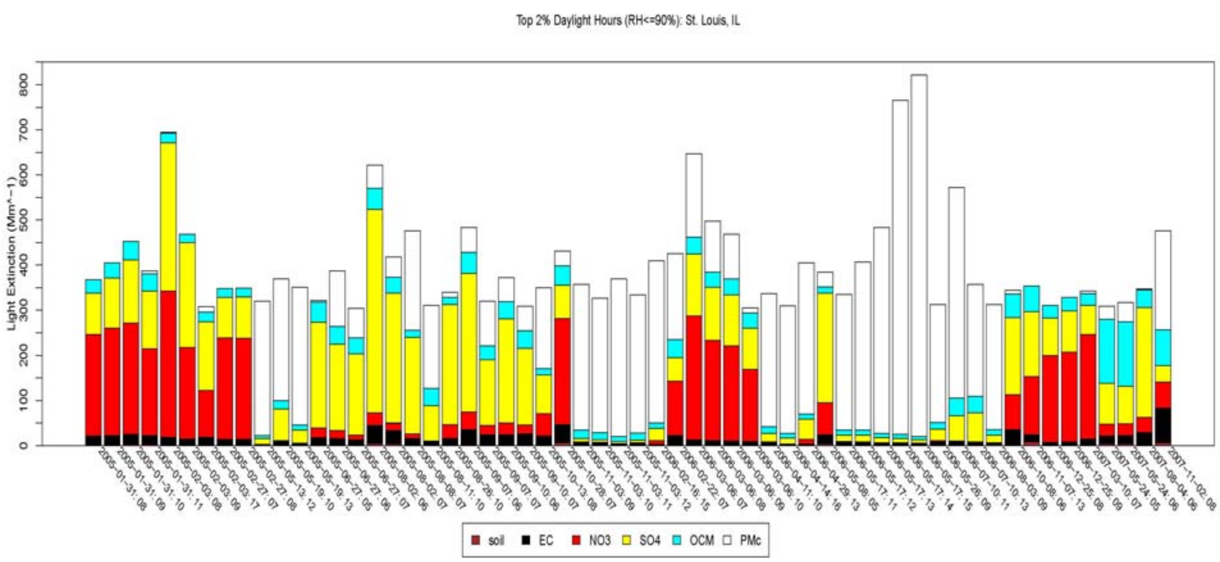
Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

St. Louis[30]

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

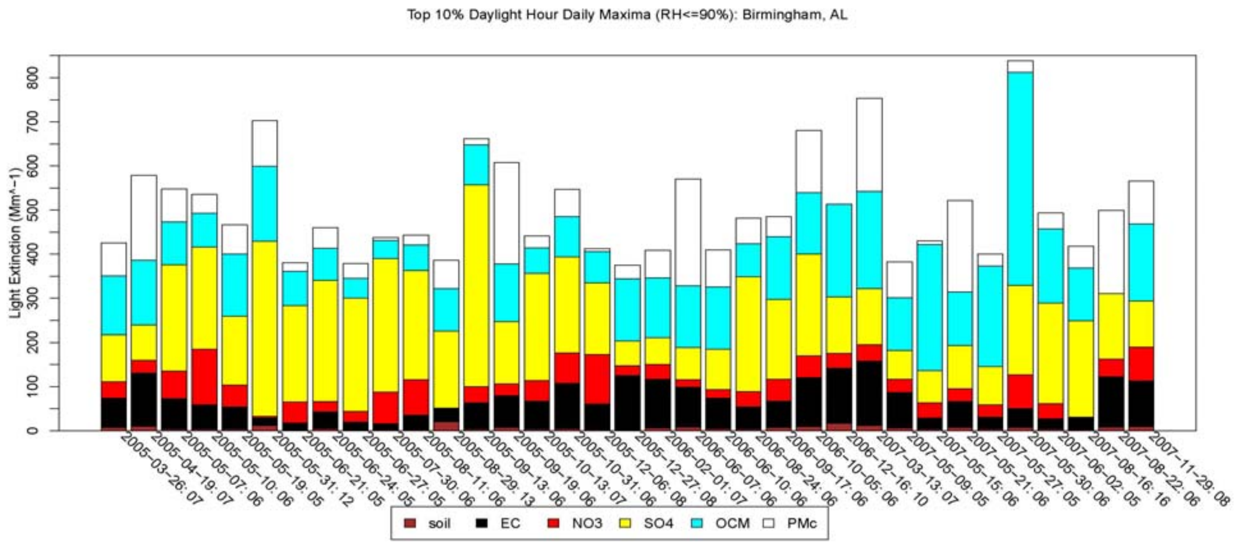


[30] See footnote 10 above regarding concerns with respect to the St. Louis results.

Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Birmingham

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

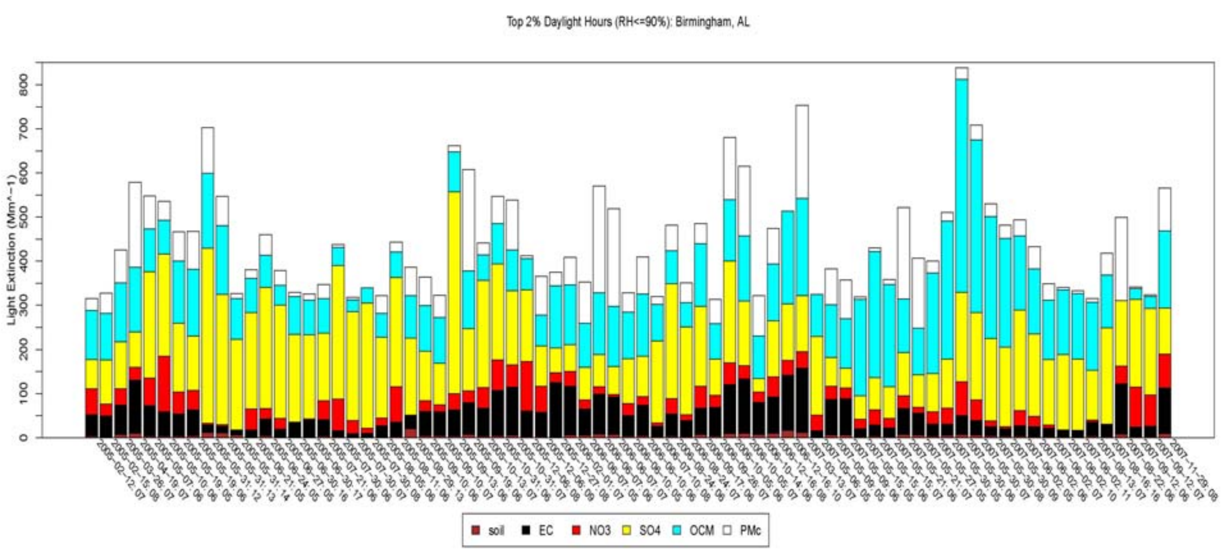
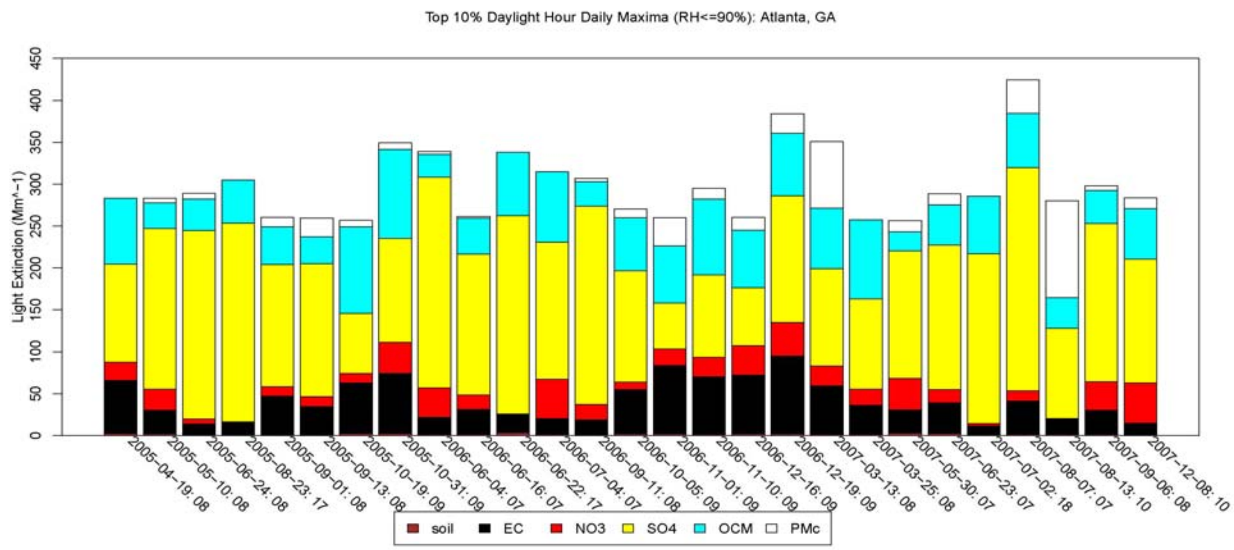


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Atlanta

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

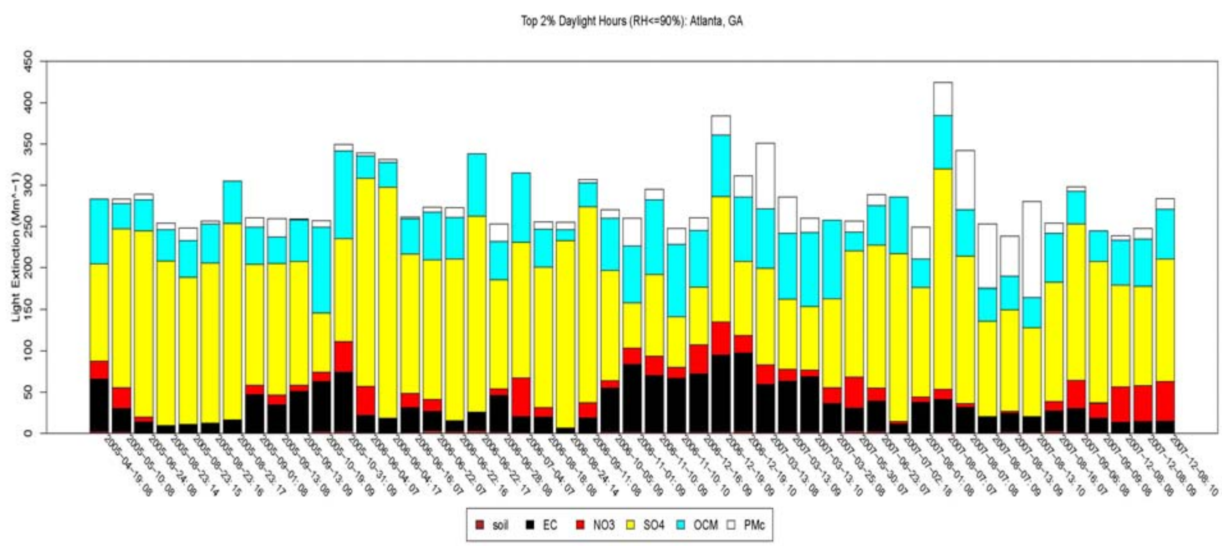
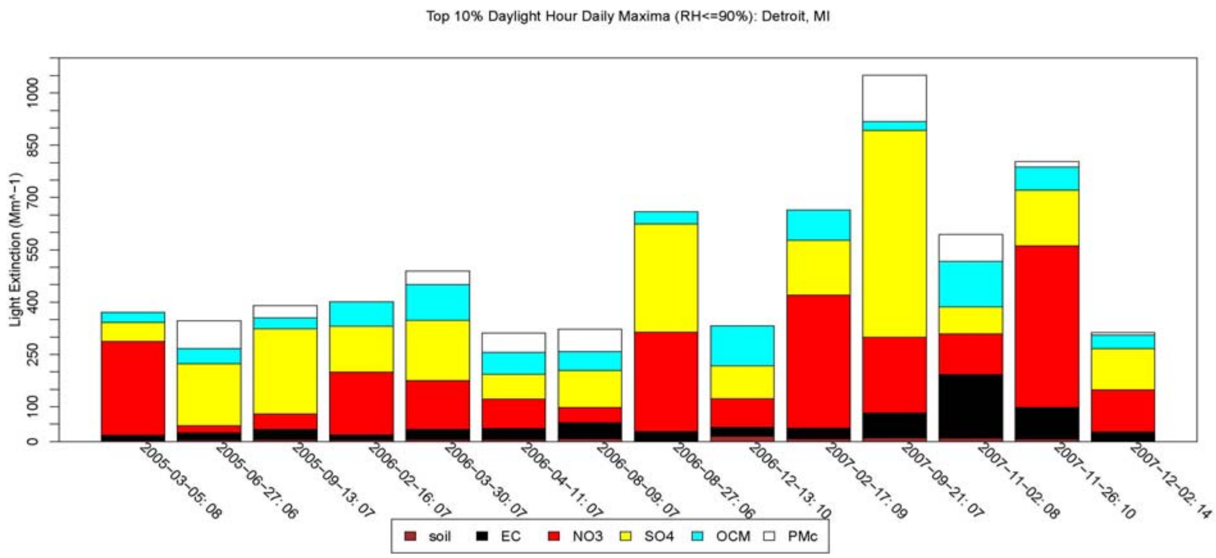


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Detroit

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

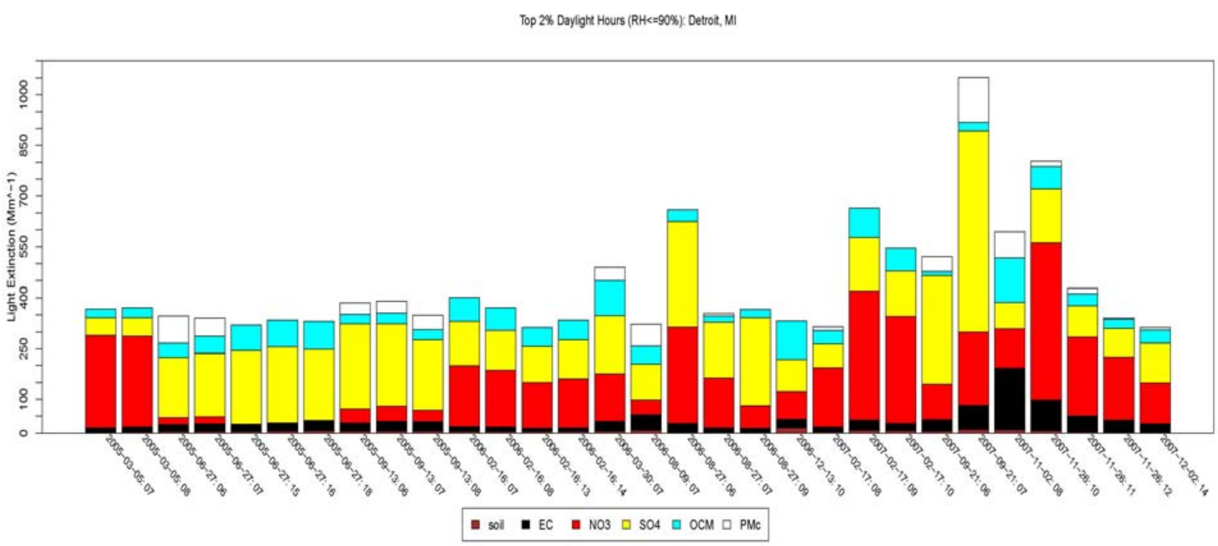
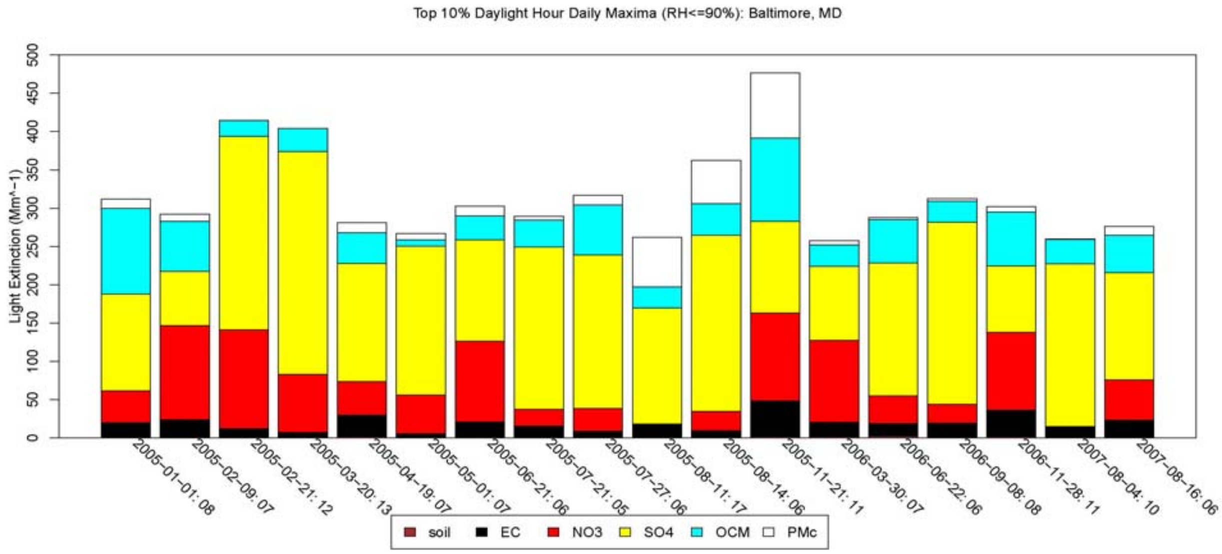


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Baltimore

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

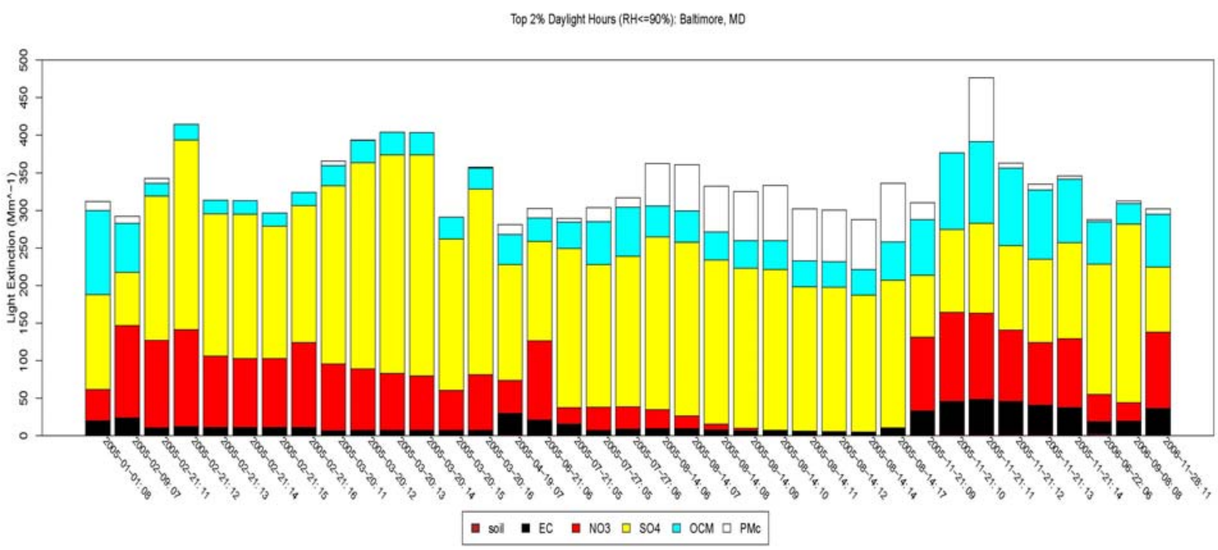
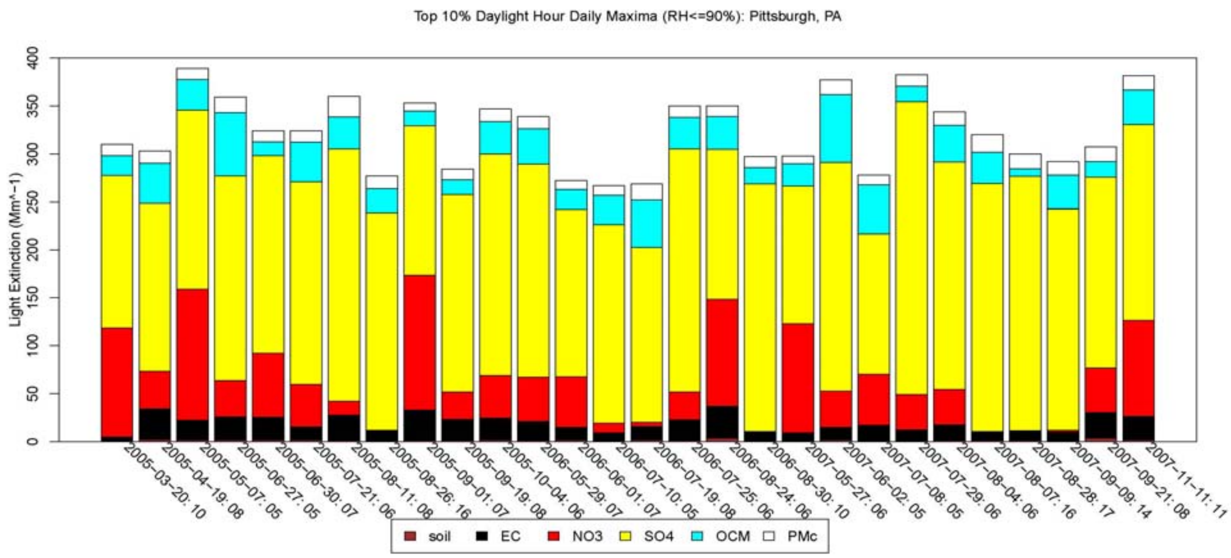


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Pittsburgh

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

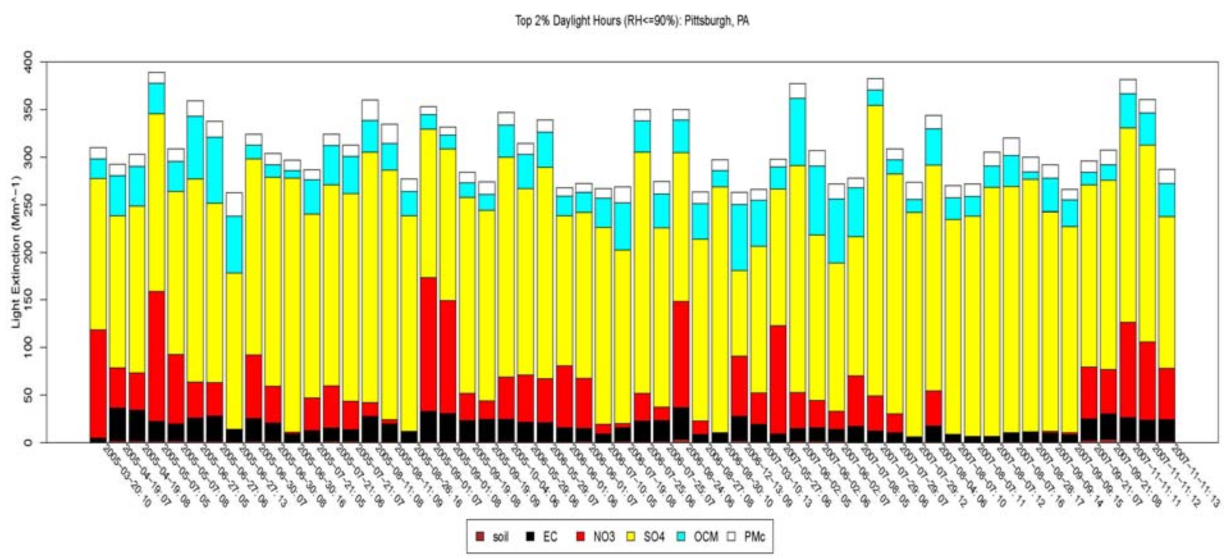
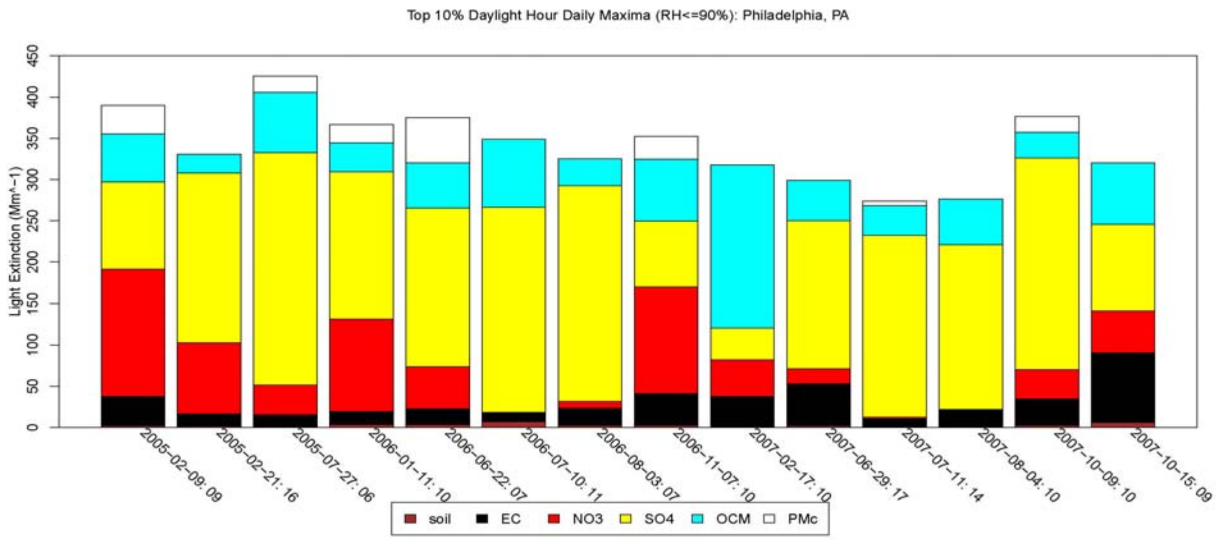


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

Philadelphia

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

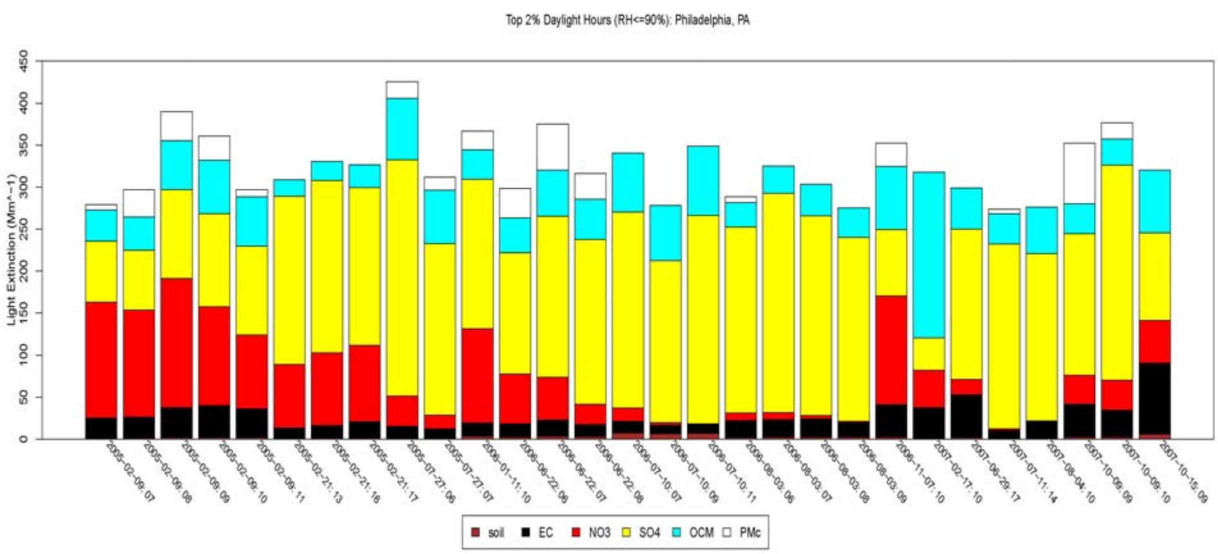
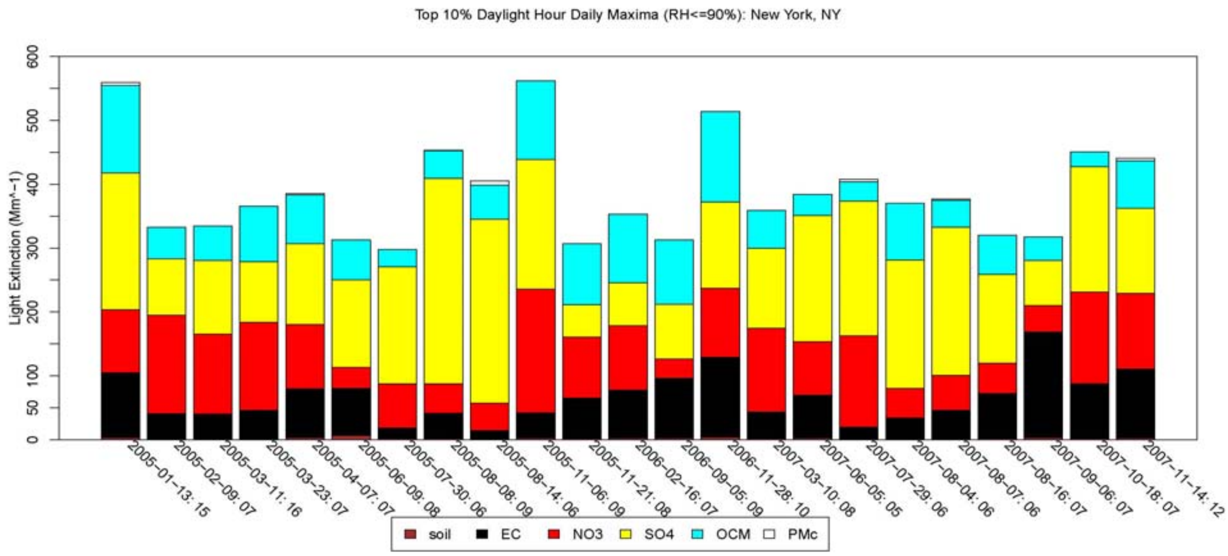


Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction and for the Top 2 Percent of Individual Daylight Hours, continued

New York

(a) Top 10 Percent of Days for Maximum Daily 1-Hour PM_{10} Light Extinction



(b) Top 2 Percent of Individual Daylight Hours

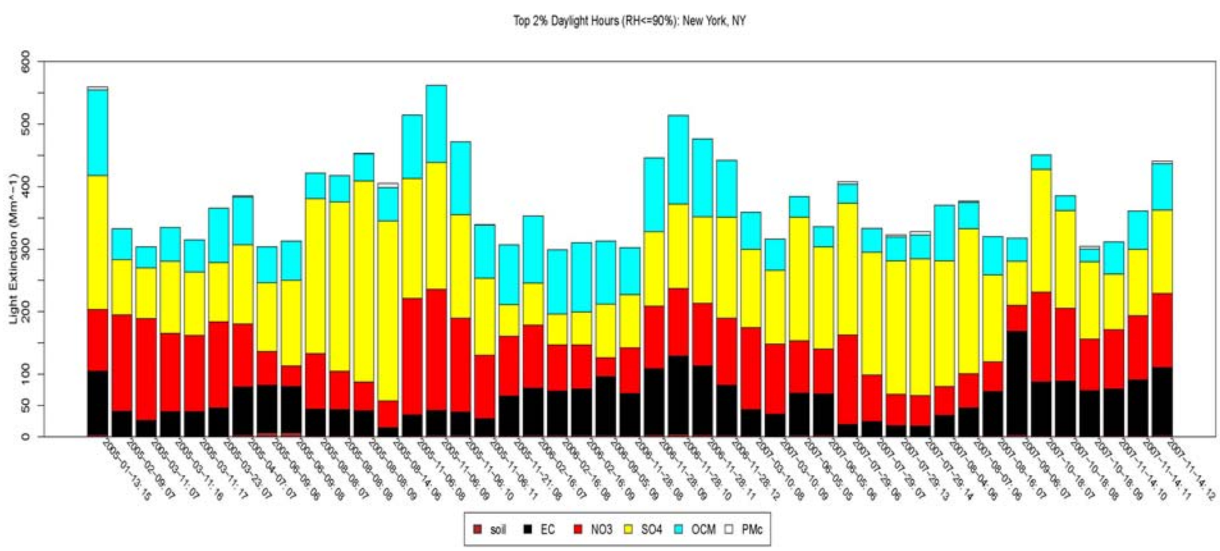


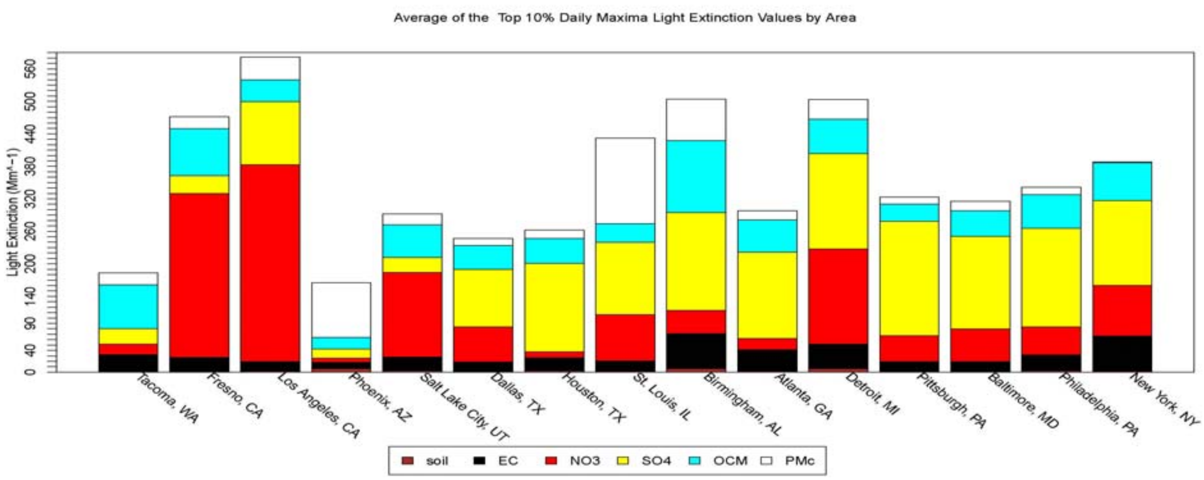
Table 3-8 shows the numbers of common and unique days selected across the two forms as well as the numbers of days selected by each form. All of the cities have more common than unique day selected by the two forms. Salt Lake City has the highest fraction of unique days, so it is likely to have greater differences in their PM component composition selected by the two forms. For example, the 2% of all hours form for Salt Lake City selected only one hour of one of the days when the PM carbonaceous components was the major contributor compared with the 4 hours with high PM carbonaceous components selected by the top 10% of maximum daily form (see Figure 3-13 for Salt Lake City). By comparison, for Salt Lake City most of the multiple hours in single days had high contributions from PM nitrate. The overall effects of these differences for Salt Lake City are more easily seen by viewing the average extinction budgets using the two forms by city as shown in Figure 3-14. The 2% of all daylight hours form has a greater contribution to light extinction by PM nitrate and a larger average light extinction than for the 10% of maximum daily 1-hour form. Differences between the average extinction budgets for the other urban areas are much smaller than for Salt Lake City.

Table 3-8. The Numbers of Common and Unique Days Selected for Each of the 15 Urban Areas by the Top 10% of Daily Maximum and the Top 2% of all Hours Form. (Also shown are the numbers of days selected for each form.)

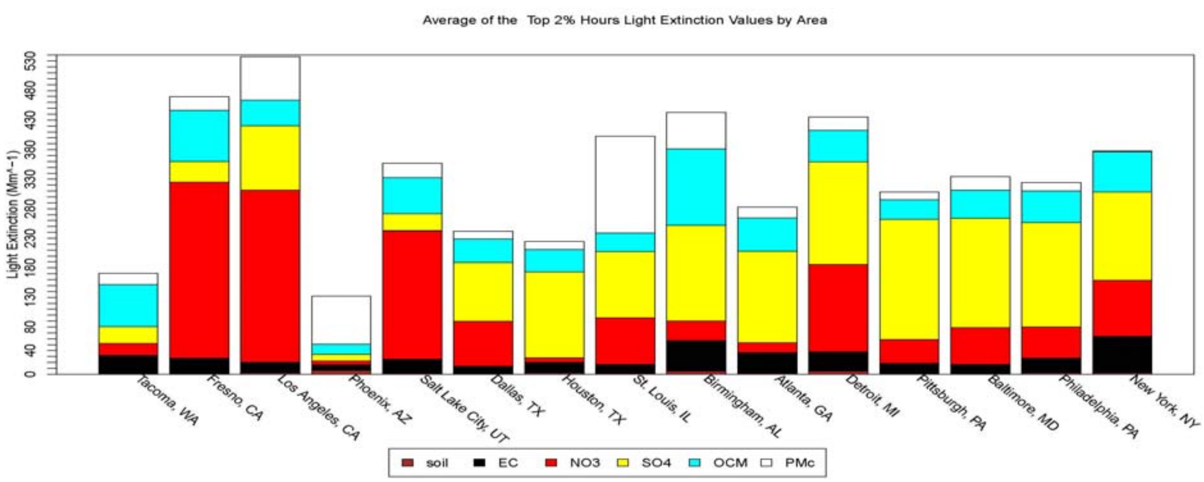
	10% vs. 2%		Number of Days	
	Common	**Unique**	**10%**	**2%**
Tacoma	11	3	11	14
Fresno	25	7	32	25
Los Angeles	29	9	30	38
Phoenix	9	6	9	14
Salt Lake City	16	15	31	16
Dallas	25	2	27	25
Houston	14	11	14	23
St. Louis	29	4	29	33
Birmingham	35	15	35	47
Atlanta	27	6	27	33
Detroit	13	1	14	13
Baltimore	13	5	18	12
Pittsburgh	28	3	28	31
Philadelphia	14	0	14	14
New York City	22	1	23	23

Figure 3-14. Average PM_{10} Light Extinction Budgets for the 15 Cities for Hours in the (a) Top10 Percent of the Maximum Daily PM_{10} Light Extinction and (b) Top 2 Percent of all Daylight Hours of PM_{10} Light Extinction.

(a)



(b)



The patterns of results for individual selected hours as shown in Figure 3-13 and for city averages as shown in Figure 3-14 are 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 PM_{10} 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 PM_{10} 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 PM_{10} 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 PM_{10} light extinction year-round.

Looking at individual urban areas, the following are some highlights:

- Tacoma has its highest PM_{10} light extinction hours in the colder months and primarily due to carbonaceous $PM_{2.5}$ components. Because coarse PM was estimated by applying a regional factor to the local $PM_{2.5}$ mass value, it would not have been possible for the results to indicate a significant coarse PM contribution to PM_{10} light extinction even if one existed at this site. However, from what EPA staff know of the area, it is unlikely that there is a significant contribution from coarse PM.
- Extreme haze hours in the two California urban areas are primarily caused by high nitrate $PM_{2.5}$, though Los Angeles has two extreme hours associated with coarse PM and several other hours with moderate contribution from coarse PM. Recall that estimates of coarse PM in Los Angeles are based in part on hourly PM_{10} measurements in Victorville, and may not represent coarse PM at the $PM_{2.5}$ mass and speciation site in Rubidoux or in the larger South Coast Basin. Also, such high coarse PM values may indicate influence from exceptional winds in Victorville. Figure B-1(b) in Appendix B shows that several other days with high daily maximum PM coarse concentrations had concentrations only about 60 percent or less than on the two days appearing in Figure 3-13; the fact that these other days do not appear among the top 10 percent indicates that other contributors to PM_{10} light extinction were low on those days. Whether or not the PM_{10} measurements in Victorville represent the $PM_{2.5}$ mass and speciation site in Rubidoux, it can be concluded that nitrate and to a lesser extent sulfate dominate PM_{10} light extinction on the days likely to be above the CPLs. Because coarse PM for Fresno was estimated by applying a regional factor to the local $PM_{2.5}$ mass value, it would not have been possible for the results to indicate a significant coarse PM contribution to PM_{10} light extinction even if one existed at the Fresno site. However, given the presence of agricultural operations and occasional high winds in the San Joaquin Valley, the possibility of a significant contribution from coarse PM in some hours cannot not be ruled out.
- Phoenix is unique among the 15 urban areas in having most of its extreme $PM_{\mathbf{10}}$ 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 $PM_{2.5}$. Unlike for Los Angeles, this domination by coarse PM is no doubt

correct. PM_{10} measurements for Phoenix come from a site near the center of the metro area, while the $PM_{2.5}$ measurements are from a more peripheral site (see Appendix A) and are probably underestimates of $PM_{2.5}$ at the PM_{10} measurement site; this would have only a small effect on estimates of coarse PM. While it is quite possible that the very highest coarse PM concentration (indicated in Figure B-1(b) to be about 500 $\mu g/m^3$) reflects the effect of exceptional winds, and might be excluded under the Exceptional Event rule, the next-highest values of PM_{10} light extinction almost certainly would also be dominated by coarse PM concentrations in the range of 150 to 200 $\mu g/m^3$ and many might not be excludable.

- 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. Because coarse PM in Salt Lake City was estimated by applying a regional factor to the local $PM_{2.5}$ mass value, it would not have been possible for the results to indicate a significant coarse PM contribution to PM_{10} light extinction even if one existed at this site. However, from what EPA staff know of the area, it is unlikely that there is a frequent large contribution from coarse PM. The area typically has at most a few days per year with measured 24-hour average PM_{10} as high as 150-200 $\mu g/m^3$. If this were all coarse PM, the contribution to 24-hour average light extinction would be 90-120 Mm^{-1}, with the possibility of much higher hourly contributions by coarse mass during these few days.
- Dallas and Houston have high sulfate $PM_{2.5}$ contributions to PM_{10} light extinction, but Dallas also has some winter hours with extreme PM_{10} light extinction with substantial contributions from nitrate and organic carbonaceous material, while Houston seems to have less contribution by nitrate. Because coarse PM in both Dallas and Houston was estimated by applying a regional factor to the local $PM_{2.5}$ mass value, it would not have been possible for the results to indicate a significant coarse PM contribution to PM_{10} light extinction even if one existed at this site. However, from what EPA staff know of the areas, it is unlikely that there is a frequent large contribution from coarse PM. Houston typically has at most a few days per year with measured 24-hour average PM_{10} as high as 150-200 $\mu g/m^3$. If this were all coarse PM, the contribution to 24-hour average light extinction would be 90-120 Mm^{-1}. Dallas typically does not have PM_{10} as high as 150 $\mu g/m^3$.
- Sulfate in the summer and nitrate in the fall and winter are responsible for most of the extreme PM_{10} light extinction at St. Louis, though there are several maximum

hourly periods where coarse PM is a major component. Recall that estimates of coarse PM in St. Louis may be affected by a very local source (see Appendix A), and thus the instances of high PM_{10} light extinction due to coarse PM may be limited in geographic scope.[31]

- Birmingham and Atlanta are similar in having sulfate year-round and winter carbonaceous $PM_{2.5}$ as major contributors to their extreme PM_{10} light extinction periods. Coarse PM for Birmingham was estimated using data from a single site, and the estimates should be reasonably representative. Coarse PM for Atlanta was estimated using data from two fairly close sites and the estimates should be reasonably representative.
- 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 several fall and winter days with high contributions from carbonaceous $PM_{2.5}$. Coarse PM makes a notable contribution on a few days. Coarse PM for Detroit was estimated using data from a single site near an automobile plant, and the estimates should be reasonably representative for that site.
- The remaining four urban locations (Pittsburgh, Baltimore, Philadelphia, and New York) are similar in that most of their extreme PM_{10} light extinction is from year-round combinations of sulfate and nitrate. New York also has some winter elemental and organic carbonaceous contributions to its extreme PM_{10} light extinction. Recall that the $PM_{2.5}$ site representing the New York area is actually in Elizabeth, NJ; emissions from diesel trucks on nearby interstate highways and/or diesel engines associated with port activities might explain the carbonaceous contributions. Coarse PM for Baltimore and Philadelphia was estimated using data from a single site in each area, and the estimates should be reasonably representative. Coarse PM for New York was estimated using data from two fairly distant sites and the estimates may not be representative of both sites. Because coarse PM was estimated for Pittsburgh by applying a regional factor to the local $PM_{2.5}$ mass value, it would not have been possible for the results to indicate a significant coarse PM contribution to PM_{10} light extinction even if one existed at this site. However, exceedances of the PM_{10} NAAQS are rare in

[31] Comments concerning unrealistically high $PM_{10-2.5}$ values for St. Louis are viewed as credible, but were received too late in the review process to permit reanalysis using an alternate data set or to remove St. Louis from all portions of this document. However, the text has been revised to caution readers with respect to the St. Louis results, and they will not be included in the visibility effects discussion in the final PM Policy Assessment document. Some graphics have been updated to exclude St. Louis results

Pittsburgh suggesting that coarse PM likely is not a frequent significant contributor to PM_{10} light extinction.

3.5 POLICY RELEVANT BACKGROUND

Policy relevant background levels of PM_{10} 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 ISA. Estimates of PRB for PM_{10} 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 final 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 final 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). More detail is provided in Appendix C.

The outcome of the procedures for estimating PRB consists of hour-specific estimates of PRB for $PM_{2.5}$ components and annual average estimates for PRB for $PM_{10-2.5}$. Thus, hour-specific estimates of PM_{10} light extinction are possible, using the same hour-specific relative humidity values as for the estimate of current conditions PM_{10} light extinction.

In addition to allowing confirmation of the obvious fact that current conditions PM_{10} light extinction values are generally well above PRB conditions, the PRB estimates only play a role in this assessment in the estimation of "what if" scenarios representing compliance with alternative NAAQS scenarios based on PM_{10} light extinction. This role is described in section 4.1.4.

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4 PM_{10} LIGHT EXTINCTION UNDER "WHAT IF" CONDITIONS OF JUST MEETING SPECIFIC ALTERNATIVE SECONDARY NAAQS

4.1 ALTERNATIVE SECONDARY NAAQS BASED ON PM_{10} LIGHT EXTINCTION AS THE INDICATOR

4.1.1 Indicator and Monitoring Method

The indicator considered for the UFVA is PM_{10} light extinction, assumed to be measured by a continuous instrument, or instrument pair, capable of reporting both light scattering and light absorption. EPA staff prepared a White Paper on Particulate Matter (PM) Light Extinction Measurements (US EPA, 2010d) for the purpose of soliciting comments on prospective measurement methods from the public and the Ambient Air Monitoring and Methods Subcommittee (AAMMS). In its review (Russell and Samet, 2010), the AAMMS made the recommendation to EPA that direct measurements be limited to $PM_{2.5}$ light extinction as this can be accomplished by a number of commercially available instruments and because $PM_{2.5}$ is generally responsible for most of the PM visibility impairment in urban areas. They indicated that it is technically more challenging at this time to accurately measure the $PM_{10-2.5}$ component of light extinction. These recommendations were received subsequent to completion of the assessments described here, so they did not influence the use of PM_{10} light extinction as the indicator.

4.1.2 Alternative Secondary NAAQS Scenarios Based on PM_{10} Light Extinction

Eighteen alternative NAAQS scenarios presented in Table 4-1 are analyzed in this section. Nine are based on daily maximum daylight 1-hour PM_{10} light extinction and nine on PM_{10} light extinction in all hours without the restriction to daily maxima. Within each set of nine, the scenarios are ordered from least to most stringent.

Table 4-1. Alternative Secondary NAAQS Scenarios for PM_{10} Light Extinction

Level	Annual Percentile	Form
Scenarios Based on Daily Maximum Daylight 1-Hour PM_{10} Light Extinction		
(a) 191 Mm^{-1}	90	3-year average of percentile value
(b) 191 Mm^{-1}	95	3-year average of percentile value
(c) 191 Mm^{-1}	98	3-year average of percentile value
(d) 112 Mm^{-1}	90	3-year average of percentile value
(e) 112 Mm^{-1}	95	3-year average of percentile value
(f) 112 Mm^{-1}	98	3-year average of percentile value
(g) 64 Mm^{-1}	90	3-year average of percentile value
(h) 64 Mm^{-1}	95	3-year average of percentile value
(i) 64 Mm^{-1}	98	3-year average of percentile value
Scenarios Based on Daylight 1-Hour PM_{10} Light Extinction (All Daylight Hours)		
(j) 191 Mm^{-1}	90	3-year average of percentile value
(k) 191 Mm^{-1}	95	3-year average of percentile value
(l) 191 Mm^{-1}	98	3-year average of percentile value
(m) 112 Mm^{-1}	90	3-year average of percentile value
(n) 112 Mm^{-1}	95	3-year average of percentile value
(o) 112 Mm^{-1}	98	3-year average of percentile value
(p) 64 Mm^{-1}	90	3-year average of percentile value
(q) 64 Mm^{-1}	95	3-year average of percentile value
(r) 64 Mm^{-1}	98	3-year average of percentile value

4.1.3 Monitoring Site Considerations for Alternative Secondary NAAQS Based on Measured PM_{10} Light Extinction

It is useful to think ahead tentatively to monitor siting aspects of NAAQS implementation, so that the results presented in the remainder of this chapter based on the 15 specific study sites can be better interpreted in terms of how well they might represent later findings if these (and other) areas were to deploy PM_{10} light extinction measurement instruments as part of implementing a secondary NAAQS.

