



# Particulate Matter Urban-Focused Visibility Assessment

Second External Review Draft

January 2010



## **DISCLAIMER**

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

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*Particulate Matter*  
*Urban-Focused Visibility Assessment*  
*Second External Review Draft*

U.S. Environmental Protection Agency  
Office of Air and Radiation  
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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

NO <sub>x</sub>	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 <sub>2.5</sub>	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 <sub>10</sub>	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 <sub>10-2.5</sub>	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	<u>S</u> ulfate, <u>A</u> adjusted <u>N</u> itrate, <u>D</u> erived <u>W</u> ater, <u>I</u> nferrred <u>C</u> arbonaceous mass approach
SEARCH	Southeastern Aerosol Research and Characterization Study
SMOKE	Sparse Matrix Operator Kernal Emissions
S	Sulfur
SO <sub>2</sub>	Sulfur Dioxide
SO <sub>x</sub>	Sulfur Oxides
STP	Standard Temperature and Pressure
TEOM	Tapered Element Oscillating Microbalance
UBC	University of British Columbia
UFVA	Urban-Focused Visibility Impact Assessment
VAQ	Visual Air Quality



# 1 INTRODUCTION

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

The current NAAQS for PM are a suite of identical primary and secondary standards established to provide protection from health and welfare effects related to fine and coarse particles, using PM<sub>2.5</sub> and PM<sub>10</sub> as indicators, respectively (71 FR 61144, October 17, 2006). With regard to the primary standards for fine particles, in 2006 EPA revised the level of the 24-hour PM<sub>2.5</sub> standard to 35 µg/m<sup>3</sup> (calculated as a 3-year average of the 98<sup>th</sup> percentile of 24-hour concentrations at each population-oriented monitor), retained the level of the annual PM<sub>2.5</sub> annual standard at 15 µg/m<sup>3</sup> (calculated as the 3-year average of the weighted annual mean PM<sub>2.5</sub> concentrations from single or multiple community-oriented monitors), and revised the form of the annual PM<sub>2.5</sub> standard by narrowing the constraints on the optional use of spatial averaging<sup>1</sup>. With regard to the primary standards for PM<sub>10</sub>, EPA retained the 24-hour PM<sub>10</sub> standard at 150 µg/m<sup>3</sup> (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 epidemiological evidence relating ambient PM concentrations to various adverse health outcomes.

The 2006 secondary standards for PM<sub>2.5</sub> and PM<sub>10</sub> were set to be identical to the primary standards, on the basis that these standards would, in conjunction with the Regional Haze

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<sup>1</sup> 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).

1 Program<sup>2</sup>, provide appropriate protection to address PM-related welfare effects, including  
2 visibility impairment, effects on vegetation and ecosystems, materials damage and soiling, and  
3 effects on climate change. (As noted below, this judgment was reversed and remanded by the  
4 Court of Appeals for the District of Columbia Circuit.)

5 The next periodic review of the PM NAAQS is now underway.<sup>3</sup> In the *Integrated*  
6 *Review Plan for the National Ambient Air Quality Standards for Particulate Matter*, March 2008  
7 (US EPA, 2008a), EPA outlined the science policy questions that will frame this review, outlined  
8 the process and schedule that the review will follow, and provided more complete descriptions of  
9 the purpose, contents, and approach for developing the key documents that will be developed in  
10 the review.<sup>4</sup> EPA has recently completed the process of assessing the latest available policy-  
11 relevant scientific information to inform the review of the PM standards. The final assessment is  
12 contained in the final Integrated Science Assessment for Particulate Matter (ISA, US EPA,  
13 2009a) which was released in December 2009. The final PM ISA includes a summary of the  
14 scientific evidence for the relationship of PM to visibility effects, remote area and urban haze  
15 conditions, the PM components responsible for visibility impacts, and studies of public  
16 preference with respect to urban visibility conditions.

17 Building upon the visibility effects evidence presented in the PM ISA, as well as CASAC  
18 advice (Samet, 2009a and b) and public comments on the plan for and first draft of the UFVA  
19 (US EPA, 2009b, c), EPA's Office of Air Quality Planning and Standards (OAQPS) has  
20 developed this second draft Urban-Focused Visibility Assessment (UFVA) describing the  
21 quantitative assessments conducted by the Agency to support the review of the secondary PM  
22 standards. This draft document presents the methods, key results, observations, and related  
23 uncertainties associated with the quantitative analyses performed. Revisions to this second draft  
24 UFVA draw upon the final ISA and reflect consideration of CASAC and public comments on the  
25 first draft UFVA, as described in section 1.2 below.

26 The final ISA and final UFVA will inform the policy assessment and rulemaking steps  
27 that will lead to final decisions on the secondary PM NAAQS. A draft Policy Assessment (PA)  
28 is now being prepared by OAQPS staff to provide a transparent staff analysis of the scientific

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<sup>2</sup> See <http://www.epa.gov/air/visibility/program.html> for more information on EPA's Regional Haze Program.

<sup>3</sup> See [http://www.epa.gov/ttn/naaqs/standards/pm/s\\_pm\\_index.html](http://www.epa.gov/ttn/naaqs/standards/pm/s_pm_index.html) for more information on the current and previous PM NAAQS reviews.

<sup>4</sup> 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.

1 basis for alternative policy options for consideration by senior EPA management prior to  
2 rulemaking. The PA is intended to help “bridge the gap” between the Agency’s scientific  
3 assessments, presented in the ISA and UFVA, and the judgments required of the Administrator  
4 in determining whether it is appropriate to retain or revise the secondary PM standards. The PA  
5 will integrate and interpret information from the ISA and the UFVA to frame policy options and  
6 to facilitate CASAC’s advice to the Agency and recommendations on any new standards or  
7 revisions to existing standards as may be appropriate, as provided for in the Clean Air Act. A  
8 very preliminary draft PA was released in September 2009 to facilitate discussion on the overall  
9 structure, areas of focus, and level of detail to be included in a first external review draft PA  
10 document, which EPA plans to release for CASAC review and public comment in February of  
11 2010. This preliminary draft PA was discussed in conjunction with CASAC review of and  
12 public comment on the second draft ISA, first draft UFVA, and first draft health risk assessment  
13 documents produced in support of this PM NAAQS rulemaking.

## 14 **1.1 PM NAAQS BACKGROUND**

15 In the review of the secondary PM NAAQS completed in 2006, EPA took into account  
16 that the Regional Haze Program, authorized under sections 169A and 169B of the CAA, was  
17 established to address all human-caused visibility impairment in federal Class I areas. The  
18 national goal of this program is to prevent any future, and remedy any existing, impairment of  
19 visibility in mandatory class I Federal areas (Class I areas) which impairment results from  
20 manmade air pollution. This program also mandates that states develop SIPs to ensure that  
21 reasonable progress is made towards meeting those goals. Because Congress explicitly targeted  
22 Class I areas for this pristine level of protection, it can be concluded that Congress did not  
23 envision such a stringent goal in non-Class I areas. See American Trucking Ass’n v. Browner,  
24 175 F. 3d 1027, 1056-57 (D. C. Cir. 2002) (upholding this position). However, Congress  
25 recognized that visibility impairment can and often does occur in areas outside federal Class I  
26 areas, including urban areas and judged that protection from visibility impairment was important  
27 in those areas as well. In this regard, Congress included visibility effects in the definition of  
28 public welfare effects that should be protected under the national ambient air quality standards  
29 (NAAQS) program authorized in sections 108 and 109 of the CAA. As a result, EPA may  
30 establish secondary standards addressing visibility impairment notwithstanding existence of the  
31 Regional Haze Program. Under the NAAQS program, it is up to the Administrator to judge what  
32 is the requisite level of public welfare visibility protection.

33 Recognizing that efforts were underway to provide increased protection to Class I areas  
34 under the Regional Haze Program, EPA focused the 2006 PM NAAQS review on visibility  
35 impairment in non-Class I areas. Because most of the available non-Class I PM data came from

1 PM monitoring sites located primarily in urban areas, the assessments took on an urban focus. In  
2 addition, EPA considered available information on people's preferences for different levels of  
3 visual air quality which came from studies conducted in urban areas and from existing urban  
4 visibility programs and goals.

5 In an effort to minimize the factors that historically had complicated efforts to address  
6 visibility impairment nationally, given the substantial East/West differences observed in Class I  
7 areas, EPA staff noted that with respect to fine particles, East/West differences are substantially  
8 smaller in urban than in rural areas. Further, relative humidity levels, though generally higher in  
9 eastern than western areas, are appreciably lower in both regions during daylight as compared to  
10 nighttime hours. The PM<sub>2.5</sub> data available at that time in urban areas were obtained using a filter  
11 –based Federal Reference Method (FRM) which captures ambient PM<sub>2.5</sub> on a filter and then dries  
12 it to get the dry PM<sub>2.5</sub> mass concentration. By drying the sample, most water and to some extent  
13 other labile PM compounds evaporate so that the original characteristics (e.g., particle size and  
14 composition) of the ambient PM are altered. Using PM and meteorological data from 161 cities,  
15 EPA staff assessed the correlations between PM<sub>2.5</sub> levels and reconstructed light extinction (RE)  
16 during daylight hours for different regions of the country. This assessment showed that the  
17 strongest correlation in the relationship of ambient PM light extinction to dry PM<sub>2.5</sub> mass  
18 concentration was during afternoon periods when lower relative humidity conditions generally  
19 prevailed in all regions of the country and ambient PM was drier (US EPA, 2005). While EPA  
20 recognized that the effect of ambient PM on visibility results from the ambient particle  
21 characteristics of size, concentration, and composition (including associated water) present in the  
22 air in the sight path of the observer, given the data availability at the time, EPA viewed the FRM  
23 altered PM<sub>2.5</sub> mass concentration as a permissible indicator for addressing ambient PM-related  
24 visibility effects at the national scale during afternoon hours. Thus, the 2005 Staff Paper chose  
25 to address the issue in terms of averaging time rather than indicator, discussing the use of a sub-  
26 daily afternoon dry PM<sub>2.5</sub> standard, because the generally lower afternoon relative humidity  
27 tended to produce a more uniform relationship between light extinction and dry PM<sub>2.5</sub> mass  
28 concentration throughout the country, therefore providing a more uniform level of visibility  
29 protection nationwide. This more uniform level of visibility protection, however, was limited to  
30 the afternoon hours of the day when relative humidity and visibility impairment tend to be the  
31 lowest.

32 Based on the above, in the 2005 PM Staff Paper, EPA staff recommended a separate sub-  
33 daily secondary standard to address visibility impairment using dried PM<sub>2.5</sub> mass concentration  
34 as the indicator, a recommendation endorsed by CASAC. In the 2006 proposal notice, however,  
35 EPA proposed to revise the secondary standards by making them identical to the suite of  
36 proposed primary standards for fine and coarse particles, to provide protection against PM-

1 related public welfare effects including visibility impairment, effects on vegetation and  
2 ecosystems, materials damage and soiling, and climate, while soliciting comment on adding a  
3 new sub-daily PM<sub>2.5</sub> secondary standard to address visibility impairment primarily in urban areas  
4 (71 FR 2620). CASAC provided additional advice to EPA in a letter to the Administrator  
5 requesting reconsideration of CASAC's recommendations for both the primary and secondary  
6 PM<sub>2.5</sub> standards as well as standards for thoracic coarse particles (Henderson, 2006). With  
7 regard to the secondary standard, CASAC reaffirmed "... the recommendation of Agency staff  
8 regarding a separate secondary fine particle standard to protect visibility.... the CASAC wishes  
9 to emphasize that continuing to rely on primary standards to protect against all PM-related  
10 adverse environmental and welfare effects assures neglect, and will allow substantial continued  
11 degradation, of visual air quality over large areas of the country" (Henderson, 2006).

12 On September 21, 2006, EPA announced its final decisions to provide increased  
13 protection of public welfare by making the secondary NAAQS identical to the revised primary  
14 standards (71 FR 61144, October 17, 2006). This suite of secondary standards was designed to  
15 address both visibility and other non-visibility welfare related effects. Specifically, with regard  
16 to the secondary welfare effect of visibility impairment, the Administrator believed that revising  
17 both the 24-hour and annual PM<sub>2.5</sub> secondary standards to be identical to the revised suite of  
18 PM<sub>2.5</sub> primary standards was a reasonable policy approach to address visibility impairment  
19 primarily in urban areas. In particular, EPA revised the level of the 24-hour PM<sub>2.5</sub> standard to 35  
20 µg/m<sup>3</sup>, retained the level of the annual PM<sub>2.5</sub> standard at 15 µg/m<sup>3</sup>, and revised the form of the  
21 annual PM<sub>2.5</sub> standard by narrowing the constraints on the optional use of spatial averaging.  
22 With regard to the other non-visibility PM-related welfare effects such as vegetation and  
23 ecosystems, materials damage and soiling, and climate, the Administrator concluded that it was  
24 appropriate to address these effects by revising the current suite of PM<sub>2.5</sub> secondary standards,  
25 making them identical in all respects to the suite of primary PM<sub>2.5</sub> standards, while retaining the  
26 current 24-hour PM<sub>10</sub> secondary standard and revoking the current annual PM<sub>10</sub> secondary  
27 standard. In particular for coarse particles, EPA retained PM<sub>10</sub> as the indicator for purposes of  
28 regulating the coarse fraction of PM<sub>10</sub> and retained the 24-hour secondary PM<sub>10</sub> standard at 150  
29 µg/m<sup>3</sup> and revoked the annual secondary PM<sub>10</sub> standard.

30 Several parties filed petitions for review following promulgation of the revised PM  
31 NAAQS in 2006. These petitions addressed a number of issues, including the decision to set the  
32 secondary PM<sub>2.5</sub> standards identical to the primary standards. On judicial review the court  
33 remanded the secondary PM<sub>2.5</sub> NAAQS to EPA because the Agency failed to adequately explain  
34 why setting the PM<sub>2.5</sub> secondary standards equal to the primary PM<sub>2.5</sub> standards provided the  
35 required protection from visibility impairment. In particular, the Agency failed to identify a  
36 target level of visibility impairment that would be requisite to protect the public welfare, and

1 improperly relied on a misleading comparison of the number of counties which would be in  
2 nonattainment for the revised primary NAAQS compared to one alternative secondary standard  
3 under consideration. Among other things, this equivalence analysis failed to address the issue of  
4 regional differences in humidity-related effects on visibility. *American Farm Bureau Federation*  
5 *v. EPA*, 559 F. 3d 512, 530-31 (D.C. Cir. 2009).

## 6 **1.2 VISIBILITY EFFECTS SCIENCE OVERVIEW**

7 Light extinction is the loss of light per unit of distance and occurs when light is scattered  
8 and/or absorbed. Particulate matter and gases can both scatter and absorb light. Light scattering  
9 by gases (e.g., nitrogen, oxygen, etc.) that comprise the pollutant free or clean atmosphere (also  
10 known as Rayleigh or clean-air scattering) is related to the density of the air, which is  
11 sufficiently constant with elevation that it can be taken to be a time invariant constant that  
12 depends principally on elevation above sea level. NO<sub>2</sub> is the only atmospheric pollutant gas that  
13 absorbs light appreciably and its effects are generally small (i.e., less than 5%) compared to PM  
14 light extinction. Hereinafter the phrase “PM light extinction” indicates that the Rayleigh  
15 contribution to light extinction (nominally considered 10 Mm<sup>-1</sup>) has been subtracted out and the  
16 NO<sub>2</sub> contribution is considered negligible or is simply excluded due to the measurement  
17 approach used. By contrast, the term “light extinction” or “total light extinction” is meant to  
18 include both the Rayleigh and NO<sub>2</sub> contributions.

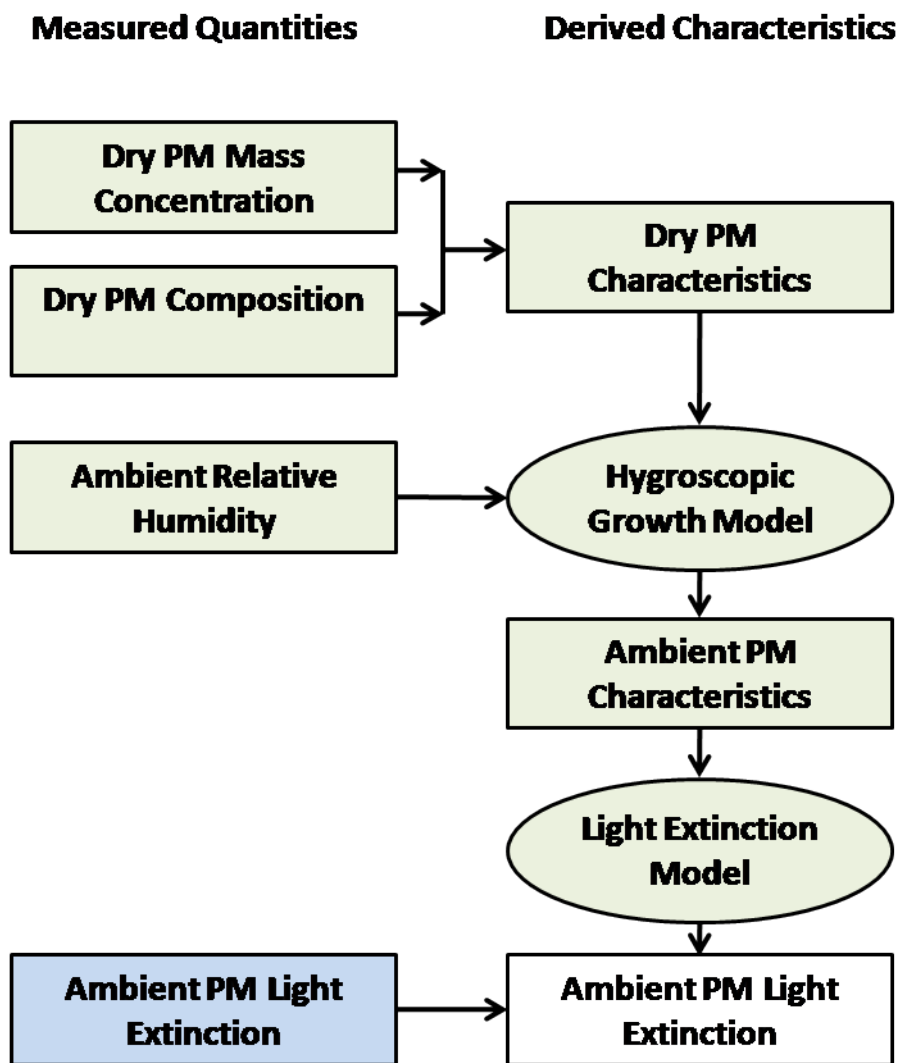
19 Visual air quality is defined as the visibility effect caused solely by air quality conditions  
20 and excluding those associated with meteorological conditions like fog and precipitation. It is  
21 commonly measured as either light extinction (in terms of inverse megameters, Mm<sup>-1</sup>) or the  
22 haziness index (in terms of deciview, dv) (Pitchford and Malm, 1993). The haziness index  
23 measured in deciview units was developed for use in visibility perception studies because it has a  
24 more linear relationship to perceived changes in haze compared with light extinction. It is  
25 defined as ten times the natural logarithmic of one tenth of the light extinction in inverse  
26 megameter units (Mm<sup>-1</sup>) (Pitchford and Malm, 1993). Light extinction and haziness are physical  
27 measures of the amount of visibility impairment (e.g., the amount of “haze”), with both  
28 increasing as the amount of haze increases.

29 PM is a heterogeneous mixture of particles of different sizes and chemical compositions.  
30 While visibility impairment has been associated most often with PM<sub>2.5</sub>, larger particles such as  
31 those found in PM<sub>10</sub> may be a significant contributor in some areas. Thus, UFVA considers the  
32 visibility impairment caused by all particles 10 microns or smaller. As stated above, the degree  
33 of visibility impairment caused by a given mass of PM depends in large part on the size, density  
34 and chemical composition of the PM. If the ambient PM has a large number of hygroscopic  
35 particles, and also occurs when the relative humidity of the air is higher, those particles will be

larger in size so that the PM will have a larger haze effect than if PM with the same concentration and composition minus the water was present and the ambient air had lower relative humidity.

As shown in Figure 1-1, the ambient PM light extinction can be estimated from dry PM mass and composition data and relative humidity using an algorithm that accounts for water present in hygroscopic PM components and uses assumed light extinction efficiencies for each of

**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 major PM species. Ambient PM light extinction is most accurately determined by direct measurements. However, because there is limited ambient PM light extinction data available in

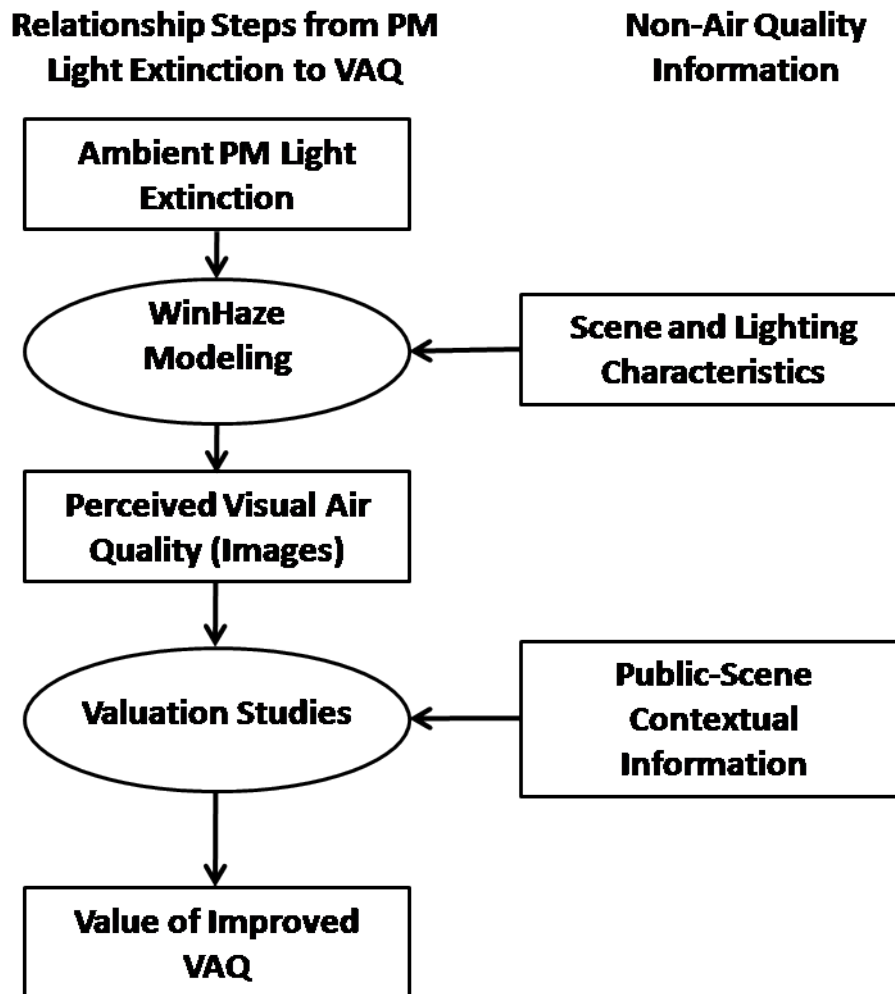
1 urban areas, the assessments below will principally use monitored and modeled dry PM mass  
2 and species estimates, along with relative humidity measurements as input to a simple algorithm  
3 for estimating ambient PM light extinction.

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

12 Survey studies have used sets of photographs or computer simulated images developed  
13 from a base photo depicting a range of visibility conditions on urban scenes to assess the  
14 individual's opinion on the acceptability of conditions. For the specific scenes used in such  
15 studies there is a known or predetermined one-to-one correspondence between the computer  
16 generated haze in the photographs and the associated amount of ambient PM light extinction.  
17 For visibility preference studies, visibility levels are generally characterized using the haze index  
18 in units of deciview (similar to the decibel scale for sound).



**Figure 1-2 Progression from PM light extinction to value of visual air quality (VAQ)**



### 1.3 GOALS AND APPROACH

The principal goal of the UFVA is to characterize recent levels of visibility impairment in 15 urban areas, as well as “just meet” scenarios for both the current secondary PM<sub>2.5</sub> standards, as well as various alternative standards, including those which utilize a different indicator, and a range of forms that may better reflect the relationship between PM and visibility impairment. In particular, this UFVA focuses on the use of a PM 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 light extinction in 15 major U.S. urban areas over the three-year period 2005-2007 to the candidate protection levels (CPLs), which are a range of light extinction values beyond which half of the participants in assessed urban visibility preference studies indicated the haze conditions were unacceptable (see discussion in chapter 2 below and Stratus Consulting Inc.,

2009). In addition, this second draft UFVA includes additional characterizations of the effectiveness of a sub-daily PM<sub>2.5</sub> 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.

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<sup>-1</sup> to ~67 Mm<sup>-1</sup>) could represent an appropriate degree of welfare protection from PM<sup>5</sup>. 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). Based on the results of this analysis, we have been able to refine the range of visibility conditions that could represent an appropriate degree of public welfare visibility protection that was put forth in the 2006 review, and to determine a central tendency value for the CPLs. These analyses and results are described below in chapter 2.

In the previous PM NAAQS review, the characterization of urban visibility conditions were based on IMPROVE algorithm estimates using the 2001 to 2003 PM<sub>2.5</sub> 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<sub>2.5</sub> 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<sup>2</sup>>0.6, slope ~6 m<sup>2</sup>/g).

The current assessment of urban visibility conditions (as described in chapter 3) uses a modeling approach to estimate hourly light extinction using PM<sub>2.5</sub> mass and speciation data with measured relative humidity. However, it differs by replacing the unrealistic assumption of constant composition for PM<sub>2.5</sub>, with composition that is made to vary during the day using urban-specific monthly mean diurnal variations of species concentrations determined from

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<sup>5</sup> Light extinction is inversely related to visual range.

1 regional air quality model results, while constraining the means of the hourly species  
2 concentration for each day to closely match the 24-hour duration measured species  
3 concentrations.

#### 4 **1.4 SCOPE OF URBAN-FOCUSED VISIBILITY ASSESSMENT**

5 This section provides an overview of the scope and key design elements of the UFVA,  
6 including the process that has been followed to design the analyses. Following initiation of this  
7 PM NAAQS review in 2007, we began the design of the assessments in the UFVA by revisiting  
8 the analyses completed during the previous PM NAAQS review (Abt Associates Inc., 2001; US  
9 EPA, 2005, chapter 6) with an emphasis on considering key limitations and sources of  
10 uncertainty recognized in that review.

##### 11 **1.4.1 Background**

12 As an initial step in this review, EPA invited a wide range of external experts as well as  
13 EPA staff, representing a variety of areas of expertise to participate in a workshop titled,  
14 “Workshop to Discuss Policy-Relevant Science to Inform EPA’s Integrated Plan for the Review  
15 of the Secondary PM NAAQS” (72 FR 34005, June 20, 2007). This workshop provided an  
16 opportunity for the participants to broadly discuss the key policy-relevant issues around which  
17 EPA would structure the PM NAAQS review and to discuss the most meaningful new science  
18 that would be available to inform our understanding of these issues. One session of this  
19 workshop centered on issues related to visibility impacts associated with ambient PM.  
20 Specifically, the discussions focused on the extent to which new research and/or improved  
21 methodologies were available to inform how EPA evaluated visibility impairment in this review.

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

30 In articulating a rationale for the urban focus of this assessment, we reviewed the  
31 available information and found the following information compelling: 1) PM levels in urban  
32 areas are often in excess of those of the surrounding region since urban haze typically includes  
33 both regional and local contributions (US EPA, 2009a; sections 9.2.3.3 and 9.2.3.4), suggesting  
34 the potential for higher levels of PM-induced visibility impairment in urban areas; 2) the

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

12 On October 6-8, 2008 the EPA sponsored an urban visibility workshop in Denver,  
13 Colorado to identify and discuss methods and materials that could be used in “next step” projects  
14 to develop additional information about people’s preferences for reducing existing impairment of  
15 urban visibility, and about the value of improving urban visibility. Invited individuals came  
16 from a broad array of relevant technical and policy backgrounds, including visual air quality  
17 (VAQ) science, sociology, psychology, survey research methods, economics, and EPA’s process  
18 of setting NAAQS. The 23 people who attended the workshop (including one via teleconference  
19 line) came from EPA, the National Oceanic and Atmospheric Administration (NOAA), National  
20 Park Service, academia, regional and state air pollution planning agencies, and consulting firms.<sup>6</sup>  
21 The information discussed at this Workshop was useful in informing subsequent steps in the  
22 process.

#### 23 **1.4.2 Selection of Alternative Scenarios for First Draft Assessments**

24 In designing the quantitative assessments to include in the first draft UFVA, EPA staff  
25 developed a planning document outlining the initial design for the PM NAAQS visibility  
26 assessment - *Particulate Matter National Ambient Air Quality Standards: Scope and Methods*  
27 *Plan for Urban Visibility Impact Assessment*, henceforth Scope and Methods Plan (US EPA,  
28 2009b). This planning document was released for CASAC consultation and public review in  
29 February 2009. Based on consideration of CASAC and public comments on the Scope and  
30 Methods Plan, along with ongoing review of the latest PM-related literature, several aspects of  
31 the original scope of the urban visibility conditions assessment, as depicted in Figure 1-1 of  
32 section 1.3 of the Scope and Methods document (US EPA, 2009b), were modified in the first  
33 draft UFVA (US EPA, 2009c). Taking into account the nature of urban versus more remote area

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<sup>6</sup> To view the complete report from the October 2008 urban visibility workshop, see:  
[http://vista.cira.colostate.edu/improve/Publications/GrayLit/gray\\_literature.htm](http://vista.cira.colostate.edu/improve/Publications/GrayLit/gray_literature.htm)

1 PM composition, and input received at the April 2, 2009 CASAC meeting, EPA staff concluded  
2 that it was unnecessary to develop a new urban-optimized algorithm at this time and that it  
3 remained appropriate in the context of this assessment to use the original IMPROVE algorithm  
4 to relate urban PM to local haze (PM light extinction). One of the primary reasons for initially  
5 considering an urban-optimized algorithm was a concern that the organic components of PM in  
6 urban areas, being generally nearer their emission sources, would have a lower ratio to the  
7 measured organic carbon mass than the ratio of organic component mass to measured organic  
8 carbon mass currently used for the more aged PM organic components found in remote areas.  
9 As described below in chapter 3, this concern has been addressed by using the SANDWICH  
10 mass balance approach to estimate the PM organic component mass, which negates the need to  
11 estimate organic component mass from measured organic carbon mass.

12 With regard to the urban visual air quality preference assessment described in the Scope  
13 and Methods document (US EPA, 2009b, section 1.3), more significant modifications occurred.  
14 EPA staff decided to conduct a reanalysis of the urban visibility preference studies available at  
15 the time of the 2006 PM NAAQS review, rather than conduct new public preference studies, as it  
16 has become apparent that the results of these studies would be unlikely to be completed in time  
17 to inform this review. Recognition that the initial plans described in the Scope and Methods  
18 document were possibly overly ambitious was also shared by members of CASAC (see  
19 individual member comments; Samet, 2009a). The analysis, therefore, relied on pre-existing,  
20 rather than new, urban visibility preference studies and was designed to explore the similarities  
21 and differences (comparability) among these studies. Information drawn from these results  
22 informed the selection of VAQ candidate protection levels (CPLs) (described in chapter 2 below)  
23 to be used in subsequent impact assessments. Further, information presented during the public  
24 comment phase of the April 2, 2009 CASAC meeting and later provided to EPA staff, led to the  
25 inclusion of a recent study by Smith and Howell (2009) for Washington, DC in the reanalysis.

#### 26 **1.4.3 Selection of Alternative Scenarios for Second Draft Assessments**

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

- 35 • Indicator: PM Light Extinction

1           There are a number of different ways to measure ambient PM: particle counts, surface  
2 area, volume, mass concentrations, and concentration of components. Each of these different  
3 characteristic of ambient PM can be important in the context of different effects. For example,  
4 particle count may be important from the perspective of cloud formation or to characterize the  
5 abundance of ultrafine PM, which is of interest for health effects. In a similar way PM light  
6 extinction measures the characteristic of ambient PM most relevant and directly related to the  
7 effect of PM visibility impairment. Thus, as described in the Scope and Methods document (US  
8 EPA, 2009b) and first draft UFVA, EPA staff is continuing to focus assessments in this second  
9 draft document in terms of ambient PM light extinction as the indicator for PM visibility  
10 impairment, instead of the traditional PM<sub>2.5</sub> mass concentration. Unlike PM mass concentration,  
11 which generally changes the composition and size of the particles by driving off most of the  
12 water, ambient PM light extinction captures the PM-induced visibility impairment of the  
13 particles as they exist in the atmosphere. PM light extinction, like conventional PM mass  
14 concentration, is a measurable physical characteristic of atmospheric PM.

15           Section 109 (b) (2) of the CAA states that “Any national secondary ambient air quality  
16 standard prescribed under subsection (a) of this section shall specify a level of air quality the  
17 attainment and maintenance of which ... is requisite to protect the public welfare from any  
18 known or anticipated adverse *effects associated with the presence of such air pollutant in the*  
19 *ambient air....*” (*emphasis added*). In addition, section 108 (a) (2) states that the air quality  
20 criteria “for an air pollutant shall accurately reflect the latest scientific knowledge useful in  
21 indicating the kind and extent of all identifiable effects on public health or welfare which may be  
22 expected from the presence of such pollutant in the ambient air, in varying quantities. The  
23 criteria ... shall include information on (A) *those variable factors (including atmospheric*  
24 *conditions) which of themselves or in combination with other factors may alter the effects* on  
25 public health or welfare of such air pollutant;...” (*emphasis added*). Thus, EPA staff believes  
26 that the visibility effects of PM important to the public welfare are precisely the visibility effects  
27 of PM occurring in the ambient air, which necessarily entails association with ambient  
28 atmospheric conditions that affect the nature or magnitude of the PM visibility effect. These  
29 ambient conditions lead to constant changes in the size and composition of particles as these  
30 particles come in contact with other pollutants or natural components, become oxidized/age as  
31 they are transported great distances, and shrink or grow in the absence or presence of water  
32 vapor, or other atmospheric gases. The combined effect of all these interactions of ambient PM  
33 with real time atmospheric conditions and chemistry on the public welfare effect of visibility  
34 impairment depends on factors other than dry PM mass concentration alone. Use of PM light  
35 extinction as the indicator for a secondary PM NAAQS is thus a more appropriate and direct

1 measure of the relationship between ambient PM and the public welfare effect of visibility  
2 impairment than any dry PM mass concentration (either PM<sub>2.5</sub> or any other dry mass fraction).

- 3
- 4 • Averaging times: Daylight Daily Max. 1 Hour or All Daylight Hours

5 It is necessary to also identify an averaging time to apply along with the CPLs in the  
6 assessments described in chapters 3 and 4. Because the nature of visibility impairment and its  
7 impact on the public welfare is sufficiently different and less well understood at night, this  
8 assessment only considers daylight hour visibility. Though not directly supported by preference  
9 or other studies, EPA staff believes that a short averaging time (e.g. an hour) may be more  
10 appropriate than longer time periods (e.g. multiple hours) since VAQ impacts are instantaneously  
11 perceived. This is also consistent with staff's belief that most individuals in an urban setting  
12 experience urban VAQ in relatively short-term incidental and intermittent periods when they  
13 have the opportunity to be outdoors (e.g. during commutes to work, school, shopping, etc.).  
14 Since this fraction of the public may experience poor VAQ during a relatively small time period  
15 and not have the opportunity to see it improve later during the same day, it seems appropriate to  
16 EPA staff to consider assessing the current and projected conditions in chapters 3 and 4 by  
17 comparing the 1-hour daily maximum light extinction to each of the three CPLs supported by the  
18 preference studies. There is uncertainty associated with predicting the duration of the effect  
19 associated with such brief periods of exposures, i.e., it is not known how long the person  
20 remembers the poor VAQ conditions once he/she goes indoors and is removed from the sight.

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

- 30
- 31 • Level: Candidate Protection Levels (CPLs)

32 In order to identify a range of light extinction levels associated with acceptable VAQ to  
33 compare to current and projected conditions in the assessment in chapters 3 and 4 of this  
34 document, CPLs have been selected in a range from 20 dv to 30 dv (74 Mm<sup>-1</sup> to 201 Mm<sup>-1</sup>) based  
35 on the composite results and the effective range of 50<sup>th</sup> percentile acceptability across the four  
36 urban preference study areas shown in Figure 2-16. A midpoint of 25 dv (122 Mm<sup>-1</sup>) was also

selected for use in the assessment. These three values provide a low, middle, and high set of light extinction conditions that are used in subsequent sections of the UFVA to provisionally define daylight hours with urban haze conditions that have been judged unacceptable by the participants of these preference studies. 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  $10 \text{ Mm}^{-1}$ ), so the PM light extinction levels that correspond to low, middle and high CPLs are about  $64 \text{ Mm}^{-1}$ ,  $112 \text{ Mm}^{-1}$  and  $191 \text{ Mm}^{-1}$ , 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 second draft 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 90<sup>th</sup> and 95<sup>th</sup> 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 98<sup>th</sup> percentile used for the current 24-hour primary and secondary standards. EPA staff is therefore considering the 90<sup>th</sup>, 95<sup>th</sup> and 98<sup>th</sup> percentiles per year in 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 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 are 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, has also been incorporated in this draft.

## 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



1 also includes a summary discussion of the results of a composite assessment of the combined  
2 results from the four urban areas (Denver, Phoenix, British Columbia, and Washington, DC, an  
3 accompanying logit (statistical) analysis, and use of these results in the selection of the  
4 alternative levels evaluated in the remainder of the assessment. Chapter 3 describes the  
5 analytical approach, methods, and data used in conducting the assessment of recent urban  
6 visibility conditions, both in terms of PM<sub>2.5</sub> and PM light extinction indicators for the set of  
7 urban case studies included in this analysis. Selected results are presented in chapter 3, with  
8 additional results found in the Appendices. Chapter 4 presents estimates of PM<sub>2.5</sub> and PM light  
9 extinction conditions generated for the urban case studies for six alternative PM<sub>2.5</sub> and light  
10 extinction scenarios. Additional information regarding approaches, results, method validation  
11 studies and uncertainty assessments for both chapters 3 and 4 are presented in Appendices A-I).

## 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 goal of this reanalysis was to provide information useful in selecting a range of light extinction CPLs for use in subsequent UFVA assessments of current and alternative VAQ conditions. The available urban visibility preference studies all used a similar group interview type of survey to investigate the level of visibility impairment that participants described as “acceptable. While each study 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.

The reanalysis included three completed urban visibility preference survey studies plus a pair of smaller focus studies designed to explore and further develop urban visibility survey instruments. The three western studies 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). A pilot focus group study was also conducted for Washington, DC (Abt Associates Inc., 2001). In response to an EPA request for public comment on the Scope and Methods Plan (74 FR 11580, March 18, 2009), 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.

### 2.1 METHODS USED IN PREVIOUS STUDIES

In all but one<sup>7</sup> 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

---

<sup>7</sup> 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.

1 weather events (e.g., rain, snow, or fog), and where measured extinction data were available  
2 from the time the photograph was taken.

3 The Phoenix study and the Washington, DC projects used computer generated  
4 photographic-quality images to present different VAQ conditions. Using an original near-  
5 pristine base photograph, additional images representing a range of VAQ conditions were  
6 generated using the WinHaze software program, which is based on a technique described in  
7 Molenar et al. (1994). The Phoenix study and the 2001 Washington, DC project projected slides  
8 of digital images prepared by WinHaze. The 2009 Washington, DC project presented images  
9 directly from the desktop version of WinHaze using either a liquid crystal display (LCD)  
10 projector or a computer monitor.

11 WinHaze analysis synthetically superimposes a uniform haze on a digitized, actual  
12 photograph. The WinHaze computer algorithm calculates how a given extinction level would  
13 impair the appearance of each individual portion of the photograph. A major advantage of  
14 presenting WinHaze-generated images is that they provide viewers depictions of alternative  
15 VAQ levels, with each image containing exactly the same scene, with identical light angle, time  
16 of day properties, weather conditions, and specific scene content details (e.g., the amount of  
17 traffic in a intersection). Additional details about WinHaze, and a discussion of the applicability  
18 of WinHaze images for regulatory purposes, is in the 2004 PM Criteria Document (U.S. EPA,  
19 2004). The desktop version of WinHaze is available online (Air Resources Specialists, 2008).

20 The first urban visibility preference study (Denver, CO; Ely et al., 1991) developed the  
21 basic survey method used in all the subsequent studies. Although there are variations in specific  
22 details in each study, all the studies use a similar overall approach (key variations are discussed  
23 in the section on each study later in this chapter). This approach consisted of conducting a series  
24 of group interview sessions, where the participants were shown a set of photographs or images of  
25 alternative VAQ conditions and asked a series of questions. The group interview sessions were  
26 conducted multiple times with different participants. Ideally the participants will be a  
27 representative sample of the residents of the metropolitan area. While all studies agree that this  
28 is the preferred approach, due to the high cost of organizing and conducting a series of in-person  
29 group interviews with a large, statistically representative sample, only the Phoenix study was  
30 able to fully meet this objective. During the group interview sessions, the participants were  
31 instructed to consider whether the VAQ in each photograph or image would meet an urban  
32 visibility standard, according to their own preferences and considering three factors:

- 33
- 34 1. The standard would be for their own urban area, not a pristine national park area  
35 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").

## 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.<sup>8</sup> 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

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<sup>8</sup> No preference data were collected at a 17<sup>th</sup> focus group session due to a slide projector malfunction.

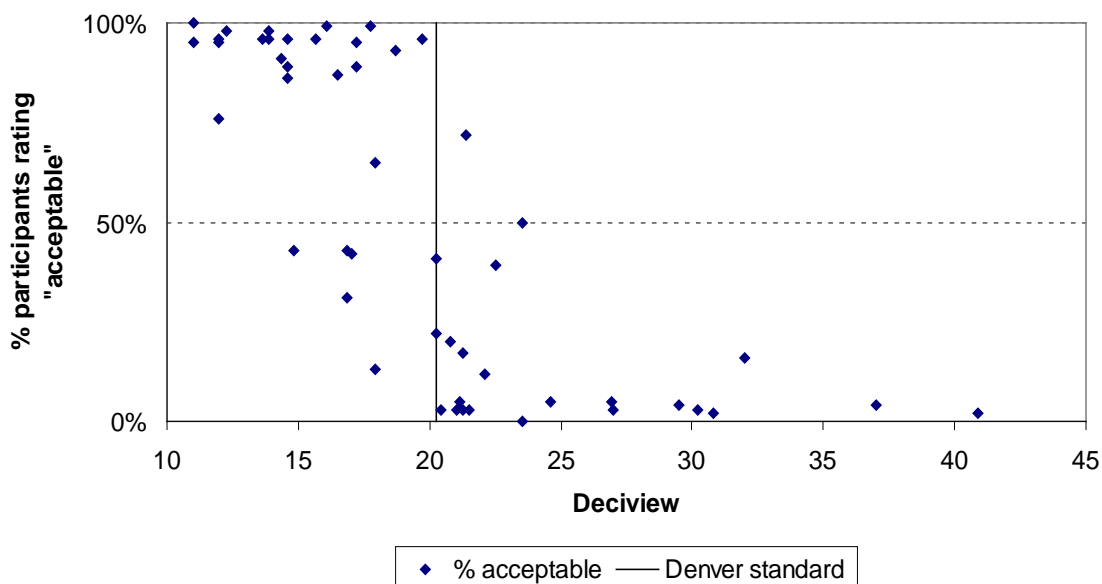
1 100 participants viewed each photograph. Projected color slides were used to present the  
2 photographs to focus group participants, and were projected on a large screen

3 The VAQ conditions in each Denver photograph were recorded when the photograph was  
4 taken and measured by a transmissometer yielding hourly average light extinction,  $b_{ext}$ . The  
5 transmissometer was located in downtown Denver, approximately eight miles from the camera  
6 and in the middle of the camera's view path. Ely et al. (1991) provide the time of day and  
7 measured extinction level for each photograph. The extinction levels presented in the Denver  
8 photographs ranged from 30 to 596  $Mm^{-1}$ . This corresponds to 11dv to 41dv, approximating the  
9 10<sup>th</sup> to 90<sup>th</sup> percentile of wintertime visibility conditions in Denver in the late 1980s.

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

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

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



18 Ely et al. (1991) introduce a "50% acceptability" criteria analysis of the Denver  
19 preference study results. The 50% acceptability criteria is designed to identify the VAQ level  
20 that best divides the photographs into two groups: those with a VAQ rated as acceptable by the  
21

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  $b_{ext} = 76 \text{ Mm}^{-1}$  (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.,  $\text{dv} < 19.3$ ) 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 ( $> 21.3 \text{ dv}$ ) 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  $76 \text{ Mm}^{-1}$  (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.

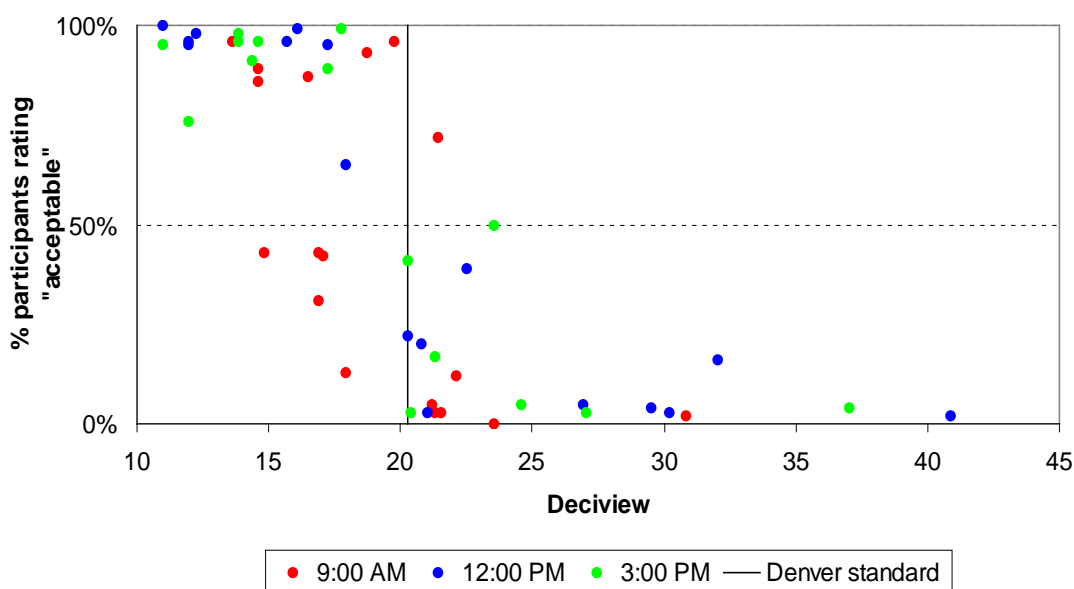
**Table 2-1. VAQ of Denver photos substantively misclassified by majority of participants**

Photograph #	VAQ in photograph in extinction ( $\text{Mm}^{-1}$ )	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.

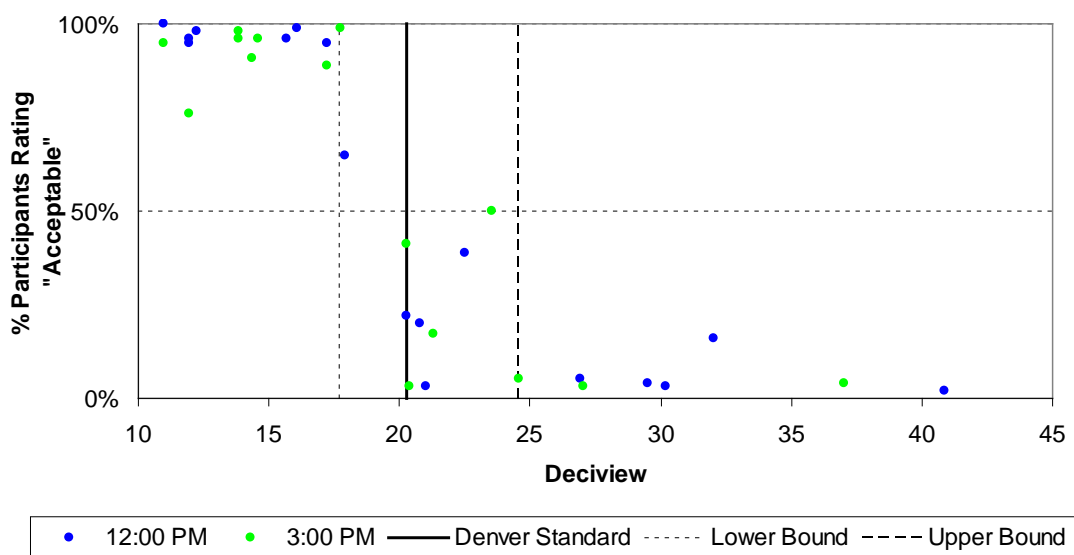
**Figure 2-2 Photograph time of day information**



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.

1

**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.



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

10  
11 **Figure 2-4 Composite Chilliwack, BC photograph shows VAQ of 14.1 dv and 34 dv.**



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

1 visibility monitoring at the Abbotsford location had only a nephelometer and collected only  $b_{sp}$   
2 data.

3 As explained in section 1.3, total light extinction is the sum of scattering by gases ( $b_{sg}$ )  
4 and particles ( $b_{sp}$ ) plus light absorption by gases ( $b_{ag}$ ) and particles ( $b_{ap}$ ). In order to present the  
5 preference results from the BC study in comparable terms,  $b_{ext}$  for the Abbotsford photographs is  
6 estimated by assuming that the average of the ratios of PM light extinction (i.e.,  $b_{ap} + b_{sp}$ ) to PM  
7 light scattering ( $b_{sp}$ ) for all ten of the Chilliwack photographs can be multiplied by the  
8 Abbotsford nephelometer determined  $b_{sp}$  values corresponding to each of its photographs to  
9 estimate its PM light extinction value. By assuming that absorption by gases ( $b_{ag}$ ) is zero, total  
10 light extinction is equal to the PM light extinction (i.e.,  $b_{ap} + b_{sp}$ ) plus particle scattering by gases  
11 (i.e.,  $b_{sg}$  that is approximately equal to  $10 \text{ Mm}^{-1}$ ). Table 2-2 presents the data from the  
12 photographs used in the BC study, including the estimated  $b_{ext}$  for the Abbotsford photographs.

13 There are two caveats to be noted about the extinction data for the photographs reported  
14 in Pryor, 1996. First, in Table 2 of the original article, two of the Abbotsford photographs are  
15 listed with the same date and time (12:00 p.m., 7/26/1993). There is no information provided for  
16 a 3:00 p.m., 7/26/1993 Abbotsford photograph, although there is a Chilliwack photograph from  
17 that time. The preference and VAQ data are presumed to be correct for both photographs and  
18 one of the two identical date/time labels is assumed to be a typographic error. The second caveat  
19 is that  $b_{sp}$  levels from the same date and time can differ substantially between Abbotsford and  
20 Chilliwack, and the relative levels can change rapidly, even though the two cities are only 25  
21 miles apart. For example, at 12:00 p.m. on 8/19/1993, the  $b_{sp}$  level in Chilliwack was about one-  
22 third of the Abbotsford  $b_{sp}$  level. By 3:00 p.m. the situation was reversed, with the Chilliwack  
23  $b_{sp}$  level 50% higher than Abbotsford. In those three hours the Chilliwack  $b_{sp}$  level had more  
24 than doubled (from  $46 \text{ Mm}^{-1}$  to  $105 \text{ Mm}^{-1}$ ), and the Abbotsford level had fallen by over half  
25 (from  $145 \text{ Mm}^{-1}$  to  $67 \text{ Mm}^{-1}$ ). Such substantial changes in measured  $b_{sp}$  levels occurring across a  
26 relatively short period of time and short distance, may reflect an inherent uncertainty introduced  
27 by using a single measure of light extinction from a portion of visual scene (where the  
28 nephelometer or transmissometer was operating) to assess visibility conditions throughout an  
29 actual photographs of a complex scene. Spatial and temporal non-uniformity of visibility  
30 conditions within a scene are an atmospheric condition known to occur on some days, and may  
31 contribute to the variability in participant responses in preference studies utilizing actual  
32 photographs.