In light of the recommendations of the AAMMS (Russell and Samet, 2010), it is most likely that the instruments that would be used if directly measured $PM_{2.5}$ light extinction were selected as the indicator to implement a secondary NAAQS would 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. The AAMMS recommendations also include advice concerning network design, and probe and siting criteria applicable to a program of directly measuring $PM_{2.5}$ light extinction.[1]

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 (Elizabeth, NJ) 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 $PM_{2.5}$ 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 $PM_{2.5}$ light extinction above the NAAQS.

4.1.4 Approach to Modeling "What If" Conditions for Alternative Secondary NAAQS Based on Measured PM_{10} 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, 95th, or 98th 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 all daylight and daily maximum daylight 1-hour PM_{10} light extinction under each of the "what if" scenarios (in which each study area "just meets" one of the 18 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. The steps are described here for the nine scenarios based on daily maximum daylight 1-hour PM_{10} light extinction; similar steps were followed for the nine scenarios based on percentiles of all daylight 1-hour PM_{10} light-extinction. The referenced tables present results for both sets of scenarios.

[1] In chapter 4 of the second review draft of the PM Policy Assessment (US EPA, 2010c), EPA staff considers as an alternative to directly measuring $PM_{2.5}$ light extinction the use of speciated $PM_{2.5}$ mass-calculated light extinction by a method similar in concept to but simpler than the method described in section 3.2. Much of the monitoring infrastructure needed to implement this approach is already deployed by state and local air agencies.

1. After excluding hours with relative humidity greater than 90 percent, identify the appropriate percentile (90^{th}, 95^{th}, or 98^{th}) daily maximum daylight 1-hour **PM_{10}** light extinction value in each year, noting the day and hour each occurred, and average these values across years to calculate the PM_{10} light extinction design value for each site consistent with the percentile form of the NAAQS scenario.[2] The three resulting design values for each area (for the 90^{th}, 95^{th}, and 98^{th} percentile forms) are shown in Table 4-2. (Note that in a number of cases, which are identified by a footnote, the study area meets one or more of the NAAQS scenarios under current conditions. In these cases, the "current conditions" PM_{10} light extinction values are not adjusted, i.e., PM_{10} light extinction values are never "rolled up.") Notice that the design values for the 90^{th} percentile maximum daily 1-hour for most cities are generally similar to the design values for the 98^{th} percentile of all daylight hours. On average there are about ten hours defined as daylight per day, so if the PM_{10} light extinction were randomly distributed among the daylight hours and days, the 90^{th} percentile maximum daily 1-hour would correspond to the 99^{th} percentile of all hours; the fact that the point of rough equivalency is the 98^{th} percentile indicates a tendency for hours with higher PM_{10} light extinction to cluster together in the same day. Figure 4-1 presents two scatter plots that relate the design values based on daily maximum 1-hour PM_{10} light extinction values and the design values based on all daylight 1-hour PM_{10} light extinction values. In Panel A, design values for the daily maximum and all hours forms are paired by the defining percentile, and colors are used to distinguish the 90^{th}, 95^{th}, and 98^{th} percentile statistical forms. It appears from Panel A that the design values for the two approaches to defining the NAAQS scenarios are highly correlated but with the all hours approach resulting in numerically lower design values than the daily maximum approach. The correlation breaks down for the 98^{th} percentile form for the few study areas with the highest levels of PM_{10} light extinction. Panel B compares the 90^{th} percentile design values based on daily maximum PM_{10} light extinction with the 90^{th}, 95^{th}, and 98^{th} percentile design values based on all daylight hours PM_{10} light extinction. There is close agreement between the 90^{th} percentile design values based on daily maximum values and the 98^{th} percentile design value based on all daylight hours.

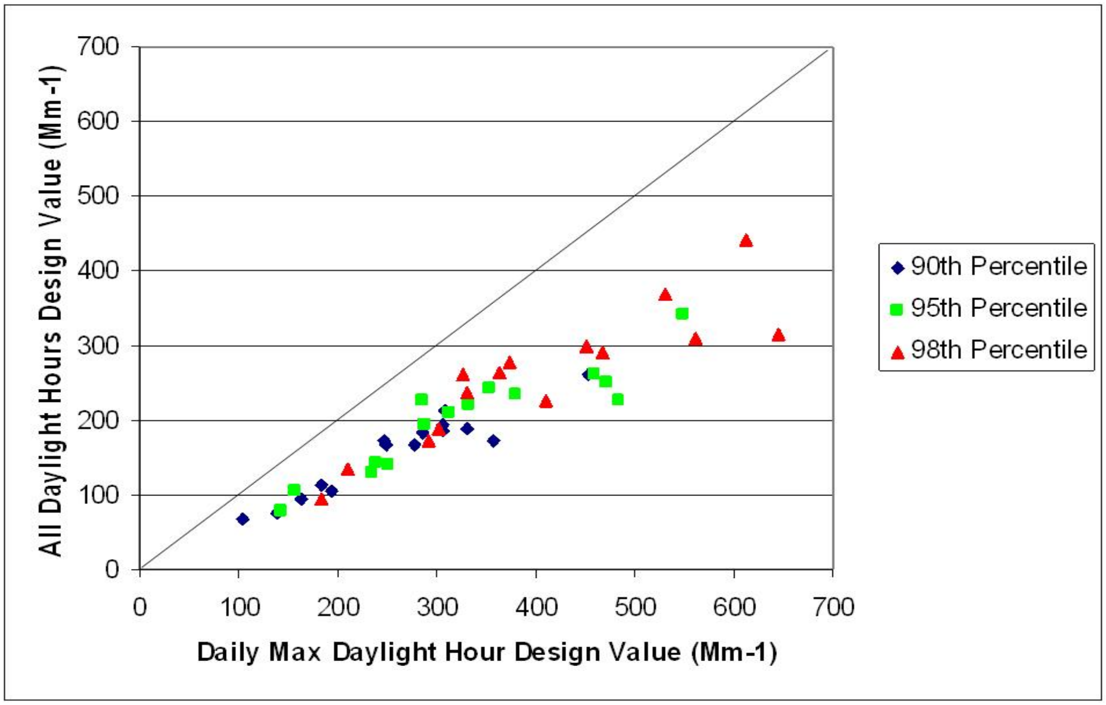
[2] Annual percentile values were picked from the set of day-specific or hour-specific estimates according to the same scheme as used for the current 24-hour secondary $PM_{2.5}$ standard, as explained in section 4.5(a) of 40 CFR 50 Appendix N. For example, if there are 60 daily maximum values in a year, the second highest value is the 98^{th} percentile value. Note that this differs from the algorithm used by some spreadsheet and other statistical programs, which may interpolate between sample values. Also, this is a different approach than that used in the Regional Haze program, in which conditions in the best and worst 20 percent of days are averaged together, rather than focusing on conditions on the specific day at the 80^{th} and 20^{th} percentile points.

Table 4-2. Current Conditions PM_{10} Light Extinction Design Values for the Study Areas.

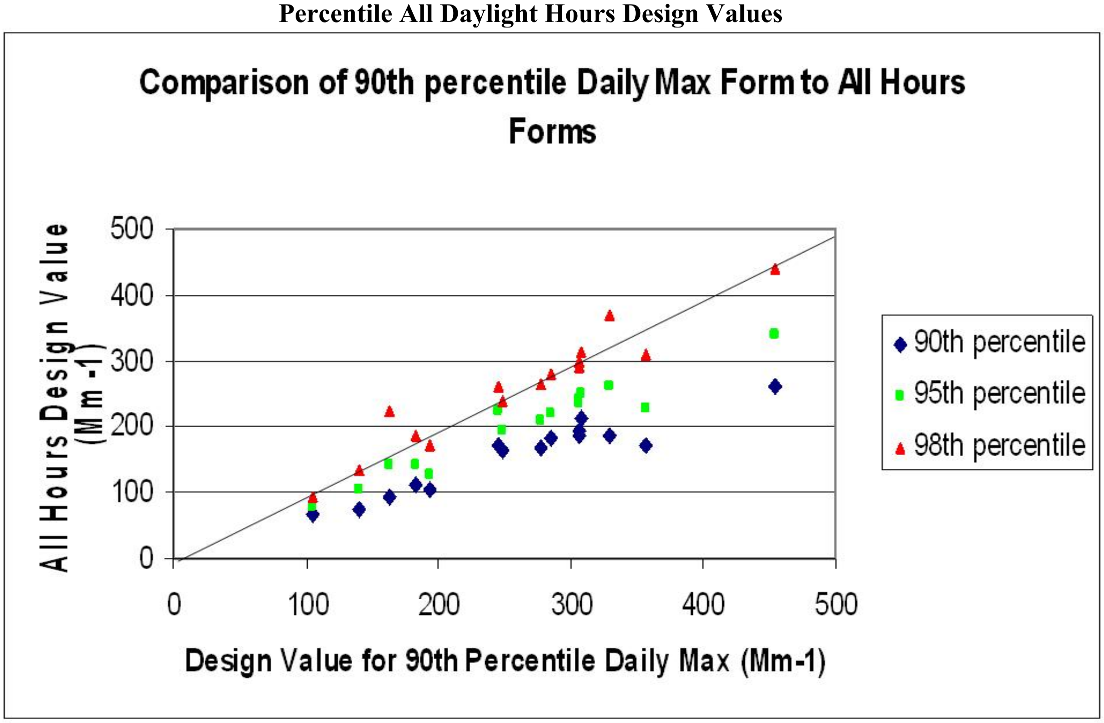
Study Area	Design Value for 90^{th} Percentile Form (Mm^{-1})	Design Value for 95^{th} Percentile Form (Mm^{-1})	Design Value for 98^{th} Percentile Form (Mm^{-1})
Design Values Based on Daily Maximum Daylight 1-Hour PM_{10} Light Extinction			
Tacoma	140*	157*	211
Fresno	330	460	530
Los Angeles	454	550	611
Phoenix	105*	144*	185
Salt Lake City	163*	252	409
Dallas	184*	239	301
Houston	194	234	291
St. Louis	306	380	467
Birmingham	357	483	562
Atlanta	249	288	331
Detroit	308	471	644
Pittsburgh	278	313	364
Baltimore	246	286	326
Philadelphia	285	334	374
New York	306	354	451
Design Values Based on Daylight 1-Hour PM_{10} Light Extinction (All Daylight Hours)			
Tacoma	76*	105*	136*
Fresno	188*	261	368
Los Angeles	261	341	441
Phoenix	68*	79*	94*
Salt Lake City	93*	141*	225
Dallas	113*	143*	188*
Houston	105*	128*	171*
St. Louis	193	235	290
Birmingham	173*	227	309
Atlanta	166*	195	238
Detroit	212	251	315
Pittsburgh	167*	209	264
Baltimore	171*	225	262
Philadelphia	183*	222	278
New York	186*	243	299
* This design value meets one or more of the NAAQS scenarios based on PM_{10} light extinction.			

Figure 4-1. Comparison of Daily Max and All Daylight Hour Design Values for PM_{10} Light Extinction

(A) Comparison of Design Values Matched by Percentile Form



(B) Comparison of 90th Percentile Daily Maximum Design Values and 90th, 95th, and 98th Percentile All Daylight Hours Design Values



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 PM_{10} 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 PM_{10} light extinction in order to reduce the design value to the PM_{10} 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 step 4 are shown in Table 4-3. Figure 4-2 presents them graphically in the form of a scatter plot, comparing the required reductions for scenarios based on daily maximum 1-hour daylight PM_{10} light extinction values to scenarios with the same level and percentile form but based on all daylight hours 1-hour PM_{10} light extinction values. For the NAAQS scenarios involving higher levels and lower percentile forms, there are some notable differences in the percentage reductions required for some area to attain. As was the case for the design values, notice in Table 4-3 that there are generally similar percentage reductions for each city and level for the 90th percentile maximum daily and 98th percentile of all daylight hours.

   As already stated, if the study area is meeting a NAAQS scenario in the current conditions case, no adjustments were made to represent the "just meeting" case. In effect, negative values for the percent reduction required to meet the NAAQS scenario calculated by the above equation were re-set to zero.

5. Turning to the entire set of day/hour-specific actual and PRB daylight PM_{10} light extinction values for the three (or two) year period, determine the non-PRB portion of PM_{10} light extinction in that hour, reduce it by the percentage determined in step 4, and add back in the PRB PM_{10} light extinction. The result is the "just meets" PM_{10} light extinction value for that day and hour.

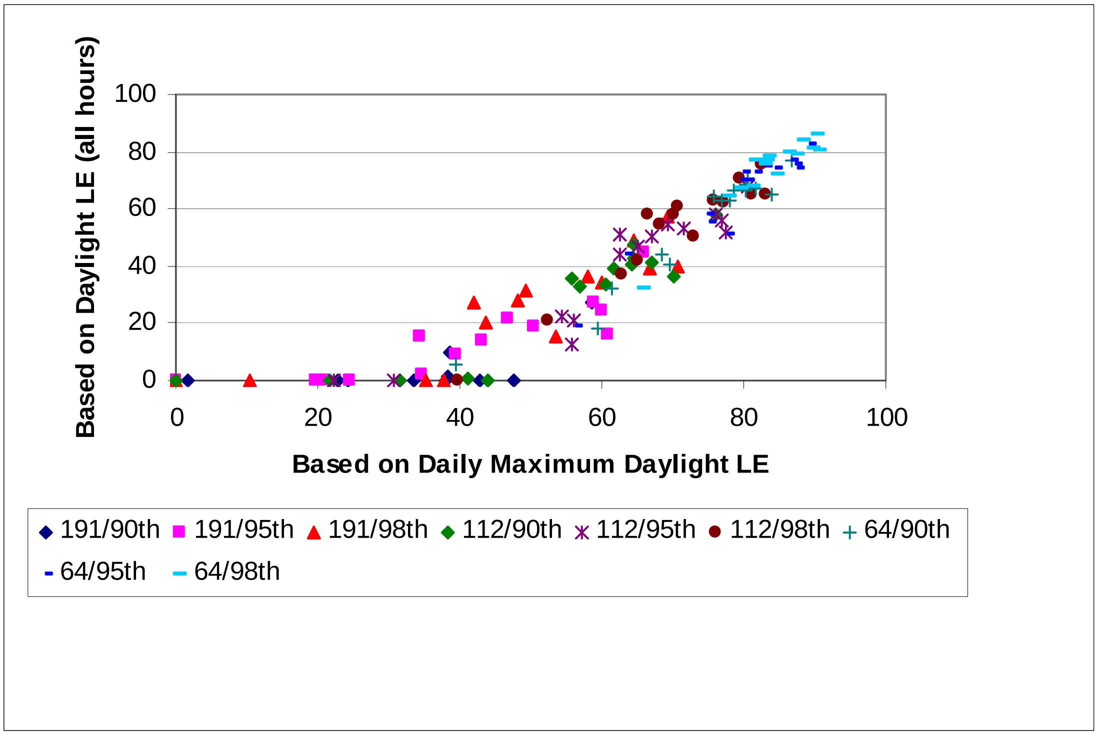
Note that in these steps, it is not necessary to make any explicit or implicit assumption about what PM components would be reduced to allow the area to meet the NAAQS scenario, as the NAAQS scenario's target design value is itself in units of light extinction. One path to meeting a NAAQS scenario would be to reduce each of the five $PM_{2.5}$ components (and thus the annual and 24-hour design values shown in Table 3-2) and $PM_{10-2.5}$ by the calculated "percent reduction required". However, a lesser reduction in one or more of the six PM concentrations could be offset by a greater reduction in one or more of the remaining concentrations. Thus, it is not possible to associate unique values of annual average and 24-hour average $PM_{2.5}$ with the "just meeting" NAAQS scenarios reported in Table 4-3.

Table 4-3. Percentage Reductions in Non-PRB PM_{10} Light Extinction Required to "Just Meet" the NAAQS Scenarios Based on Measured Light Extinction (Mm^{-1})[3]

	NAAQS Scenarios Based on Daily Maximum 1-Hour Daylight PM_{10} Light Extinction								
Scenario	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
Level/Form	191/90th	191/95th	191/98th	112/ 90th	112/95th	112/98th	64/90th	64/95th	64/98th
Area	Percentage Reduction Required in Non-PRB PM_{10} Light Extinction								
Tacoma	0	0	10	22	31	52	59	63	78
Fresno	43	59	64	67	76	79	82	87	89
Los Angeles	59	66	69	76	81	82	87	89	90
Phoenix	0	0	0	0	22	40	39	56	66
Salt Lake City	0	24	54	32	56	73	61	75	85
Dallas	0	21	38	41	54	65	69	75	81
Houston	2	20	35	44	56	63	70	78	80
St. Louis	38	51	60	64	72	77	80	85	88
Birmingham	48	61	67	70	77	81	84	87	90
Atlanta	24	35	44	57	63	68	77	80	83
Detroit	39	60	71	65	77	83	80	87	91
Pittsburgh	32	40	48	60	65	70	78	81	83
Baltimore	23	34	42	56	63	67	76	80	82
Philadelphia	34	43	49	62	67	71	79	82	84
New York	38	47	58	64	69	76	80	83	87
	NAAQS Scenarios Based on 1-Hour Daylight PM_{10} Light Extinction								
Scenario	(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)
Level/Form	191/90th	191/95th	191/98th	112/90th	112/95th	112/98th	64/90th	64/95th	64/98th
Area	Percentage Reduction Required in Non-PRB PM_{10} Light Extinction								
Tacoma	0	0	0	0	0	21	18	44	64
Fresno	0	27	49	41	58	70	67	77	84
Los Angeles	27	45	57	58	68	75	77	82	86
Phoenix	0	0	0	0	0	0	5	19	32
Salt Lake City	0	0	15	0	21	51	32	55	72
Dallas	0	0	0	1	23	42	44	58	68
Houston	0	0	0	0	13	37	40	51	67
St. Louis	1	19	35	43	53	62	68	74	79
Birmingham	0	16	39	36	52	65	65	74	81
Atlanta	0	2	20	33	44	55	63	70	75
Detroit	10	24	40	48	56	65	71	75	81
Pittsburgh	0	9	28	34	47	58	63	70	77
Baltimore	0	15	28	35	51	58	64	73	77
Philadelphia	0	14	32	39	51	61	66	73	78
New York	0	22	36	40	55	63	67	75	79

[3] As a result of a formula error, the intended values of PRB PM_{10} light extinction were not properly used in calculating the entries in this table, generally resulting in the required reductions shown here to be slightly smaller than they should be. For a more detailed explanation of this issue, see the 2010 Lorang memo, "Explanation of Error in Table 4-3 (Percentage reductions in non-PRB PM_{10} light extinction required to 'just meet' the NAAQS scenarios based on measured light extinction) of the final Urban Focused Visibility Assessment", July 23, 2010. As discussed in that memo, the only other results presented in this document that were affected by this error were Figure 4-2, Figure 4-3(a), and Panels (a) through (r) of Appendix F. The effect on those figures was judged too negligible to warrant regenerating them for this final version.

Figure 4-2. Comparison of Required Percentage Reductions in Non-PRB PM_{10} Light Extinction Needed to Meet NAAQS Scenarios



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 final assessment, EPA staff have modeled two "what if" scenarios using the same indicators and averaging periods as defined in the current suite of $PM_{2.5}$ NAAQS set in 2006. The first scenario uses the current suite of $PM_{2.5}$ NAAQS levels and the second a suite of lower levels considered in the health risk assessment (US EPA, 2010e):

- 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.

- 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.

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 Dallas 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 (section 3.2.3), 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	
	(s) Annual $PM_{2.5}$ NAAQS = 15 µg/m^3 24-Hour $PM_{2.5}$ NAAQS = 35 µg/m^3	(t) 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	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	19	43
Pittsburgh	19	43
Baltimore	6	33
Philadelphia	8	35
New York	17	41

* These areas meet this NAAQS scenario under current conditions.

4.3 RESULTS FOR EACH "JUST MEET" ALTERNATIVE SECONDARY NAAQS SCENARIO

The modeling described in sections 4.1 and 4.2 resulted in estimates of PM_{10} light extinction for each day and hour in each study area, for each NAAQS scenario. Four summaries of these conditions are presented here. Figure 4-3 shows two box-and-whisker plots of daily maximum daylight 1-hour PM_{10} light extinction. The top panel (a) is for the single illustrative scenario of a NAAQS based on daily maximum daylight 1-hour PM_{10} light extinction with a level of 112 Mm^{-1} and a 90th percentile form, which was chosen for this illustration because it is approximately mid-way among the nine scenarios based on daily maximum PM_{10} light extinction in terms of stringency.[4] The bottom panel (b) is for the scenario of meeting the current suite of secondary $PM_{2.5}$ NAAQS standards: 15 µg/m^3 annual average and 35 µg/m^3 24-hour average (98th percentile form). A notable feature of this comparison is that in the top panel, all the study

[4] Plots of the distribution of daily maximum PM_{10} light extinction for all 18 NAAQS scenarios based on daily maximum PM_{10} light extinction, and of individual hourly PM_{10} light extinction for all 18 NAAQS scenarios based on individual daylight hours, are provided in Appendix F.

areas have a similar distribution of the daily maximum daylight 1-hour PM_{10} light extinction, while in the bottom panel this is not the case. This is expected, since a NAAQS based on a measured daily maximum PM_{10} light extinction indicator will of course result in areas achieving similar daily maximum PM_{10} 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 PM_{10} 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 PM_{10} light extinction.

Tables 4-5 and 4-6 summarize the "just meet" conditions in the NAAQS scenarios in terms of the PM_{10} light extinction design values. Table 4-5 addresses the 18 scenarios of NAAQS based on measured PM_{10} light extinction. When an area just meets a NAAQS scenario, its design value in principle should exactly equal the NAAQS level, so preparation of this table serves as a check against calculation errors. 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. Closer investigation has revealed that this is mostly a result of hours switching their ranking in the rollback process. Hours can switch rank because the level of PRB PM_{10} 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 PM_{10} light extinction; a lower ranking hour can thereby move up in the post-rollback ranking. 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.

Table 4-6 addresses the two scenarios of NAAQS based on $PM_{2.5}$ mass, with PM_{10} light extinction design values shown for the 90^{th}, 95^{th} , and 98^{th} percentile forms.

Figure 4-3. Distributions of Daily Maximum Daylight 1-Hour PM_{10} Light Extinction Under Two "Just Meet" Secondary NAAQS Scenarios (Excluding Hours with Relative Humidity Greater Than 90 Percent)

(a) Secondary NAAQS Based on Daily Maximum Daylight 1-Hour PM_{10} Light Extinction with a Level of 112 Mm^{-1} and a 90^{th} Percentile Form

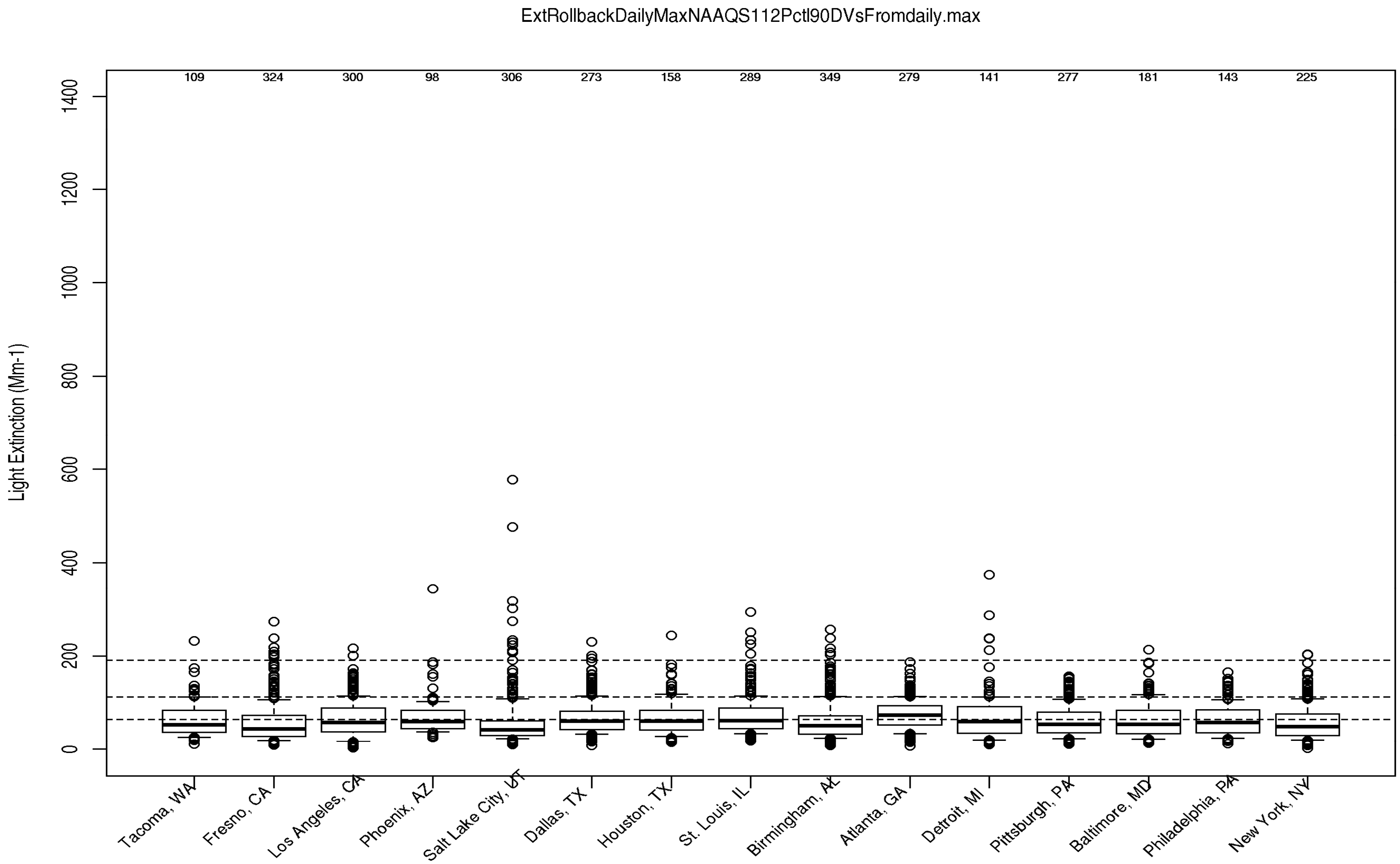


Figure 4-3. Distributions of Daily Maximum Daylight 1-Hour PM_{10} Light Extinction Under Two "Just Meet" Secondary NAAQS Scenarios (Excluding Hours with Relative Humidity Greater Than 90 Percent), continued

(b) Secondary NAAQS of 15 µg/m^3 for the Annual Average and 35 µg/m^3 for the 98th Percentile 24-Hour Average

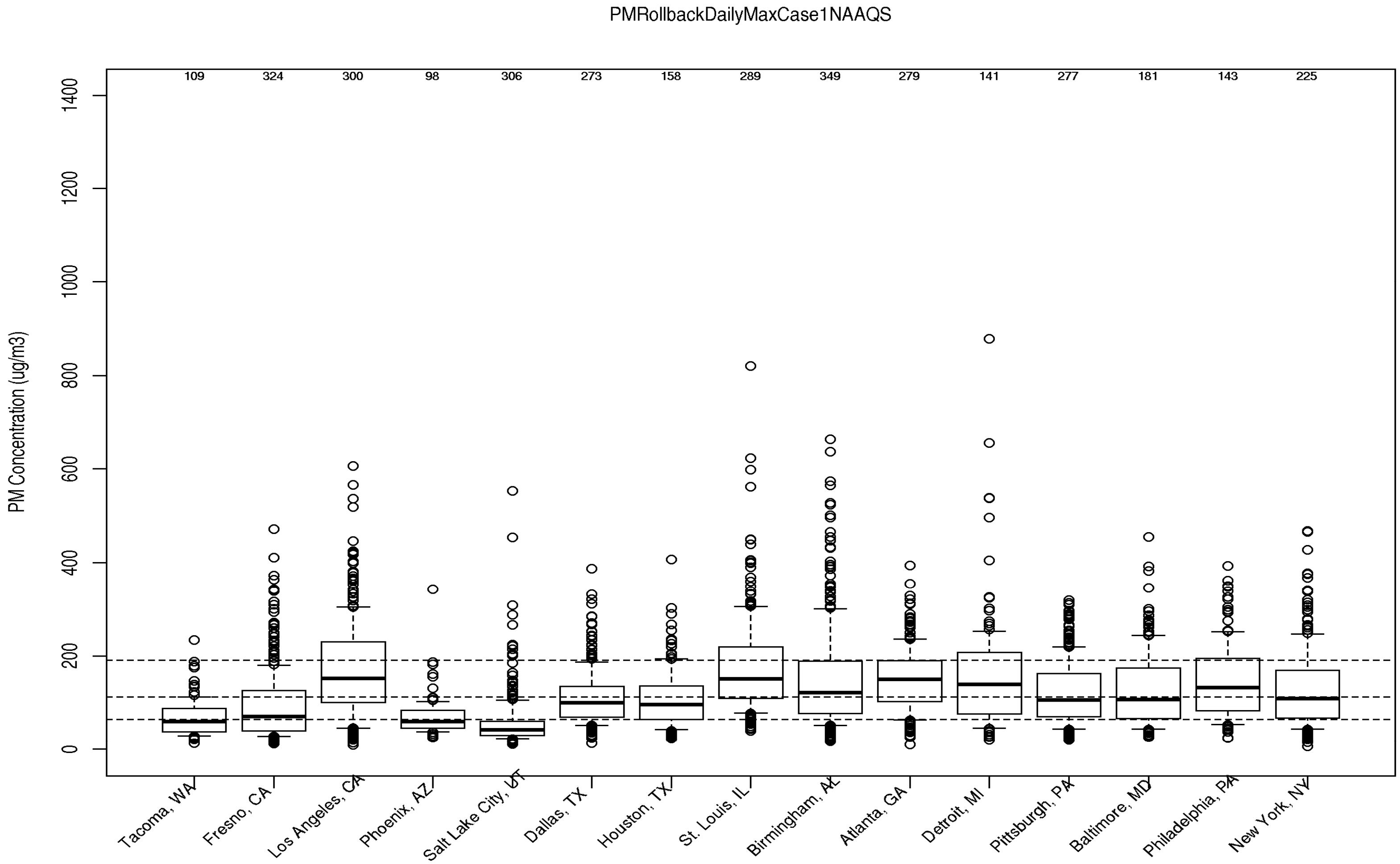


Table 4-5. PM_{10} Light Extinction Design Values for "Just Meet" Secondary NAAQS Scenarios Based on Measured PM_{10} Light Extinction (Excluding Hours with Relative Humidity Greater Than 90 Percent)

	Secondary NAAQS Scenarios Based on Daily Maximum								
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
Level (Mm^{-1})	191	191	191	112	112	112	64	64	64
Percentile Form	90th	95th	98th	90th	95th	98th	90th	95th	98th
	PM_{10} Light Extinction Design Value (based on same percentile form as the NAAQS scenario)								
Tacoma, WA	140	157	191	112	115	108	66	74	58
Fresno, CA	191	191	191	113	112	112	65	64	64
Los Angeles, CA	191	191	191	113	112	112	65	64	64
Phoenix, AZ	105	144	185	105	112	112	64	64	64
Salt Lake City, UT	163	191	191	112	112	112	65	64	64
Dallas, TX	184	191	191	112	113	112	64	65	65
Houston, TX	191	191	191	114	111	112	67	61	67
St. Louis, IL	191	191	191	112	112	112	65	64	64
Birmingham, AL	191	191	191	113	113	112	64	66	64
Atlanta, GA	191	191	191	112	112	112	64	64	65
Detroit, MI	191	191	191	112	112	112	64	64	65
Pittsburgh, PA	191	191	191	112	112	112	64	64	64
Baltimore, MD	191	191	191	111	112	112	63	64	64
Philadelphia, PA	191	191	191	112	112	112	64	64	64
New York, NY	191	191	191	112	112	112	64	64	64
	Secondary NAAQS Scenarios Based on All Daylight Hours								
	(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)
Level (Mm^{-1})	191	191	191	112	112	112	64	64	64
Percentile Form	90th	95th	98th	90th	95th	98th	90th	95th	98th
	PM_{10} Light Extinction Design Value (based on same percentile form as the NAAQS scenario)								
Tacoma, WA	76	105	136	76	105	112	63	64	59
Fresno, CA	188	192	191	112	113	111	65	64	63
Los Angeles, CA	191	191	191	112	113	112	64	65	64
Phoenix, AZ	68	79	94	68	79	94	64	64	64
Salt Lake City, UT	93	141	191	93	112	112	64	64	64
Dallas, TX	113	143	188	112	112	113	65	64	66
Houston, TX	105	128	171	105	113	111	65	66	61
St. Louis, IL	191	191	191	112	112	112	65	64	65
Birmingham, AL	173	191	191	112	112	112	65	64	65
Atlanta, GA	166	191	192	113	112	113	65	63	65
Detroit, MI	191	191	191	112	112	112	64	65	64
Pittsburgh, PA	167	191	191	113	113	112	65	65	65
Baltimore, MD	171	191	191	112	112	112	64	65	64
Philadelphia, PA	183	191	191	112	112	113	65	64	65
New York, NY	186	191	192	112	112	113	65	65	65

Table 4-6. PM_{10} Light Extinction Design Values for "Just Meet" Secondary NAAQS Scenarios Based on $PM_{2.5}$ Mass (Excluding Hours with Relative Humidity Greater Than 90 Percent)

Annual/24-Hour $PM_{2.5}$ NAAQS	(s) 15µg/m³ / 35µg/m³			(t) 12µg/m³ / 25µg/m³		
City Name	90th %tile Design Value (Mm^{-1})	95th %tile Design Value (Mm^{-1})	98th %tile Design Value (Mm^{-1})	90th %tile Design Value (Mm^{-1})	95th %tile Design Value (Mm^{-1})	98th %tile Design Value (Mm^{-1})
	Design Values Based on Daily Maximum Daylight 1-Hour PM_{10} Light Extinction					
Tacoma, WA	119	131	178	93	102	136
Fresno, CA	191	266	304	142	196	224
Los Angeles, CA	312	361	429	231	261	355
Phoenix, AZ	105*	143*	185*	96	135	161
Salt Lake City, UT	110	167	269	83	125	198
Dallas, TX	183*	239*	301*	172	224	282
Houston, TX	185	222	276	148	178	220
St. Louis, IL	286	354	441	252	289	363
Birmingham, AL	285	394	464	213	300	365
Atlanta, GA	230	266	307	181	208	243
Detroit, MI	256	387	536	187	277	401
Pittsburgh, PA	229	258	299	167	188	218
Baltimore, MD	233	272	308	169	202	221
Philadelphia, PA	263	308	346	190	222	254
New York, NY	255	295	376	182	213	268
	Design Values Based on Daylight 1-Hour PM_{10} Light Extinction (All Daylight Hours)					
Tacoma, WA	65	88	113	52	70	84
Fresno, CA	110	152	214	83	113	160
Los Angeles, CA	173	228	294	129	169	220
Phoenix, AZ	68*	79*	94*	60	70	86
Salt Lake City, UT	63	95	150	49	72	112
Dallas, TX	113*	143*	188*	106	134	176
Houston, TX	99	122	163	81	99	131
St. Louis, IL	180	221	271	147	183	237
Birmingham, AL	140	183	247	105	138	186
Atlanta, GA	154	180	220	123	144	174
Detroit, MI	175	208	257	130	155	188
Pittsburgh, PA	138	173	218	102	127	159
Baltimore, MD	163	213	248	121	155	184
Philadelphia, PA	169	205	258	123	149	187
New York, NY	155	203	249	113	148	178

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

Table 4-7 summarizes all 20 scenarios in terms of the percentage of days (across 2005 to 2007, but after rollback) in which the daily maximum daylight 1-hour PM_{10} light extinction under "just meeting" conditions exceeds each of the CPLs. Part A of the table applies to NAAQS scenarios based on daily maximum 1-hour PM_{10} light extinction values. Part B of the table applies to the scenarios based on 1-hour PM_{10} light extinction values during all daylight hours. Note that the reported percentages in both Part A and Part B is the percentage of days in which the daily maximum daylight 1-hour PM_{10} light extinction under "just meet" conditions exceeds each of the CPLs; this allows comparison of the "effectiveness" of the two NAAQS approaches using a consistent metric. (The 15/35 and 12/25 NAAQS scenarios are the same in Part A and Part B, and are repeated only for convenience in making comparisons.) Hours with relative humidity above 90 percent have been excluded from consideration, consistent with the definition of the NAAQS scenarios. Also shown at the bottom of the table in each column representing a NAAQS scenario is the average of these percentages of time across the 15 study areas (this is the simple column average, not weighted by the number of days available in each area). 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 18 scenarios in terms of protecting visual air quality. Notice that the most restrictive of the two NAAQS scenarios based on $PM_{2.5}$ mass would reduce the projected 1-hour maximum daily PM_{10} light extinction above the least restrictive CPL (191Mm^{-1}) to less than 10 percent of the time for most of the urban areas (only L.A., St. Louis, and Birmingham have values above 10 percent).[5] However at the current PM NAAQS level (i.e., 15/35) all of the eastern urban areas and Los Angeles exceed the least restrictive CPL more than 10% of the time. Comparison of Parts A and B of Figure 4-7 indicates that basing a PM_{10} light extinction NAAQS scenario on daily maximum 1-hour PM_{10} light extinction has a lower percentage in excess of the 1-hour daily maximum versus the NAAQS scenario based on all daylight hours PM_{10} light extinction for a given level and percentile form of the NAAQS. This is consistent with the results presented in Table 4-2 and Figure 4-1, which indicated that current conditions design values are generally lower for the all hours approach. Again there is near equivalence between the 90th percentile daily maximum and 98th percentile all daylight hours in terms of the percent of days exceeding the daily maximum CPL values in Table 4-7.

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[5] Comments were received concerning unrealistically high $PM_{10-2.5}$ values for St. Louis and to a lesser extent for Los Angeles. High contributions by $PM_{10-2.5}$ would help explain why a $PM_{2.5}$ standard would be less effective in reducing visibility impacts. EPA staff view the comments concerning unreliable $PM_{10-2.5}$ values for St. Louis as credible, but these comments were received too late in the review process to permit reanalysis using an alternate data set or to remove St. Louis from this document. However, the text has been revised to caution readers with respect to the St. Louis results, and they will not be forwarded to the visibility effects discussion in the PM Policy Assessment document.

Table 4-7. Percentage of Days with Maximum 1-Hour Daylight PM_{10} Light Extinction Above CPLs For Each NAAQS Scenario Under "Just Meet" Conditions Across Three Years (or Two in the Case of Phoenix and Houston)

(A) NAAQS Scenarios Based on Daily Maximum 1-Hour PM_{10} Light Extinction

	Days with Max Hour Above 64 Mm^{-1}											Days with Max Hour Above 112 Mm^{-1}											Days with Max Hour Above 191 Mm^{-1}										
Scenario	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**s**	**t**	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**s**	**t**	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**	**s**	**t**
NAAQS Level Mm^{-1}	**191**	**191**	**191**	**112**	**112**	**112**	**64**	**64**	**64**			**191**	**191**	**191**	**112**	**112**	**112**	**64**	**64**	**64**			**191**	**191**	**191**	**112**	**112**	**112**	**64**	**64**	**64**		
NAAQS Percentile Form	**90**	**95**	**98**	**90**	**95**	**98**	**90**	**95**	**98**			**90**	**95**	**98**	**90**	**95**	**98**	**90**	**95**	**98**			**90**	**95**	**98**	**90**	**95**	**98**	**90**	**95**	**98**		
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	52	52	48	40	34	16	12	10	2	43	28	22	22	14	11	7	2	1	1	0	11	5	4	4	3	1	1	0	0	0	0	1	0
Fresno	54	40	32	31	19	13	10	5	3	54	40	29	16	11	9	5	3	2	0	0	29	17	9	5	3	2	0	0	0	0	0	9	5
Los Angeles	74	64	58	43	32	27	12	6	3	85	79	40	31	26	11	6	3	1	0	0	69	52	11	6	3	1	0	0	0	0	0	37	19
Phoenix	44	44	44	44	27	10	10	5	2	44	40	6	6	6	6	5	2	2	1	1	6	6	1	1	1	1	1	1	1	0	0	1	1
Salt Lake City	44	27	13	24	11	5	10	5	1	24	15	17	11	5	10	5	1	4	1	0	9	6	8	5	1	4	1	0	1	0	0	4	2
Dallas	80	66	50	48	25	14	10	5	1	81	77	41	22	12	10	5	1	1	0	0	41	37	10	5	1	1	0	0	0	0	0	10	8
Houston	77	65	55	47	30	18	13	3	3	75	64	43	28	16	12	4	3	1	0	0	41	23	11	6	2	1	1	0	0	0	0	11	3
St. Louis	81	71	54	46	34	20	11	6	2	97	89	45	30	18	12	6	2	2	1	0	73	57	11	5	3	2	1	0	0	0	0	36	20
Birmingham	63	49	40	33	19	14	10	6	3	84	70	30	18	12	10	5	3	1	0	0	55	38	10	5	2	1	0	0	0	0	0	24	13
Atlanta	85	80	76	62	51	34	9	5	1	90	85	59	47	30	11	5	1	0	0	0	71	54	11	4	2	0	0	0	0	0	0	25	8
Detroit	74	52	41	46	22	6	11	4	3	80	74	45	17	6	11	4	3	4	1	0	61	49	10	4	3	4	1	0	1	0	0	33	10
Pittsburgh	70	63	54	40	31	23	9	6	2	79	63	37	29	21	9	6	1	0	0	0	48	28	9	5	1	0	0	0	0	0	0	16	5
Baltimore	67	61	54	41	30	25	11	4	2	78	64	39	29	23	11	5	2	1	0	0	47	31	12	6	2	1	0	0	0	0	0	19	8
Philadelphia	72	66	60	41	31	27	8	6	3	85	74	38	31	24	8	5	3	0	0	0	61	38	8	5	3	0	0	0	0	0	0	29	9
New York	63	59	40	33	27	18	9	6	2	76	62	32	24	16	9	6	2	1	0	0	46	30	10	6	2	1	0	0	0	0	0	19	8
Average	**67**	**57**	**48**	**41**	**28**	**18**	**10**	**6**	**2**	**72**	**62**	**35**	**24**	**16**	**10**	**5**	**2**	**1**	**0**	**0**	**45**	**31**	**9**	**5**	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**18**	**8**

(B) NAAQS Scenarios Based on PM_{10} Light Extinction During All Daylight Hours*

	Days with Max Hour Above 64 Mm^{-1}											Days with Max Hour Above 112 Mm^{-1}											Days with Max Hour Above 191 Mm^{-1}										
Scenario	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**	**j**	**k**	**l**	**m**	**n**	**o**	**p**	**q**	**r**	**s**	**t**
NAAQS Level Mm^{-1}	191	191	191	112	112	112	64	64	64			191	191	191	112	112	112	64	64	64			191	191	191	112	112	112	64	64	64		
NAAQS Percentile Form	90	95	98	90	95	98	90	95	98			90	95	98	90	95	98	90	95	98			90	95	98	90	95	98	90	95	98		
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	52	52	52	52	52	40	40	23	10	43	28	22	22	22	22	22	11	12	4	1	11	5	4	4	4	4	4	1	1	0	0	1	0
Fresno	76	65	51	56	41	27	30	17	7	54	40	52	37	25	30	17	7	9	4	1	29	17	29	17	7	10	5	1	2	0	0	9	5
Los Angeles	86	83	76	75	61	46	40	27	14	85	79	73	58	42	41	27	14	10	3	1	69	52	42	27	13	12	3	1	1	0	0	37	19
Phoenix	44	44	44	44	44	44	44	29	17	44	40	6	6	6	6	6	6	6	5	3	6	6	1	1	1	1	1	1	1	1	1	1	1
Salt Lake City	44	44	33	44	27	15	24	12	6	24	15	17	17	14	17	12	5	9	5	2	9	6	8	8	5	8	5	2	4	1	1	4	2
Dallas	80	80	80	80	63	45	42	21	11	81	77	41	41	41	41	21	10	9	4	1	41	37	10	10	10	10	4	1	0	0	0	10	8
Houston	77	77	77	77	70	53	49	35	13	75	64	44	44	44	44	33	13	13	8	1	41	23	11	11	11	11	7	2	1	1	0	11	3
St. Louis	98	92	84	78	65	51	39	27	15	97	89	76	62	48	39	27	15	9	4	2	73	57	39	27	14	9	4	2	1	0	0	36	20
Birmingham	89	85	72	74	59	42	42	25	15	84	70	64	55	39	42	25	14	14	8	3	55	38	34	26	14	15	9	3	3	1	0	24	13
Atlanta	91	91	87	81	76	63	51	31	14	90	85	75	73	62	48	30	12	5	1	0	71	54	31	30	12	6	2	0	0	0	0	25	8
Detroit	84	78	72	66	57	45	41	27	10	80	74	63	55	45	41	26	9	6	4	4	61	49	40	26	9	6	4	4	3	1	1	33	10
Pittsburgh	85	83	73	69	55	42	35	22	11	79	63	57	53	40	34	22	11	8	1	0	48	28	26	22	11	8	2	0	0	0	0	16	5
Baltimore	80	72	66	60	44	38	28	14	10	78	64	50	43	34	28	14	9	4	2	1	47	31	23	14	9	5	2	1	0	0	0	19	8
Philadelphia	86	82	73	68	59	43	34	23	9	85	74	63	58	41	33	24	8	6	1	0	61	38	31	24	8	8	1	0	0	0	0	29	9
New York	83	74	64	62	44	34	31	18	11	76	62	59	42	32	30	18	10	8	3	1	46	30	28	18	10	8	3	1	0	0	0	19	8
Average	**77**	**73**	**67**	**66**	**54**	**42**	**38**	**23**	**12**	**72**	**62**	**51**	**44**	**36**	**33**	**22**	**10**	**9**	**4**	**1**	**45**	**31**	**24**	**18**	**9**	**8**	**4**	**1**	**1**	**0**	**0**	**18**	**8**

* Note that the table reports results based on daily maximum daylight hour, while the NAAQS scenarios in Panel B are based on all daylight hours (in both cases excluding hours with RH>90%).

5 SUMMARY

This chapter integrates the key information on the purpose, approach, principal results, and significant technical issues of the assessment efforts that are characterized in greater detail in chapters 2, 3 and 4 and the appendices of this final Urban Focused Visibility Assessment (UFVA). Earlier versions of the UFVA[1] document the original assessment and its evolution in response to Clean Air Science Advisory Committee (CASAC) and public comments. This chapter is organized by the three separate assessments that are described in greater detail in chapters 2 through 4.

5.1 Urban Visibility Preference Studies Reanalysis

Purpose: The overall purpose in conducting a reanalysis of urban preference studies is to determine whether there is a credible range of acceptable visual air quality conditions above which the national public welfare is adversely affected. Similar, though not identical, visibility preference studies were conducted in four metropolitan areas including Denver, CO; Vancouver, BC (Canada); Phoenix, AZ; and Washington, DC. These studies were performed separately to support the development of local visibility protection efforts, except for Washington, DC which was the subject of two separate pilot studies designed to better understand visibility preference studies. The common feature in each of these studies was that study participants were asked to individually rate the acceptability of scenic images shown to them one at a time in random order that depicted visibility impairment over a range of conditions from nearly pristine to highly impaired.

Approach: The methodology used in the reanalysis involved a critical review of data generated for each study to identify issues of consistency and to identify whether and when it might be appropriate to compare/combine the studies' results. The results were displayed as points on plots of percent of participants that rated each visibility condition acceptable versus the amount of visibility impairment as measured in deciview units (i.e., a logarithmic transformation of light extinction). Logit regression analysis was used to develop best fit curves for each of the four urban area study results and to determine whether they differed significantly from each other.

Principal Results: Logit regression applied to the results for each of the four urban areas defined statistically significant relationships for each that are similarly shaped but with different visibility impairment threshold value, defined here as the 50th percentile acceptability criteria in

[1] Available at http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_risk.html

each urban area study. The range of 50th percentile values is from ~20 dv to ~30 dv, which when expressed in terms of PM_{10} light extinction corresponds to 64 Mm^{-1} to 191 Mm^{-1}. The upper and lower bounds of the range and a mid-point value of 25 dv (corresponding to 112 Mm^{-1}) were selected as Candidate Protective Levels (CPLs) to compare with the distributions of current conditions for 15 urban areas (chapter 3) and to define alternative standards to be included in the assessment (chapter 4).

Technical Issues: Each of the four urban preference study areas produced well defined though statistically significant different results with respect to what visibility impairment level divides acceptable from unacceptable conditions. A number of hypotheses concerning why the results differed for each area are discussed in chapter 2. However, additional research to better understand why the response distributions differed by location could usefully inform future PM reviews.

5.2 Current Visibility Conditions

Purpose: The goal of this assessment is to develop a daylight hourly averaged PM_{10} light extinction dataset for several large urban areas to characterize current visibility conditions and compare them to the CPLs in order to determine the extent, frequency and causes of visibility impairment in cases where the CPLs are exceeded.

Approach: A simple linear algorithm, the IMPROVE algorithm,[2] was used to estimate PM_{10} light extinction for 15 urban areas for the period from 2005 to 2007 from hourly $PM_{2.5}$ and $PM_{10-2.5}$ mass and $PM_{2.5}$ component concentrations and relative humidity data (used to estimate the water component of the PM under ambient conditions). While $PM_{2.5}$ mass concentration and relative humidity data are available from continuous instruments on an hourly averaged basis, $PM_{2.5}$ composition data available from the Chemical Speciation Network (CSN) is based on 24-hour average filter samples which are only collected on a one-day-in-three or one-day-in-six basis. The methodology used to estimate hourly daylight $PM_{2.5}$ components involved use of CMAQ regional air quality modeling to generate monthly averaged species-specific diurnal patterns (ratio of each hour to the 24-hour mean) for each of the urban areas. These are used to calculate the hourly relative mix of species that are then scaled so that the sum of the $PM_{2.5}$ component concentrations equals the measured hourly $PM_{2.5}$ mass concentration. PM_{10} continuous monitoring data was available at a few of the urban areas permitting hourly $PM_{10-2.5}$ concentrations to be determined by subtracting the hourly $PM_{2.5}$ concentration. Elsewhere $PM_{10-2.5}$ was estimated using ratios of $PM_{2.5}$ to PM_{10}. The resulting estimates of hourly averaged $PM_{2.5}$ component concentrations, $PM_{10-2.5}$ mass concentration and the measured relative humidity were

[2] Malm, et al., 1994 and DeBell, 2006. (See also ISA, section 9.2.2.2, pgs. 9-7 and 9-8.)

used as input to the IMPROVE algorithm to estimate hourly PM_{10} light extinction to be calculated for daylight hours with relative humidity no greater than 90%. Resulting daylight 1-hour averaged PM_{10} light extinction values were compiled on the basis of all hours and maximum daily values for relative humidity conditions less than or equal to 90% to examine the frequency that they exceed CPLs by urban area. Tables and plots of the total and component contributions to PM_{10} light extinction were produced to characterize the nature and causes of visibility impairment.

Principal Results: All of the results are for 1-hour PM_{10} light extinction during daylight hours when relative humidity is no greater than 90% for the 15 selected urban areas.

- The use of this relative humidity cap significantly reduced the occurrence of visibility impairment caused by meteorological conditions like fog and precipitation.
- Maximum daily hourly PM light extinction values exceeded the low, middle and high CPL 77%, 52% and 26% of the days, respectively, when averaged across the 15 urban areas. Eastern and California urban areas have the highest frequencies and non-California Western urban areas have the lowest frequencies above each CPL.
- All hours PM_{10} light extinction values exceeded the low, middle and high CPLs 45%, 22% and 7% of the hours, respectively, averaged across the 15 urban areas, with the Eastern and California urban areas having the highest frequencies and non-California Western urban areas having the lowest frequencies above each CPL.
- The range of PM_{10} light extinction values and relative contributions by $PM_{2.5}$ components for the most impaired 10% of maximum daily 1-hour hours are similar to the most impaired 2% of all hours, because they include hours from a large number of days in common.
- During the most visibility impaired hours $PM_{2.5}$ nitrate is the dominant light extinction contributor for several western urban areas (Fresno, LA, and Salt Lake City) while sulfate tends to be the largest contributor in the Eastern urban areas. Carbonaceous $PM_{2.5}$ (i.e., organic mass plus elemental carbon) is a major contributor at Tacoma and a significant contributor at several other urban areas. Phoenix has significant light extinction contribution by $PM_{10-2.5}$. Thus, regional differences in the dominant component contributing to visibility impairment are apparent.

Technical Issues: The approach used to determine the hourly $PM_{10-2.5}$ concentrations varied among the sites. Four of the sites had collocated continuous $PM_{2.5}$ and PM_{10} measurements, while six urban areas used data from separate sites to determine the $PM_{10-2.5}$ by difference, and the remaining five urban areas used regionally determined ratios of $PM_{10-2.5}$ to $PM_{2.5}$ to infer the $PM_{10-2.5}$. The quality of the $PM_{10-2.5}$ data inferred from separate sites for St. Louis have been called into question in review comments on an earlier version of the UFVA and are no longer viewed as credible. Therefore, the St. Louis results were appropriately labeled in the subsequent analyses in the final UFVA. A similar concern was raised regarding the LA data, but the $PM_{10-2.5}$ values are low during most of the visibility impaired days so they are less of an issue compared with that of St. Louis and thus, were retained in these and subsequent assessments. $PM_{10-2.5}$ is a small component of the light extinction for all of the other urban areas except for Phoenix, where high values are considered more plausible. Collocated continuous PM_{10} and $PM_{2.5}$ monitoring at a greater number of urban areas would better address this issue in the future.

While yielding generally reasonable results, the process employed to develop the hourly PM_{10} component information used as input to the IMPROVE algorithm is complex and subject to comments that there are alternate approaches that could have been employed. The use of regional modeling to generate $PM_{2.5}$ species specific monthly averaged diurnal patterns would be unnecessary if continuous $PM_{2.5}$ speciation monitoring were more readily available. Use of an algorithm to estimate PM_{10} light extinction would be unnecessary if direct measurements of continuous PM_{10} light extinction were commonly available.

5.3 Visibility Conditions for Alternative Secondary PM NAAQS Scenarios

Purpose: The goal is to evaluate the effectiveness of alternative secondary $PM_{2.5}$ NAAQS, including 2 that use the $PM_{2.5}$ mass concentration indicator (i.e., the current 15 $\mu g/m^3$ annual, 35 $\mu g/m^3$ 24-hour $PM_{2.5}$ NAAQS and a more restrictive 12 $\mu g/m^3$/25 $\mu g/m^3$ alternative), and 18 that use a 1-hour daylight PM_{10} light extinction indicator (i.e., all combinations of both a maximum daily 1-hr indicator and a 1-hr indicator based on all daylight hours with 3 percentile forms (90^{th}, 95^{th} and 98^{th}) and 3 levels (CPLs) for the 15 urban areas).

Approach: The hourly averaged PM_{10} light extinction data set developed to characterize current conditions for the 15 urban areas was used as the starting point for a rollback adjustment to simulate just meeting the various alternative PM NAAQS scenarios. Rollback is not applied to the PRB portion of the $PM_{2.5}$ as estimated using CMAQ modeling, though it is applied uniformly to all other $PM_{2.5}$ components. This process produces adjusted daylight hourly PM_{10} light extinction data sets for each urban area that would just meet each of the alternative NAAQS scenarios that can be assessed with respect to their visibility protection effectiveness.

Principal Results: Each of the PM NAAQS scenarios that used PM_{10} light extinction as the indicator produced similar distributions of hourly PM_{10} light extinction across the 15 urban areas. This is not the case for the two scenarios that used $PM_{2.5}$ mass concentration as the indicator, where for example the 90^{th} percentile PM_{10} light extinction values vary among the 15 urban areas by as much as a factor of 2 to 3. The maximum daily 1-hour form of the alternative NAAQS is more restrictive for any percentile than the all-hours form. In fact the 90^{th} percentile of the maximum daily form is nearly identical with respect to design values for current conditions and the percent reduction required to just meet it as the 98th percentile for the all-hours form.

Technical Issues: The rollback approach implicitly assumes all non-PRB $PM_{2.5}$ components will be uniformly reduced to meet any of the alternative standards. In practice, emission control programs that would be developed to meet standards will not operate in this manner, nor will they be so fine tuned that each urban area would just meet the PM NAAQS. In that sense, the rollback assessment produces idealized results which for the PM_{10} light extinction based NAAQS scenarios are more uniform across urban areas than is likely should such a standard be implemented. The use of this nationally uniform emissions rollback approach is justified by it providing a common basis for assessing the variations in the magnitude of emissions controls required to meet NAAQS scenarios for urban areas across the country.

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6 REFERENCES

Abt Associates Inc., 2001. Assessing Public Opinions on Visibility Impairment due to Air Pollution: Summary Report. Prepared for EPA Office of Air Quality Planning and Standards; funded under EPA Contract No. 68-D-98-001. Abt Associates Inc., Bethesda, MD. January. Available: http://www.epa.gov/ttncaaa1/t1/reports/vis_rpt_final.pdf. Accessed 9/16/2008.

Air Resource Specialists. 2003. 2003 WinHaze Air Quality Modeler, Version 2.9. Air Resource Specialists, Inc. Available: http://www.air-resource.com/downloads.php. Accessed 9/16/2008.

Arizona Department of Environmental Quality. 2003. Recommendation for a Phoenix Area Visibility Index. Visibility Index Oversight Committee. Available: http://www.phoenixvis.net/PDF/vis_031403final.pdf. Accessed 9/16/2008. BBC Research & Consulting. 2002. Phoenix Area Visibility Survey. Draft Report. Available: http://www.azdeq.gov/environ/air/download/vis_021903f.pdf. Accessed 9/16/2008.

BBC Research & Consulting. 2003. *Phoenix Area Visibility Survey. Draft Report*. Available: http://www.azdeq.gov/environ/air/download/vis_021903f.pdf. Accessed 9/16/2008.

DeBell L. (2006). Spatial and seasonal patterns and temporal variability of haze and its constituents in the United States: Report IV. 1Cooperative Institute for Research in the Atmosphere. Colorado State University Fort Collins, CO. 156388

Ely, D.W., J.T. Leary, T.R. Stewart, and D.M. Ross. 1991. The Establishment of the Denver Visibility Standard. Presented at the 84th Annual Meeting & Exhibition of the Air and Waste Management Association. June 16-21.

Frank NH. (2006). Retained nitrate, hydrated sulfates, and carbonaceous mass in federal reference method fine particulate matter for six eastern U.S. cities. J Air Waste Manag Assoc, 56: 500-11

Henderson, R. (2006) Letter from Dr. Rogene Henderson, Chair, Clean Air Scientific Advisory Committee to the Honorable Stephen L. Johnson, Administrator, US EPA. Clean Air Scientific Advisory Committee Recommendations Concerning the Proposed National Ambient Air Quality Standards for Particulate Matter. March 21, 2006. Available: http://www.epa.gov/sab/pdf/casac-ltr-06-002.pdf

Henderson, R. (2008) Letter from Dr. Rogene Henderson, Chair, Clean Air Scientific Advisory Committee to the Honorable Stephen L. Johnson, Administrator, US EPA. Clean Air Scientific Advisory Committee Consultation on EPA's Draft Integrated Review Plan for the National Ambient Air Quality Standards for Particulate Matter January 3, 2008.

Jacques Whitford AXYS. 2007. The View Ahead; Identifying Options for a Visibility Management Framework for British Columbia. Report for the British Columbia Ministry of Environment. Available: http://www.env.gov.bc.ca/air/airquality/pdfs/view_ahead.pdf. Accessed 8/5/2009.

Malm WC; Trijonis J; Sisler J; Pitchford M; Dennis RL (1994). Assessing the effect of SO2 emission changes on visibility. Atmos Environ, 28: 1023-1034.

Molenar, J.V., W.C. Malm, and C.E. Johnson. 1994. Visual air quality simulation techniques. *Atmospheric Environment* 28(5):1055-1063.

NARSTO (2004) Particulate Matter Science for Policy Makers: A NARSTO Assessment. P. McMurry, M. Shepherd, and J. Vickery, eds. Cambridge University Press, Cambridge, England. ISBN 0 52 184287 5

Pitchford, M. and W. Malm. 1993. Development and applications of a standard visual index. *Atmospheric Environment* 28(5):1049-1054.

Pryor, S.C. 1996. Assessing public perception of visibility for standard setting exercises. *Atmospheric Environment* 30(15):2705-2716.

Russell, A; Samet, J.M. (2010). Letter from the Clean Air Science Advisory Committee (CASAC) Ambient Air Monitoring and Methods Subcommittee (AAMMS) to the Honorable Lisa P, Jackson, Administrator, US EPA. Review of the White Paper on Particulate Matter (PM) Light Extinction Measurements. April 29, 2010, Available at: http://yosemite.epa.gov/sab/sabproduct.nsf/264cb1227d55e02c85257402007446a4/92C9F5AA09A76A93852577150004A782/$File/EPA-CASAC-10-010-unsigned.pdf

RWDI AIR. 2008. Final Report: Establishing a Visibility Goal for Wilderness and Urban areas in British Columbia and Canada. Report to the British Columbia Ministry of Environment. Available: http://www.env.gov.bc.ca/air/airquality/pdfs/visibility_goal_report_final.pdf. Accessed 8/5/2009.

Samet, J. (2009a) Letter from Clean Air Scientific Advisory Committee (CASAC) to the Honorable Lisa P. Jackson, Administrator, US. EPA. Consultation on EPA's *Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Urban Visibility Impact Assessment*. May 21, 2009. Available: http://yosemite.epa.gov/sab/sabpeople.nsf/WebCommittees/CASAC.

Samet, J. (2009b) Letter from Clean Air Scientific Advisory Committee (CASAC) to the Honorable Lisa P. Jackson, Administrator, US. EPA. Review of the *Particulate Matter Urban-Focused Visibility Assessment* (First External Review Draft); November 24, 2009. - Available: http://yosemite.epa.gov/sab/sabpeople.nsf/WebCommittees/CASAC.

Samet, J. (2010a). Letter from Clean Air Scientific Advisory Committee (CASAC) to the Honorable Lisa P. Jackson, Administrator, US EPA. Review of Particulate Matter Urban-Focused Visibility Assessment (Second External Review Draft, January 2010). April 20, 2010. Available: http://yosemite.epa.gov/sab/sabproduct.nsf/0D5CB76AFE7FA77C8525770D004EED55/$File/EPA-CASAC-10-009-unsigned.pdf

Samet, J. (2010b). Letter from Clean Air Scientific Advisory Committee to the Honorable Lisa P. Jackson, Administrator, US EPA. CASAC Review of Policy Assessment for the Review of the PM NAAQS (First External Revew Draft, March 2010). May 17, 2010. Available: http://yosemite.epa.gov/sab/sabproduct.nsf/264cb1227d55e02c85257402007446a4/E504EE3276D87A9E8525772700647AFB/$File/EPA-CASAC-10-011-unsigned.pdf/.

Schmidt. M; Frank, N.; Mintz, D.; Rao, T.; McCluney, L. (2005). Analyses of particulate matter (PM) data for the PM NAAQS review. Memorandum to PM NAAQS review docket EPA-HQ-OAR-2001-0017. June 30, 2005. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_cr_td.html

Smith, A. 2009. Comments on the First External Review Draft of EPA's "Integrated Science Assessment for Particulate Matter." CRA International, Washington, DC. March 30. Prepared for the Utility Air Regulatory Group. Submitted as public comment to the public meeting EPA Clean Air Science Advisory Council. April 2.

Smith, A.E. and S. Howell. 2009. An Assessment of the Robustness of Visual Air Quality Preference Study Results. CRA International, Washington, DC. March 30. Prepared for the Utility Air Regulatory Group. Submitted as supplemental material to presentation by Anne Smith to the public meeting of the EPA Clean Air Science Advisory Council. April 2.

Statistics Canada. 2009a. Population and Dwelling Count Highlight Tables, 2006 Census. Available: http://www12.statcan.gc.ca/census-recensement/2006/dp-pd/hlt/97-550/Index.cfm?Page = INDX&LANG = Eng. Accessed 7/13/2009.

Statistics Canada. 2009b. Population: Chilliwack, British Columbia (Census Agglomeration). Available: http://www12.statcan.ca/census-recensement/2006/dp-pd/prof/92-591/details/page.cfm?Lang = E&Geo1 = CMA&Code1 = 930__&Geo2 = PR&Code2 = 59&Data = Count&SearchText = Chilliwack&SearchType = Begins&SearchPR = 01&B1 = Population&Custom. Accessed 7/13/2009.

Stratus Consulting Inc., 2009. Review of Urban Visibility Public Preference Studies: Final Report. Prepared for EPA Office of Air Quality Planning and Standards; funded under EPA Contract No. EP-D-08-100 with Abt Associates Inc., Bethesda, MD. September. Available: http://www.regulations.gov/search/Regs/home.html#documentDetail?R=0900006480a296e2

Trijonis, J. C. 1990. Natural Background Conditions for Visibility/Aerosols. Washington (DC): National Acid Precipitation Assessment Program. NAPAP State of Science and Technology Report no. 24. http://www.epa.gov/ttncaaa1/t1/memoranda/rh_envcurhr_gd.pdf

US EPA (1996a). Air Quality Criteria for Particulate Matter. Research Triangle Park, NC: National Center for Environmental Assessment-RTP Office; report no. EPA/600/P-95/001aF-cF. 3v. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_pr_cd.html.

US EPA (1996b). Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper. Research Triangle Park, NC 27711: Office of Air Quality Planning and Standards; report no. EPA-452/R-96-013. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_pr_sp.html.

U.S. EPA. (2003) Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Program. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA-454/B-03-005

US EPA (2004). Air Quality Criteria for Particulate Matter. National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711; report no. EPA/600/P-99/002aF and EPA/600/P-99/002bF. October 2004. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_cr_cd.html

US EPA (2005). Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper. Research Triangle Park, NC 27711: Office of Air Quality Planning and Standards; report no. EPA EPA-452/R-05-005a. December 2005. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_cr_sp.html

U.S. Environmental Protection Agency. (2007). Draft Integrated Review Plan for the National Ambient Air Quality Standards for Particulate Matter. October 2007. U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA 452/P-08-006. Available at: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_pd.html

US EPA (2008a). Integrated Review Plan for the National Ambient Air Quality Standards for Particulate Matter. National Center for Environmental Assessment and Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. Report No. EPA 452/R-08-004. March 2008. Available at: http://www.epa.gov/ttn/naaqs/standards/pm/data/2008_03_final_integrated_review_plan.pdf

U.S. EPA (2008b). Integrated Science Assessment for Particulate Matter: First External Review Draft. National Center for Environmental Assessment-RTP Division, Office of Air Quality Planning and Standards, Research Triangle Park, NC. EPA/600/R-08/139 and 139A. December 2008. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_isa.html.

US EPA (2009a). Integrated Science Assessment for Particulate Matter: Final Report. National Center for Environmental Assessment-RTP Division, Office of Air Quality Planning and Standards, Research

Triangle Park, NC. EPA/600/R-08/139F. December 2009. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_isa.html.

US EPA (2009b). Particulate Matter National Ambient Air Quality Standards: Scope and Methods Plan for Urban Visibility Assessment. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. EPA-452/P-09-001. February 2009. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_pd.html.

US EPA (2009c). Particulate Matter Urban-Focused VisibilityAssessment: First External Review Draft. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. EPA-452/P-09-005. September 2009. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_pd.html

US EPA (2009d). Policy Assessment for the Review of the Particulate Matter National Ambient Air Quality Standards – Preliminary Draft. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. EPA-452/P-09-007. September 2009. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_pa.html.

US EPA (2010a). Particulate Matter Urban-Focused Visibility Assessment – Second External Review Draft. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. EPA-452/P-10-002. January 2010. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_risk.html.

US EPA (2010b). Policy Assessment for the Review of the Particulate Matter National Ambient Air Quality Standards-First External Review Draft. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. EPA 452/P-10-003. March 2010. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_pa.html.

US EPA (2010c). Particulate Matter Urban-1 Focused Visibility Assessment – Second External Review Draft. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. EPA-452/P-10-002. January 2010. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_risk.html.

US EPA (2010d). White Paper on PM Light Extinction Measurements. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. January 2010. Available at: http://yosemite.epa.gov/sab/sabproduct.nsf/264cb1227d55e02c85257402007446a4/823a6c8842610e768525764900659b22!OpenDocument

US EPA (2010e). Quantitative Risk Assessment for Particulate Matter – Final Report. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. EPA-452/R-10-005. June 2010. Available: http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_2007_risk.html.

APPENDICES[1]

A. $PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM_{10} Light Extinction in the 15 Study Areas

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

C. Development of PRB Estimates of $PM_{2.5}$ Components, $PM_{10\text{-}2.5}$, and PM_{10} Light Extinction

D. Relationships between PM Mass Concentration and PM_{10} Light Extinction under Current Conditions

E. Differences in Daily Patterns of Relative Humidity and PM_{10} Light Extinction between Areas and Seasons

F. Distributions of Maximum Daily Daylight PM_{10} Light Extinction under "Just Meets" Conditions

G. Additional Information on the Exclusion of Daylight Hours with Relative Humidity Greater than 90 Percent

H. Inter-Year Variability

I. Daylight Hours

J. Logit Memorandum

[1]When viewing St. Louis results throughout these appendices, the reader should keep in mind that credible comments concerning unrealistically high $PM_{10\text{-}2.5}$ values were received but too late in the review process to permit reanalysis using an alternate data set or to remove St. Louis from all portions of this document. However, the text in the body of this document has been revised to caution readers with respect to the St. Louis results, and they will not be included in the visibility effects discussion in the final PM Policy Assessment document. Some graphics have been updated to exclude St. Louis results.

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APPENDIX A

$PM_{2.5}$ MONITORING SITES AND MONITORS PROVIDING 2005-2007 DATA FOR THE ANALYSIS OF PM_{10} LIGHT EXTINCTION IN THE 15 STUDY AREAS

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM_{10} 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 $PM_{2.5}$ nonattainment area Neighborhood Scale Parameters taken from this site: • 24-hour FRM $PM_{2.5}$ mass (AQS parameter 88101; one-in-three sampling schedule) • PM2.5 speciation (one-in-six sampling schedule) • 1-hour PM2.5 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..	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 $PM_{2.5}$ 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

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM_{10} 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 $PM_{2.5}$ DV site in the San Joaquin nonattainment area. Neighborhood Scale Parameters taken from this site: • 24-hour FRM $PM_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • $PM_{2.5}$ speciation (one-in-three sampling schedule) • 1-hour $PM_{2.5}$ mass (AQS parameter 88501, $PM_{2.5}$ Raw Data) Met-One BAM No continuous PM_{10} monitoring at this site, see right hand column..	NA	$PM_{10-2.5}$ values were determined using regional average $PM_{10-2.5}$: $PM_{2.5}$ ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM$_{10}$ 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$_{10-2.5}$**
Los Angeles	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 PM$_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • PM$_{2.5}$ speciation (one-in-three sampling schedule) • 1-hour PM$_{2.5}$ (AQS parameter 88502, Acceptable PM$_{2.5}$ AQI & Speciation Mass) R&P 1400 TEOM No continuous PM$_{10}$ 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 PM$_{2.5}$ 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 PM$_{10}$ STP mass (AQS parameter 81102) • Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET • Sample Analysis Method: TEOM-GRAVIMETRIC 6% of PM$_{10-2.5}$ values were determined using regional average PM$_{10-2.5}$: PM$_{2.5}$ ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM_{10} 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 $PM_{2.5}$ mass (AQS parameter 88101; one-in-six sampling schedule) • $PM_{2.5}$ speciation (one-in-three sampling schedule) No continuous PM_{10} 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 40^{th} 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 $PM_{2.5}$ 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 PM_{10} STP mass (AQS parameter 81102) Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET Sample Analysis Method: TEOM-GRAVIMETRIC 2% of $PM_{10-2.5}$ values were determined using regional average $PM_{10-2.5}$: $PM_{2.5}$ ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM_{10} 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 $PM_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • $PM_{2.5}$ speciation (one-in-three sampling schedule) • 1-hour $PM_{2.5}$ mass (AQS parameter 88501, $PM_{2.5}$ Raw Data) FDMS-Gravimetric No continuous PM_{10} monitoring at this site, see right hand column.	NA	$PM_{10-2.5}$ values were determined using regional average $PM_{10-2.5}$: $PM_{2.5}$ ratios from 2005 Staff Paper
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 $PM_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • $PM_{2.5}$ speciation (one-in-three sampling schedule) • 1-hour $PM_{2.5}$ mass (AQS parameter 88502, Acceptable $PM_{2.5}$ AQI & Speciation Mass) TEOM Gravimetric 50 deg C No continuous PM_{10} monitoring at this site, see right hand column..	NA	$PM_{10-2.5}$ values were determined using regional average $PM_{10-2.5}$: $PM_{2.5}$ ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM$_{10}$ 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 PM$_{2.5}$ mass (AQS parameter 88101; one-in-six day 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) TEOM Gravimetric 50 deg C No continuous PM$_{10}$ monitoring at this site, see right hand column.	NA	PM$_{10-2.5}$ values were determined using regional average PM$_{10-2.5}$: PM$_{2.5}$ ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM$_{10}$ 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$_{10-2.5}$**
St. Louis	AQS ID 295100085 State: Missouri City: St. Louis MSA: St, Louis, MO-IL Local Site Name: BLAIR STREET CATEGORY A CORE SLAM PM$_{2.5}$. 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 PM$_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • PM$_{2.5}$ speciation (one-in-three sampling schedule) • 1-hour PM$_{2.5}$ mass (AQS parameter 88502, Acceptable PM$_{2.5}$ AQI & Speciation Mass) TEOM Gravimetric 30 deg C No continuous PM$_{10}$ 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 PM$_{2.5}$ 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 PM$_{10}$ STP mass (AQS parameter 81102) • Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET • 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 PM$_{2.5}$ 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 PM$_{10}$ STP mass (AQS parameter 81102) • Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET • Sample Analysis Method: TEOM-GRAVIMETRIC • 4% of PM$_{10-2.5}$ values were determined using regional average PM$_{10-2.5}$: PM$_{2.5}$ ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM$_{10}$ 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 PM$_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • PM$_{2.5}$ speciation (one-in-three sampling schedule) • 1-hour PM$_{2.5}$ mass (AQS parameter 88502, Acceptable PM$_{2.5}$ AQI & Speciation Mass) TEOM Gravimetric 50 deg C • 1-hour PM$_{10}$ STP mass (AQS parameter 81102) Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET Sample Analysis Method: TEOM-GRAVIMETRIC	NA	Same as PM$_{2.5}$ site. 0.3% of PM$_{10-2.5}$ values were determined using regional average PM$_{10-2.5}$: PM$_{2.5}$ ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM$_{10}$ 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 PM$_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • PM$_{2.5}$ speciation (one-in-three sampling schedule) • 1-hour PM$_{2.5}$ mass (AQS parameter 88502, Acceptable PM$_{2.5}$ AQI & Speciation Mass) TEOM Gravimetric 30 deg C No continuous PM$_{10}$ 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 PM$_{2.5}$ site Neighborhood Scale Parameters taken from this site: • 1-hour PM$_{10}$ STP mass (AQS parameter 81102) Sample Collection Method: INSTRUMENT MET ONE 4 MODELS Sample Analysis Method: BETA ATTENUATION 8% of PM$_{10-2.5}$ values were determined using regional average PM$_{10-2.5}$: PM$_{2.5}$ ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM_{10} 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	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 $PM_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • $PM_{2.5}$ speciation (one-in-six sampling schedule) • 1-hour $PM_{2.5}$ mass (AQS parameter 88501, $PM_{2.5}$ Raw Data) TEOM Gravimetric 50 deg C • 1-hour PM_{10} STP mass (AQS parameter 81102) Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET Sample Analysis Method: TEOM-GRAVIMETRIC	NA	Same as $PM_{2.5}$ site. 2% of $PM_{10-2.5}$ values were determined using regional average $PM_{10-2.5}$: $PM_{2.5}$ ratios from 2005 Staff Paper

PM$_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM$_{10}$ 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 PM$_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • PM$_{2.5}$ speciation (one-in-three sampling schedule) • 1-hour PM$_{2.5}$ mass (AQS parameter 88502, Acceptable PM$_{2.5}$ AQI & Speciation Mass) TEOM Gravimetric 50 deg C No continuous PM$_{10}$ monitoring at this site, see right hand column.	NA	PM$_{10-2.5}$ values were determined using regional average PM$_{10-2.5}$: PM$_{2.5}$ ratios from 2005 Staff Paper
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 PM$_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • PM$_{2.5}$ speciation (one-in-three sampling schedule) • 1-hour PM$_{10}$ 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 PM$_{2.5}$ mass (AQS parameter 88502, Acceptable PM$_{2.5}$ AQI & Speciation Mass) TEOM Gravimetric 50 deg C	Same as PM$_{2.5}$ site. 5% of PM$_{10-2.5}$ values were determined using regional average PM$_{10-2.5}$: PM$_{2.5}$ ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM_{10} 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	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 Wilmington, 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 $PM_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • $PM_{2.5}$ speciation (one-in-six sampling schedule) • 1-hour $PM_{2.5}$ mass (AQS parameter 88501, $PM_{2.5}$ Raw Data) Beta Attenuation • 1-hour PM_{10} STP mass (AQS parameter 81102)	NA	Same as $PM_{2.5}$ site. 3% of $PM_{10-2.5}$ values were determined using regional average $PM_{10-2.5}$: $PM_{2.5}$ ratios from 2005 Staff Paper
New York	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 $PM_{2.5}$ mass (AQS parameter 88101; every day sampling schedule) • $PM_{2.5}$ speciation (one-in-three sampling schedule) • 1-hour $PM_{2.5}$ mass (AQS parameter 88502, Acceptable $PM_{2.5}$ AQI & Speciation Mass) TEOM Gravimetric 30 deg C No continuous PM_{10} 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 PM_{10} STP mass (AQS parameter 81102) Sample Collection Method: INSTRUMENTAL-R&P SA246B-INLET Sample Analysis Method: TEOM-GRAVIMETRIC 2% of $PM_{10-2.5}$ values were determined using regional average $PM_{10-2.5}$: $PM_{2.5}$ ratios from 2005 Staff Paper

$PM_{2.5}$ Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM_{10} 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 $PM_{10-2.5}$**

Notes:

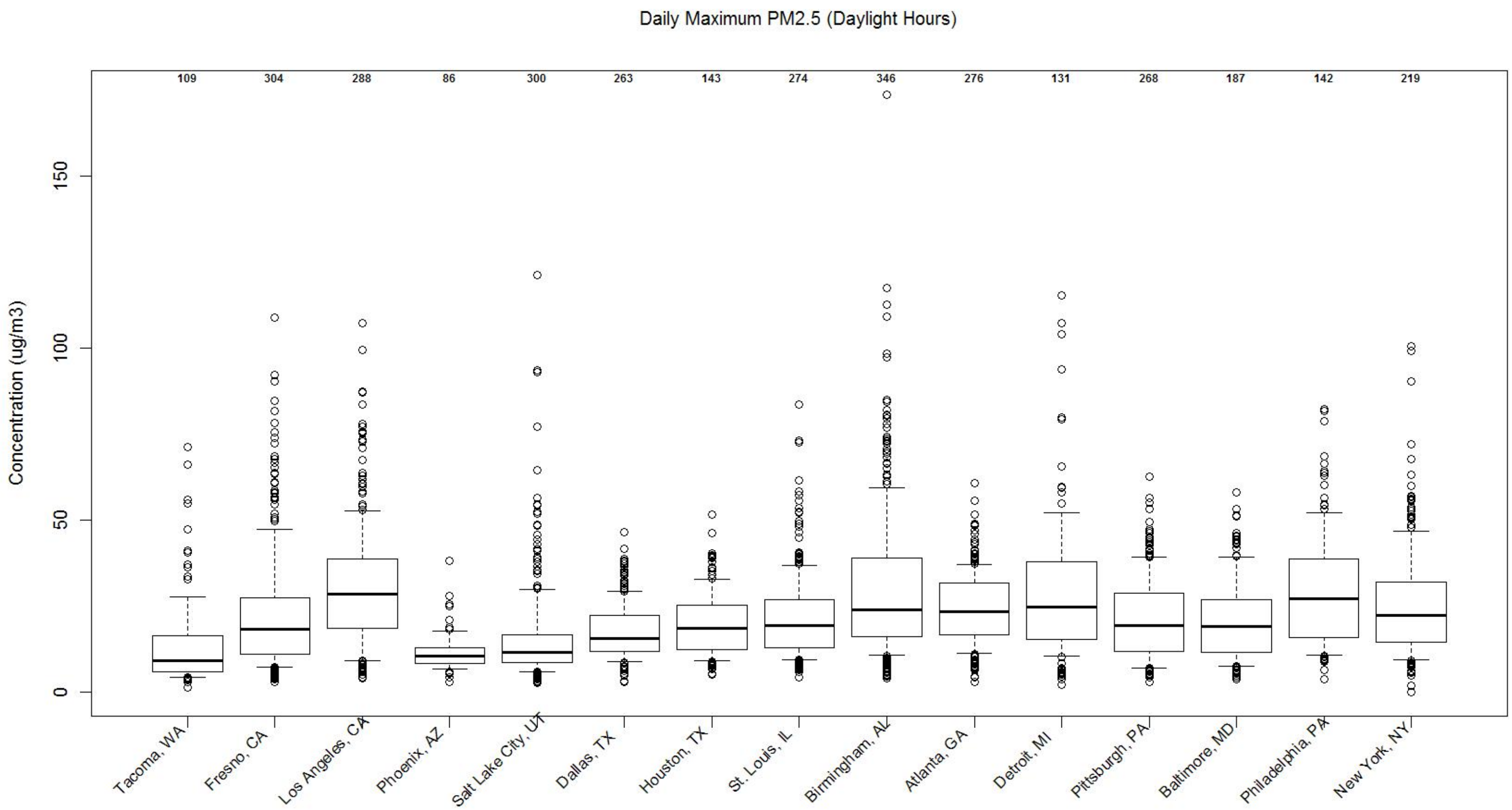
- In this Table, the 1-hour concentration parameter "88502, Acceptable $PM_{2.5}$ AQI & Speciation Mass" is the same as the ISA refers to as "FRM-like" $PM_{2.5}$ mass. An entry of "88501, $PM_{2.5}$ Raw Data" indicates that the monitoring agency makes no representation as to the degree of correlation 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.
- All continuous $PM_{2.5}$ data were obtained through the AirNow data system rather than from AQS, as an initial exploration indicated that not all the desired 1-hour data from all sites had been submitted to AQS. Data are submitted to the AirNow system within hours of collection and may not be subject to as much data validation review as is typical for data in AQS, despite the opportunity offered by the AirNow system for monitoring agencies to correct data after initial submission.

APPENDIX B

DISTRIBUTIONS OF ESTIMATED $PM_{2.5}$ AND OTHER COMPONENTS

Figure B-1 – Distribution of Daily Maximum $PM_{2.5}$ and $PM_{10-2.5}$ Across the 2005-2007 Period, by Study Area

(a) Daily Maximum Daylight $PM_{2.5}$



(b) Daily Maximum Daylight $PM_{10\text{-}2.5}$

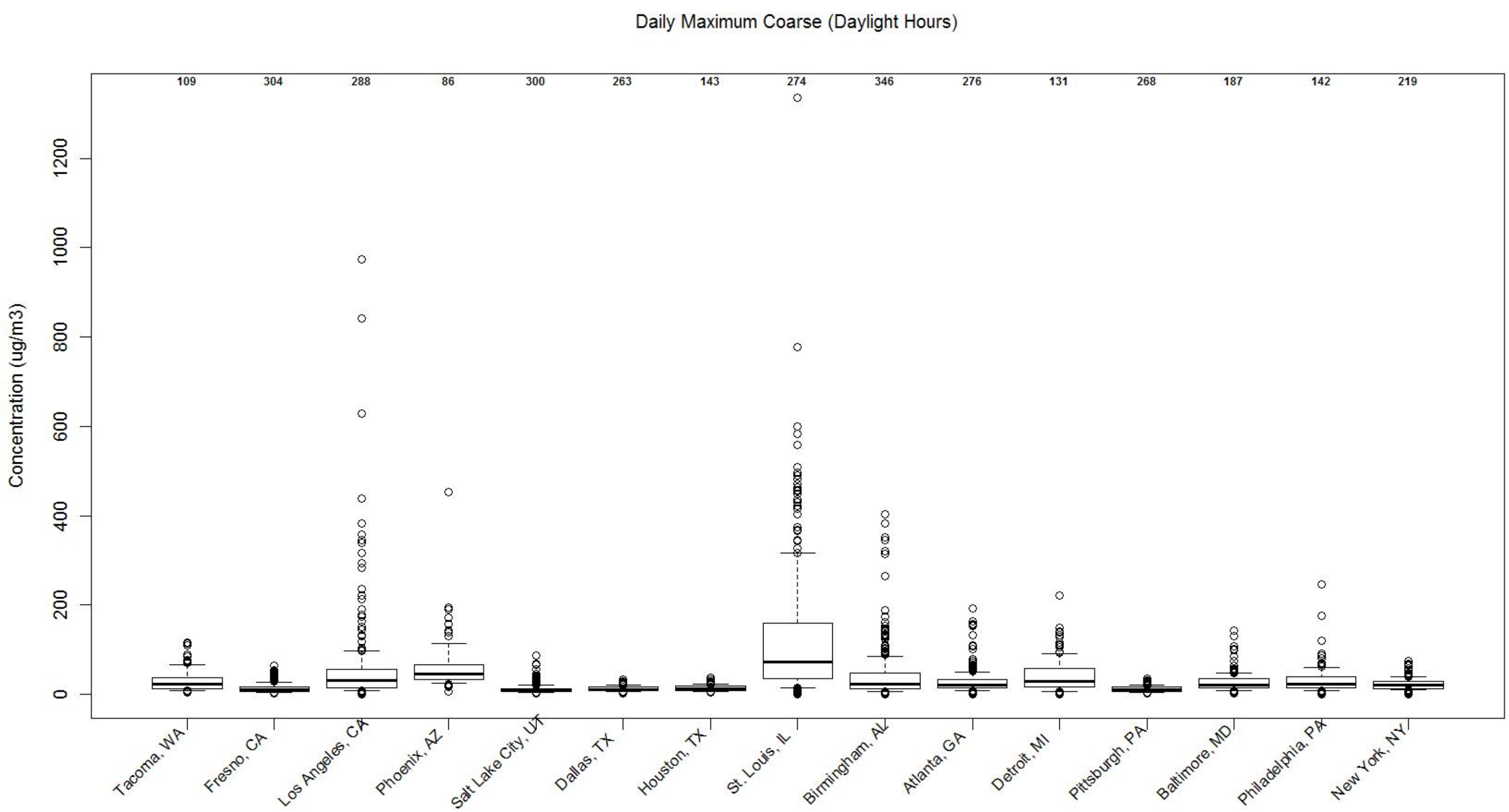


Figure B-2 – Distribution of Hourly $PM_{2.5}$ Components Across the 2005-2007 Period, by Study Area

(a) 1-Hour Daylight Sulfate (dry, fully neutralized)

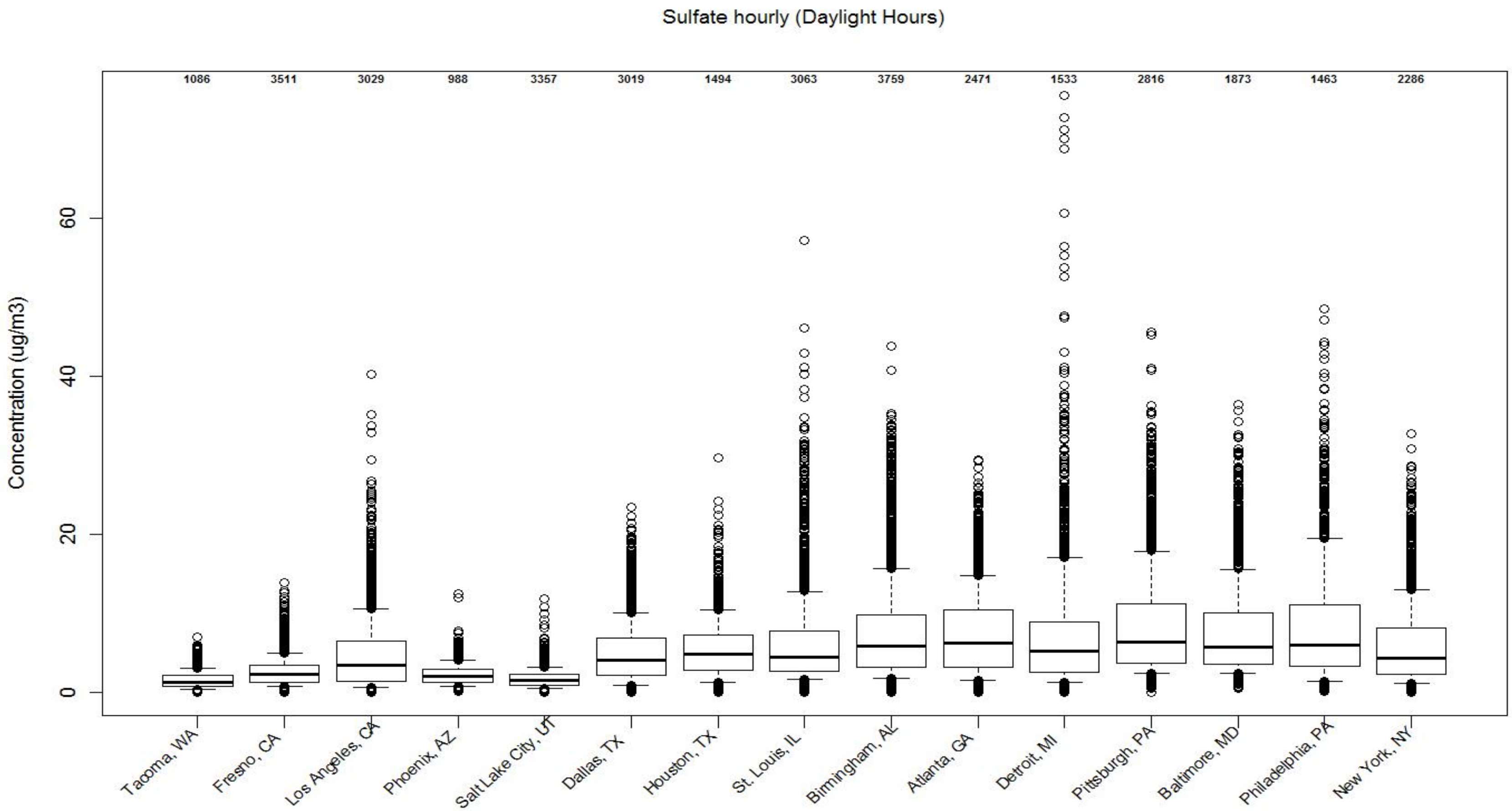


Figure B-2 – Distribution of Hourly $PM_{2.5}$ Components Across the 2005-2007 Period, by Study Area, continued

(b) 1-Hour Daylight Nitrate (dry, fully neutralized, CSN method consistent)

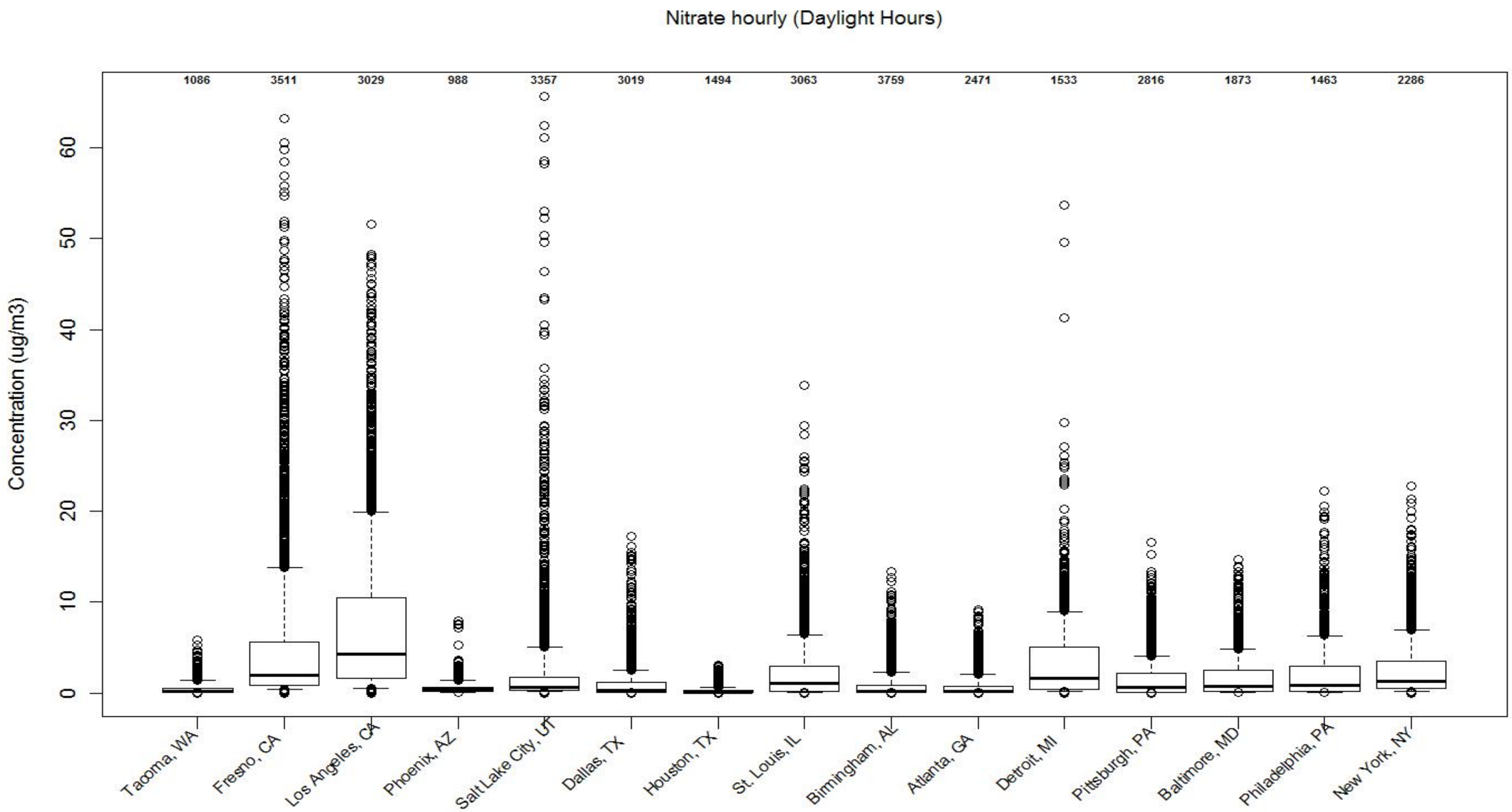


Figure B-2 – Distribution of Hourly $PM_{2.5}$ Components Across the 2005-2007 Period, by Study Area, continued