33  
34  
35  
36 **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
<b>Chilliwack</b>						
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
<b>Average</b>		<b>62</b>	<b>102</b>	<b>1.476</b>		<b>21.96</b>
<b>Abbotsford</b>						
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
<b>Average</b>		<b>76</b>			<b>122</b>	<b>23.67</b>

2

3

4

5

6

7

8

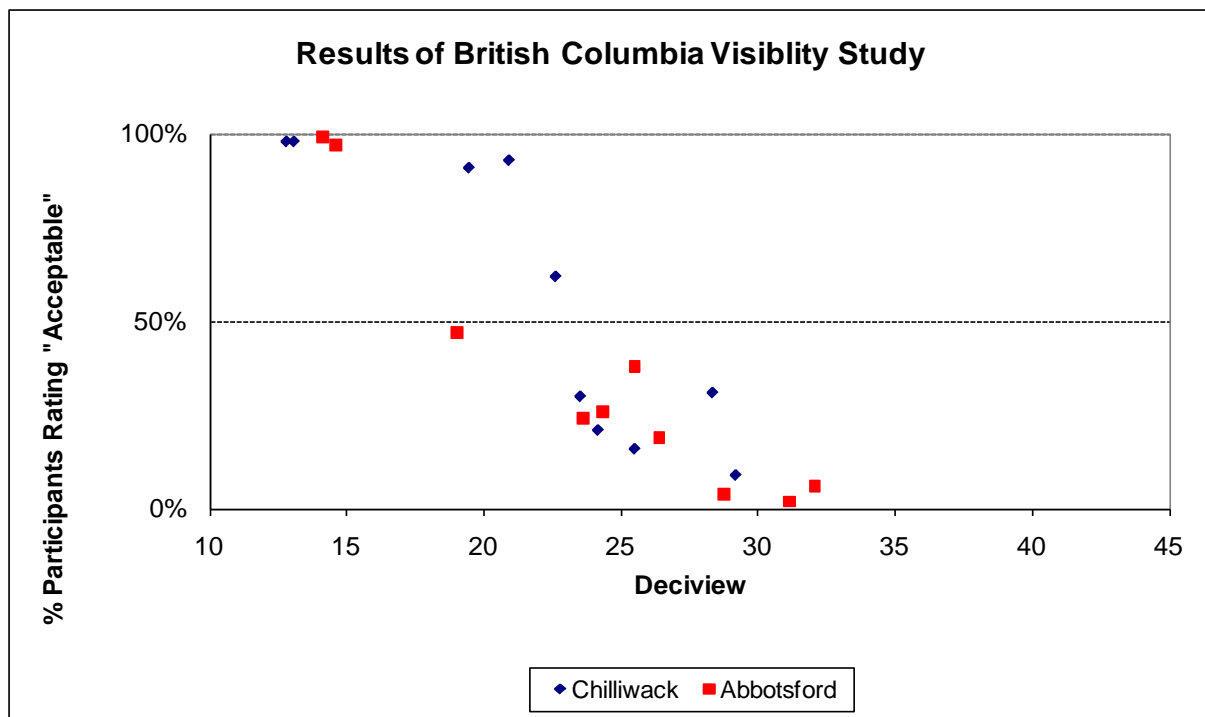
9

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, 2002), which was conducted on behalf of the Arizona Department of Environmental Quality, used

1 group interviews based on the methods used in the Denver study, with two major exceptions: (1)  
2 the focus group participants were selected as a representative sample of the Phoenix area  
3 population, and (2) the pictures presented in the focus groups were computer-generated images  
4 to depict specific uniform haze conditions.

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

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

18 Photographic-quality slides of the images were developed using the WinHaze software  
19 (Molenar et al., 1994). The scene used in the Phoenix study images was taken at a water  
20 treatment plant. The view is toward the southwest, including downtown Phoenix, with the Sierra  
21 Estrella Mountains in the background at a distance of 25 miles. Figure 2-6 shows the image with  
22 the best VAQ (15 dv).  
23

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



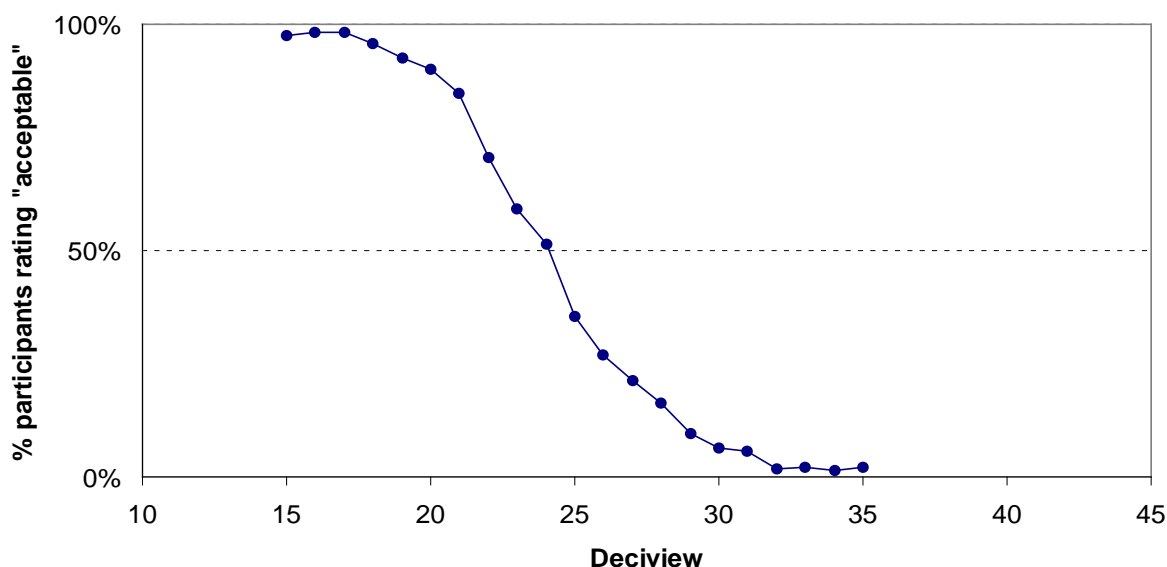
1  
2 The study used a total of 21 unique WinHaze images. Four of the 21 unique images were  
3 randomly selected and used twice to evaluate consistency; participants viewed a total of  
4 25 images. The 25 images were randomly ordered, with all participants viewing the images in  
5 the same order. The WinHaze images used in the Phoenix study do not include layered haze, a  
6 frequent and widely recognized form of visibility impairment in the Phoenix area.

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

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

1

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



2

3 Ninety percent or more of the participants rated a VAQ of 20 dv or better as acceptable, and 70%  
 4 rated a VAQ of 22 dv or better as acceptable. The “50% acceptable criteria” was met at  
 5 approximately 24.3 dv (with 51.3% of the participants rating that image as acceptable). The  
 6 percent acceptability declines rapidly as VAQ worsens; only 27% of the participants rated a  
 7 26 DV image as acceptable, and fewer than 10% rated a 29 dv image as acceptable.

8 The Phoenix urban visibility study formed the basis of the decision of the Phoenix  
 9 Visibility Index Oversight Committee for a visibility index for the Phoenix metropolitan area  
 10 (Arizona Department of Environmental Quality, 2003). The Phoenix Visibility Index establishes  
 11 an indexed system with 5 categories of visibility conditions, ranging from “Excellent” (14 dv or  
 12 less, which was a better VAQ than any of the images used in the Phoenix study) to “Very Poor”  
 13 (29 dv or greater, which less than 10% of the study participants rated as acceptable). The  
 14 “Good” range is 15 dv to 20 dv (more than 90% of the participants rated images in this VAQ  
 15 range as acceptable). The environmental goal of the Phoenix urban visibility program is to  
 16 achieve continued progress through 2018 by moving the number of days in poorer quality  
 17 categories into better quality categories.

## 18 **2.5 WASHINGTON, DC**

19 One of the Washington, DC urban visibility pilot studies was conducted on behalf of  
 20 EPA (Abt Associates Inc., 2001). It was designed to be a pilot focus group study, an initial

1 developmental trial run of a larger study. The intent of the pilot study was to refine both focus  
2 group method design and potential survey questions. Due to funding limitations, only a single  
3 focus group session took place, consisting of one extended session with nine participants. No  
4 further urban visibility focus group sessions were held in Washington, DC on behalf of EPA.

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

14 Both the Abt Associates Inc. (2001) study results and the results of the Smith and Howell  
15 (2009) study are discussed below.

### 16 **2.5.1 Washington, DC 2001**

17 The EPA's Washington, DC study (Abt Associates Inc., 2001) adopted the general study  
18 methods used in the Denver, BC, and Phoenix studies, modifying them appropriately to be  
19 applicable in an eastern urban setting. Washington's (and the entire East's) current visibility  
20 conditions are typically substantially worse than western cities and have different characteristics.  
21 Washington's visibility impairment is primarily a uniform whitish haze dominated by sulfates,  
22 and the relative humidity levels are higher compared with the western study areas. In addition,  
23 the relatively low-lying terrain<sup>9</sup> in Washington, DC provides substantially shorter maximum  
24 sight distances. Many residents are not well informed that anthropogenic emissions impair  
25 visibility on hazy days.

26 The Washington, DC focus group session included questions on valuation, as well as on  
27 preferences. The focus group content dealing with preferences for an urban visibility standard  
28 was similar to the focus group sessions in the western studies.

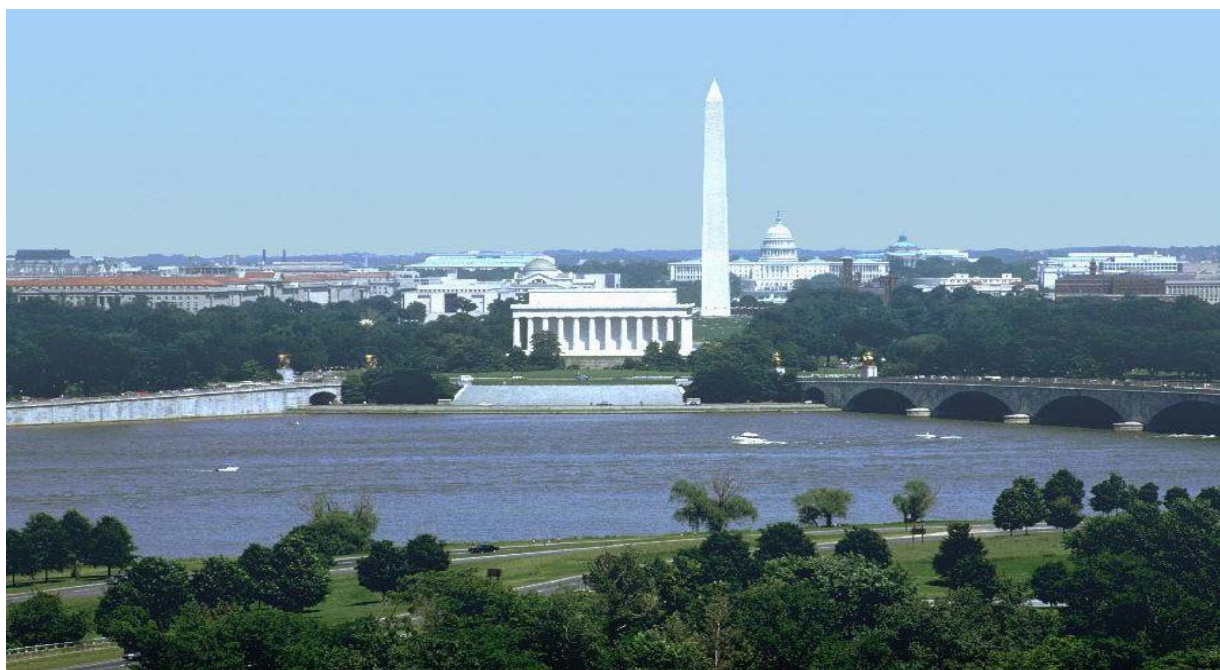
29 A single scene of a panoramic photograph taken from Arlington National Cemetery in  
30 Virginia was used, and included an iconic view of the Potomac River, the National Mall, and  
31 downtown Washington, DC. All of the distinct buildings in the scene are less than four miles  
32 from the camera,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

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<sup>9</sup>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.**

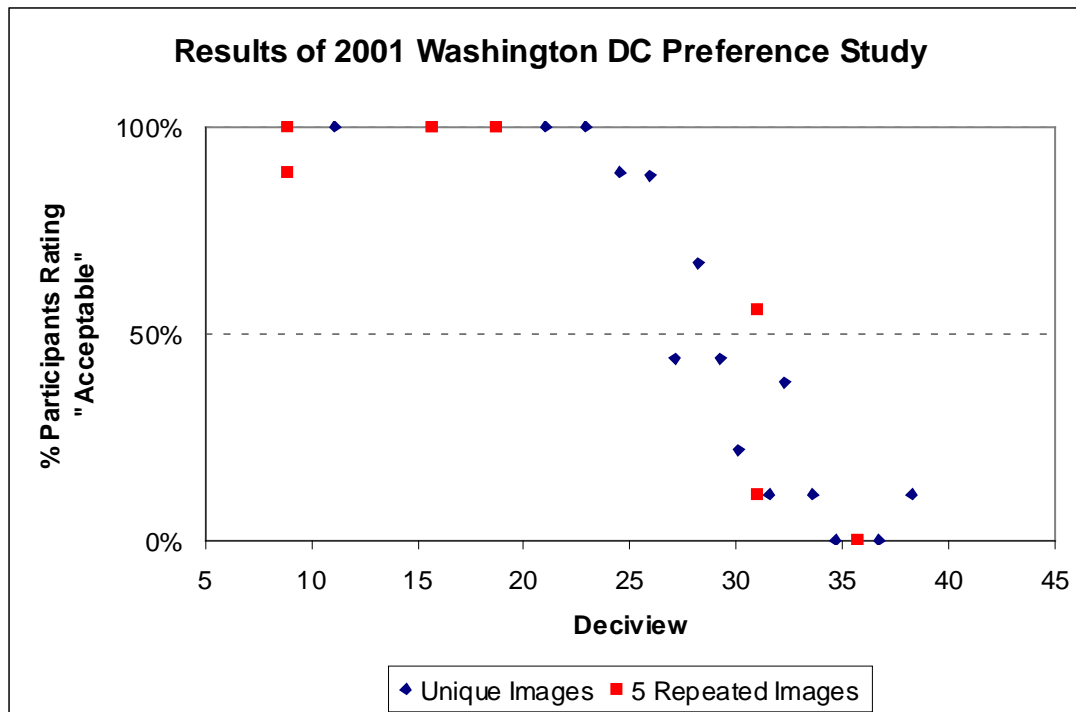


The Washington, DC study used 20 unique images generated by WinHaze, each prepared from the same original photograph. Humidity and gaseous light scattering was held constant in preparing the WinHaze images, as was the relative chemical mix of aerosol particulates in the photos (i.e., only the aerosol 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 range of 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.

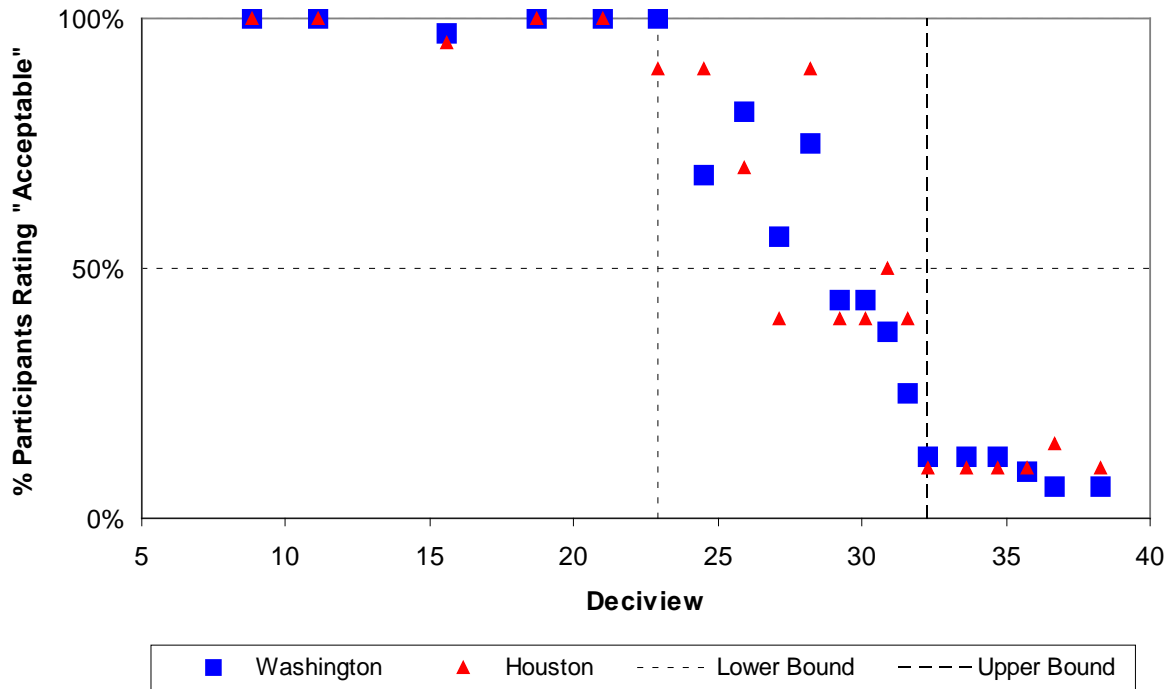
Eight of the Washington-based participants and all of the Houston participants viewed the WinHaze images on a desktop computer monitor. The remaining Washington participants viewed the images projected on a screen.

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 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.

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

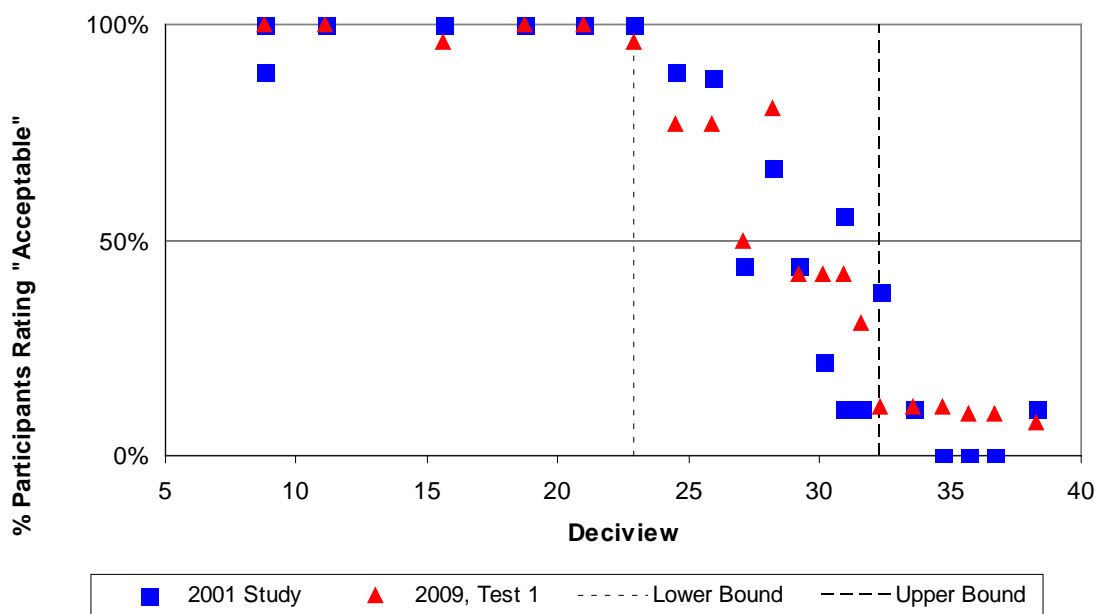
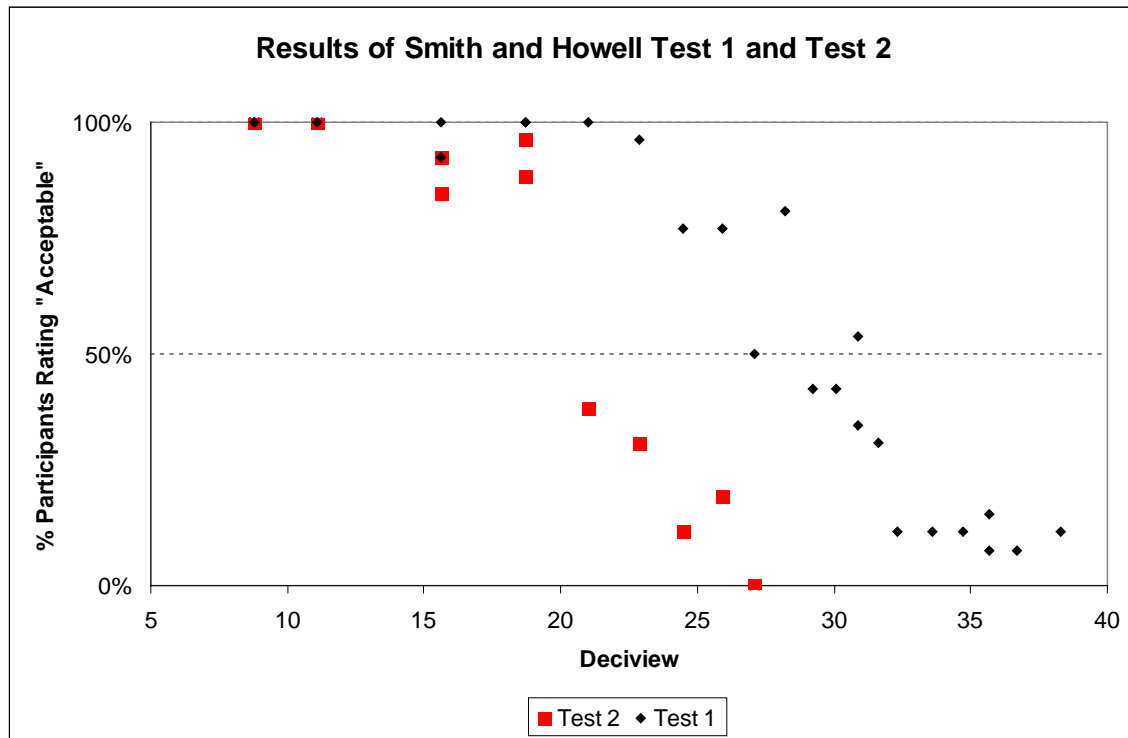


Figure 2-12 presents the Test 1 and Test 2 results. Test 2 found a substantial shift in the responses regarding which VAQ levels are considered acceptable. The smaller number of images used in Test 2 made identifying the range of the 50% acceptability criteria more difficult than in Test 1. The lower 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 all the studies may be influenced by the range of VAQ images presented.

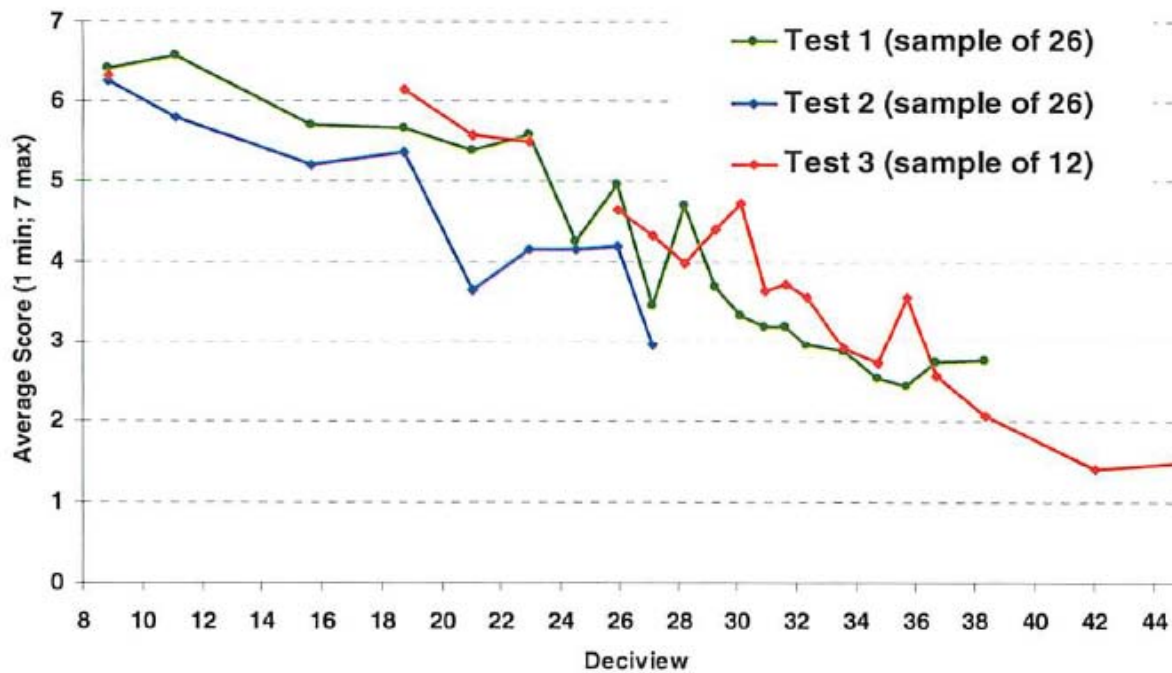
**Figure 2-12 Comparison of results from Test 1 and Test 2 (Smith and Howell, 2009).**



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 quality of 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<sup>10</sup> 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 them 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 do not reflect an enduring view on the “unacceptability” of different levels of VAQ degradation.

<sup>10</sup> 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.”

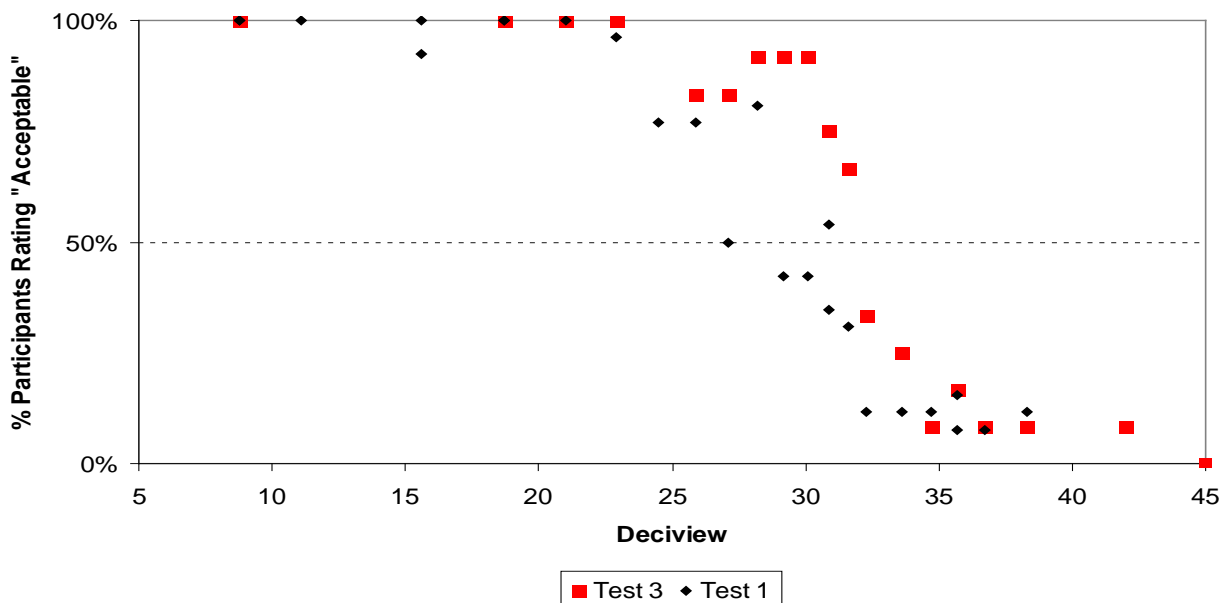
1 However, there is an alternative explanation. It seems more likely that the use of such a severely  
2 truncated range of VAQ conditions in Test 2, which did not include any of the images of VAQ  
3 that previous studies identified as unacceptable, in effect fundamentally changed the implied  
4 instructions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

10 In Test 3, Smith and Howell expanded the VAQ range of WinHaze images shown to the  
11 participants, including two new images with a worse VAQ. The new images had a VAQ of 42  
12 dv and 45 dv, raising the upper end of the VAQ range by 6.7 dv. Test 3 also reduced the total  
13 number of images shown to participants to 19 images by eliminating the use of the five repeat  
14 images in Test 1, and also eliminated three additional images in order to reduce the participants'  
15 time burden. The three deleted images had a VAQ of 11.1, 15.6, and 24.5 dv. The best VAQ  
16 image shown to Test 3 participants was 8.8 dv (same as the best VAQ image in Tests 1 and 2).  
17 However, in Test 3 there were no images with VAQ between 8.8 dv and 18.7 dv, creating a  
18 significant "hole" in the distribution of VAQ conditions presented to the Test 3 participants.  
19 Test 3 was conducted with 12 participants from the CRA Washington office (none of whom  
20 participated in Test 1 or Test 2). No Houston participants were involved with Test 3. Figure 2-  
21 13 shows that the Test 3 average ratings from 1 to 7 during the VAQ rating exercise increased  
22 the average participant rating by about 1 at the low end of the scale (very poor VAQ). The  
23 results of Test 3 are shown in Figure 2-14, along with the results of Test 1.

24 Test 3 resulted in an overall increase in the percent of respondents rating as acceptable  
25 the VAQ images used in both tests. In Test 3 all images with a VAQ below 22.9 dv were rated  
26 acceptable by 100% of the participants (similar to the Test 1 results), implying there was no  
27 general change in the acceptability of the images with good VAQ. However, for all VAQ  
28 images (that were used in both studies) between 25.9 dv and 33.6 dv, a noticeably larger  
29 percentage of the participants in Test 3 rated the image as acceptable than in Test 1. At VAQ  
30 levels worse than 33.6 dv, the majority of the participants found the VAQ level not acceptable in  
31 both tests. While the differences are noticeable, the small number of participants in Test 3 (i.e.  
32 12) makes the significance of the difference unclear.

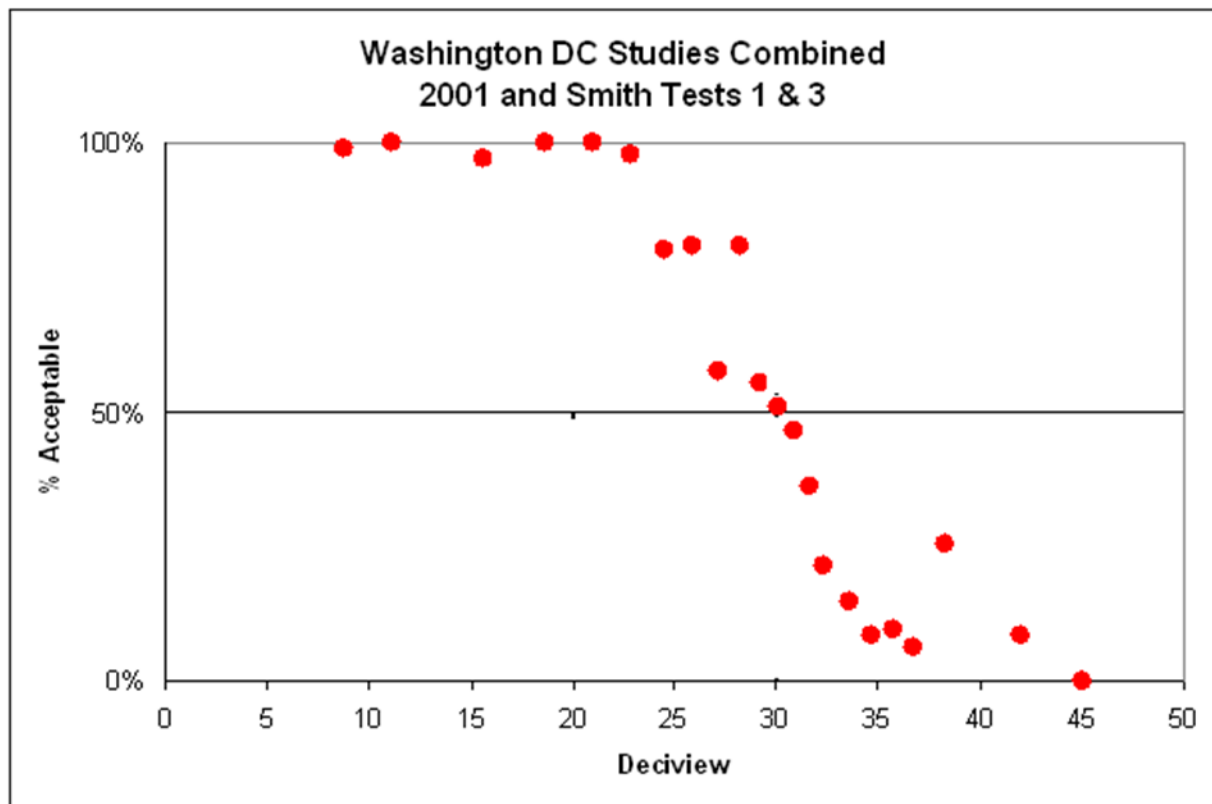


**Figure 2-14 Comparison of results from the Smith and Howell (2009) Test 1 and Test 3.**



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. In that sense, Test 3 results may be considered somewhat more reliable than those from Test 1 and the original Washington, DC pilot study. However 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. 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 and from Tests 1 and 3) of each image were developed to increase the number of participant ratings for each image. Figure 2-15 shows the composite results of these three groups involving a 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%). This analysis does not address the question of whether a significant “hole” in the Test 3 VAQ distribution between 8.8 dv and 18.7 dv potentially had an effect on participant acceptability responses.

Figure 2-15 Composite results from Smith and Howell (2009) Tests 1 and 3, and Abt (2001) Washington, DC pilot study.



## 2.6 SUMMARY OF PREFERENCE STUDIES AND SELECTION OF CANDIDATE PROTECTION LEVELS

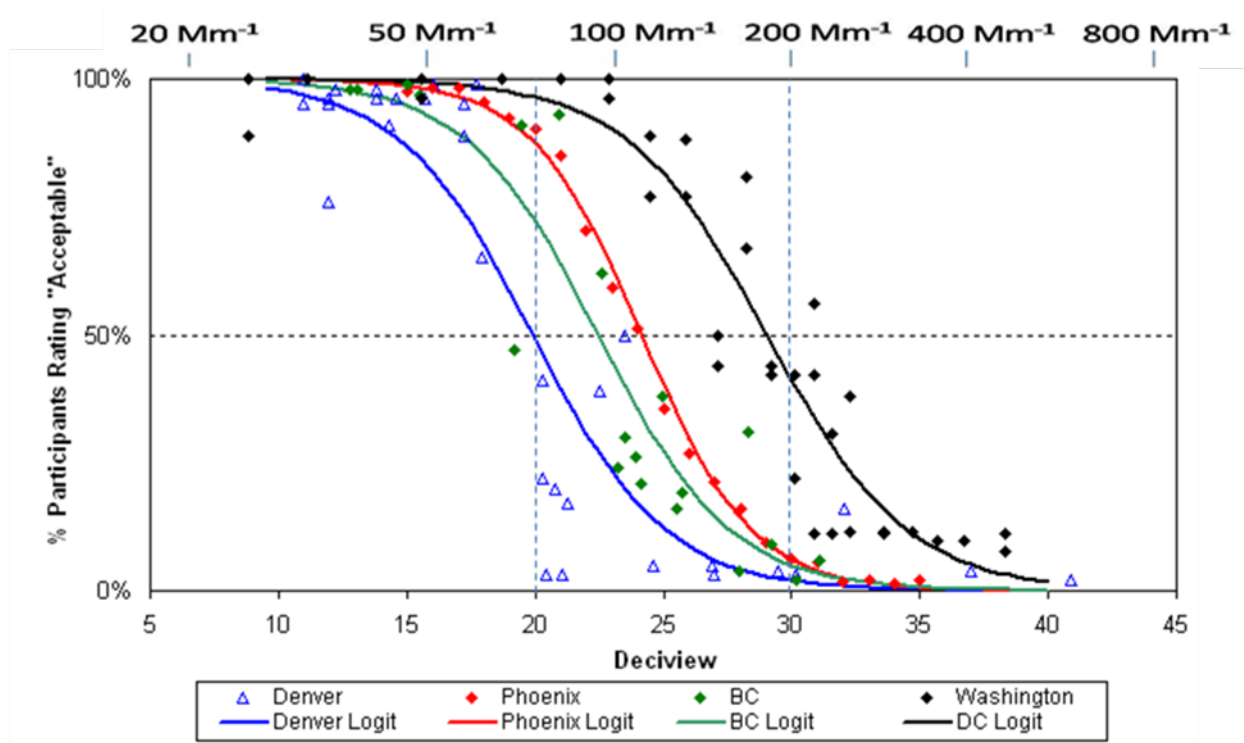
Each of the studies reviewed in this assessment investigates the common question, “What level of visibility degradation is acceptable?” The approaches used in the four studies are similar and are all derived from the method first developed for the Denver urban visibility study. As a result, EPA staff has concluded that it is reasonable to compare the results 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.

**Figure 2-16 Summary of results of urban visibility studies in four cities, showing the identified range of the 50% acceptance criteria .<sup>11</sup>**



For clarity in Figure 2-16, the Denver results omit the 9:00 a.m. photograph results, the Chilliwack and Abbotsford photographs appear as a single set of data for the BC study, and the results from 2001 and 2009 (Test 1) studies of VAQ preferences in Washington, DC are presented as a single combined set of data. The results from the 2009 Washington, DC study Tests 2 and 3 are not included on Figure 2-16; Test 2 is not a comparable study because it restricted the range of VAQ conditions to only those rated average to best (e.g., 3-7) visibility in

<sup>11</sup> 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

the VAQ ratings, and Test 3 is not included because of concerns for the effects on having a significant “hole” in the VAQ distributions shown to participants between 8.8 dv and 18.7 dv.

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.

In the context of the preference studies, the logit model determines a function that best estimates the percentage of respondents that rate an image 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 image acceptable) or 0 (unacceptable). For this application, the logit model determines an equation estimating the proportion of participants who will find any particular deviciew level acceptable. There were two basic types of explanatory (independent) variables used: one continuous numerical variable (the image’s haziness level or VAQ in deciviews), and a set of discrete variables that identify which city the observation is from.

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;

$$z = \beta_o + \beta_1 x_1 + \beta_2 x_2 + \dots$$

In this analysis the estimated logistic function  $f(z)$  is the estimated probability of the participants in the study rating an image as acceptable, given the dv value of the image and what city the observation came from. In this application the logit is

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

The variables BC (British Columbia), DC (Washington, DC), and Phoenix are “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 for a different city. Denver is used as the omitted city dummy variable, allowing the estimated coefficients on the other three city dummy variables to estimate if the response function is different in those cities than in Denver. For example the estimated total intercept for Washington becomes  $Intercept + \beta_4$ , and the estimated slope of the function is  $\beta_4 + \beta_5$ . A statistically significant estimate of the interaction

term coefficient ( $\beta_3$ ,  $\beta_5$ , or  $\beta_7$ ) for a particular city implies that the response function has a different slope than the Denver function.

The logit analysis was conducted using STATA<sup>®</sup> Data Analysis and Statistical Software (Release ES 10.1), using the LOGIT procedure. Table 2-3 presents the parameter estimates from the logit analysis, which investigates whether both slope and the intercept of the estimated response function differ between cities. The pseudo- $R^2$  estimate was 0.4756 and the loglikelihood  $\chi^2$  test also strongly rejects the null hypothesis that there is no effect of the explanatory variables on the probability that a respondent would find a image acceptable ( $\Pr(\chi^2=0 < 0.000)$ ). In other words, the acceptability ratings depend both on the deciview value and city.

**Table 2-3 Logit Analysis Results**

Variable	Coefficient	Standard Error	z-statistic	Pr /z/ = 0	5% confidence estimate	95% confidence estimate
Dv	-0.3862	0.0094	-41.16	~0	-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	1.2873	4.6026
Phoenix	3.5682	0.3015	11.84	~0	2.9773	4.1591
BC x dv	-0.0029	0.0162	-0.18	0.86	-0.0345	0.0288
Wash. X dv	0.0200	0.0293	0.68	0.495	-0.0374	0.0774
Phoenix x dv	-0.0797	0.0136	-5.88	~0	-0.1063	-0.0531
Constant	7.6844	0.1830	41.99	~0	7.3257	8.0431

The city intercept coefficients 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, indicating that the Phoenix response function has a different slope than the other three cities, as can be seen in Figure 2-16. The negative estimated coefficient on the Phoenix interaction term results in the Phoenix response function being steeper than the other cities' functions. 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 2-4.

**Table 2-4 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
<b>50% Acceptability criteria</b>	<b>19.90</b>	<b>22.45</b>	<b>24.15</b>	<b>29.03</b>
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.<sup>12</sup> Similarly, only one image with a VAQ above 30 dv was rated acceptable by more than 50% of the participants who viewed it.<sup>13</sup> These upper and lower range values are also supported by the logit model data which estimates 50<sup>th</sup> 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 others.<sup>14</sup> 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

<sup>12</sup> Only 47% of the BC participants rated a 19.2 dv photograph as acceptable.

<sup>13</sup> 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).

<sup>14</sup> Variability here refers to the degree of scatter of the average acceptability ratings for each image around the logit curve for that city.

1 because the same base photograph is used (i.e. no intrinsic change in scene appearance) and the  
2 modeled haze that is displayed in the photograph is determined based on uniform light extinction  
3 throughout the scene.

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

11 A third hypothesis promoted by Smith and Howell (2009) is that the range of VAQ  
12 images presented in the survey may influence the results. As discussed above, a more plausible  
13 explanation is that the range of haze images shown to participants in the VAQ 1 to 7 rating  
14 exercise was interpreted by participants as a restriction on acceptability rating exercise to confine  
15 their rating to the range VAQ conditions shown, which for Test 2 was curtailed to only average  
16 to good VAQ conditions. When other evidence is taken into account, the Smith and Howell  
17 hypothesis seems an even more unlikely explanation for the differences in results between the  
18 four urban preference studies. For example the Denver study included photographs with the  
19 haziest conditions among the four studies, but resulted in the lowest haze condition for the 50<sup>th</sup>  
20 percentile preference ratings among the four, not the highest as might be expected if the range of  
21 haze levels were a significant factor influencing the results of preference studies. Also,  
22 inspection of the average VAQ 1 to 7 ratings for the Phoenix and Denver studies showed that  
23 they spanned the full ratings range of values similar to those for the Smith and Howell Test 1 and  
24 3, so the participants in those studies were not presented with a restricted range within which to  
25 select acceptable VAQ conditions, suggesting that the range itself was not an important factor  
26 influencing their results. Values for the British Columbia 1 to 7 VAQ rating exercise were not  
27 readily available.

28 A fourth major hypothesis is that urban visibility preferences may differ by location, and  
29 the differences may arise from inherent differences in the cityscape scene used in each city. The  
30 key evidence to suggest this hypothesis is that the apparent differences between the Denver  
31 results (which found the 50% acceptance criteria occurred in the best VAQ levels among the four  
32 cities) and the Washington, DC results (which found the 50% acceptance criteria occurred at the  
33 worst VAQ levels among the four cities). This hypothesis suggests that these results may occur  
34 because the most prominent and picturesque feature of the cityscape of Denver is the clearly  
35 visible snow-covered mountains in the distance, while the prominent and picturesque features of

1 the Washington, DC cityscape are buildings relatively nearby without prominent and/or valued  
2 scenic features that are more distant.

3 Finally, and perhaps of significant importance is that the sensitivity of individual scenes  
4 to perceived changes in VAQ under changing light extinction levels can be quite different. As in  
5 the fourth hypothesis, this may in part explain why the Denver study scene, with its long distance  
6 to the mountain backdrop, resulted a preference for the best VAQ level, with a 50% criteria value  
7 of about 20 dv, while the Washington, DC study scene, with much shorter sight paths yielded a  
8 50% criteria VAQ value at a substantially worse level of about 30 dv. The distinction between  
9 the last two hypotheses are that the earlier one speaks to the desirability of seeing distant  
10 mountains versus this hypothesis which concerns the ability to perceive changes in haze at lower  
11 light extinction levels. Additional studies, including directly comparable studies using similar  
12 methods in diverse cities, would be useful to gain further understanding of preferences for urban  
13 visibility.

14 Based on the composite results and the effective range of 50<sup>th</sup> percentile acceptability  
15 across the four urban preference studies shown in Figure 2-16, CPLs have been selected in a  
16 range from 20 dv to 30 dv ( $74 \text{ Mm}^{-1}$  to  $201 \text{ Mm}^{-1}$ ) for the purpose of comparing to current and  
17 projected conditions in the assessment in chapters 3 and 4 of this document. A midpoint of 25  
18 dv ( $122 \text{ Mm}^{-1}$ ) was also selected for use in the assessment. These three values provide a low,  
19 middle, and high set of light extinction conditions that are used in subsequent chapters of the  
20 UFVA to provisionally define daylight hours with urban haze conditions that have been judged  
21 unacceptable by the participants of these preference studies. As discussed earlier (section 1.2)  
22 PM light extinction is taken to be light extinction minus the Rayleigh scatter (i.e. light scattering  
23 by atmospheric gases is about  $10 \text{ Mm}^{-1}$ ), so the low, middle and high CPL levels correspond to  
24 PM light extinction levels of about  $64 \text{ Mm}^{-1}$ ,  $112 \text{ Mm}^{-1}$  and  $191 \text{ Mm}^{-1}$ .



### **3 ESTIMATION OF CURRENT PM CONCENTRATIONS AND PM LIGHT EXTINCTION**

The goals of the “current conditions” portion of this urban-focused visibility impact assessment are to characterize hourly PM light extinction conditions in a set of urban study areas during 2005-2007, in order (1) to improve understanding of the levels, patterns, and causes of daylight hours PM light extinction; (2) to provide the starting point for projections of PM light extinction levels under “what if” scenarios; and (3) to examine the correlation between PM light extinction and potential alternative indicator(s) based on PM<sub>2.5</sub> mass concentration. This chapter addresses the first goal. Chapter 4 addresses the second goal regarding “what if” scenarios. Appendix D addresses the third goal. A number of other appendices address related topics of particular interest in more detail.

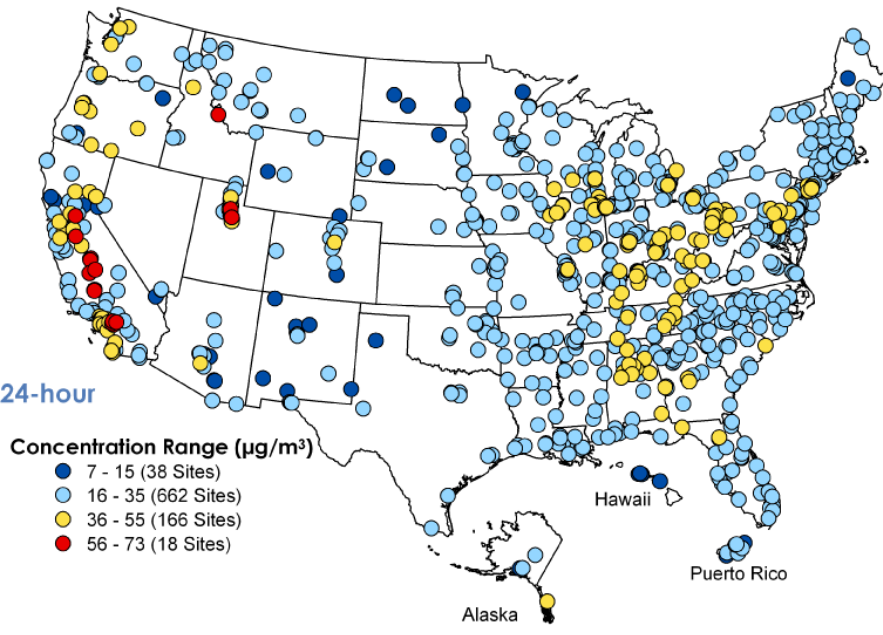
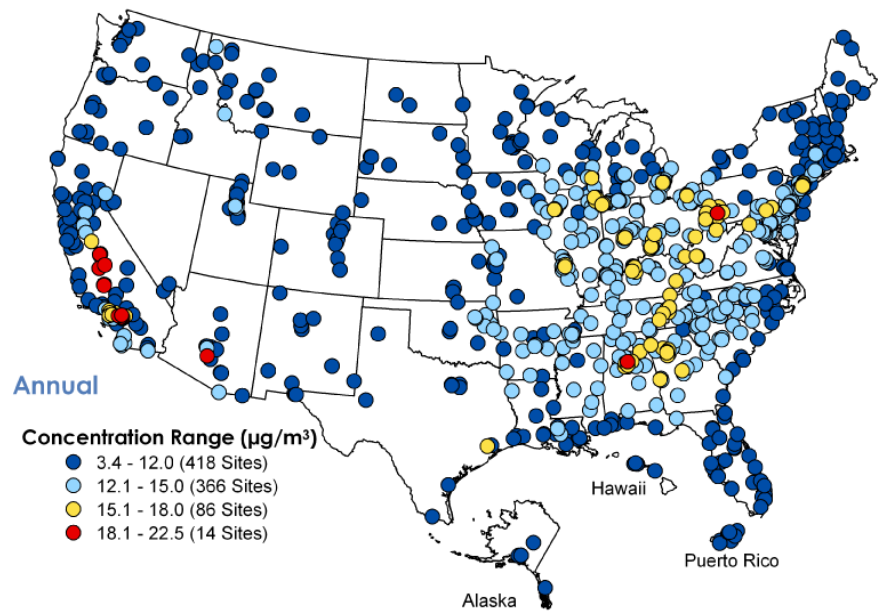
#### **3.1 SUMMARY OF PREVIOUS CHARACTERIZATIONS OF PM CONCENTRATIONS AND LIGHT EXTINCTION**

##### **3.1.1 PM<sub>2.5</sub> and PM<sub>10-2.5</sub>**

Chapter 2 of the 2005 Staff Paper from the previous review and chapters 3 (especially section 3.5) and 9 (especially section 9.2.3) and Annex A of the final ISA (US EPA, 2009a) from the current review present extensive characterizations of the levels, composition, and temporal and spatial patterns of PM<sub>2.5</sub> in U.S. urban areas. Both documents present data summaries based on the approximately 1000 PM<sub>2.5</sub> 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<sub>2.5</sub> in many areas as a result of emission reductions of PM<sub>2.5</sub> 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<sub>2.5</sub> NAAQS set at a level of 15 µg/m<sup>3</sup> in 1997 and retained in the last review completed in 2006. Seventy-six areas violated the 2006 24-hour NAAQS level of 35 µg/m<sup>3</sup>. 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<sub>2.5</sub> concentrations in 2005 were high relative to the next three years. Figure 3-1 illustrates PM<sub>2.5</sub> 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 98<sup>th</sup> percentile 24-hour concentration, in both cases in that one year.

1 **Figure 3-1. Annual average and 24-hour (98<sup>th</sup> percentile 24-hour concentrations) PM<sub>2.5</sub>**  
2 **concentrations in  $\mu\text{g}/\text{m}^3$ , 2007.**  
3



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

8 Midwestern, southeastern, and eastern urban areas have much higher sulfate levels than  
9 do more western areas, attributable to the much higher emissions of SO<sub>2</sub> in and upwind of them.  
10 Upper midwestern areas and to a lesser extent upper eastern areas have notable nitrate  
11 concentrations in winter but not in summer, while southeastern areas generally lack notable  
12 nitrate even in winter. Many western urban areas have notable nitrate year round. In all areas,  
13 carbonaceous material is an important component of PM<sub>2.5</sub> and is attributable to many emission  
14 sources of organic material in PM form and of organic PM precursor gases. In some areas with  
15 high local use of wood for residential heating carbonaceous material is dominant during the  
16 heating season. PM<sub>2.5</sub> derived from crustal sources is generally a small fraction of total mass,  
17 except during local high wind events or due to brief periods of intercontinental transport of dust  
18 from Africa or Asia.

19 Comparison of PM<sub>2.5</sub> species concentrations within and outside urban areas leads to the  
20 conclusion that, in the eastern areas with high sulfate concentrations, the large majority of the  
21 sulfate affecting any given urban area originates outside that area. Inward transport and local  
22 generation of nitrate and carbonaceous material are more evenly balanced in eastern areas, with  
23 some differences among areas. In western areas, local sources dominate for carbonaceous  
24 material and nitrate, with the origins of the small sulfate component being more balanced. See  
25 Figure 9-24 of the final ISA (US EPA, 2009a).

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

34 There is at present no systematic monitoring network in place for PM<sub>10-2.5</sub>, as states have  
35 until January 1, 2011, to implement required monitoring sites for PM<sub>10-2.5</sub>. Consequently,  
36 estimates of PM<sub>10-2.5</sub> must be developed using data from PM<sub>2.5</sub> and PM<sub>10</sub> 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 15 study areas, which are reported below in section 3.3.2.

Additional detail on  $PM_{2.5}$ ,  $PM_{10}$ , and  $PM_{10-2.5}$  concentrations, composition, and patterns appears in section 3.5.1.1 of the 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 light extinction**

While total light extinction is directly measurable using a transmissometer and PM 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.<sup>15</sup> Consequently, any characterization of PM 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 light extinction in

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<sup>15</sup> 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.