(c) 1-Hour Daylight Elemental Carbon

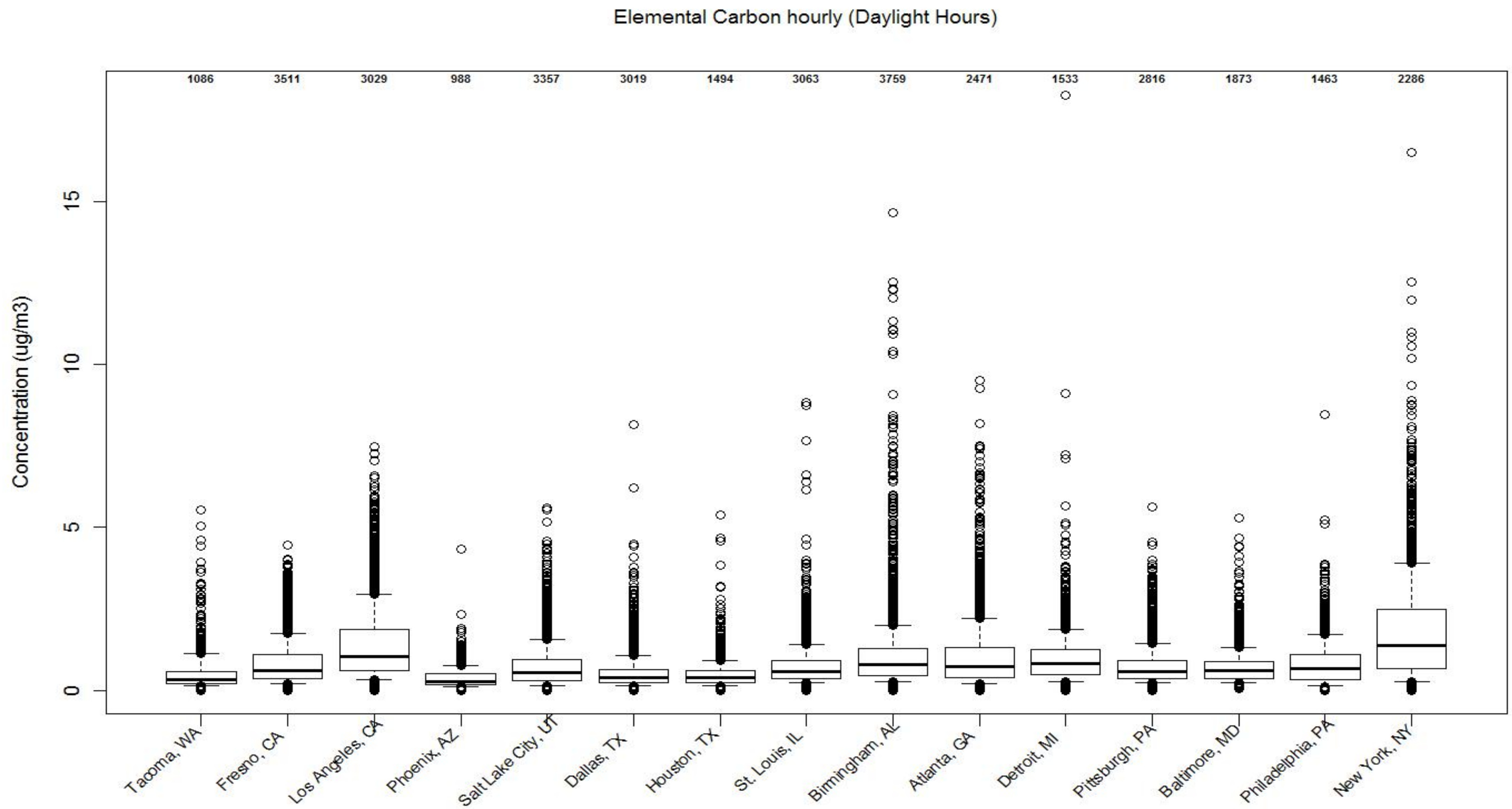


Figure B-2 – Distribution of Hourly $PM_{2.5}$ Components Across the 2005-2007 Period, by Study Area, continued

(d) 1-Hour Daylight Organic Carbonaceous Material (by SANDWICH method)

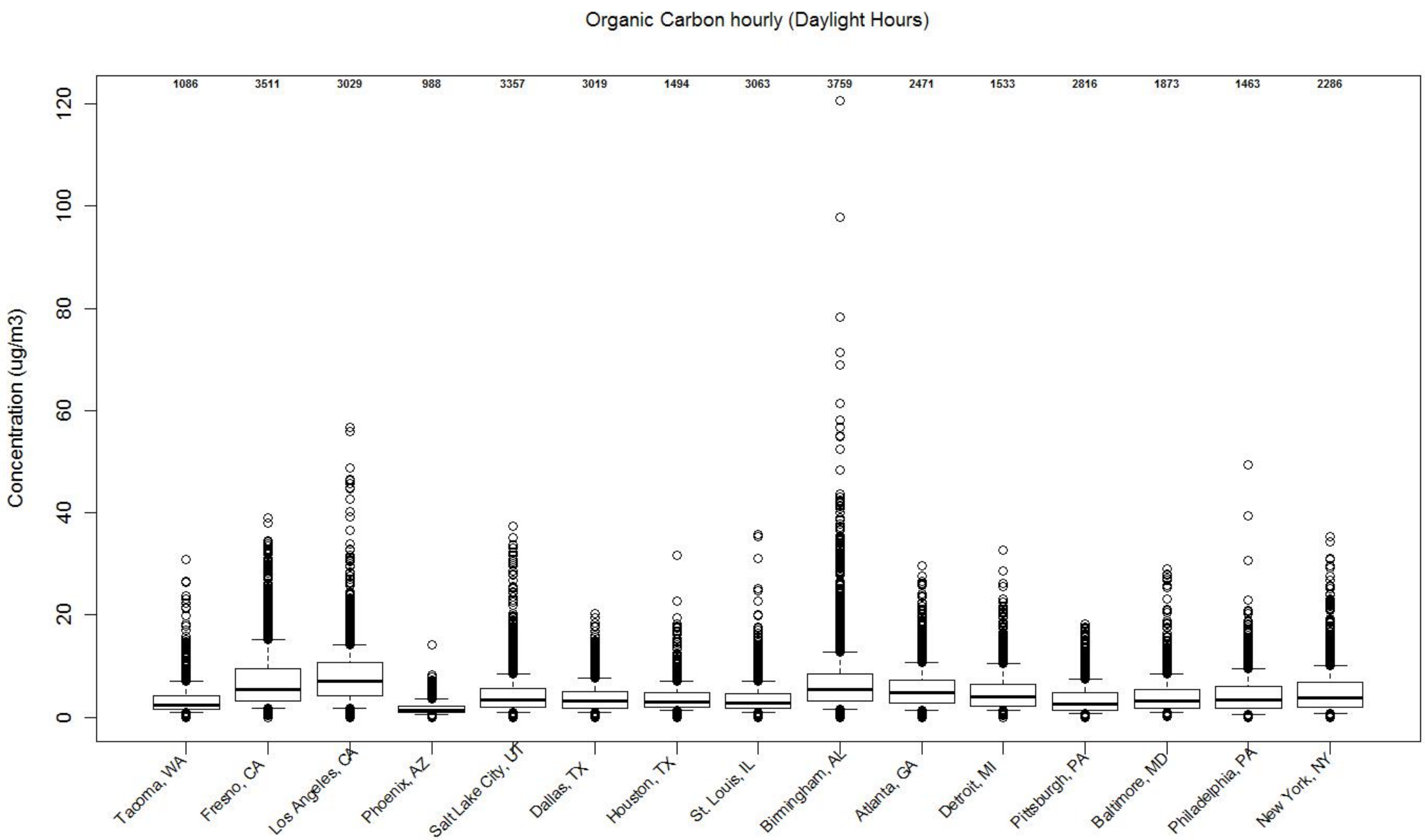
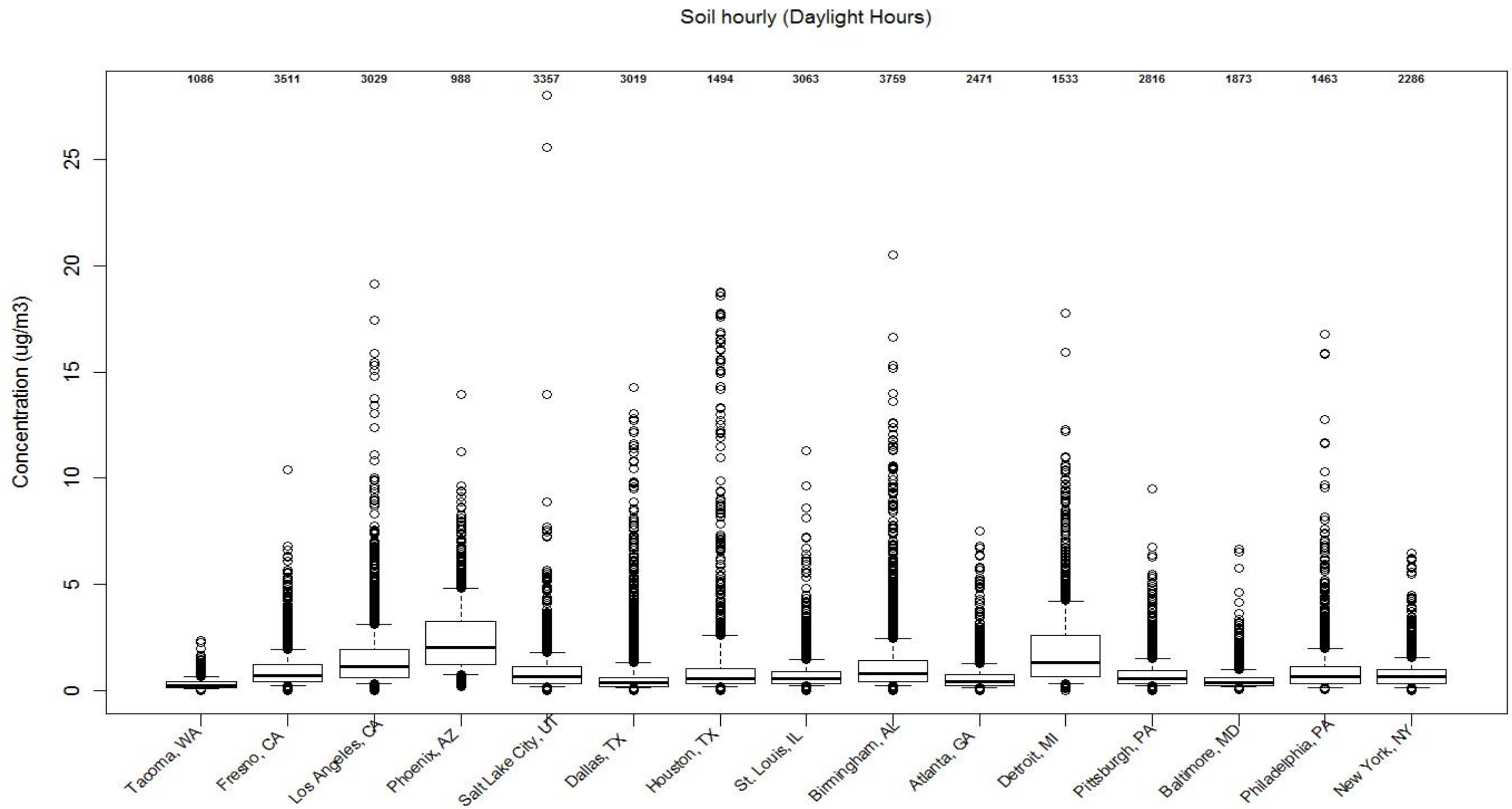


Figure B-2 – Distribution of Hourly $PM_{2.5}$ Components Across the 2005-2007 Period, by Study Area, continued

(e) 1-Hour Daylight Fine Soil



APPENDIX C

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

Policy relevant background levels of PM_{10} 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 ISA (US EPA, 2009a). Estimates of PRB for PM_{10} 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 ISA (US EPA, 2009a).

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. We generally observed that PRB concentrations did not vary greatly across the several grid cells overlaying the urbanized area of a given study area; this is reasonable given the exclusion of local anthropogenic sources from this CMAQ model run. CMAQ estimates of PRB for the five $PM_{2.5}$ components averaged across grid cells and months were not adjusted in any.[2]

There are too many values of PRB to present or illustrate them comprehensively in this document. Table C-1 presents annual average concentrations by study area to summarize these PRB estimates for the $PM_{2.5}$ components (including the specific form assumed for sulfate, nitrate, and organic carbon). The right hand column of the table shows the $PM_{2.5}$ mass calculated from the CMAQ-estimated components, including factors to fully neutralize sulfate and nitrate (but with no water mass added). One notable feature of the annual average of the PRB estimates is the relatively high values for elemental and organic carbon PRB for the Tacoma study area. This area is often affected by wildfires for extended

[2] This approach to estimation of PRB for $PM_{2.5}$ shares the same information source but is more disaggregated than the approach used in the health risk assessment for this review of the PM NAAQS (US EPA, 2010e). In the health risk assessment, PRB estimates for $PM_{2.5}$ mass concentration are taken from the same CMAQ model run, but are averaged by calendar quarter and by region of the country.

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.

Another notable feature of the PRB estimates is that the values for nitrate and fine soil/crustal are low relative to previous estimates of natural background concentrations of these fine PM components in Class I areas. These previous estimates by Trijonis (1990), repeated in the 2003 EPA guidance document "Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Program" (US EPA, 2003), are 0.10 $\mu g/m^3$ for (neutralized) nitrate and 0.50 $\mu g/m^3$ for fine soil. These estimates are based largely on data from the earliest of the IMPROVE monitoring stations, and thus may include some influence from non-PRB emissions. On the other hand, it is understandable that the unadjusted output from the PRB CMAQ scenario would underestimate nitrate and fine soil. CMAQ is known to underestimate actual nitrate in many situations when provided with a complete NOx inventory, and the nonanthropogenic emission inventory for NOx itself has uncertainties. The non-anthropogenic emission inventory for the PRB CMAQ run may also quite easily underestimate nonanthropogenic emissions of fine soil. However, even if the estimates for PRB nitrate and fine soil were increased to match the Trijonis (1990) estimates, the resulting values for PRB PM_{10} light extinction would increase only a little. Even at 90 percent relative humidity, the contribution to PM_{10} light extinction calculated from the Trijonis estimates is 1.7 Mm^{-1}, versus the average of about 0.5 Mm^{-1} using the estimates in Table C-1. The increment of 1.2 Mm^{-1} would be only about 10 to 20 percent of the PRB PM_{10} light extinction estimates shown in Table C-4, and would not significantly affect the calculation of PM_{10} light extinction values under the "what if" scenarios.

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	Calculated $PM_{2.5}$
Tacoma	0.45	0.026	0.15	1.3	0.31	2.4
Fresno	0.4	0.00062	0.08	0.74	0.19	1.6
Los Angeles	0.36	0.0037	0.028	0.3	0.036	0.9
Phoenix	0.31	0.000052	0.02	0.26	0.015	0.7
Salt Lake City	0.25	0.00028	0.025	0.26	0.034	0.7
Dallas	0.27	0.0022	0.055	0.59	0.092	1.1
Houston	0.3	0.0055	0.091	0.86	0.17	1.5
St. Louis	0.31	0.0027	0.047	0.53	0.07	1.1
Birmingham	0.29	0.007	0.099	1.1	0.19	1.8
Atlanta	0.3	0.016	0.1	1.1	0.19	1.8
Detroit-Ann	0.34	0.00062	0.024	0.32	0.018	0.8
Pittsburgh	0.3	0.00052	0.029	0.36	0.034	0.8
Baltimore	0.34	0.0016	0.039	0.44	0.054	1.0
Philadelphia	0.34	0.00097	0.03	0.36	0.032	0.9
New York City	0.36	0.0038	0.026	0.31	0.022	0.9
Average	0.33	0.00	0.06	0.59	0.10	1.20

It is also necessary to have estimates of PRB for $PM_{10-2.5}$, to feed into the IMPROVE algorithm. It is not EPA's practice to rely on coarse PM estimates from CMAQ modeling, so other sources of PRB estimates were considered. The final 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 (reproduced here as Table C-3). For sites in the lower 48 states, these annual means ranged from a low of 1.8 $\mu g/m^3$ to a high of 10.8 $\mu g/m^3$. No cross-year average or median values were provided that could be used as the point estimates needed in this assessment. Therefore, 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). 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 for PRB for coarse PM are shown in Table C-2. Lacking any other information, these PRB values are taken to apply to every hour of the year. The contour map and thus these values are influenced by data from IMPROVE sites that were not considered in the 2004 Criteria Document because they are not sufficiently isolated from the influence of anthropogenic emissions, including three IMPROVE sites in urban areas which clearly are influenced by anthropogenic emissions, and thus may be overestimates of PRB for coarse PM. Nevertheless, these values are generally within the range of values presented in the Criteria Document for the more isolated sites. These values for the more isolated sites are reproduced here in Table C-3 for ease of comparison. Further, these PRB values are low enough that their exact values have little effect on the results of "what if" estimation of PM_{10} light extinction levels under possible secondary PM NAAQS.

Table C-4 presents the resulting 2005-2007 average PRB daylight PM_{10} light extinction by study area, determined by using each daylight hour's f(RH),[3] the hour-specific PRB $PM_{2.5}$ component estimates (summarized only 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. While for conciseness Table C-4 presents

[3] Hour-specific relative humidity for PRB conditions was assumed to be the same as measured for current conditions.

only the annual average PRM for PM_{10} light extinction for all daylight hours in 2005-2007 in the rollback analysis of "what if" conditions hour-specific PRB values are retained and used.

The values of PRB PM_{10} light extinction in Table C-4 range between 5 and 11 Mm^{-1}. For comparison, the default estimates of natural visibility conditions in the 2003 EPA guidance document for Class I areas range between about 15 and 20 Mm^{-1}, including the Rayleigh contribution of about 10 Mm^{-1}. Thus, on an annual average basis the range of PRB estimates for PM_{10} light extinction used for this assessment is very consistent with the range of total light extinction values recommended in the guidance document.

Figure C-1. Selection of PRB Values for $PM_{10-2.5}$ Based on Contoured IMPROVE Monitoring Data

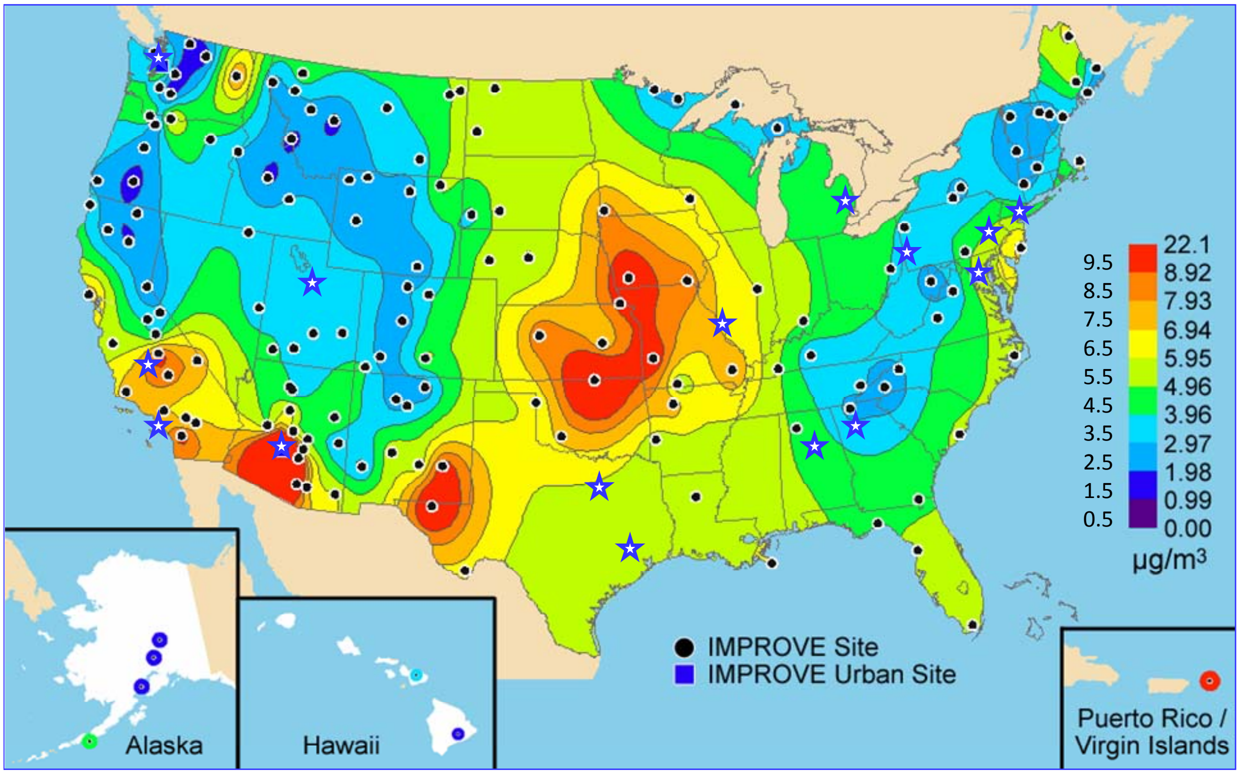


Table C-2. Policy Relevant Background Concentrations of $PM_{10-2.5}$ Used in This Assessment, Based on Measurements at IMPROVE Sites

Study Area	PRB $PM_{10-2.5}$ Mass (µg/m^3)
Tacoma	4.5
Fresno	5.5
Los Angeles	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	9.5
Pittsburgh	3.5
Baltimore	3.5
Philadelphia	6.5
New York	3.5

Table C-3. Ranges of 1990-2002 Annual Mean PM Concentrations at IMPROVE Monitoring Sites (µg/m^3)

	$PM_{2.5}$		PM_{10}		
Site	Nonsulfate	(Total)	Nonsulfate	(Total)	Coarse PM
Acadia National Park, ME	2.6-4.7	(4.9-8.2)	4.6-11.3	(7.3-15.0)	1.8-6.0
Big Bend National Park, TX	2.7-4.9	(5.0-7.8)	8.8-15.7	(11.3-18.6)	5.6-10.8
Boundary Waters Canoe Area, MN	2.6-3.9	(4.4-5.8)	5.0-10.2	(7.0-12.0)	2.3-7.3
Bryce Canyon National Park, UT	1.7-2.4	(2.6-3.4)	4.4-7.6	(5.3-8.5)	2.5-5.6
Bridger Wilderness, WY	1.5-2.2	(2.1-2.9)	3.7-6.5	(4.3-7.3)	1.9-4.7
Canyonlands National Park, UT	1.9-3.2	(2.8-4.0)	5.1-10.5	(6.3-11.7)	3.2-8.0
Denali National Park, AK	0.7-2.4	(1.1-3.2)	2.0-7.5	(2.4-8.3)	1.1-5.6
Gila Wilderness, NM	2.4-3.4	(3.4-4.5)	4.9-7.9	(6.0-9.2)	2.5-5.0
Glacier National Park, MT	3.8-5.5	(4.8-6.5)	7.6-14.2	(8.5-15.2)	3.7-9.6
Lassen Volcanic National Park, CA	1.7-4.5	(2.1-5.1)	4.0-8.1	(4.6-8.5)	1.8-6.4
Lone Peak Wilderness, UT	3.1-5.3	(4.1-6.9)	7.1-10.9	(8.1-12.5)	3.7-6.0
Lye Brook Wilderness, VT	2.3-4.8	(4.5-8.8)	4.2-9.7	(7.0-13.6)	1.6-4.8
Redwood National Park, CA	2.8-4.6	(3.6-5.4)	6.0-10.6	(7.2-11.7)	3.3-6.5
Three Sisters Wilderness, OR	2.0-5.4	(2.7-6.5)	4.0-8.1	(4.6-9.1)	1.9-4.4
Voyageurs National Park 1, MN	3.2-3.5	(5.1-5.9)	5.7-11.2	(8.1-13.1)	2.8-7.8
Voyageurs National Park 2, MN	2.6-5.4	(4.1-7.2)	5.2-10.8	(7.0-12.5)	2.6-5.3
Yellowstone National Park 1, WY	2.0-3.0	(2.6-3.6)	6.0-9.2	(6.6-9.9)	3.8-7.0
Yellowstone National Park 2, WY	1.7-4.1	(2.3-4.7)	3.6-9.0	(4.2-9.6)	1.9-5.0

Source: Table 3E-1 of the 2004 Air Quality Criteria Document for PM (US EPA, 2004)

Table C-4. 2005-2007 Average Policy Relevant Background Daylight PM_{10} Light Extinction

Study Area	2005-2007 Average Policy Relevant Background Daylight PM_{10} Light Extinction, Mm^{-1}
Tacoma	11
Fresno	11
Los Angeles	9
Phoenix	8
Salt Lake City	5
Dallas	8
Houston	10
St. Louis	9
Birmingham	9
Atlanta	10
Detroit	7
Pittsburgh	7
Baltimore	8
Philadelphia	8
New York	8

APPENDIX D

RELATIONSHIPS BETWEEN PM MASS CONCENTRATION AND PM_{10} LIGHT EXTINCTION UNDER CURRENT CONDITIONS

In the last review, the 2005 Staff Paper (US EPA, 2005) examined the correlation between PM_{10} 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 PM_{10} 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 on diurnal profiles from CMAQ modeling (see section 3.2.2).

Five scatter plot figures relating $PM_{2.5}$ mass concentrations and PM_{10} light extinction are presented here for the individual study areas, using different time periods for the two parameters; these time periods are not always matched. In each figure, the solid red curve was estimated by applying locally weighted scatter plot smoothing (LOESS) to the data. LOESS is a form of locally weighted polynomial regression (see http://support.sas.com/rnd/app/papers/loesssugi.pdf) and is a convenient way to visualize whether a dense data cloud in a scatter plot reflects a more linear or more nonlinear relationship. The LOESS results in each case indicate a generally linear relationship as a central tendency but with considerable variability around that central tendency.

Table D-1 presents squared correlation coefficients between observed and LOESS model-predicted values for all five figures. Because the LOESS regressions are generally linear, comparisons among these correlation coefficients should lead to the same qualitative conclusions as if coefficients from linear regressions were compared. All values of PM_{10} light extinction presented here are based on excluding daylight hours with relative humidity greater than 90 percent; hence, a nominally 4-hour period might have as few a one 1-hour PM_{10} light extinction value, although this is rare in this data set (see the tile plots in Figure 3-12). However, values of $PM_{2.5}$ mass concentration do not exclude any hours within the time period specified. Note that if several study areas were grouped by region and combined into a single scatter plot and LOESS fit, similar to the analysis of this topic in the 2005 Staff Paper, the correlations would be weaker than observed here for individual study areas.

Figure D-1 compares 24-hour $PM_{2.5}$ mass (as measured by the FRM/FEM filter-based sampler) to daily maximum daylight PM_{10} light extinction. The scatter is due the variations in

$PM_{2.5}$ concentration, in the mix of $PM_{2.5}$ components, and in relative humidity during the day and across days. Variations in $PM_{10-2.5}$ concentrations also contribute to the scatter, in all five comparisons presented here, since very high levels of $PM_{10-2.5}$ substantially influence PM_{10} light extinction. This source of variability in the scatter plots is particularly important for Los Angeles, Phoenix, and St. Louis which have many (Phoenix) or some (Los Angeles and St. Louis) hours with high $PM_{10-2.5}$.

Because of the large scatter and low correlation coefficients when using 24-hour $PM_{2.5}$ mass concentration to predict daily maximum daylight PM_{10} light extinction, it is natural to investigate how much the correlation improves when the $PM_{2.5}$ mass indicator is limited to shorter periods of time. The next four figures investigate correlations during such shorter periods, both matched and un-matched in time.

Figure D-2 compares hourly $PM_{2.5}$ mass (as actually measured by the continuous instruments) vs. same-hour daylight PM_{10} light extinction. Lack of agreement due to mismatch of time period is not a factor in this comparison. However, there is still considerable scatter due to variations in the mix of $PM_{2.5}$ components and in relative humidity across hours and days. In addition, continuous $PM_{2.5}$ mass instruments do not register the mass of each component consistently with FRM/FEM and CSN samplers and lab analysis methods. This affects the scatter in this figure because the estimates of hourly PM_{10} light extinction are linked to the FRM/FEM and CSN measurements more strongly than to the continuous $PM_{2.5}$ measurements. Note that the correlation values in Table D-1 for this comparison are better than those for the 24-hour comparison in most but not all study areas. An implication of this figure and the information in Table D-1 is that a wide range of PM_{10} light extinction levels can prevail in hours that have the same $PM_{2.5}$ mass concentration, even at a single site. Additional variability no doubt exists across areas.

Figure D-3 compares 12-4 pm average $PM_{2.5}$ mass vs. 12-4 pm average PM_{10} light extinction. The 2005 Staff Paper observed that because this time period is generally the time of lowest relative humidity, the relationship between $PM_{2.5}$ mass and PM_{10} light extinction (i.e., the ratio of the two or the slope of the regression line) is more uniform across areas during this period than the relationship for values of each averaged over all 24 hours in a day. In addition, the longer averaging period might be expected to reduce the effect of variability in the measurement of hourly $PM_{2.5}$ mass. However, comparison of Figures D-2 (time-matched single hours) and D-3 (time-matched 4 afternoon hours) and the corresponding columns of Table D-1 indicates that, after exclusion of hours with relatively humidity greater than 90 percent, the scatter in Figure D-3 is about the same as in Figure D-2. This residual scatter is due to composition differences from hour-to-hour, as well as to variations in relative humidity during hours with relative humidity of 90 percent or less. It can also be observed by comparing Figures

D-2 and D-3 that the period between 12 pm and 4 pm generally has lower levels of PM_{10} light extinction than for all daylight hours taken together, even after the exclusion of the hours with the highest relative humidity. (Note the change in scale between these two figures.)

Figure D-4 compares 12-4 pm average $PM_{2.5}$ mass vs. daily maximum daylight 1-hour PM_{10} light extinction. This time-unmatched comparison tests the usefulness of a 12-4 pm $PM_{2.5}$ mass indicator as a predictor of the daily PM_{10} light extinction metric of potentially greatest interest. The scatter in Figure D-4 is typically more than in Figure D-3 (4 time-matched afternoon hours), because daily maximum daylight 1-hour PM_{10} light extinction often occurs earlier in the day than the 12-4 pm period used to average the $PM_{2.5}$ mass, and the time period mismatch introduces prediction errors due to changes in $PM_{2.5}$ concentration and composition and relative humidity. An implication is that while a secondary NAAQS based on 12-4 pm average $PM_{2.5}$ mass might achieve a given level of protection across days and areas in avoiding high levels of PM_{10} light extinction between 12 and 4 pm, with some variation across areas due to composition and relative humidity differences, there could be considerable additional variation in the level of protection against PM_{10} light extinction during the earlier hours of the day when some areas often have their highest PM_{10} light extinction levels.

Figure D-5 compares 8 am-12 pm average $PM_{2.5}$ mass vs. daily maximum daylight 1-hour PM_{10} light extinction. This comparison is of interest because it may reduce the number of instances of time mismatch, versus the comparison made in Figure D-4, if the daily maximum PM_{10} light extinction often occurs between 8 am and 12 pm. The scatter in Figure D-5 is typically less than in Figure D-4 and the squared correlation coefficients larger, indicating that this earlier averaging period for $PM_{2.5}$ mass more often encompasses the period of maximum PM_{10} light extinction. However, the scatter in Figure D-5 is greater than that in Figure D-3 (4 time-matched afternoon hours).

Figure D-6 provides another perspective on the possible use of $PM_{2.5}$ mass concentration as an indicator for a secondary PM NAAQS aimed at protecting visual air quality. Figure D-6 shows in box-and-whisker plot form two versions of the ratios of PM_{10} light extinction to $PM_{2.5}$ mass concentration, allowing a comparison across the 15 study areas of the central tendencies and the distributions of these ratios. The Panel A version corresponds to the comparison in Figure D-1 (24-hour averages of $PM_{2.5}$ mass and PM_{10} light extinction) and the Panel B version corresponds to the comparison in Figure D-2 (time-matched single hour values). The data points in Figure D-6 were prepared as follows. In each day for each study area, the value of the indicated PM_{10} light extinction (24-hour average or 1-hour value) was divided by the indicated $PM_{2.5}$ concentration metric (24-hour average or 1-hour value). Ratios that reflect $PM_{2.5}$ concentrations less than 5 $\mu g/m^3$ or PM_{10} light extinction less than 64 Mm^{-1} were eliminated before plotting, as such data points represent days or hours that could not play any role in determining compliance with any of the NAAQS scenarios considered in this assessment; also, some of these low-concentration/extinction data pairs produced extreme ratios that obscured the pattern for data pairs of most policy interest. The maximum ratio value for the vertical scale in these plots is set at 40 to allow closer examination of the portion of the plot representing the bulk of the data; this prevents a very small number of daily maximum data points for a few study areas from appearing in Panel A and a very small percentage of 1-hour data points for a few study areas (Los Angeles and St. Louis in particular) from appearing in Panel B. The notable variation in the vertical positions of the 25-75 percentile boxes and the 90 percentile whiskers representing the ratios in the 15 areas illustrates the point that because of differences in PM composition mix and relative humidity (even after excluding hours with relative humidity greater than 90 percent) across study areas, a secondary NAAQS based on $PM_{2.5}$ mass concentration would not give equal protection in terms of PM_{10} light extinction levels across cities, days, and hours.

In the first public review draft of this assessment, it was notable that the correlation values for St. Louis and Philadelphia were much lower than for other areas. In this version (reflecting both corrections to relative humidity inputs and exclusion of hours with very high relative humidity) the correlation value for Philadelphia is about that for other eastern areas. The correlation values for St. Louis remain notably low relative to the average of all areas, for all five scatter plots. This is likely due to the influence of the high estimated values for $PM_{10-2.5}$. In several other cases of notably low correlation, the small available range of $PM_{2.5}$values relative to other areas contributes to the lower correlation values, e.g., in Phoenix, Dallas, and Houston.

Table D-1. Squared Correlation Coefficients between Observed and LOESS Model-predicted Values of PM_{10} Light Extinction

Area	Figure D-1 24-Hour $PM_{2.5}$ Mass vs. Daily Maximum Daylight 1-Hour PM_{10} Light Extinction	Figure D-2 1-Hour $PM_{2.5}$ Mass vs. Same-Hour PM_{10} Light Extinction	Figure D-3 12-4 pm Average $PM_{2.5}$ Mass vs. 12-4 pm Average PM_{10} Light Extinction	Figure D-4 12-4 pm Average $PM_{2.5}$ Mass vs. Daily Maximum Daylight 1-Hour PM_{10} Light Extinction	Figure D-5 8 am-12pm Average $PM_{2.5}$ Mass vs. Daily Maximum Daylight 1-Hour PM_{10} Light Extinction
Tacoma	0.48	0.80	0.78	0.29	0.65
Fresno	0.76	0.83	0.90	0.69	0.83
Los Angeles	0.57	0.63	0.66	0.52	0.69
Phoenix	0.22	0.67	0.73	0.18	0.20
Salt Lake City	0.88	0.89	0.95	0.80	0.89
Dallas	0.45	0.59	0.54	0.20	0.36
Houston	0.46	0.61	0.62	0.20	0.30
St. Louis	0.40	0.43	0.20	0.18	0.36
Birmingham	0.61	0.81	0.78	0.34	0.44
Atlanta	0.54	0.72	0.80	0.40	0.70
Detroit	0.62	0.55	0.61	0.11	0.30
Pittsburgh	0.73	0.63	0.66	0.52	0.62
Baltimore	0.78	0.69	0.69	0.58	0.71
Philadelphia	0.61	0.61	0.57	0.39	0.50
New York	0.69	0.77	0.76	0.51	0.62
AVERAGE	**0.59**	**0.68**	**0.68**	**0.39**	**0.54**

Figure D-1. Relationship Between 24-Hour $PM_{2.5}$ Mass vs. Daily Maximum Daylight 1-Hour PM_{10} Light Extinction.

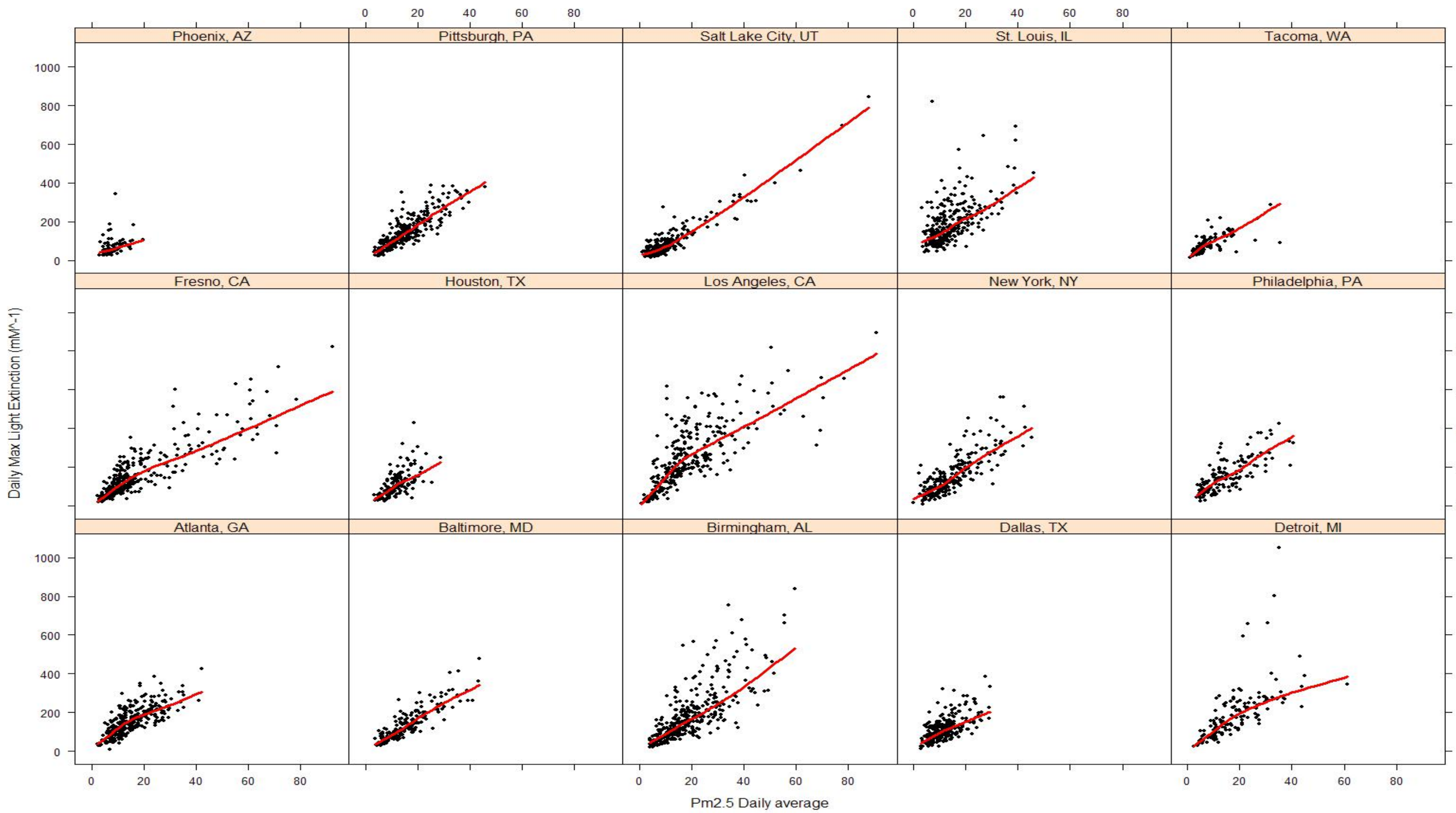


Figure D-2. Relationship Between Daylight 1-Hour $PM_{2.5}$ Mass vs. Same-Hour PM_{10} Light Extinction.

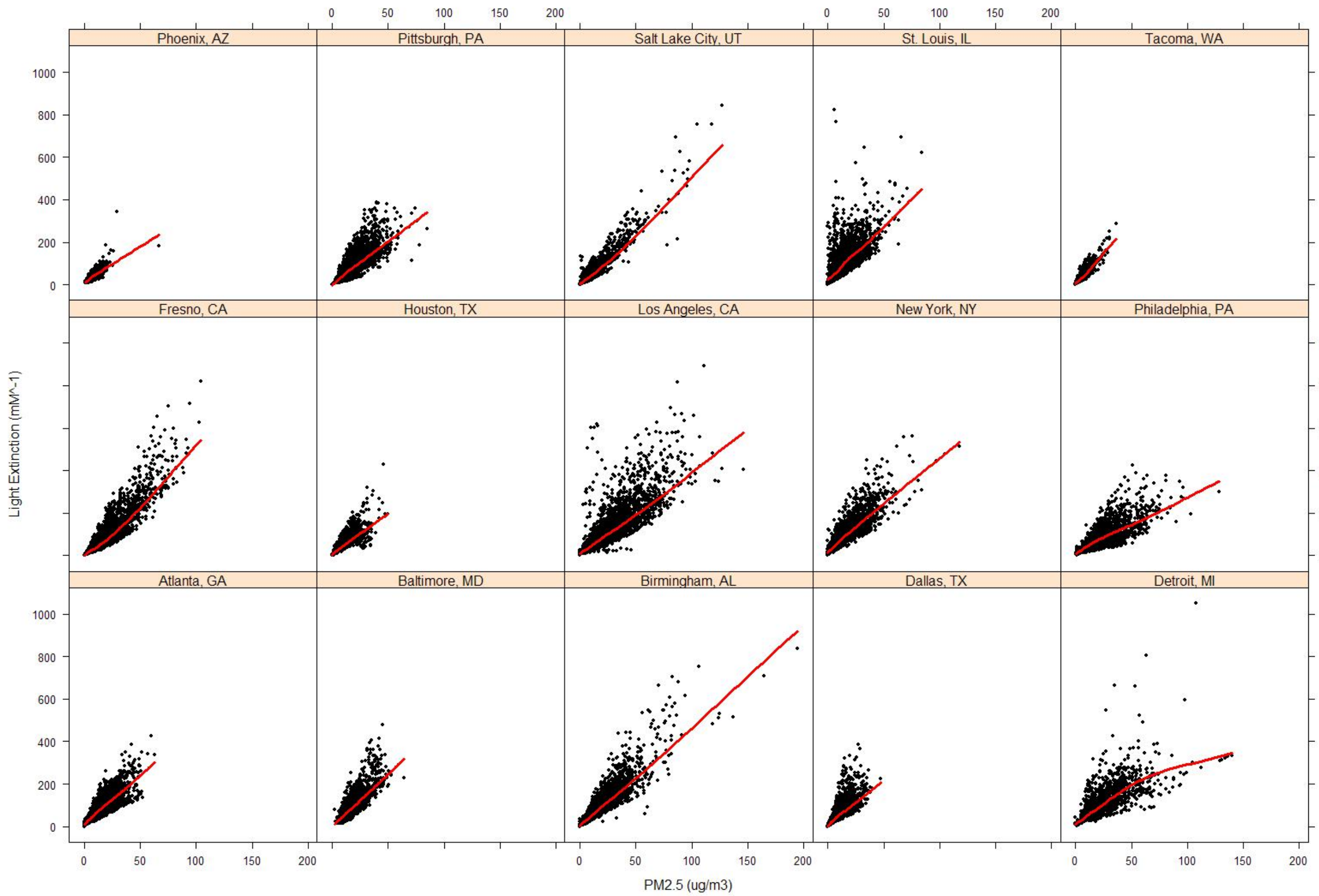


Figure D-3. Relationship Between 12-4 pm Average $PM_{2.5}$ Mass vs. 12-4 pm Average PM_{10} Light Extinction.

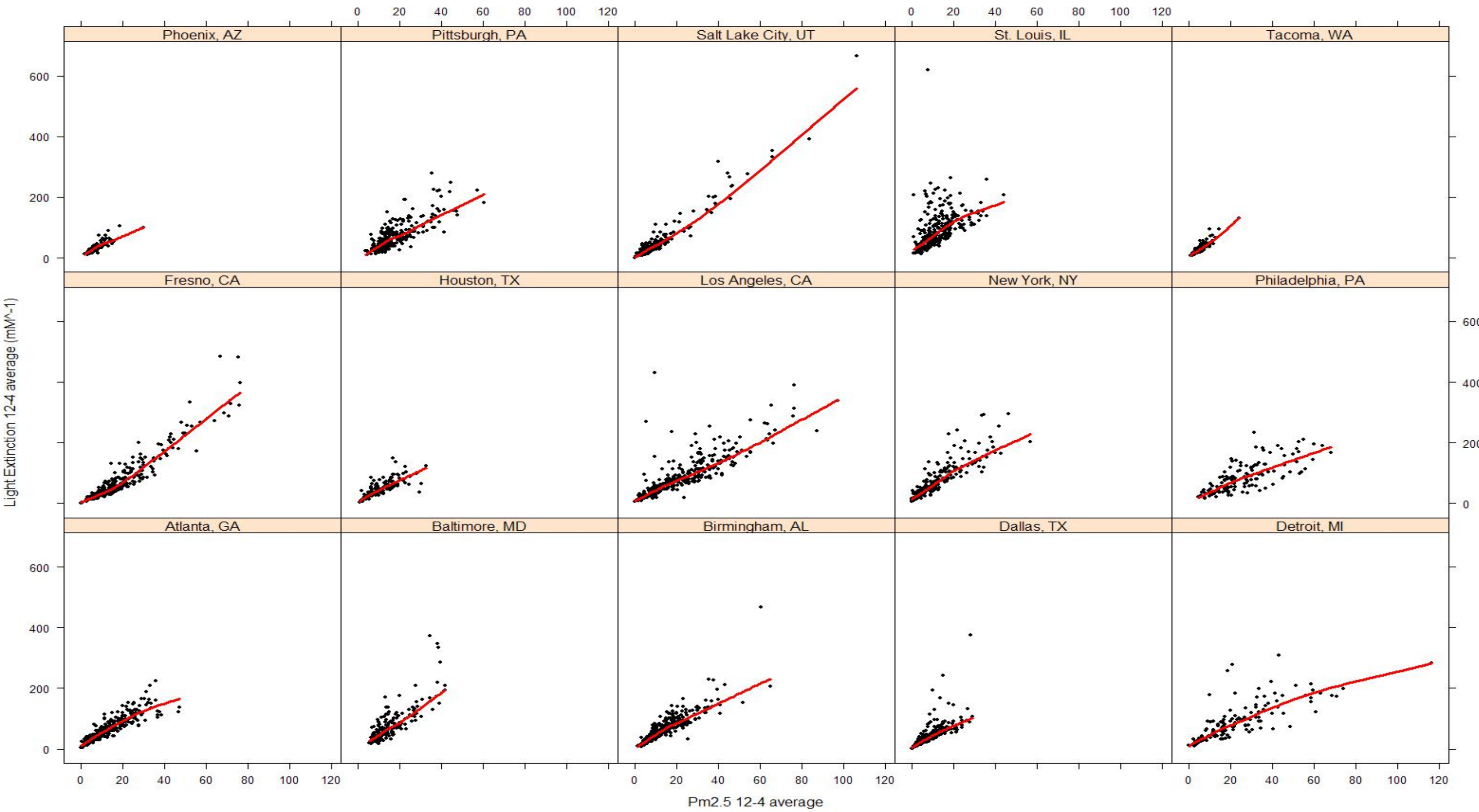


Figure D-4. Relationship Between 12-4 pm Average $PM_{2.5}$ Mass vs. Daily Maximum Daylight 1-Hour PM_{10} Light Extinction.