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

3 PM light extinction can be “reconstructed” from measurements of PM<sub>2.5</sub> mass  
4 components and PM<sub>10-2.5</sub> concentrations, in combination with relative humidity values, using  
5 either of two versions of the formula known as the IMPROVE algorithm but excluding its term  
6 for Rayleigh scattering by gases in clean air. (Section 9.2.2.2 of the ISA gives an overview of  
7 the algorithm and its basis. Section 3.2.3 of this document discusses the application of the  
8 original version of the IMPROVE algorithm in this assessment. PM<sub>2.5</sub> component measurements  
9 are generally available only on a 24-hour average basis, so it generally is possible to estimate  
10 only 24-hour average PM light extinction, unless additional information on hourly patterns is  
11 brought to bear.<sup>16</sup> Because EPA’s Regional Haze Rule (RHR) currently requires states to  
12 address visibility problems in Class I visibility protection areas, which are nearly all rural and  
13 remote, there is a large body of literature characterizing light extinction in remote rural areas,  
14 based on data from the IMPROVE network’s 24-hour samplers and on special studies. Sections  
15 9.2.3.2 and 9.2.3.4 of the ISA summarize this literature. Section 9.2.3.3 of the ISA contrasts  
16 concentrations of PM and PM components between rural and urban areas using data from the  
17 rural IMPROVE network and the urban Chemical Speciation Network (CSN), but does not  
18 present estimates of light extinction in urban areas.

19 The CSN network provides 24-hour PM<sub>2.5</sub> species measurements at about 200 urban  
20 sites, from which mass components can be derived. These sites have a mix of daily, one day in  
21 three, and one day in six sampling schedules. The 2005 Staff Paper (and its references) may be  
22 the only readily available prior assessment to use these urban PM<sub>2.5</sub> speciation monitoring data,  
23 along with estimates of PM<sub>10-2.5</sub> concentrations and data on relative humidity, to reconstruct daily  
24 24-hour average light extinction in urban areas, for the year 2003.<sup>17</sup> One presentation of the  
25 results was in the form of a scatter plot of daily 24-hour reconstructed light extinction versus 24-  
26 hour PM<sub>2.5</sub> concentration. This graphic appears here as Figure 3-2. (For the immediate purpose  
27 of this section, it is the distribution of the data points along the y-axis that is of interest, not the  
28 relationship between light extinction and PM<sub>2.5</sub> concentrations; the latter subject is addressed in

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<sup>16</sup> When the IMPROVE algorithm is used to estimate 24-hour light extinction from 24-hour PM<sub>2.5</sub> species and PM<sub>10-2.5</sub> concentrations, an assumption is made that every hour has the same PM concentrations but its own relative humidity value. Hourly estimates of light extinction, including the strongly non-linear effect of relative humidity, are then averaged to get the 24-hour light extinction estimate.

<sup>17</sup> Estimates of light extinction in the 2005 Staff Paper include Rayleigh scattering of 10 Mm<sup>-1</sup> and thus represent “total” light extinction (excluding NO<sub>2</sub> absorption). Adjustment for consistency must be made before any close comparisons to PM light extinction values in this document.

Appendix D.) Generally, most days have light extinction below 200 inverse megameters ( $\text{Mm}^{-1}$ ), but a small percentage of values were as high as about  $750 \text{ Mm}^{-1}$ .<sup>18</sup>

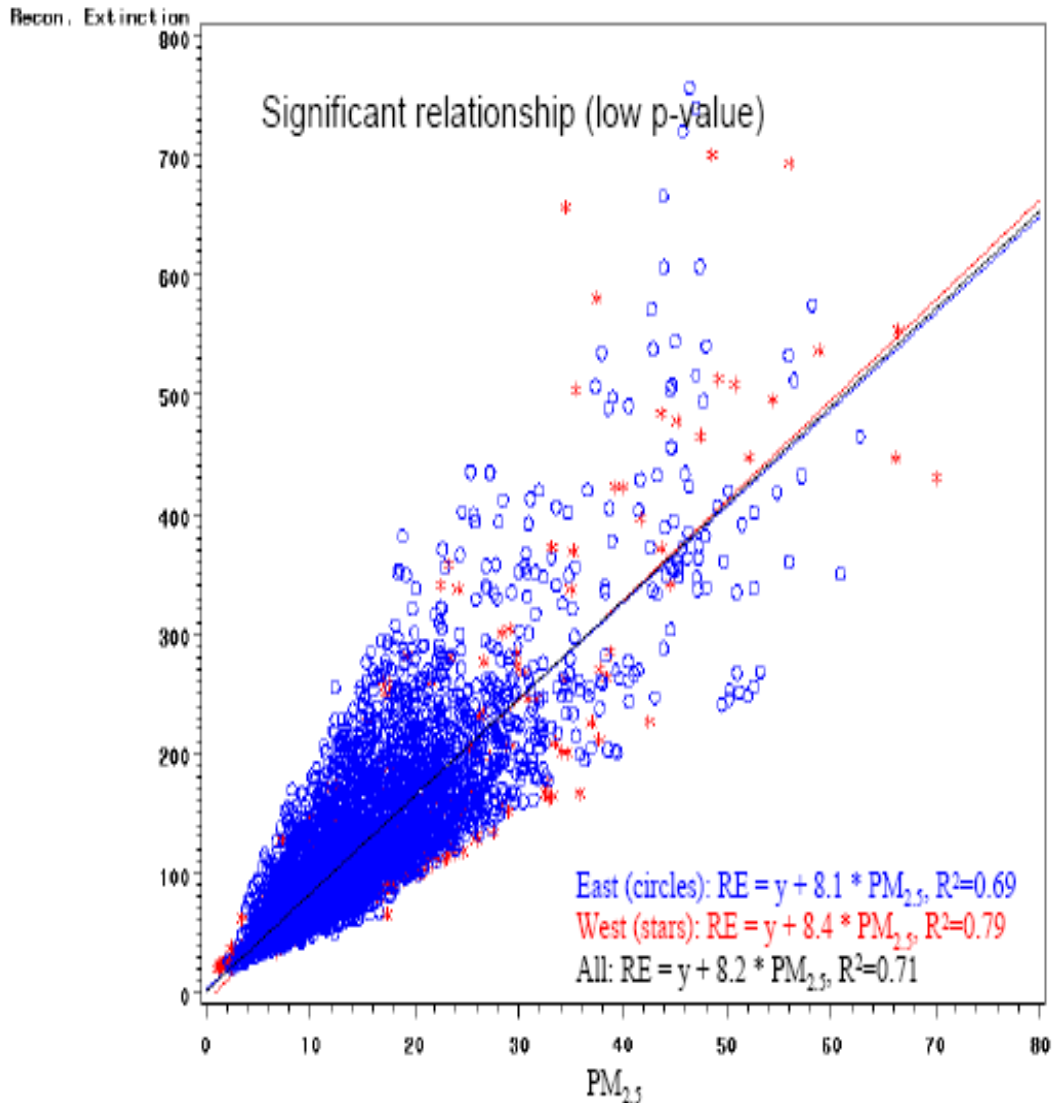
**Figure 3-2. Reconstructed 24-hour light extinction in U.S. urban areas in 2003**

Source: Schmidt et al., 2005

Output D.3

(Relationship RE & PM<sub>2.5</sub>; Diurnal RE; Timeframe)

2 of 30




Relationship between reconstructed light extinction (RE) and 24-hour average PM<sub>2.5</sub>, 2003. Using actual  $f(RH)$

<sup>18</sup> 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.

In addition to this scatter plot, a table developed for the previous PM NAAQS review presented the annual average of estimates of 24-hour reconstructed light extinction values, averaged across 161 urban areas grouped into seven regions (Schmidt, et al., 2005). Table 3-1 reproduces these estimates. For regions excluding Southern California, annual average 24-hour light extinction ranged from 73 to 118  $\text{Mm}^{-1}$ . The estimate of the annual average 24-hour light extinction for Southern California was 168  $\text{Mm}^{-1}$ . 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 ( $\text{Mm}^{-1}$ )**

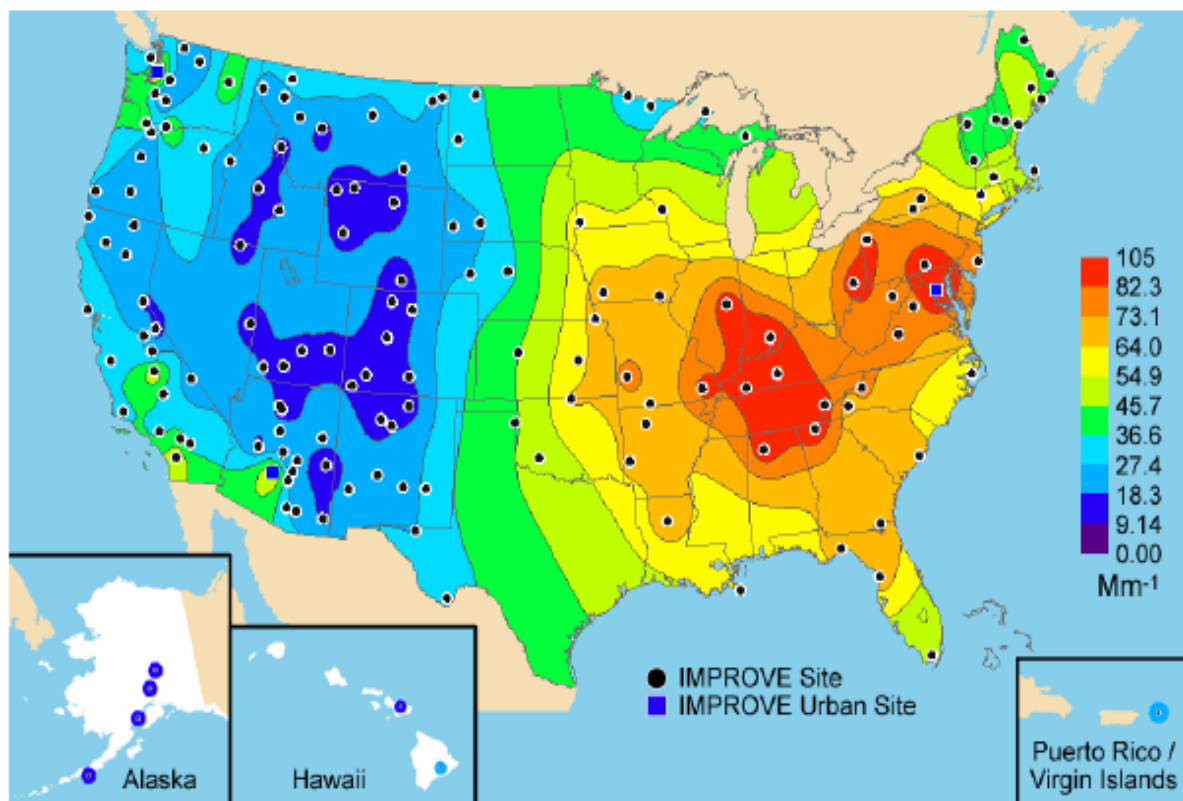
Region	Reconstructed 24-hour Light Extinction in 2003
Northeast	108
Southeast	98
Industrial Midwest	118
Upper Midwest	80
Southwest	73
Northwest	76
Southern California	168

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

Figure 3-3 is a contour map of annual average reconstructed 24-hour total 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 particulate 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, November 2006.)

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

One-hour light extinction values of course vary above and below the 24-hour average, due to diurnal variations in  $PM_{2.5}$  component concentrations,  $PM_{10-2.5}$  concentrations, and relative humidity. Although light extinction was formally reconstructed on an hourly basis in the 2005 Staff Paper analysis for the last review cited above, the actual full strength of the diurnal



1 pattern could not be discerned in that analysis because component mix was assumed not to vary  
2 from hour to hour. Under the unverified assumption of constant component mix and using actual  
3 hourly relative humidity data, the daily maximum daylight 1-hour light extinction values were  
4 roughly 50 percent higher than the 24-hour average light extinction values.<sup>19</sup> The new analysis  
5 presented in this document includes a closer look at diurnal patterns, for 15 study areas.

### 6 **3.2 OVERVIEW OF APPROACH AND DATA SOURCES FOR URBAN STUDY** 7 **ANALYSIS**

8 As explained above, there are limited data from direct measurements of light extinction in  
9 urban areas. Consequently, this assessment has reconstructed hourly PM light extinction levels  
10 for daylight hours from values of hourly PM<sub>2.5</sub> components, PM<sub>10-2.5</sub>, and relative humidity.  
11 Hourly monitoring data for PM<sub>2.5</sub> components and PM<sub>10-2.5</sub> are also generally lacking, so the  
12 estimates of these parameters necessarily in turn have been developed from a combination of  
13 other available ambient monitoring data and air quality modeling results from a chemical  
14 transport model (CTM) run. Specifically, the ambient monitoring data starting points are 24-  
15 hour PM<sub>2.5</sub> mass measured by filter-based Federal Reference Method (FRM) or Federal  
16 Equivalent Method (FEM) monitors<sup>20</sup>, 24-hour PM<sub>2.5</sub> components measured by the filter-based  
17 monitors of the Chemical Speciation Network, and hourly PM<sub>2.5</sub> mass measured by continuous  
18 instruments such as the Tapered Element Oscillating Microbalance (TEOM), beta attenuation  
19 monitors (BAMs), and nephelometers, which were used at different sites. The CTM-based  
20 diurnal profiles for individual components, in conjunction with hourly PM<sub>2.5</sub> measurements, are  
21 used to adjust and allocate the 24-hour PM<sub>2.5</sub> components measurements to individual hours of  
22 each day, as described in detail below. In addition, levels of hourly PM<sub>10-2.5</sub> mass are calculated  
23 from separate measurements of hourly PM<sub>10</sub> and hourly PM<sub>2.5</sub> if both are available, or by  
24 applying PM<sub>10-2.5</sub> to PM<sub>2.5</sub> ratios to hourly PM<sub>2.5</sub> data if both types of hourly measurements are  
25 not available. The ambient data are from 2005-2007 and were all obtained from AQS in the first  
26 half of 2009.

27 The CTM run was the “actual emissions” or “validation” run of the 2004 CMAQ  
28 modeling platform with boundary conditions provided by GEOS-Chem global scale CTM.<sup>21</sup> The  
29 CTM modeling is used as one element in the development of realistic diurnal variations for each

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<sup>19</sup> These observations on diurnal patterns come from examination of “Output D.3 (Relationship RE & PM<sub>2.5</sub>; Diurnal RE; Timeframe) 8 of 30” and “Output D.3 (Relationship RE & PM<sub>2.5</sub>; Diurnal RE; Timeframe) 17 of 30”, Analyses of Particulate Matter (PM) Data for the PM NAAQS Review, Schmidt et al., 2005.

<sup>20</sup> 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.

<sup>21</sup> 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<sub>2.5</sub> presented in section 3.6 of the ISA (US EPA, 2009a).

1 of the major PM<sub>2.5</sub> components used to estimate PM light extinction, anchored to site-specific,  
2 day-specific measurements of 24-hour concentrations. That is, monthly averaged diurnal  
3 profiles for the five major components were generated using the CTM results, which were then  
4 combined with hour-specific measurements of PM<sub>2.5</sub> to generate hourly concentration variations  
5 for each of the 24-hour CSN sample days during the 2005-2007 period.

### 6 **3.2.1 Study Period, Study Areas, Monitoring Sites, and Sources of Ambient PM Data**

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

17 For efficiency in the analysis, this visibility assessment uses the same 15 urban study  
18 areas selected for the health risk assessment. These areas are listed in Table 3-2, along with the  
19 area-wide (maximum) FRM-based 2005-2007 annual and 24-hour PM<sub>2.5</sub> design values for each  
20 study area based on the highest-reading monitor in each area, and for the specific site used in this  
21 assessment.<sup>22</sup> (See below for an explanation of the “site-specific” columns in Table 3-2.)  
22

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<sup>22</sup> 2005-2007 PM<sub>2.5</sub> 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<sub>2.5</sub> NAAQS. Except in Dallas and Fresno, the area-wide design values are the highest design values of any monitoring site in the designated (1997 NAAQS) nonattainment area that has sufficiently complete data to allow the calculation of a design value according to the provisions of 40 CFR 50 appendix N. For Dallas, the design values come from a site with nearly complete data, and are somewhat higher than the highest values from a site with complete data (see the draft PM Risk Assessment, US EPA, 2009c, section 3.2.3). For Fresno, the area-wide design value is for the Fresno-Madera CSA, which is only a portion of the San Joaquin Valley nonattainment area. Also, note that there are three cases in which the nonattainment area does not include certain areas sometimes thought of as being part of the area named in Table 2; monitors in these non-included areas were not considered in this assessment. (1) The design value shown for Pittsburgh is for the Pittsburgh-Beaver nonattainment area; the Liberty-Clairton nonattainment area is within the Pittsburgh CBSA but is distinct for regulatory purposes, and was not considered in this assessment. (2) Baltimore was treated separately, although part of a CSA with Washington DC. (3) Berks Co., PA is part of the Philadelphia-Camden-Vineland CSA, but not part of the Philadelphia-Wilmington nonattainment area.

**Table 3-2. Urban Visibility Assessment Study Areas**

Study Area	Area-wide 2005-2007 Annual Design Value ( $\mu\text{g}/\text{m}^3$ )	Area-wide 2005-2007 24-hour Design Value ( $\mu\text{g}/\text{m}^3$ )	Site-specific 2005-2007 Annual Design Value ( $\mu\text{g}/\text{m}^3$ )	Site-specific 2005-2007 24-hour Design Value ( $\mu\text{g}/\text{m}^3$ )	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 (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  $\text{PM}_{2.5}$  and its components, because the contribution of  $\text{PM}_{2.5}$  components to PM light extinction will typically dominate the contribution from  $\text{PM}_{10-2.5}$ . Ideally, within each study area the three types of  $\text{PM}_{2.5}$  data (FRM  $\text{PM}_{2.5}$ , CSN  $\text{PM}_{2.5}$  components, continuous  $\text{PM}_{2.5}$ ) 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  $\text{PM}_{2.5}$  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

1 site – Tacoma – is presented here as Table 3-3 as an example. When viewing this document  
2 electronically, the site IDs in these tables are active links and can be used to view the location of  
3 the site via GoogleMaps.<sup>23</sup>

4 In 11 of the study areas, the three types of PM<sub>2.5</sub> data were available at a common site. In  
5 the remaining four areas, Phoenix, AZ, Pittsburgh, PA, Baltimore, MD, and St. Louis, MO-IL,  
6 two types of data were available at one site, but the remaining type of data had to be taken from  
7 another site and treated as being representative of the former site.

8 The monitoring agencies described all but one of these sites as neighborhood or urban  
9 scale, indicating those agencies' opinion that the sites represent concentrations in an area at least  
10 0.5 to 4 km across. An aerial view of the remaining site (in Phoenix) which did not have a scale  
11 characterization recorded in AQS suggests that it may be middle or neighborhood scale. As  
12 already stated, selected sites are not necessarily the locations of the maximum measured annual  
13 or 24-hour PM<sub>2.5</sub> levels in their urban area.

14 Site days which were missing 1-hour PM<sub>2.5</sub> concentration data points for more than 25  
15 percent of daylight hours were excluded from the analysis, because such data gaps were judged  
16 to result in too much uncertainty in estimates of 1-hour PM<sub>2.5</sub> components, 1-hour light  
17 extinction, and daily maximum light extinction. Days with fewer missing 1-hour PM<sub>2.5</sub>  
18 concentration data points were retained, but no estimate of light extinction was made for hours  
19 without 1-hour PM<sub>2.5</sub> concentration data (see below for more explanation).

20 Hourly PM<sub>10-2.5</sub> presented more varied challenges. In four areas (Birmingham, Detroit,  
21 Baltimore, and Philadelphia) the site that provides the continuous PM<sub>2.5</sub> data also hosts a  
22 continuous FEM PM<sub>10</sub> monitor, and hourly PM<sub>10-2.5</sub> could be calculated by difference for most  
23 hours. In other areas, this was not the case, and either (1) hourly instruments at two different  
24 sites were used in this subtraction (Tacoma, Los Angeles-South Coast Air Basin, Phoenix, St.  
25 Louis, Atlanta, and New York-N. New Jersey) or (2) a single regionally applicable PM<sub>10-2.5</sub> to  
26 PM<sub>2.5</sub> ratio calculated as part of the last review based on 2001-2003 24-hour FRM/FEM PM<sub>10</sub>  
27 and PM<sub>2.5</sub> samples was applied to 2005-2007 hourly PM<sub>2.5</sub> data to estimate hourly PM<sub>10-2.5</sub>  
28 (Fresno, Salt Lake City, Dallas, Houston, and Pittsburgh). In the case of Los Angeles-South  
29 Coast Air Basin, the continuous PM<sub>10</sub> and PM<sub>2.5</sub> sites were quite distant and separated by a range  
30 of hills, so the estimates of PM<sub>10-2.5</sub> and its contribution to PM light extinction are more uncertain  
31 than if the monitors were clearly within the same air mass. Obviously, for the five study areas  
32 for which 1-hour PM<sub>10-2.5</sub> was estimated by application of ratios, PM<sub>10-2.5</sub> estimates can only

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<sup>23</sup> Additional meta data on each monitoring site, and access to daily and annual data listings, can be conveniently  
obtained using GoogleEarth and the PM<sub>2.5</sub>, PM<sub>10</sub>, and CSN monitoring network KML files that can be downloaded  
from [http://www.epa.gov/airexplorer/monitor\\_kml.htm](http://www.epa.gov/airexplorer/monitor_kml.htm).

1 represent broad trends, not hour-specific conditions at the particular site. More description of the  
2 methods used for estimating hourly  $PM_{10-2.5}$  appears in section 3.3.2.

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

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

**Table 3-3. PM<sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Tacoma Study Area**

Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Tacoma	<p>AQS ID <a href="#">530530029</a>            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<sub>2.5</sub> DV site in the Seattle-Tacoma-Olympia, WA annual PM<sub>2.5</sub> nonattainment area            Neighborhood Scale            Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>◆ 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; one-in-three sampling schedule)</li> <li>◆ PM<sub>2.5</sub> speciation (one-in-six sampling schedule)</li> <li>◆ 1-hour PM<sub>2.5</sub> mass (AQS parameter 88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass)              Correlated Radiance Research M903 Nephelometry</li> </ul> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column.</p>	N/A	<p>AQS ID <a href="#">530530031</a>            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<sub>2.5</sub> site            Neighborhood Scale            Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>◆ 1-hour PM<sub>10</sub> STP mass (AQS parameter 81102)</li> <li>◆ Sample Collection Method: INSTRUMENTAL-R&amp;P SA246B-INLET</li> <li>◆ Sample Analysis Method: TEOM-GRAVIMETRIC</li> </ul> <p>7% of PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>:PM<sub>2.5</sub> ratios from 2005 Staff Paper</p>
<p>Additional Explanation</p> <ul style="list-style-type: none"> <li>• In this Table, the 1-hour concentration parameter “88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass” is the same as the ISA refers to as “FRM-like” PM<sub>2.5</sub> mass. An entry of “88501, PM<sub>2.5</sub> Raw Data” indicates that the monitoring agency makes no representation as to the degree of correlation with FRM PM<sub>2.5</sub> mass. The latter type of continuous PM<sub>2.5</sub> data were used only when the former were unavailable.</li> <li>• Where PM<sub>10</sub> was reported in STP, it was converted to LC before PM<sub>10-2.5</sub> was calculated.</li> <li>• For convenience, continuous PM<sub>2.5</sub> 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.</li> </ul>			

**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	110	0	0	0	0	13	15	15	14	13	13	14	13
Fresno	324	19	24	27	27	30	29	29	27	26	28	30	28
Los Angeles	302	28	28	22	28	26	26	27	22	21	26	24	24
Phoenix	86	0	13	11	14	12	13	11	12	0	0	0	0
Salt Lake City	306	27	28	30	26	20	28	31	20	23	25	19	29
Dallas	274	22	24	26	22	23	23	24	24	18	23	24	21
Houston	149	21	20	10	14	14	12	8	12	15	14	9	0
St. Louis	294	27	27	24	27	28	19	27	29	29	25	22	10
Birmingham	350	30	30	29	30	29	29	30	30	30	30	27	26
Atlanta	295	22	25	25	24	28	27	26	27	25	19	26	21
Detroit	141	12	12	10	11	12	13	11	15	11	11	12	11
Pittsburgh	284	26	23	25	23	22	25	24	26	22	22	23	23
Baltimore	187	19	17	15	11	15	16	19	18	12	12	17	16
Philadelphia	145	15	11	13	10	9	13	10	13	13	14	12	12
New York	228	22	23	13	15	23	19	18	21	19	15	19	21
Note: Only days with matched and sufficiently complete data were retained in the assessment.													

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

Because systematic monitoring data on hourly PM<sub>2.5</sub> 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.<sup>24</sup> The main use of this platform in the ISA is to estimate policy-relevant background concentrations of PM<sub>2.5</sub>. 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<sub>2.5</sub> components.

The 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.<sup>25</sup> We then extracted from the detailed model output for these grid cells the day/hour-specific concentrations of sulfate, nitrate, elemental carbon, organic carbon, and “crustal/unspecciated” PM<sub>2.5</sub> during 2004, and then we averaged across grid cells and then across days within the month for each individual hour of the day.<sup>26</sup> Thus, for each species, EPA staff 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

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<sup>24</sup> Similar modeling was not available for 2005, 2006, or 2007.

<sup>25</sup> 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.

<sup>26</sup> 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/unspecciated” CMAQ output results from non-reactive dispersion of that portion of the PM<sub>2.5</sub> 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.



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<sub>2.5</sub> components, for the Detroit study area for the months of January and August. Diurnal profiles like these were applied to 24-hour CSN measurements of component concentrations, as explained in detail below.

### 3.2.3 Use of Original IMPROVE Algorithm to Estimate PM 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.<sup>27</sup> To maintain consistency with the form of the candidate protection levels (CPLs) for PM 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 light extinction using the traditional IMPROVE algorithm but without the Rayleigh scattering term is shown below.

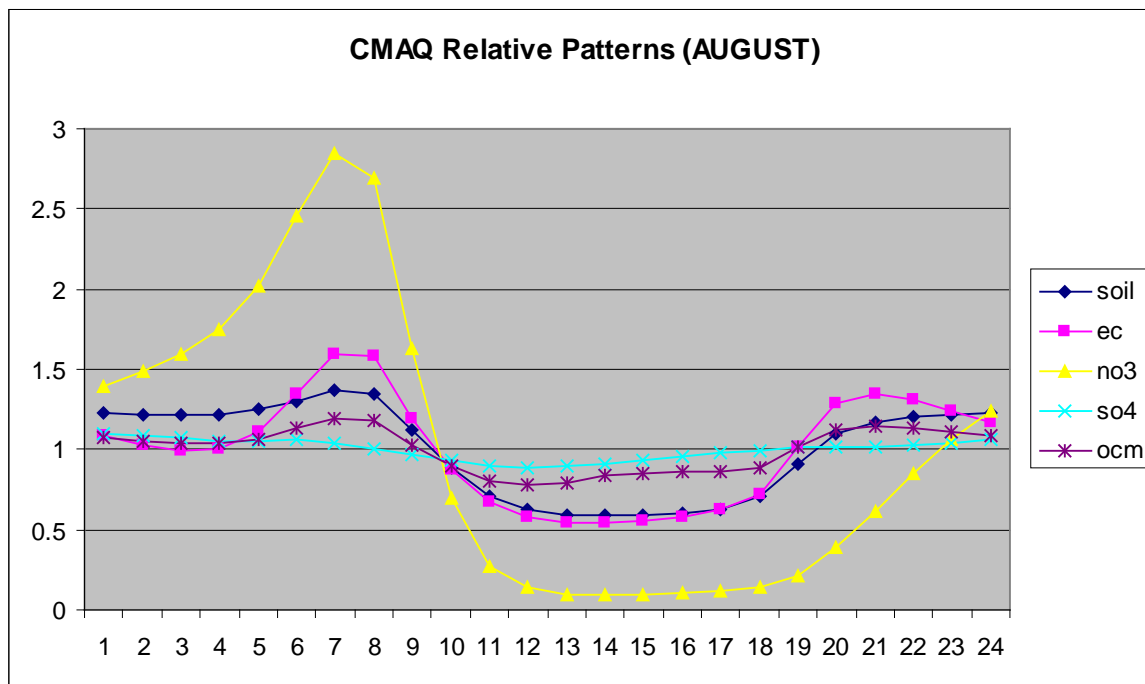
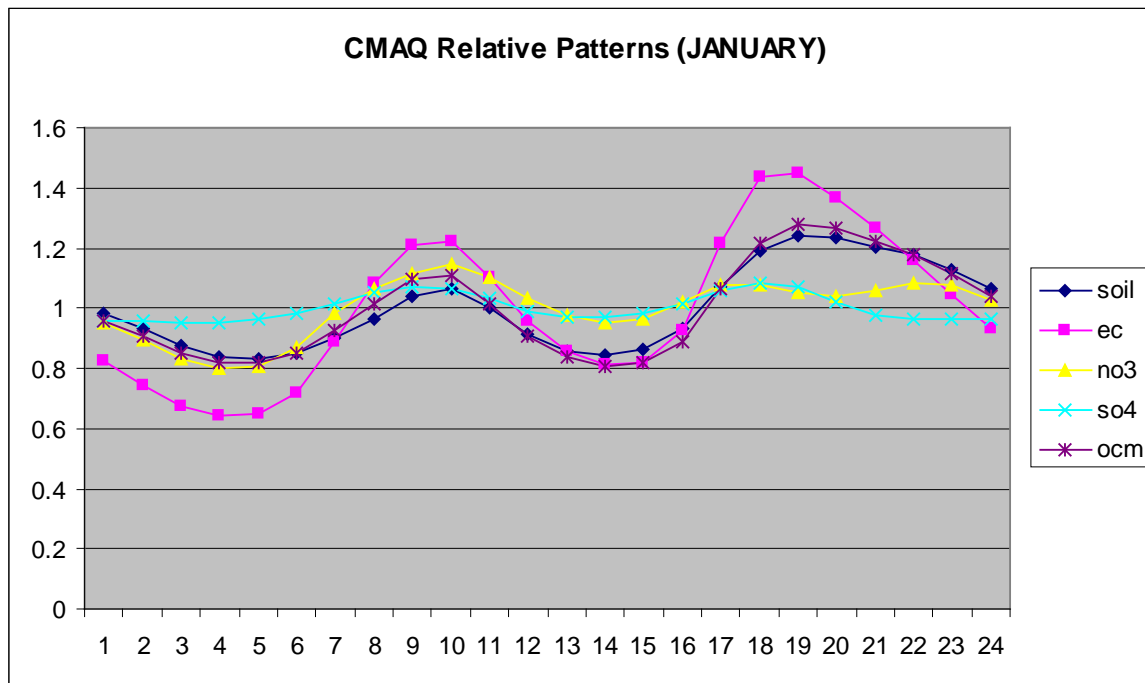
$$\begin{aligned} b_{\text{extPM}} = & 3 \times f(\text{RH}) \times [\text{Sulfate}] \\ & + 3 \times f(\text{RH}) \times [\text{Nitrate}] \\ & + 4 \times [\text{Organic Mass}] \\ & + 10 \times [\text{Elemental Carbon}] \\ & + 1 \times [\text{Fine Soil}] \\ & + 0.6 \times [\text{Coarse Mass}] \end{aligned}$$

PM light extinction ( $b_{\text{extPM}}$ ) is in units of  $\text{Mm}^{-1}$ , the mass concentrations of the components indicated in brackets are in  $\mu\text{g}/\text{m}^3$ , and  $f(\text{RH})$  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<sub>2.5</sub> 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  $f(\text{RH})$  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

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<sup>27</sup> 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<sub>2</sub> light absorption when NO<sub>2</sub> data are available. Their exclusion in this assessment is not expected to make any appreciable difference to the results or conclusions.

Figure 3-4. January and August monthly average diurnal profiles of PM<sub>2.5</sub> components derived from the 2004 CMAQ modeling platform, for the Detroit study area.



1 IMPROVE algorithm.

## 2 **3.3 DETAILED STEPS**

### 3 **3.3.1 Hourly PM<sub>2.5</sub> Component Concentrations**

4 The task of estimating hourly PM<sub>2.5</sub> component concentrations is in a sense over-  
5 determined, given the four types of available information: 24-hour PM<sub>2.5</sub> mass by filter-based  
6 FRM, 24-hour component concentrations by CSN, hourly PM<sub>2.5</sub> mass by continuous instrument,  
7 and diurnal profiles of components from the 2004 CMAQ run. There are multiple ways in which  
8 two or three of these four data sources could be used to estimate hourly PM<sub>2.5</sub> component  
9 concentrations, and the result generally can be expected to be at least somewhat inconsistent with  
10 the information in the remaining data source(s). For example, each 24-hour PM<sub>2.5</sub> component  
11 mass from CSN sampling can be apportioned to hours based on the monthly average diurnal  
12 profile developed from the 2004 CMAQ run, but then in general the hourly values of PM<sub>2.5</sub> mass  
13 determined by summing the components in an hour would not exactly match the data from the  
14 continuous PM<sub>2.5</sub> instrument. EPA staff therefore used a sequence of steps which achieves a  
15 prioritized compromise among the data sources. In this sequence, we have given greater weight  
16 to the 24-hour FRM, CSN, and continuous PM<sub>2.5</sub> mass data because these are instrument-based  
17 and location- and day-specific, than to the CMAQ-based profiles which are CTM-based,  
18 averaged to the month, and extrapolated from 2004 to each of 2005, 2006, and 2007.

19 Because of differences in filter materials, sample collection, laboratory analysis, and data  
20 reporting, there are differences between the contribution of some PM components to PM<sub>2.5</sub> mass  
21 as reported by a filter-based 24-hour FRM sampler, and the mass of the same components as  
22 reported by CSN (or IMPROVE) sampling. The following summary of these differences may be  
23 helpful in understanding the steps used to develop estimates of hourly PM<sub>2.5</sub> components in this  
24 analysis. In the IMPROVE algorithm for reconstructing light extinction, the light extinction  
25 contribution multipliers per unit of mass concentration of components are not all the same for the  
26 five principal components. Consequently, care is required to estimate these components as  
27 consistently as possible with the IMPROVE sampling and analytical methods so that particle  
28 mass is correctly assigned to the right component.

- 29 • **Nitrate:** CSN (and IMPROVE) sampling uses a Nylon filter for purposes of nitrate ion  
30 quantification, while FRM sampling uses a Teflon filter for PM<sub>2.5</sub> mass as a whole. The  
31 Nylon filter limits the loss of nitrate in the form of nitric acid vapor which could  
32 otherwise occur if the filter temperature rises above the temperature at the time of  
33 collection, compared to the Teflon filter. The fine particle nitrate ion collected on nylon  
34 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<sup>28</sup>.

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<sub>2.5</sub> mass, particularly under warm ambient conditions. The latter steps make nitrate mass as reported for a CSN (or IMPROVE) site higher than the nitrate contribution to PM<sub>2.5</sub> mass reported by a FRM sampler at the same site. On the other hand, FRM sampling may result in some water that is associated with nitrate being included in the reported PM<sub>2.5</sub> mass, while the nitrate mass reported by CSN (or IMPROVE) sampling excludes all water. Continuous PM<sub>2.5</sub> samplers employ a variety of methods for measuring PM<sub>2.5</sub> mass, with correspondingly different behaviors regarding retention/loss of nitrate. In this assessment's approach to estimating actual ambient concentrations and PM 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 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 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<sub>2.5</sub> 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 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.<sup>29</sup> 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

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<sup>28</sup> 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.

<sup>29</sup> 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.

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<sub>2.5</sub>:** The continuous instruments used for measuring hourly PM<sub>2.5</sub> 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<sub>2.5</sub> mass from a FRM sampler or the sum-of-components reportable from CSN sampling. Differences can arise because of differences in water capture and retention, inconsistent absorption and loss of organic vapors and nitric acid vapor, etc. 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<sub>2.5</sub> from hour-to-hour, with less reliance on the absolute accuracy of the continuous instruments.<sup>30</sup>

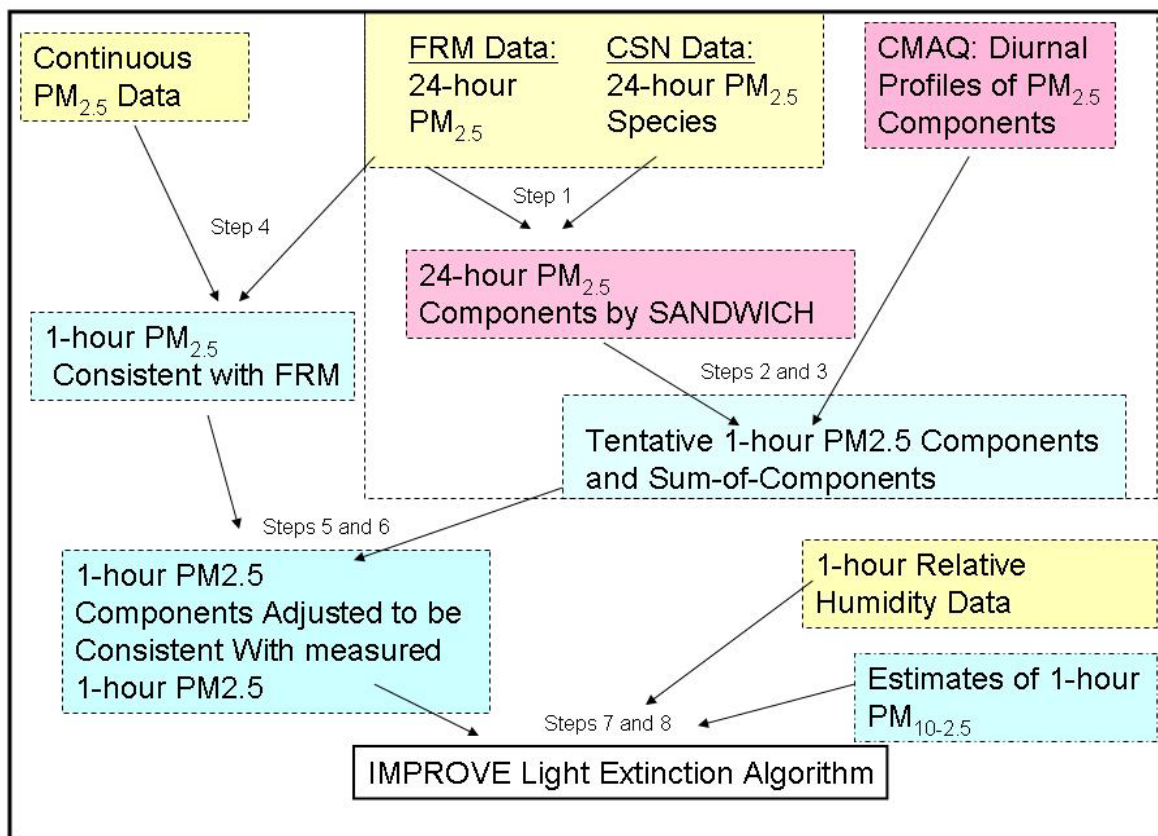
Taking into consideration the above information, EPA staff combined the four types of available PM<sub>2.5</sub> data in each study area using the following steps. Figure 3-5 provides a flow chart to assist in understanding these steps.

1. The SANDWICH method (Frank, 2006) was used to subdivide the 24-hour PM<sub>2.5</sub> 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<sub>2.5</sub> 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.

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<sup>30</sup> In 2006, EPA developed and promulgated criteria for approval of continuous PM<sub>2.5</sub> 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.

**Figure 3-5. Sequence of steps used to estimate hourly PM<sub>2.5</sub> components and PM light extinction**

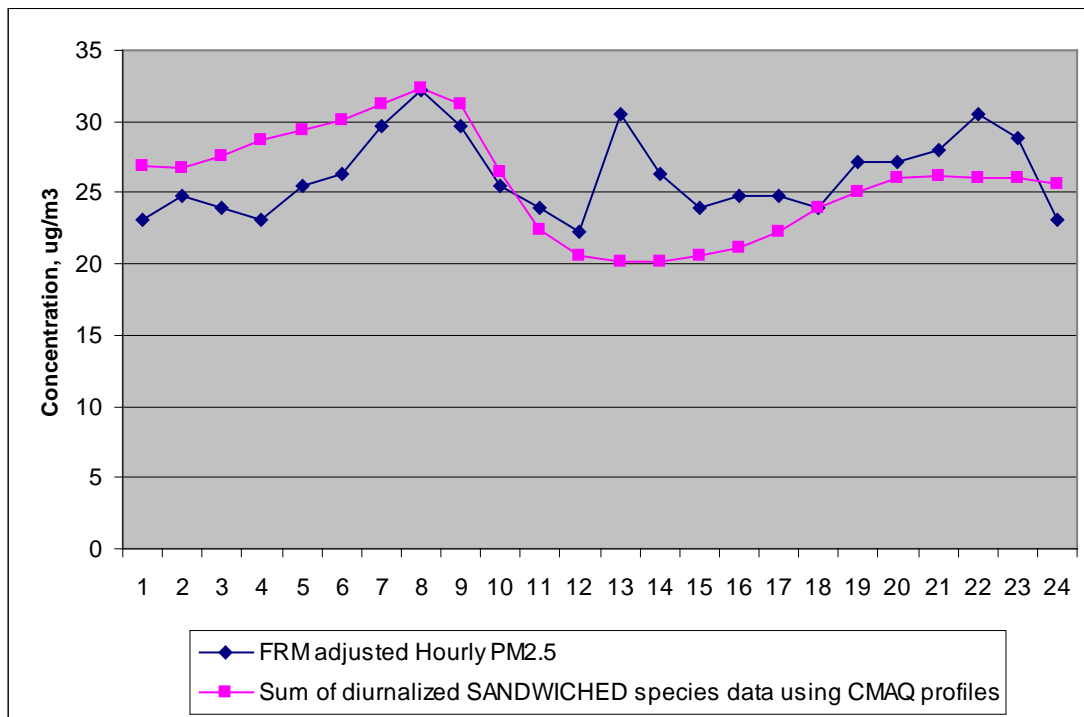


2. The CMAQ-derived monthly diurnal profiles for the sulfate, nitrate, elemental carbon, organic carbon and fine soil/crustal components, like the examples for Detroit in Figure 3-4, were multiplied by the day-specific SANDWICH-based estimates of the 24-hour average concentrations of these five PM<sub>2.5</sub> 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<sub>2.5</sub> mass for the day of the FRM sampling.
4. The hourly data from the continuous PM<sub>2.5</sub> 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<sub>2.5</sub> mass data were missing for more than 25 percent of daylight hours.) This profile was applied to the 24-hour PM<sub>2.5</sub> mass reported by the FRM sampler, to get a preliminary, FRM-consistent estimate of hourly PM<sub>2.5</sub> mass for the day of the FRM sampling. This is straightforward when all 24 values of 1-hour

PM<sub>2.5</sub> mass were available for the day. However, for some (but not many) days, some values for continuously measured hourly PM<sub>2.5</sub> mass were missing. In such cases, EPA staff used only the hours with valid 1-hour PM<sub>2.5</sub> 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<sub>2.5</sub> values equal to the 24-hour value from the FRM sampler.

5. The two estimates of hourly PM<sub>2.5</sub> 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<sub>2.5</sub> 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<sub>2.5</sub> 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<sub>2.5</sub> measurements to FRM PM<sub>2.5</sub> 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<sub>2.5</sub> 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.<sup>31</sup>
  - 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.
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

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<sup>31</sup> 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.



1 does not retain nitrate, the initial FRM-consistent nitrate estimate derived by applying the  
2 SANDWICH method to the FRM and CSN data can be zero. Such a zero value makes it  
3 impossible to use the ratio approach in 7(b). Instead, the adjustment was made as  
4 follows:

- 5 a. The 24-hour CSN value for nitrate ion (not SANDWICHed, no ammonium or  
6 water) was multiplied by 1.29 to reflect an assumption of full neutralization by  
7 ammonia.
- 8 b. This 24-hour value was then diurnalized using the CMAQ-based profile, similar  
9 to step 2.
- 10 c. Each resulting hourly value of nitrate was further multiplied by the  $A_i$  factor from  
11 step 6.
- 12 d. This new estimate of hourly nitrate was used to replace the initial nitrate value  
13 that had resulted from step 6.

14 For cooler areas and days in which the 24-hour SANDWICH results include some nitrate,  
15 the effect of these steps for nitrate are exactly the same as the effects of step 7 for sulfate  
16 (except for the 1.29 vs. 1.375 neutralization factor). For warmer areas and days in which  
17 the 24-hour SANDWICH results did not include any nitrate even though nitrate was  
18 measured on the CSN Nylon filter, the effect of these steps is to assign the CSN nitrate to  
19 each hour using a combination of the information in the CMAQ-based profiles and the  
20 information provided by the continuous  $PM_{2.5}$  sampler. As in Step 6, it is possible for the  
21 24 final hourly nitrate estimates to no longer be exactly consistent with the 24-hour CSN  
22 nitrate measurement.

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

- 26 • The 24-hour average of the hourly nitrate concentrations used to estimate hourly PM light  
27 extinction agrees closely but not exactly with the 24-hour value provided by the CSN  
28 sampling, and generally is higher than the contribution of nitrate to the FRM measure of  
29  $PM_{2.5}$  mass. In some mid-day hours in some areas, estimated hourly nitrate is zero which  
30 is a more realistic approach than applying a 24-hour species mix to each hour.
- 31 • The 24-hour average of the hourly organic carbonaceous material concentrations used to  
32 estimate hourly PM light extinction achieves FRM mass balance closure, taking into  
33 account also the difference in nitrate and the possibly partial neutralization of sulfate ion  
34 on the FRM filter. Because the Teflon filter used in FRM sampling is less subject to  
35 positive artifacts for organic material, this approach sidesteps an area of uncertainty in the  
36 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.<sup>32</sup>

- The 24-hour average of the hourly elemental carbon concentrations used to estimate hourly PM 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<sub>2.5</sub> mass. Elemental carbon is generally defined by the thermal optical transmission method used in CSN, rather than the thermal optical reflectance method used in IMPROVE.

### 3.3.2 Hourly PM<sub>10-2.5</sub> Concentrations

Three different paths were used to estimate hourly PM<sub>10-2.5</sub> concentrations depending on data availability, in the following order of preference:

1. When hourly data from a collocated PM<sub>10</sub> instruments were available at the continuous PM<sub>2.5</sub> site in a study area, PM<sub>2.5</sub> was subtracted hour-by-hour from PM<sub>10</sub>. 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<sub>10-2.5</sub> 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<sub>10</sub> data were not available at the continuous PM<sub>2.5</sub> site in a study area, but continuous PM<sub>10</sub> data were available at another site in or near the same study area, PM<sub>10-2.5</sub> was estimated by subtraction, implicitly assuming that the latter site was also representative of PM<sub>10</sub> 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<sub>10-2.5</sub> 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<sub>10</sub> site in Victorville may represent influences from agricultural operations rather than typical urban influences. In St. Louis, the PM<sub>10</sub> site may also have been influenced by particular local sources. In both cases, very high estimates of hourly PM<sub>10-2.5</sub> may not represent reality at the PM<sub>2.5</sub> site, although they may be reasonable estimates for the PM<sub>10</sub> site.
3. If neither of the first two methods was possible, a regional average ratio of PM<sub>10-2.5</sub> to PM<sub>2.5</sub> determined from an analysis of 24-hour data for the 2005 Staff Paper was applied to hourly PM<sub>2.5</sub> 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<sub>10-2.5</sub>.

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<sup>32</sup> 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.

1 The estimation of PM<sub>10-2.5</sub> was further complicated because some types of data were  
2 missing for isolated hours in the 2005-2007 period. As result, even for a single study area more  
3 than one method sometimes had to be used to estimate hourly PM<sub>10-2.5</sub>. Appendix A gives more  
4 specifics about the estimation of hourly PM<sub>10-2.5</sub> in each study area.

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

### 11 **3.3.3 Hourly Relative Humidity Data**

12 Hourly relative humidity (RH) data for each study area's primary monitoring site were  
13 obtained hour-by-hour from the closest available non-missing relative humidity measurement, as  
14 reported by either an air monitoring station reporting such data to AQS or a National Weather  
15 Service (NWS) station. For the AQS RH data, parameter 62201 values were utilized. RH data  
16 from both sources are expressed as percentages.<sup>33</sup>

### 17 **3.3.4 Calculation of Daylight 1-Hour PM Light Extinction**

18 Because the interest in this analysis is on visibility during daylight hours, EPA staff  
19 applied a scheme to denote those hours that would be considered daylight hours. For simplicity,  
20 all the days within each "season" in all study areas were considered to have the same daylight  
21 hours.<sup>34</sup> Table 3-5 shows the dividing times used to denote daylight hours for the study areas.  
22 Unless otherwise stated, all subsequent discussion of the results refers only to the values of  
23 parameters during these daylight hours.

24 The original IMPROVE algorithm was applied hour-by-hour to estimate PM light  
25 extinction in each study area for each daylight hour. When doing so, we capped the value of the  
26 humidity adjustment factor in the IMPROVE algorithm ("f(RH)") at the value of 7.4 that it has  
27 for a relative humidity of 95 percent. The effect of measurement errors in relative humidity at  
28 values above 95 percent on the value of f(RH) and thus on reconstructed PM light extinction is

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<sup>33</sup> After release of the first public review draft of this assessment, an error was discovered in the data processing that assembled the relative humidity data base, such that the nearest site was not used as described here. That error has been corrected in this second public review draft. See also "Corrections to Relative Humidity Values Used in the Draft UFVA, Corrected Graphics, Tables, and Availability of Detailed Data File for Current Conditions", P. Lorang, November 10, 2009.

<sup>34</sup> 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.

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.<sup>35</sup>

**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 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 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 indicator/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 National Weather Service monitoring sites near 11 of 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 estimate of PM light extinction are not available<sup>36</sup>. For these sites, we compared the occurrence of liquid precipitation, hail, other frozen precipitation, fog, and haze/mist during daylight hours with humidity greater than 90 percent and during all other daylight hours. These five conditions are generally considered natural causes of reduced visibility. Table 3-6 presents this comparison. The percentages of hours with each of these five conditions individually and for any one or more of the five conditions together are shown for the two sets of daylight hours. 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

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<sup>35</sup> The IMPROVE program also caps the value of f(RH) at its value for a relative humidity of 95% when reporting visibility in deciviews.

<sup>36</sup> Through an oversight, EPA staff did not obtain NWS data for Los Angeles, St. Louis, Houston, and Detroit in time for processing and incorporation of results into Table 3-6. These data will be added in the final version of this assessment.

1 provided the relative humidity value for the light extinction estimate. AQS sites could not be  
2 used for this analysis because they generally do not report similar weather condition data.

3 The comparison for the 11 sites shows that in the set of hours with relative humidity  
4 above 90 percent, the frequencies of liquid precipitation (rain), fog and haze/mist individually  
5 and the frequency of any one or more of them together were considerably higher than in the set  
6 of hours with lower relative humidity.<sup>37</sup> The frequencies of hail and other frozen precipitation  
7 were too low for meaningful comparisons. Moreover, except in Tacoma, the frequency of rain or  
8 fog at the observation moments during the hours with relative humidity less than or equal to 90  
9 percent was less than 6 percent. Also, a separate analysis (not shown) indicated that rainy hours  
10 with lower relative humidity experience considerably less accumulation than rainy hours with  
11 higher relative humidity. Based on this assessment, the 90% relative humidity cutoff criteria is  
12 effective in that on average less than 6% of the hours are removed from consideration, yet those  
13 hours have on average over twelve times the likelihood of weather conditions that directly reduce  
14 visibility compared to hours with 90% or less relative humidity.

15 Rain, fog, and mist cause a natural reduction in visibility, independent of PM  
16 concentrations. To reduce the likelihood of a secondary PM NAAQS based on an indicator/form  
17 that could be affected by measurements made under natural weather conditions that reduce  
18 visibility, for this assessment EPA staff eliminated the estimates of PM light extinction from any  
19 daylight hours with relative humidity above 90 percent from design value calculations.<sup>38</sup> Also,  
20 because PM light extinction during such hours is not as likely to be the primary cause of adverse  
21 effects on the public, all figures and tables in the body of this document and in Appendices that  
22 present PM light extinction values or statistics exclude values for such hours (unless explicitly  
23 stated to include them), so that the patterns of PM light extinction during the remaining daylight  
24 hours can be seen clearly. Figures and tables that present PM component concentrations and  
25 relative humidity values are based on all daylight hours, however.

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

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<sup>37</sup> The “haze/mist” category is not an original NWS reporting category. It is a combination of three original NWS weather categories: mist, smoke, and haze that were prepared earlier by EPA staff for another purpose. EPA staff was unable to separate the occurrence of these three conditions in time for this version of this assessment. Of these, only mist, defined as fog-like conditions that do not impair visibility below 0.5 nautical miles, is clearly a natural condition during which people would not consider limited visibility to be aesthetically undesirable. Consequently, the columns of Table 3-6 for “haze/mist” and “any” must be interpreted accordingly.

<sup>38</sup> 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.