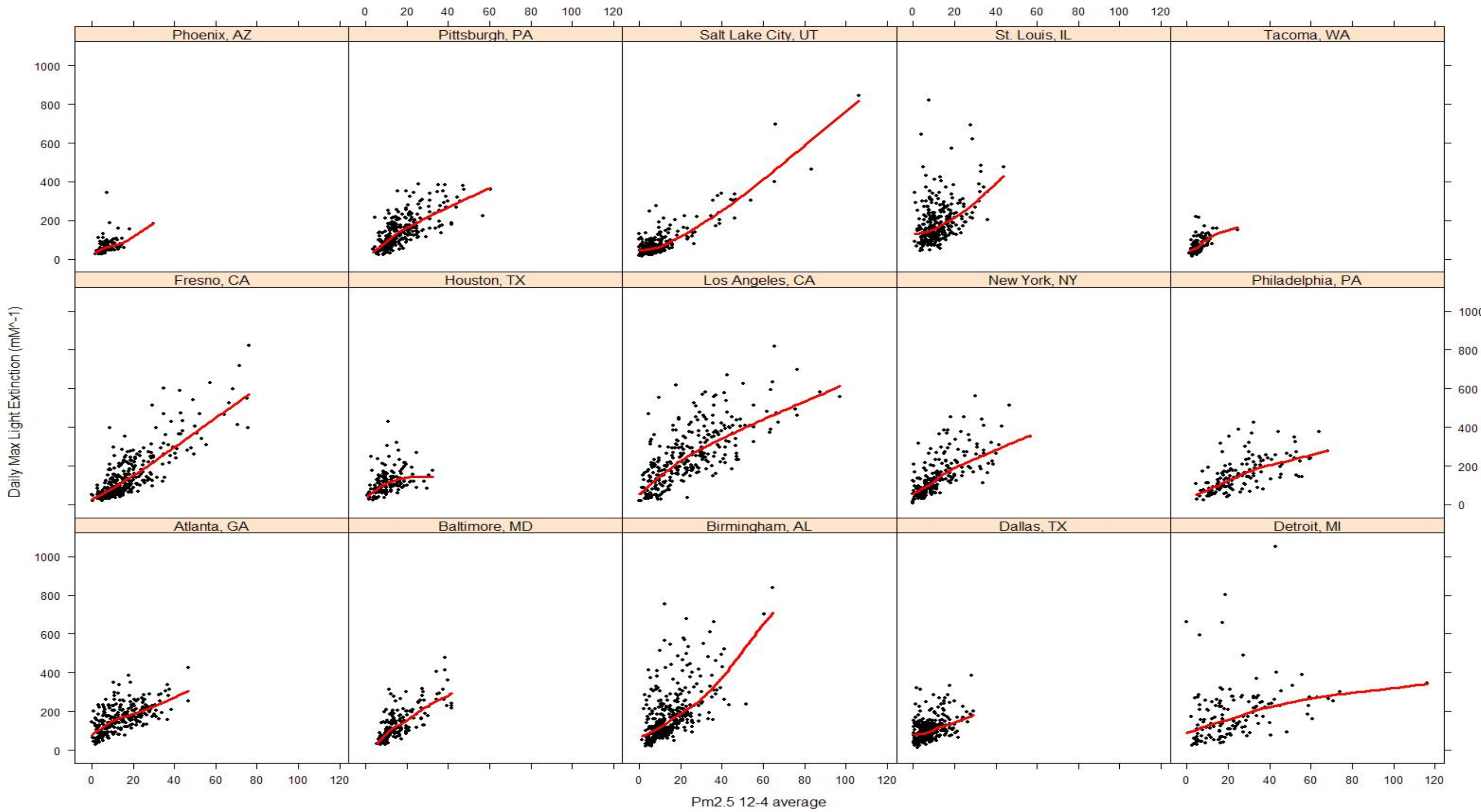


Figure D-5. Relationship Between 8 am-12 pm Average $PM_{2.5}$ Mass vs. Daily Maximum Daylight 1-Hour PM_{10} Light Extinction

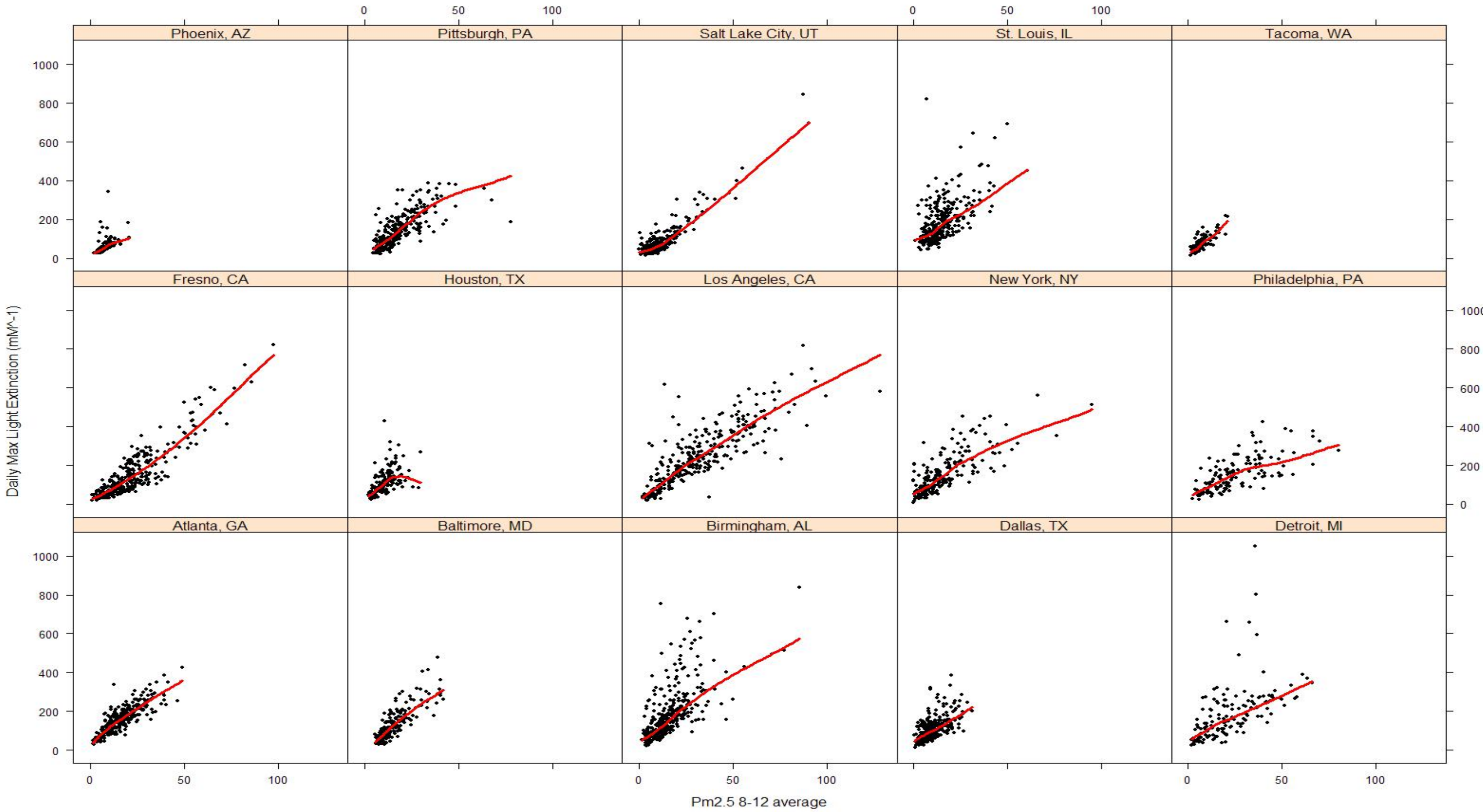
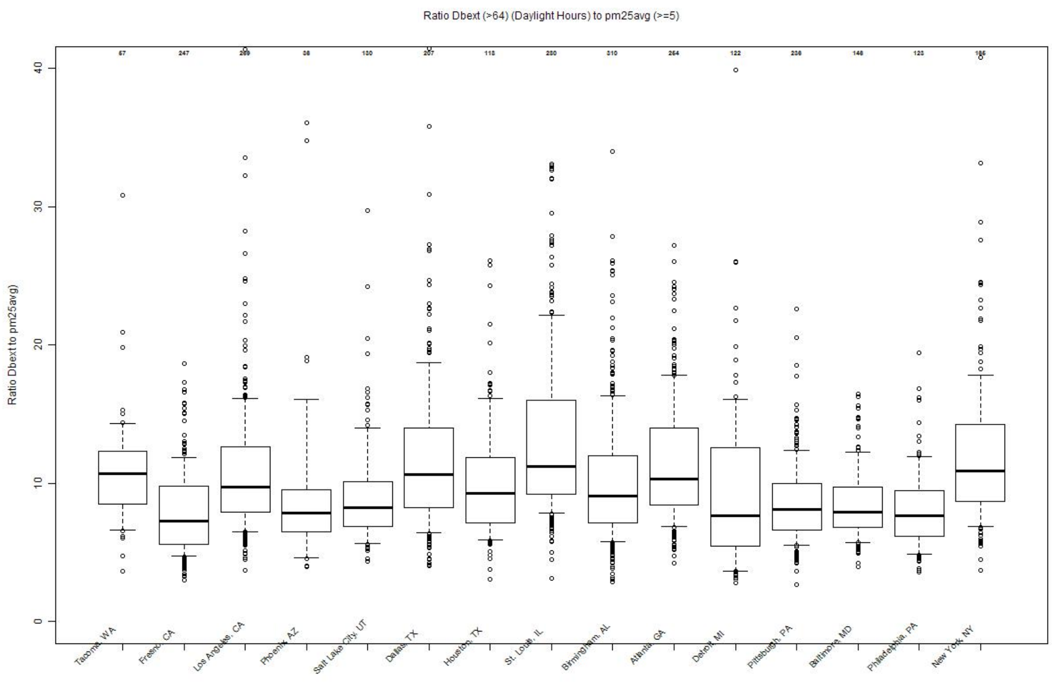
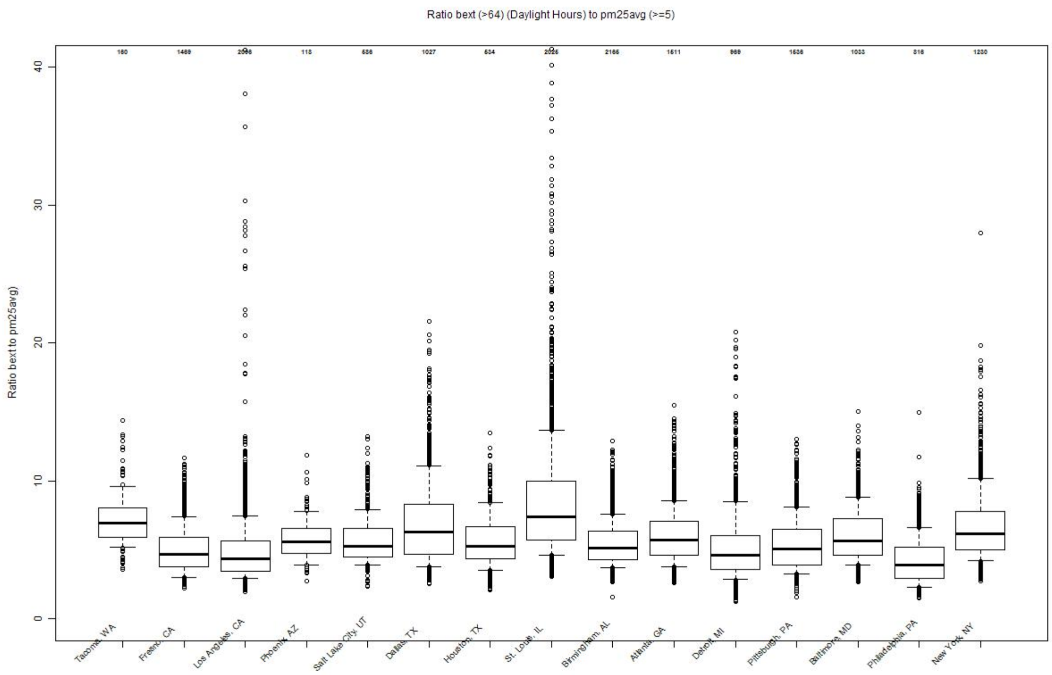


Figure D-6. Distribution of Ratios of 1-Hour PM_{10} Light Extinction and $PM_{2.5}$ Mass Concentration.

A – Ratios of Daily Maximum Daylight 1-Hour PM_{10} Light Extinction to 24-Hour Average $PM_{2.5}$ Concentration.



B – Ratios of Daylight 1-Hour PM_{10} Light Extinction to Same-Hour $PM_{2.5}$ Concentration



APPENDIX E

DIFFERENCES IN DAILY PATTERNS OF RELATIVE HUMIDITY AND PM_{10} LIGHT EXTINCTION BETWEEN AREAS AND SEASONS

In the last review of the secondary PM NAAQS, the pattern of PM_{10} light extinction during the day was of particular interest. It was noted, using estimates of hourly PM_{10} light extinction based on a simpler approach than described for this analysis, that both (1) mid-day PM_{10} light extinction and (2) the slope of the relationship between PM_{10} 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 PM_{10} light extinction and relative humidity for the four "daylight seasons." These graphics exclude hours with relative humidity greater than 90 percent. 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 PM_{10} 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 PM_{10} light extinction among areas in the morning than at mid-day, although the morning variation has been reduced (relative to same information in the first public review draft of this assessment) by the exclusion of hours with relative humidity greater than 90 percent.

Figure E-1. Diurnal and Seasonal Patterns of Relative Humidity (percent) and PM_{10} Light Extinction (Mm^{-1}) for 2005-2007

(a) November-January

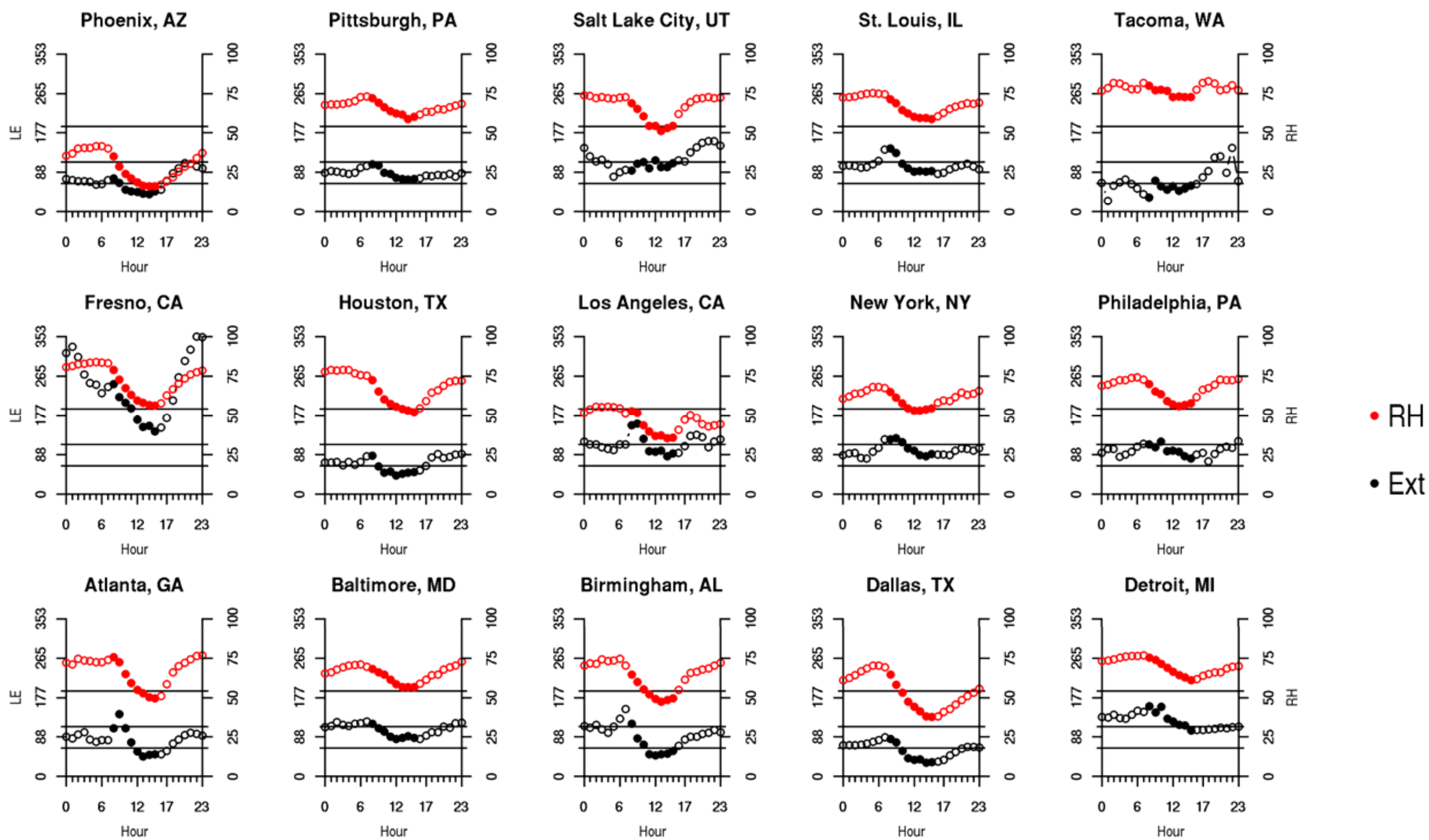


Figure E-2. Diurnal and Seasonal Patterns of Relative Humidity (percent) and PM_{10} Light Extinction (Mm^{-1}) for 2005-2007, continued

(b) February-April

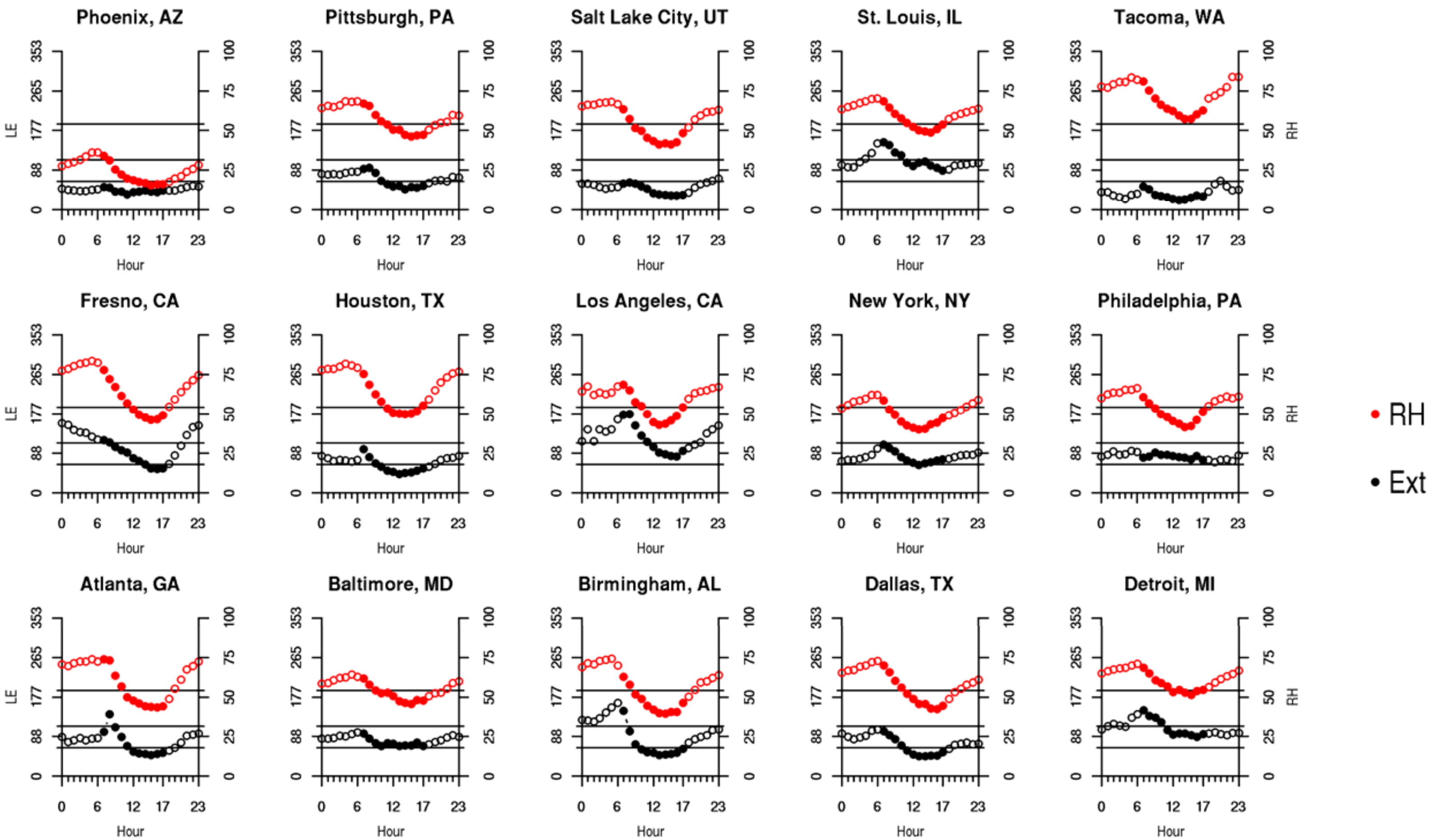


Figure E-3. Diurnal and Seasonal Patterns of Relative Humidity (percent) and PM_{10} Light Extinction (Mm^{-1}) for 2005-2007, continued

(c) May-July

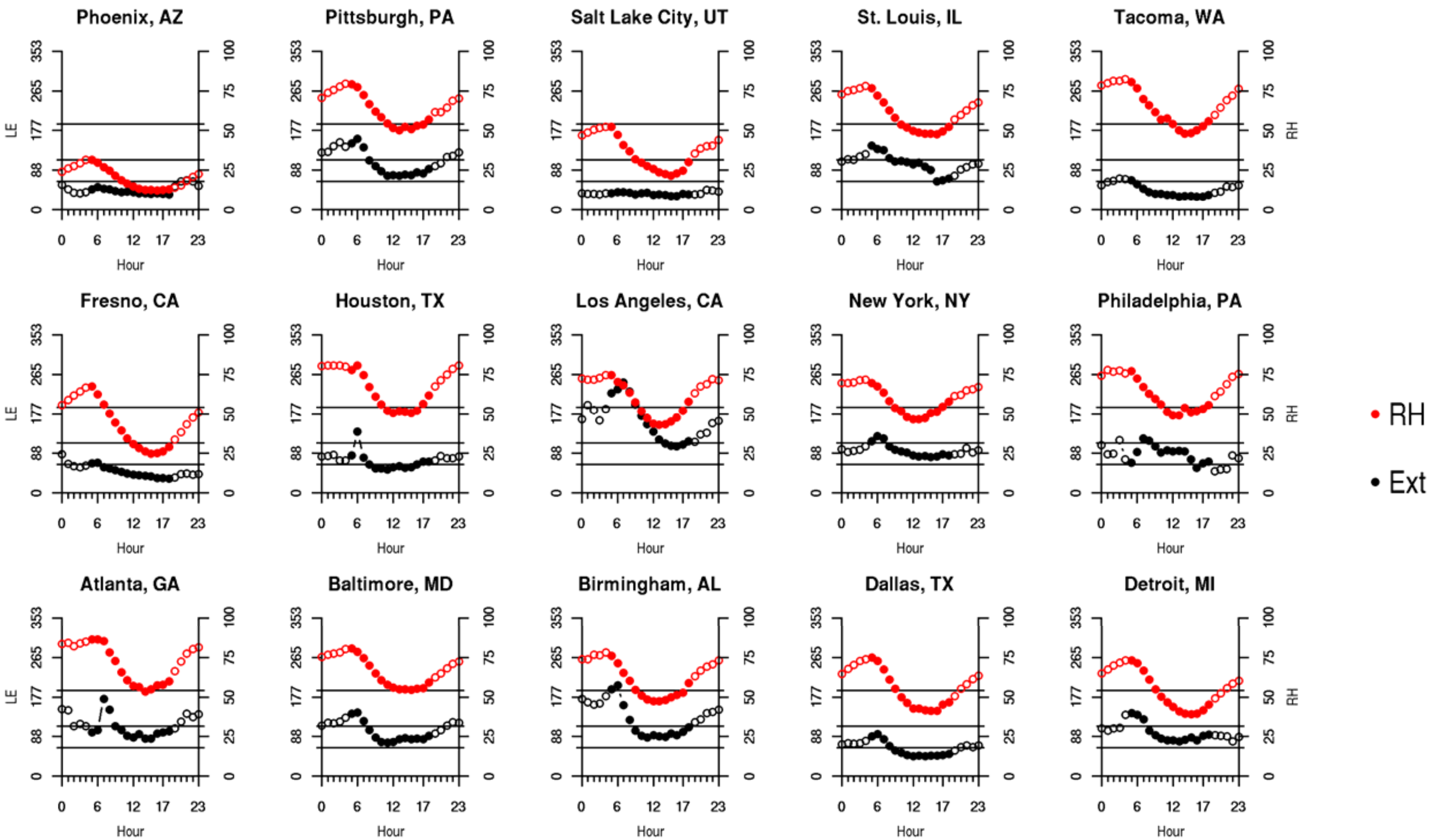
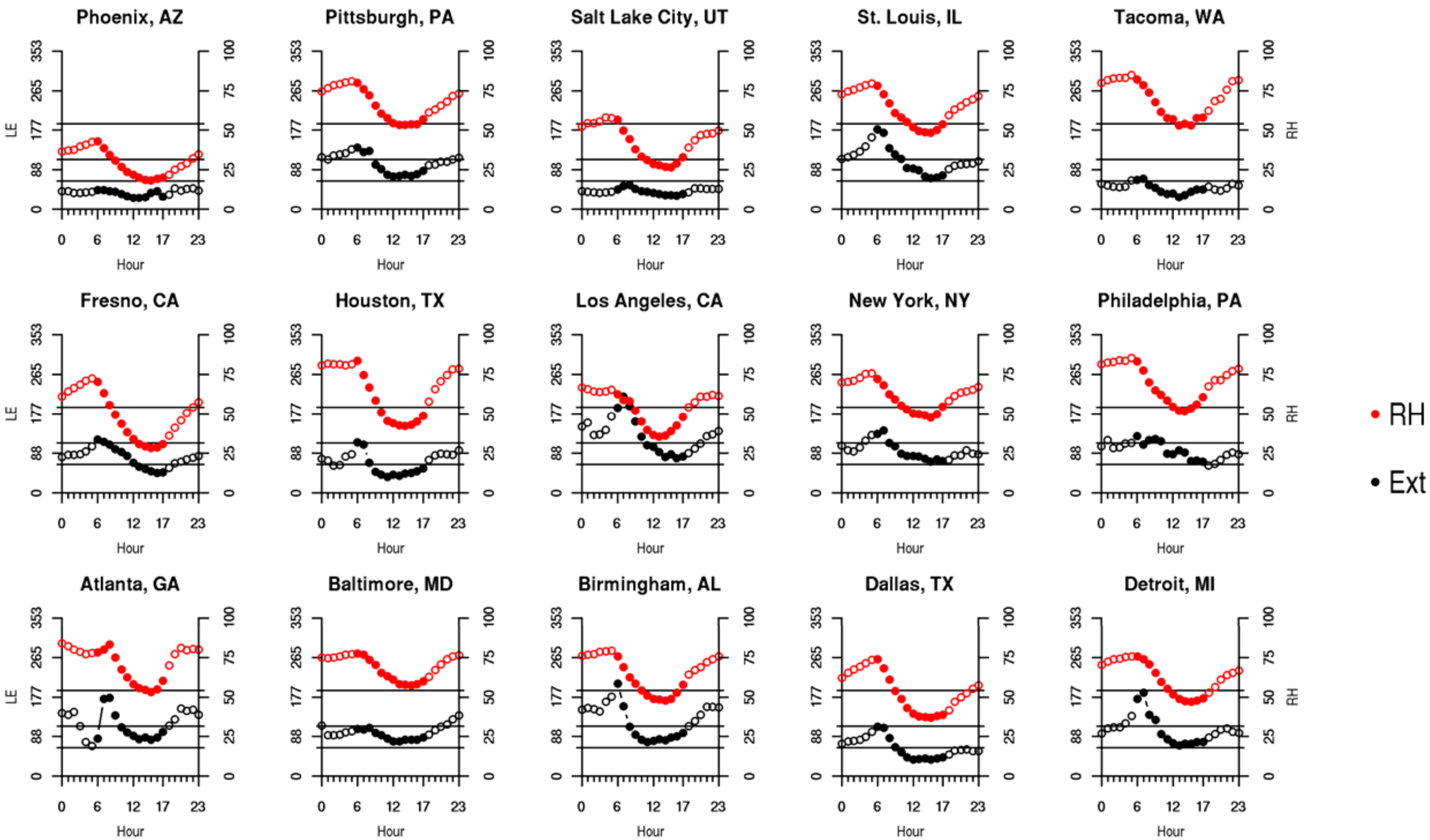


Figure E-4. Diurnal and Seasonal Patterns of Relative Humidity (percent) and PM_{10} Light Extinction (Mm^{-1}) for 2005-2007, continued

(d) August-October



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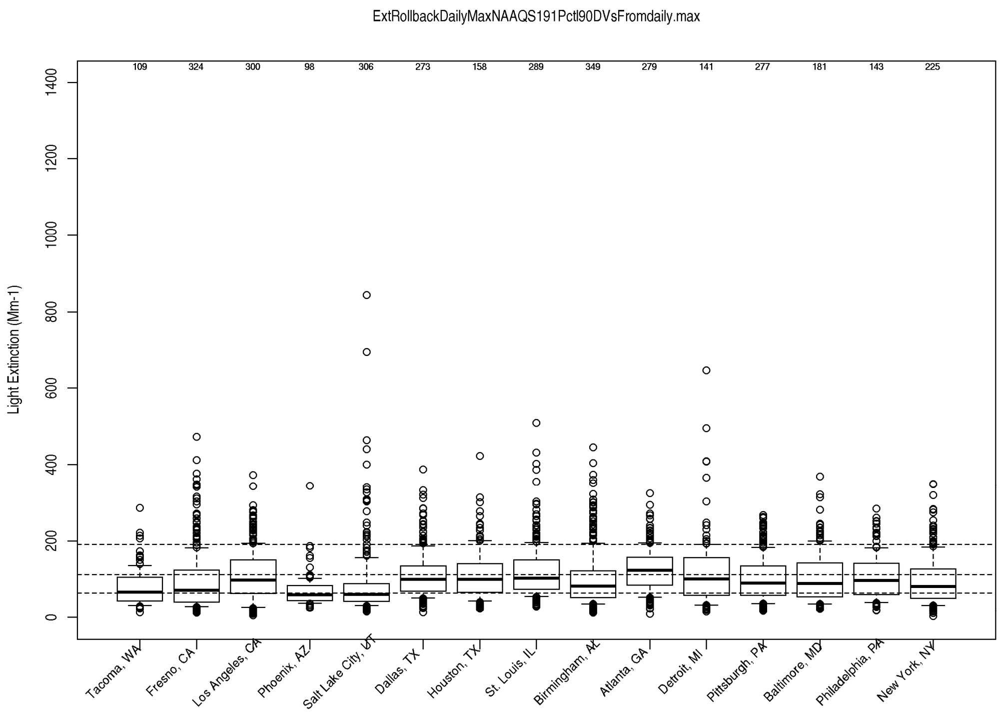
APPENDIX F

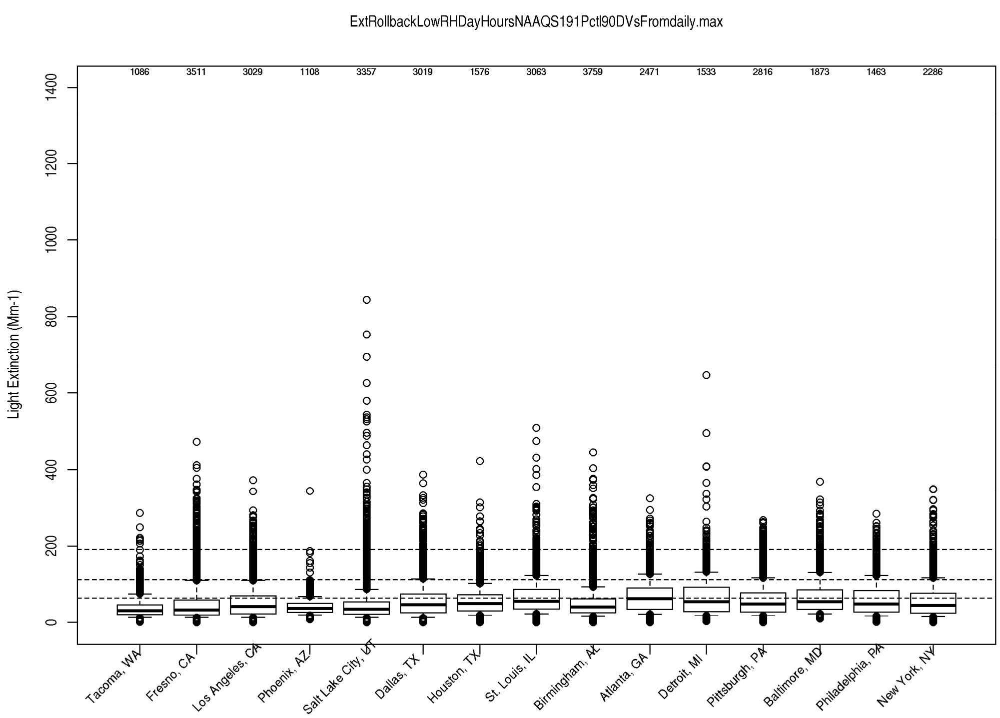
DISTRIBUTIONS OF MAXIMUM DAILY AND HOURLY DAYLIGHT PM_{10} LIGHT EXTINCTION - UNDER “JUST MEET” CONDITIONS

(a) NAAQS Scenario
Daily Max
191 Mm^{-1}
90^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

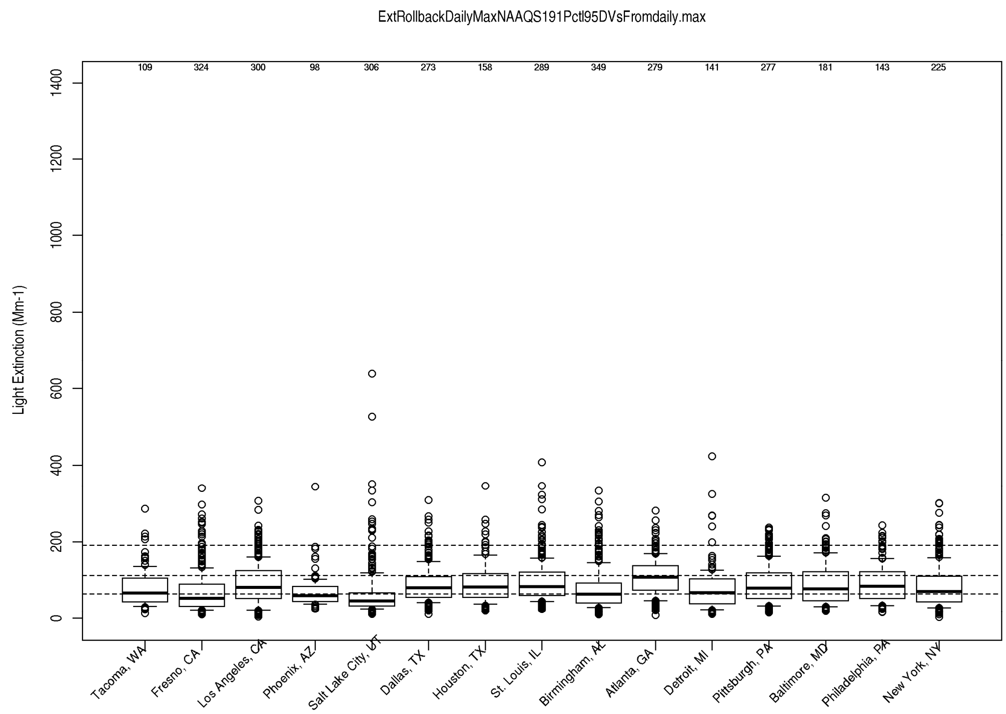


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

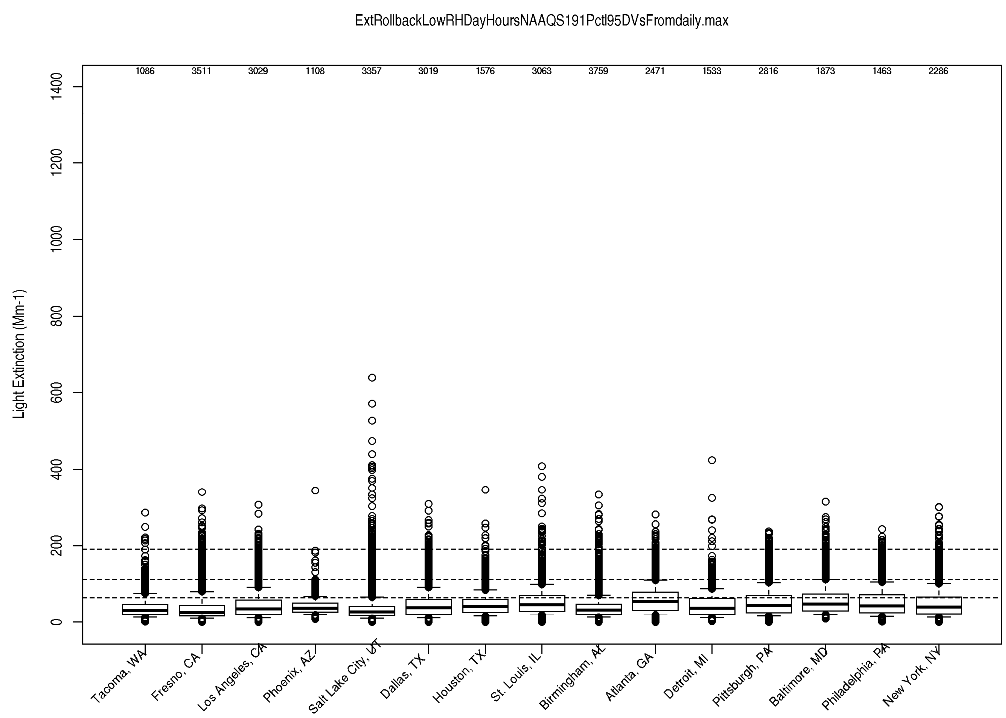


(b) NAAQS Scenario
Daily Max
191 Mm^{-1}
95^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

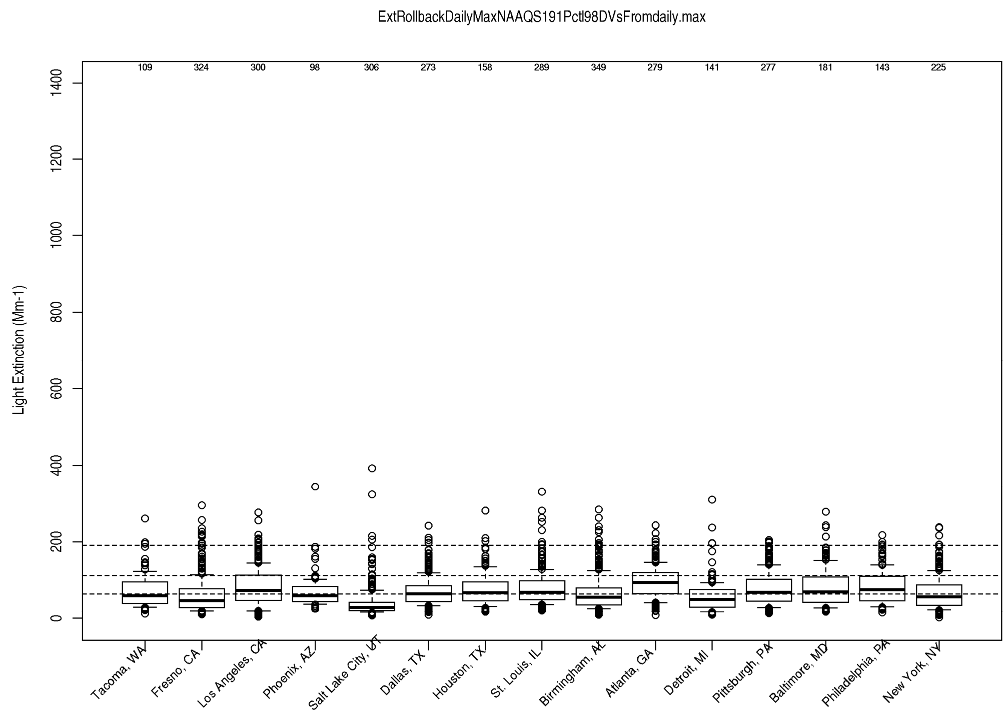


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

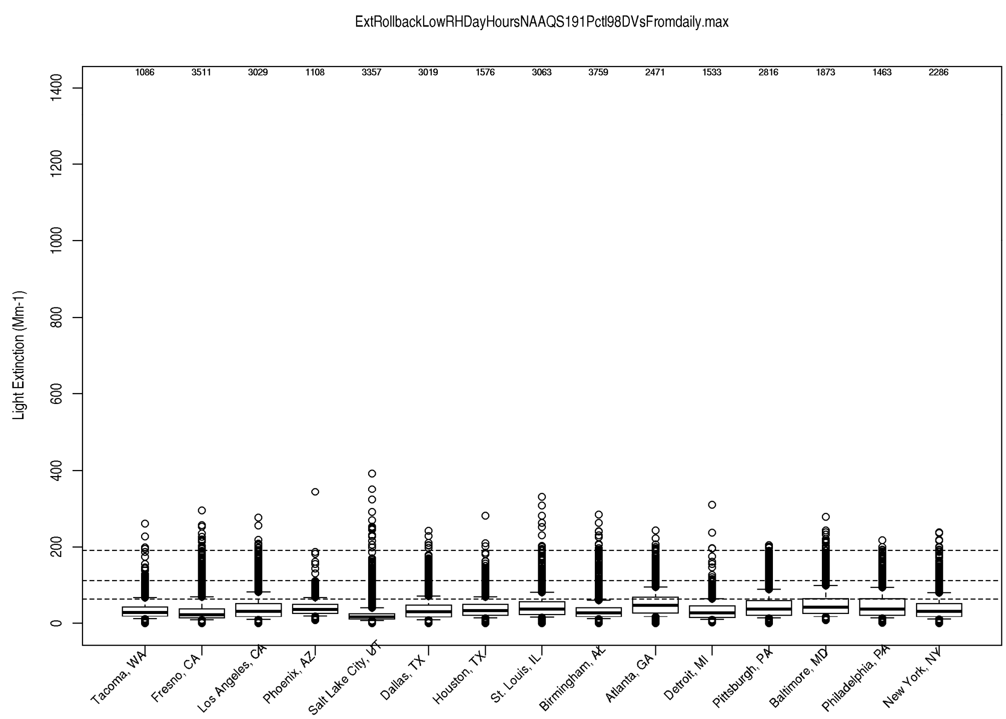


(c) NAAQS Scenario
Daily Max
191 Mm^{-1}
98^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

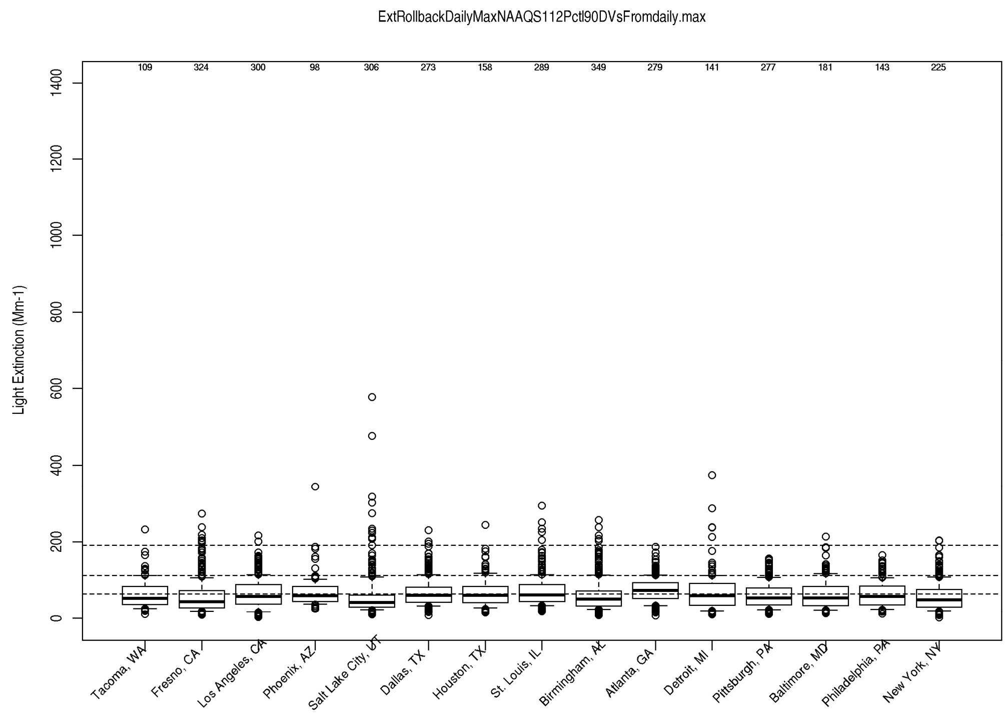


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

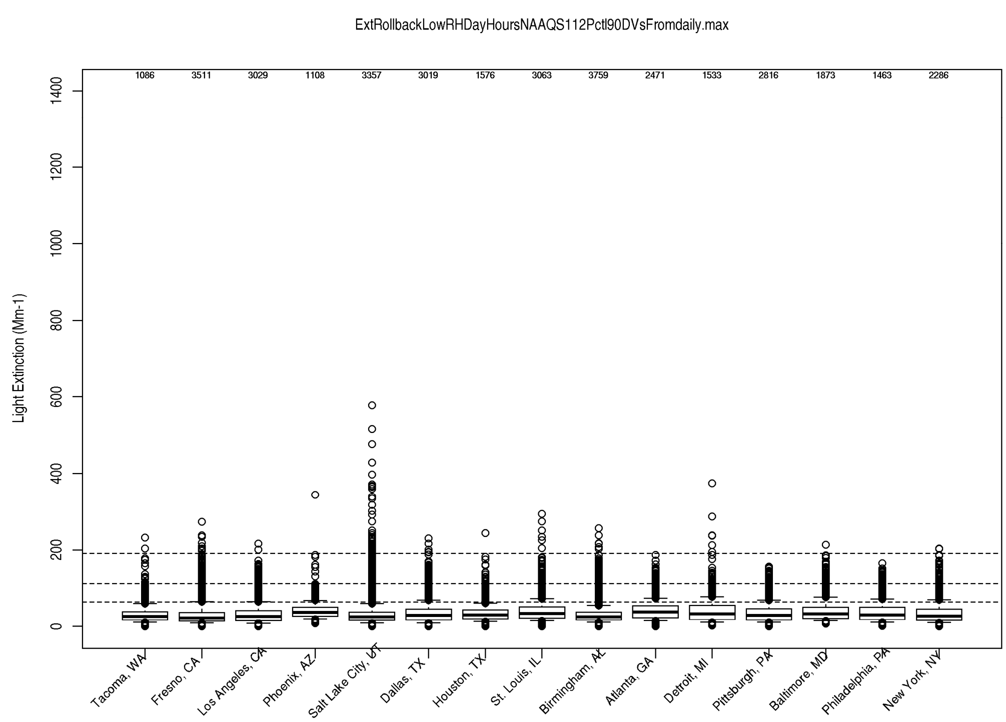


(d) NAAQS Scenario
Daily Max
112 Mm^{-1}
90^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

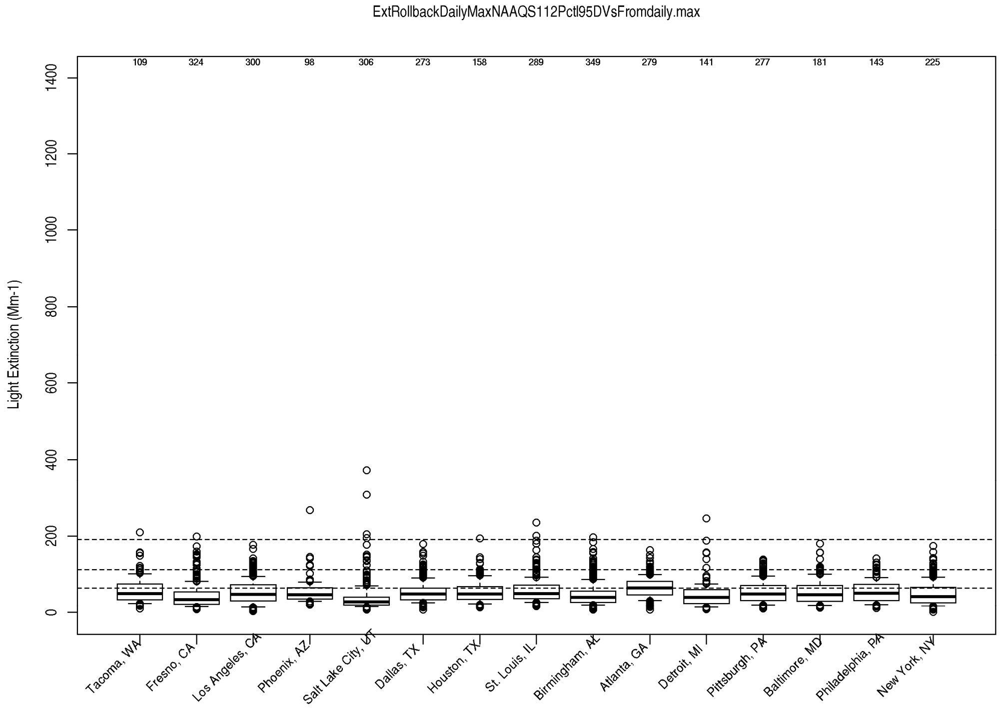


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

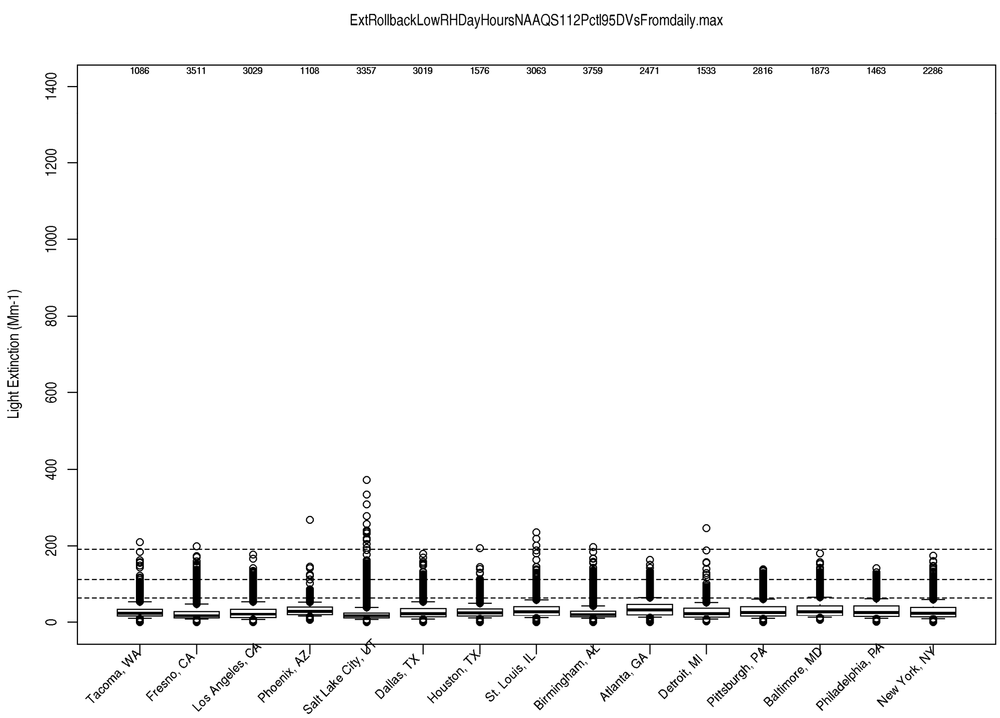


(e) NAAQS Scenario
Daily Max
112 Mm^{-1}
95^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