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

1 **Table 3-6 Comparison of Meteorological Parameters for Daylight Hours with Relative Humidity Greater than 90**  
2 **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 Condition						Number of Hours	Percentage of Hours with Weather Condition					
		Liquid Precip.	Hail	Other Frozen Precip.	Fog	Haze/Mist	Any		Liquid Precip.	Hail	Other Frozen Precip.	Fog	Haze/Mist	Any
Tacoma	18293	12	0	0	0	3	13	7987	24	0	1	7	26	45
Fresno	24245	3	0	0	2	16	18	1615	12	0	0	44	60	79
Los Angeles														
Phoenix	26045	1	0	0	0	0	1	235	50	0	0	11	27	56
Salt Lake City	24989	4	0	2	1	4	8	1291	21	0	30	33	57	69
Dallas	25519	3	0	0	1	4	6	761	47	0	1	18	71	80
Houston														
St. Louis														
Birmingham	23826	4	0	0	1	8	11	2454	30	0	0	32	55	61
Atlanta	23696	5	0	0	1	7	10	2584	39	0	0	34	61	71
Detroit														
Pittsburgh	22254	5	0	7	1	8	17	4026	36	0	9	26	54	69
Baltimore	22867	4	0	1	2	9	12	3413	36	0	3	30	64	74
Philadelphia	24302	6	0	0	1	6	11	1978	44	0	4	26	64	80
New York	24963	6	0	1	1	9	13	1317	52	0	8	41	79	89

### 3.3.6 Calculation of Daily Maximum 1-Hour PM Light Extinction

Daily maximum 1-hour PM 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 light extinction and the corresponding PM 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<sub>2.5</sub> 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 light extinction.

## 3.4 SUMMARY OF RESULTS FOR CURRENT CONDITIONS

### 3.4.1 Levels of Estimated PM<sub>2.5</sub>, PM<sub>2.5</sub> Components, PM<sub>10-2.5</sub>, 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<sub>2.5</sub> (the diurnalized FRM value, resulting from step 4 in section 3.4.1), PM<sub>10-2.5</sub>, 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<sub>2.5</sub> and PM<sub>10-2.5</sub> concentrations and relative humidity are available in Appendix B, as are plots of all daylight 1-hour values for each of the PM<sub>2.5</sub> component species.<sup>39</sup>

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

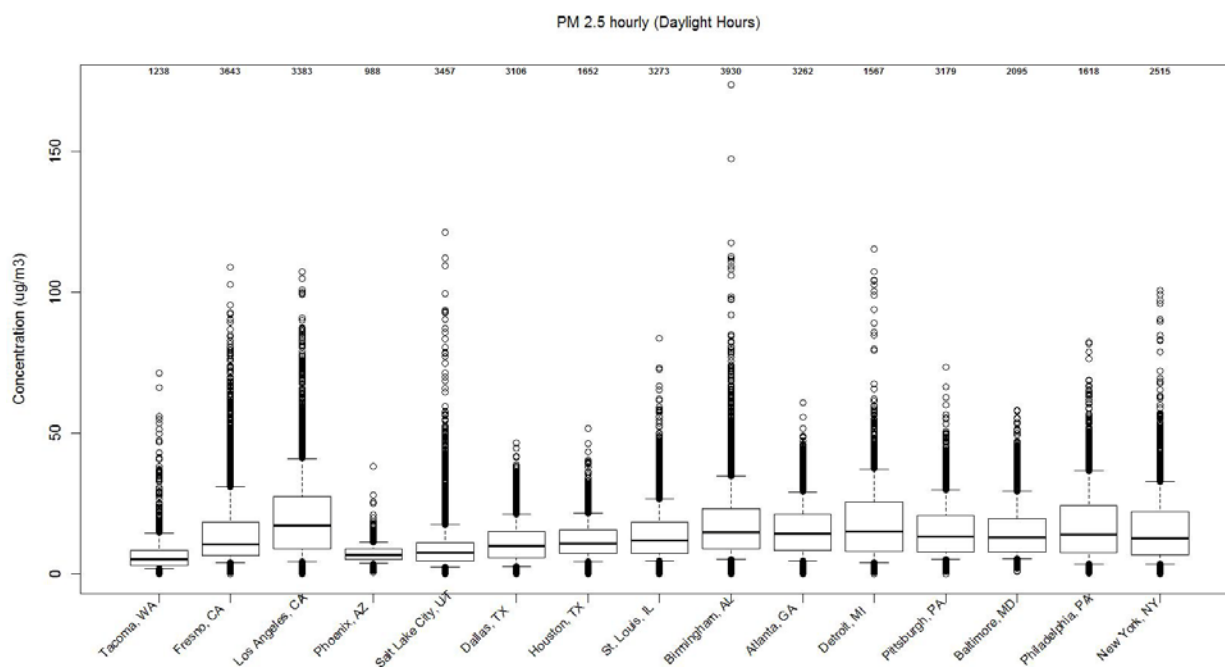
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<sup>39</sup> In all box-and-whisker plots in this document, the box represents the 25<sup>th</sup> to 75<sup>th</sup> percentile range and the whiskers represent the 10<sup>th</sup> and 90<sup>th</sup> percentile points of the data; individual data points below the 10<sup>th</sup> percentile and above the 90<sup>th</sup> 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 on as an interger).



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

**(a) Estimates of 1-hour PM<sub>2.5</sub> mass, based on applying continuous instrument-based diurnal profiles to 24-hour FRM PM<sub>2.5</sub> mass**



**(b) Estimates of 1-hour PM<sub>10-2.5</sub>**

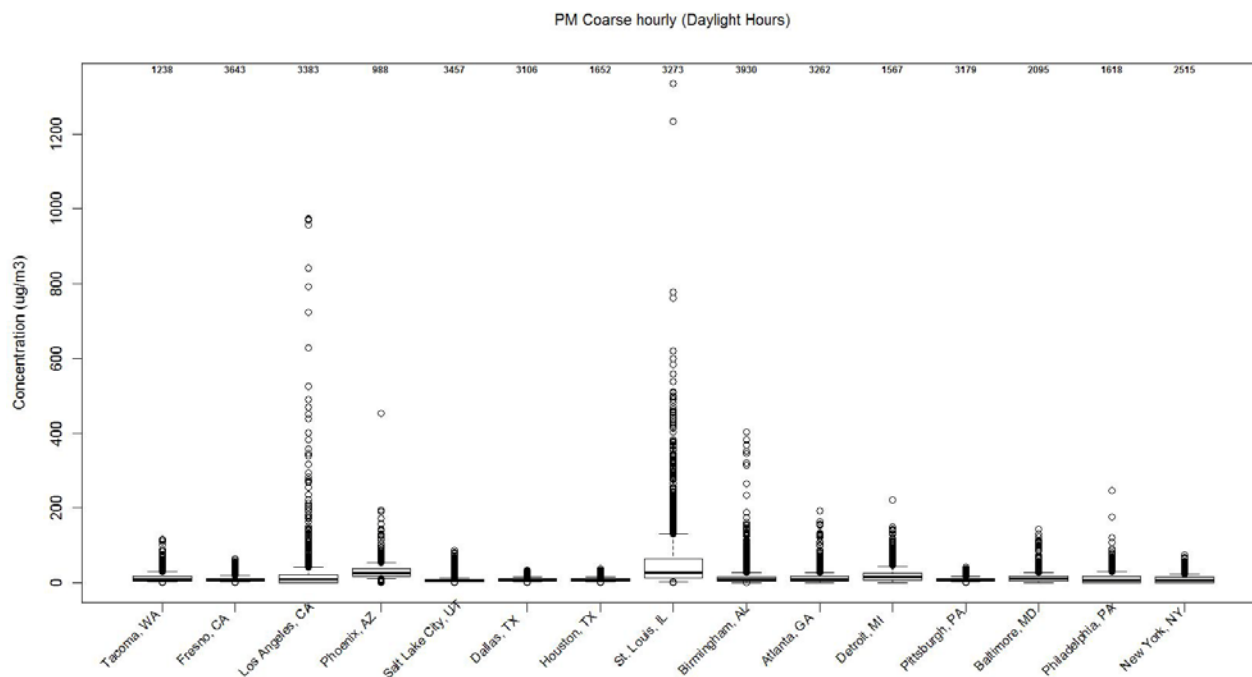
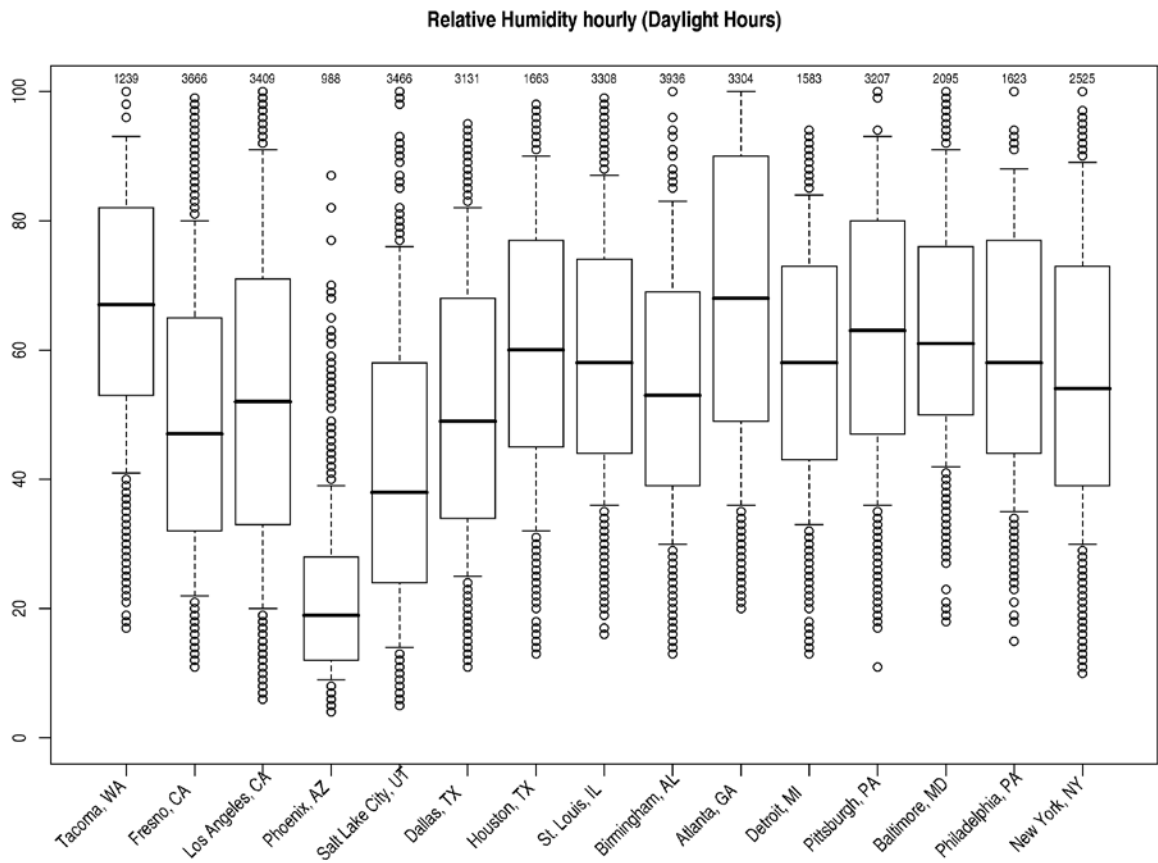


Figure 3-7. (cont.). Distribution of PM parameters and relative humidity across the 2005-2007 period, by study area

(c) 1-hour relative humidity



### 3.4.2 Levels of Estimated PM light extinction

Figure 3-8 presents box-and-whisker plots to illustrate the distributions of the estimates of daylight 1-hour reconstructed PM 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 candidate protection levels (CPLs) for PM light extinction as discussed in section 2.6. These benchmarks for PM light extinction are 64, 112, and 191  $\text{Mm}^{-1}$ , 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 light extinction level was greater than each of the three candidate protection levels (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  $\text{PM}_{2.5}$  concentration box and whisker plots in Figure 3-7, the high percentile hourly PM 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 light extinction values are higher (Figure 3-8b), as expected, than for all hours (Figure 3-8a). Both Figure 3-8 and Table 3-7 indicate that all 15 urban areas have daily maximum hourly PM 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 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 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  $\text{PM}_{2.5}$ . 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 light extinction levels in specific daylight hours, Figure 3-9 shows the distributions of 1-hour PM 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 light extinction can occur during any of the daylight hours, though for most of these urban areas the morning hours

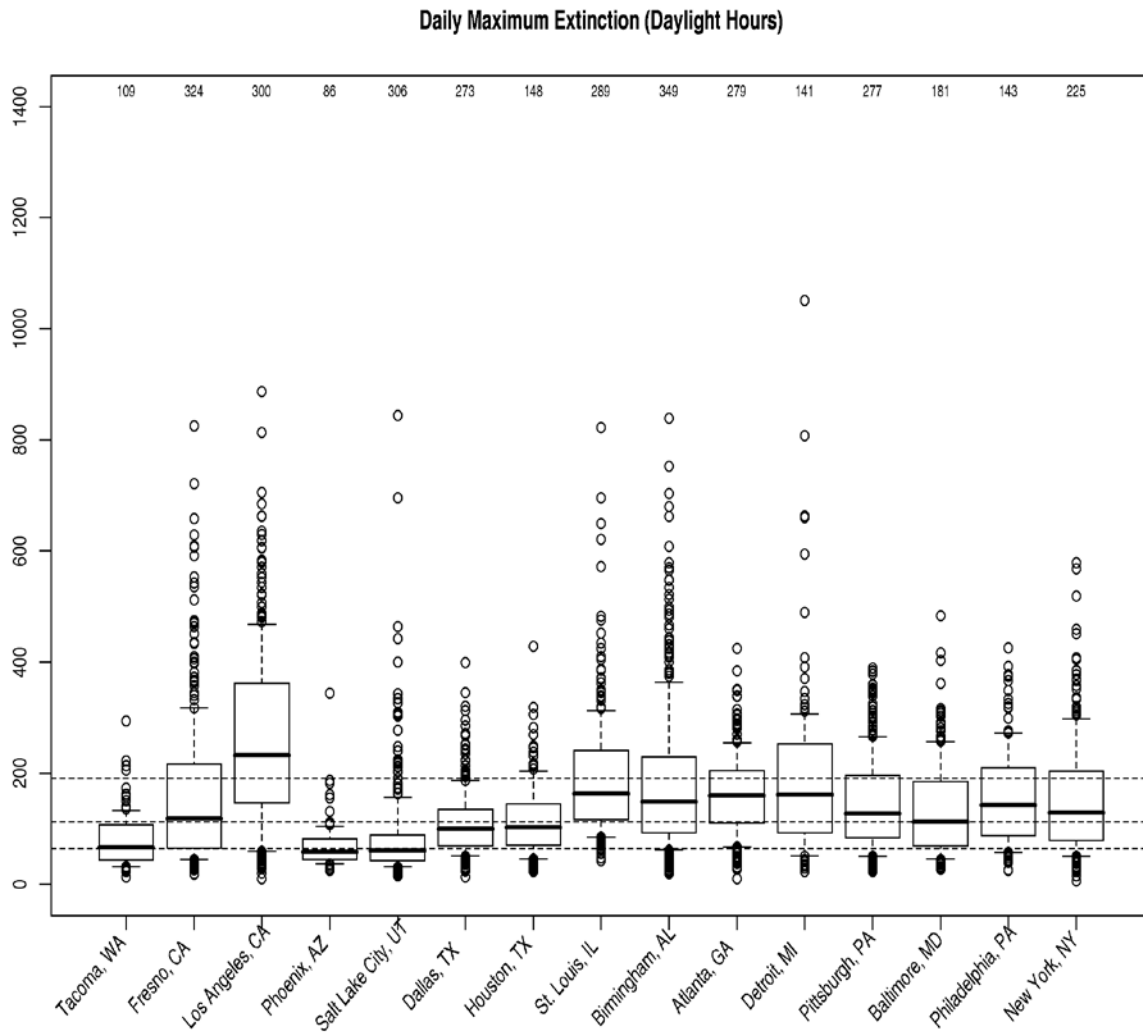
1 have somewhat higher PM light extinction than in the afternoon.<sup>40</sup> Urban areas without a  
2 preference for morning high PM light extinction include Phoenix, AZ; Salt Lake City, UT;  
3 Tacoma, WA; Fresno, CA; and Philadelphia, PA.  
4

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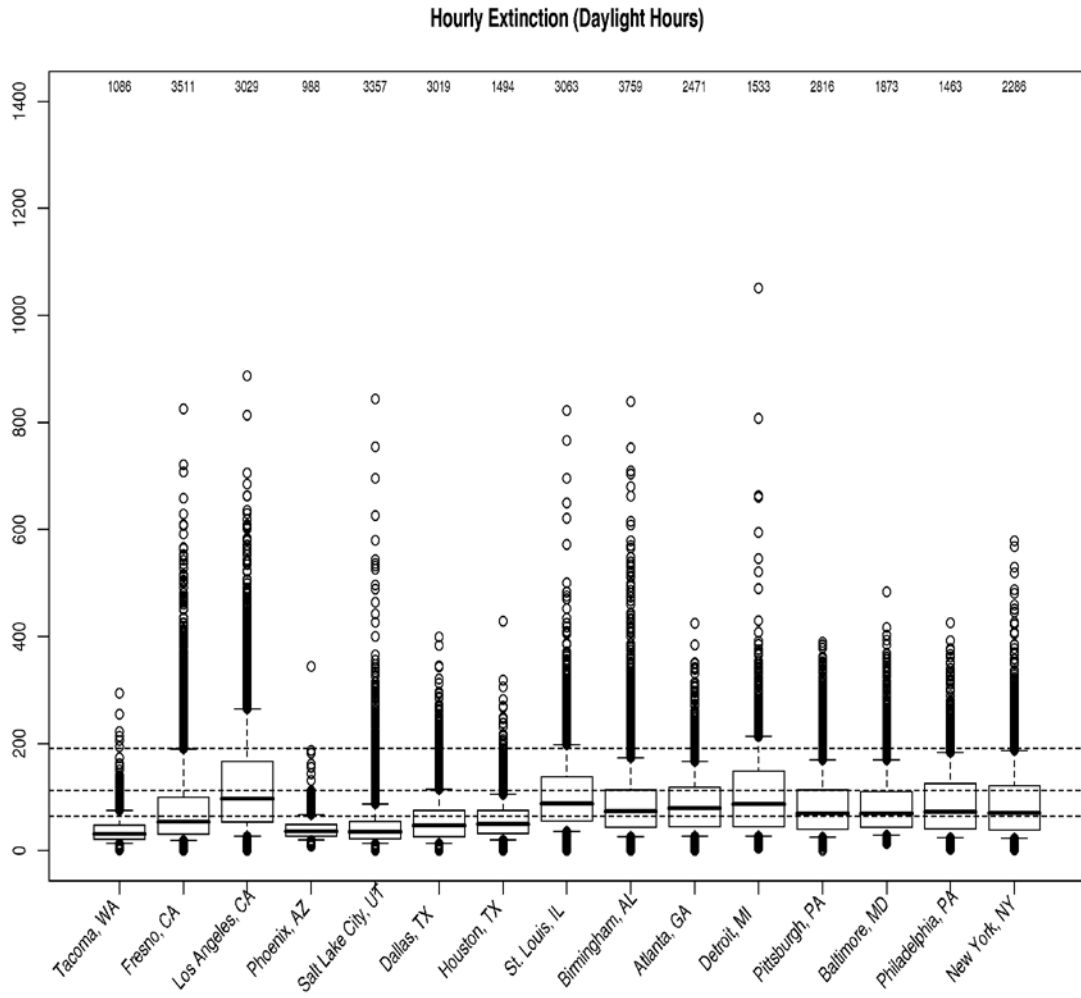
<sup>40</sup> If hours with relative humidity greater than 90 percent were not eliminated, the tendency for higher PM light extinction in the morning hours would be stronger.

**Figure 3-8. Distributions of estimated daylight 1-hour PM light extinction and maximum daily daylight 1-hour PM light extinction across the 2005-2007 period, by study area (excluding hours with relative humidity greater than 90 percent).**

**(a) Maximum daily values**



1 (b) Individual 1-hour values

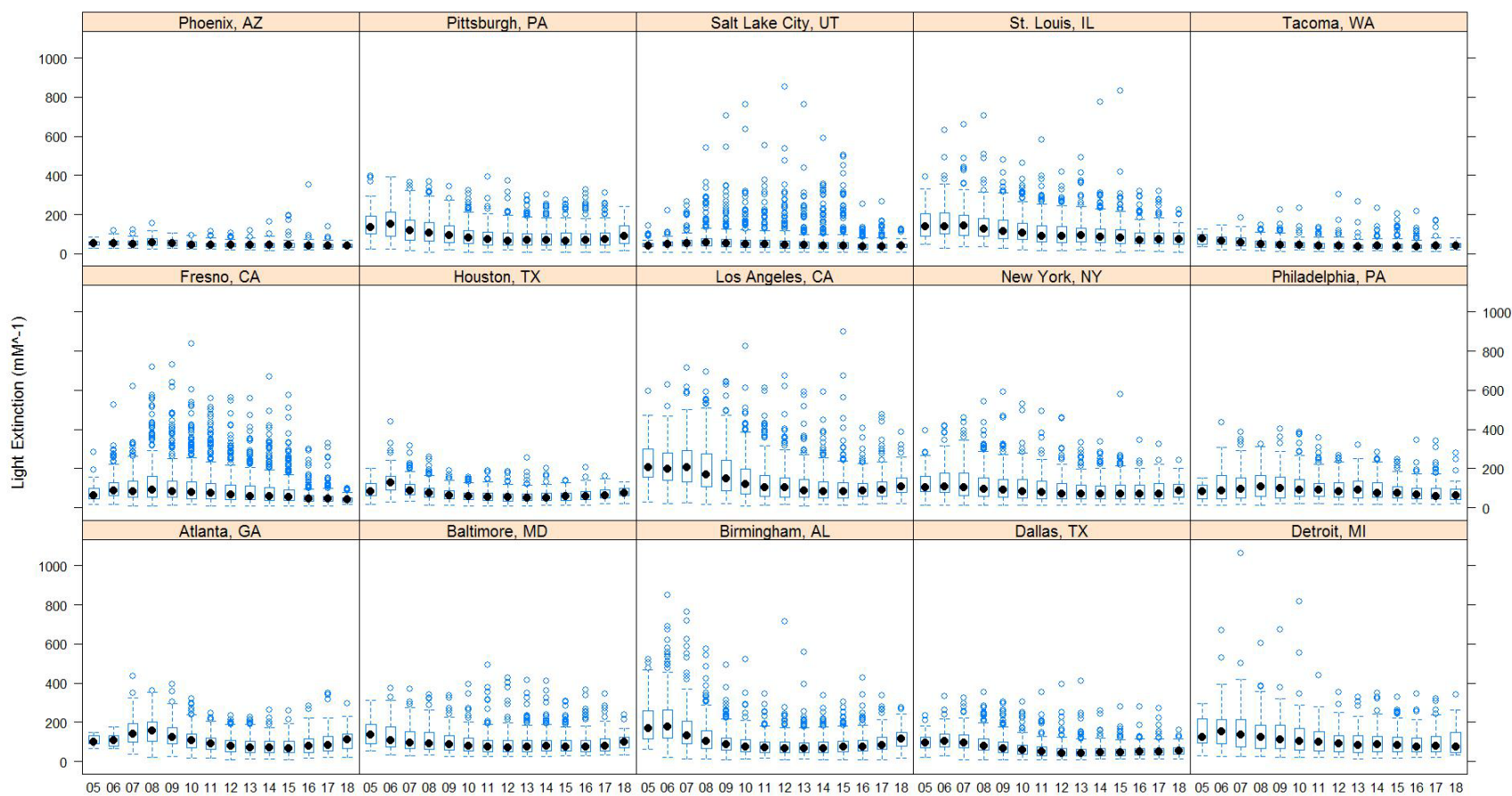


2  
3  
4  
5  
6

**Table 3-7 Percentage of daily maximum hourly values and individual hourly values of daylight PM light extinction exceeding CPLs (excluding hours with relative humidity greater than 90 percent).**

Study Area	Number of Days with Estimates	Candidate Protection Level		
		64Mm <sup>-1</sup>	112 Mm <sup>-1</sup>	191 Mm <sup>-1</sup>
		(a) Percentage of Daily Maximum Hourly Values Exceeding CPL		
Tacoma	109	52	22	4
Fresno	324	75	52	30
Los Angeles	300	90	83	62
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	65	34
Atlanta	279	91	75	31
Detroit	141	87	68	43
Pittsburgh	277	85	57	26
Baltimore	181	80	50	23
Philadelphia	143	86	64	31
New York	225	83	59	28
<i>Average</i>	<b>229</b>	<b>77</b>	<b>52</b>	<b>26</b>
	Number of Daylight Hours with Estimates	(b) Percentage of Individual Daylight Hours Exceeding CPL		
Tacoma	1087	14	4	1
Fresno	3533	41	21	10
Los Angeles	3048	68	43	20
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
<i>Average</i>	<b>2397</b>	<b>45</b>	<b>22</b>	<b>7</b>

**Figure 3-9. Distributions of 1-hour PM 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 light extinction

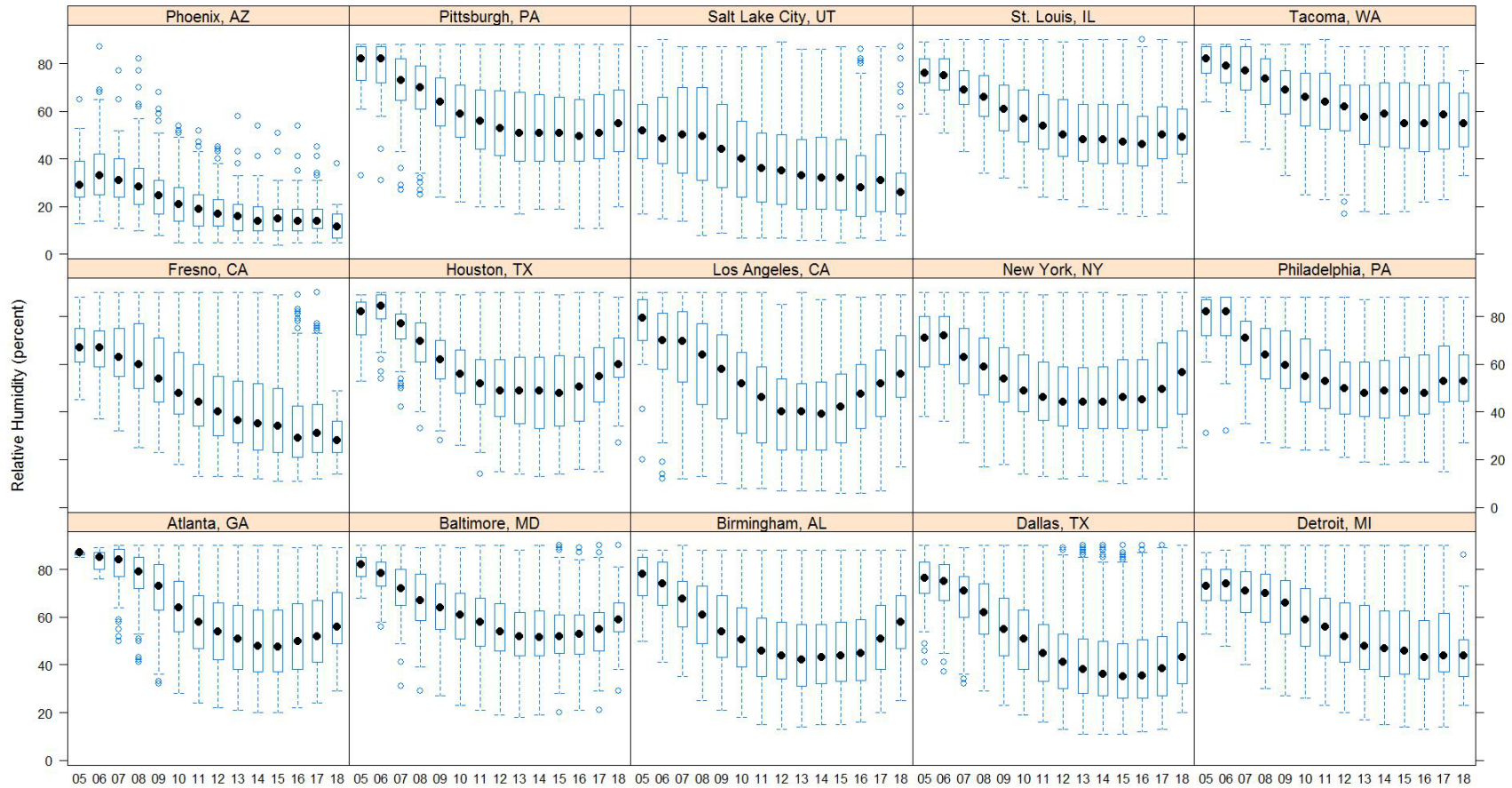
Figure 3-10 shows the distribution of relative humidity values at each daylight hour, for each study area across 2005-2007 (excluding hours with relative humidity greater than 90 percent).<sup>41</sup> As expected, in every area relative humidity is lowest in the early afternoon, typically the warmest 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 light extinction values and relative humidity values, Figure 3-11 is a scatter plot of actual 1-hour relative humidity and 1-hour reconstructed PM 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 light extinction and a vertical line in each for the 90 percent relative humidity cutoff. There are many instances with PM light extinction greater than the candidate protection levels when relative humidity is 90 percent or lower. Notice that in Figure 3-11 there also are plenty of high humidity conditions for each urban area that correspond to low PM light extinction values. This is because humid air does not by itself contribute to light extinction. Particles composed of material that absorbs water in high relative humidity conditions (e.g., sulfate and nitrate PM) swell to larger solution droplets that scatter more light than their smaller dry particle counterparts in a less humid environment. The magnitude of the relative humidity effect on light extinction depends directly on the concentration of these hygroscopic PM components. (Figure 3-11 reveals skips in reported relative humidity values for some but not all the study areas. This is a result of calculations of relative humidity from dry and wet bulb temperatures reported to the nearest whole Celsius degree.)

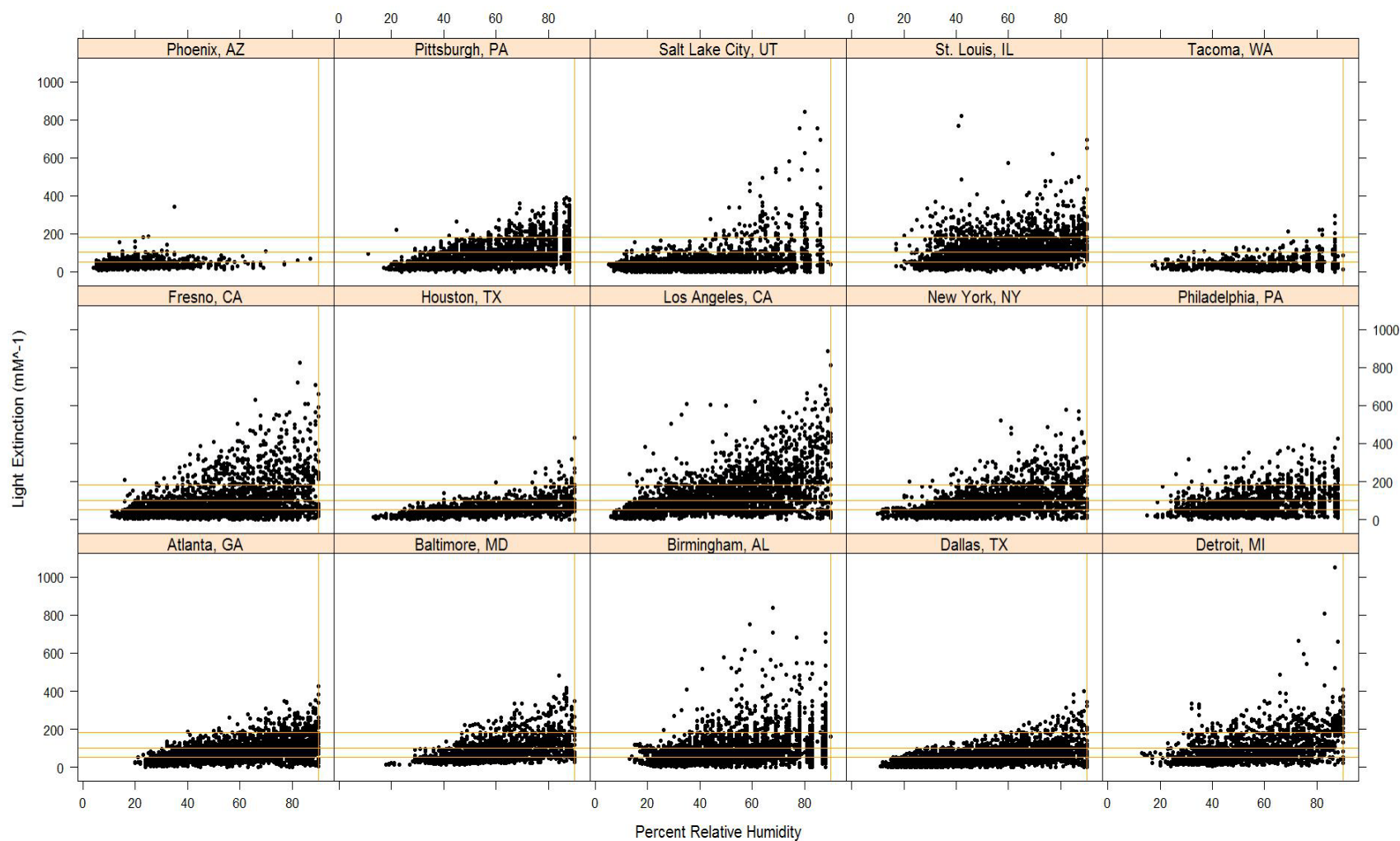
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<sup>41</sup> Similar information on diurnal patterns but broken out by season is given in Appendix E.

**Figure 3-10. Distributions of 1-hour relative humidity levels by daylight hour across the 2005-2007 period, by study area (excluding hours with relative humidity greater than 90 percent).**



1 **Figure 3-11. Scatter plot of daylight 1-hour relative humidity (percent) vs. reconstructed PM light extinction ( $\text{Mm}^{-1}$ ) across**  
 2 **the 2005-2007 period, by study area (excluding hours with relative humidity greater than 90 percent).**  
 3



4  
5

#### 3.4.4 Tile Plots of Hourly PM Light Extinction

Figure 3-12 consists of “tile plots” that show the estimated levels of 1-hour PM 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 light extinction occur, both separately and together.

Time runs horizontally with each row of tiles representing a single day from midnight (left side) 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 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 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<sub>2.5</sub> data from the continuous instrument have no estimates of PM 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 light extinction excluded because of high relative humidity have other hours with high PM light extinction which are not excluded.

Although none of the PM light extinction NAAQS scenarios considered in Chapter 4 are based on a averaging period longer than one hour, these tile plots can be used to get a rough sense of whether hours with high PM 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

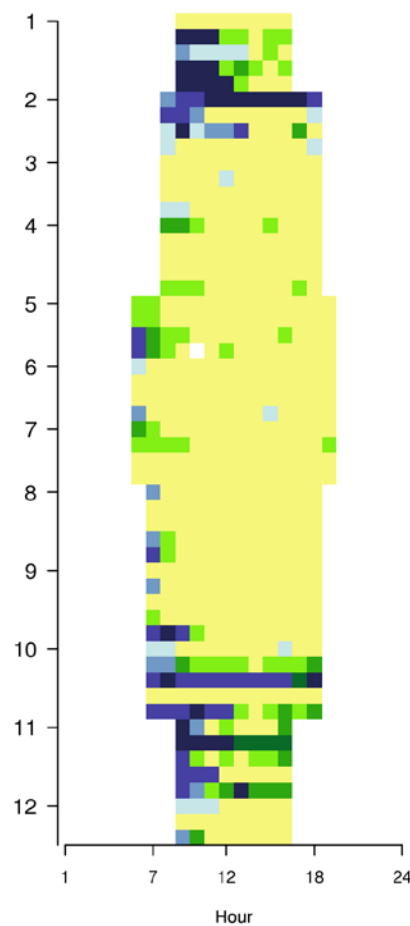
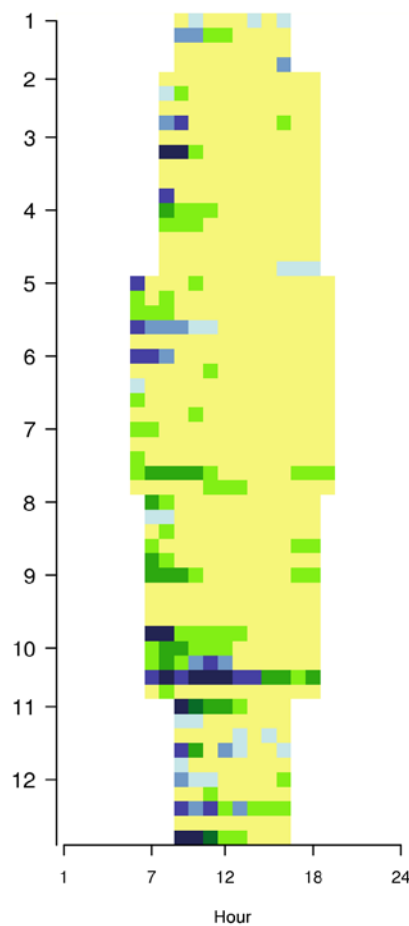
1 winter, and Los Angeles and Atlanta in the summer). Some of the urban areas have morning  
2 haze levels that diminish later in the day on a year-around basis (e.g. Dallas) or seasonally (e.g.  
3 Los Angeles, Birmingham and Atlanta in winter and Tacoma, Fresno, and St. Louis in the  
4 summer). This type of information may be useful in this regard during the subsequent  
5 preparation of the Policy Assessment Document.  
6