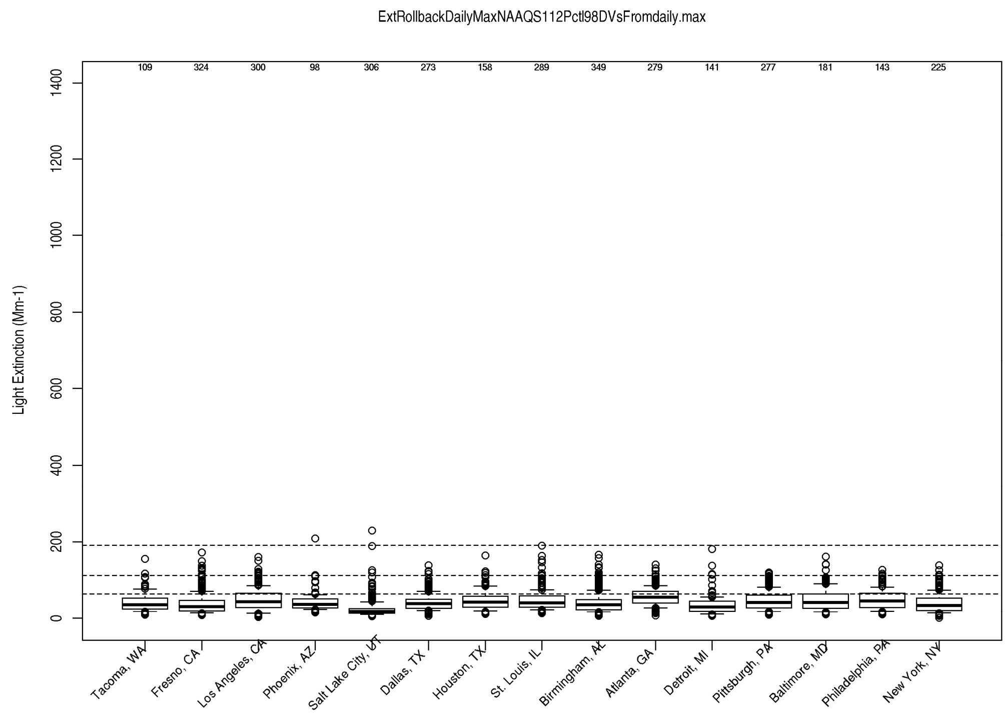


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

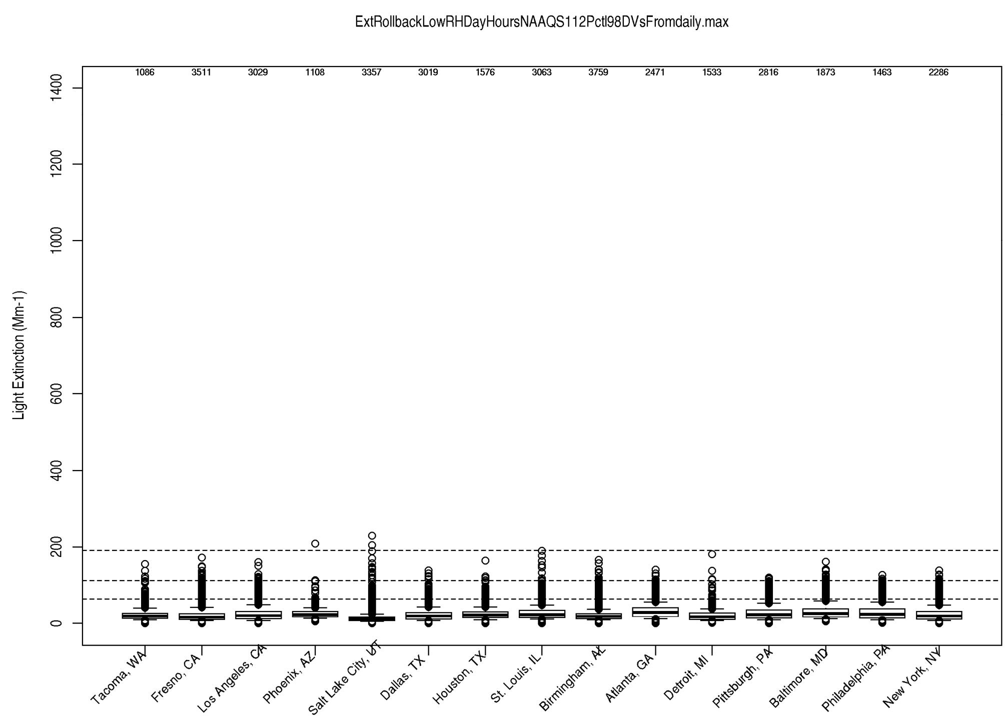


(f) NAAQS Scenario
Daily Max
112 Mm^{-1}
98^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

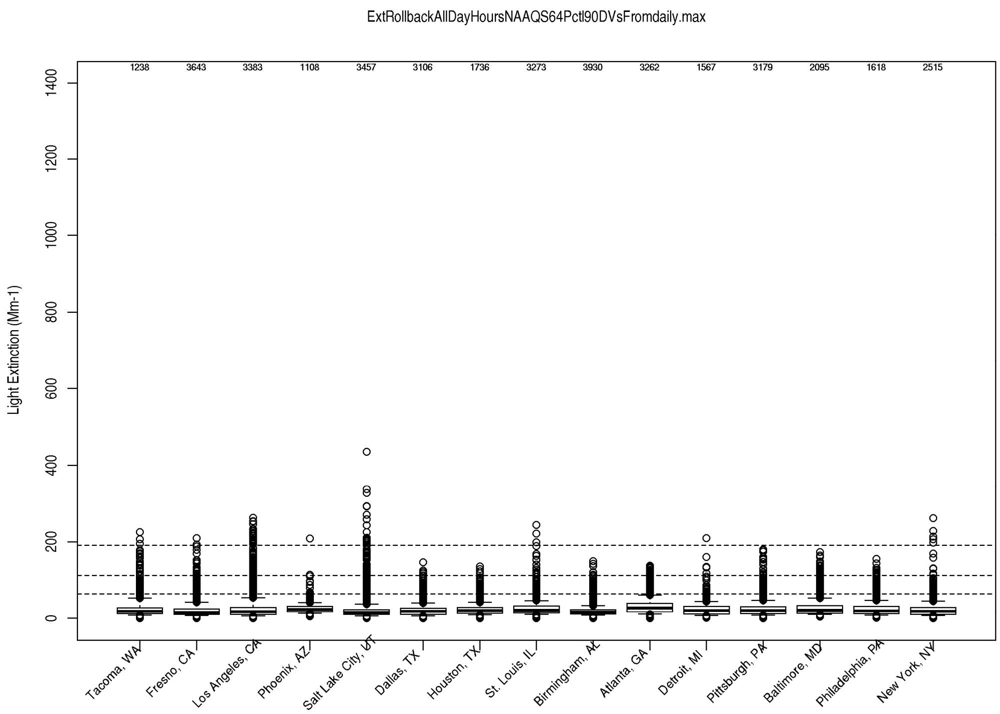


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

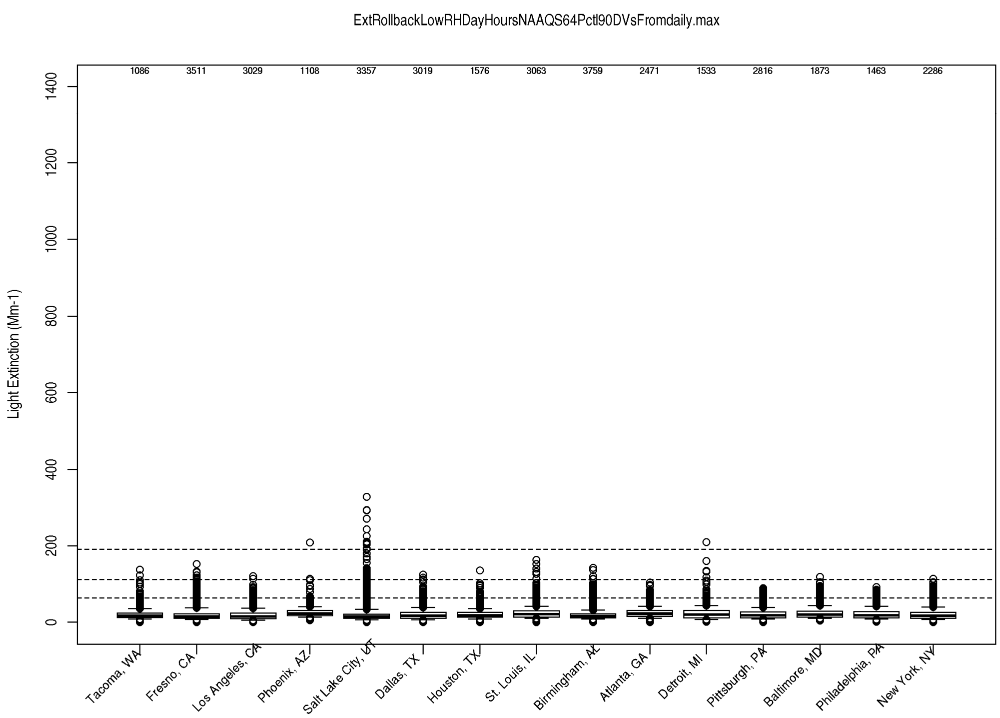


(g) NAAQS Scenario
Daily Max
64 Mm^{-1}
90^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

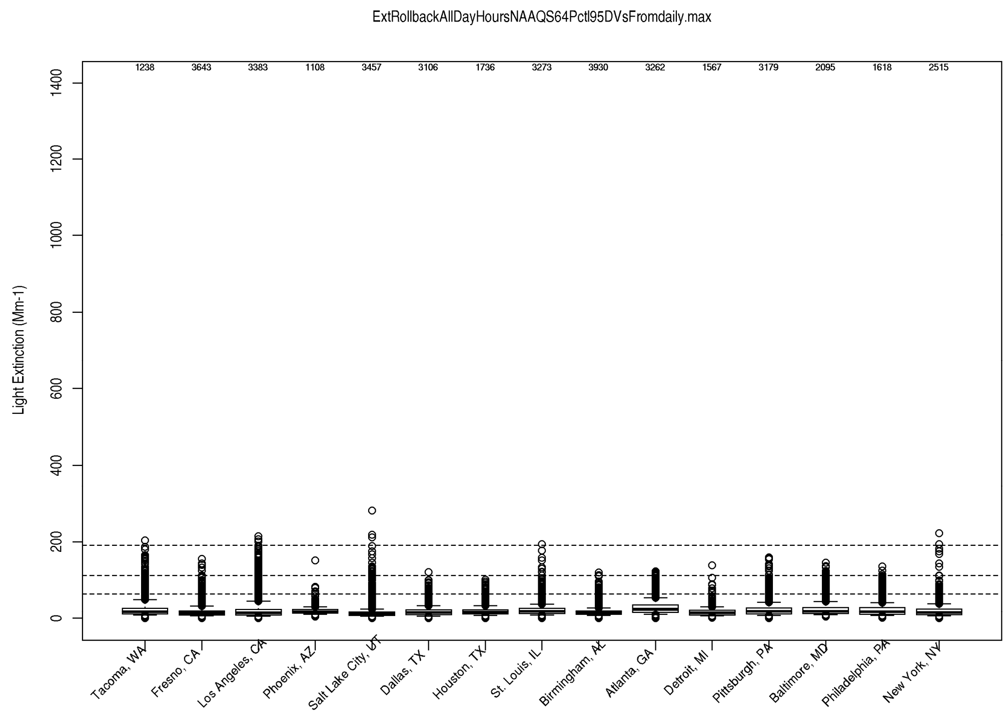


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

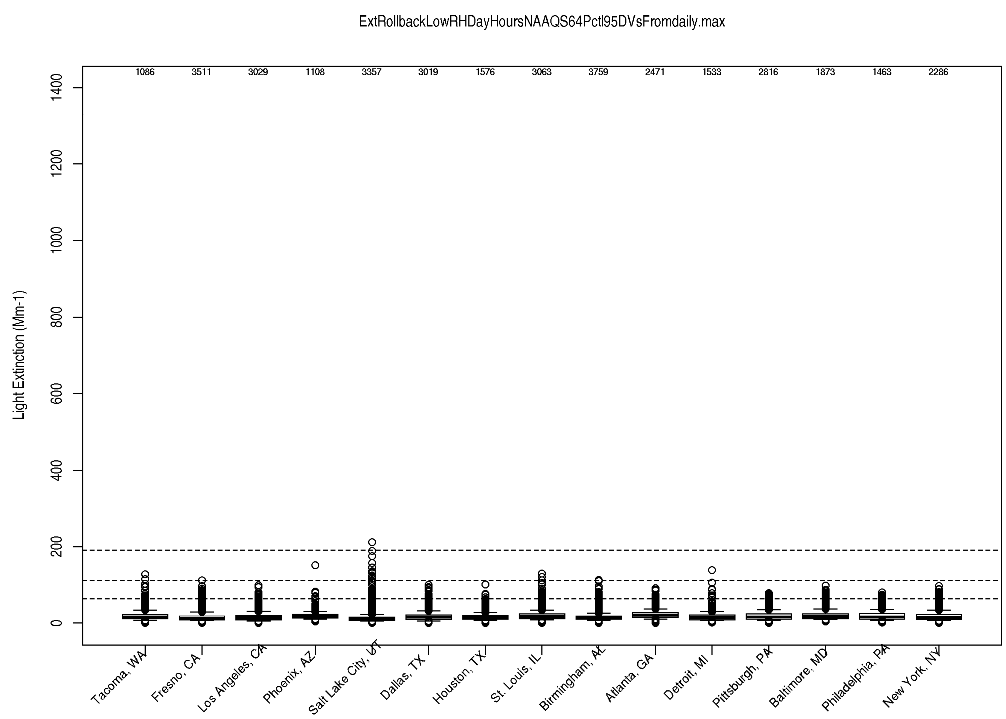


(h) NAAQS Scenario
Daily Max
64 Mm^{-1}
95^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

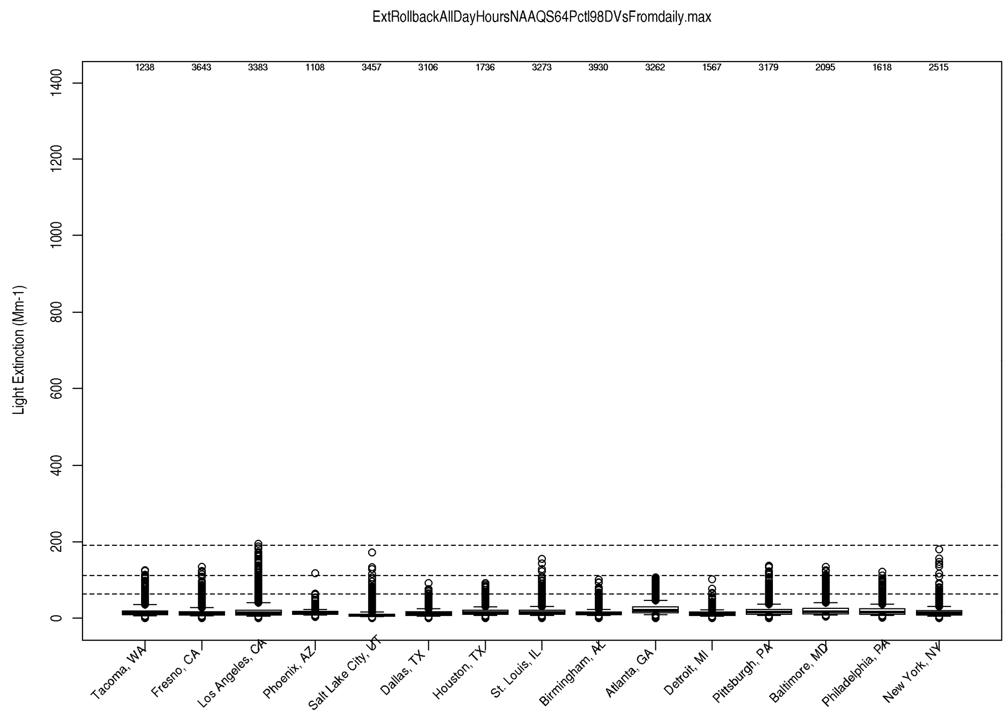


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

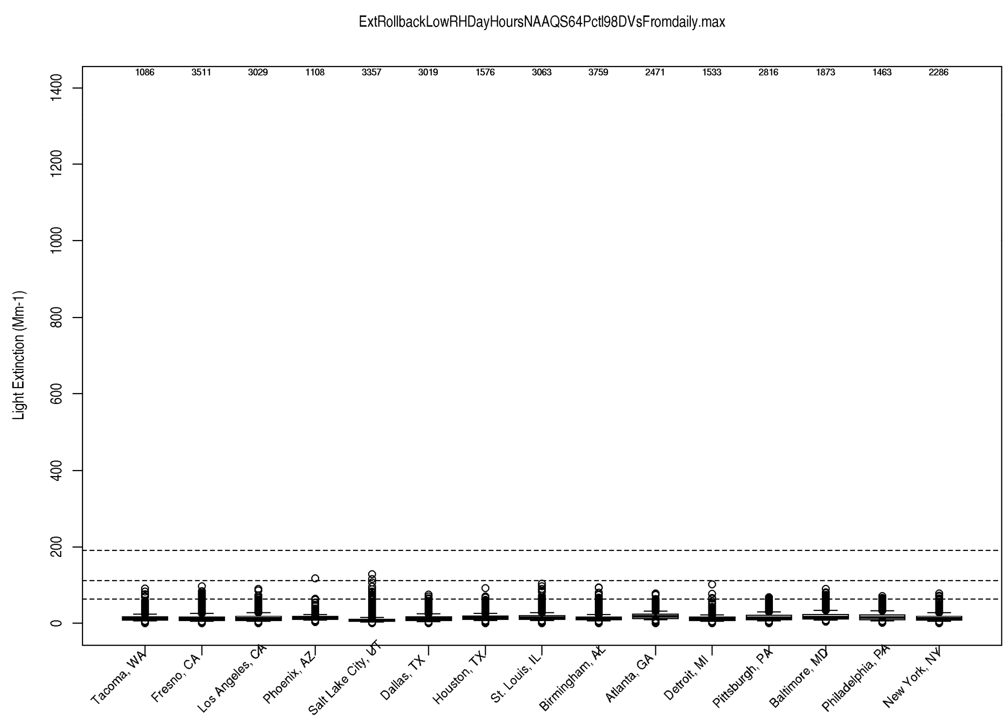


(i) NAAQS Scenario
Daily Max
64 Mm^{-1}
98^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

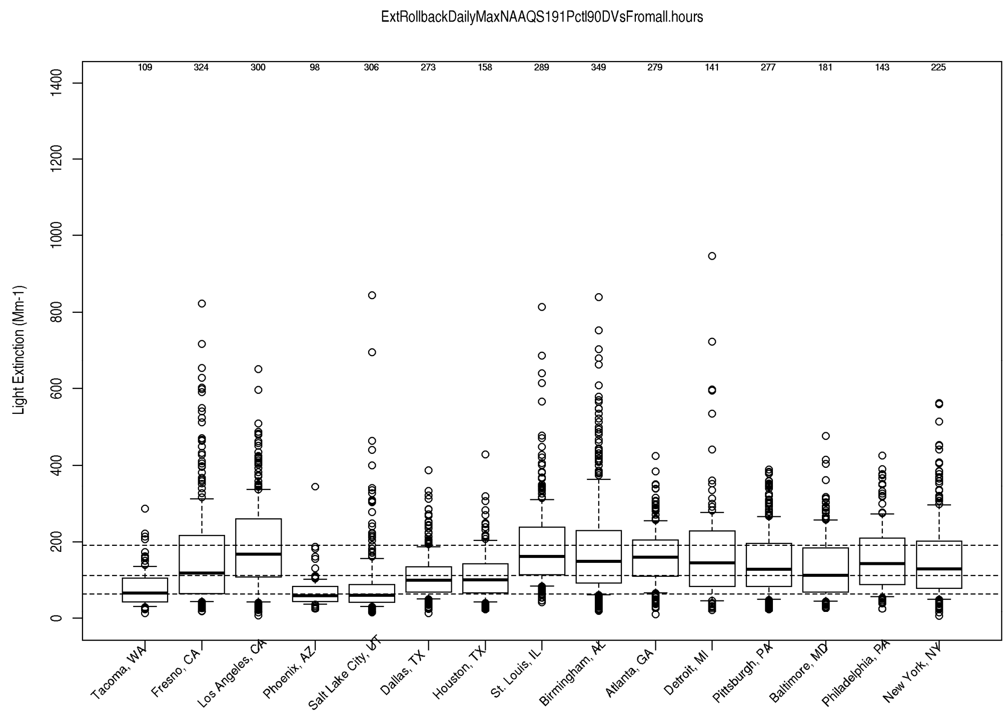


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

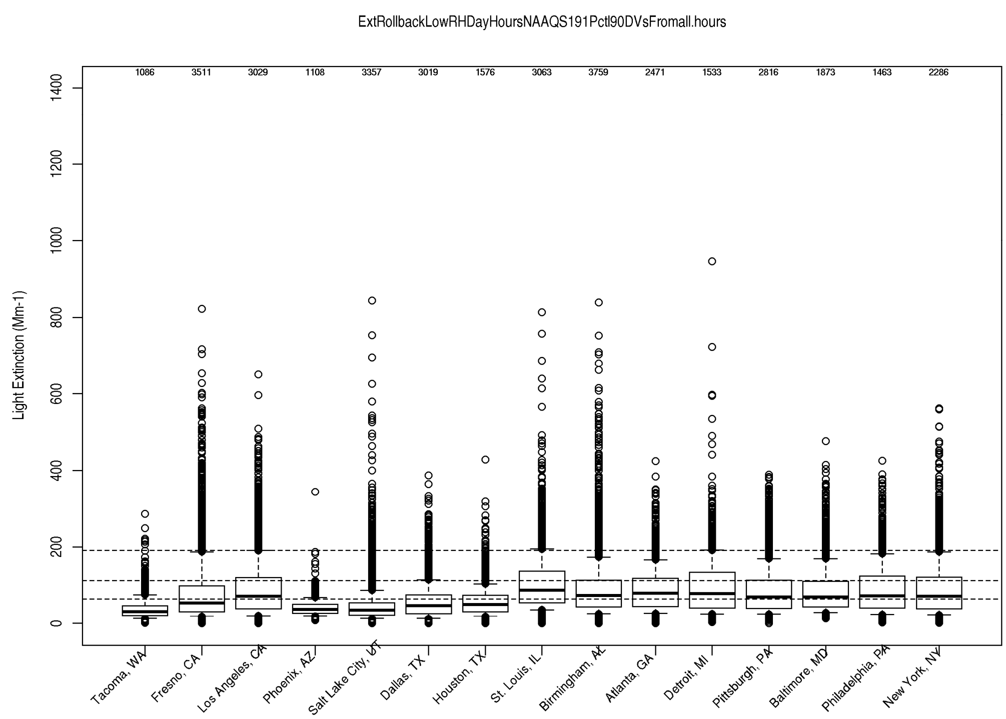


(j) NAAQS Scenario
All hours
191 Mm^{-1}
90^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

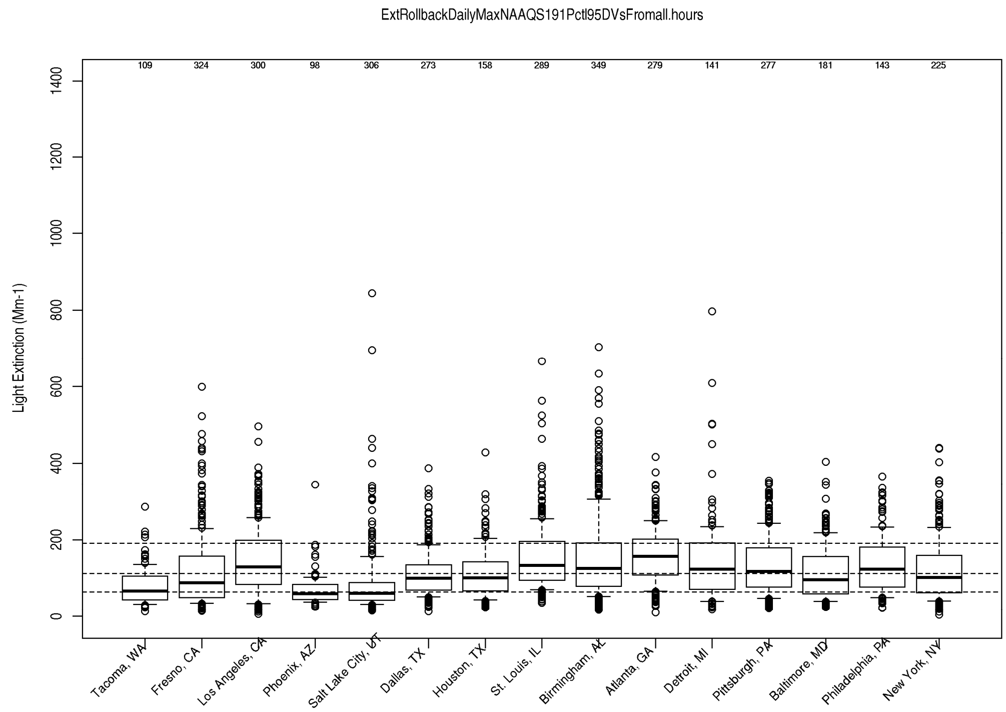


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

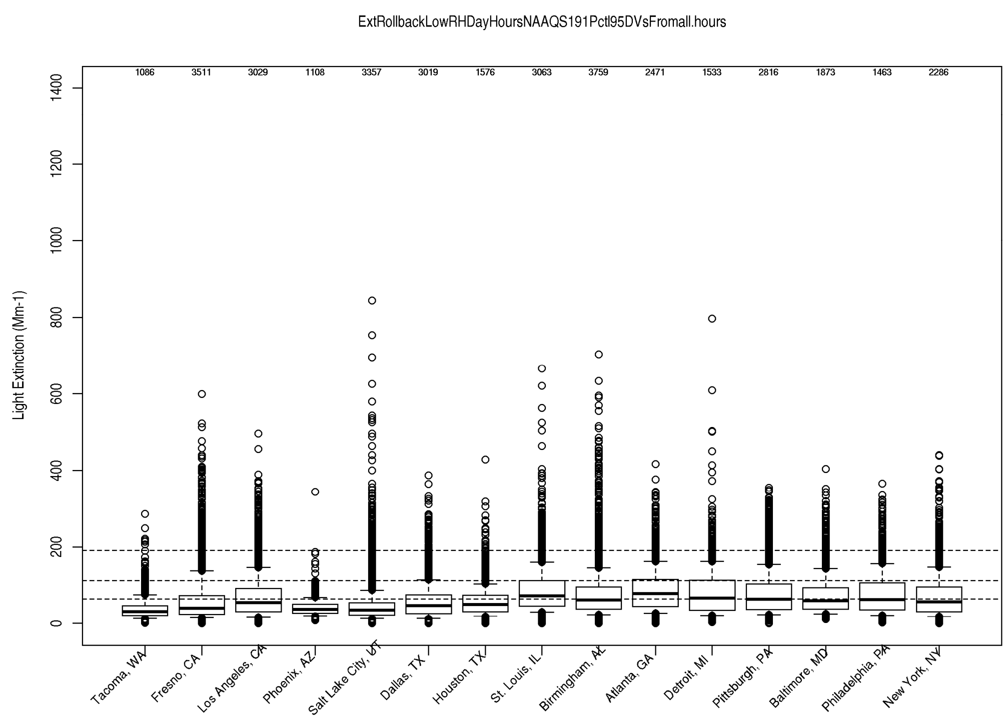


(k) NAAQS Scenario
All hours
191 Mm^{-1}
95^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

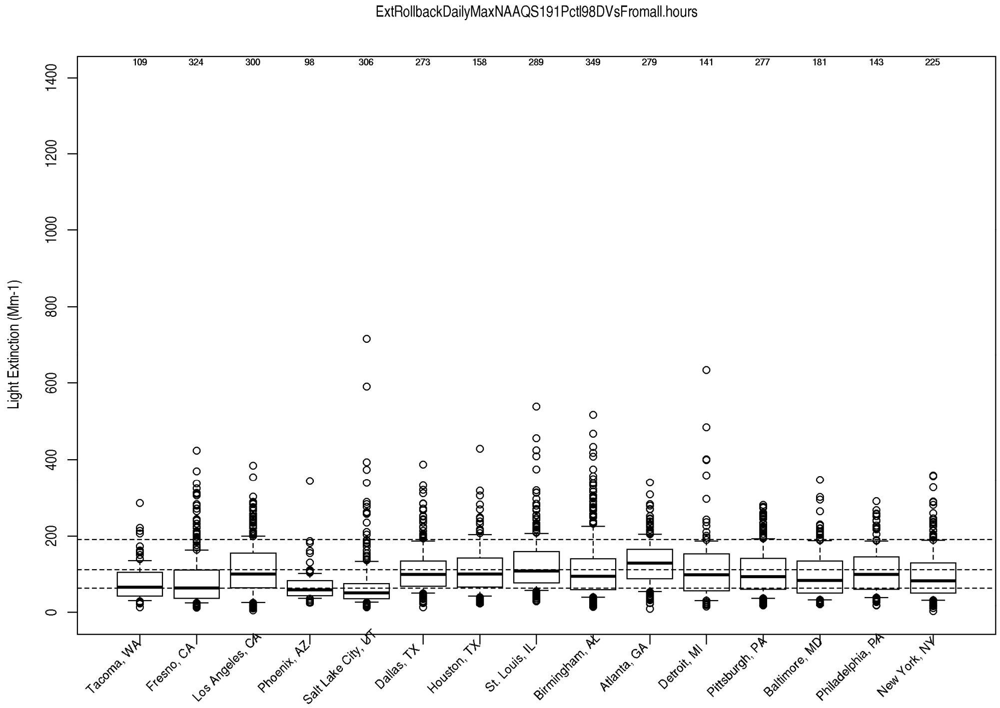


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

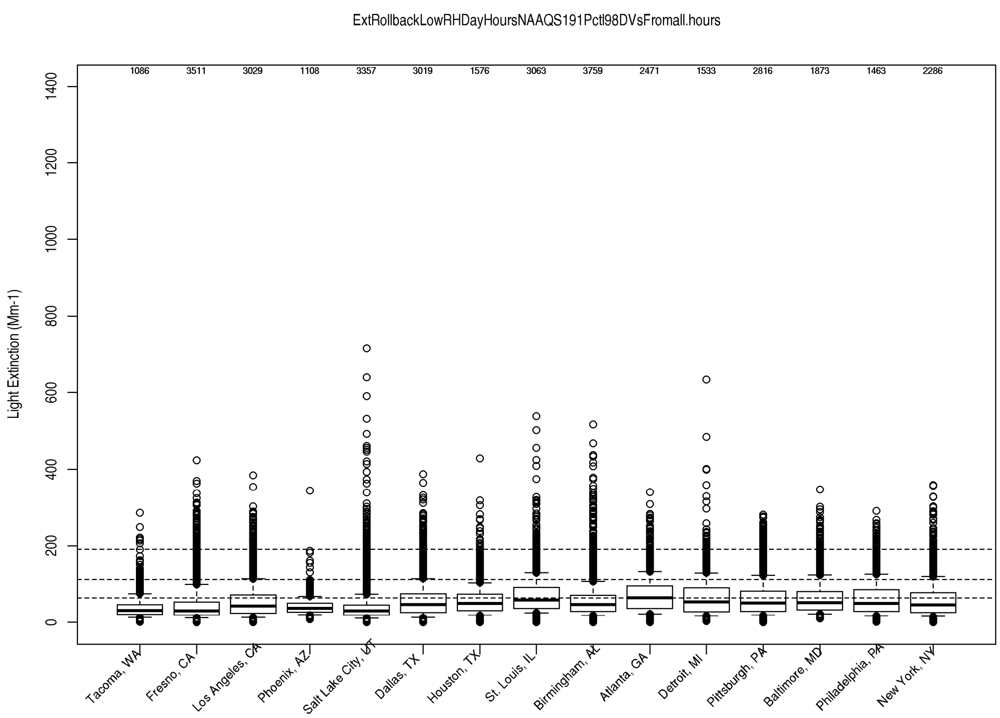


(l) NAAQS Scenario
All hours
191 Mm^{-1}
98^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

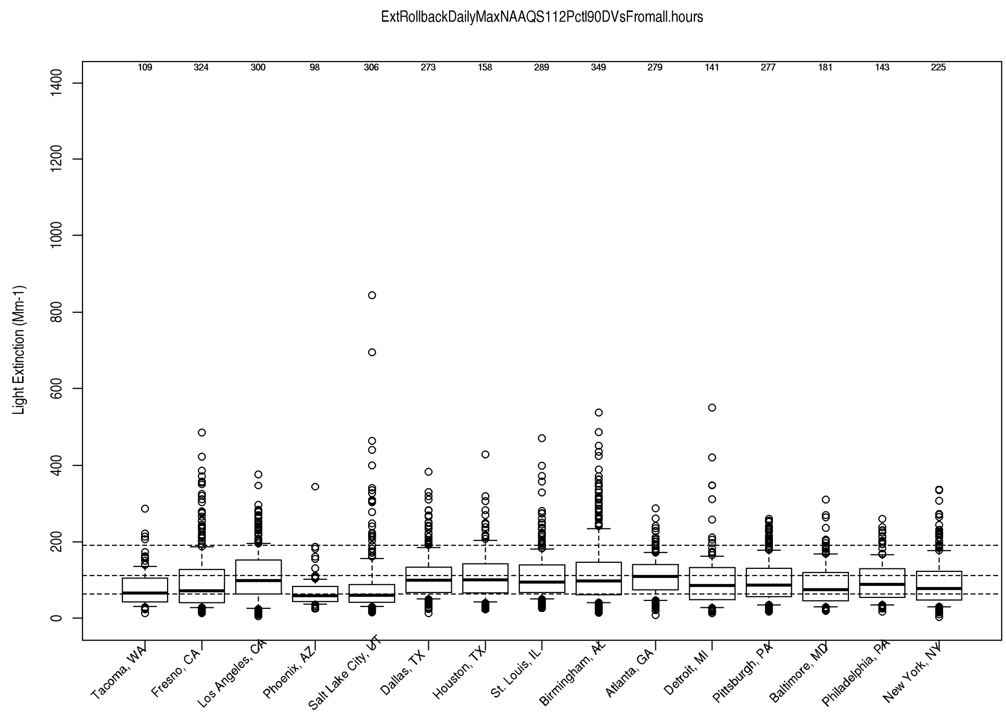


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

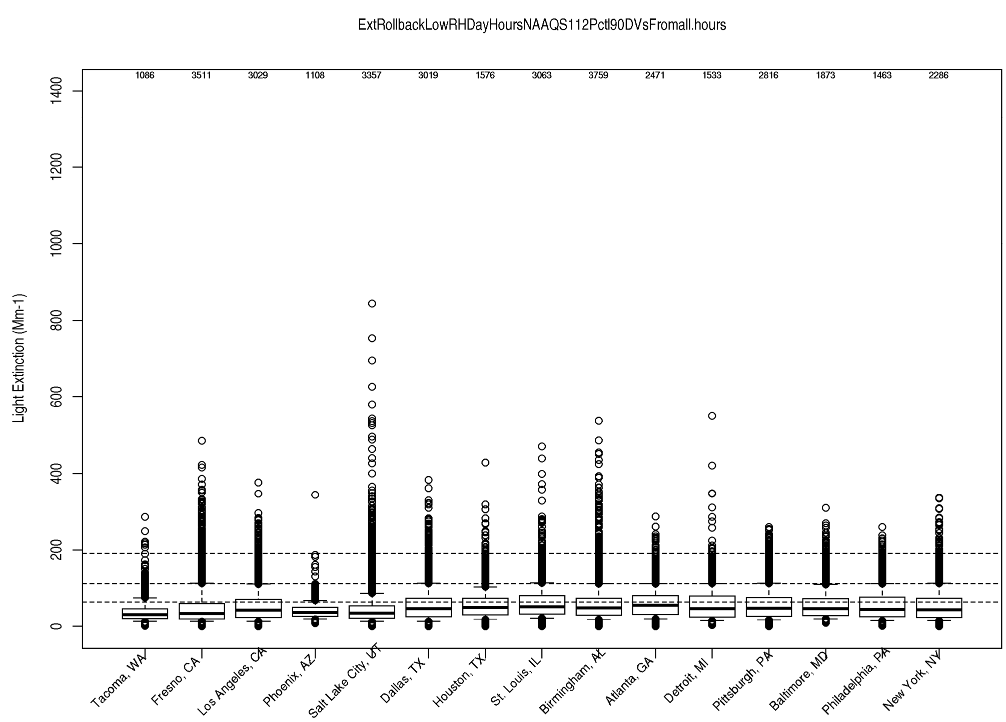


(m) NAAQS Scenario
All hours
112 Mm^{-1}
90^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

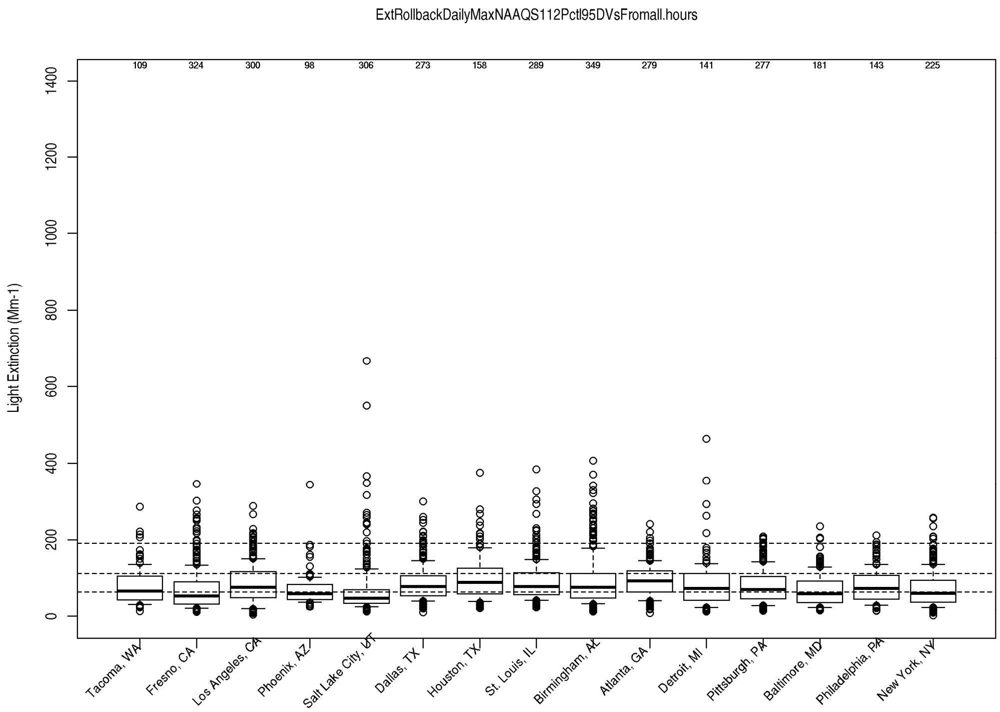


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

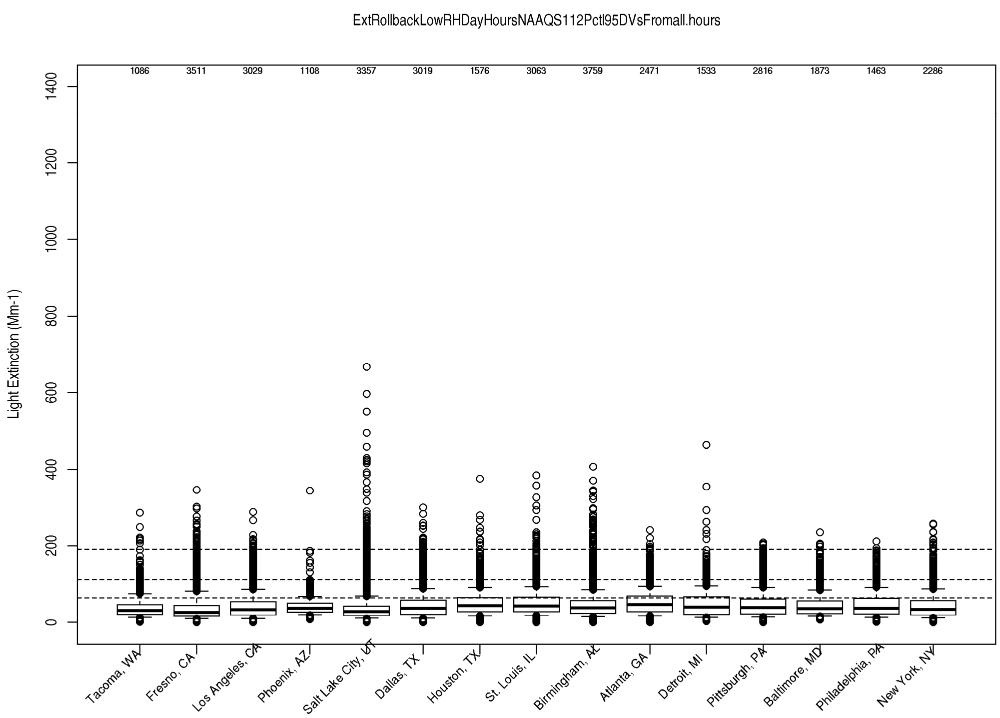


(n) NAAQS Scenario
All hours
112 Mm^{-1}
95^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

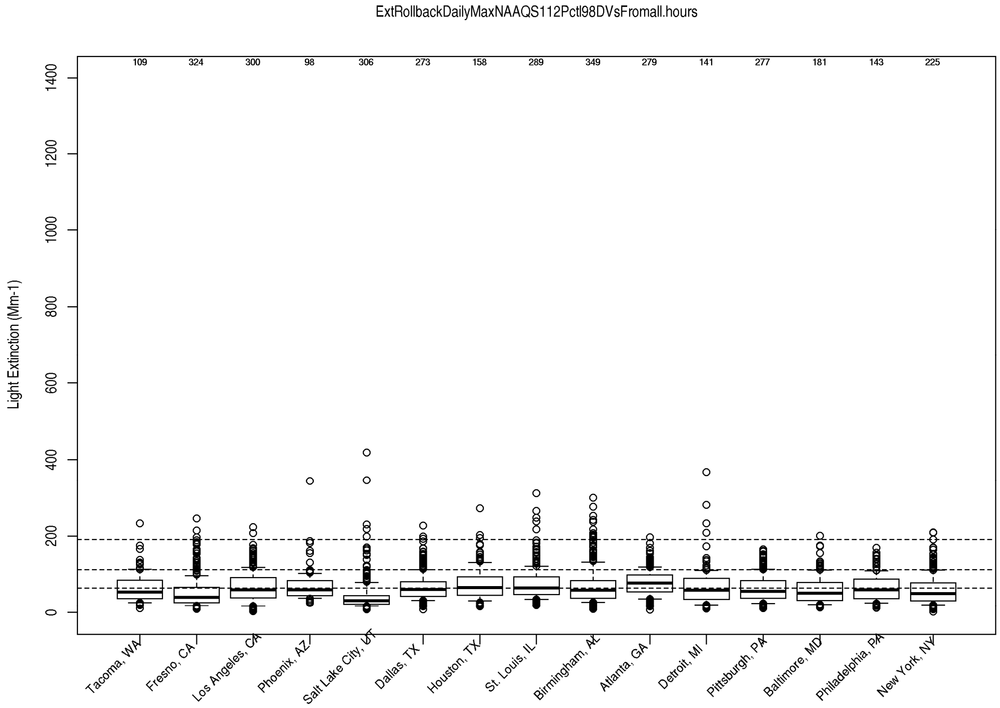


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

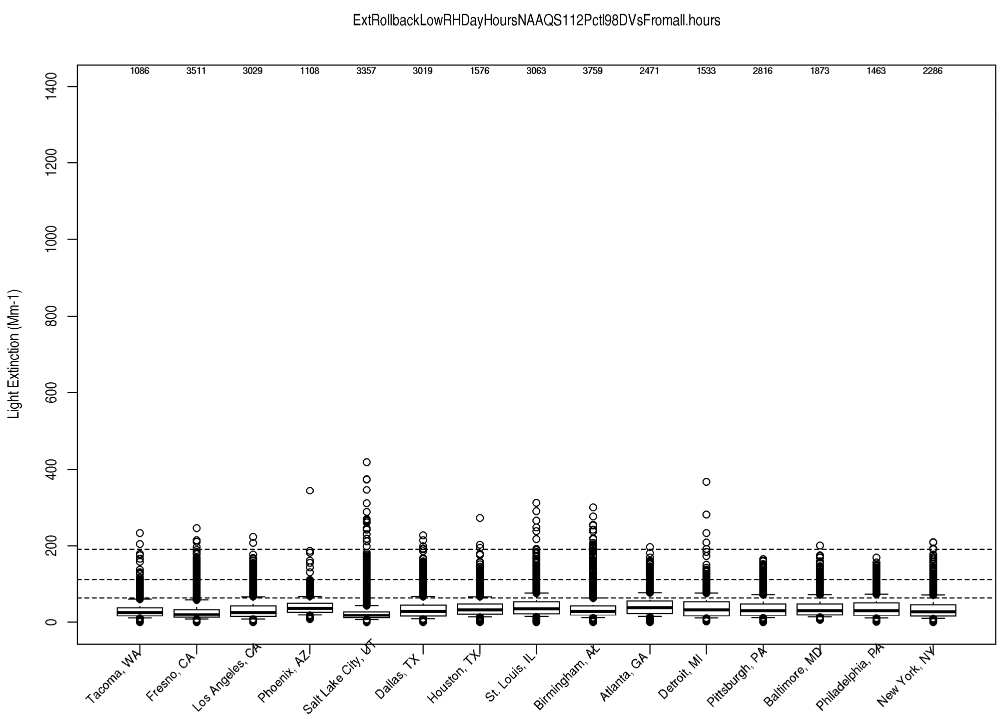


(o) NAAQS Scenario
All hours
112 Mm^{-1}
98^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

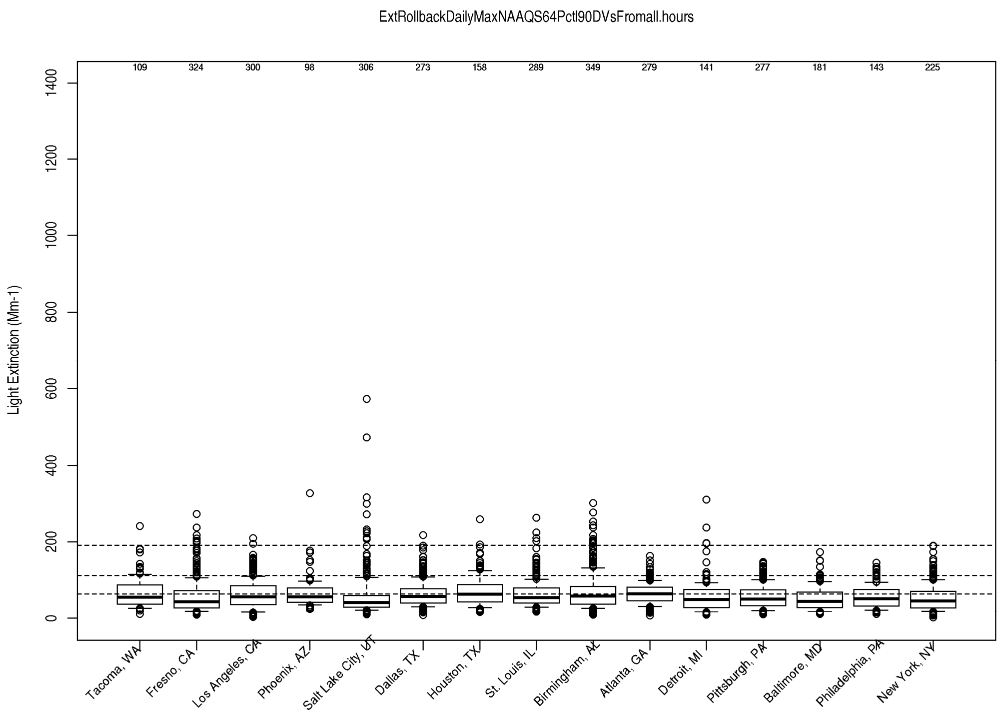


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

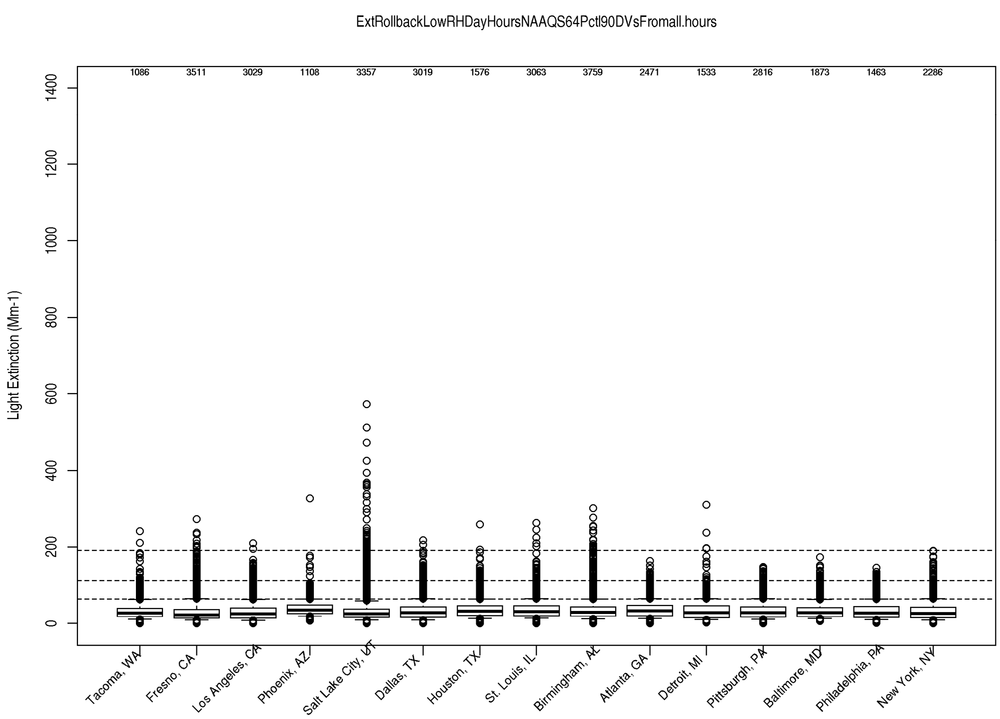


(p) NAAQS Scenario
All hours
64 Mm^{-1}
90^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

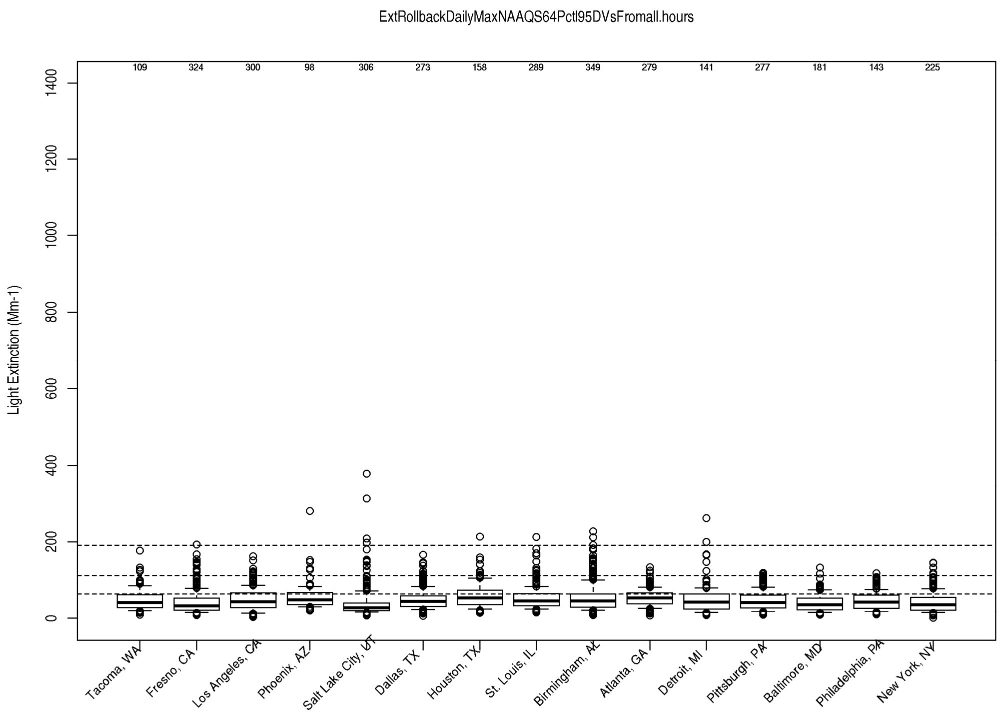


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

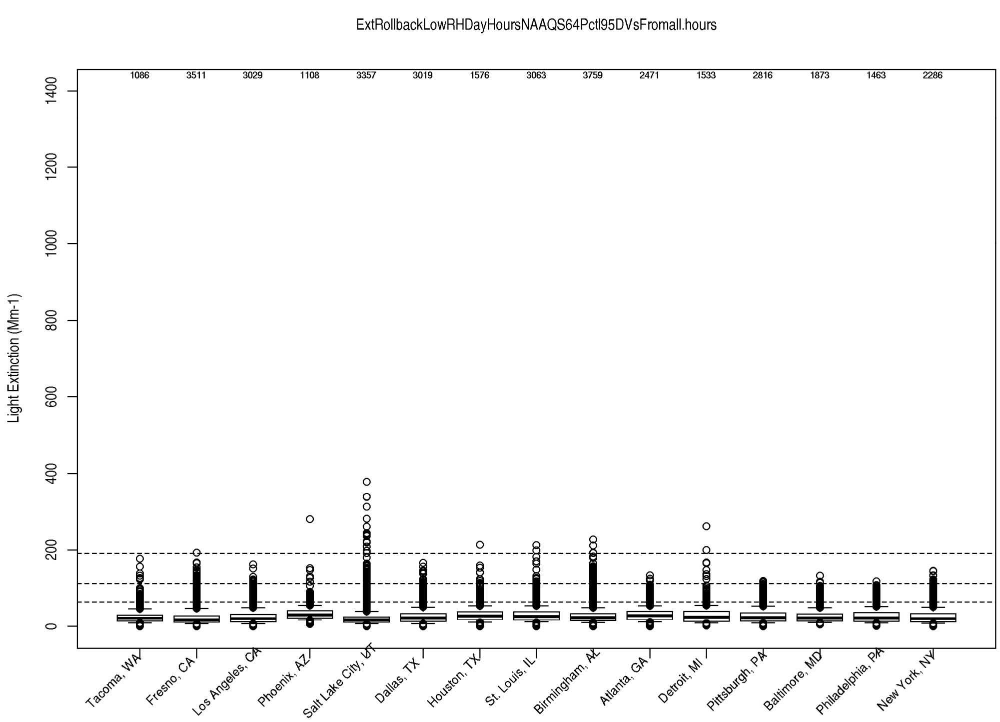


(q) NAAQS Scenario
All hours
64 Mm^{-1}
95^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

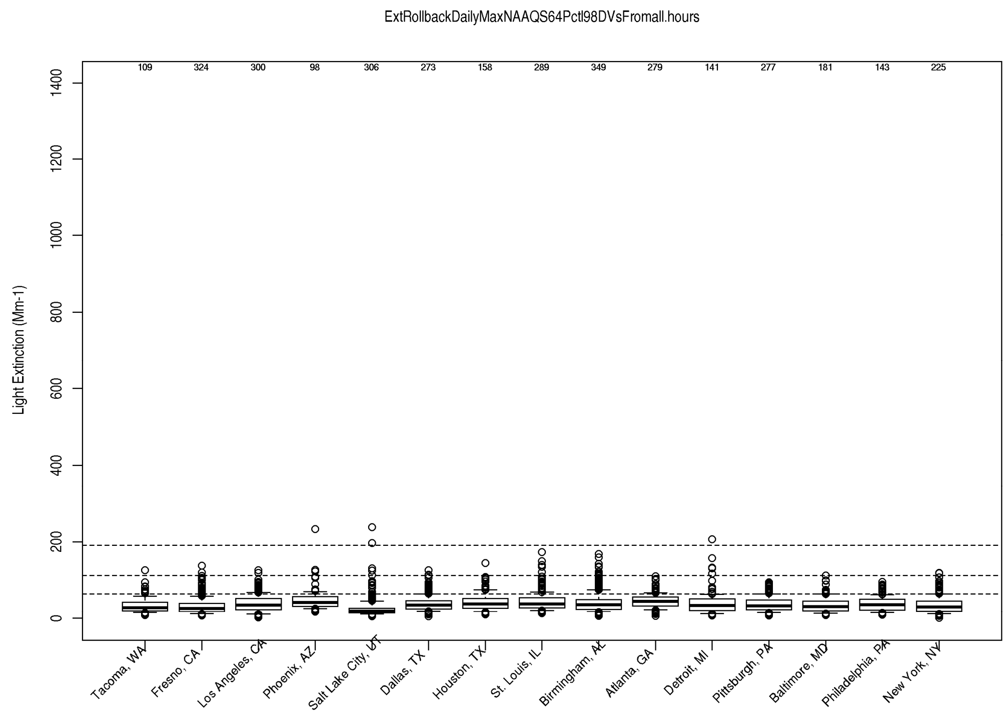


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

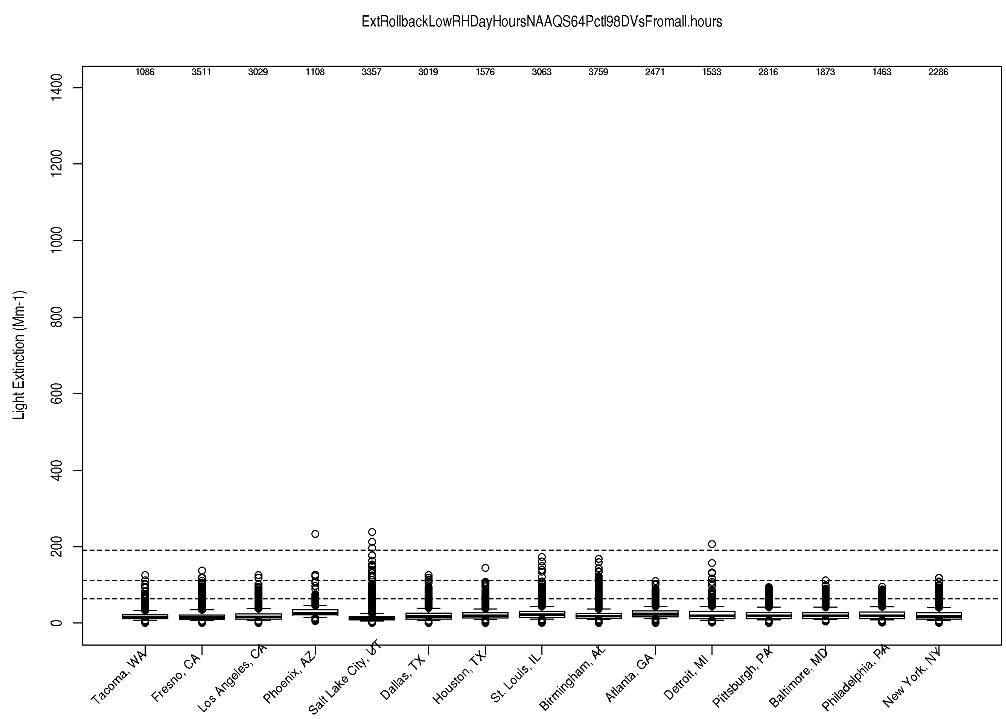


(r) NAAQS Scenario
All hours
64 Mm^{-1}
98^{th} percentile

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

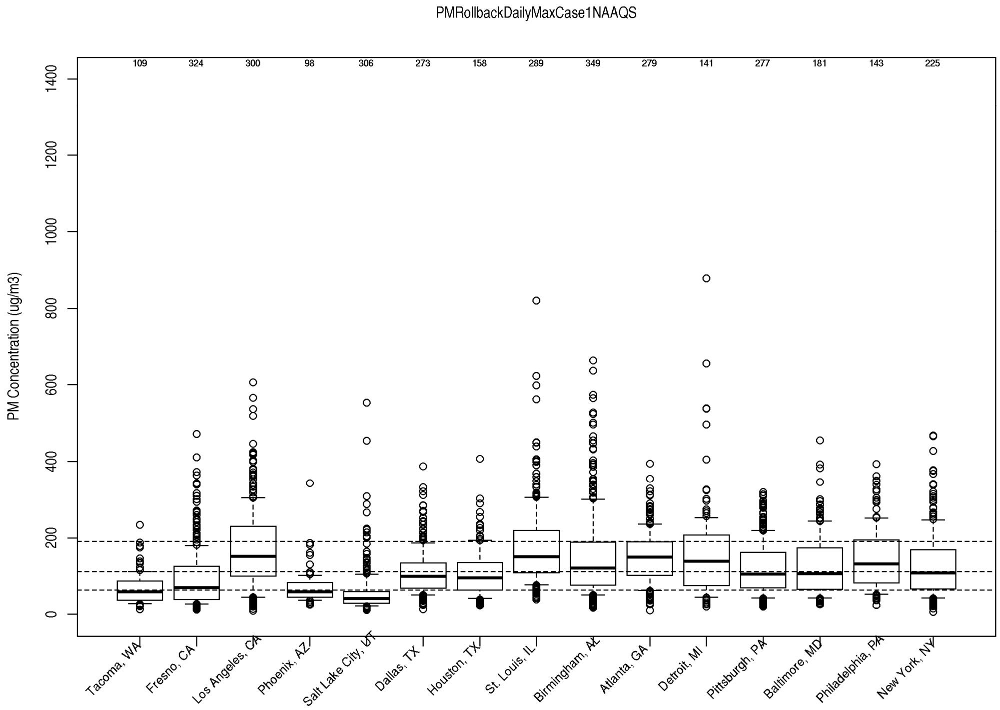


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

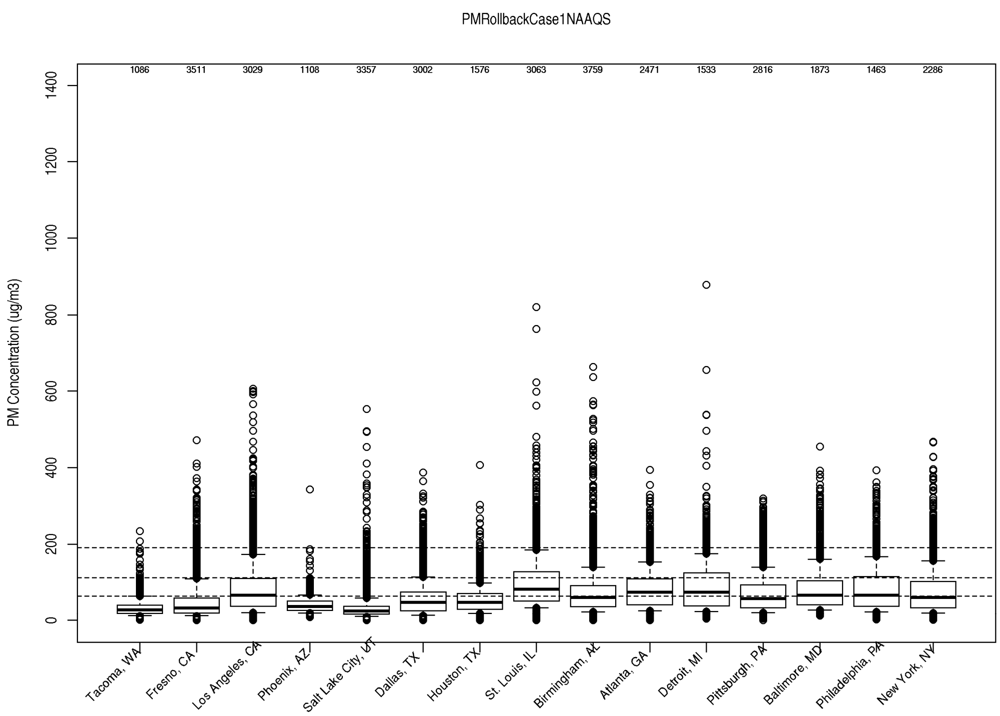


(s) NAAQS Scenario
15 µg/m³ annual
35 µg/m³ 24-hour

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)

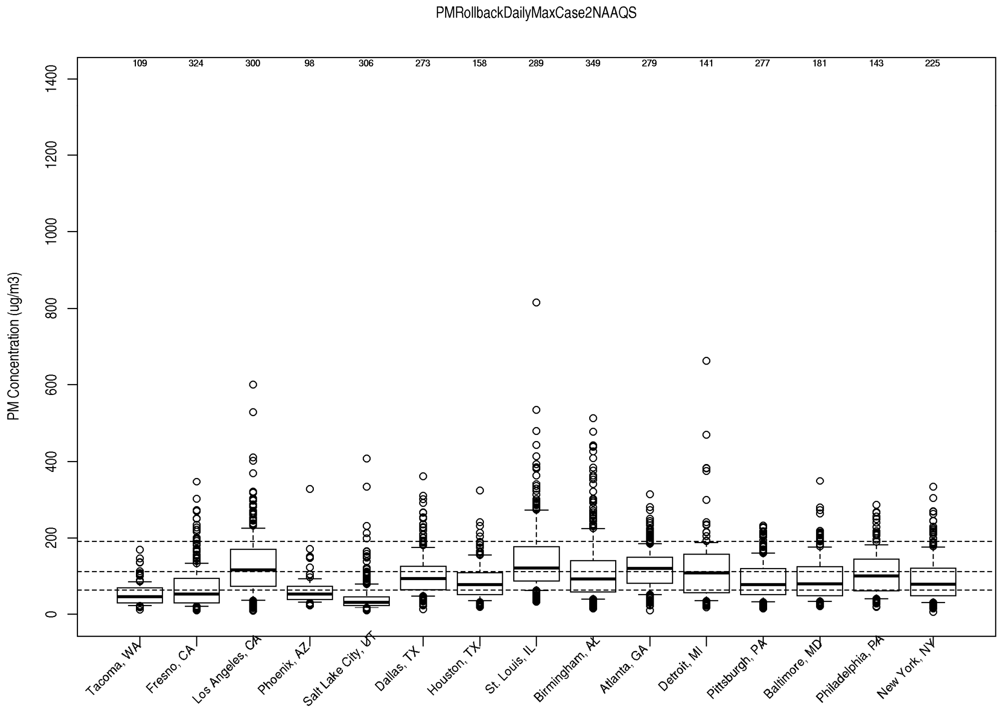


Displayed: Hourly Daylight PM_{10} Light Extinction (excluding hours >90% RH)

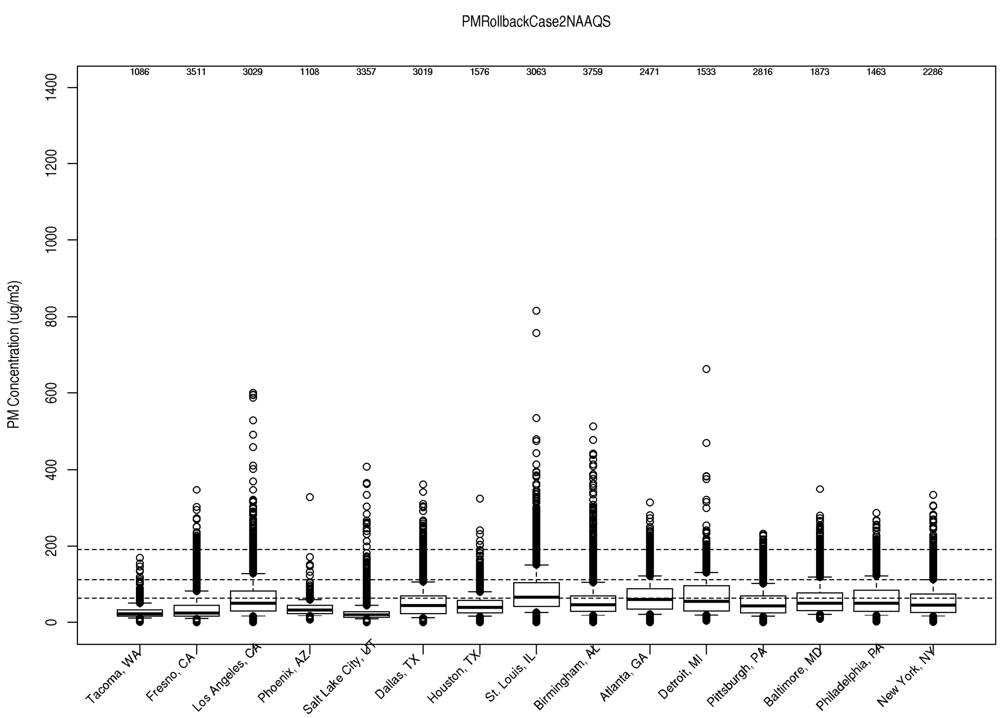


(t) NAAQS Scenario
12 µg/m³ annual
25 µg/m³ 24-hour

Displayed: Daily Max Daylight PM_{10} Light Extinction (excluding hours >90% RH)



Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)



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APPENDIX G

ADDITIONAL INFORMATION ON THE EXCLUSION OF DAYLIGHT HOURS WITH RELATIVE HUMIDITY GREATER THAN 90 PERCENT

This appendix provides detailed information related to the exclusion of daylight hours with relative humidity greater than 90 percent from the design value formula for the secondary NAAQS scenarios based on PM_{10} light extinction, as discussed in section 3.3.5. As described in that section, these hours have also been excluded from graphical displays of the distribution of PM_{10} light extinction under current conditions and the various NAAQS scenarios, and from the denominator of percentages of day or hours (as in Table 4-7).[4]

Table G-1 shows how many estimates of 1-hour daylight PM_{10} light extinction were excluded, based both on individual hours and on days that were affected by the exclusion of one or more daylight hours. Phoenix was not affected at all. Among the other areas, Detroit was the least affected. For all areas, comparison of the percentage of hours affected to the percentage of days affected indicates that several hours with high relatively humidity tend to occur in the same day, rather than being evenly distributed across all days. For example, in Atlanta 24 percent of daylight hours have relative humidity greater than 90 percent, which corresponds to about 876 hours per year (assuming there were data for every day of the year and given that on average there are about 10 fully daylight hours per day). However, only 80 percent of the days (corresponding to 292 days, if there were data for every day of the year) are affected. Thus, on average, an affected day in Atlanta has about 3 affected hours. The tile plots in Figure 3-12 also illustrate the tendency for hours with high PM_{10} light extinction to cluster in some days.

Figure G-1 shows when during the daylight hours these hours with relative humidity greater than 90 percent occurred, prior to the their exclusion. Some but not all areas have a strong tendency for the affected hours to be in the morning. The counts in this figure are across all the days in 2006-2008 that have estimates of PM_{10} light extinction, not all the actual calendar days in that three year period. Given the regularity of the monitoring schedules, these results should represent year-round conditions reasonably well. However, the estimates of PM_{10} light extinction for Phoenix and Houston are not seasonally balanced due to one calendar quarter with no data in each case (see Table 3-4), so the true year-round time-of-day distributions of excluded hours for these two areas may be somewhat different than shown here.

Figure G-2 contrasts the distribution of daylight PM_{10} light extinction estimates before and after the exclusion, based on both daily maximum values and all daylight hourly values individually. The differences observable in the figure are consistent with the information on the percentages of hours and day affected in the study areas. In most cases, the highest values of light extinction are notably lower after exclusion, on both a daily maximum basis and individual

[4] This appendix was prepared prior to the discovery of the SANDWICH processing error noted in the footnote on page 3-22 of the main document, and has not been updated to incorporate that correction. Values for PM_{10} light extinction in Figure G-2 and Table G-2 are therefore slightly inconsistent with values presented in the main report, but this should have a negligible effect on the comparisons presented.

hour basis, indicating that PM concentrations in some of the excluded hours are fairly high. If only low-PM hours were excluded by the relative humidity screen, the highest values of PM_{10} light extinction would not have been affected.

Finally, Table G-2 contrasts PM_{10} light extinction design values before and after the exclusion, for the 90th and 95th percentile forms based on daily maximum daylight 1-hour PM_{10} light extinction, for current conditions. (A similar comparison for the 98th percentile form was not generated.) As expected, design values are notably lower after the exclusion. For both percentile forms, the largest reduction is in Los Angeles (represented by the Rubidoux site in the far eastern part of the South Coast Air Basin). Phoenix had no hours with relative humidity greater than 90 percent, and accordingly Table G-2 shows that its PM_{10} light extinction design values are not affected by the exclusion. Similarly, Detroit and Dallas had only a few hours with relative humidity greater than 90 percent, and their design values are affected very little by the exclusion.

Table G-1. Percent of Daylight Hours and Days Affected by the Elimination of Hours with Relative Humidity Greater Than 90 Percent

Study Areas	Percent of Daylight Hours Excluded	Percent of Days with at Least One Daylight Hour Excluded
Tacoma	12.3	49.1
Fresno	3.6	15.7
Los Angeles	10.6	49.7
Phoenix	0.0	0.0
Salt Lake City	2.9	13.7
Dallas	2.8	12.8
Houston	9.6	40.9
St. Louis	6.4	21.1
Birmingham	4.4	19.1
Atlanta	24.1	80.7
Detroit	2.3	7.1
Pittsburgh	11.4	41.2
Baltimore	10.6	33.2
Philadelphia	9.6	31.7
New York	9.1	22.4

Figure G-1. Distribution by Time of Day of Eliminated Daylight Hours with Relative Humidity Greater Than 90 Percent.

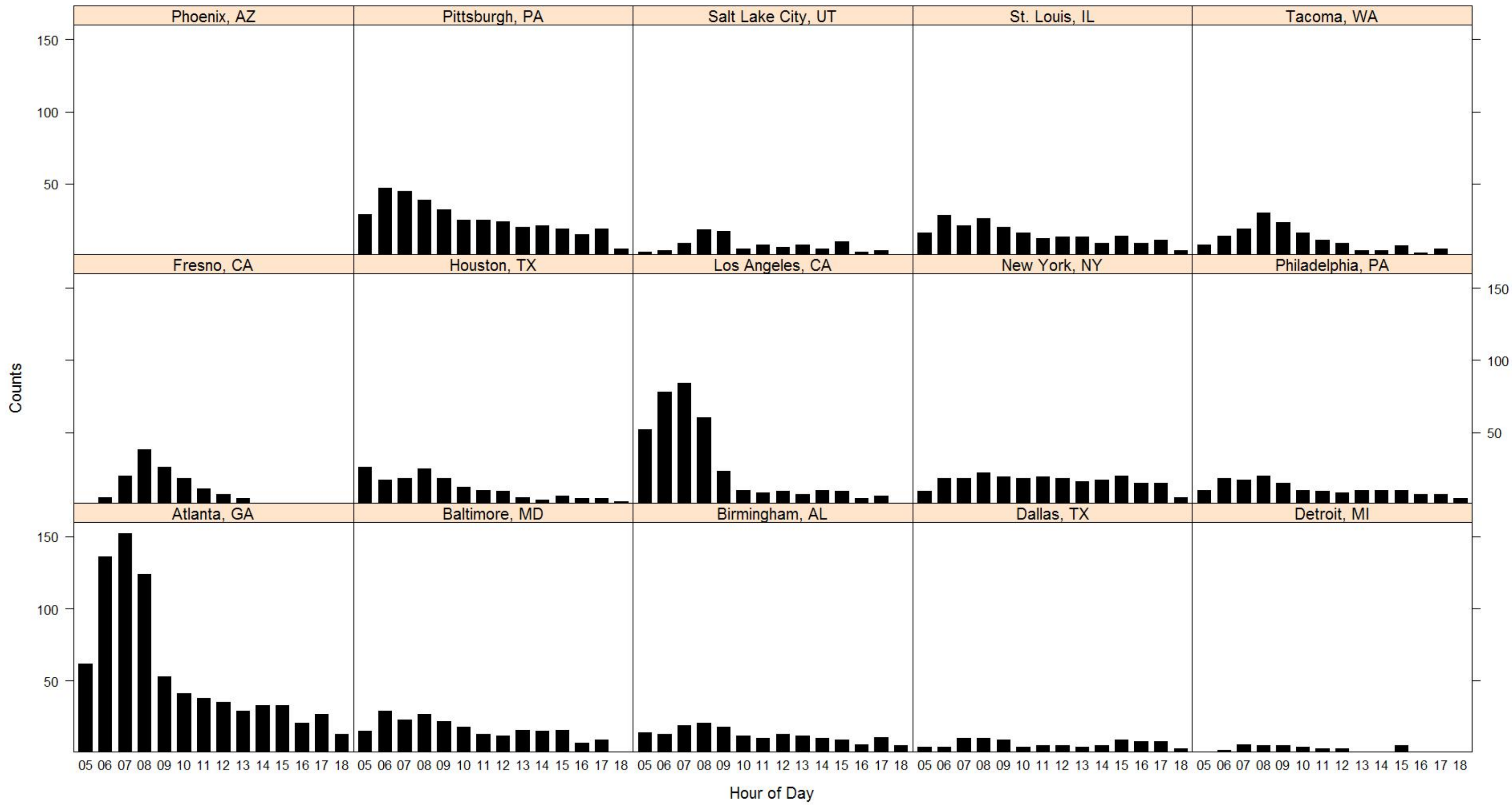
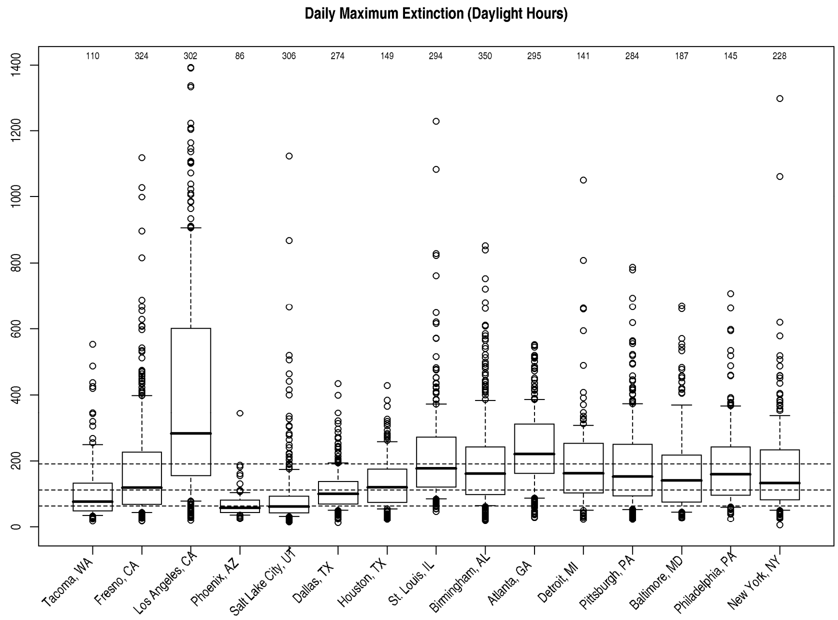


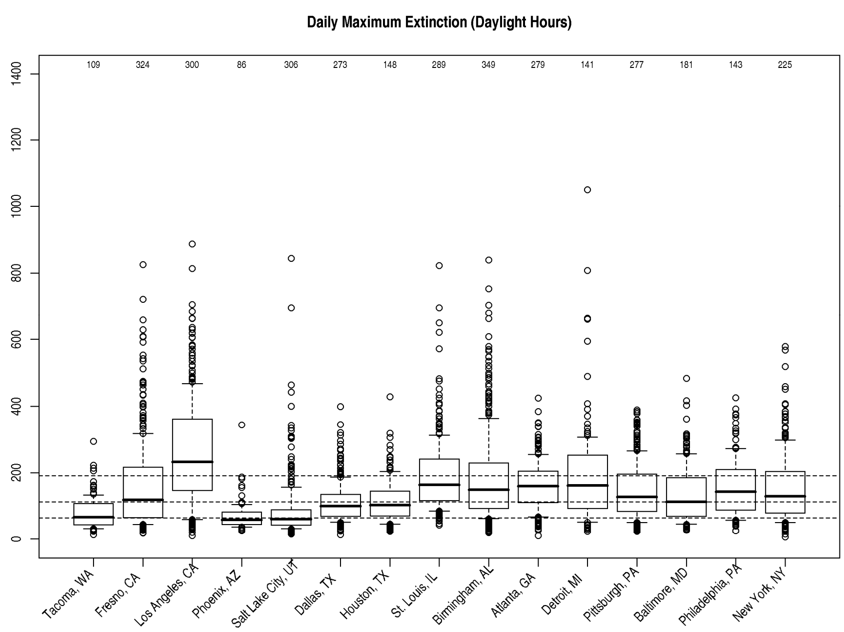
Figure G-2. Comparison of Distributions of Estimated Daylight 1-Hour PM_{10} Light Extinction and Maximum Daily Daylight 1-Hour PM_{10} Light Extinction Across the 2005-2007 Period for Current Conditions, by Study Area, Before and After Elimination of Hours with Relative Humidity Greater Than 90 Percent.

(a) Maximum Daily Values:

Before Elimination

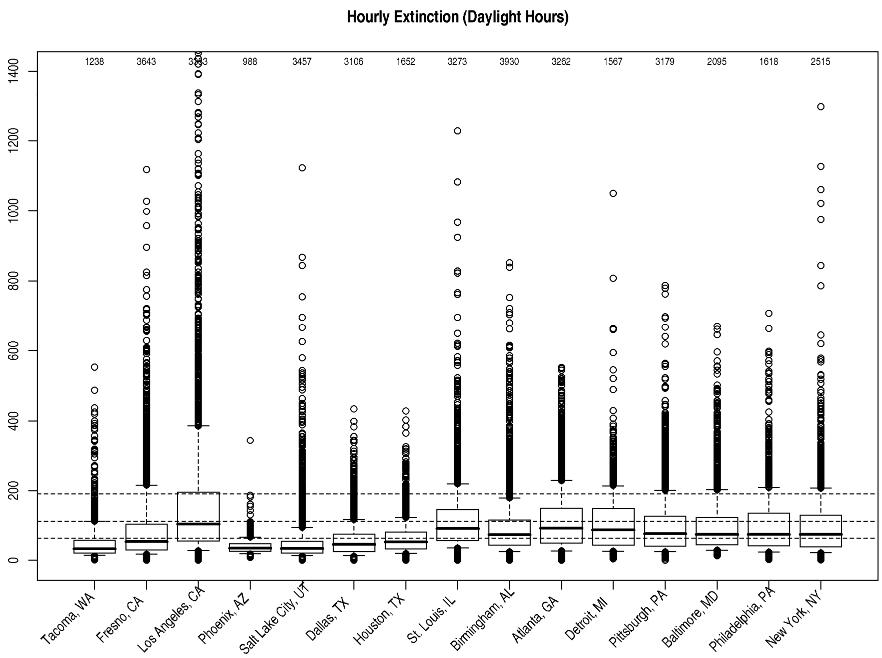


After Elimination



(b) Individual 1-Hour Values:

Before Elimination



After Elimination

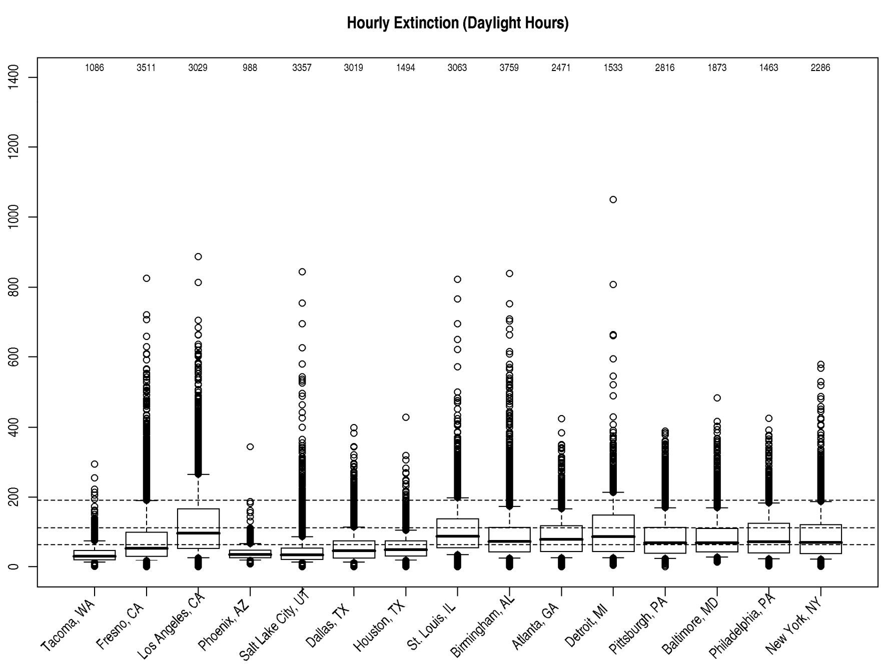


Table G-2. Comparison of 90th and 95th Percentile PM_{10} Light Extinction Design Values for the 2005-2007 Period for Current Conditions Based on Maximum Daily 1-Hour Daylight PM_{10} Light Extinction, Before and After Elimination of Hours with Relative Humidity Greater Than 90 Percent

Study Areas	PM_{10} Light Extinction Design Values Based on Daily Maximum 1-Hour Values					
	90th Percentile			95th Percentile		
	Before Exclusion	After Exclusion	Reduction Due to Exclusion	Before Exclusion	After Exclusion	Reduction Due to Exclusion
Tacoma	244	140	104	371	157	215
Fresno	381	338	43	533	463	70
Los Angeles	919	469	450	114 0	554	586
Phoenix	105	105	0	144	144	0
Salt Lake City	176	164	12	266	252	13
Dallas	189	183	5	239	239	0
Houston	253	194	59	279	234	44
St. Louis	359	307	52	423	381	42
Birmingham	366	357	9	496	483	13
Atlanta	380	249	131	462	288	174
Detroit	313	310	3	473	473	0
Pittsburgh	368	278	90	500	313	187
Baltimore	399	246	153	446	286	159
Philadelphia	382	286	96	449	339	110
New York	339	306	33	415	355	61

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APPENDIX H

INTER-YEAR VARIABILITY

One aspect of a NAAQS is whether it is based on the level of the selected indicator for a single year, or the average of the level of that indicator over multiple years. The NAAQS scenarios examined in this assessment are all based on a three-year average approach. That is, design values are based on the average of specified percentile values of PM_{10} light extinction from 2005, 2006, and 2007. Table H-1 presents more detailed information on the variability of these percentiles across these three years.

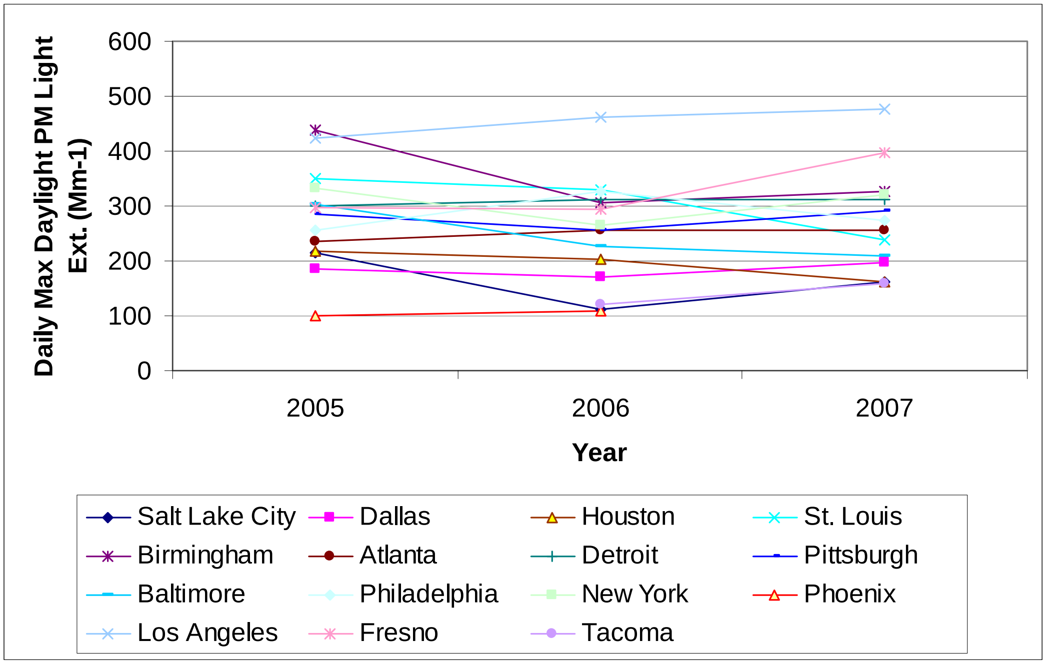
Figure H-1 presents some of the information in Table H-1 in graphical form, specifically for the 90th percentile form for both the daily maximum and all hour approaches.

Table H-1. Year-specific Percentile Values of PM_{10} Light Extinction for 2005, 2006, and 2007

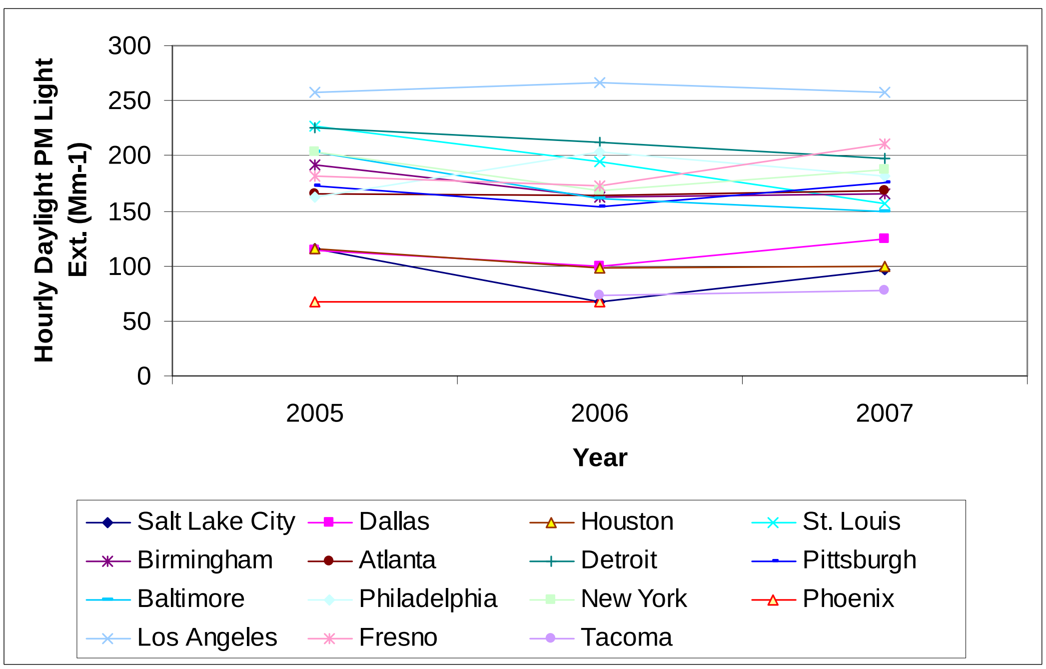
Study Areas	90th Percentile Form				95th Percentile Form				98th Percentile Form			
	2005	2006	2007	2005-2007 Average	2005	2006	2007	2005-2007 Average	2005	2006	2007	2005-2007 Average
	Based on Daily Maximum 1-Hour Daylight PM_{10} Light Extinction (Excluding hours with relative humidity greater than 90%)											
Tacoma	NA	121	158	140	NA	141	173	157	NA	214	207	211
Fresno	298	293	398	330	549	363	467	460	653	398	540	530
Los Angeles	424	461	477	454	507	523	619	550	582	594	658	611
Phoenix	100	110	NA	105	156	131	NA	144	182	187	NA	185
Salt Lake City	216	112	161	163	309	142	305	252	341	191	696	409
Dallas	184	170	197	184	252	223	242	239	312	321	271	301
Houston	217	204	161	194	269	238	196	234	306	319	248	291
St. Louis	350	329	239	306	432	405	303	380	483	572	347	467
Birmingham	438	307	325	357	547	410	493	483	608	513	565	562
Atlanta	235	255	257	249	283	295	286	288	305	338	351	331
Detroit	300	312	313	308	347	401	664	471	391	490	1051	644
Pittsburgh	284	257	292	278	347	272	320	313	360	350	382	364
Baltimore	303	227	208	246	362	258	239	286	415	302	260	326
Philadelphia	257	325	274	285	331	352	318	334	426	375	320	374
New York	333	265	320	306	405	272	384	354	559	353	441	451
	Based on 1-Hour Daylight PM_{10} Light Extinction (All Hours) (Excluding hours with relative humidity greater than 90%)											
Tacoma	NA	73	78	76	NA	101	109	105	NA	120	151	136
Fresno	181	172	211	188	255	254	273	261	391	326	387	368
Los Angeles	258	267	257	261	314	353	357	341	393	451	478	441
Phoenix	67	68	NA	68	79	78	NA	79	92	96	NA	94
Salt Lake City	116	67	97	93	193	83	148	141	255	116	304	225
Dallas	114	100	125	113	145	126	158	143	184	176	203	188
Houston	116	98	100	105	143	122	119	128	191	174	148	171
St. Louis	227	195	157	193	276	240	188	235	334	309	226	290
Birmingham	191	162	166	173	251	204	226	227	340	267	319	309
Atlanta	166	164	168	166	188	194	202	195	233	233	248	238
Detroit	226	212	198	212	268	252	234	251	320	312	313	315
Pittsburgh	173	153	176	167	217	193	218	209	284	237	272	264
Baltimore	203	161	150	171	290	190	196	225	342	225	218	262
Philadelphia	163	203	182	183	209	234	223	222	279	298	258	278
New York	203	169	187	186	264	222	244	243	313	267	317	299

Figure H-1. Inter-year Variability in 90th Percentile 1-Hour Daylight PM_{10} Light Extinction (excluding hours with relative humidity greater than 90 percent)

(a) Daily Maximum Approach



(b) All Daylight Hours Approach



APPENDIX I

DAYLIGHT HOURS

Table 3-5 shows the simple scheme used in this analysis to denote hours as fully daylight and thus eligible for consideration in the calculation of design values for the secondary NAAQS scenarios based on PM_{10} light extinction. This scheme also has been used to select which hours to show in various graphics. The scheme is based on applying a fixed set of fully daylight hours for each three-month season (November to January, etc.). In reality, the local time minutes of daylight vary continuously during the year, with latitude, and with the east-west position of a city within its time zone. The hours that are fully daylight will change in increments rather than continuously. This appendix examines how well the simple scheme reflects actual conditions and how disparities if any might affect the results presented and the answers to policy relevant questions that may be addressed in the subsequent policy assessment document.

Six study areas were selected for this examination: Tacoma, Los Angeles, Phoenix, Houston, Detroit, and New York. These areas cover the extremes with regard to latitude and to east-west position within time zone. For each area, the times of sunrise (defined by the leading or top edge of the sun appearing above the horizon) and of sunset (defined by the leading or bottom edge of the sun disappearing below the horizon) were obtained for each day of the year. It is several minutes after each of these times that the sun is fully visible in the morning and not visible at all in the evening.

Figure I-1 shows the relationship between these sunrise and sunset times and the simple scheme used to denote hours as fully daylight. The vertical scale is in hours with zero corresponding to local noon. The smooth curves represent the actual times of sunrise (top of figure) and sunset (bottom of figure). The stepped lines represent the scheme used to select the first and last hour denoted as fully daylight. Months are indicated on the horizontal axis. The figure indicates that the simple scheme has the effect of treating some hours as daylight that in fact contain minutes prior to sunrise or after sunset, and conversely treating some hours as not daylight that include no such minutes. In particular:

- In February, the hours from 7 am to 8 am and from 5 pm to 6 pm are treated as daylight but include non-daylight minutes in most of the example areas.
- In April, the hour from 6 am to 7 am is treated as non-daylight but in many areas includes only minutes that are after sunrise.
- In most of June and most of July, for Detroit and Tacoma only, the hour of 7 pm to 8 pm is treated as non-daylight but in fact has no minutes after sunset.

- In October, the hours of 6 am to 7 am and 5 pm to 6 pm are treated as daylight but include non-daylight minutes in all of the example areas.

The tile plots in Figure 3-12 can be used to assess the significance of these disparities, i.e., whether they are likely to significantly affect PM_{10} light extinction design values. Table I-1 contains observations for each of the 24 combinations of the four time periods listed above and the six example areas. Taken together, these observations make it likely that refining the scheme for designating hours as fully daylight would not significantly change conclusions that can be drawn from this assessment as it has been performed. Changing the scheme would involve considerable effort in updating virtually every table and graphic in the assessment, however.