# Tacoma, WA

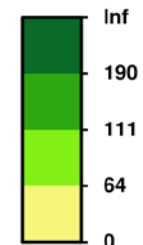
2005

2006

2007



Low RH bext



High RH bext

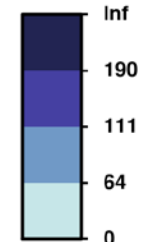


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Fresno, CA

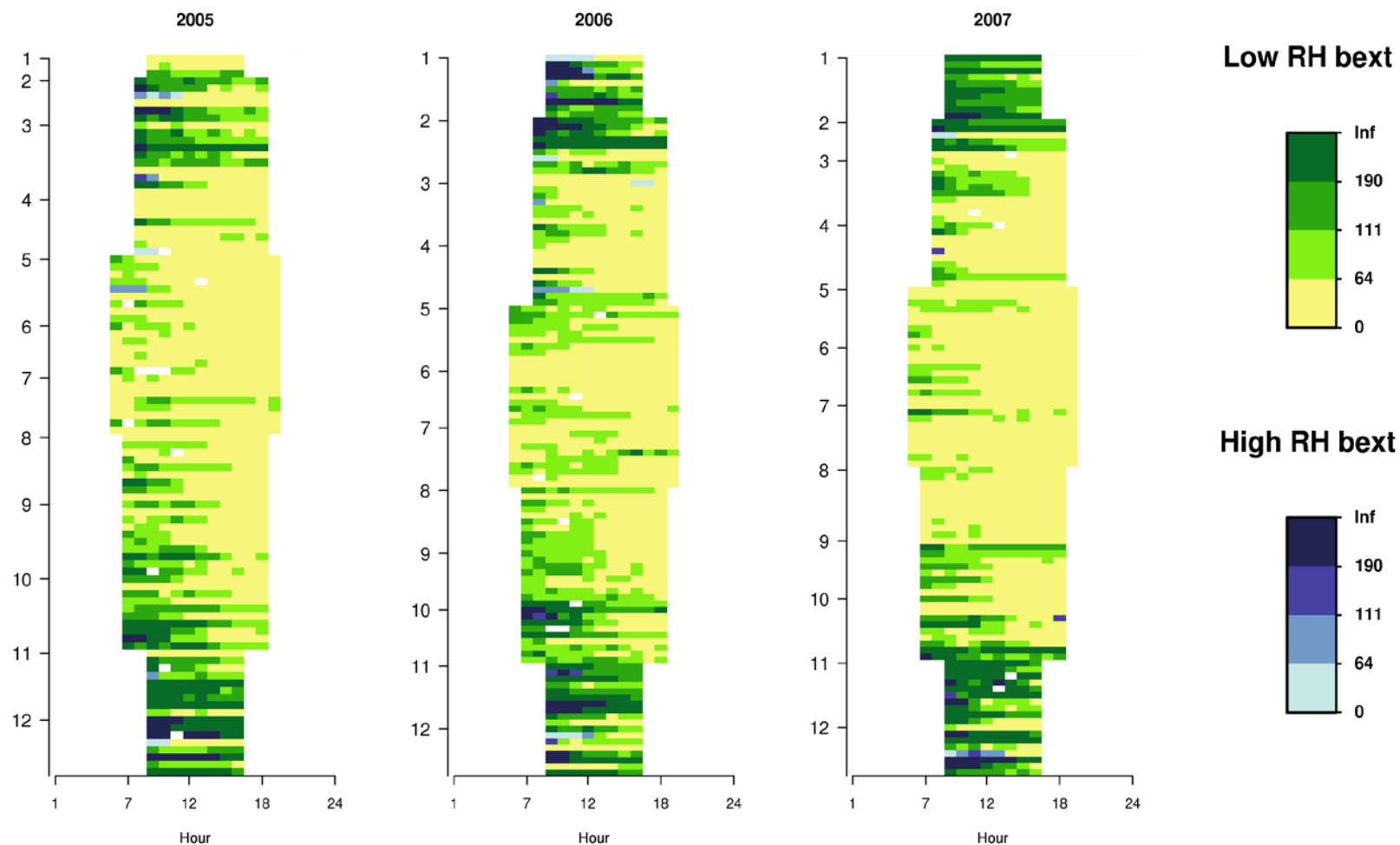


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Los Angeles, CA

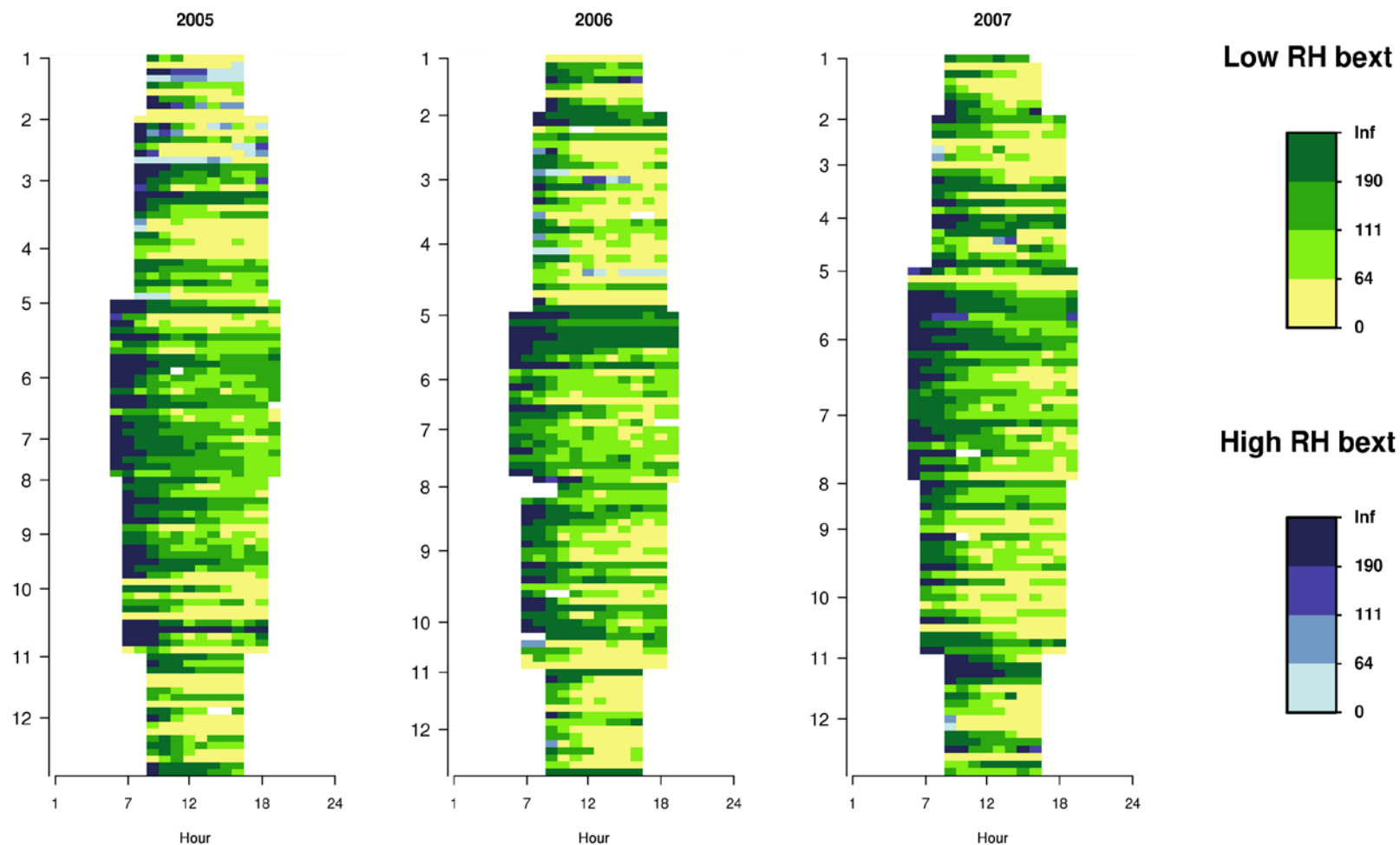




Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Phoenix, AZ

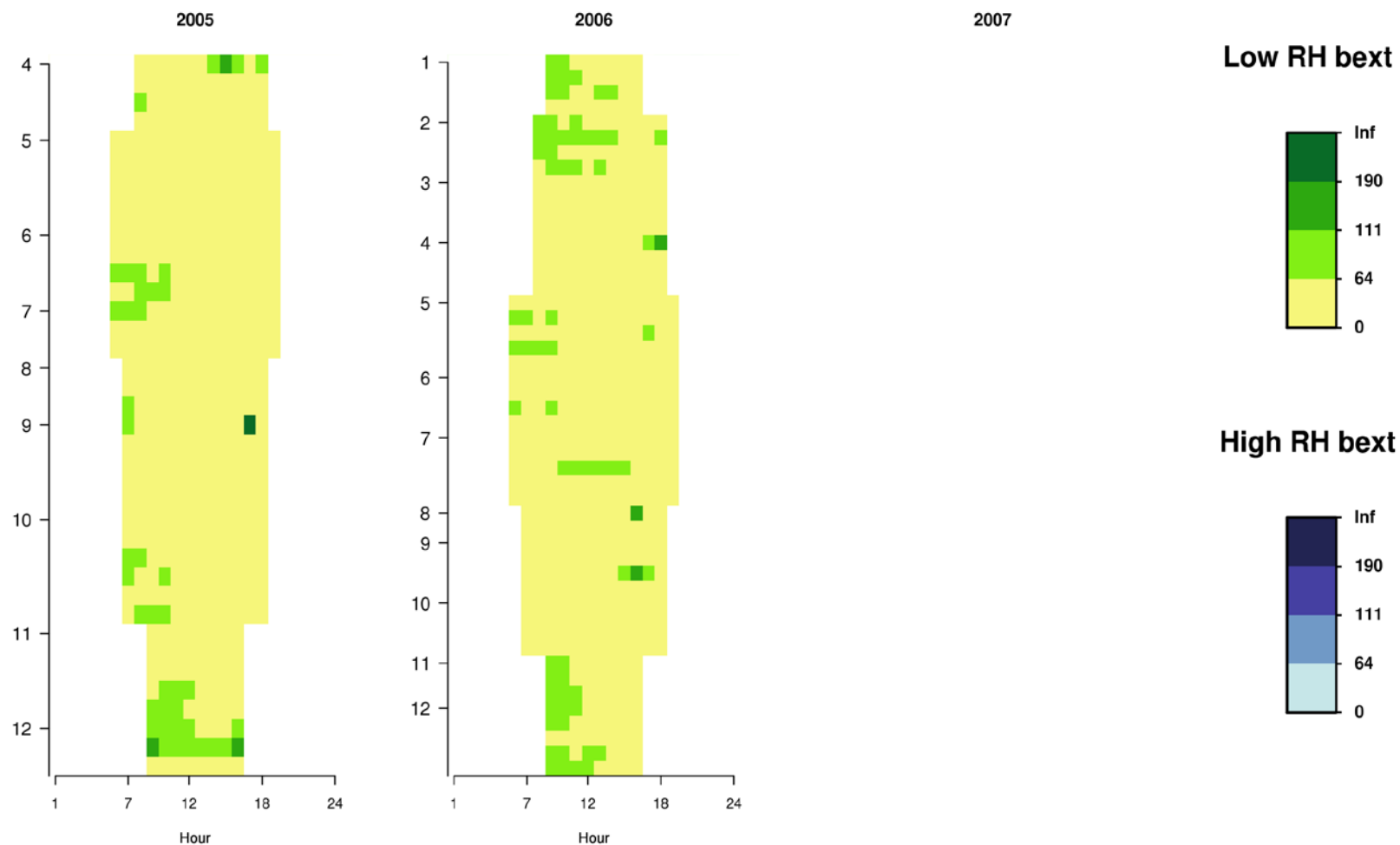


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Salt Lake City, UT

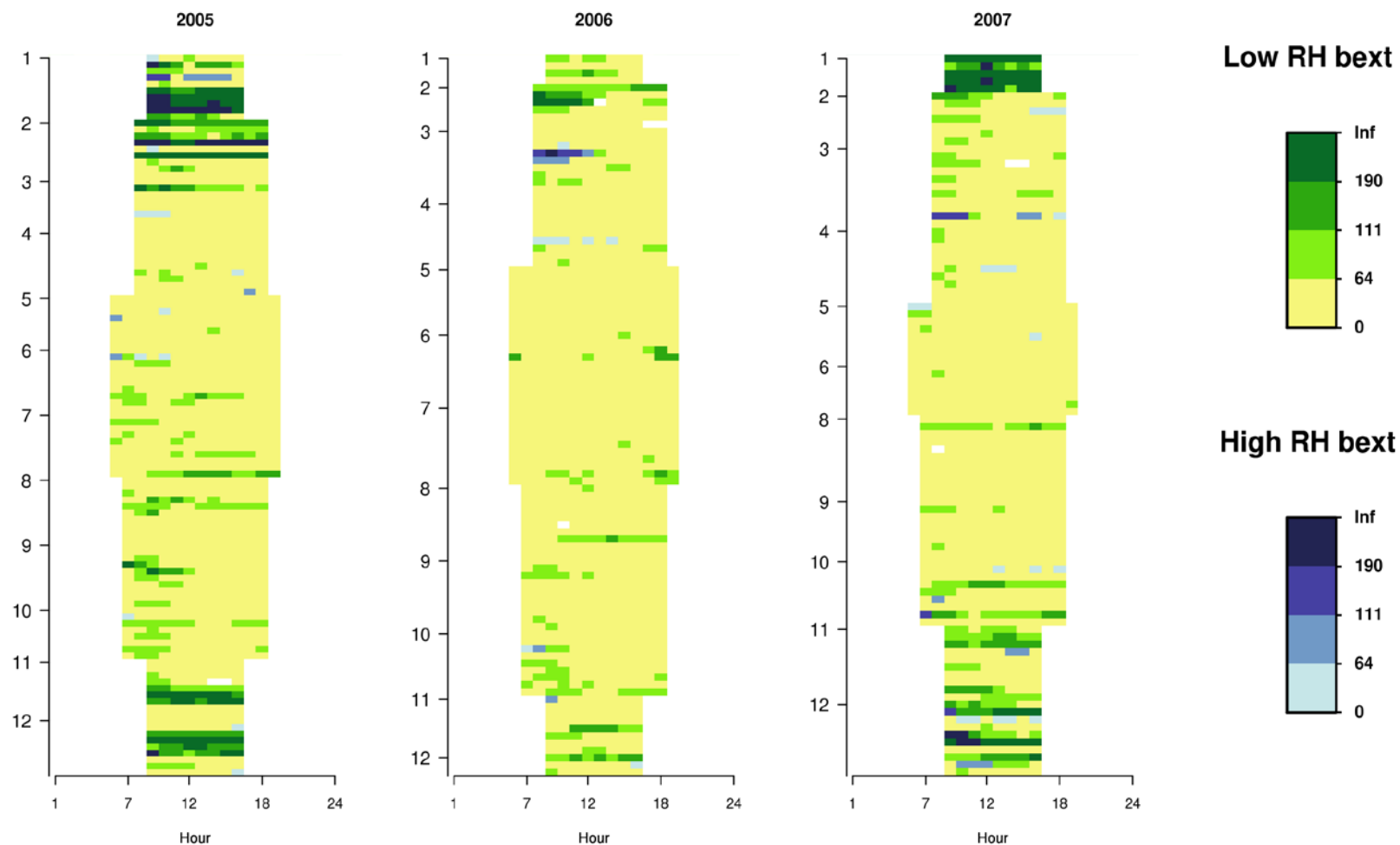


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Dallas, TX

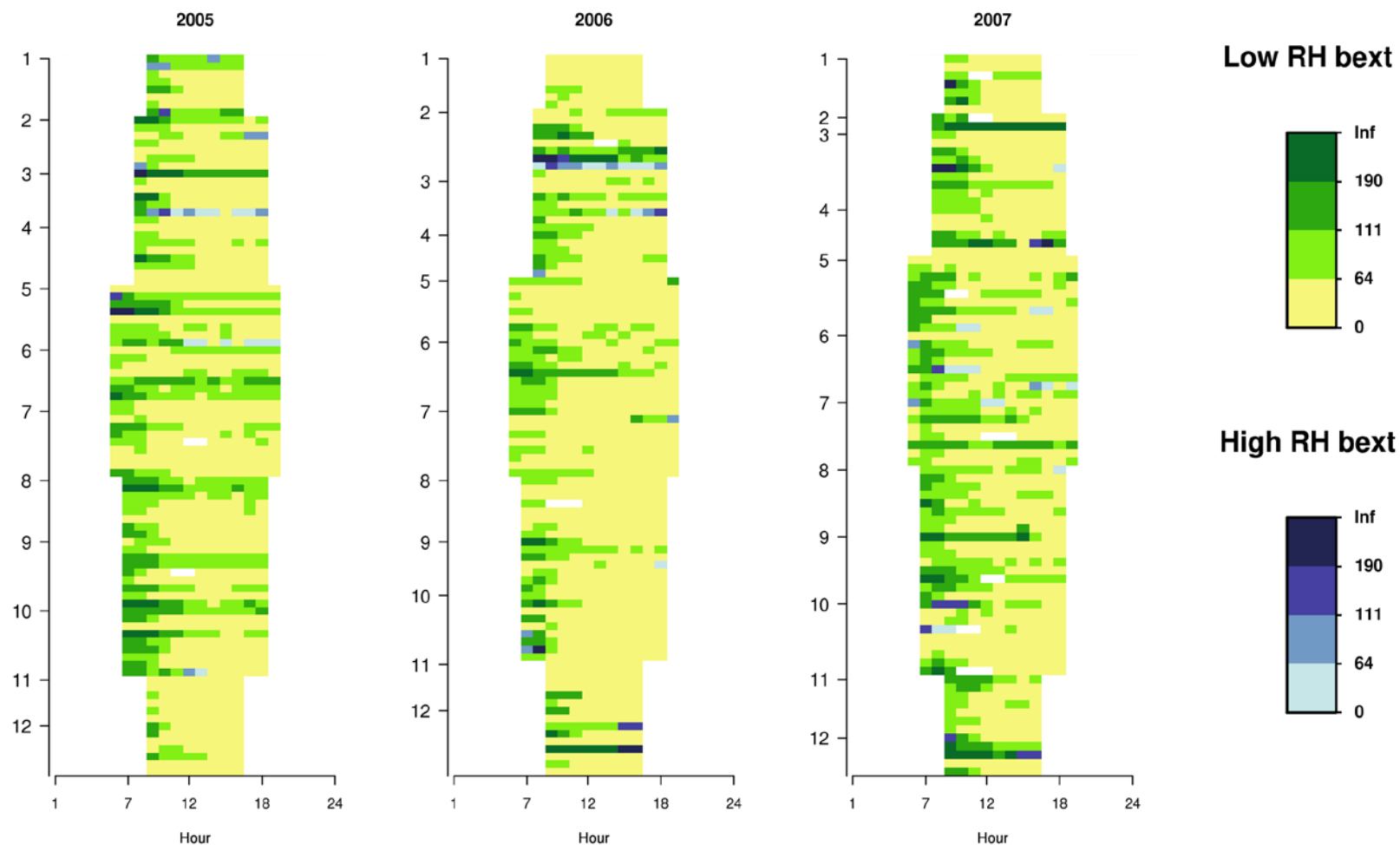


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Houston, TX

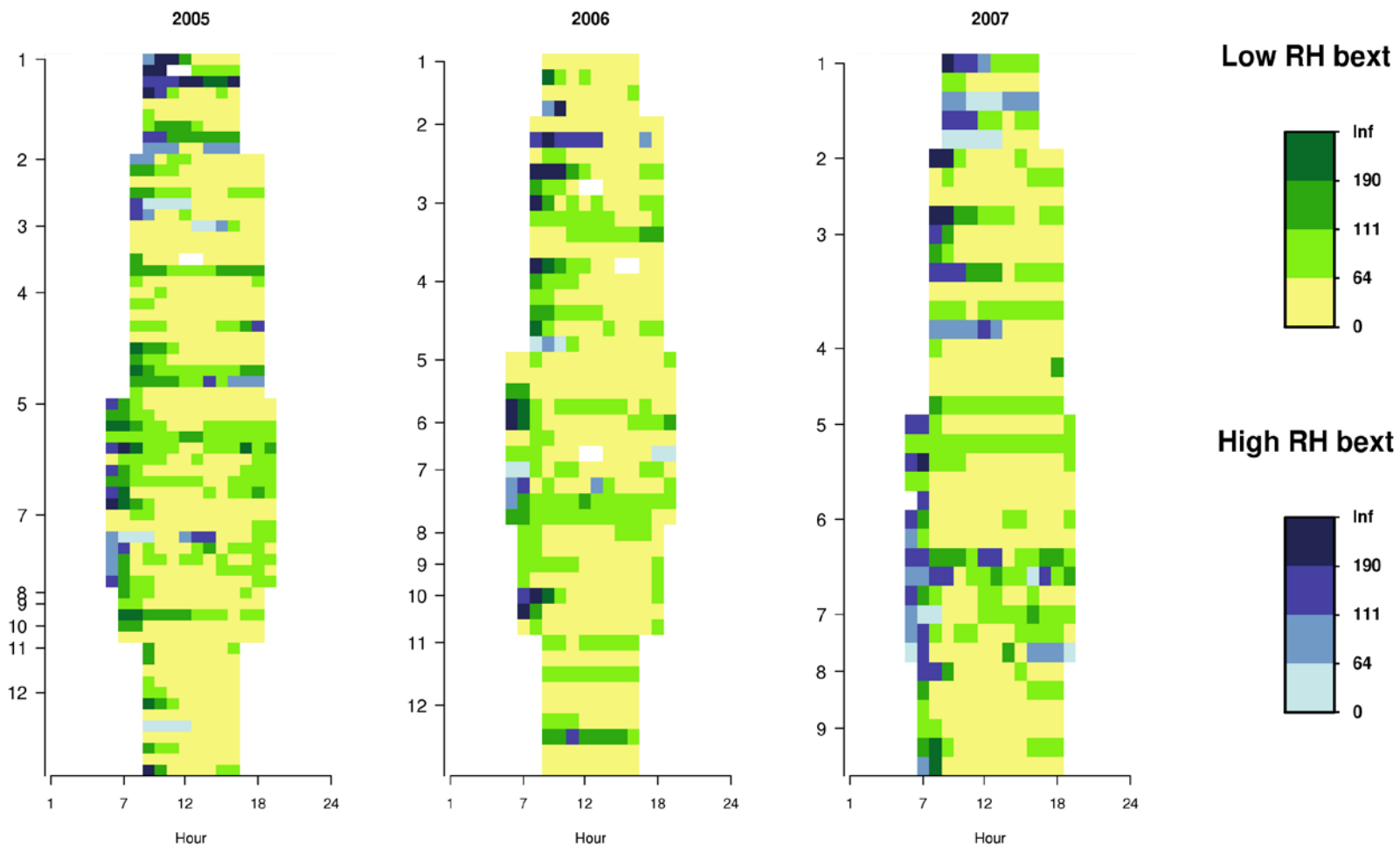


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## St. Louis, IL

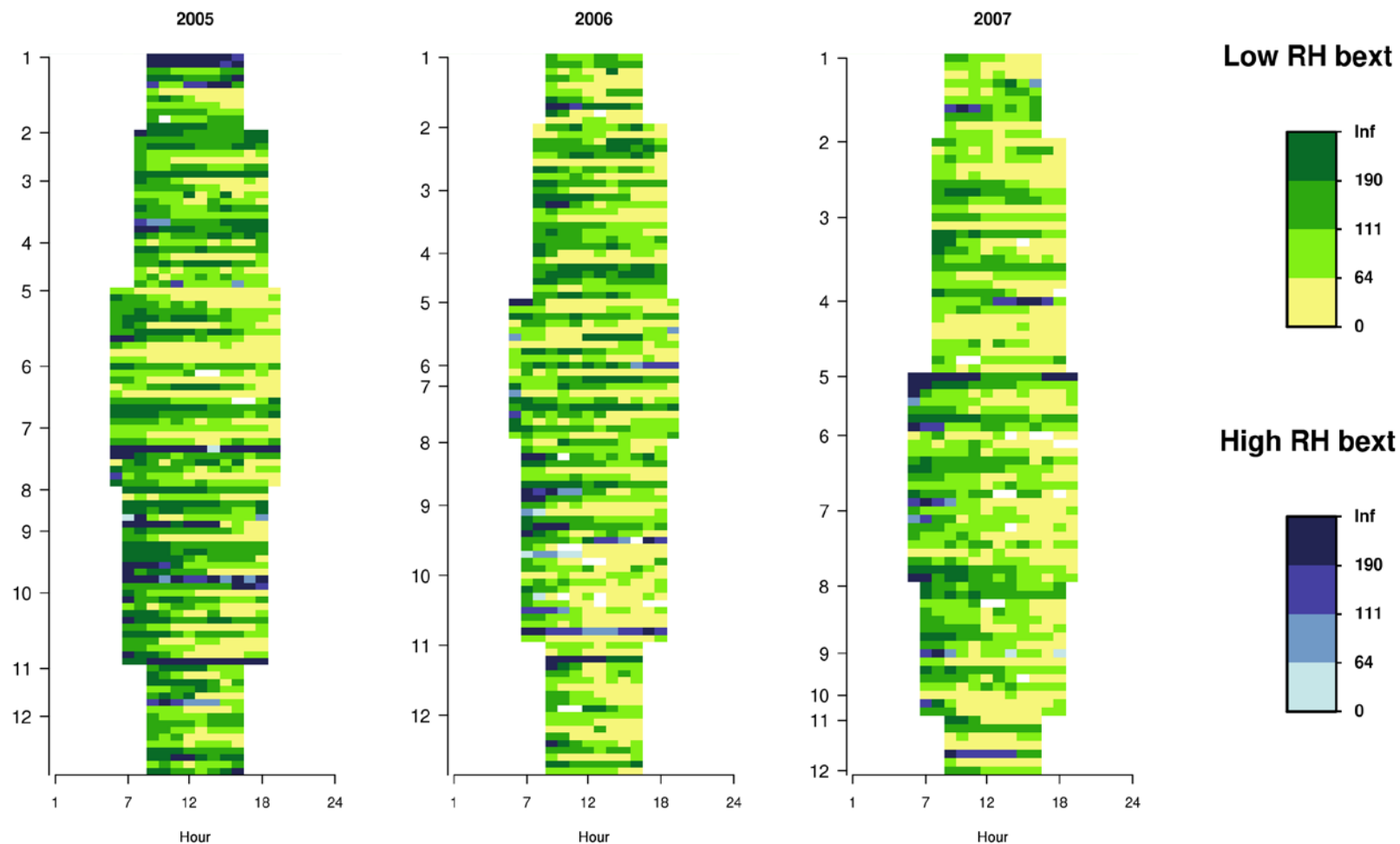


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Birmingham, AL

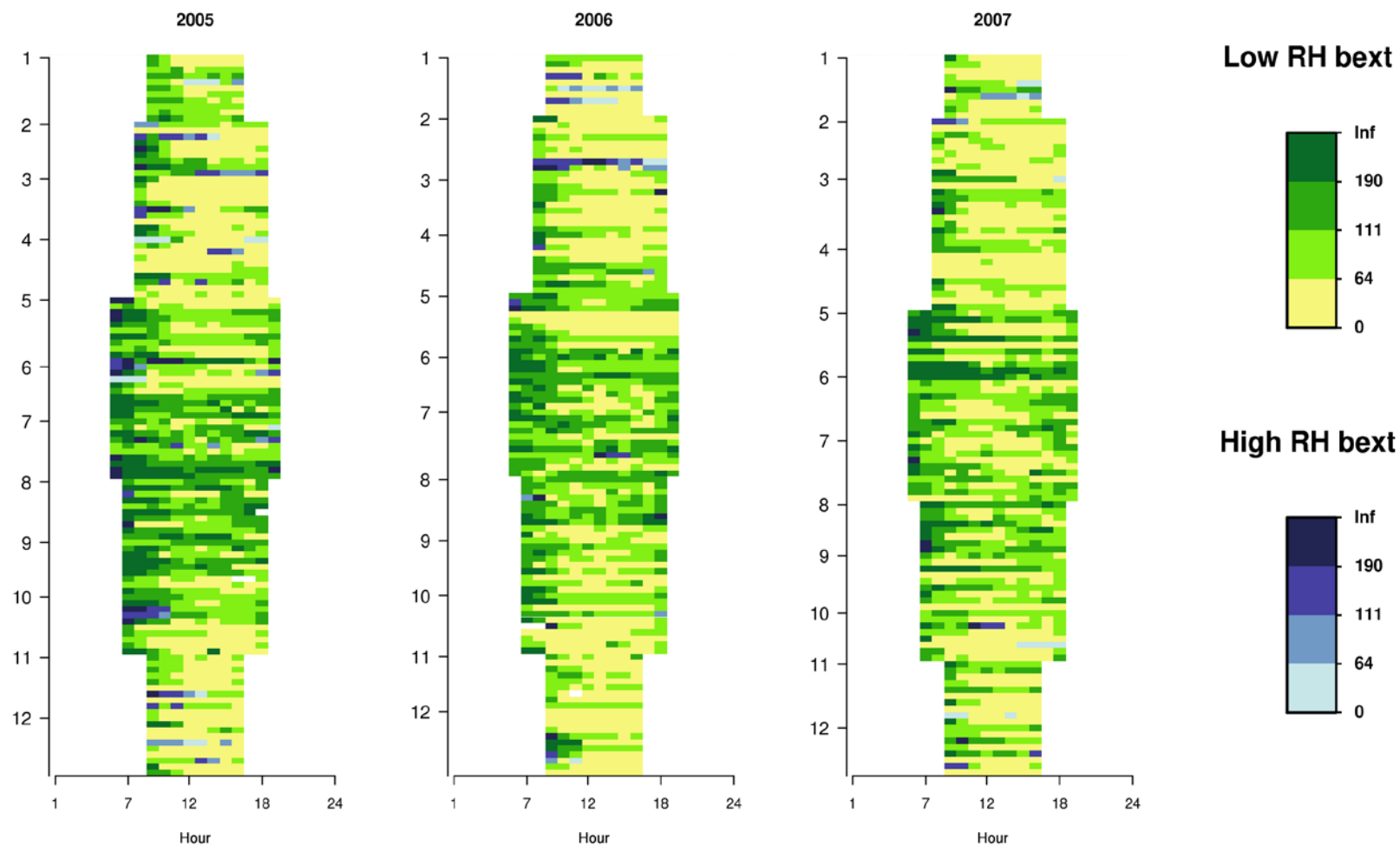


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Atlanta, GA

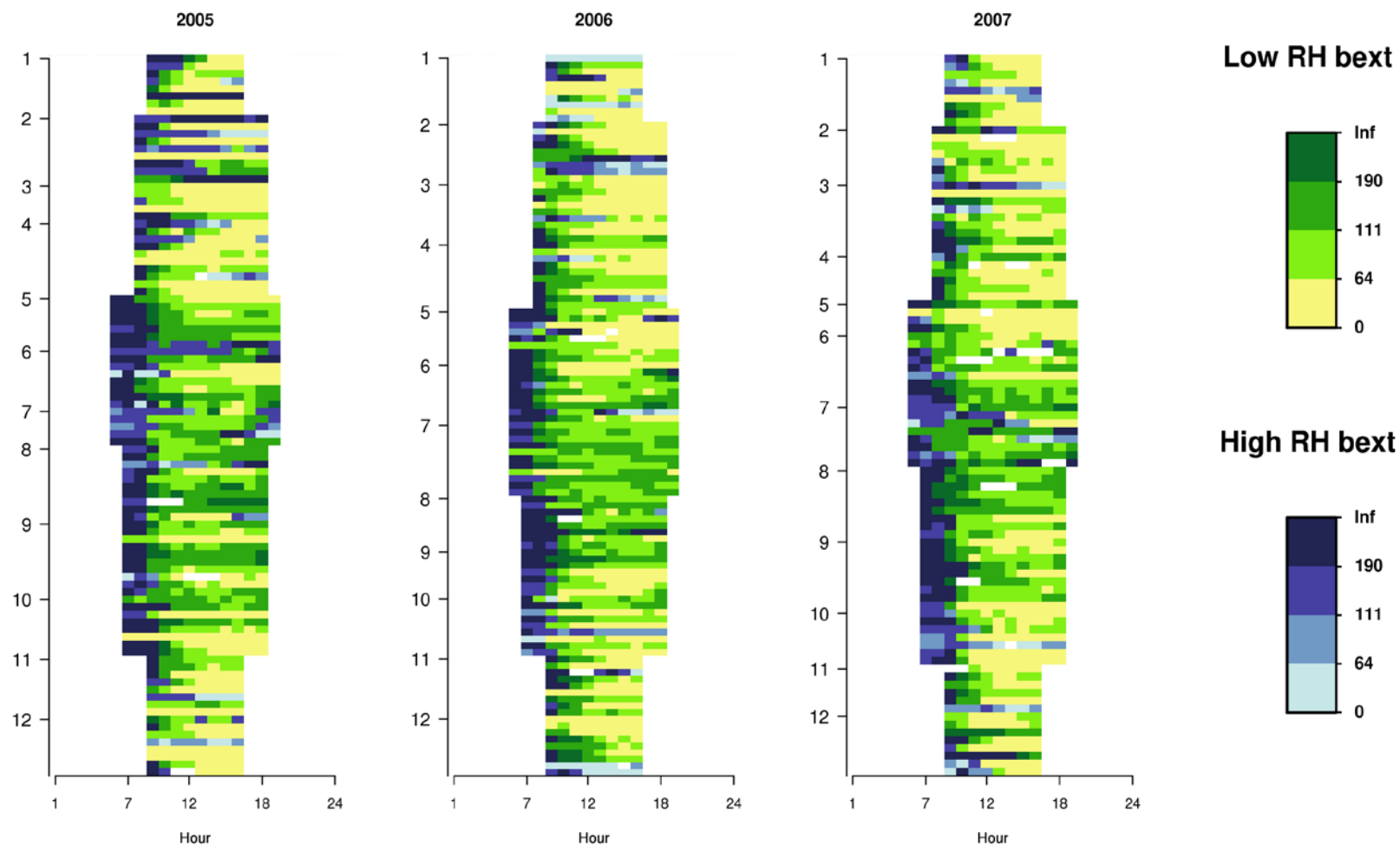


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Detroit, MI

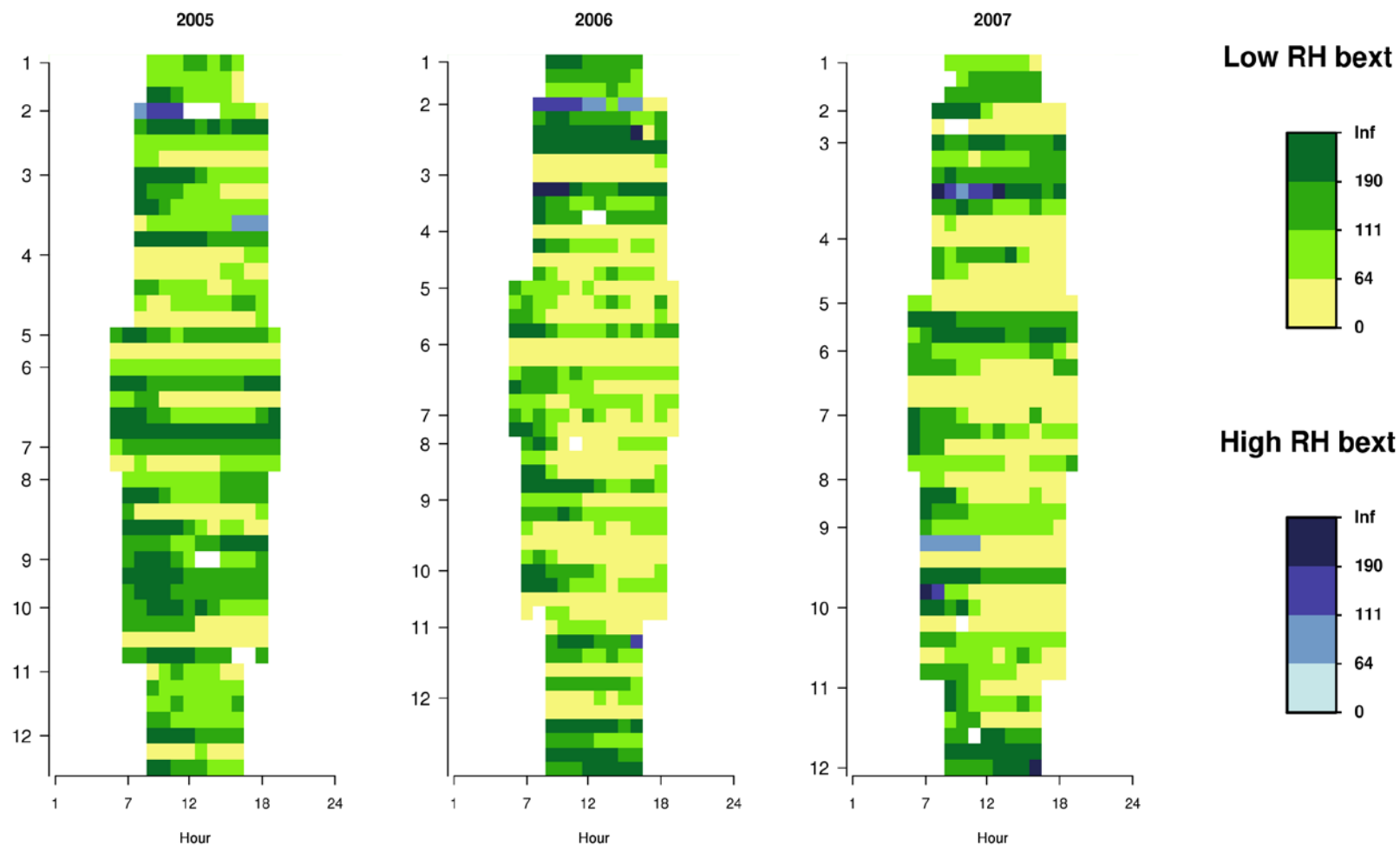




Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Pittsburgh, PA

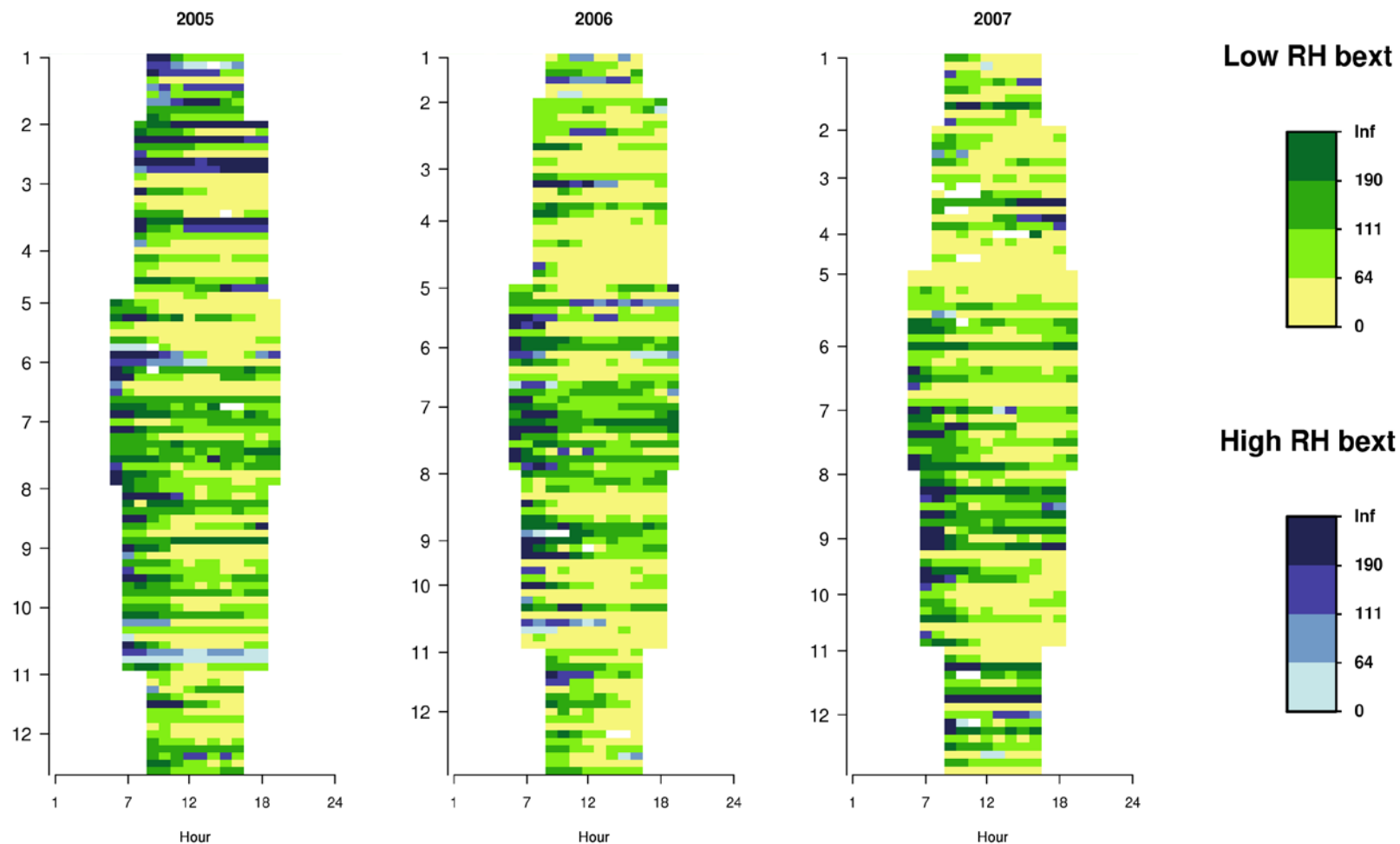


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Baltimore, MD

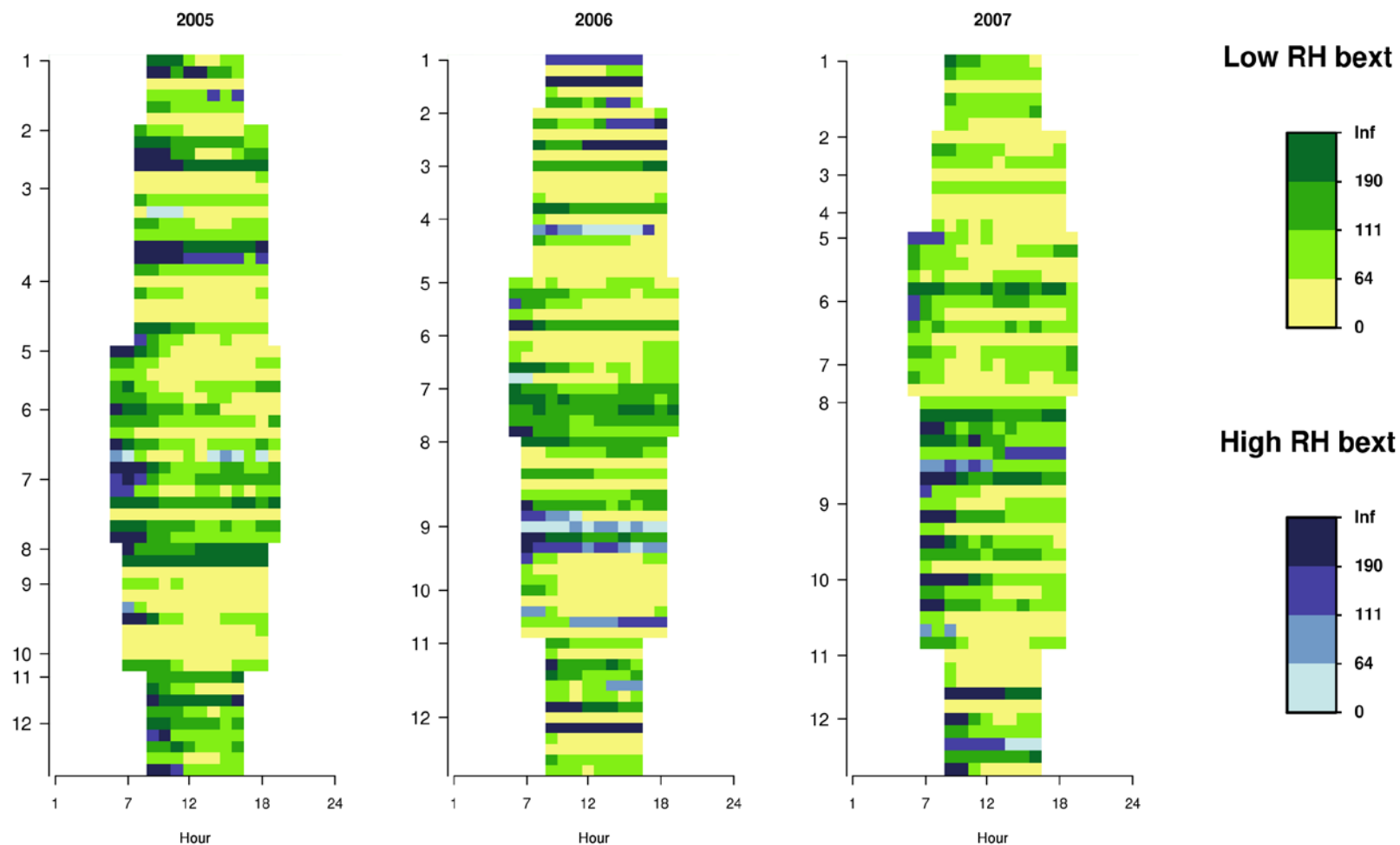


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## Philadelphia, PA

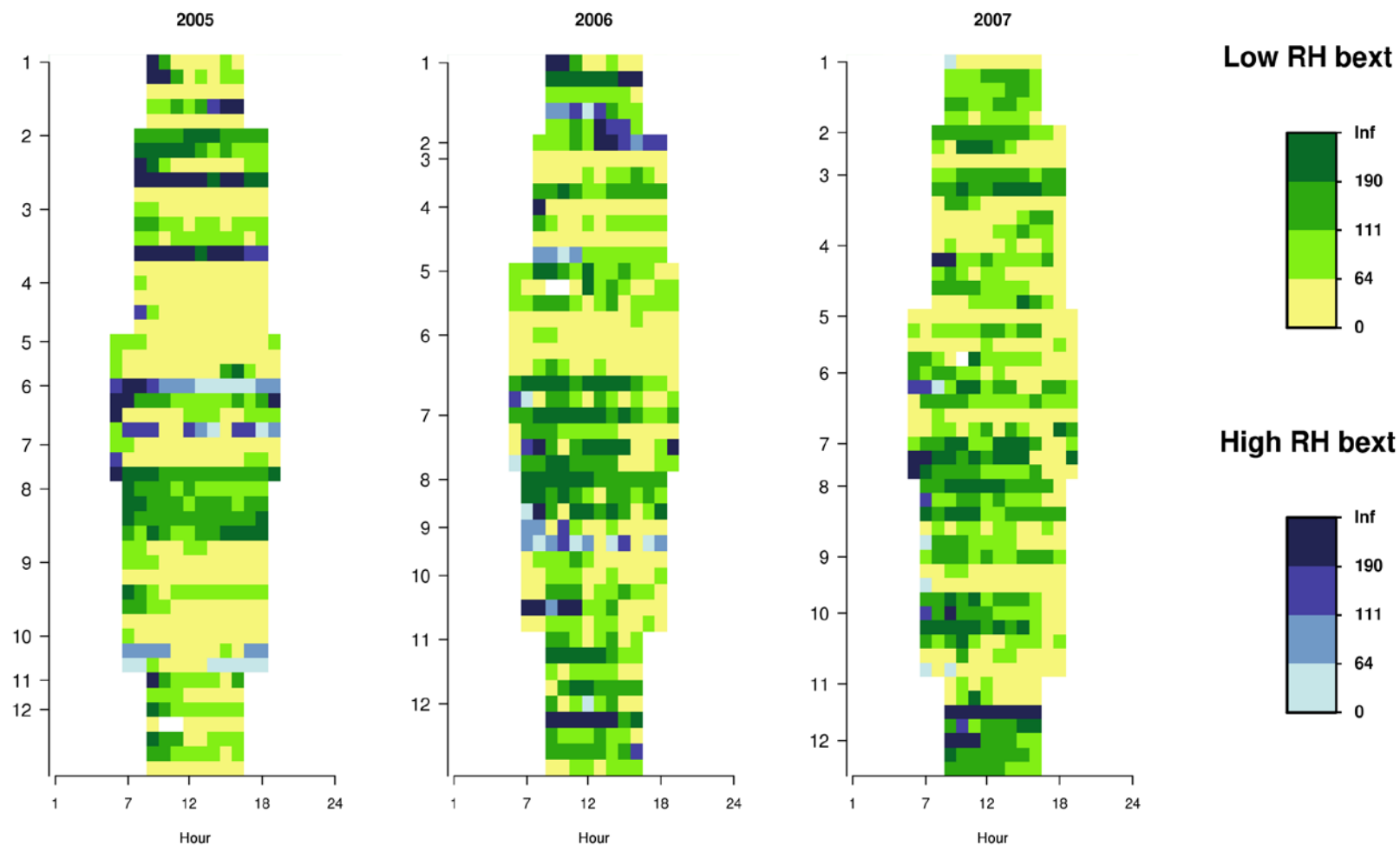
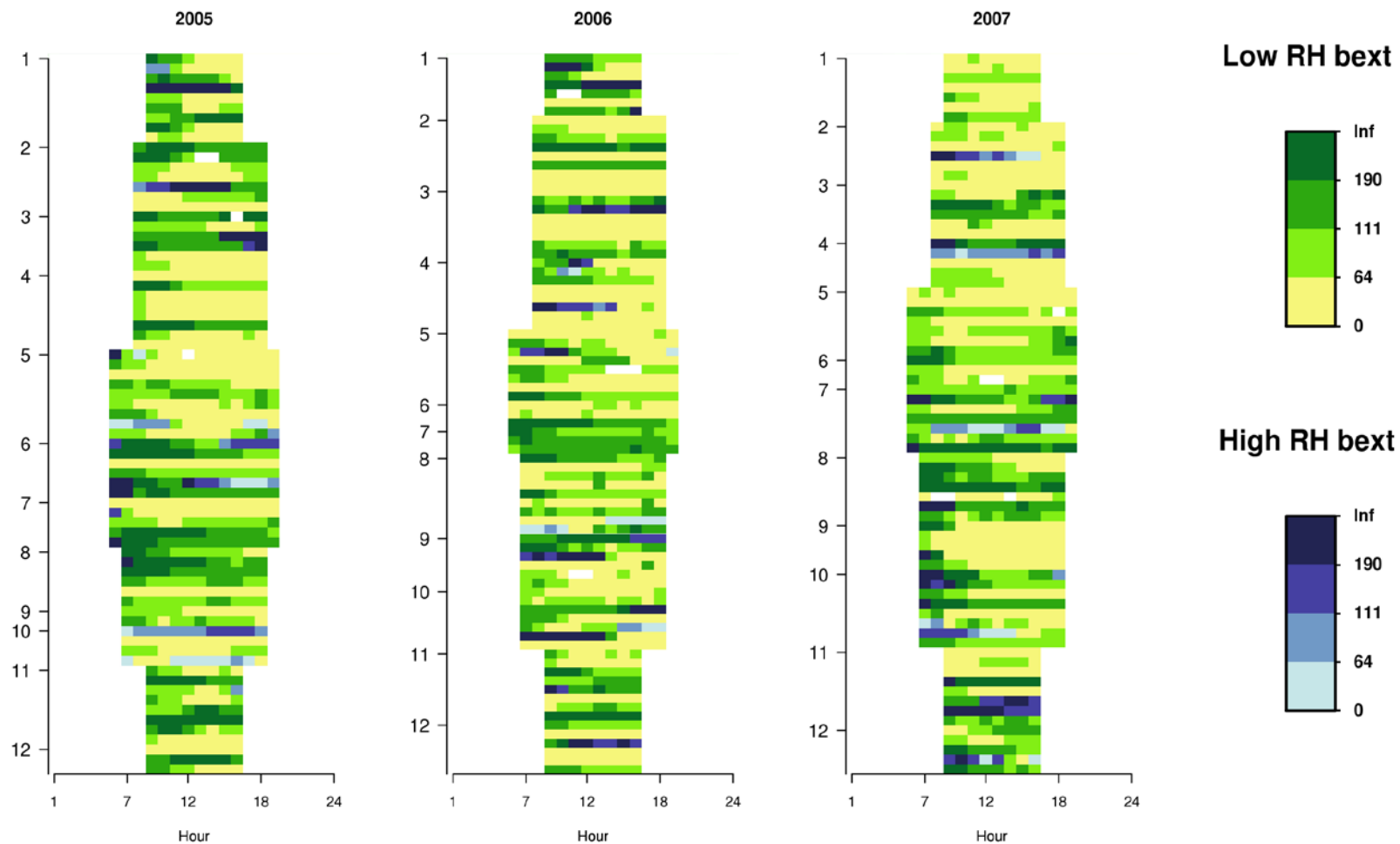


Figure 3-12. Tile Plots of Hourly PM Light Extinction, continued

## New York, NY



### 3.4.5 Extinction Budgets for High PM Light Extinction Conditions

An extinction budget for a single period shows the contribution that each PM component makes to PM 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 light extinction.

Figure 3-13 presents (a) day-specific maximum daylight 1-hour light extinction budgets for the 10 percent of the days in each study area that have the highest daily maximum 1-hour PM light extinction levels (excluding hours with relative humidity greater than 90 percent), and (b) similar but more aggregated information based on all individual daylight hours. For the maximum daily budgets, the day and hour of each hourly budget are indicated on the horizontal axis, and the hours are arranged chronologically. There are too many individual daylight hours within the top 10 percent group to display separately, so component concentrations for all days within 10 one-percentile-point-range “bins” have been averaged together for display.<sup>42</sup> Note that the vertical scale differs from figure to figure, to accommodate the wide variation in PM light extinction values. The pattern of results shown in Figures 3-13 is generally as expected in light of emissions and climate differences among study areas. Except for the PM<sub>2.5</sub> soil component, each of the components of PM light extinction is a major contributor to extreme light extinction events at some time and location. In the West, carbonaceous PM<sub>2.5</sub> (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<sub>2.5</sub> components that are the large contributors to PM light extinction. From the sample period dates we can determine the seasonal variations in major components. Nitrate and carbonaceous PM<sub>2.5</sub> contribute more to the extreme light extinction periods during winter, while sulfate contributes more in the summer. In many of the more northerly eastern urban areas, a combination of sulfate and nitrate contributes to high light extinction year-round.

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

- Tacoma has its highest light extinction hours in the colder months and primarily due to carbonaceous PM<sub>2.5</sub> components. Because coarse PM was estimated by applying a regional factor to the local PM<sub>2.5</sub> mass value, it would not have been possible for the results to indicate a significant coarse PM contribution to PM light extinction even if one existed at this site. However, from what EPA staff

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<sup>42</sup> Note that this binning approach may combine days with dissimilar extinction budgets into one bin because their PM light extinction values are similar, obscuring some of the heterogeneity among hours.

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<sub>2.5</sub>, 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<sub>10</sub> measurements in Victorville, and may not represent coarse PM at the PM<sub>2.5</sub> 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 next 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 light extinction were low on those days. Whether or not the PM<sub>10</sub> measurements in Victorville represent the PM<sub>2.5</sub> mass and speciation site in Rubidoux, it can be concluded that nitrate and to a lesser extent sulfate dominate PM 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<sub>2.5</sub> mass value, it would not have been possible for the results to indicate a significant coarse PM contribution to PM 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 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<sub>2.5</sub>. Unlike for Los Angeles, this domination by coarse PM is no doubt correct. PM<sub>10</sub> measurements for Phoenix come from a site near the center of the metro area, while the PM<sub>2.5</sub> measurements are from a more peripheral site (see Appendix A) and are probably underestimates of PM<sub>2.5</sub> at the PM<sub>10</sub> 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 µg/m<sup>3</sup>) reflects the effect of exceptional winds, and might be excluded under the Exceptional Event rule, the next-highest non-excludable values of PM light extinction almost certainly would also be dominated by coarse

PM concentrations in the range of 150 to 200  $\mu\text{g}/\text{m}^3$  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  $\text{PM}_{2.5}$  being the major contributor. Because coarse PM in Salt Lake City was estimated by applying a regional factor to the local  $\text{PM}_{2.5}$  mass value, it would not have been possible for the results to indicate a significant coarse PM contribution to PM 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  $\text{PM}_{10}$  as high as of 150-200  $\mu\text{g}/\text{m}^3$ . If this were all coarse PM, the contribution to 24-hour average light extinction would be 90-120  $\text{Mm}^{-1}$ , with the possibility of much higher hourly contributions by coarse mass during these few days.
- Dallas and Houston have high contributions to PM light extinction by sulfate  $\text{PM}_{2.5}$ , but Dallas has some winter hours with extreme PM 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  $\text{PM}_{2.5}$  mass value, it would not have been possible for the results to indicate a significant coarse PM contribution to PM 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  $\text{PM}_{10}$  as high as of 150-200  $\mu\text{g}/\text{m}^3$ . If this were all coarse PM, the contribution to 24-hour average light extinction would be 90-120  $\text{Mm}^{-1}$ . Dallas typically does not have  $\text{PM}_{10}$  as high as 150  $\mu\text{g}/\text{m}^3$ .
- Sulfate in the summer and nitrate in the fall and winter are responsible for most of the extreme light extinction at St. Louis, though there are several maximum hourly periods where coarse PM is a major component. 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 light extinction due to coarse PM may be limited in geographic scope.
- Birmingham and Atlanta are similar in having sulfate year-round and winter carbonaceous  $\text{PM}_{2.5}$  as major contributors to their extreme 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

1 estimated using data from two fairly close sites and the estimates should be  
2 reasonably representative.

- 3 • Detroit has frequent large light extinction contributions from nitrate  $PM_{2.5}$ , mostly  
4 in the winter, as well as some contributions from sulfate  $PM_{2.5}$  year-round and  
5 several fall and winter days with high contributions from carbonaceous  $PM_{2.5}$ .  
6 Coarse PM makes a notable contribution on a few days. Coarse PM for Detroit  
7 was estimated using data from a single site near an automobile plant, and the  
8 estimates should be reasonably representative for that site.
- 9 • The remaining four urban locations (Pittsburgh, Baltimore, Philadelphia, and New  
10 York) are similar in that most of their extreme light extinction is from year-round  
11 combinations of sulfate and nitrate. New York also has some winter elemental  
12 and organic carbonaceous contributions to its extreme light extinction. Recall that  
13 the  $PM_{2.5}$  site representing the New York area is actually in Elizabeth, NJ;  
14 emissions from diesel trucks on nearby interstate highways and/or diesel engines  
15 associated with port activities might explain the carbonaceous contributions.  
16 Coarse PM for Baltimore and Philadelphia was estimated using data from a single  
17 site in each area, and the estimates should be reasonably representative. Coarse  
18 PM for New York was estimated using data from two fairly distant sites and the  
19 estimates may not be representative of both sites. Because coarse PM was  
20 estimated for Pittsburgh by applying a regional factor to the local  $PM_{2.5}$  mass  
21 value, it would not have been possible for the results to indicate a significant  
22 coarse PM contribution to PM light extinction even if one existed at this site.  
23 However, exceedances of the  $PM_{10}$  NAAQS are rare in Pittsburgh suggesting that  
24 coarse PM likely is not a frequent significant contributor to PM light extinction.

### 25 3.5 POLICY RELEVANT BACKGROUND

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

33 It is also necessary to have estimates of PRB for  $PM_{10-2.5}$ , as input to the IMPROVE  
34 algorithm. The final ISA for this review does not present any new information on this subject.  
35 The approach used in the two previous reviews was to present the historical range of annual



1 means of PM<sub>10-2.5</sub> concentrations from IMPROVE monitoring sites selected as being least  
2 influenced by anthropogenic emissions (US EPA, 2004, Table 3E-1). For this assessment, EPA  
3 staff estimated PRB for PM<sub>10-2.5</sub> using a contour map based on average 2000-2004 PM<sub>10-2.5</sub>  
4 concentrations from all IMPROVE monitoring sites, found in a recent report from the  
5 IMPROVE program (DeBell, 2006). More detail is provided in Appendix C.

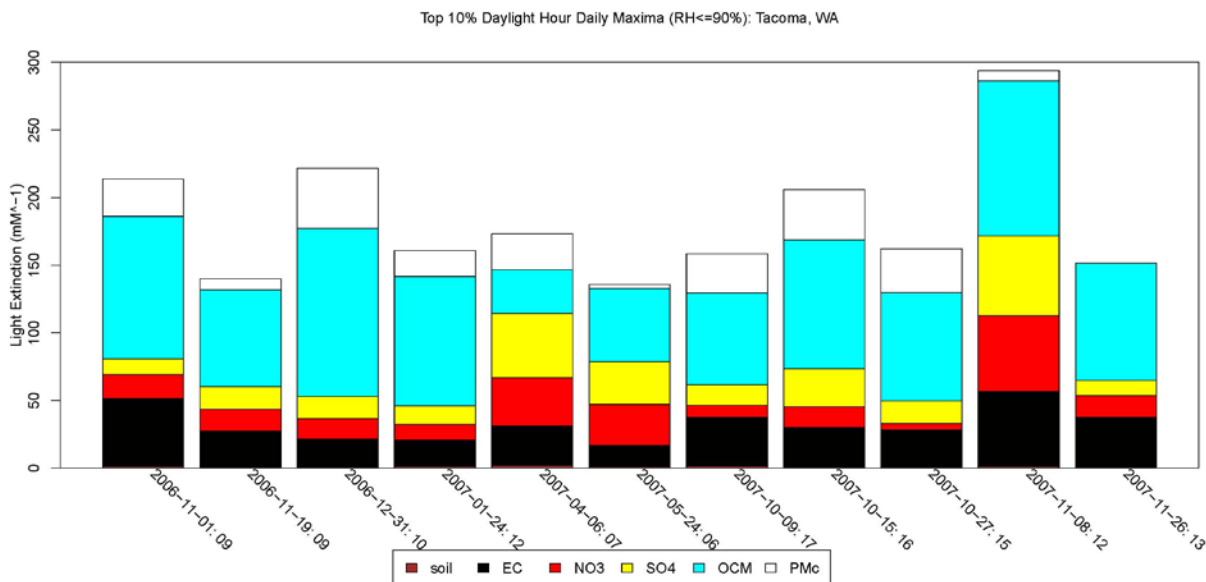
6 The outcome of the procedures for estimating PRB consists of hour-specific estimates of  
7 PRB for PM<sub>2.5</sub> components and annual average estimates for PRB for PM<sub>10-2.5</sub>. Thus, hour-  
8 specific estimates of PM light extinction are possible, using the same hour-specific relative  
9 humidity values as for the estimate of current conditions PM light extinction.

10 The PRB estimates play a role in this assessment (other than allowing confirmation of the  
11 obvious fact that current conditions PM light extinction values are generally well above PRB  
12 conditions) only in the estimation of “what if” scenarios representing compliance with alternative  
13 NAAQS scenarios based on PM light extinction. This role is described in section 4.1.4.  
14  
15

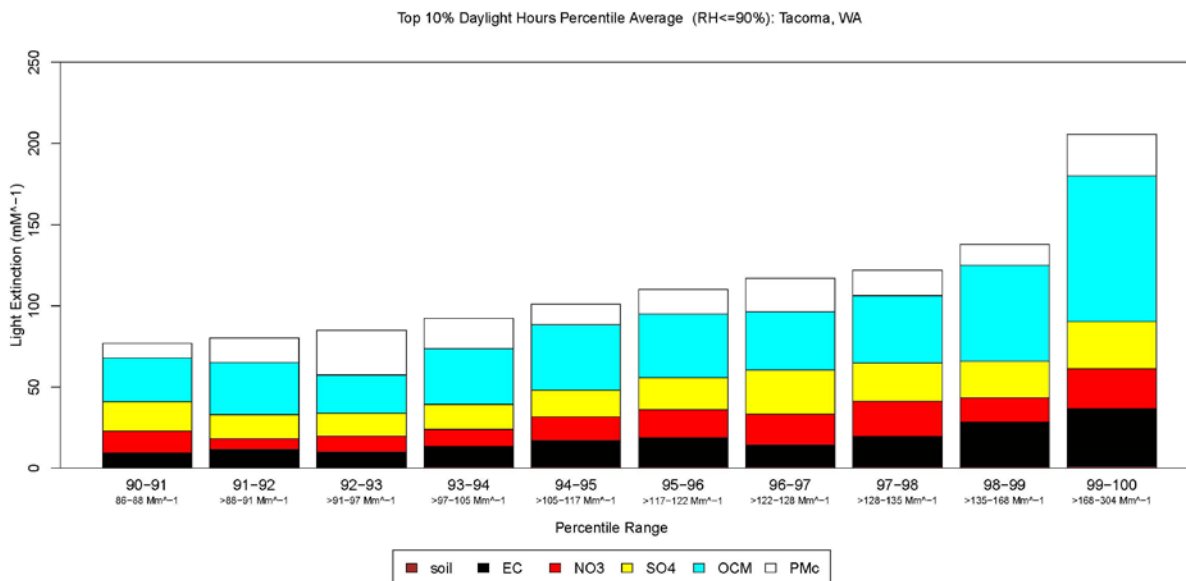
**Figure 3-13 Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours**

## Tacoma

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



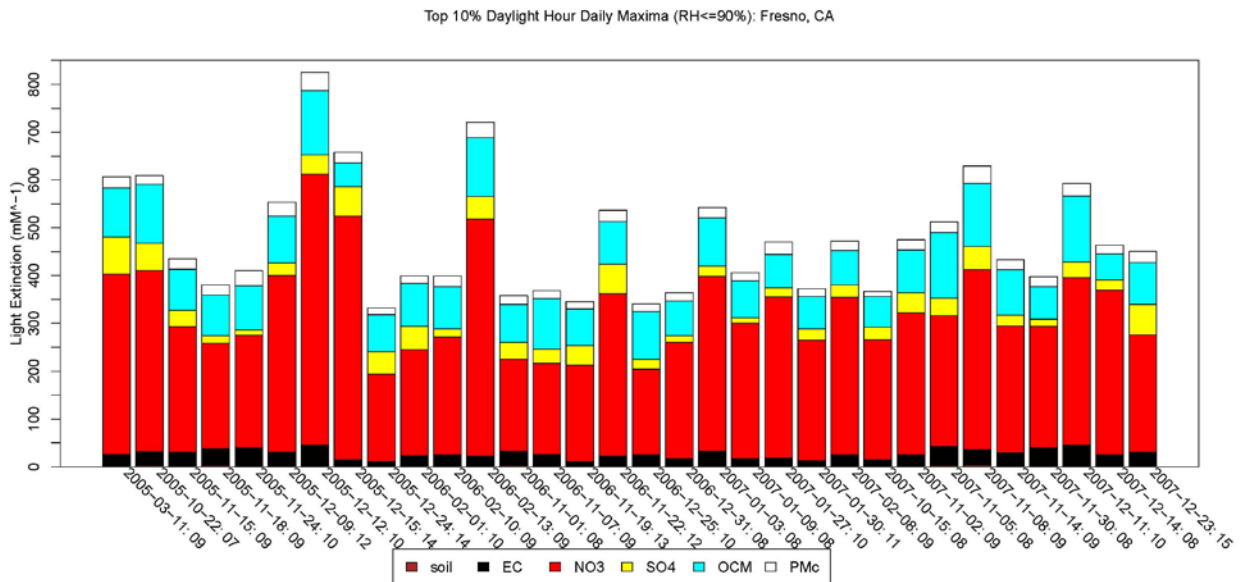
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



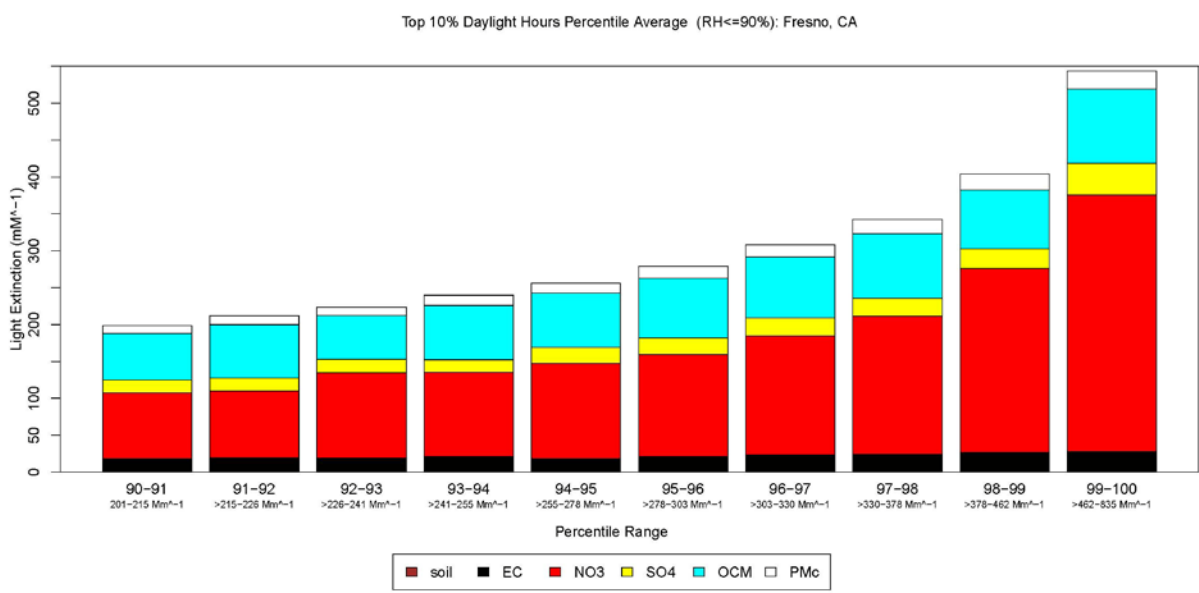
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Fresno**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



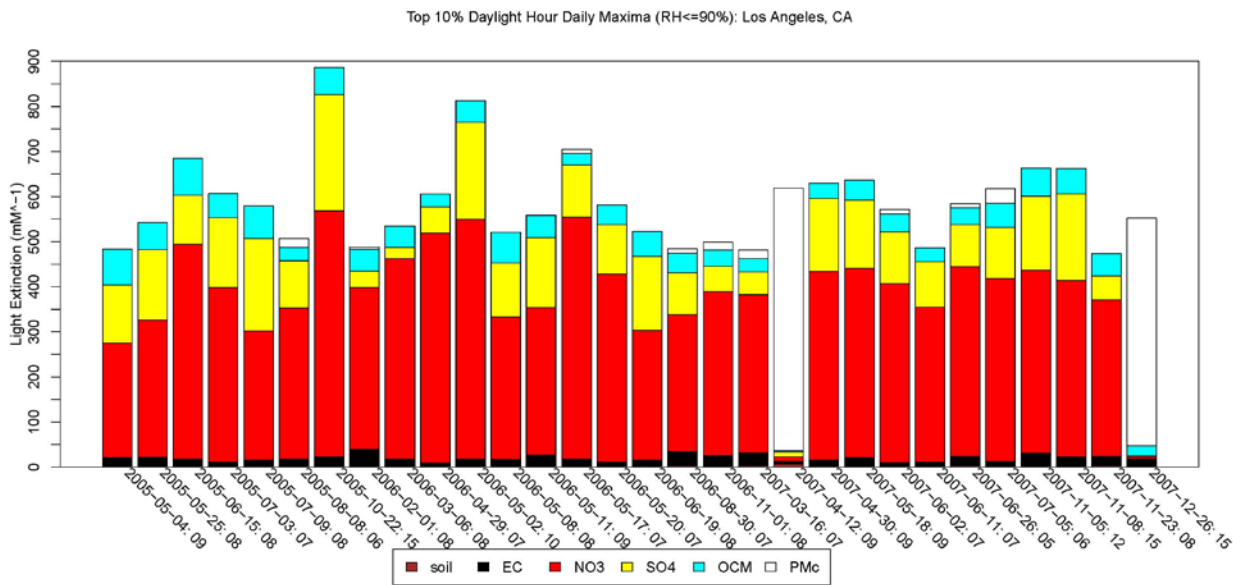
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



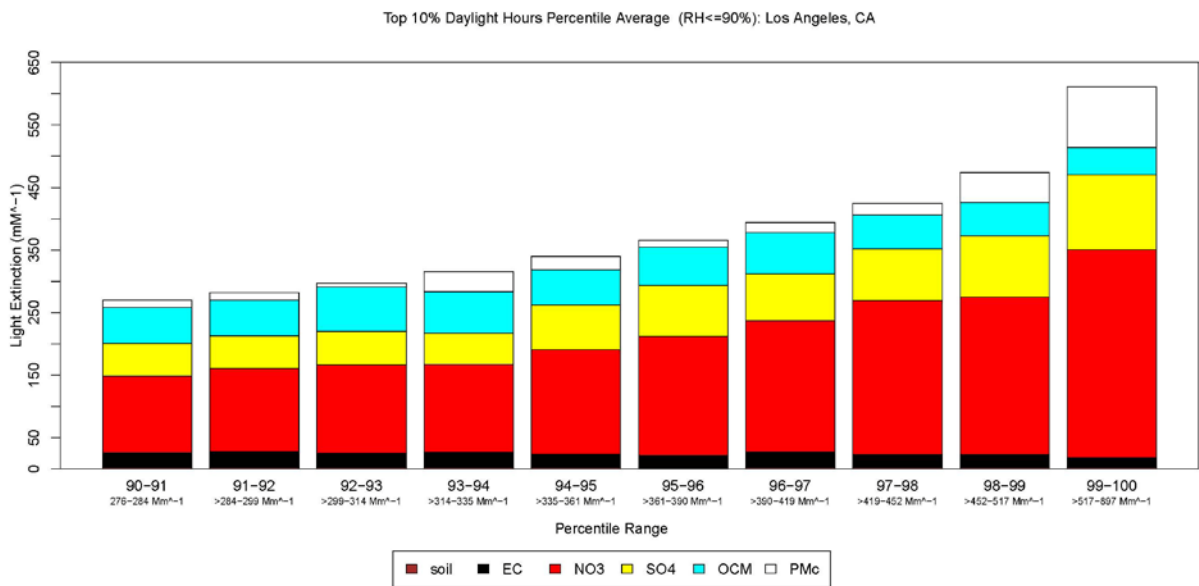
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Los Angeles**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



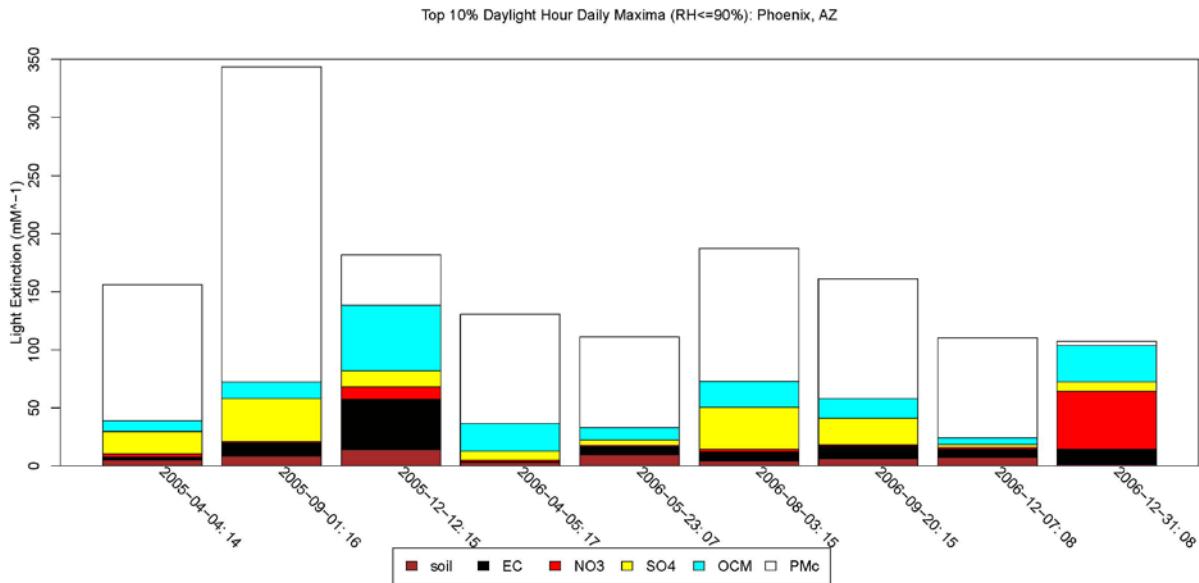
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



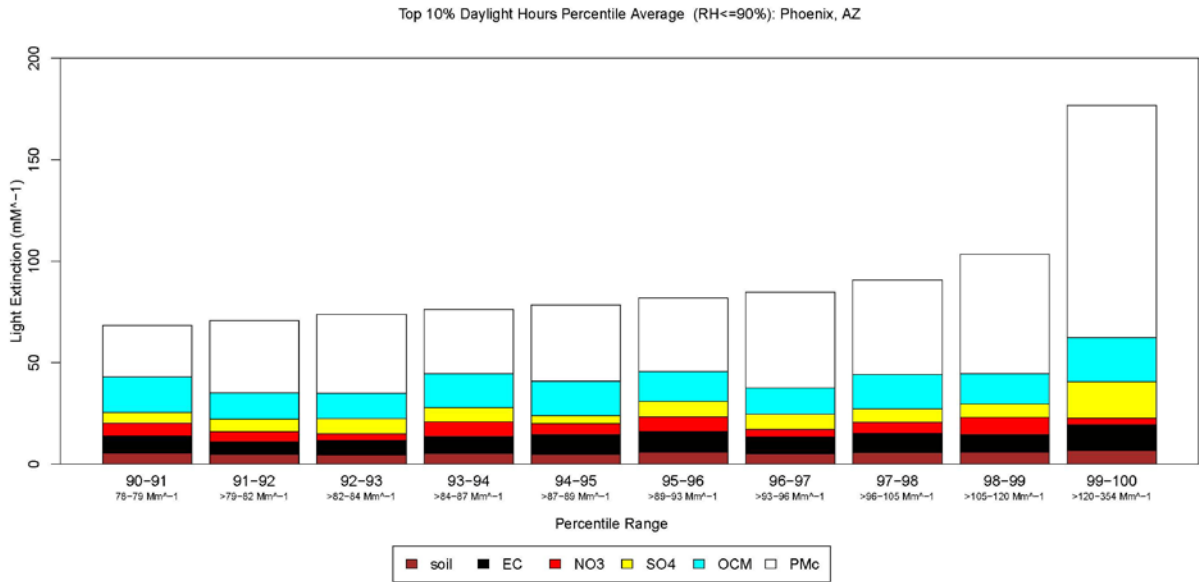
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Phoenix**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



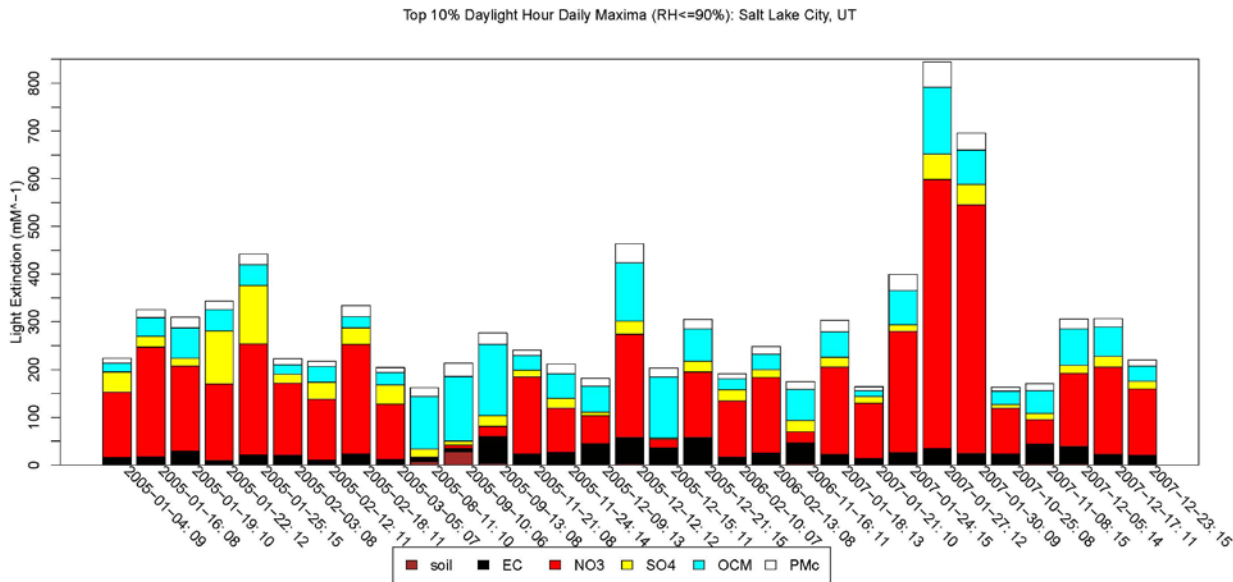
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



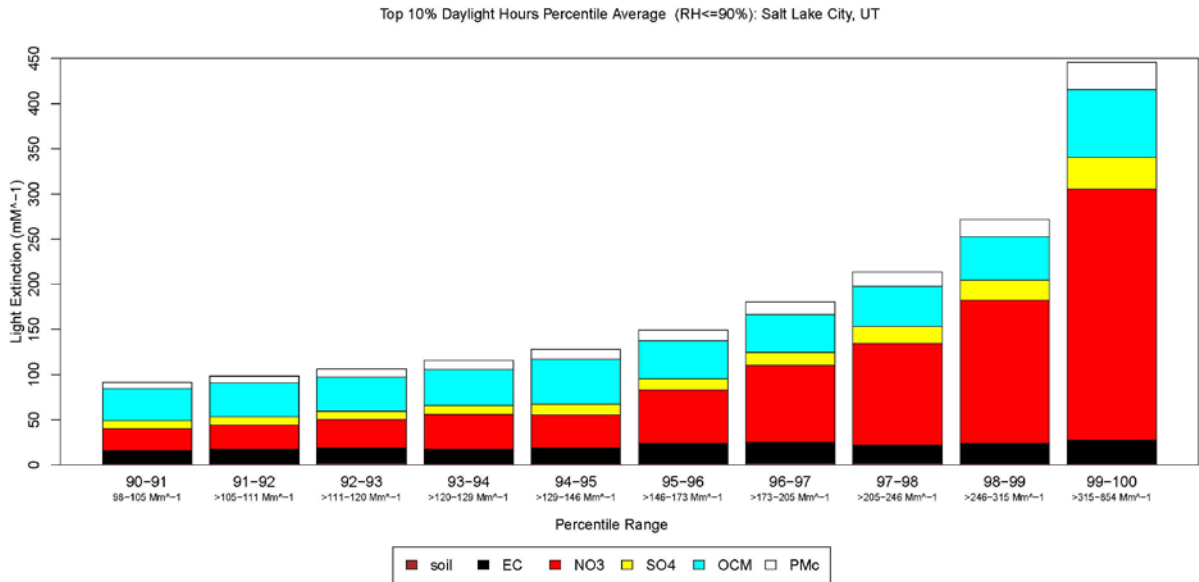
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Salt Lake City**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



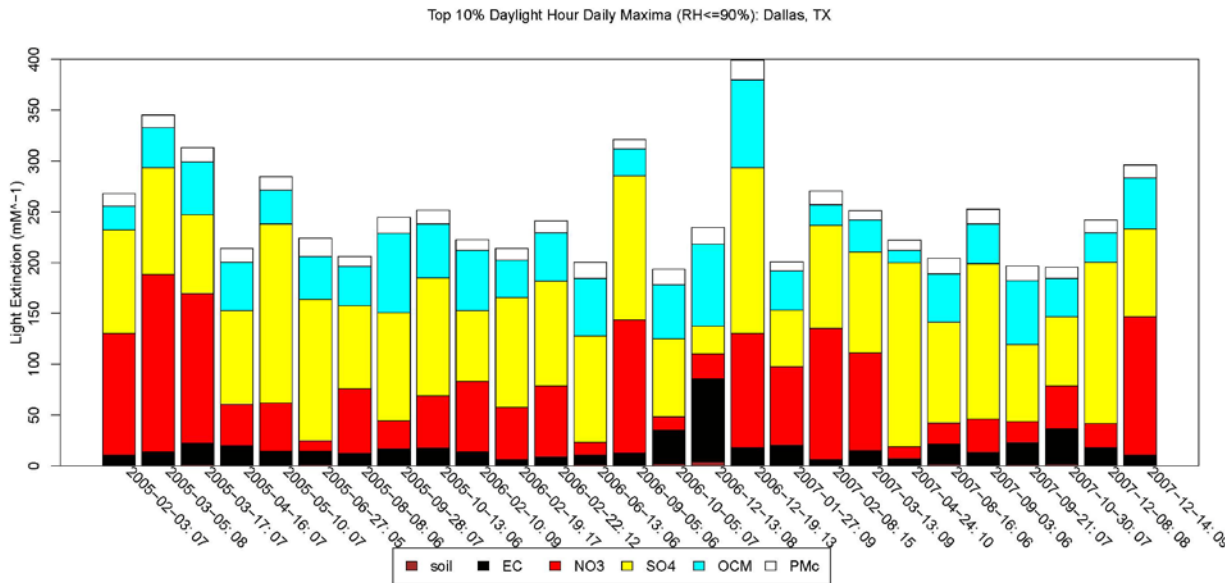
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



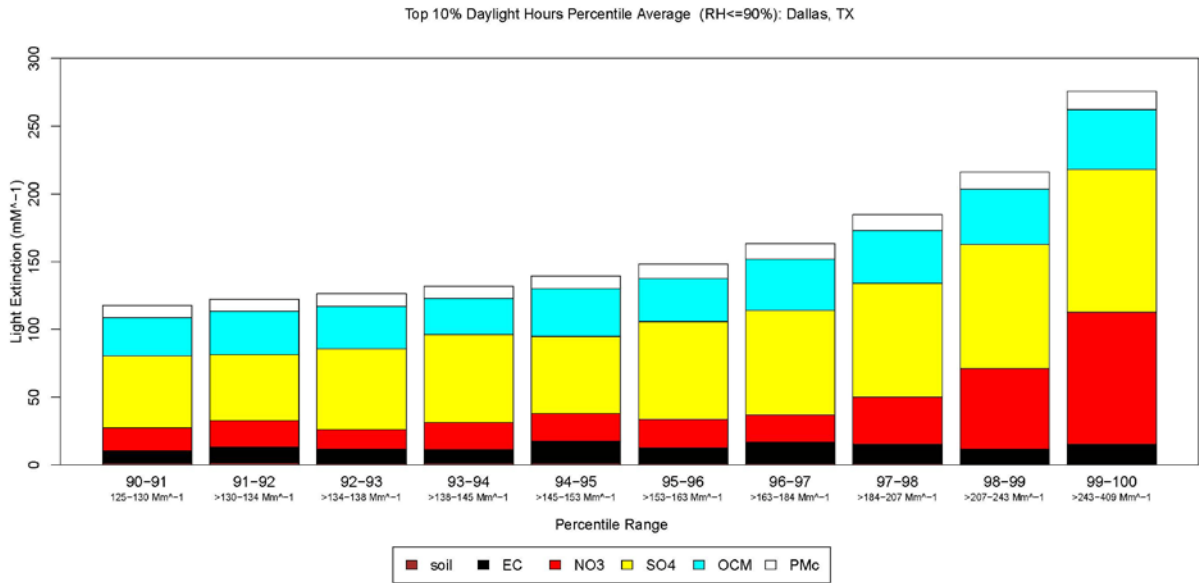
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Dallas**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



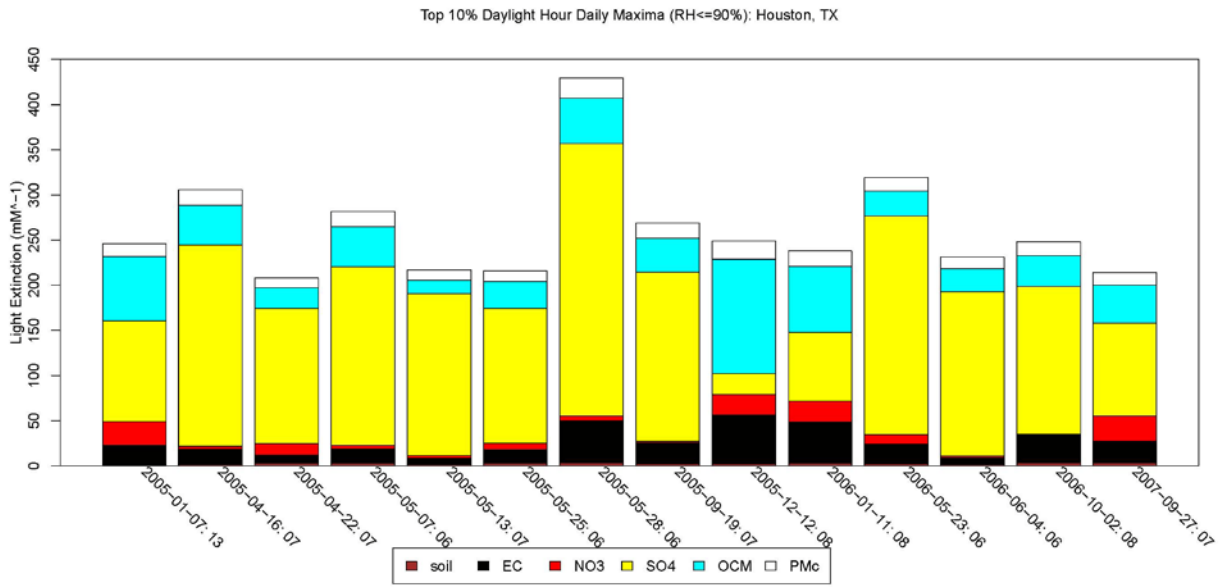
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



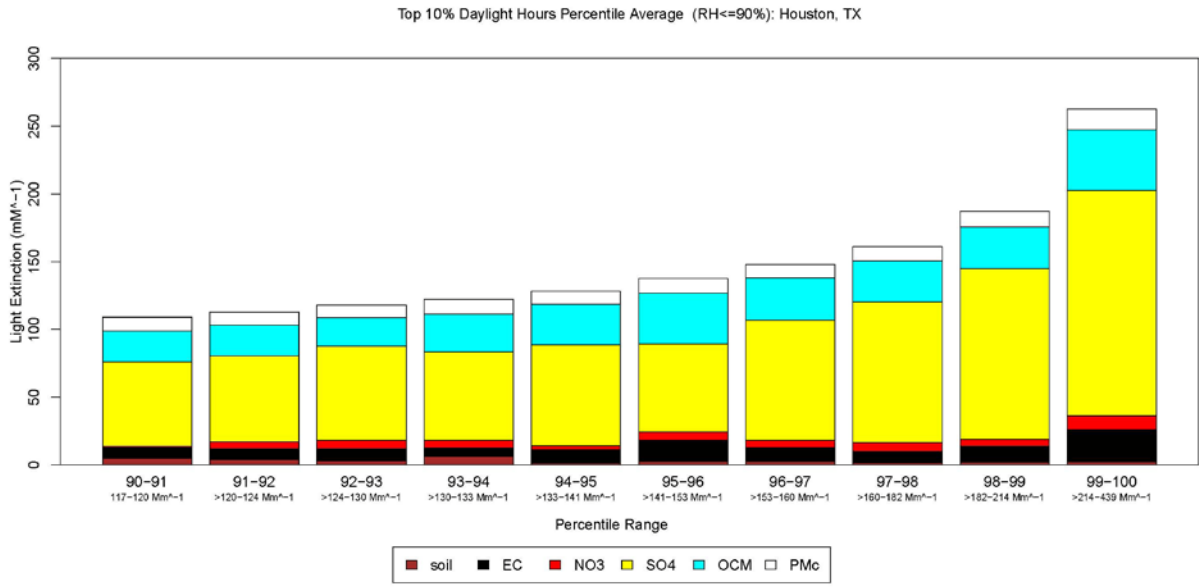
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Houston**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**

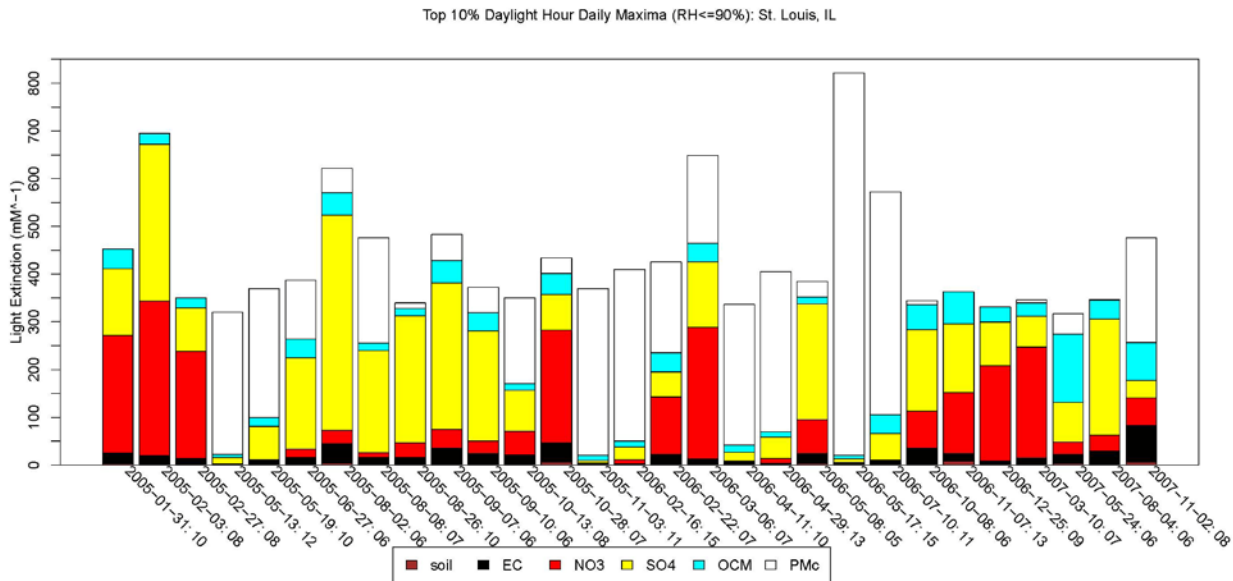




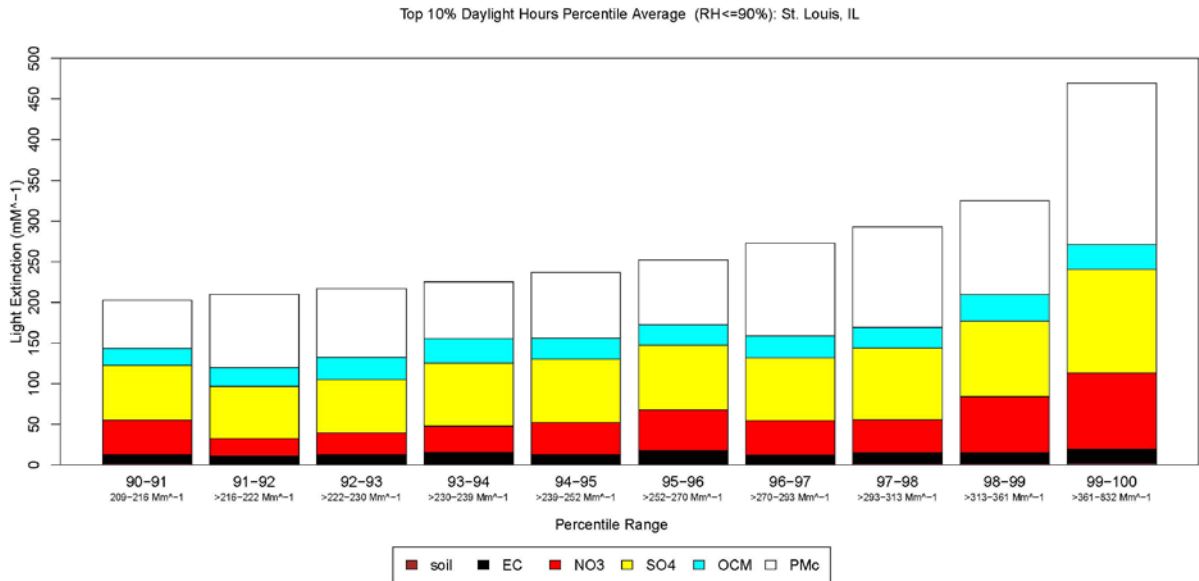
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**St. Louis**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



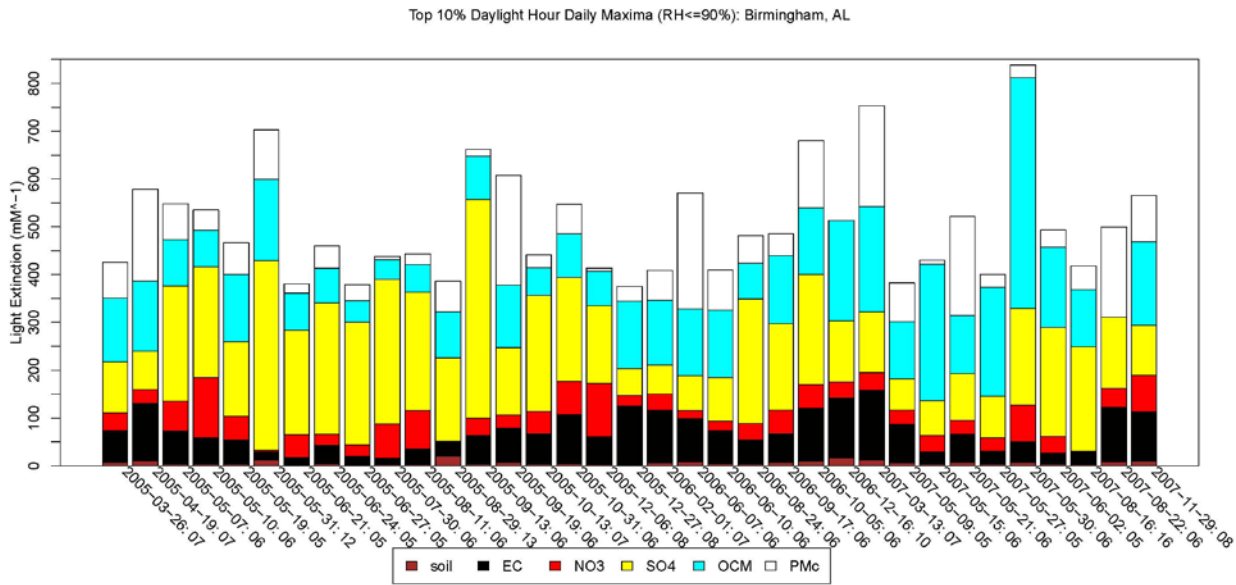
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



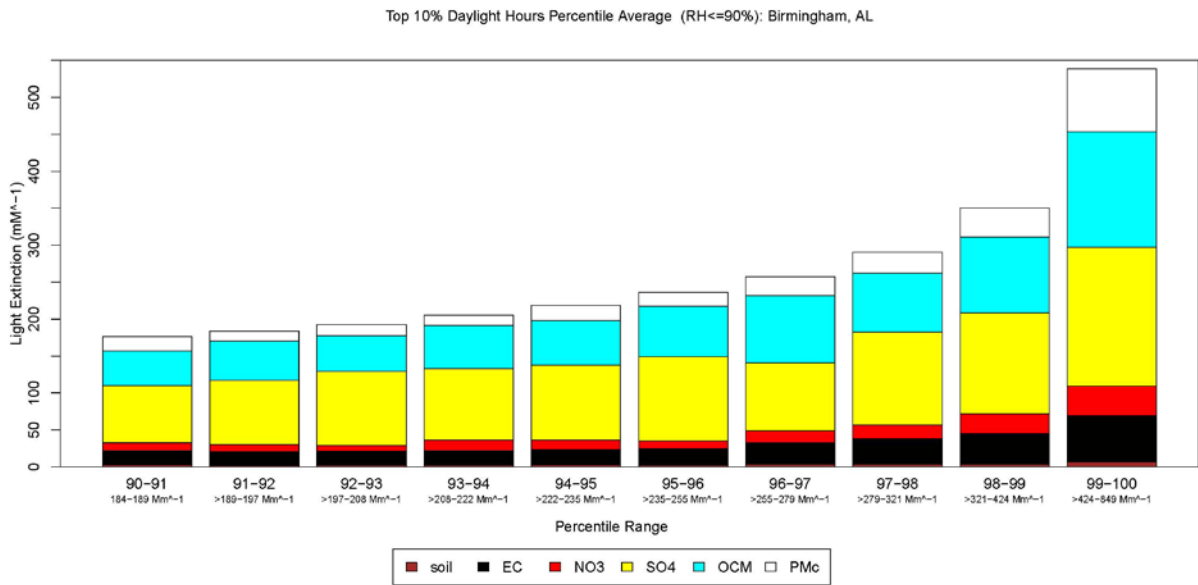
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Birmingham**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



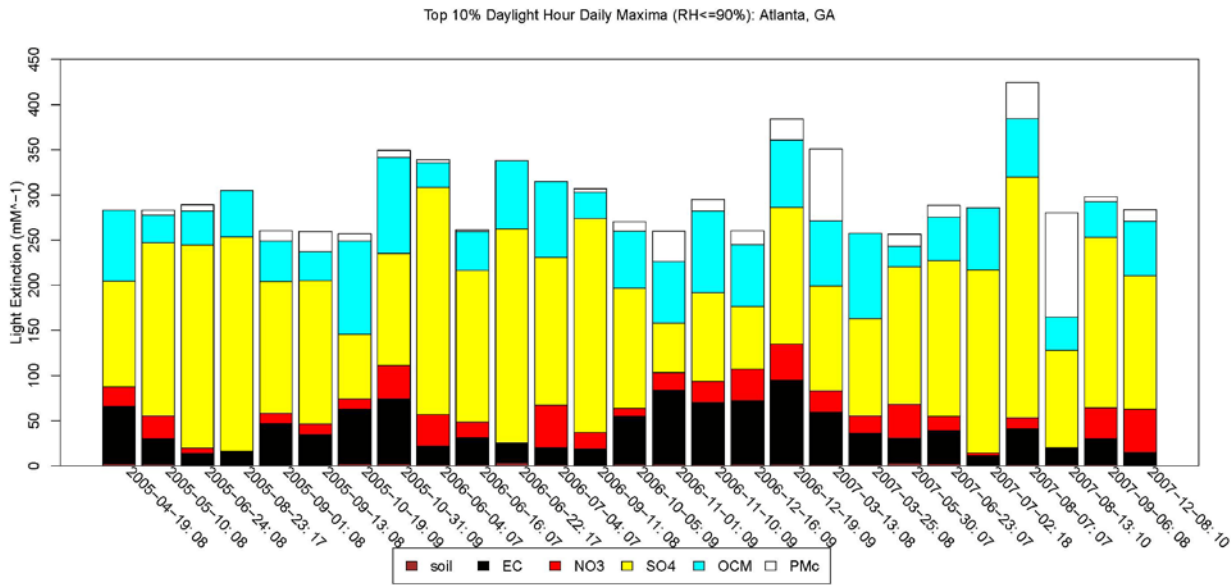
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



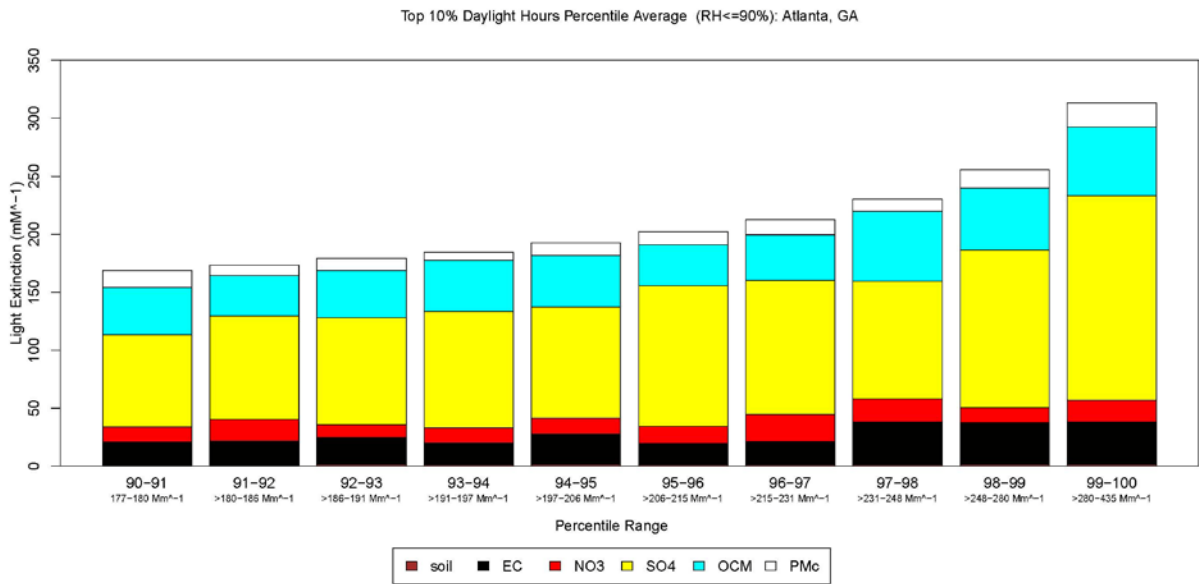
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Atlanta**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



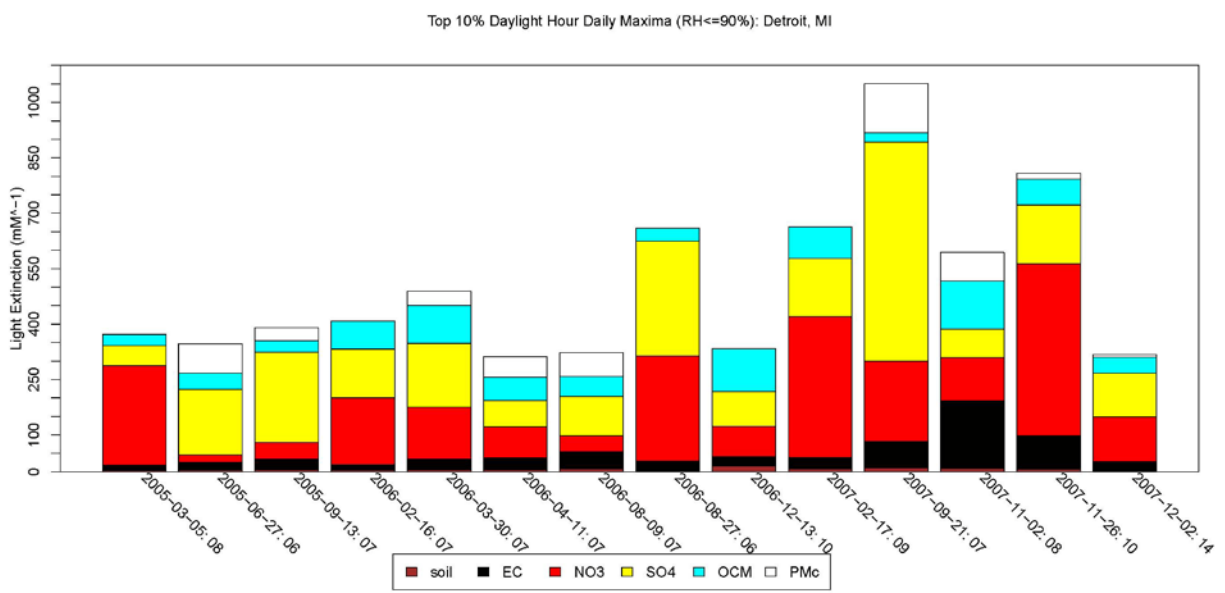
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



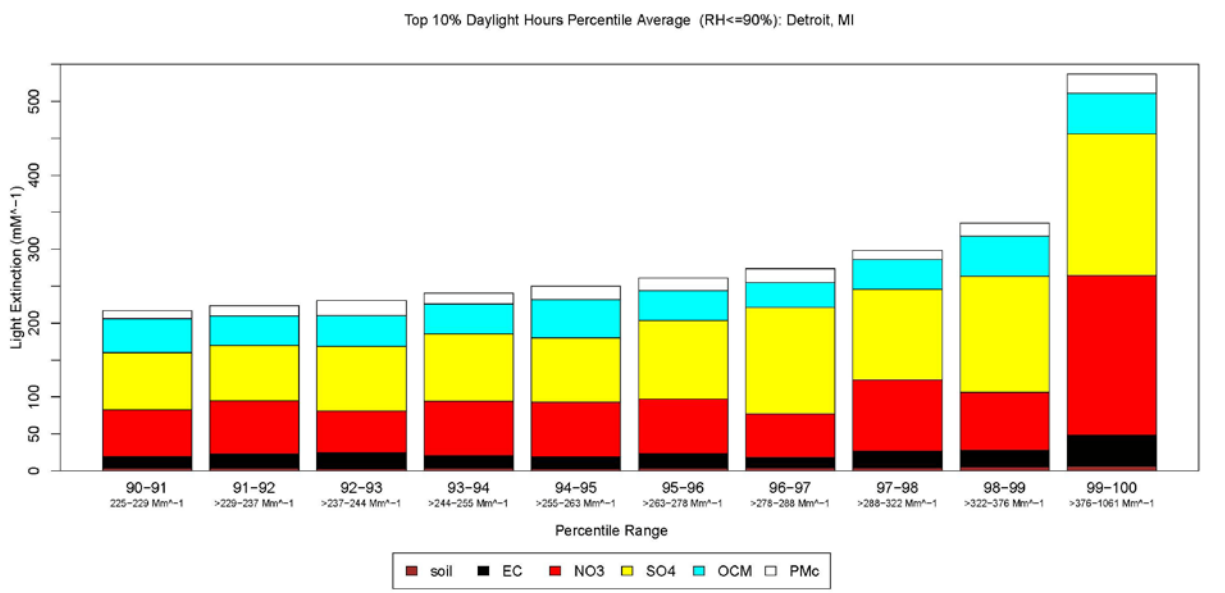
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Detroit**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



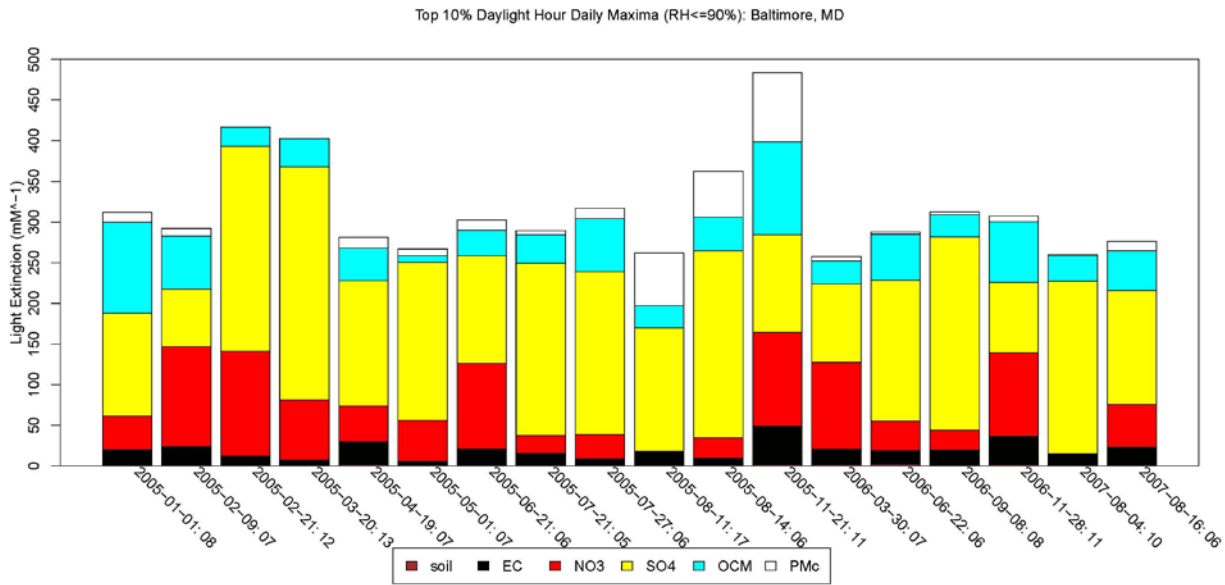
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



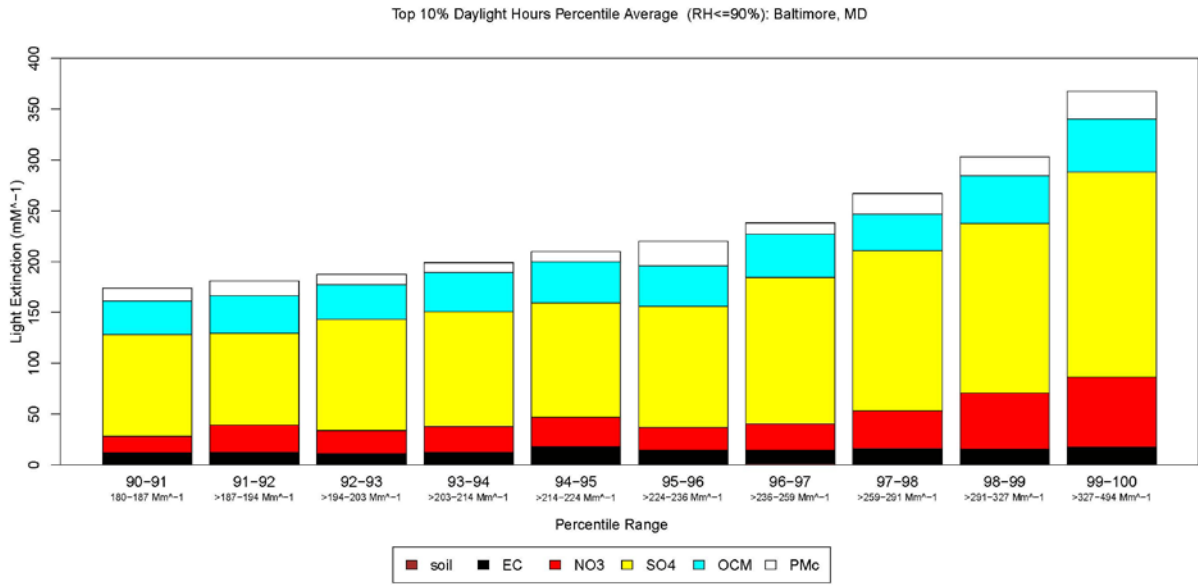
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Baltimore**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



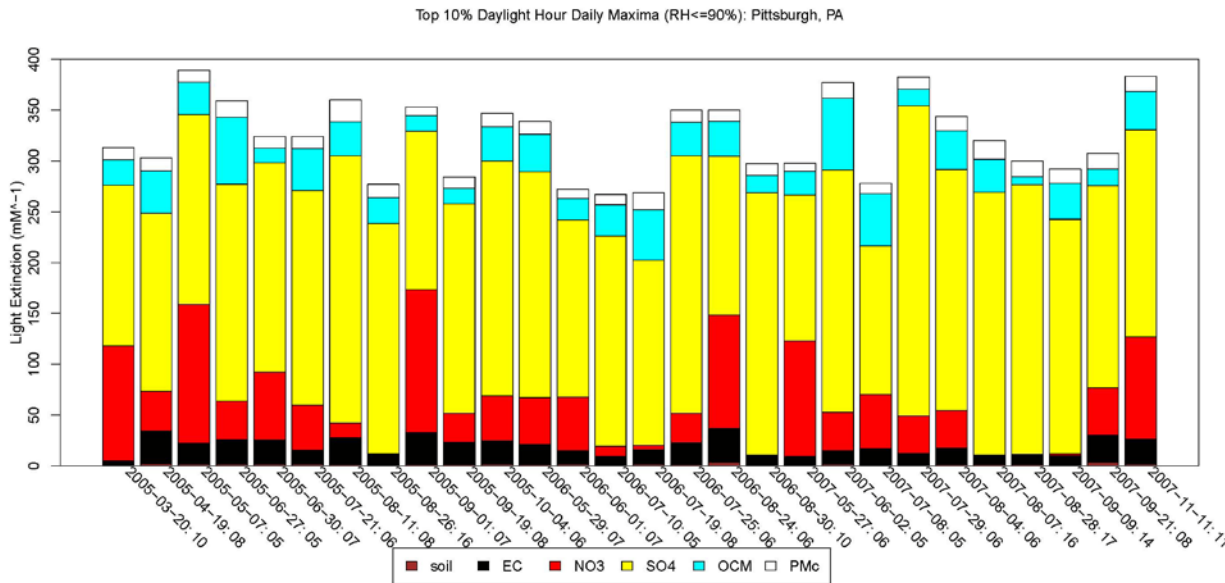
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



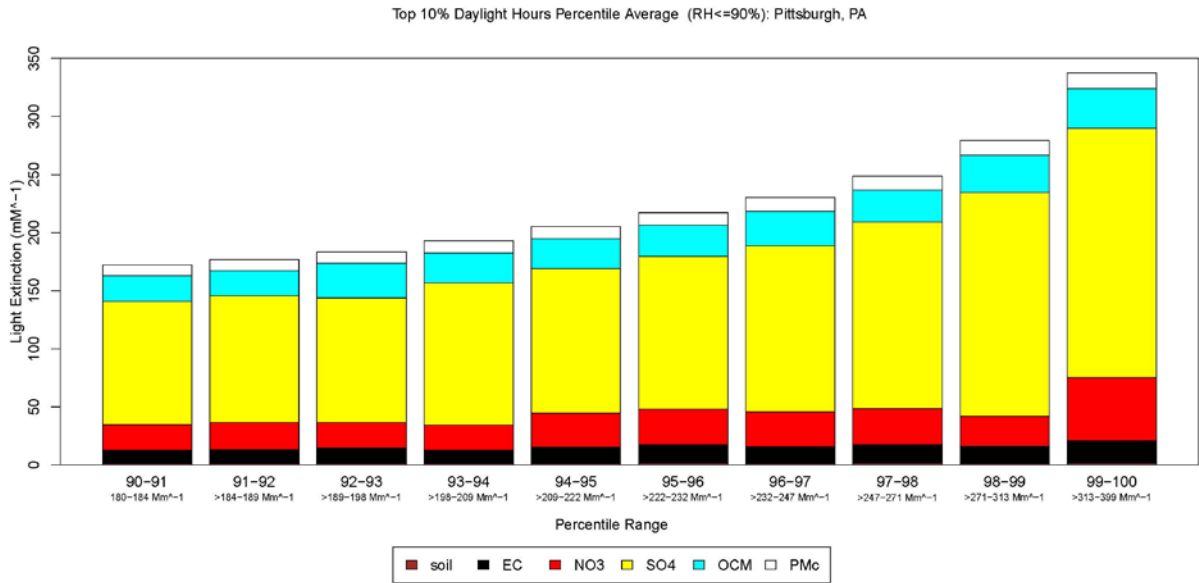
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Pittsburgh**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



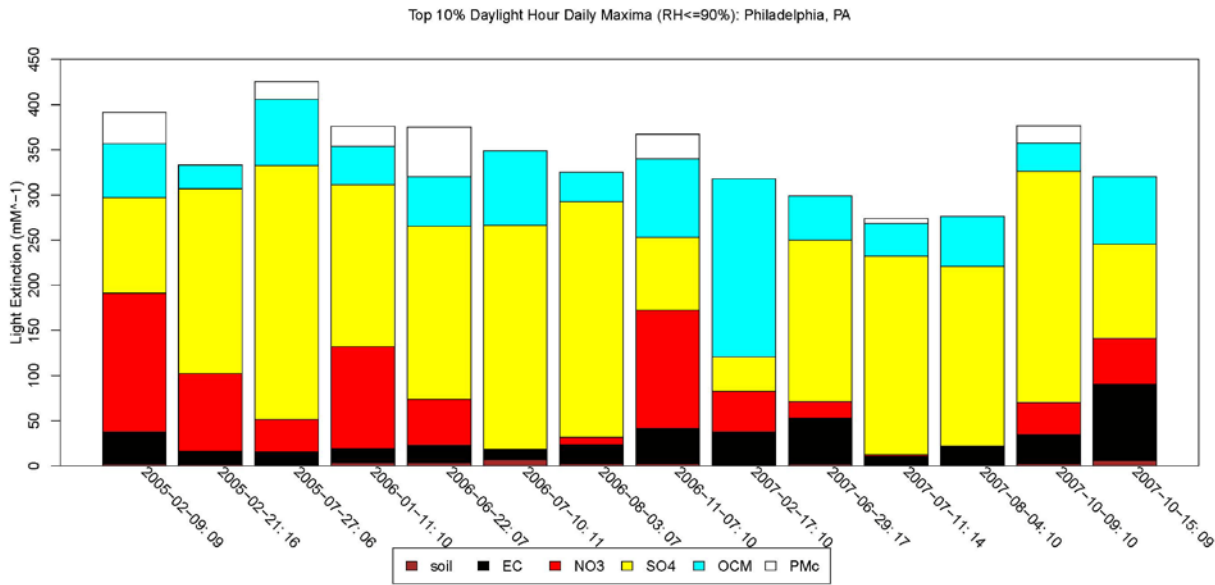
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