Figure I-1. Comparison of Actual Sunrise and Sunset Times to this Assessment's Scheme to Denote Hours as Fully Daylight

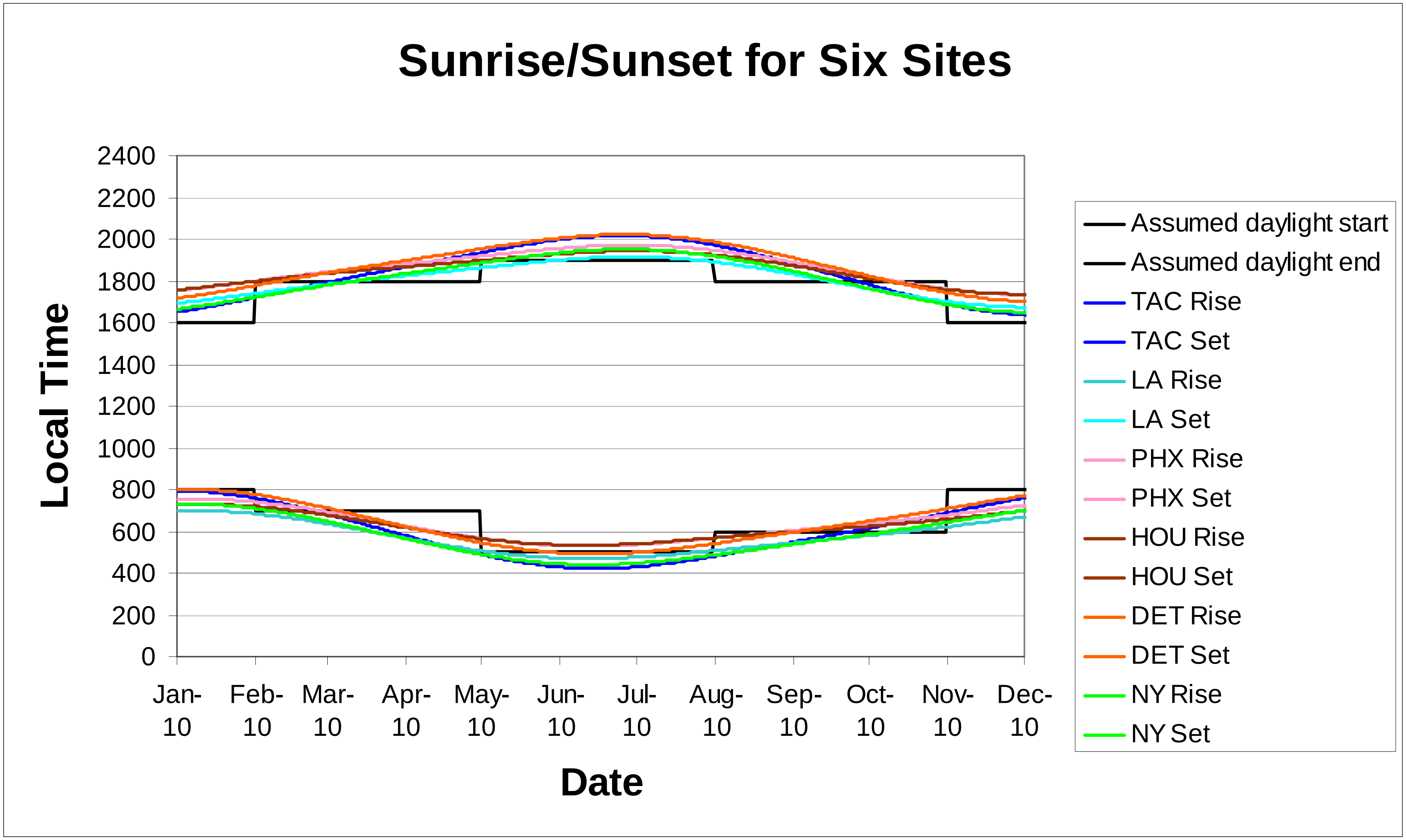


Table I-1. Observations from Tile Plots for Hours with Questionable Daylight/Non-Daylight Status in Six Study Areas

Study Area	February (AM and PM)	April (AM)	June-July (PM)	October (AM and PM)
Tacoma	The morning hour with questionable daylight status tends to have RH > 90%. The evening hour in question tends to either have low PM light extinction or to have RH > 90%.	The tile plot does not show data for the morning hour that may better be denoted daylight, but the instances of high PM light extinction that do appear typically last multiple hours.	Very late afternoon typically is not a period of high PM light extinction.	Instances of high light extinction involving the questionable hours are multi-hour and/or involve RH > 90%.
Los Angeles	Instances of high light extinction involving the questionable hours are multi-hour and/or involve RH > 90%.	The tile plot does not show data for the morning hour that may better be denoted daylight, but the instances of high PM light extinction that do appear typically last multiple hours.	NA	Instances of high light extinction involving the questionable hours are multi-hour and/or involve RH > 90%.
Phoenix	Instances of high light extinction involving the questionable hours are multi-hour.	The tile plot does not show data for the morning hour that may better be denoted daylight, but early morning in April typically is not a time of high PM light extinction.	NA	PM light extinction is usually low in October; on those days with moderate levels in the questionable hours, another hour in the central part of the day has a similar level.
Houston	Instances of high light extinction involving the questionable hours are multi-hour and/or involve RH > 90%.	The tile plot does not show data for the morning hour that may better be denoted daylight, but the instances of high PM light extinction that do appear typically last multiple hours and/or involve RH >90%.	NA	The amount of information is limited due to missing data. On those days with moderate to high PM light extinction during the questionable hours, another hour has a similar level, or RH >90% plays a role.
Detroit	Instances of high light extinction involving the questionable hours are multi-hour.	The tile plot does not show data for the morning hour that may better be denoted daylight, but the instances of high PM light extinction that do appear typically last multiple hours.	July generally is a time of high PM light extinction for the hours currently considered daylight. Adding one more late afternoon hour likely would not affect design values.	Instances of high light extinction involving the questionable hours are multi-hour.
New York	All but one instance of high light extinction involving the questionable hours are multi-hour.	The tile plot does not show data for the morning hour that may better be denoted daylight, but the instances of high PM light extinction that do appear typically last multiple hours.	NA	Instances of high light extinction involving the questionable hours are multi-hour and/or involve RH > 90%.

APPENDIX J

LOGIT MEMORANDUM

Memorandum

To: Vicki Sandiford, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency

From: Leland Deck and Megan Lawson, Stratus Consulting Inc.

Date: 2/3/2010

Subject: Statistical analysis of existing urban visibility preference studies

During the CASAC meeting on October 5-6, 2009, Dr. Bill Malm and other CASAC members suggested that a limited dependent variable statistical analysis could be used to analyze the acceptability criteria responses in the four cities for which there are existing urban visibility preference studies. It was the view of those Panel members that successful statistical analyses of the studies results would provide an estimate of a "best fit" central tendency function describing the results of the preference studies, as well as confidence intervals around the estimated functions. Such analyses would also make it possible to conduct hypothesis testing, such as examining whether the estimated 50% criteria level in one study is statistically different than the 50% criteria level in another study.

On the basis of the CASAC comments and the information available in the previous Stratus Report (Stratus Consulting, 2009), EPA concluded it was appropriate to conduct further statistical analyses on the available urban visibility preference studies. Subsequently, EPA asked Stratus Consulting to re-examine the data from these studies and identify several methods for statistical analyses along the lines CASAC members suggested. This memorandum provides a description of the statistical analyses we conducted, and summarizes the results.

Data

While we do not have complete original response data from each preference study, certain data available in all four studies can be used to derive a set of data for an analysis comparing the results from each of the four[1] cities. This available data is the percentage of respondents that rated each individual photograph (or image) as acceptable. We also know the total number of individuals that rated each photograph, as well as the haziness level in each photograph, measured in deciviews (dv). Using these pieces of information we were able to assemble a master data set of 19,280 observations from the original data. Each observation is associated

[1] In the initial set of analyses discussed in this memorandum we combine the results from the 2001 Washington, DC focus group study with all 26 participants in the "Test 1" analysis from Smith and Howell (2009). "Test 1" was designed to replicate the 2001 focus group study, with a goal of making two sets of results directly comparable. Additional analysis described later in this memorandum uses a different set of statistical techniques to examine the Washington, DC studies in more detail.

with an individual binary "yes" or "no" acceptability answer, the dv level, and the city location for a single photograph.

For example, in the Phoenix study 385 participants rated each of 21 different WinHaze images. Hence the Phoenix study contributes 8,085 (385 × 21) observations, nearly 41.9% of the total set of 19,280 observations in the master data set. The 32 photographs used in the Denver study contribute 6,848 observations (35.5% of the total), the 20 photographs in the British Columbia contribute 3,600 observations (18.7% of the total), and the combined Washington, DC studies (combining data from the DC-2001 study with the Test 1 data from the DC-2009 study) contribute 747 (3.9% of the total). The 19,280 observations are fairly evenly split, with 9,452 "yes" observations, and 9,828 "no" responses.

The participants in each study viewed a series of images with different dv levels. While the data collected by the original researchers included information linking each individual with their ratings on each picture, such detailed information is currently only available for the Washington, DC study conducted in 2009. Access to this additional level of information in the 2009 Washington study allows us to conduct an additional type of analysis accounting for individual heterogeneity of preferences regarding acceptable levels of visibility.

Statistical Analysis Models

All of the analyses described in this memorandum are logistic regressions using the logit model. The logit model is a generalized linear model used for binomial regression analysis which fits explanatory data about binary outcomes (in this case, a person rating a photograph acceptable or not) to a logistic function curve.

In the context of the preference studies, the logit model estimates the function that best approximates the percentage of respondents that will rate a photograph acceptable based on a set of explanatory variables. The observations on the dependent variable have one of two discrete values: 1 (the person rated the photograph acceptable) or 0 (unacceptable). In our context, the logit model estimates the proportion of participants who will find any particular dv level acceptable. In our analysis, there were two basic types of explanatory (independent) variables; one continuous numerical variable (the photograph's haziness level in dv), and a set of discrete variables that identify which city the observation is from. We estimate two variations of the logit model, using the basic explanatory variables in different ways.

The fundamental form of a logistic function is:

$$probability("yes") = f(z) = \frac{1}{1+e^{-z}}.$$

where the variable z, known as the logit, is the influence of all the explanatory variables:

$$z = \beta_o + \beta_1 x_1 + \beta_2 x_2 + ... + \varepsilon.$$

In our analysis the estimated logistic function f (z) is the estimated probability of the participants in the study rating a photograph acceptable, given the dv value of the photograph and what city the observation came from.

We conducted the logit analysis using two alternative forms of the logit model.

Model 1 is a simple form of the logit model, and includes the dv value and uses the city information to create a set of categorical indicator variables. This analysis assumes that all respondents have a similar shape to their response function (the probability function of responding "yes" given the dv level of a photograph), but investigates whether the location of the response function differs in the four cities.

The logit for Model 1 is:

$$z = Intercept + \beta_1 dv + \beta_2 BC + \beta_3 DC + \beta_4 Phoenix + \varepsilon \ .$$

The variables BC (British Columbia), DC (Washington), and Phoenix are the indicator (or "dummy" variables. For example, the BC variable is set equal to one if the observation is from the BC study, and set to zero if that observation is from a study in a different city study. Denver is used as the omitted city indicator variable, allowing the estimated coefficients on the other three city indicator variables to estimate if the response function is different in those cities than in Denver. The term ε represents the error with which the model was estimated, or the difference between the actual and predicted values of z. The logit model assumes that ε has a mean of zero.

The Model 1 form of the logit model estimates a single "slope" for the response function in all cities as β_1, the coefficient for haziness (dv). The other terms shift the intercept. The intercept for Denver is simply the estimated parameter *Intercept*. The effective intercept for the other cities becomes the sum of Intercept plus the coefficient on the city's indicator variable, for example the intercept for Washington is *Intercept* + β_3.

Model 1 creates one test of the hypothesis that the responses in each city are the same. If the estimated coefficient on a particular city variable is statistically significant, the analysis would imply that the city's response function is likely shifted relative to the Denver function, and that city would have a different dv value for the 50% criteria. A positive and significant city coefficient shifts that city's response function to the right, resulting in the dv level where 50% criteria level in that particular city is higher than Denver's.

Model 2 is a more general model than Model 1, and relaxes the assumption in Model 1 that the slope of the response function is the same in every city. Model 2 includes not only dv and the city indicator variables as in Model 1, but also a set of interaction terms, where each city dummy variable is multiplied by the dv level. The logit for Model 2 is:

$$z = Intercept + \beta_1 dv + \beta_2 BC + \beta_3 (dv \times BC) + \beta_4 DC$$
$$+ \beta_5 (dv \times DC) + \beta_6 Phoenix + \beta_7 (dv \times Phoenix) + \varepsilon.$$

For example, in Model 2 the estimated total intercept for Washington becomes *Intercept* + β_4, and the estimated slope of the Washington function is $\beta_4 + \beta_5$.

In the fully interacted Model 2 a statistically significant estimate of the city indicator variable coefficients (β_2, β_4, or β_6) has the same implication as in Model 1; the response function is likely shifted relative to the Denver function. A statistically significant estimate of the interaction term coefficient (β_3, β_5, or β_7) for a particular city implies that the response function has a different slope than the Denver function.

The fully interacted model produces the same results as conducting a separate logit analysis for each of the four cities. The interacted model, however, makes it easier to conduct hypothesis testing on the estimated mean response functions.

The predicted mean dv values at each of the acceptance criteria presented here are a function of the coefficients on dv and the other explanatory variables, each of which have their mean and standard deviation. Therefore, a confidence interval constructed around this predicted mean must account for both the variance and covariance of the parameter estimates. Using a Monte Carlo estimation approach, we made 1000 random draws from the joint distribution of the coefficients using the mean vector and variance-covariance matrix of the parameter estimates for the distribution parameters. For each of these draws we then calculated the predicted mean dv. After removing the lower and upper 5% of the simulated values, the lower and upper end of the range of predicted values represent the lower and upper range of the 95% confidence interval. Confidence intervals calculated using this procedure are known as Krinsky-Robb confidence intervals (Krinsky and Robb, 1986). Because estimating Krinsky-Robb confidence intervals requires a separate Monte Carlo analysis for each acceptability criteria dv level, we only estimate confidence intervals for five different acceptability levels: 90%, 75%, 50%, 25%, and 10%.

The Krinsky-Robb procedure assumes that the estimated parameters are normally distributed, which may or may not be true. To explore the potential impact of this assumption, for one logit analysis we also conducted an alternative procedure that does not assume a normal distribution. This alternative procedure (Hole, 2007) uses a bootstrap method to estimate the confidence intervals for the estimated mean 50% criteria. The confidence intervals using the bootstrap were within 1% of the confidence intervals using the Krinsky-Robb procedure, indicating that the multivariate normal assumption imposed by the Krinsky-Robb procedure is not unreasonable. We also conducted hypothesis tests using the median dv values estimated using the bootstrapping procedure. The conclusions from these hypothesis tests were identical to the conclusions from the other hypothesis tests.

Statistical Analysis Results, Inter-City analyses

We conducted all the logit analyses described in this document using STATA® Data Analysis and Statistical Software (Release ES 10.1), using the LOGIT procedure. The Krinsky-Robb analysis used STATA's "wtpcikr" module. The bootstrap method (Hole, 2007) was conducted using STATA's "bootstrap" module.

Model 1 Results, Inter-City Analysis

Table 1 presents the parameter estimates from the logit analysis with city indicators (Model 1) which effectively shift the intercept. The Washington, DC data in this analysis includes both DC-2001 and DC-2009 (Test 1) data. The Denver study is the omitted indicator city in this analysis, so the intercept term coefficient for Denver is equal to the Constant. The intercept for the other cities is the sum of the constant plus the coefficient for the respective city. The coefficient for variable dv is the estimated slope for all four cities.

Table 1. Model 1 logit analysis results

Variable	Coefficient (β)	Standard error	z-statistic	Pr |β| = 0	5% confidence estimate	95% confidence estimate
dv	-0.4187	0.0059	-71.09	< 0.001	-0.430	-0.407
British Columbia	1.1164	0.0630	17.72	< 0.001	0.993	1.240
Washington, DC	3.8743	0.1325	29.25	< 0.001	3.615	4.134
Phoenix	1.8021	0.0576	31.31	< 0.001	1.689	1.915
Constant	8.3073	0.1186	70.07	< 0.001	8.075	8.540

McFadden's pseudo-R^2 for the Model 1 estimate[2] was 0.474.

[2] While pseudo-R^2 is, like traditional R^2, bounded between zero and one, it does not have the same interpretation. R^2 can be interpreted as the percentage of the variation in the dependent variable explained by variation in the independent variables. Pseudo-R^2, on the other hand, is the percent improvement in log likelihood from using the full set of explanatory variables, relative to a model that uses only a constant. It offers a sense for how much better the model fits when the explanatory variables are added, but cannot tell us the percentage of variation we are explaining. Pseudo R^2, instead of traditional R^2, must be used in evaluating logit and other maximum likelihood estimation models. Similar to R^2, a higher pseudo-R^2 indicates a model with a better fit.

The Log likelihood chi^2 test strongly rejects the null hypothesis there is no effect of explanatory variables on the probability that a respondent would find a photograph acceptable (Pr (chi^2) = 0 < 0.000).

The z-statistic (also known as the Wald z-statistic) in a logit analysis is analogous to the t-statistic in a conventional linear regression. The z-statistic is simply the ratio of the estimated coefficient to its standard error, and can be used to estimate the probability that the estimated coefficient is equal to zero. The column in Table 1 labeled "Pr |β| = 0" is the 2-tailed p-value used in testing the null hypothesis that the estimated parameter is zero. The Pr |β| values shown in Table 1 are all less than 0.005 ("~0"), indicating that all of the estimated coefficients are very statistically significant. Because the city dummy variables are significant, in Model 1 we reject the hypothesis that the four studies have an identical response function.

Figure 1 shows the estimated response functions in each city for the logit analysis with city indicators, as well as the underlying data as was shown in Figure 14 of the Stratus Consulting final report (Stratus Consulting, 2009). While Model 1 estimates the shape of a response function that is identical in each city, the positive and significant coefficients on the city variables in Model 1 result in the response functions for the different cities to shift to the right of the Denver function.

The logit analysis results also support estimating the dv value where the 50% acceptability criteria are met in each city. The 50% acceptability criteria occur at the level of haziness where half the survey participants said the visibility is acceptable, and half said it was not acceptable. In Figure 1, the 50% criteria level is the dv value where the estimated response function crosses the 50% response level on the y axis.

As a sensitivity analysis, it is also possible to calculate the dv levels that meet alternative decision criteria. For example, one can calculate the estimated dv level at which 75% of the participants said the visibility was acceptable. This 75% criterion would occur at better visibility (i.e., lower dv values) than the 50% criteria. Similarly, one can also calculate the estimated the dv level that any desired percentage of the participants said was acceptable. The Model 1 estimates of alternative acceptability criteria dv values for each city are shown in Table 2.

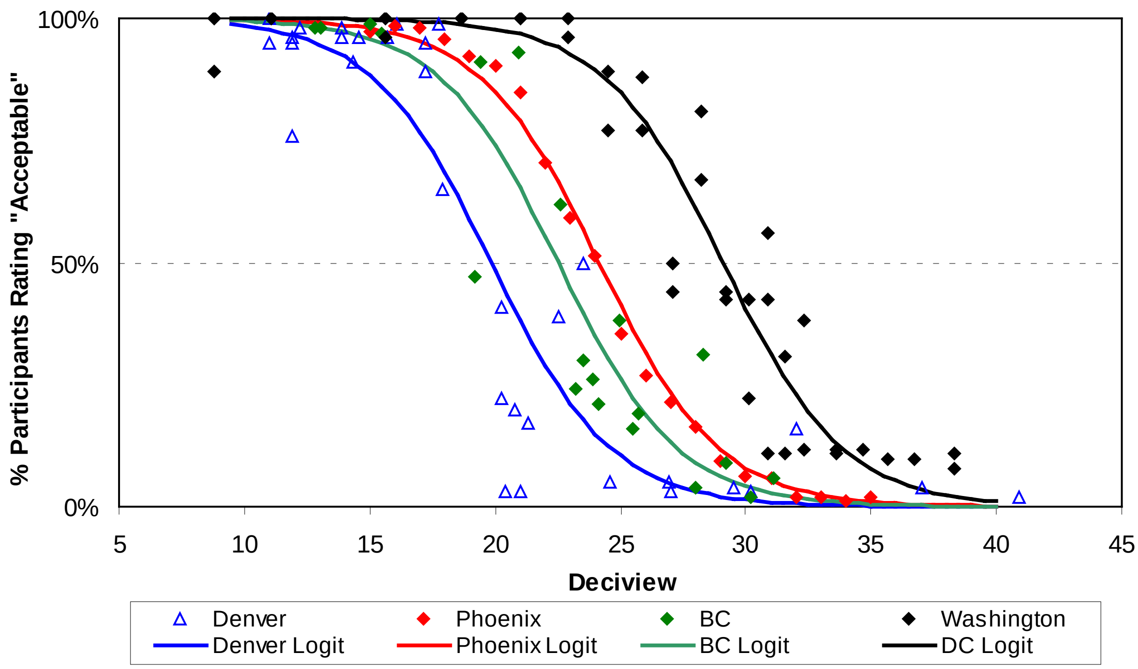


Figure 1. Estimated response functions for full cities using the Model 1 logit analysis.

Table 2. Model 1 estimated haziness (dv) levels of alternative acceptability criteria

	Denver	British Columbia	Washington, DC	Phoenix
90% acceptability criteria	14.59	17.26	23.85	18.90
75% acceptability criteria	17.22	19.88	26.47	21.52
50% acceptability criteria	19.84	22.51	29.10	24.15
25% acceptability criteria	22.47	25.13	31.72	26.77
10% acceptability criteria	25.09	27.76	34.34	29.39

The range of the Model 1 estimates of the 50% acceptability criteria is very consistent with the Candidate Protection Level (CPL) range of 20 dv to 30 dv identified in the U.S. EPA (2009) report *Particulate Matter Urban-Focused Visibility Assessment; External Review Draft* (UFVA).

Model 2 Results, Inter-City Results

Table 3 presents the parameter estimates from the fully interacted logit analysis, which investigates whether both slope and the intercept of the estimated response function differ between cities. Denver was again used as the omitted city in the fully interacted model.

Table 3. Model 2 logit analysis results

Variable	Coefficient (β)	Standard error	z-statistic	Pr |β| = 0	5% confidence estimate	95% confidence estimate
dv	-0.3862	0.0094	-41.16	< 0.001	-0.4045	-0.3678
British Columbia	1.0496	0.3589	2.92	0.003	0.3463	1.7530
Washington, DC	2.9450	0.8458	3.48	< 0.001	1.2873	4.6026
Phoenix	3.5682	0.3015	11.84	< 0.001	2.9773	4.1591
BC × dv	-0.0029	0.0162	-0.18	0.860	-0.0345	0.0288
Wash. × dv	0.0200	0.0293	0.68	0.495	-0.0374	0.0774
Phoenix × dv	-0.0797	0.0136	-5.88	< 0.001	-0.1063	-0.0531
Constant	7.6844	0.1830	41.99	< 0.001	7.3257	8.0431

The pseudo-R^2 for the Model 2 estimate was 0.4756 (very similar to the Model 1 results), and the Model 2 log likelihood chi^2 test also strongly rejects the null hypothesis there is no effect of the explanatory variables on the probability that a respondent would find a photograph acceptable (Pr (chi^2) = 0 < 0.000).

The city indicator coefficients in this full interaction model are all positive and statistically significant, as they were in Model 1, indicating that the response functions for different cities shifted right (relative to Denver). However, of all the interactions only the Phoenix interaction term is significant, indicating that the Phoenix response function has a different slope than the other three cities.

Figure 2 shows the estimated response functions in each city for Model 2, as well as the underlying data.

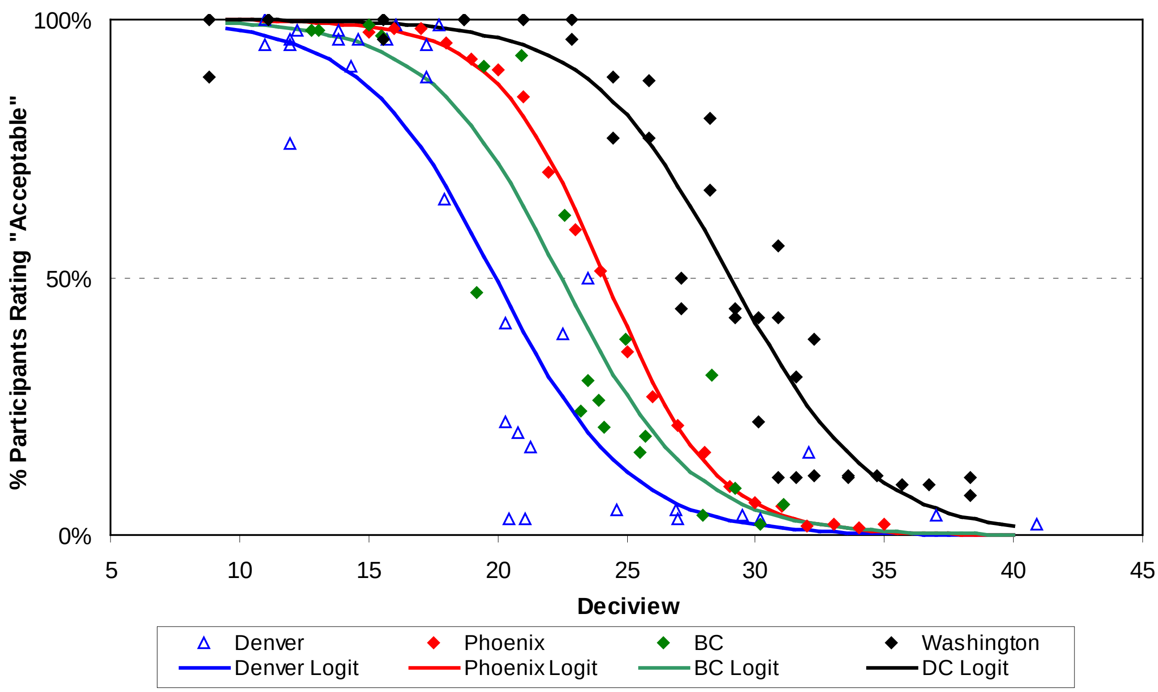


Figure 2. Estimated response functions for four cities using the fully interacted logit analysis.

The significantly different slope of the Phoenix response function is clearly visible in Figure 2. The negative estimated coefficient on the Phoenix interaction term results in the Phoenix response function being steeper than the other cities' functions. In other words, Phoenix respondents' acceptance probabilities were more sensitive to changes in dv levels. Figure 2 also shows the Washington, DC function is modestly less steep than the others, but the decrease in the slope is not statistically significant. Therefore, while Washington, DC respondents are more likely to accept worse visibility overall, they are just as responsive to changes in dv as respondents in Denver and British Columbia.

As with Model 1, it is possible to use the Model 2 results to estimate the dv values where the estimated response functions cross the 50% acceptability level, as well as any alternative criteria levels. The Model 2 estimates of alternative acceptability dv values for each city are shown in Table 4.

Table 4. Model 2 estimated haziness (dv) levels of alternative acceptability criteria

	Denver	British Columbia	Washington, DC	Phoenix
90% acceptability criteria	14.21	16.80	23.03	24.15
75% acceptability criteria	17.05	19.63	26.03	21.80
50% acceptability criteria	**19.90**	**22.45**	**29.12**	**24.15**
25% acceptability criteria	22.74	25.28	32.03	26.51
10% acceptability criteria	25.59	28.10	35.03	28.87

The Model 2 estimates of the 50% acceptability criteria are nearly identical to the Model 1 estimates; the biggest difference is a 0.07 dv decrease in the Washington, DC 50% acceptability criteria. The essentially identical estimates of the 50% acceptability criteria in Models 1 (city indicator only) and Model 2 (full interaction) indicates the choice of model form does not change the conclusion that the logit results are consistent with the 20 to 30 dv CPL range identified in the draft UFVA (EPA, 2009).

We also conducted hypothesis testing with the four city data used in this section to examine the probability that the 50% acceptance criteria in the four different cities are the same. We used the full interaction model results for the hypothesis testing. Our approach estimated the mean 50% criteria dv levels and standard error (based on the Krinsky-Robb confidence intervals) for each of the four cities. We then conducted a hypothesis testing using a t-test to estimate the probability the mean 50% criteria dv levels are the same in each pair of cities. The null hypothesis in this hypothesis test is that the means are the same. As shown in Table 5, the null hypothesis is strongly rejected for all pairs of cities, indicating that the mean 50% criteria dv levels differ for all four cities.

Table 5. Hypothesis testing on whether the full interaction model mean 50% criteria dv levels are the same

	British Columbia Mean dv = 22.45	Phoenix Mean = 24.15	Washington, DC Mean dv = 29.12
Denver Mean dv = 19.90	t-stat = 16.89 Pr(Den = BC) ~0	t-stat = 35.15 Pr(Den = Ph) ~ 0	t-stat = 30.21 Pr(Den = DC) ~ 0
British Columbia	–	t-stat =12.08 Pr(BC = Ph)~0	t-stat = 21.23 Pr(BC = DC) ~ 0
Phoenix		–	t-stat = 16.53 Pr(Ph = DC) ~ 0

Analysis of Washington, DC Preference Studies

There are two related studies of visibility preferences in Washington, DC. In 2001, in a project sponsored by the U.S. Environmental Protection Agency, Abt Associates conducted a pilot focus group study (DC-2001) of urban visibility preferences in Washington, DC. In 2009, in a study for the Utility Air Regulatory Group, Smith and Howell conducted a series of three tests of urban visibility preferences in Washington, DC. In their first test (DC-Test 1), Smith and Howell used all the images used in the DC-2001 study, trying to replicate the DC-2001 study. Their second test (DC-Test 2) used fewer of the Washington images, restricting the study to the 12 images with better visibility (images with visibility of 27.1 dv or better). In the third test (DC-Test 3), they expanded the range of images to include two hazier images (adding a 42 and 45 dv images, and deleting images at 11.1, 15.6, and 24.5 dv).

An important question is whether the participant responses obtained in the DC-2001 study are similar to the responses in Test 1, which was designed to replicate the DC-2001 study. A related question is whether the responses in Tests 2 and 3 are similar to Test 1. To investigate these questions we estimated logit response functions using the data from the four different Washington, DC data sets (DC-2001, DC-Test 1, DC-Test 2, and DC-Test 3), using the full interaction logit model specification.

The estimated coefficients from a full interacted model are presented in Table 6. The DC-2001 test is used as the omitted interaction variable.

Table 6. Logit regression results with full interacted model of Washington, DC studies

Variable	Coefficient (β)	Standard error	z-statistic	Pr |β| = 0	5% confidence estimate	95% confidence estimate
dv	-0.4035	0.0567	-7.12	< 0.001	-0.5146	-0.2925
Test 1	-1.5425	1.8785	-0.82	0.412	-5.2242	2.1392
Test 2	-0.7431	2.0737	-0.36	0.720	-4.8075	3.3212
Test 3	3.4109	2.6980	1.26	0.206	-1.8772	8.6990
Test 1 × dv	0.0616	0.0632	0.97	0.330	-0.0624	0.1855
Test 2 × dv	-0.1043	0.0804	-1.30	0.194	-0.2618	0.0532
Test 3 × dv	-0.0607	0.0868	-0.70	0.485	-0.2309	0.1095
Constant	11.5621	1.6777	6.89	< 0.001	8.2739	14.8504

Figure 3 shows the estimated full interaction logit function for the separate Washington, DC Test data, including the DC-2001 data.

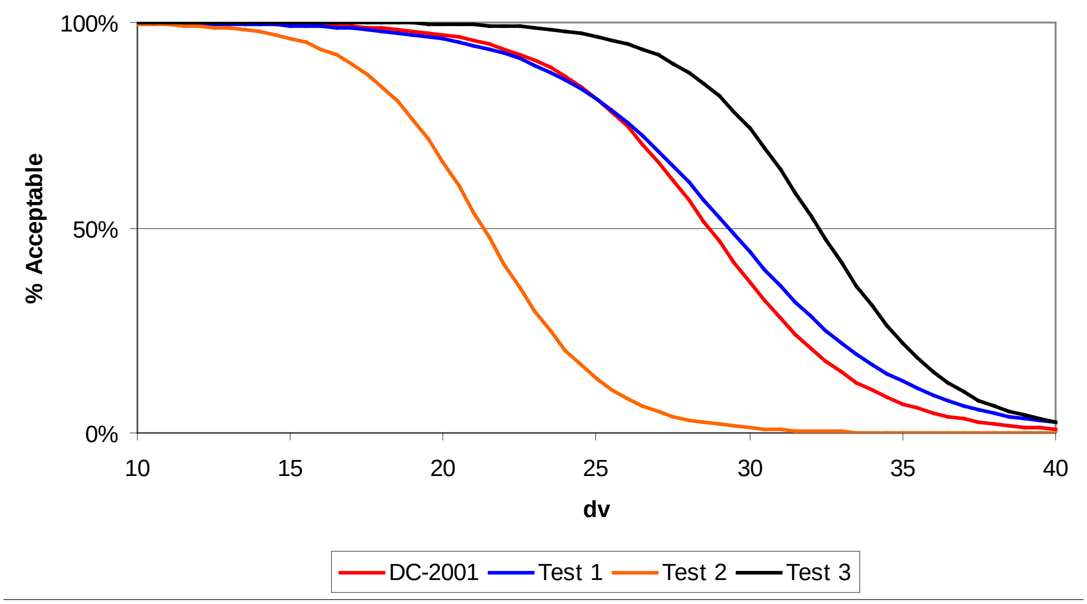


Figure 3. Full interaction logit results for four separate DC data sets.

Figure 3 suggests that while the logit functions from DC-2001 and Test 1 appear to be similar, Test 2 and Test 3 appear to be substantially different. Estimating the 50% criteria levels, along with the Krinsky-Robb confidence intervals, confirms this observation. Table 7 presents the estimated mean 50% criteria levels and the Krinsky-Robb confidence intervals.

Table 7. Mean 50% criteria levels, and Krinsky-Robb confidence intervals

	Mean dv	5% confidence estimate	95% confidence estimate
Test 1	29.30	28.59	29.97
Test 2	21.30	20.57	22.03
Test 3	32.26	31.37	33.16
DC-2001	28.65	27.46	29.70

Hypothesis testing using the predicted mean dv distribution from the Krinsky-Robb procedure provides statistical support for the conclusion that the Test 1 and DC-2001 results are similar, but Test 2 and Test 3 results are different. The hypothesis testing results are presented in Table 8.

Table 8. Hypothesis testing on the individual coefficients in the full interaction model is the same for the four different Washington, DC experiments

	Test 2 Mean dv = 21.30	Test 3 Mean = 32.26	DC-2001 Mean dv = 28.65
Test 1 Mean dv = 29.30	Reject hypothesis that Test 1 = Test 2 (pr < 0.001)	Reject hypothesis that Test 1 = Test 3 (pr < 0.001)	Cannot reject hypothesis that Test 1 = DC-2001 (pr = 0.15)
Test 2	–	Reject hypothesis that Test 2 = Test 3 (pr < 0.001)	Reject hypothesis that Test 3 = DC-2001 (pr < 0.001)
Test 3		–	Reject hypothesis that Test 3 = DC-2001 (pr < 0.001)

As shown in Table 8, we cannot reject (at the 5% confidence level) the hypothesis that the mean 50% criteria level in the DC-2001 data and the Test 1 data are the same. In other words, it is likely that the mean dv in Test 1 is the same as the mean dv in DC-2001. Thus, this hypothesis test supports combining those two data sets together, as we did in the four city analysis presented above. The results in Table 8 reject the hypothesis that Test 2 and Test 3 are the same as either the Test 1 or DC-2001 results.

Further Analysis of the Washington, DC Test 1 Data

Smith and Howell conducted Test 1 using three distinct groups of respondents. Four of the respondents in Test 1 were Washington, DC area residents that were used in a pilot test of the testing procedure. Twelve of the respondents were CRA International employees who live in the Washington, DC area, and ten of the respondents were CRA International employees who live in the Houston, Texas area. The Test 1 participants were all shown the same images of Washington, DC haze levels as the DC-2001 participants, and were asked about their preferences for urban visibility in Washington, DC.

We investigated heterogeneity among these three groups' responses by conducting a full interaction logit analysis using information about which of the three groups (pilot, DC area or Houston area) the respondents were in. We also included the DC-2001 respondents (who were all DC area residents) in this analysis to conduct hypothesis tests on whether the Test 1 groups were different than the DC-2001 respondents. We used the pilot test respondents as the omitted group in a full interaction model analysis. The results of the logit analysis are presented in Table 9.

Table 9. Logit regression results with full interacted model of the 3 Test 1 groups and the DC-2001 participants

Variable	Coefficient (β)	Standard error	z-statistic	Pr |β| = 0	5% confidence estimate	95% confidence estimate
dv	-0.5719	0.1310	-4.36	0.000	-0.8287	-0.3151
Test 1/DC	-0.8344	3.7361	-0.22	0.823	-8.1570	6.4881
Test 1/ Houston	-4.8831	3.5486	-1.38	0.169	-11.8382	2.0719
DC-2001	-2.4042	3.7273	-0.65	0.519	-9.7095	4.9012
Test 1/DC × dv	0.1439	0.1420	1.01	0.311	-0.1344	0.4222
Test 1/Houston × dv	0.2643	0.1372	1.93	0.054	-0.0047	0.5332
DC-2001 × dv	0.1684	0.1428	1.18	0.238	-0.1114	0.4482
Constant	13.9663	3.3284	4.20	0.000	7.4428	20.4898

Using the estimated coefficients in Table 9, we calculated estimated 50% criteria levels for each group, along with the Krinsky-Robb confidence intervals, which are shown in Table 10.

Table 10. Mean 50% criteria levels, and Krinsky-Robb intervals for the Test 1 groups and the DC-2001 participants

	Mean dv	5% confidence level	95% confidence level
Test 1/DC	30.68	29.79	31.51
Test 1/Houston	29.52	28.30	30.66
Test 1/Pilot	24.42	22.37	25.97
DC-2001	28.65	27.46	29.70

Table 10 suggests that the mean 50% acceptance criteria level for the Washington, DC area residents in the 2001 study are closest to the mean 50% criteria level for the Test 1 Houston area residents, and differ to a greater degree from the mean 50% criteria level for the Test 1 Washington area residents. Hypothesis testing confirms this finding, as shown in Table 11.

Table 11. Hypothesis tests of the mean 50% acceptance criteria level for the three groups in the Test 1 data and the DC-2001

	Houston Mean dv = 29.52	Pilot Mean dv = 24.42	DC-2001 Mean dv = 28.65
Test 1/DC area Mean dv = 30.68	Reject hypothesis Houston = Test 1/DC (pr = 0.06)	Reject hypothesis Pilot = Test 1/DC (pr < 0.001)	Reject Test 1/DC = 2001-DC (pr < 2%)
Test 1/Houston area	–	Reject Houston = Pilot (pr < 0.001)	Cannot reject Houston = DC-2001 at 5% confidence (pr = 14%)
Test 1/Pilot		–	Reject Pilot = DC-2001 (pr <0.001)

These hypothesis test results in Table 11 provide some insight into the hypothesis tests in Table 8, which found the 50% mean criteria level (mean = 29.30 dv) estimated using the combined Test 1 data is similar to the 50% criteria level from the DC-2001 data (mean = 28.65 dv). The Table 11 results suggest that the Table 8 results could be the result of the Test 1 pilot participants (mean = 24.42 dv) offsetting the Test 1/DC area participants (mean = 30.68 dv), giving us a mean estimate for the combined sample closest to the Houston area participants (mean = 29.52 dv).

Individual Heterogeneity

Individual respondents will likely have different general attitudes regarding haze than other respondents, reflecting their individual preferences about urban visibility. An individual's preferences may affect how they rate the acceptability of different dv levels. In the Smith and Howell (2009) Washington, DC study we can track an individual's responses over all dv levels.[3] This enables us to account for individual heterogeneity in our estimation procedure using individual-specific indicators. These are called fixed-effect models and control for unobserved differences between respondents.

We conducted a logit analysis on Test 1 data using individuals as the indicator variable. We included slope interaction terms for the Washington and Houston area residents (with the pilot slope interaction term omitted). Each individual[4] also has an indicator which becomes the

[3] While this level of data was originally collected for the studies in Denver, Phoenix, British Columbia and the 2001 Washington, DC study, the original data is not available at this time.

[4] Respondents 1 and 13 are dropped in the individual heterogeneity analysis because they had identical responses, accepting every dv level. The form of the logit model used in this analysis cannot be estimated when all the responses are identical.

intercept term for that individual. The terms for Respondents 2 through 12 are intercept shifters for DC respondents. Respondents 14 through 22 were Houston respondents, and Respondents 23 through 25 were pilot respondents. The results from this model are presented in Table 12.

Table 12. Logit analysis results of individual heterogeneity analysis

Variable	Coefficient (β)	Standard error	z-statistic	Pr |β| = 0	5% confidence estimate	95% confidence estimate
dv	-0.7315	0.1911	-3.83	0	-1.1060	-0.3569
Houston × dv	0.1207	0.2139	0.56	0.573	-0.2986	0.5399
DC × dv	-0.3588	0.2658	-1.35	0.177	-0.8799	0.1622
Respondent 2 (DC)	35.2050	5.9847	5.88	0	23.4752	46.9349
Respondent 3 (DC)	35.2050	5.9847	5.88	0	23.4752	46.9349
Respondent 4 (DC)	29.9950	5.2578	5.7	0	19.6900	40.3001
Respondent 5 (DC)	34.3924	5.8635	5.87	0	22.9002	45.8846
Respondent 6 (DC)	32.0347	5.5755	5.75	0	21.1070	42.9624
Respondent 7 (DC)	31.0845	5.4326	5.72	0	20.4369	41.7322
Respondent 8 (DC)	25.7365	4.5956	5.6	0	16.7293	34.7438
Respondent 9 (DC)	36.1200	6.1617	5.86	0	24.0434	48.1966
Respondent 10 (DC)	34.3924	5.8635	5.87	0	22.9002	45.8846
Respondent 11 (DC)	28.7572	5.0615	5.68	0	18.8369	38.6775
Respondent 12 (DC)	35.2050	5.9847	5.88	0	23.4752	46.9349
Respondent 14 (H)	16.6104	2.8047	5.92	0	11.1133	22.1075
Respondent 15 (H)	15.9236	2.7170	5.86	0	10.5984	21.2488
Respondent 16 (H)	15.9236	2.7170	5.86	0	10.5984	21.2488
Respondent 17 (H)	18.3145	2.9999	6.11	0	12.4348	24.1942
Respondent 18 (H)	20.8740	3.3153	6.3	0	14.3761	27.3719
Respondent 19 (H)	13.3405	2.3443	5.69	0	8.7457	17.9353
Respondent 20 (H)	19.8140	3.1722	6.25	0	13.5966	26.0315
Respondent 21 (H)	16.6104	2.8047	5.92	0	11.1133	22.1075
Respondent 22 (H)	18.8166	3.0538	6.16	0	12.8313	24.8019
Respondent 23 (P)	16.0044	4.3526	3.68	0	7.4736	24.5353
Respondent 24 (P)	17.1746	4.6884	3.66	0	7.9854	26.3637
Respondent 25 (P)	19.9838	5.4132	3.69	0	9.3742	30.5933
Respondent 26 (P)	18.2301	4.9705	3.67	0	8.4882	27.9720

As in the analyses previously described, we used the logit analysis coefficients in Table 12 to estimate the mean value for the 50% acceptance criteria. We also estimated the Krinsky-Robb confidence intervals for each data subset using the fixed effects model. Because three of the Test

1 participants were deleted in the individual heterogeneity analyses, for comparison purposes we also re-estimated a model without accounting for individual heterogeneity using the same data set (i.e., with the two individuals deleted). The results are presented in Table 13.

Table 13. Estimated mean 50% criteria levels, and Krinsky-Robb intervals for the Test 1 data accounting for individual heterogeneity

	Mean dv	**Lower bound 95%**	**Upper bound 95%**
Washington area residents	30.57	29.97	31.18
Houston area residents	29.40	28.41	30.33
Pilot (DC residents)	24.40	22.60	25.91
Mean dv estimates without individual heterogeneity (using same data)			
Washington area residents	30.02	29.19	30.77
Houston area residents	28.50	27.25	29.58
Pilot (DC area residents)	24.42	22.37	25.97

Table 13 shows that including individual heterogeneity in the model modestly increased the estimated mean 50% criteria levels.

Table 14 shows the results of hypothesis testing on the individual heterogeneity results. Modeling with individual heterogeneity leads to rejecting the hypothesis that the mean dv levels are the same in any of the three respondent groups.

Table 14. Hypothesis tests of the mean 50% acceptance criteria level for the three groups in the Test 1 data modeled with individual heterogeneity

	Houston area Mean dv = 29.40	**Pilot (DC area) Mean dv = 24.40**
DC area Mean dv = 30.57	Reject hypothesis Houston = DC (pr = 0.02)	Reject hypothesis Pilot = DC (pr < 0.001)
Houston area	–	Reject Houston = Pilot (pr < 0.001)

Summary

This memorandum describes a series of logit regression analyses that estimated the percentage of respondents that rated a haze (dv) level acceptable in four different studies of urban visibility. The first analysis in this report estimated a separate logit function for each of the four studies: Denver, British Columbia, Phoenix and Washington, DC (combining the data from the DC-2001 study and all Test 1 data from the DC-2009 study). The estimated mean 50% criteria levels in the four cities (Table 4) are different, with the mean estimate ranging from 19.90 dv (Denver) to 29.03 dv (Washington, DC). The hypothesis tests presented in Table 5 found that there is a statistically different logit function in each city (rejecting the null hypothesis that there was a single function that applies to more than one city). The range of mean estimates from the 4 city logit analysis is similar to the Candidate Protection Level range of 20 dv to 30 dv described in the draft UFVA (EPA, 2009).

The remainder of this memorandum examined in more detail the data from the two Washington, DC studies. In the first analysis focusing on only the Washington, DC data, we compared the estimated mean 50% criteria levels from the 2001 study to the mean estimates from each of the three tests in the 2009 study. Figure 3 and Table 7 show the estimated mean levels in the 2001 (mean = 28.65 dv) and 2009, Test 1 (mean = 29.30 dv) studies were similar, while the Test 2 (21.30 dv) and Test 3 (32.26) mean levels were quite different. The hypothesis tests presented in Table 8 support that overall observation. The only hypothesis not rejected was the hypothesis that the DC-2001 and Test 1 are the same (i.e., we cannot reject the hypothesis that they have the same mean 50% criteria level). This finding supports our approach of combining the DC-2001 and the DC-2009, Test 1 data in the four city analysis.

In the second analysis of the Washington, DC data, we investigated whether the study participants who lived in the Washington, DC Metro area had the same mean 50% criteria levels as the participants who lived in the Houston metro area. This analysis involved three groups of Washington, DC residents (the DC-2001 participants, the pilot project participants in the DC-2009 study, and participants 1 through 12 in Test 1 of DC-2009). The hypothesis tests results in Table 11 show that the participants in the DC-2001 and the Houston area residents in the DC-2009 study are similar (i.e., we cannot reject the hypothesis they have the same mean 50% criteria level). Our hypothesis testing further found however, that the DC-2001 participants had statistically significantly different mean 50% criteria levels than either of the two groups of Washington, DC area residents included in the DC-2009, Test 1 results.

The third analysis of the Washington, DC data investigated the effect of individual heterogeneity of preferences. This analysis was limited to the DC-2009 data because it required more complete information on the responses of each participant. The individual heterogeneity analysis found modestly higher mean 50% criteria levels than the second analysis of the Washington, DC area

residents. The hypothesis testing in this analysis rejected the hypothesis that the mean dv levels were the same for the three groups who participated in Test 1.

This apparent inconsistency with the two hypothesis tests of analyses of subsets the Washington, DC studies with the results of the hypothesis tests comparing the DC-2001 data with all of the DC-2009, Test 1data may be due to having subdivided the participants of Test 1 into subsets with too few members to provide stable results. Combining the DC-2001 data with all the Test 1 data provides the largest sample size available to estimate the logit preference function for Washington, DC.

References

Hole, A.R. 2007. A comparison of approaches to estimating confidence intervals for willingness to pay measures. *Health Economics* 16:827–840.

Krinsky, I. and L. Robb. 1986. On approximating the statistical properties of elasticities. *The Review of Economics and Statistics* 68(4):715–719.

Smith, A.E. and S. Howell. 2009. An Assessment of the Robustness of Visual Air Quality Preference Study Results. CRA International, Washington, DC. March 30. Prepared for the Utility Air Regulatory Group. Submitted as supplemental material to presentation by Anne Smith to the public meeting of the EPA Clean Air Science Advisory Council. April 2.

Stratus Consulting. 2009. Review of Urban Visibility Preference Studies. Prepared for Vicki Sandiford, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. Stratus Consulting Inc., Boulder, CO. September 21.

U.S. EPA. 2009. Particulate Matter Urban-Focused Visibility Assessment; External Review Draft. U.S. Environmental Protection Agency. September.

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