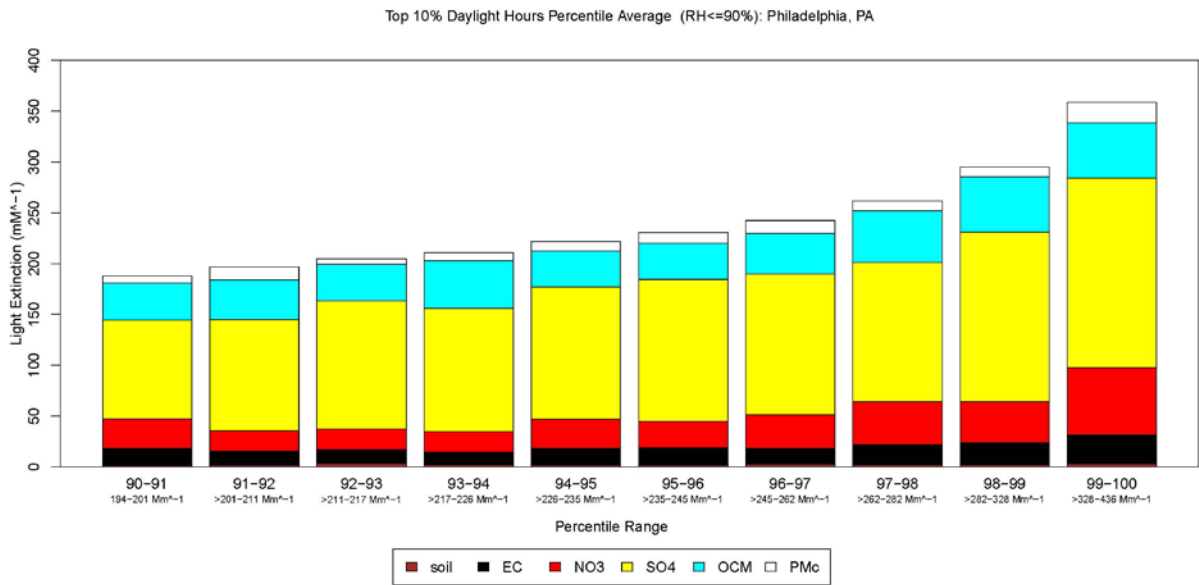
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**Philadelphia**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



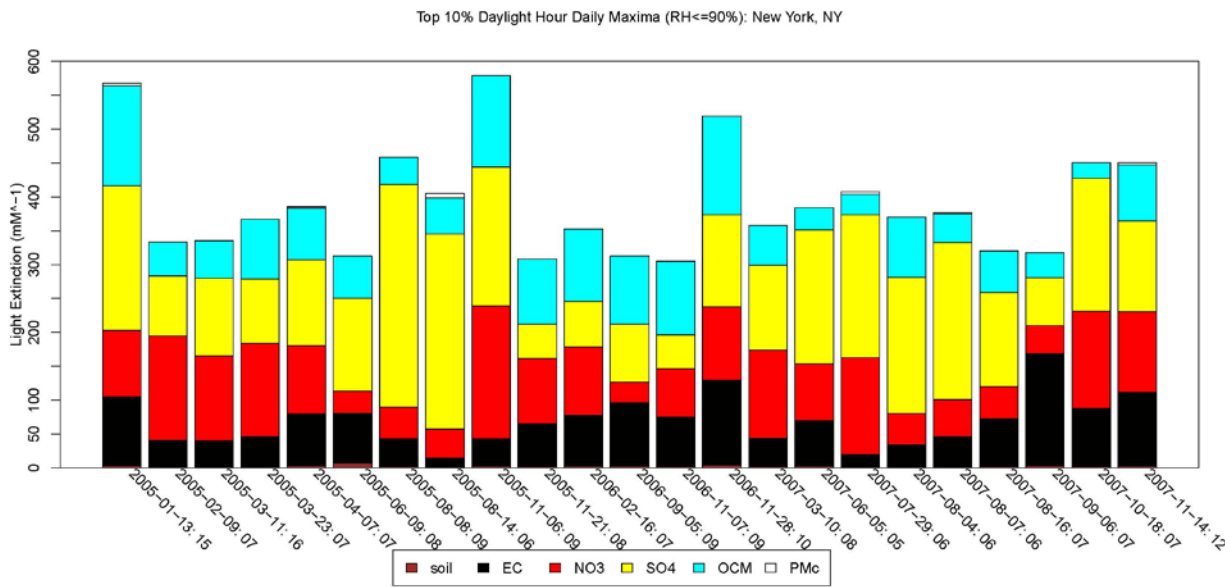
**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**



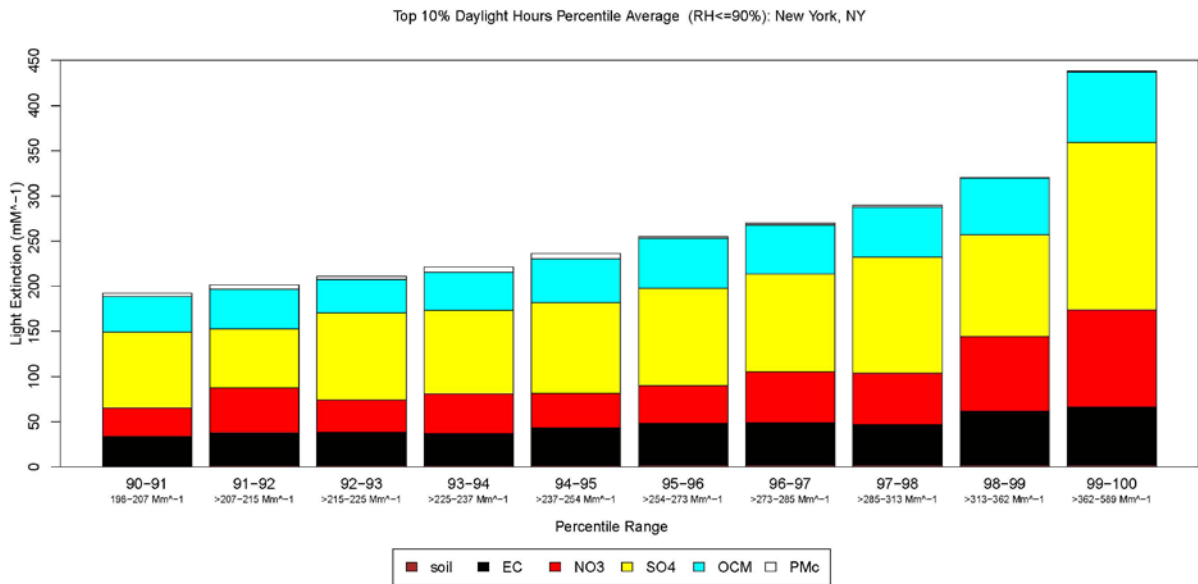
**Figure 3-13. Light Extinction Budgets for the Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction and for the Top 10 Percent of Individual Daylight Hours, continued**

**New York**

**(a) Top 10 Percent of Days for Maximum Daily 1-hour PM light Extinction**



**(b) Top 10 Percent of Individual Daylight Hours (Aggregated)**





## **4 PM LIGHT EXTINCTION UNDER “WHAT IF” CONDITIONS OF JUST MEETING SPECIFIC ALTERNATIVE SECONDARY NAAQS**

### **4.1 ALTERNATIVE SECONDARY NAAQS BASED ON MEASURED PM LIGHT EXTINCTION AS THE INDICATOR**

#### **4.1.1 Indicator and Monitoring Method**

The indicator considered in this section is PM light extinction, assumed to be measured by a continuous instrument, or instrument pair, capable of reporting both light scattering and light absorption. For example, the measurement method could be an Aethalometer® or similar instrument for measuring light absorption paired with a nephelometer, with both instruments using a PM<sub>10</sub> inlet so that PM light extinction due to PM<sub>2.5</sub> and PM<sub>10-2.5</sub> combined would be measured. A measurement of light absorption using an Aethalometer® or similar instrument based on optical analysis of collected PM would not be affected by ambient NO<sub>2</sub> concentrations. Also, if a nephelometer is calibrated to zero using filtered or zero air and spanned using a light-scattering span gas with a well characterized scattering coefficient, such as carbon dioxide, SUVA 134A, Freon 12, or Freon 22, then subsequent measurements of light extinction would reflect PM light scattering, without including the effect of Rayleigh scattering.

#### **4.1.2 Alternative Secondary NAAQS Scenarios based on Measured PM 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 light extinction and nine on 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 Light Extinction**

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

#### **4.1.3 Monitoring Site Considerations for Alternative Secondary NAAQS Based on Measured PM 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 light extinction measurement instruments as part of implementing a secondary NAAQS.

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

It would be logical to require that in any urban area for which light extinction monitoring is deemed a necessary requirement, at least one monitoring site would be placed in an area

1 expected to have the maximum PM light extinction conditions, subject to the above scale of  
2 representation consideration and possibly also subject to the condition that the site be in an area  
3 (or reasonably represent such an area) where valued urban scenes are able to be perceived by  
4 people. i.e., that the site is “population oriented.” It is difficult to imagine a neighborhood scale  
5 monitoring location within the census-defined urbanized area of an urban area which would not  
6 be “population oriented” for purposes of visual air quality, as “neighborhood” size land areas  
7 typically would have residents, workers, etc. somewhere within them during daylight hours.

8 With regard to the monitoring sites used in this assessment, all are reported to be, or  
9 appear to be, neighborhood or larger scale, and all are in areas where people are present during  
10 daylight hours. The sites in Detroit (Dearborn) and New York (Elizabeth, NJ) are, however,  
11 rather close to an industrial source and a major interstate highway interchange/turnpike exit,  
12 respectively. Significantly, most of the study sites are not the highest PM<sub>2.5</sub> concentration site in  
13 their urban area, so a “what if” scenario that manipulates the “current conditions” at these sites to  
14 “just meet” an alternative secondary NAAQS might implicitly leave other parts of their urban  
15 areas with PM light extinction above the NAAQS.

16 Probe height is another consideration. For purposes of a secondary NAAQS aimed to  
17 protect visibility, monitoring probes logically should be placed so that the sampled air is  
18 reasonably representative of the air along the sight path to the valued scene, which may be  
19 different than the probe heights of the monitors that provided data for this assessment.<sup>43</sup> We  
20 have not yet studied this issue further.

#### 21 **4.1.4 Approach to Modeling “What If” Conditions for Alternative Secondary** 22 **NAAQS Based on Measured PM Light Extinction**

23 Before modeling “what if” conditions, EPA staff augmented the data set described in  
24 Table 4 so that the sets of study days for Houston and Phoenix were seasonally balanced despite  
25 the lack of actual monitoring data for one quarter in each city. For the first quarter of 2005 in  
26 Phoenix, we substituted the available 12 days from the first quarter of 2006. For the fourth  
27 quarter of 2007 in Houston, we substituted 13 randomly drawn days from the fourth quarters of  
28 2005 and 2006.

29 Also, Tacoma (originally) and Phoenix (after this augmentation) each have only two  
30 calendar years of suitable data, while the form of the alternative NAAQS scenarios requires the  
31 averaging of the 90<sup>th</sup>, 95<sup>th</sup>, or 98<sup>th</sup> percentile values from three years. In Tacoma and Phoenix,  
32 for every step in the analysis at which a design value is used as an input or reported as an output,  
33 we averaged the percentile values from the only two available years.

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<sup>43</sup> Probe height influence on measured PM light extinction might alternatively be taken into consideration in setting the level of a NAAQS.

We modeled daylight and daily maximum daylight 1-hour PM 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 light extinction; similar steps were followed for the nine scenarios based on percentiles of all daylight 1-hour PM light-extinction. The referenced tables present results for both sets of scenarios.

1. After excluding hours with relative humidity greater than 90 percent, identify the appropriate percentile (90<sup>th</sup>, 95<sup>th</sup>, or 98<sup>th</sup>) daily maximum daylight 1-hour light extinction value in each year, noting the day and hour each occurred, and average these values across years to calculate the light extinction design value for each site consistent with the percentile form of the NAAQS scenario.<sup>44</sup> The three resulting design values for each area (for the 90<sup>th</sup>, 95<sup>th</sup>, and 98<sup>th</sup> 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 scenario under current conditions. In these cases, the “current conditions” PM light extinction values are not adjusted, i.e., PM light extinction values are never “rolled up.”) Notice that the design values for the 90<sup>th</sup> percentile maximum daily 1-hour for most cities are generally similar to the design values for the 98<sup>th</sup> percentile of all daylight hours. On average there are about ten hours defined as daylight per day, so if the light extinction were randomly distributed among the daylight hours and days, the 90<sup>th</sup> percentile maximum daily 1-hour would correspond to the 99<sup>th</sup> percentile of all hours; the fact that the point of rough equivalency is the 98<sup>th</sup> percentile indicates a tendency for hours with higher 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 light extinction values and the design values based on all daylight 1-hour 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<sup>th</sup>, 95<sup>th</sup>, and 98<sup>th</sup> 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<sup>th</sup> percentile form for the few study areas with the highest levels of PM light extinction. Panel B compares the

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<sup>44</sup> 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<sub>2.5</sub> 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<sup>th</sup> 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 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<sup>th</sup> and 20<sup>th</sup> percentile points.

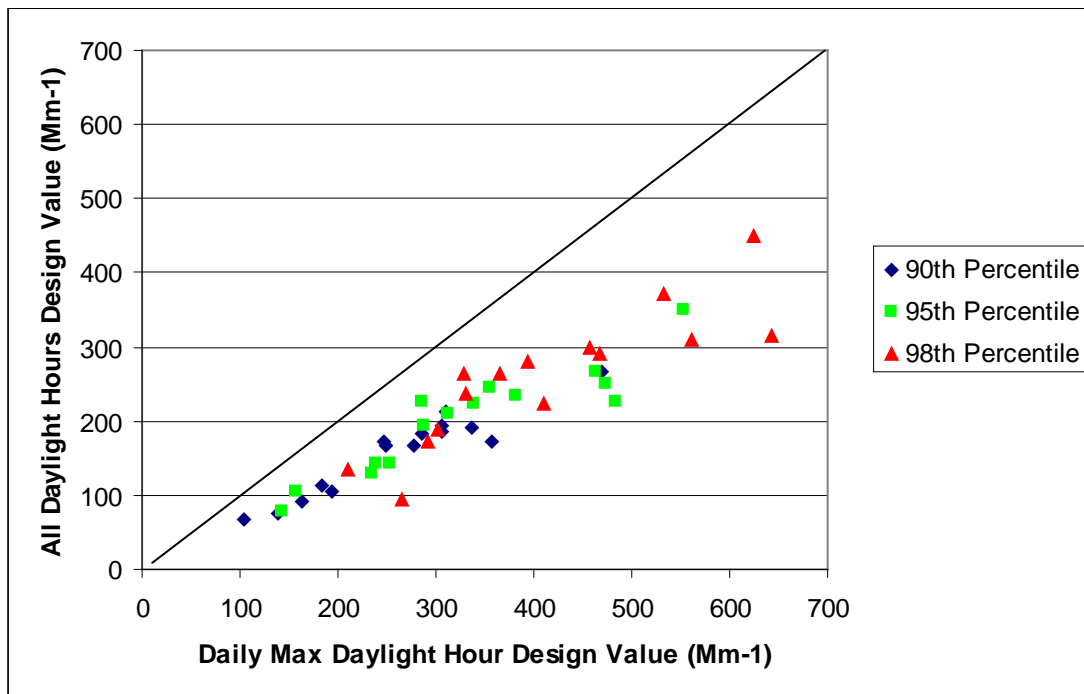
90<sup>th</sup> percentile design values based on daily maximum PM light extinction with the 90<sup>th</sup>, 95<sup>th</sup>, and 98<sup>th</sup> percentile design values based on all daylight hours PM light extinction. There is close agreement between the 90<sup>th</sup> percentile design values based on daily maximum values and the 98<sup>th</sup> percentile design value based on all daylight hours.

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

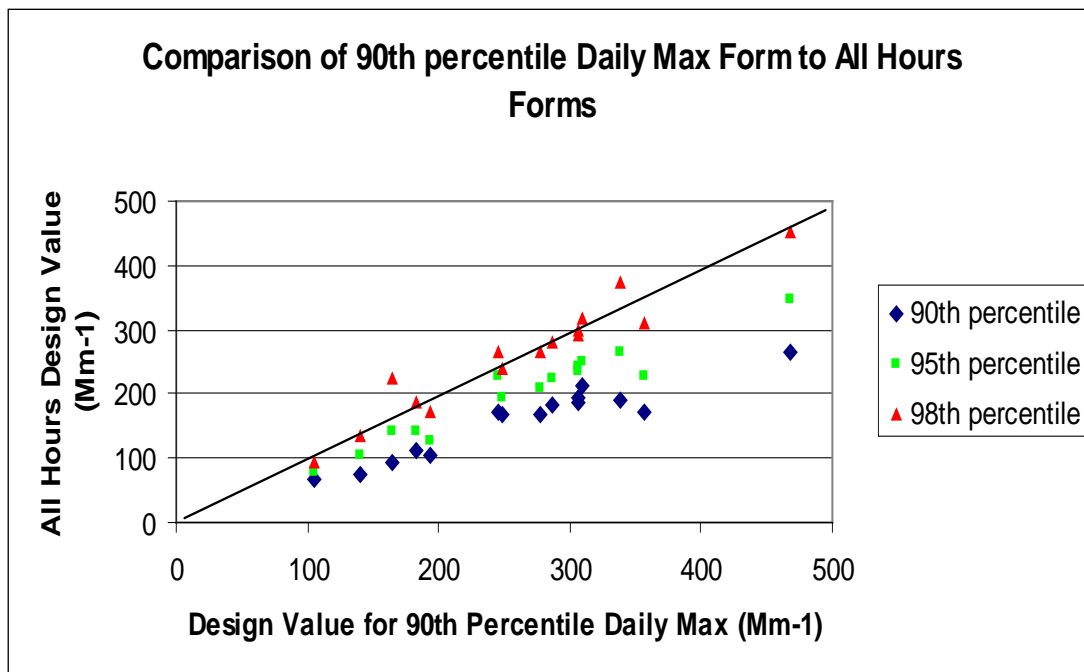
Study Area	Design Value for 90 <sup>th</sup> Percentile Form (Mm <sup>-1</sup> )	Design Value for 95 <sup>th</sup> Percentile Form (Mm <sup>-1</sup> )	Design Value for 98 <sup>th</sup> Percentile Form (Mm <sup>-1</sup> )
<b>Design Values Based on Daily Maximum Daylight 1-hour PM Light Extinction</b>			
Tacoma	140*	157*	210
Fresno	338	463	533
Los Angeles	469	554	624
Phoenix	105*	144*	266
Salt Lake City	164*	252	410
Dallas	183*	239	302
Houston	194	234	291
St. Louis	307	381	467
Birmingham	357	483	562
Atlanta	249	288	331
Detroit	310	473	644
Pittsburgh	278	313	364
Baltimore	246	286	328
Philadelphia	286	339	393
New York	306	355	457
<b>Design Values Based on Daylight 1-hour PM Light Extinction (All Daylight Hours)</b>			
Tacoma	76*	106*	136*
Fresno	190*	266	373
Los Angeles	266	349	451
Phoenix	68*	79*	94*
Salt Lake City	93*	142*	225
Dallas	113*	143*	188*
Houston	105*	128*	171*
St. Louis	194	235	290
Birmingham	173*	227	309
Atlanta	166*	195	238
Detroit	212	251	315
Pittsburgh	167*	209	264
Baltimore	172*	227	265
Philadelphia	183*	222	279
New York	186*	244	300
* This design value meets one or more of the NAAQS scenarios based on PM light extinction.			

Figure 4-1 Comparison of Daily Max and All Daylight Hour Design Values

(A) Comparison of design values matched by percentile form



(B) Comparison of 90<sup>th</sup> percentile daily maximum design values and 90<sup>th</sup>, 95<sup>th</sup>, and 98<sup>th</sup> 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 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 light extinction in order to reduce the design value to the PM light extinction level that defines the NAAQS scenario, using the following equation:

$$\text{Percent reduction required} = 1 - (\text{NAAQS level} - \text{PRB portion of the design value}) / (\text{non-PRB portion of the design value})$$

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 light extinction values to scenarios with the same level and percentile form but based on all daylight hours 1-hour PM 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 is 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 light extinction values for the three (or two) year period, determine the non-PRB portion of PM light extinction in an hour, reduce it by the percentage determined in step 4, and add back in the PRB PM light extinction. The result is the “just meets” PM 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<sub>2.5</sub> components (and thus the annual and 24-hour design values shown in Table 3-2) and PM<sub>10-2.5</sub> 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 or more of the remaining concentrations. Thus, it is not

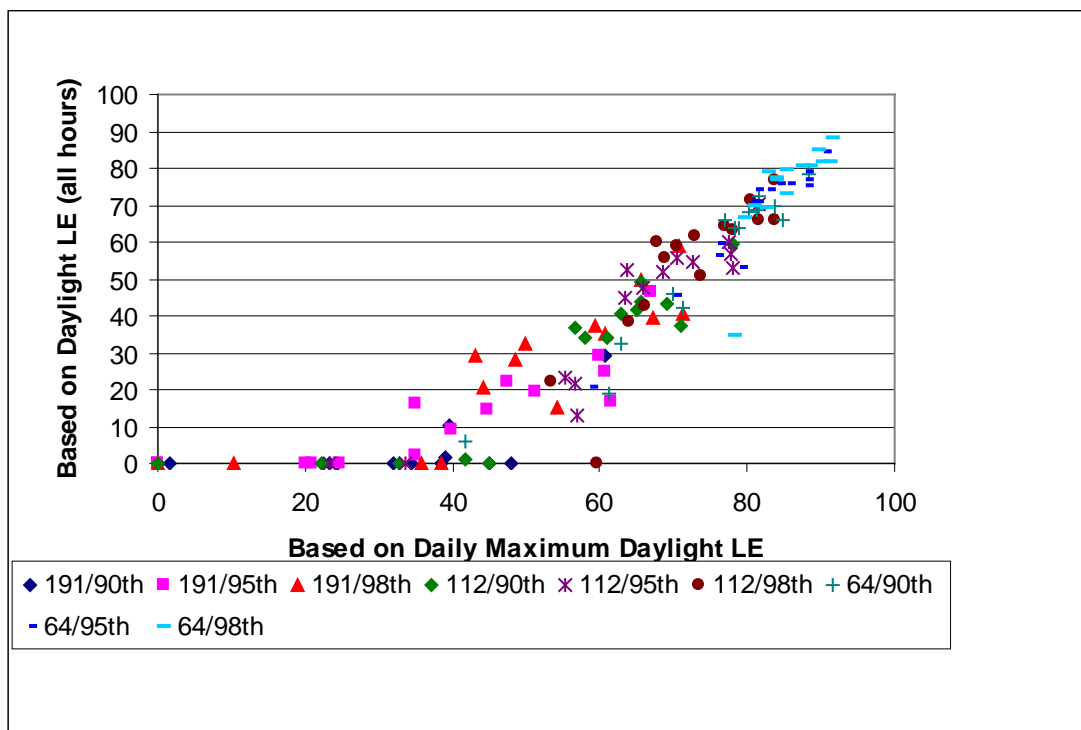
1 possible to associate unique values of annual average and 24-hour average PM<sub>2.5</sub> with the “just  
2 meeting” NAAQS scenarios reported in Table 4-3.  
3



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

	NAAQS Scenarios Based on Daily Maximum 1-hour Daylight PM light extinction, Average of Percentile Value Over Three Years								
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
<b>Level (Mm-1)</b>	<b>191</b>	<b>191</b>	<b>191</b>	<b>112</b>	<b>112</b>	<b>112</b>	<b>64</b>	<b>64</b>	<b>64</b>
<b>Percentile Form</b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>
<b>Area</b>	Percentage Reduction Required in Non-PRB PM light extinction								
Tacoma	0	0	10	22	34	53	61	70	80
Fresno	45	60	65	69	77	81	84	88	90
Los Angeles	61	67	71	78	82	84	88	90	91
Phoenix	0	0	0	0	23	60	42	59	78
Salt Lake City	0	25	54	33	57	74	63	76	85
Dallas	0	21	39	42	55	66	70	76	83
Houston	2	20	36	45	57	64	71	79	81
St. Louis	39	51	61	66	73	78	82	86	89
Birmingham	48	61	67	71	78	82	85	88	90
Atlanta	25	35	44	58	64	69	78	81	84
Detroit	39	61	71	66	78	84	82	88	91
Pittsburgh	32	40	48	61	66	70	79	81	84
Baltimore	23	35	43	57	64	68	77	81	83
Philadelphia	34	45	52	63	68	73	80	83	85
New York	39	48	59	65	70	77	81	84	88
	NAAQS Scenarios Based on 1-hour Daylight PM light extinction, Average of Percentile Value Over Three Years (All Daylight Hours)								
	(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)
<b>Level (Mm-1)</b>	<b>191</b>	<b>191</b>	<b>191</b>	<b>112</b>	<b>112</b>	<b>112</b>	<b>64</b>	<b>64</b>	<b>64</b>
<b>Percentile Form</b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>
<b>Area</b>	Percentage Reduction Required in Non-PRB PM light extinction								
Tacoma	0	0	0	0	0	22	19	46	67
Fresno	0	29	50	43	60	72	70	79	85
Los Angeles	29	47	59	60	70	77	78	84	88
Phoenix	0	0	0	0	0	0	6	20	34
Salt Lake City	0	0	15	0	22	51	33	56	73
Dallas	0	0	0	1	23	42	46	59	69
Houston	0	0	0	0	13	38	42	53	70
St. Louis	1	19	35	44	54	63	70	76	80
Birmingham	0	17	39	37	53	66	66	75	82
Atlanta	0	2	21	34	45	55	64	71	77
Detroit	10	25	40	49	57	66	73	77	82
Pittsburgh	0	9	28	34	48	59	64	71	78
Baltimore	0	16	29	37	52	60	66	74	79
Philadelphia	0	15	32	41	52	62	68	74	79
New York	0	22	37	42	56	64	69	76	81

**Figure 4-2 Comparison of Required Percentage Reductions in Non-PRB PM Light Extinction Needed to Meet NAAQS Scenarios**



## 4.2 ALTERNATIVE SECONDARY PM<sub>2.5</sub> NAAQS BASED ON ANNUAL AND 24-HOUR PM<sub>2.5</sub> MASS

### 4.2.1 Secondary NAAQS Scenarios Based on Annual and 24-hour PM<sub>2.5</sub> Mass

In this second draft version of the assessment, EPA staff have modeled two “what if” scenarios based on the same indicators and averaging periods as define the current secondary PM<sub>2.5</sub> NAAQS:

- 15 µg/m<sup>3</sup> weighted annual average PM<sub>2.5</sub> concentration and 35 µg/m<sup>3</sup> 24-hour average PM<sub>2.5</sub> concentration with a 98<sup>th</sup> percentile form, both averaged over three years. These are the current secondary NAAQS for PM<sub>2.5</sub>.
- 12 µg/m<sup>3</sup> weighted annual average PM<sub>2.5</sub> concentration and 25 µg/m<sup>3</sup> 24-hour average PM<sub>2.5</sub> concentration with a 98<sup>th</sup> percentile form, both averaged over three years.

These are the highest and lowest alternative NAAQS scenarios considered in the health risk assessment, and therefore encompass the full range of alternative primary PM<sub>2.5</sub> NAAQS being analyzed by EPA staff.

#### 4.2.2 Approach to Modeling Conditions If Secondary PM<sub>2.5</sub> NAAQS Based on Annual and 24-hour PM<sub>2.5</sub> Mass Were Just Met

Because these NAAQS scenarios are based on PM<sub>2.5</sub> 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<sub>2.5</sub> components.

1. Apply proportional rollback to all the PM<sub>2.5</sub> monitoring sites in each study area, taking into account PRB PM<sub>2.5</sub> 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<sub>2.5</sub> mass need to “just meet” the NAAQS scenario, for each study area. These percentage reductions are shown in Table 4-4. Note that Phoenix and Salt Lake City meet the 15/35 NAAQS scenario under current conditions, and require no reduction. PM<sub>2.5</sub> levels in these two cities were not “rolled up.”
2. For each day and hour for each PM<sub>2.5</sub> 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<sub>2.5</sub> components. Add back the PRB portion of the component.
4. Re-apply the IMPROVE algorithm, using the reduced PM<sub>2.5</sub> component concentrations, the current conditions PM<sub>10-2.5</sub> concentration for the day and hour, and relative humidity for the day and hour. Include the term for Rayleigh scattering.

The results of these steps are shown in Table 4-6.

**Table 4-4. Percentage reductions required in non-PRB PM<sub>2.5</sub> mass to “just meet” NAAQS scenarios based on annual and 24-hour PM<sub>2.5</sub> mass**

Study Area	Percentage Reduction Required	
	(s) Annual PM <sub>2.5</sub> NAAQS = 15 µg/m <sup>3</sup> 24-hour PM <sub>2.5</sub> NAAQS = 35 µg/m <sup>3</sup>	(t) Annual PM <sub>2.5</sub> NAAQS = 12 µg/m <sup>3</sup> 24-hour PM <sub>2.5</sub> NAAQS = 25 µg/m <sup>3</sup>
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 “JUST MEETING” EACH ALTERNATIVE SECONDARY NAAQS SCENARIO

The modeling described in sections 4.1 and 4.2 resulted in estimates of PM 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 light extinction. The top panel (a) is for the single illustrative scenario of a NAAQS based on daily maximum daylight 1-hour light extinction with a level of 112 Mm<sup>-1</sup> and a 90<sup>th</sup> percentile form, which was chosen for this illustration because it is approximately mid-way among the nine scenarios based on daily maximum light extinction in terms of stringency.<sup>45</sup> The bottom panel (b) is for the scenario of meeting the current secondary PM<sub>2.5</sub> NAAQS of 15 µg/m<sup>3</sup> for the annual average and 35 µg/m<sup>3</sup> for the 98<sup>th</sup> percentile 24-hour average. A notable feature of this comparison is that in the top panel, all the study areas have a similar distribution of the daily

<sup>45</sup> Plots of the distribution of daily maximum light extinction for all 18 NAAQS scenarios based on daily maximum light extinction, and of individual hourly light extinction for all 18 NAAQS scenarios based on individual daylight hours, are provided in Appendix F.

1 maximum daylight 1-hour PM light extinction, while in the bottom panel this is not the case.  
2 This is expected, since a NAAQS based on a measured daily maximum PM light extinction  
3 indicator will of course result in areas achieving similar daily maximum PM light extinction  
4 patterns once each area reaches a “just meets” condition. In areas with generally higher relative  
5 humidity conditions, concentrations of PM<sub>2.5</sub> components and/or PM<sub>10-2.5</sub> would need to be lower  
6 to achieve the “just meet” condition. In contrast, in the NAAQS scenario represented by the  
7 bottom panel, concentrations of PM<sub>2.5</sub> mass will be similar across areas, but concentrations of  
8 PM<sub>2.5</sub> components may not be, and levels of PM light extinction will not be similar in areas with  
9 dissimilar levels of relative humidity. The specific differences among areas in the bottom panel  
10 are generally as expected, with the drier study areas having lower levels of PM light extinction.

11 Tables 4-5 and 4-6 summarize the “just meets” conditions in the NAAQS scenarios in  
12 terms of the PM light extinction design values when just meeting. Table 4-5 addresses the 18  
13 scenarios of NAAQS based on measured PM light extinction. When an area just meets a  
14 NAAQS scenario, its design value in principle should exactly equal the NAAQS level, so  
15 preparation of this table serves as a check against calculation errors. Note that the design values  
16 in Table 4-5, resulting from the rollback steps described in section 4.1.4, in some cases do not  
17 exactly equal the assumed level of the NAAQS, although all are quite close. Closer investigation  
18 has revealed that this is mostly a result of hours switching their ranking in the rollback process.  
19 Hours can switch rank because the level of PRB PM light extinction varies with each hour, so a  
20 uniform percentage reduction in non-PRB light extinction (step 5) can result in non-uniform  
21 percentage reductions in actual PM light extinction; a lower ranking hour can thereby move up in  
22 the post-rollback ranking. In principle, rollback could be iterated to exactly achieve a design  
23 value equal to the level of the NAAQS for each scenario. However, the discrepancies indicated  
24 in Table 4-5 were judged too small to justify iterative rollback, given other uncertainties in the  
25 analysis.

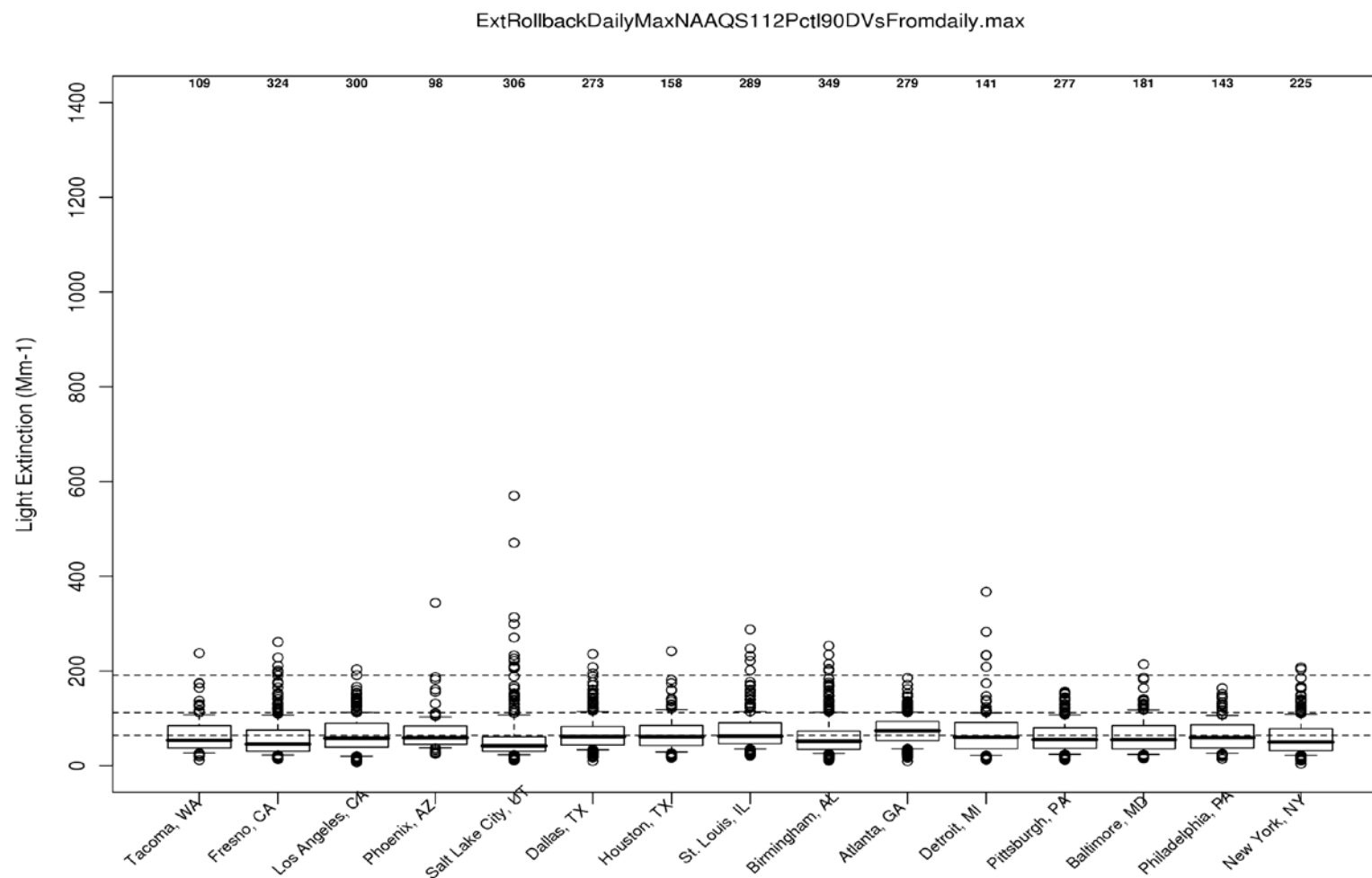
26 Table 4-6 addresses the two scenarios of NAAQS based on PM<sub>2.5</sub> mass, with PM light  
27 extinction design values shown for the 90<sup>th</sup>, 95<sup>th</sup>, and 98<sup>th</sup> percentile forms.

28 Table 4-7 summarizes all 20 scenarios in terms of the percentage of days (across 2005 to  
29 2007, but after rollback) in which the daily maximum daylight 1-hour PM light extinction under  
30 “just meeting” conditions exceeds each of the CPLs. Part A of the table applies to NAAQS  
31 scenarios based on daily maximum 1-hour PM light extinction values. Part B of the table applies  
32 to the scenarios based on 1-hour PM light extinction values during all daylight hours. Note that  
33 the reported percentages in both Part A and Part B is the percentage of days in which the daily  
34 maximum daylight 1-hour PM light extinction under “just meeting” conditions exceeds each of  
35 the CPLs; this allows comparison of the “effectiveness” of the two NAAQS approaches using a  
36 consistent metric. (The 15/35 and 12/25 NAAQS scenarios are the same in Part A and Part B,

1 and are repeated only for convenience in making comparisons.) Hours with relative humidity  
2 above 90 percent have been excluded from consideration, consistent with the definition of the  
3 NAAQS scenarios. Also shown at the bottom of the table in each column representing a  
4 NAAQS scenario is the average of these percentages of time across the 15 study areas (this is the  
5 simple column average, not weighted by the number of days available in each area).  
6 Comparisons of these percentages allows a rough indication of how the two scenarios of a  
7 NAAQS based on PM<sub>2.5</sub> mass compare to the other 18 scenarios in terms of protecting visual air  
8 quality. Notice that the most restrictive of the two NAAQS scenarios based on PM<sub>2.5</sub> mass  
9 would reduce the projected 1-hour maximum daily light extinction above the least restrictive  
10 CPL (191Mm<sup>-1</sup>) to less than 10 percent of the time for most of the urban areas (only L.A., St.  
11 Louis, and Birmingham have values above 10 percent). However at the current PM NAAQS  
12 level (i.e., 15/35) all of the eastern urban areas and Los Angeles exceed the least restrictive CPL  
13 more than 10% of the time. Comparison of Parts A and B of Figure 4-7 indicates that basing a  
14 PM light extinction NAAQS scenario on daily maximum 1-hour light extinction has a lower  
15 percentage in excess of the 1-hour daily maximum versus the NAAQS scenario based on all  
16 daylight hours light extinction for a given level and percentile form of the NAAQS. This is  
17 consistent with the results presented in Table 4-2 and Figure 4-1, which indicated that current  
18 conditions design values are generally lower for the all hours approach. Again there is near  
19 equivalence between the 90<sup>th</sup> percentile daily maximum and 98<sup>th</sup> percentile all daylight hours in  
20 terms of the percent of days exceeding the daily maximum CPL values in Table 4-7.

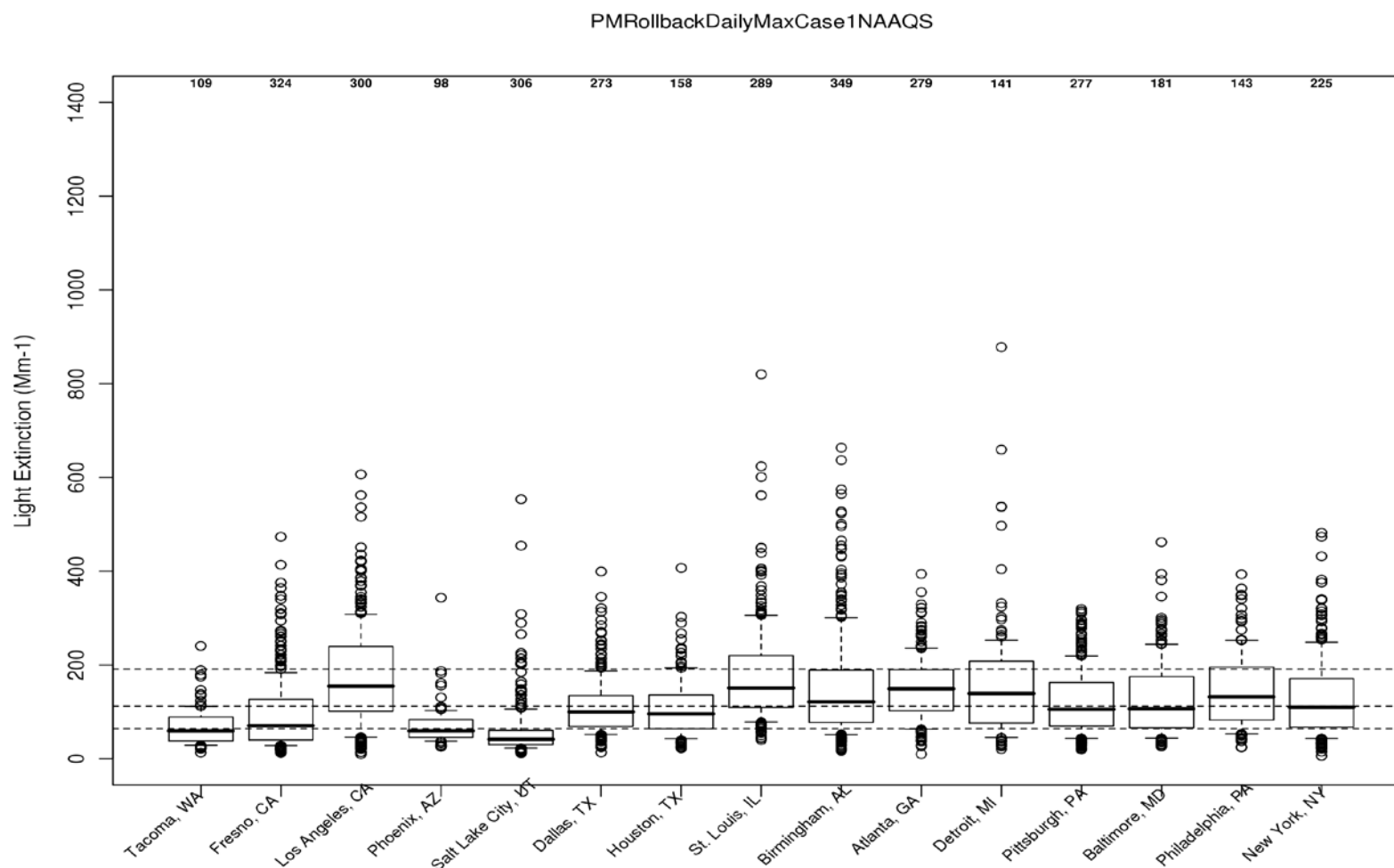
**Figure 4-3 Distributions of daily maximum daylight 1-hour PM light extinction under two “just meeting” secondary NAAQS scenarios (excluding hours with relative humidity greater than 90 percent)**

**(a) Secondary NAAQS based on daily maximum daylight 1-hour PM light extinction with a level of 112 Mm-1 and a 90th percentile form**



**Figure 4-3. Distributions of daily maximum daylight 1-hour PM light extinction under two “just meeting” secondary NAAQS scenarios (excluding hours with relative humidity greater than 90 percent), continued**

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





**Table 4-5. PM light extinction design values for “just meeting” secondary NAAQS scenarios based on measured PM light extinction (excluding hours with relative humidity greater than 90 percent)**

	<b>Secondary NAAQS Scenarios Based on Daily Maximum</b>								
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
<b>Level (Mm<sup>-1</sup>)</b>	<b>191</b>	<b>191</b>	<b>191</b>	<b>112</b>	<b>112</b>	<b>112</b>	<b>64</b>	<b>64</b>	<b>64</b>
<b>Percentile Form</b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>
	<b>PM light extinction Design Value (based on same percentile form as the NAAQS scenario)</b>								
Tacoma, WA	140	157	191	112	112	108	66	70	60
Fresno, CA	191	191	191	112	112	112	64	64	64
Los Angeles, CA	191	191	191	112	112	112	65	64	64
Phoenix, AZ	105	144	185	105	112	112	64	64	64
Salt Lake City, UT	164	191	191	112	112	112	64	64	64
Dallas, TX	183	191	191	113	113	112	64	66	66
Houston, TX	191	191	191	115	112	112	67	61	67
St. Louis, IL	191	191	191	113	112	112	65	64	64
Birmingham, AL	191	192	191	113	114	112	64	66	64
Atlanta, GA	191	191	191	112	111	112	64	63	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	65
Philadelphia, PA	191	191	191	112	112	112	65	64	64
New York, NY	192	191	191	113	112	112	65	64	64
	<b>Secondary NAAQS Scenarios Based on All Daylight Hours</b>								
	(j)	(k)	(l)	(m)	(n)	(o)	(p)	(q)	(r)
<b>Level (Mm<sup>-1</sup>)</b>	<b>191</b>	<b>191</b>	<b>191</b>	<b>112</b>	<b>112</b>	<b>112</b>	<b>64</b>	<b>64</b>	<b>64</b>
<b>Percentile Form</b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>	<b>90<sup>th</sup></b>	<b>95<sup>th</sup></b>	<b>98<sup>th</sup></b>
	<b>PM light extinction Design Value (based on same percentile form as the NAAQS scenario)</b>								
Tacoma, WA	76	106	136	76	106	112	63	64	59
Fresno, CA	190	191	191	113	112	112	65	64	64
Los Angeles, CA	192	191	192	113	112	112	66	64	64
Phoenix, AZ	68	79	94	68	79	94	64	64	64
Salt Lake City, UT	93	142	191	93	112	112	64	64	64
Dallas, TX	113	143	188	112	112	113	66	64	67
Houston, TX	105	128	171	105	113	110	65	66	61
St. Louis, IL	191	191	191	113	112	111	65	65	65
Birmingham, AL	173	191	192	113	112	113	65	64	65
Atlanta, GA	166	191	192	113	111	113	66	63	65
Detroit, MI	191	191	191	112	113	112	64	65	64
Pittsburgh, PA	167	191	191	113	113	112	65	66	64
Baltimore, MD	172	191	191	112	112	112	64	65	64
Philadelphia, PA	183	191	191	112	112	113	64	64	65
New York, NY	186	191	191	112	112	113	64	66	66

**Table 4-6. PM light extinction design values for “just meeting” secondary NAAQS scenarios based on PM<sub>2.5</sub> mass (excluding hours with relative humidity greater than 90 percent)**

Annual/1-hour PM <sub>2.5</sub> NAAQS	(s) 15µg/m <sup>3</sup> / 35µg/m <sup>3</sup>			(t) 12µg/m <sup>3</sup> / 25µg/m <sup>3</sup>		
	90 <sup>th</sup> %tile Design Value (Mm <sup>-1</sup> )	95 <sup>th</sup> %tile Design Value (Mm <sup>-1</sup> )	98 <sup>th</sup> %tile Design Value (Mm <sup>-1</sup> )	90 <sup>th</sup> %tile Design Value (Mm <sup>-1</sup> )	95 <sup>th</sup> %tile Design Value (Mm <sup>-1</sup> )	98 <sup>th</sup> %tile Design Value (Mm <sup>-1</sup> )
<b>Design Values Based on Daily Maximum Daylight 1-hour PM Light Extinction</b>						
Tacoma, WA	120	131	177	94	102	136
Fresno, CA	195	267	306	144	197	225
Los Angeles, CA	323	365	436	239	263	360
Phoenix, AZ	105*	143*	265*	97	135	250
Salt Lake City, UT	110	168	269	83	125	198
Dallas, TX	183*	239*	302*	172	224	282
Houston, TX	185	222	276	148	178	220
St. Louis, IL	286	355	441	253	289	364
Birmingham, AL	285	394	464	213	300	365
Atlanta, GA	230	266	307	181	208	243
Detroit, MI	257	389	536	189	278	401
Pittsburgh, PA	229	258	299	167	188	218
Baltimore, MD	233	272	310	169	202	222
Philadelphia, PA	264	313	364	194	226	269
New York, NY	255	296	381	183	213	272
<b>Design Values Based on Daylight 1-hour PM Light Extinction (All Daylight Hours)</b>						
Tacoma, WA	65	88	113	52	70	84
Fresno, CA	112	154	217	84	115	161
Los Angeles, CA	176	233	299	131	172	223
Phoenix, AZ	68*	79*	94*	60	70	86
Salt Lake City, UT	63	95	150	48	72	112
Dallas, TX	113*	143*	188*	106	134	176
Houston, TX	99	122	163	81	99	131
St. Louis, IL	181	221	271	147	183	237
Birmingham, AL	140	183	247	105	138	186
Atlanta, GA	154	180	220	123	144	174
Detroit, MI	176	209	258	130	155	188
Pittsburgh, PA	138	173	218	102	127	159
Baltimore, MD	163	215	251	121	157	184
Philadelphia, PA	169	206	258	123	150	187
New York, NY	156	204	250	113	148	179

\* Phoenix and Dallas meet 15 µg/m<sup>3</sup>/35 µg/m<sup>3</sup> under current conditions, so these entries are essentially the same as for current conditions.

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

(A) NAAQS Scenarios Based on Daily Maximum 1-hour PM Light Extinction

	Days with max hour above 64 Mm <sup>-1</sup>											Days with max hour above 112 Mm <sup>-1</sup>											Days with max hour above 191 Mm <sup>-1</sup>										
	(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 <sup>-1</sup>	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	49	40	32	17	11	7	2	43	28	22	22	14	10	7	2	1	1	0	10	5	4	4	3	1	1	0	0	0	0	1	0
Fresno	55	42	34	31	20	15	10	4	3	54	40	30	16	12	10	5	3	1	0	0	30	17	10	5	3	2	0	0	0	0	0	10	5
Los Angeles	74	67	60	44	35	28	11	6	3	85	79	41	32	26	10	6	3	0	0	0	69	53	10	6	3	1	0	0	0	0	0	39	20
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	14	24	11	5	10	5	1	24	15	17	11	5	9	5	1	4	1	0	9	6	8	5	1	4	1	0	1	0	0	4	2
Dallas	80	66	51	49	28	14	11	5	1	81	77	41	23	13	10	5	1	1	0	0	41	37	10	5	1	1	0	0	0	0	0	10	8
Houston	77	65	57	47	31	20	13	4	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	83	72	57	47	35	21	12	6	2	97	89	45	30	19	12	6	2	1	0	0	74	57	11	5	3	2	1	0	0	0	0	36	21
Birmingham	63	51	41	34	20	16	10	6	3	84	70	31	18	12	10	5	3	1	0	0	55	38	10	5	2	1	0	0	0	0	0	24	13
Atlanta	86	81	77	62	52	37	10	5	1	90	85	59	47	31	11	5	1	0	0	0	71	54	11	4	2	0	0	0	0	0	0	25	8
Detroit	74	54	43	48	23	6	11	4	3	80	74	45	18	6	10	4	3	4	1	0	61	50	10	4	3	4	1	0	1	0	0	33	10
Pittsburgh	70	64	54	40	32	24	9	6	2	78	63	38	29	22	9	6	1	0	0	0	48	28	9	6	1	0	0	0	0	0	0	16	5
Baltimore	68	62	55	43	31	27	12	4	2	78	64	40	29	23	12	5	2	1	0	0	48	31	12	6	2	1	0	0	0	0	0	19	8
Philadelphia	73	66	61	43	33	28	8	6	3	85	74	39	30	25	8	5	3	0	0	0	61	38	8	5	3	0	0	0	0	0	0	28	9
New York	63	59	42	35	28	18	9	6	2	76	62	32	25	16	10	6	2	1	0	0	45	30	10	6	2	1	0	0	0	0	0	19	8
Average	67	58	49	42	29	19	10	5	2	72	62	35	24	16	10	5	2	1	0	35	45	32	9	5	2	1	0	0	0	0	0	18	8

(B) NAAQS Scenarios Based on PM Light Extinction During All Daylight Hours\*

	Days with max hour above 64 Mm <sup>-1</sup>											Days with max hour above 112 Mm <sup>-1</sup>											Days with max hour above 191 Mm <sup>-1</sup>										
	(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 <sup>-1</sup>	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	24	10	43	28	22	22	22	22	22	10	10	4	1	10	5	4	4	4	4	4	1	1	0	0	1	0
Fresno	75	65	52	57	42	29	30	18	9	54	40	52	37	26	30	16	8	9	3	1	30	17	30	16	8	10	5	1	2	0	0	10	5
Los Angeles	86	83	76	76	61	47	44	27	13	85	79	73	58	44	42	28	13	10	2	1	69	53	42	27	12	12	3	1	0	0	0	39	20
Phoenix	44	44	44	44	44	44	44	30	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	34	44	28	15	24	11	6	24	15	17	17	14	17	11	6	9	5	1	9	6	8	8	5	8	5	2	4	1	1	4	2
Dallas	80	80	80	80	64	48	43	21	11	81	77	41	41	41	41	21	10	9	3	1	41	37	10	10	10	10	4	1	1	0	0	10	8
Houston	77	77	77	77	70	53	51	35	13	75	64	44	44	44	44	34	13	12	8	1	41	23	11	11	11	11	7	2	1	1	0	11	3
St. Louis	98	93	85	78	69	52	40	28	15	97	89	76	62	48	39	28	15	8	3	2	74	57	39	27	15	9	4	2	1	0	0	36	21
Birmingham	89	85	73	74	59	43	42	26	15	84	70	65	56	40	42	25	14	14	7	3	55	38	34	26	14	15	9	3	3	1	0	24	13
Atlanta	91	91	87	82	76	64	52	30	15	90	85	75	73	62	48	30	13	5	1	0	71	54	31	30	12	6	1	0	0	0	0	25	8
Detroit	84	78	73	67	57	47	41	29	11	80	74	64	55	45	40	26	9	5	4	4	61	50	40	26	9	6	4	4	1	1	1	33	10
Pittsburgh	85	83	74	69	55	44	36	23	11	78	63	57	53	40	35	22	11	8	1	0	48	28	26	22	11	8	2	0	0	0	0	16	5
Baltimore	80	72	66	61	45	38	29	15	9	78	64	50	43	34	28	14	8	4	2	0	48	31	23	14	8	5	2	1	0	0	0	19	8
Philadelphia	86	83	74	68	60	45	34	23	9	85	74	64	58	41	33	24	8	5	1	0	61	38	31	24	8	7	1	0	0	0	0	28	9
New York	83	74	63	62	46	36	31	19	11	76	62	59	42	33	30	18	10	7	3	1	45	30	28	18	10	8	3	1	0	0	0	19	8
Average	77	74	67	66	55	43	39	24	12	72	62	51	44	36	33	22	10	8	3	1	45	32	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%).

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## **APPENDICES**

**A. PM<sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas**

**B. Distributions of Estimated PM<sub>2.5</sub> and Other Components under Current Conditions**

**C. Development of PRB Estimates of PM<sub>2.5</sub> components, PM<sub>10-2.5</sub>, and PM light extinction**

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

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

**F. Distributions of Maximum Daily Daylight PM 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**



# APPENDIX A - PM<sub>2.5</sub> MONITORING SITES AND MONITORS PROVIDING 2005-2007 DATA FOR THE ANALYSIS OF PM LIGHT EXTINCTION IN THE 15 STUDY AREAS

PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Tacoma	<p>AQS ID <a href="#">530530029</a>  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</p> <p>2005-2007 annual DV = 10.2  2005-2007 24-hr DV = 43  This is the highest 24-hour PM<sub>2.5</sub> DV site in the Seattle-Tacoma-Olympia, WA annual PM<sub>2.5</sub> nonattainment area</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; one-in-three sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-six sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass) Correlated Radiance Research M903 Nephelometry</li> </ul> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column..</p>	NA	<p>AQS ID <a href="#">530530031</a>  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<sub>2.5</sub> site</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 1-hour PM<sub>10</sub> STP mass (AQS parameter 81102)</li> <li>• Sample Collection Method: INSTRUMENTAL-R&amp;P SA246B-INLET</li> <li>• Sample Analysis Method: TEOM-GRAVIMETRIC</li> </ul> <p>7% of PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>: PM<sub>2.5</sub> ratios from 2005 Staff Paper</p>

PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Fresno	<p>AQS ID <a href="#">060190008</a>  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</p> <p>2005-2007 annual DV = 17.4  2005-2007 24-hr DV = 63  This is not the highest annual or 24-hr PM<sub>2.5</sub> DV site in the San Joaquin nonattainment area.</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-three sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88501, PM<sub>2.5</sub> Raw Data) Met-One BAM</li> </ul> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column..</p>	NA	PM <sub>10-2.5</sub> values were determined using regional average PM <sub>10-2.5</sub> : PM <sub>2.5</sub> ratios from 2005 Staff Paper

PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Los Angeles	<p>AQS ID <a href="#">060658001</a>  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.</p> <p>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.</p> <p>Neighborhood scale.</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-three sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> (AQS parameter 88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass) R&amp;P 1400 TEOM</li> </ul> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column..</p>	NA	<p>AQS ID <a href="#">060710306</a>  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<sub>2.5</sub> site, on the other side of a range of hills. 0.4 miles from I-15</p> <p>Measurement Scale not given in AQS, but appears Neighborhood by aerial image.</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 1-hour PM<sub>10</sub> STP mass (AQS parameter 81102)</li> <li>• Sample Collection Method: INSTRUMENTAL-R&amp;P SA246B-INLET</li> <li>• Sample Analysis Method: TEOM-GRAVIMETRIC</li> </ul> <p>6% of PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>: PM<sub>2.5</sub> ratios from 2005 Staff Paper</p>

PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Phoenix	<p>AQS ID <a href="#">040137020</a> (FRM &amp; 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.</p> <p>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.</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; one-in-six sampling schedule)</li> <li>PM<sub>2.5</sub> speciation (one-in-three sampling schedule)</li> </ul> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column.</p>	<p>AQS ID <a href="#">040139998</a> (Continuous)  State: Arizona  City: Phoenix  MSA: Phoenix-Mesa, AZ  Local Site Name: Vehicle Emissions Laboratory  Address: 600 N 40<sup>th</sup> St &amp; Fillmore St</p> <p>Measurement Scale not available; 0.75 miles from intersection of two freeways, 1 mile from Phoenix airport.</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>1-hour PM<sub>2.5</sub> mass. Nephelometer.</li> </ul>	<p>AQS ID <a href="#">040133002</a>  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</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>1-hour PM<sub>10</sub> STP mass (AQS parameter 81102)</li> </ul> <p>Sample Collection Method: INSTRUMENTAL-R&amp;P SA246B-INLET  Sample Analysis Method: TEOM-GRAVIMETRIC</p> <p>2% of PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>: PM<sub>2.5</sub> ratios from 2005 Staff Paper</p>

PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Salt Lake City	<p>AQS ID <a href="#">490353006</a>  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</p> <p>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.</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-three sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88501, PM<sub>2.5</sub> Raw Data) FDMS-Gravimetric</li> </ul> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column.</p>	NA	PM <sub>10-2.5</sub> values were determined using regional average PM <sub>10-2.5</sub> : PM <sub>2.5</sub> ratios from 2005 Staff Paper
Dallas	<p>AQS ID <a href="#">481130069</a>  State: Texas  City: Dallas  MSA: Dallas, TX  Local Site Name: DALLAS HINTON  Address: 1415 HINTON STREET  4.5 miles NE of central Dallas</p> <p>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.</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-three sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass) TEOM Gravimetric 50 deg C</li> </ul> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column..</p>	NA	PM <sub>10-2.5</sub> values were determined using regional average PM <sub>10-2.5</sub> : PM <sub>2.5</sub> ratios from 2005 Staff Paper

PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Houston	<p>AQS ID <a href="#">482010024</a>  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</p> <p>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.</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; one-in-six day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-six sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass)</li> </ul> <p>TEOM Gravimetric 50 deg C</p> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column.</p>	NA	<p>PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>: PM<sub>2.5</sub> ratios from 2005 Staff Paper</p>

PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
St. Louis	<p>AQS ID <a href="#">295100085</a>  State: Missouri  City: St. Louis  MSA: St, Louis, MO-IL  Local Site Name: BLAIR STREET  CATEGORY A CORE SLAM  PM<sub>2.5</sub>.  Address: BLAIR S  2 miles north of central St. Louis</p> <p>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.</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-three sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass) TEOM Gravimetric 30 deg C</li> </ul> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column.</p>	NA	<p>AQS ID <a href="#">295100092</a> (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<sub>2.5</sub> site, across the street from the eastern edge of what appears to be a recycling/municipal works yard.</p> <p>Middle Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 1-hour PM<sub>10</sub> STP mass (AQS parameter 81102)</li> <li>• Sample Collection Method: INSTRUMENTAL-R&amp;P SA246B-INLET</li> <li>• Sample Analysis Method: TEOM-GRAVIMETRIC Site was on the other (western) side of the recycling/municipal works yard as site 295100093, below.</li> </ul> <p><a href="#">295100093</a> (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<sub>2.5</sub> site, across the street from the western edge of what appears to be a recycling/municipal works yard.</p> <p>Middle Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 1-hour PM<sub>10</sub> STP mass (AQS parameter 81102)</li> <li>• Sample Collection Method: INSTRUMENTAL-R&amp;P SA246B-INLET</li> <li>• Sample Analysis Method: TEOM-GRAVIMETRIC</li> <li>• 4% of PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>: PM<sub>2.5</sub> ratios from 2005 Staff Paper</li> </ul>

PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Birmingham	<p>AQS ID <a href="#">010730023</a>            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</p> <p>2005-2007 annual DV = 18.7            2005-2007 24-hr DV = 44            This is the highest DV site in the            Birmingham nonattainment area</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-three sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass)</li> </ul> <p>TEOM Gravimetric 50 deg C</p> <ul style="list-style-type: none"> <li>• 1-hour PM<sub>10</sub> STP mass (AQS parameter 81102)</li> </ul> <p>Sample Collection Method:            INSTRUMENTAL-R&amp;P SA246B-INLET            Sample Analysis Method: TEOM-GRAVIMETRIC</p>	NA	<p>Same as PM<sub>2.5</sub> site.</p> <p>0.3% of PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>: PM<sub>2.5</sub> ratios from 2005 Staff Paper</p>



PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Atlanta	<p>AQS ID <a href="#">130890002</a>  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</p> <p>2005-2007 annual DV = 15.7  2005-2007 24-hr DV = 33  This is not the highest DV site in the Atlanta nonattainment area.</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-three sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass) TEOM Gravimetric 30 deg C</li> </ul> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column.</p>	NA	<p>AQS ID <a href="#">131210048</a>  State: Georgia  City: Atlanta  MSA: Atlanta, GA  Local Site Name: Georgia Tech, Ford Environmental Science and Technology Bldg, roof  Address: GA. TECH., Ford ES&amp;T Bldg, 311 Ferst St NW, Atlanta GA  8.6 miles NW of PM<sub>2.5</sub> site</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 1-hour PM<sub>10</sub> STP mass (AQS parameter 81102)</li> </ul> <p>Sample Collection Method: INSTRUMENT MET ONE 4 MODELS  Sample Analysis Method: BETA ATTENUATION</p> <p>8% of PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>: PM<sub>2.5</sub> ratios from 2005 Staff Paper</p>

PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Detroit	<p>AQS ID <a href="#">261630033</a>  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</p> <p>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</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-six sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88501, PM<sub>2.5</sub> Raw Data) TEOM Gravimetric 50 deg C</li> <li>• 1-hour PM<sub>10</sub> STP mass (AQS parameter 81102)</li> </ul> <p>Sample Collection Method: INSTRUMENTAL-R&amp;P SA246B-INLET  Sample Analysis Method: TEOM-GRAVIMETRIC</p>	NA	<p>Same as PM<sub>2.5</sub> site.</p> <p>2% of PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>: PM<sub>2.5</sub> ratios from 2005 Staff Paper</p>

PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Pittsburgh	<p>AQS ID <a href="#">420030008</a>            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</p> <p>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.</p> <p>Urban Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-three sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass) TEOM Gravimetric 50 deg C</li> </ul> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column.</p>	NA	PM <sub>10-2.5</sub> values were determined using regional average PM <sub>10-2.5</sub> : PM <sub>2.5</sub> ratios from 2005 Staff Paper
Baltimore	<p>AQS ID <a href="#">240053001</a> (FRM &amp; CSN)            State: Maryland            City: Essex            MSA: Baltimore, MD            Local Site Name: Essex            Address: 600 Dorsey Avenue            7 miles east of central Baltimore</p> <p>2005-2007 annual DV = 14.5            2005-2007 24-hr DV = 35            This is not the highest DV site in the Baltimore nonattainment area.</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-three sampling schedule)</li> <li>• 1-hour PM<sub>10</sub> LC mass (AQS parameter 85101)</li> </ul>	<p>AQS ID <a href="#">245100040</a> (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</p> <p>Middle Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass) TEOM Gravimetric 50 deg C</li> </ul>	<p>Same as PM<sub>2.5</sub> site.</p> <p>5% of PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>: PM<sub>2.5</sub> ratios from 2005 Staff Paper</p>

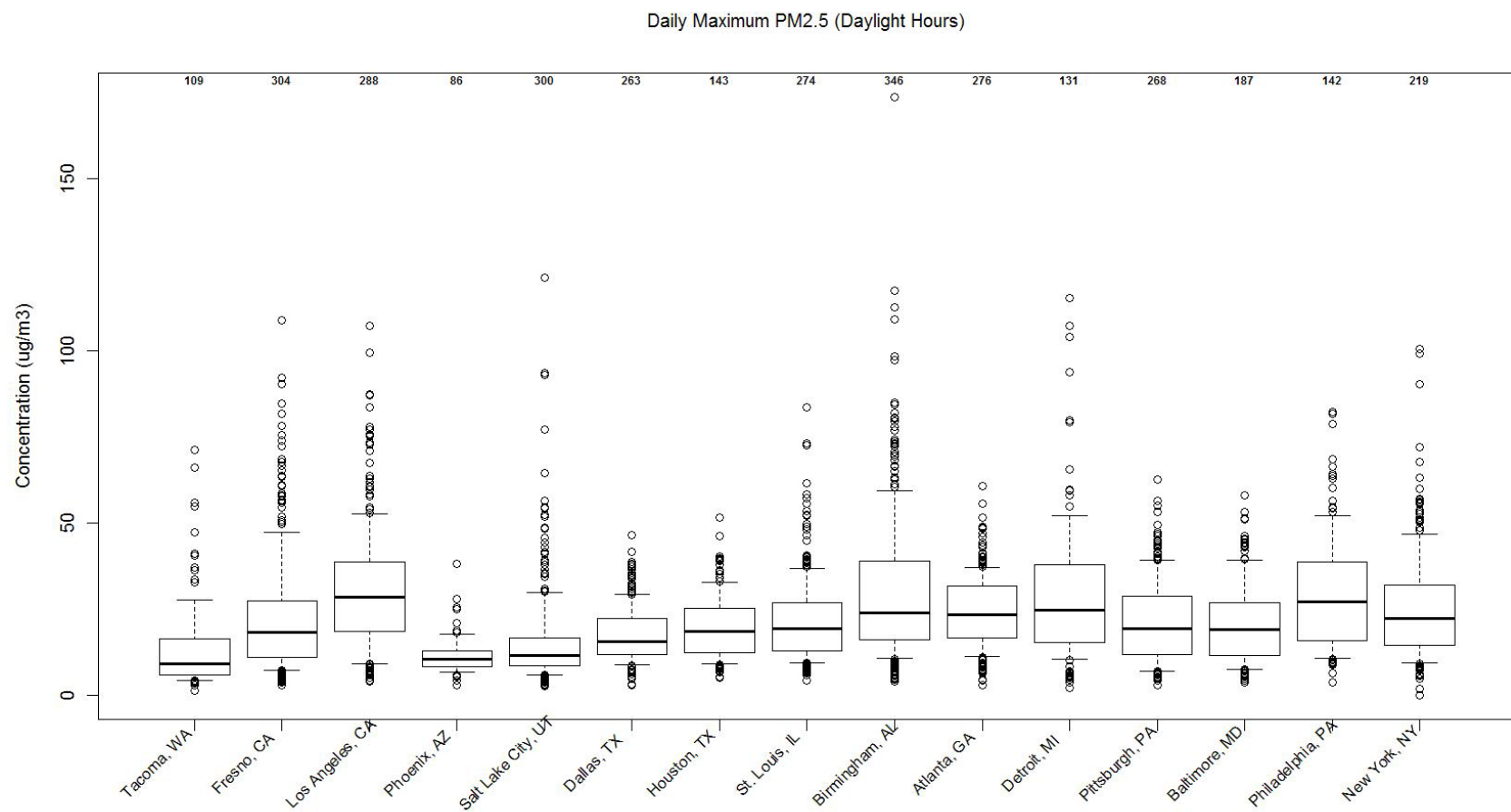
PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
Philadelphia	<p>AQS ID <a href="#">100032004</a> (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</p> <p>2005-2007 annual DV = 14.7            2005-2007 24-hr DV = 37            This is not the highest DV site in the Philadelphia nonattainment area</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-six sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88501, PM<sub>2.5</sub> Raw Data) Beta Attenuation</li> <li>• 1-hour PM<sub>10</sub> STP mass (AQS parameter 81102)</li> </ul>	NA	<p>Same as PM<sub>2.5</sub> site.</p> <p>3% of PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>: PM<sub>2.5</sub> ratios from 2005 Staff Paper</p>
New York	<p>AQS ID <a href="#">340390004</a> (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</p> <p>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</p> <p>Neighborhood Scale</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 24-hour FRM PM<sub>2.5</sub> mass (AQS parameter 88101; every day sampling schedule)</li> <li>• PM<sub>2.5</sub> speciation (one-in-three sampling schedule)</li> <li>• 1-hour PM<sub>2.5</sub> mass (AQS parameter 88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass) TEOM Gravimetric 30 deg C</li> </ul> <p>No continuous PM<sub>10</sub> monitoring at this site, see right hand column.</p>	NA	<p>AQS ID <a href="#">360610125</a>            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</p> <p>Measurement scale not stated.</p> <p>Parameters taken from this site:</p> <ul style="list-style-type: none"> <li>• 1-hour PM<sub>10</sub> STP mass (AQS parameter 81102)</li> </ul> <p>Sample Collection Method: INSTRUMENTAL-R&amp;P SA246B-INLET            Sample Analysis Method: TEOM-GRAVIMETRIC</p> <p>2% of PM<sub>10-2.5</sub> values were determined using regional average PM<sub>10-2.5</sub>: PM<sub>2.5</sub> ratios from 2005 Staff Paper</p>

PM <sub>2.5</sub> Monitoring Sites and Monitors Providing 2005-2007 Data for the Analysis of PM light extinction in the 15 Study Areas			
Study Area	First PM <sub>2.5</sub> Monitoring Site	Second PM <sub>2.5</sub> Monitoring Site (if applicable)	PM <sub>10</sub> data source for PM <sub>10-2.5</sub>
<p>Notes:</p> <ul style="list-style-type: none"> <li>• In this Table, the 1-hour concentration parameter “88502, Acceptable PM<sub>2.5</sub> AQI &amp; Speciation Mass” is the same as the ISA refers to as “FRM-like” PM<sub>2.5</sub> mass. An entry of “88501, PM<sub>2.5</sub> Raw Data” indicates that the monitoring agency makes no representation as to the degree of correlation with FRM PM<sub>2.5</sub> mass. The latter type of continuous PM<sub>2.5</sub> data were used only when the former were unavailable.</li> <li>• Where PM<sub>10</sub> was reported in STP, it was converted to LC before PM<sub>10-2.5</sub> was calculated.</li> <li>• All continuous PM<sub>2.5</sub> 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.</li> </ul>			

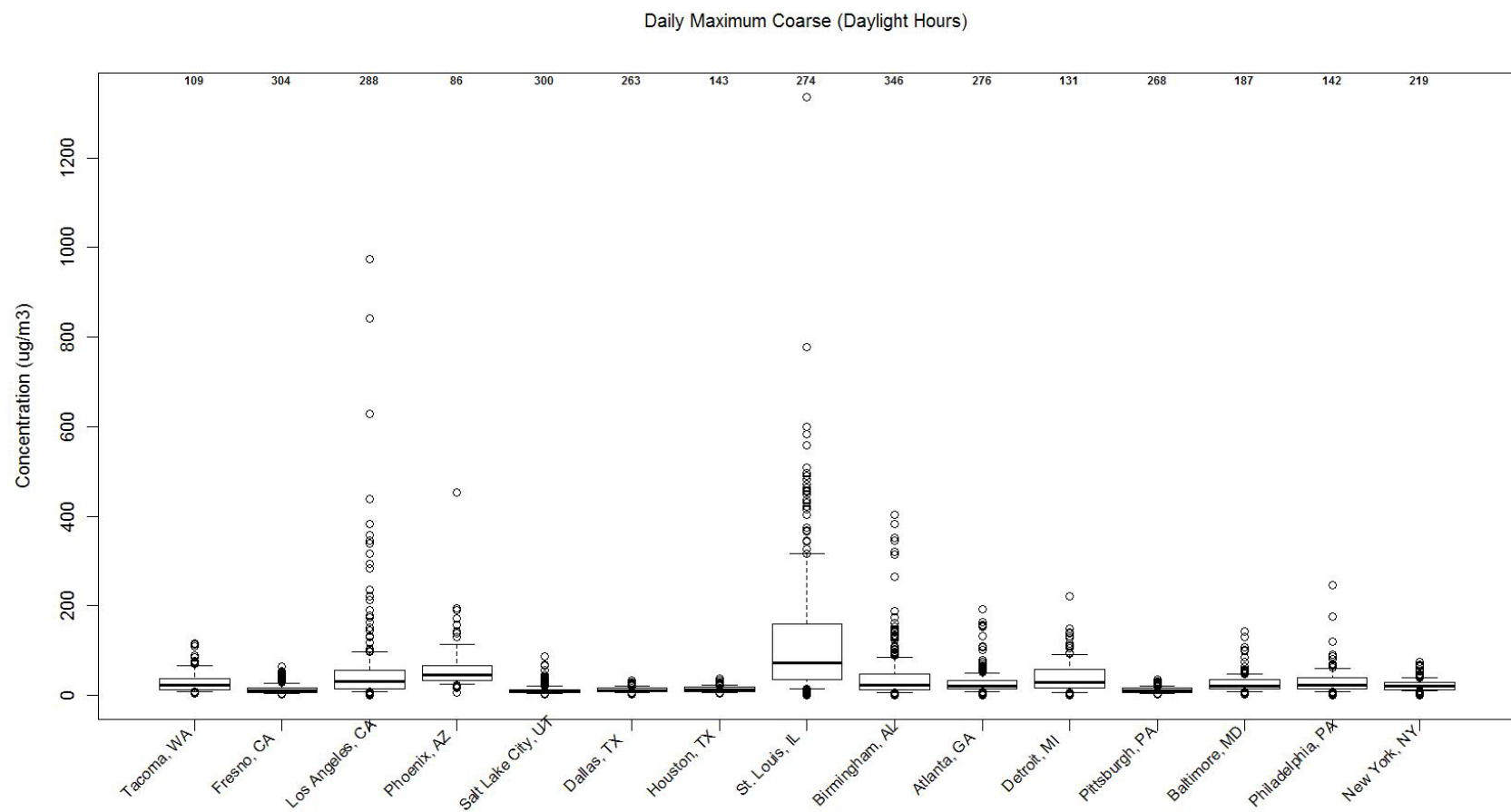
## **APPENDIX B - DISTRIBUTIONS OF ESTIMATED PM<sub>2.5</sub> AND OTHER COMPONENTS**

**Figure B-1 – Distribution of daily maximum PM<sub>2.5</sub> and PM<sub>10-2.5</sub> across the 2005-2007 period, by study area**

(a) Daily maximum daylight PM<sub>2.5</sub>



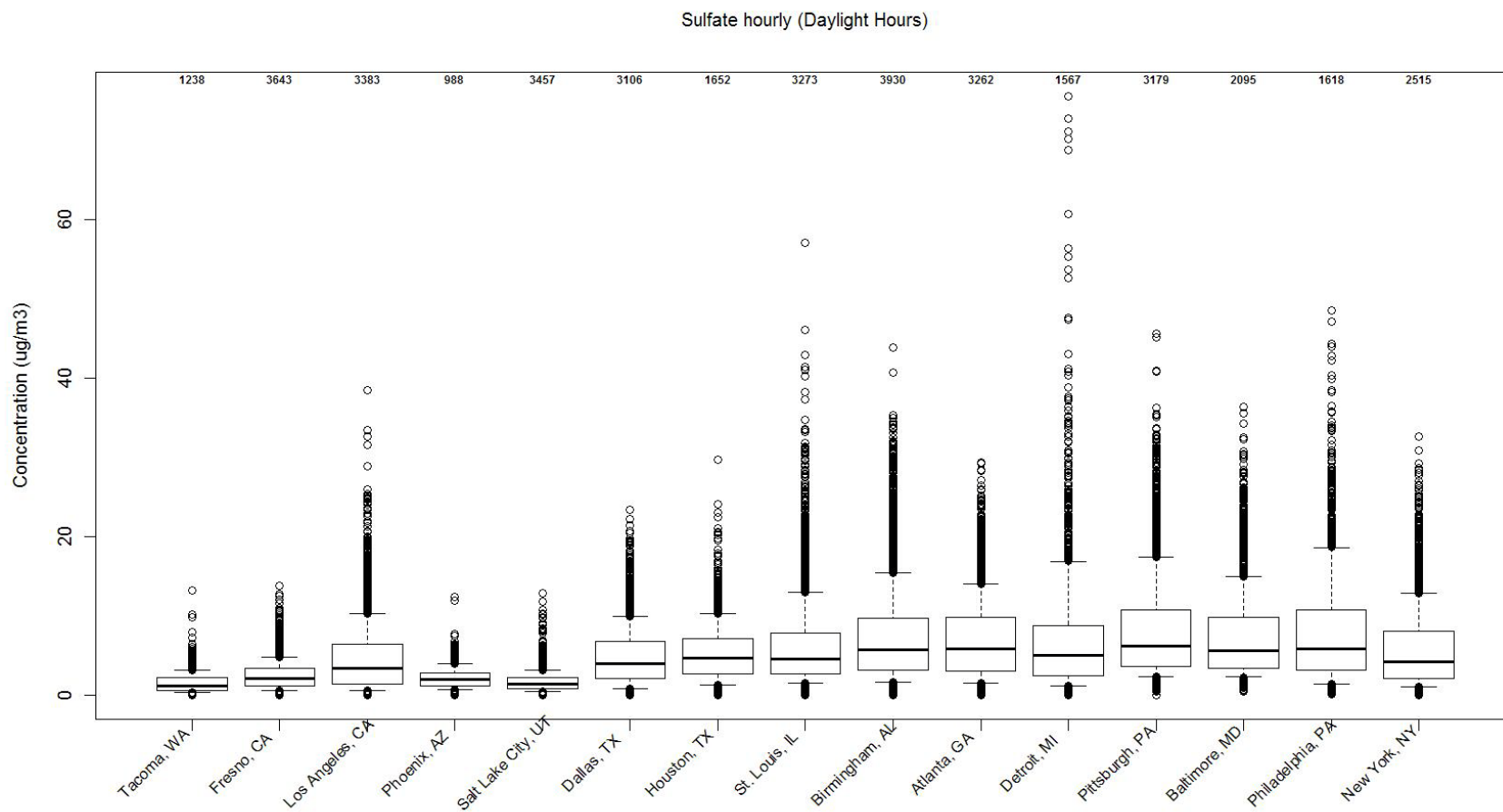
(b) Daily maximum daylight PM<sub>10-2.5</sub>





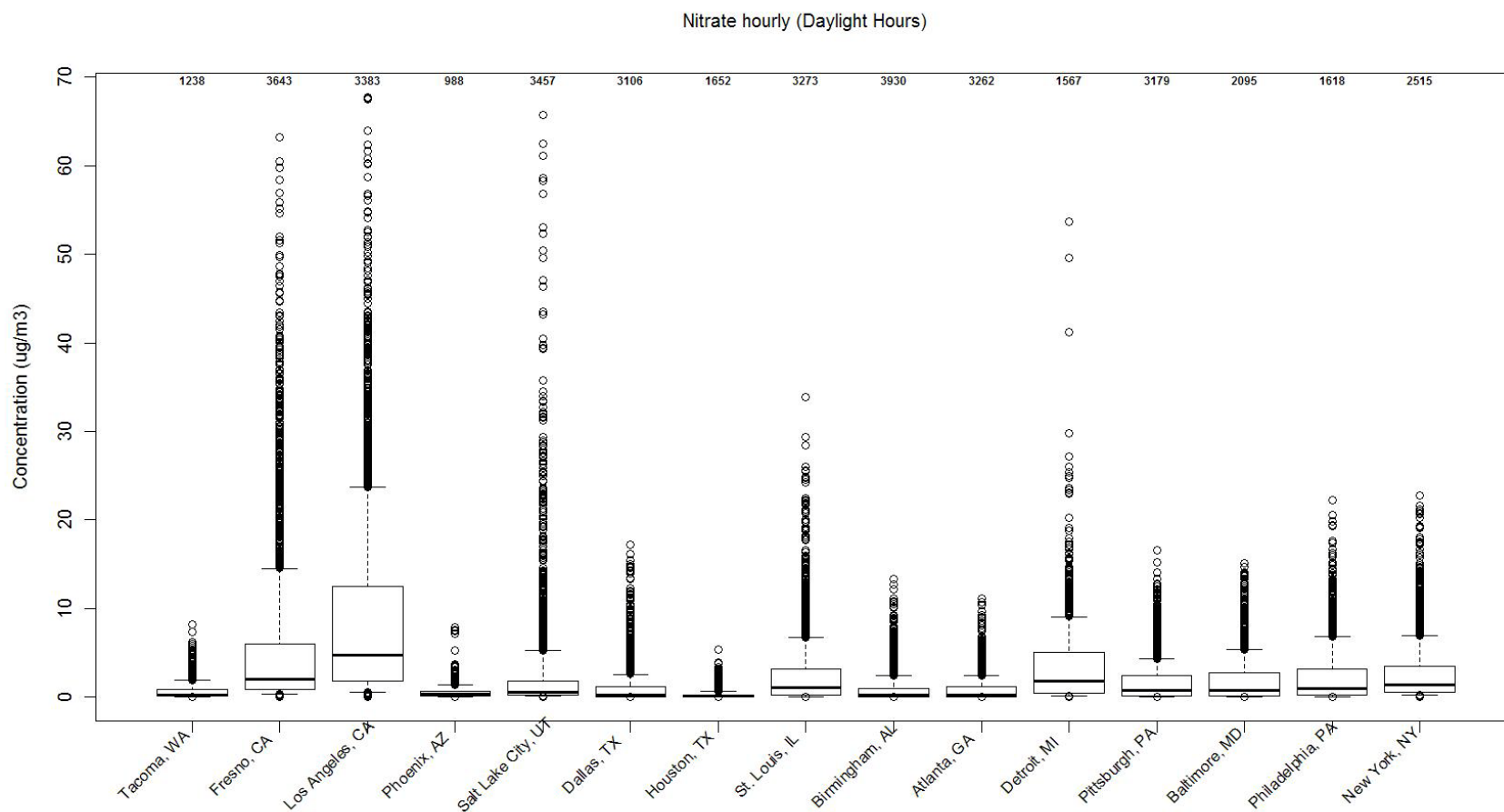
**Figure B-2 – Distribution of hourly PM<sub>2.5</sub> components across the 2005-2007 period, by study area**

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



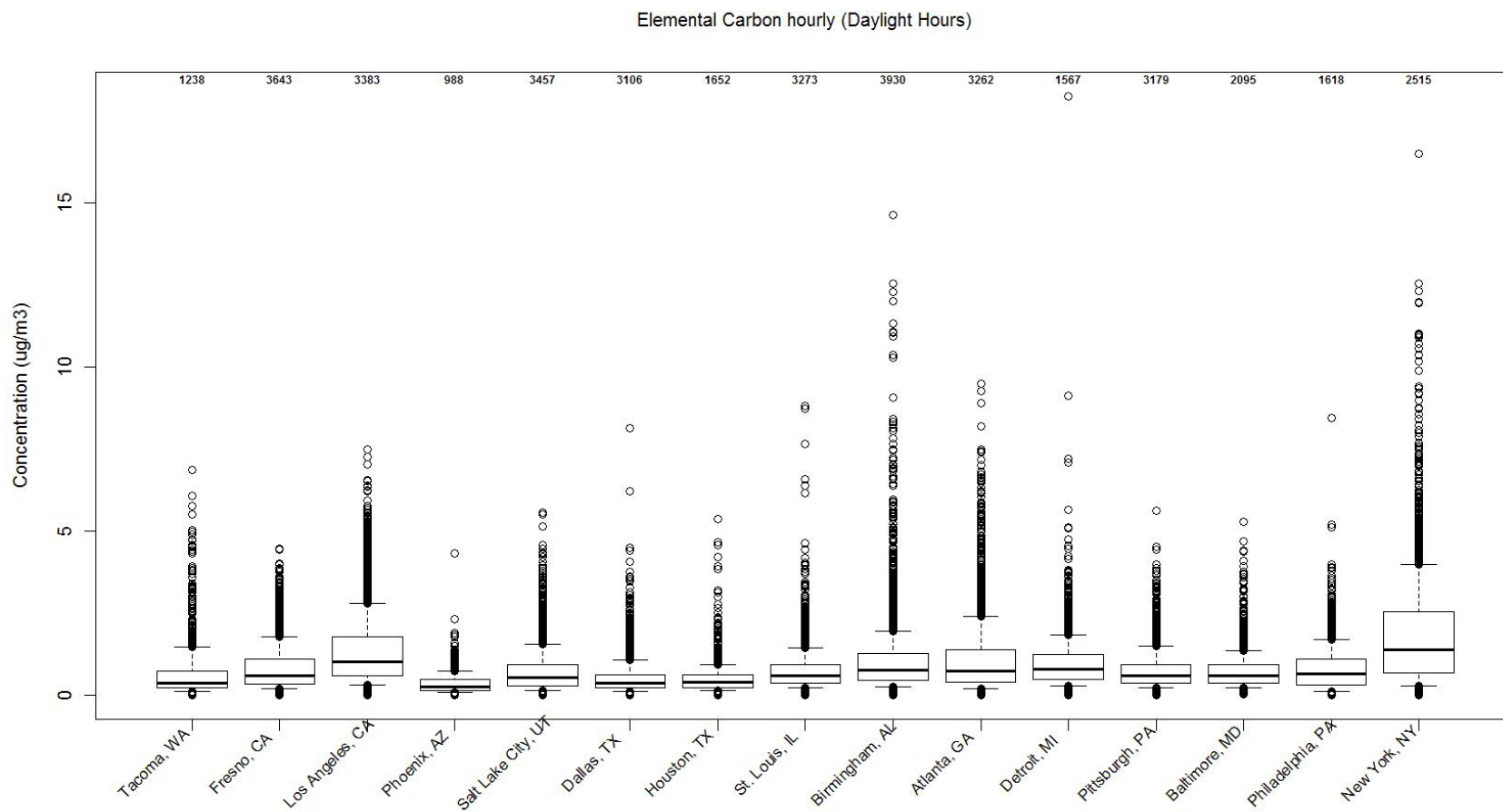
**Figure B-2 – Distribution of hourly PM<sub>2.5</sub> components across the 2005-2007 period, by study area, continued**

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



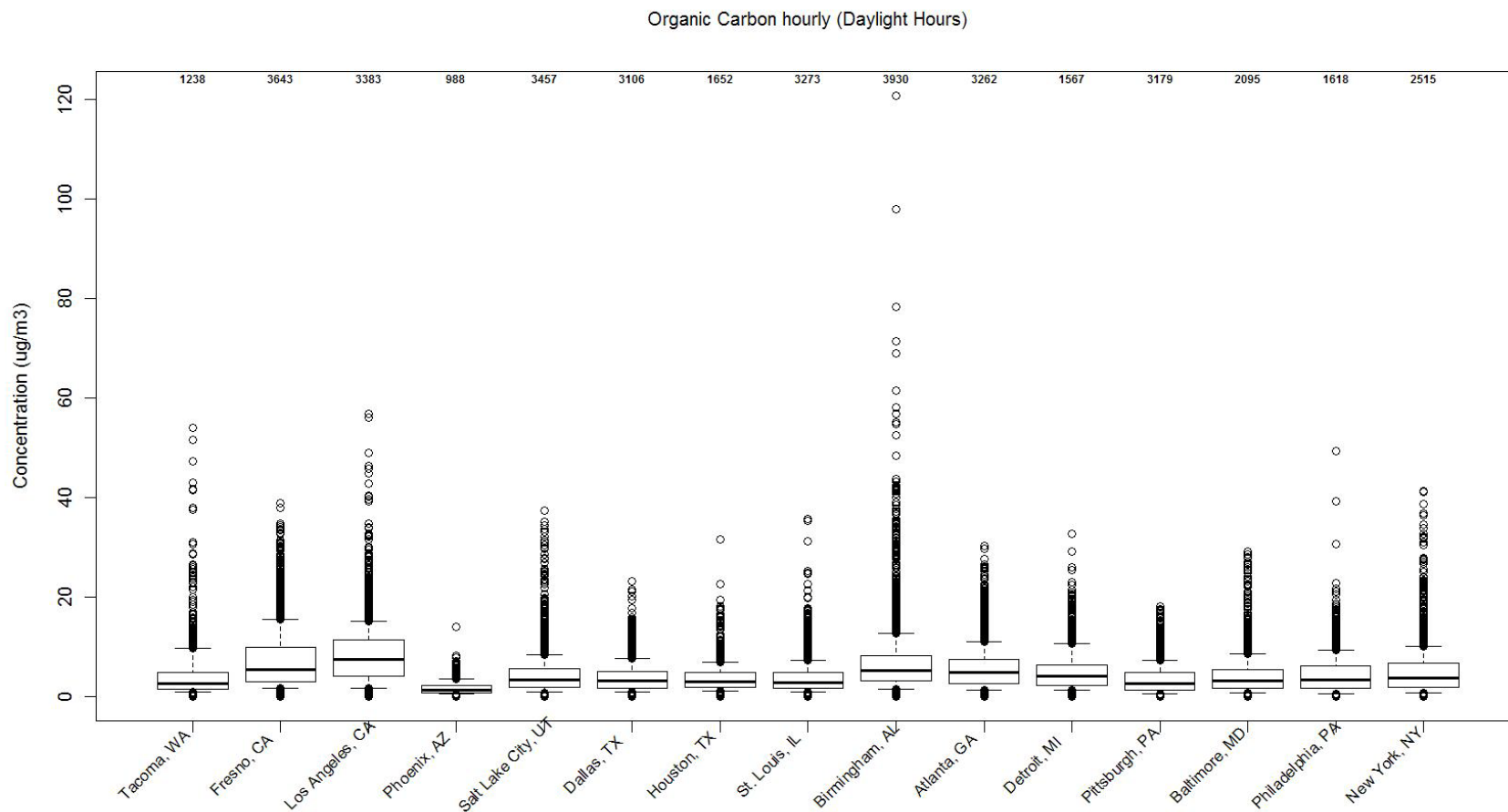
**Figure B-2 – Distribution of hourly PM<sub>2.5</sub> components across the 2005-2007 period, by study area, continued**

(c) 1-hour daylight elemental carbon



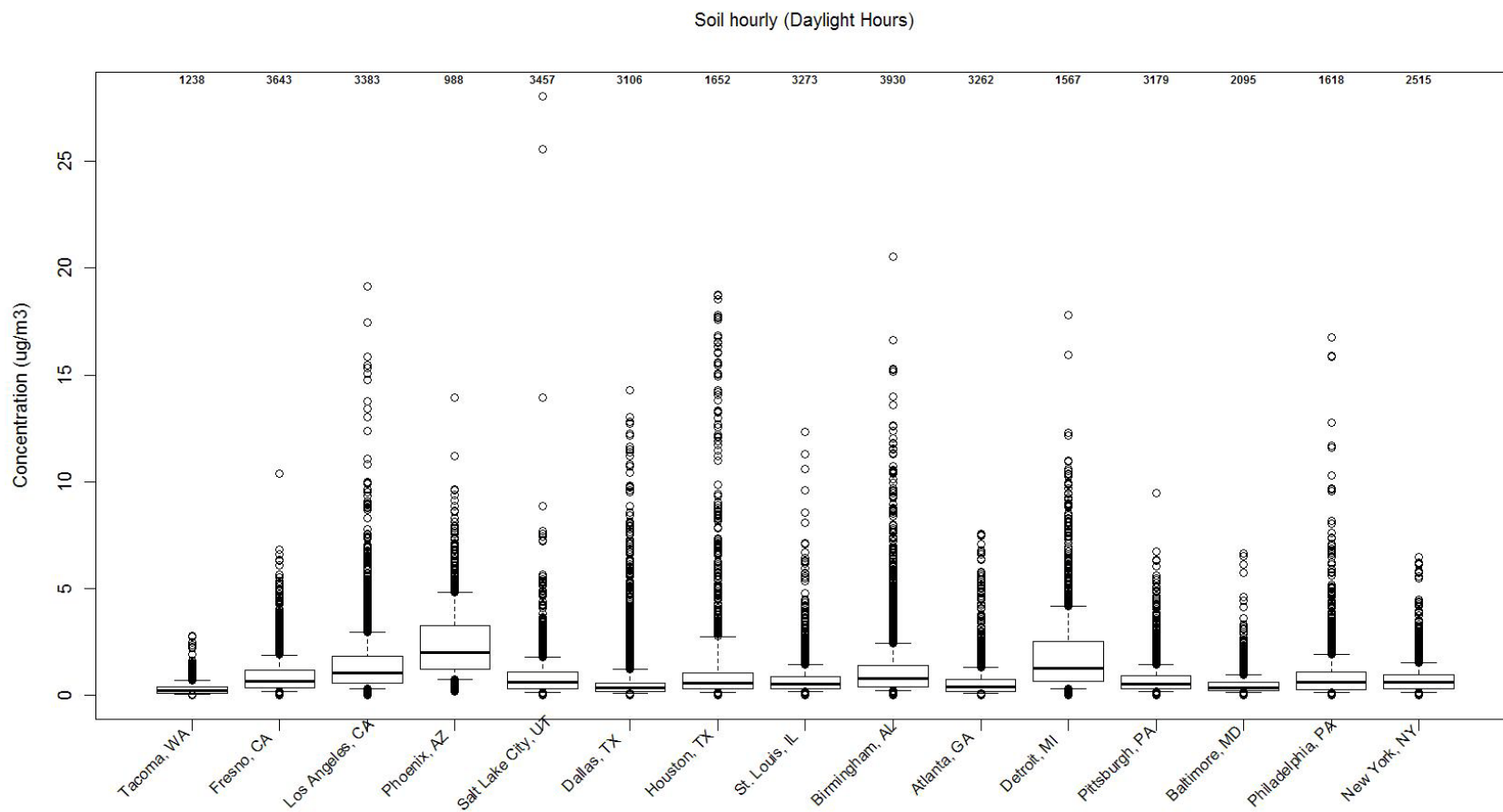
**Figure B-2 – Distribution of hourly PM<sub>2.5</sub> components across the 2005-2007 period, by study area, continued**

(d) 1-hour daylight organic carbonaceous material (by SANDWICH method)



**Figure B-2 – Distribution of hourly PM<sub>2.5</sub> components across the 2005-2007 period, by study area, continued**

(e) 1-hour daylight fine soil



## **APPENDIX C - DEVELOPMENT OF PRB ESTIMATES OF PM<sub>2.5</sub> COMPONENTS, PM<sub>10-2.5</sub>, AND PM LIGHT EXTINCTION**

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

More specifically, for each study area, EPA staff overlaid CMAQ grid cells over shapes representing the Census-defined urbanized area for each study area, and visually identified the CMAQ grid cells that had a substantial portion of their area coincident with the urbanized area. For each such grid cell, for each of the 12 months of the year, we obtained the 24 values of the hour-specific average concentrations of the five PM<sub>2.5</sub> 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<sub>2.5</sub> components averaged across grid cells and months were not adjusted in any.<sup>46</sup>

There 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<sub>2.5</sub> components (including the specific form assumed for sulfate, nitrate, and organic carbon). The right hand column of the table shows the PM<sub>2.5</sub> 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 periods in the

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<sup>46</sup> This approach to estimation of PRB for PM<sub>2.5</sub> 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. In the health risk assessment, PRB estimates for PM<sub>2.5</sub> mass concentration are taken from the same CMAQ model run, but is averaged by calendar quarter and by region of the country.

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, repeated in the 2003 EPA guidance document “Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Program”, are  $0.10 \mu\text{g}/\text{m}^3$  for (neutralized) nitrate and  $0.50 \mu\text{g}/\text{m}^3$  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 NO<sub>x</sub> inventory, and the nonanthropogenic emission inventory for NO<sub>x</sub> 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 estimates, the resulting values for PRB PM light extinction would increase only a little. Even at 90 percent relative humidity, the contribution to PM light extinction calculated from the Trijonis estimates is  $1.7 \text{ Mm}^{-1}$ , versus the average of about  $0.5 \text{ Mm}^{-1}$  using the estimates in Table C-1. The increment of  $1.2 \text{ Mm}^{-1}$  would be only about 10 to 20 percent of the PRB PM light extinction estimates shown in Table C-4, and would not significantly affect the calculation of PM light extinction values under the “what if” scenarios.

**Table C-1. Summary of PRB estimates for the five PM<sub>2.5</sub> components: average 1-hour values across 2005-2007**

Study Area	Average 1-Hour PRB Concentration Across 2005-2007 (µg/m <sup>3</sup> )					
	Sulfate (dry, no ammonium)	Nitrate (dry, no ammonium)	Elemental Carbon	Organic Carbonaceous Material	Fine Soil/Crustal	Calculated PM <sub>2.5</sub>
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<sub>10-2.5</sub>, 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<sub>10-2.5</sub> 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 µg/m<sup>3</sup> to a high of 10.8 µg/m<sup>3</sup>. 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<sub>10-2.5</sub> using a contour map based on average 2000-2004 PM<sub>10-2.5</sub> 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 light extinction levels under possible secondary PM NAAQS.

Table C-4 presents the resulting 2005-2007 average PRB daylight PM light extinction by study area, determined by using each daylight hour's f(RH),<sup>47</sup> the hour-specific PRB PM<sub>2.5</sub> component estimates (summarized only as annual averages in Table C-1), the PRB PM<sub>10-2.5</sub> 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,

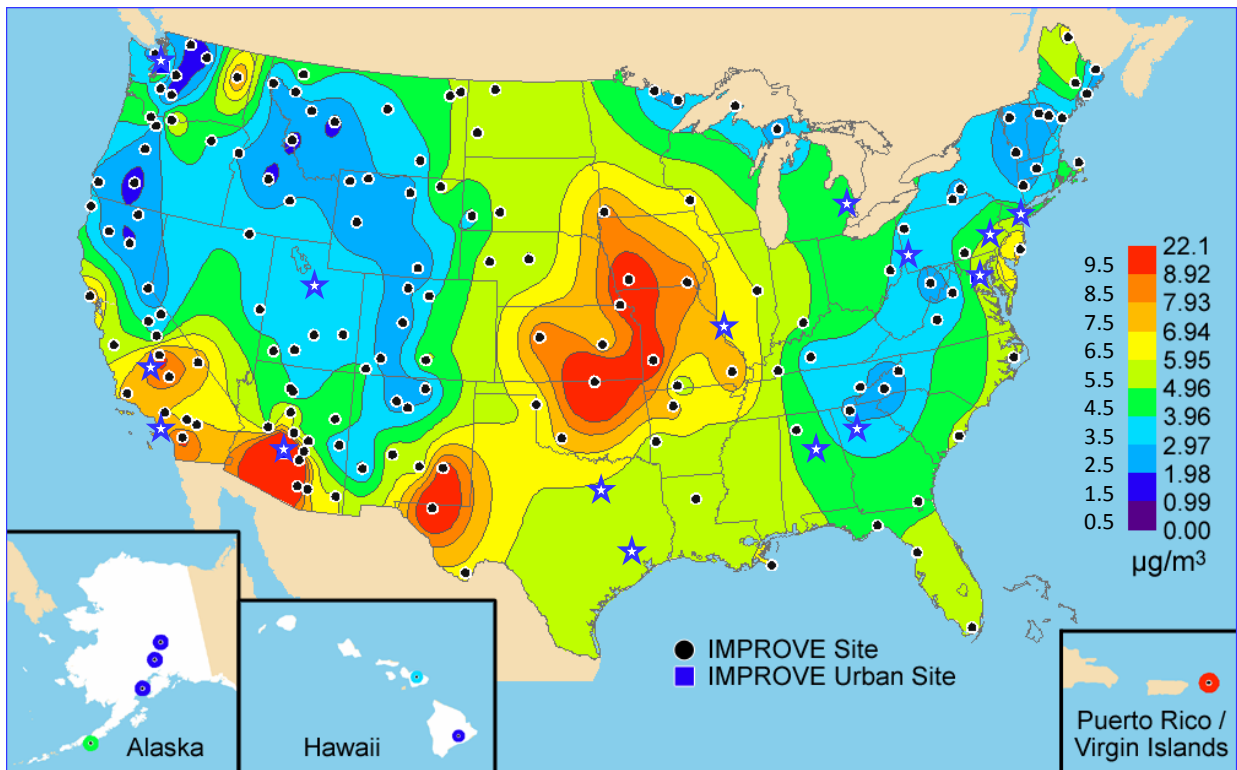
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<sup>47</sup> Hour-specific relative humidity for PRB conditions was assumed to be the same as measured for current conditions.

before being used in the IMPROVE algorithm. While for conciseness Table C-4 presents only the annual average PRM for PM light extinction for all daylight hours in 2005-2007 (excluding hours with relative humidity greater than 90 percent), in the rollback analysis of “what if” conditions hour-specific PRB values are retained and used.

The values of PRB PM light extinction in Table C-4 range between 5 and 11  $\text{Mm}^{-1}$ . 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  $\text{Mm}^{-1}$ , including the Rayleigh contribution of about 10  $\text{Mm}^{-1}$ . Thus, on an annual average basis the range of PRB estimates for PM 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<sub>10-2.5</sub> Used in This Assessment, Based on Measurements at IMPROVE Sites**

Study Area	PRB PM <sub>10-2.5</sub> Mass (µg/m <sup>3</sup> )
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<sup>3</sup>)**

Site	PM <sub>2.5</sub>		PM <sub>10</sub>		Coarse PM
	Nonsulfate	(Total)	Nonsulfate	(Total)	
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**

**Table C-4. 2005-2007 Average Policy Relevant Background Daylight PM light extinction  
(excluding hours with relative humidity above 90%)**

<b>Study Area</b>	<b>2005-2007 Average Policy Relevant Background Daylight PM light extinction, Mm<sup>-1</sup></b>
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 LIGHT EXTINCTION UNDER CURRENT CONDITIONS**

In the last review, the 2005 Staff Paper examined the correlation between PM light extinction and PM<sub>2.5</sub> mass concentrations, each defined for various consistent time periods. The 2005 Staff Paper analysis assumed that the percentage mix of PM<sub>2.5</sub> 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 light extinction in this new assessment allows these correlations to be re-examined, with the more realistic treatment in which the mix of PM<sub>2.5</sub> 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<sub>2.5</sub> mass concentrations and PM 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 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 as one 1-hour PM light extinction value, although this is rare in this data set (see the tile plots in Figure 3-12). However, values of PM<sub>2.5</sub> 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<sub>2.5</sub> mass (as measured by the FRM/FEM filter-based sampler) to daily maximum daylight PM light extinction. The scatter is due the variations in PM<sub>2.5</sub> concentration, in the mix of PM<sub>2.5</sub> components, and in relative humidity during the day and across days. Variations in PM<sub>10-2.5</sub> concentrations also contribute to the scatter, in all five comparisons presented here, since very high levels of PM<sub>10-2.5</sub> substantially influence PM 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 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 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 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 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 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 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 relative 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 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<sub>2.5</sub> mass vs. daily maximum daylight 1-hour PM light extinction. This time-unmatched comparison tests the usefulness of a 12-4 pm PM<sub>2.5</sub> mass indicator as a predictor of the daily PM 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 light extinction often occurs earlier in the day than the 12-4 pm period used to average the PM<sub>2.5</sub> mass, and the time period mismatch introduces prediction errors due to changes in PM<sub>2.5</sub> concentration and composition and relative humidity. An implication is that while a secondary NAAQS based on 12-4 pm average PM<sub>2.5</sub> mass might achieve a given level of protection across days and areas in avoiding high levels of PM 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 light extinction during the earlier hours of the day when some areas often have their highest PM light extinction levels.

Figure D-5 compares 8 am-12 pm average PM<sub>2.5</sub> mass vs. daily maximum daylight 1-hour PM 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 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<sub>2.5</sub> mass more often encompasses the period of maximum PM 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<sub>2.5</sub> 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 light extinction to PM<sub>2.5</sub> 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<sub>2.5</sub> mass and PM 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 light extinction (24-hour average or 1-hour value) was divided by the indicated PM<sub>2.5</sub> concentration metric (24-hour average or 1-hour value). Ratios that reflect PM<sub>2.5</sub> concentrations less than 5 µg/m<sup>3</sup> or PM light extinction less than 64 Mm<sup>-1</sup> 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



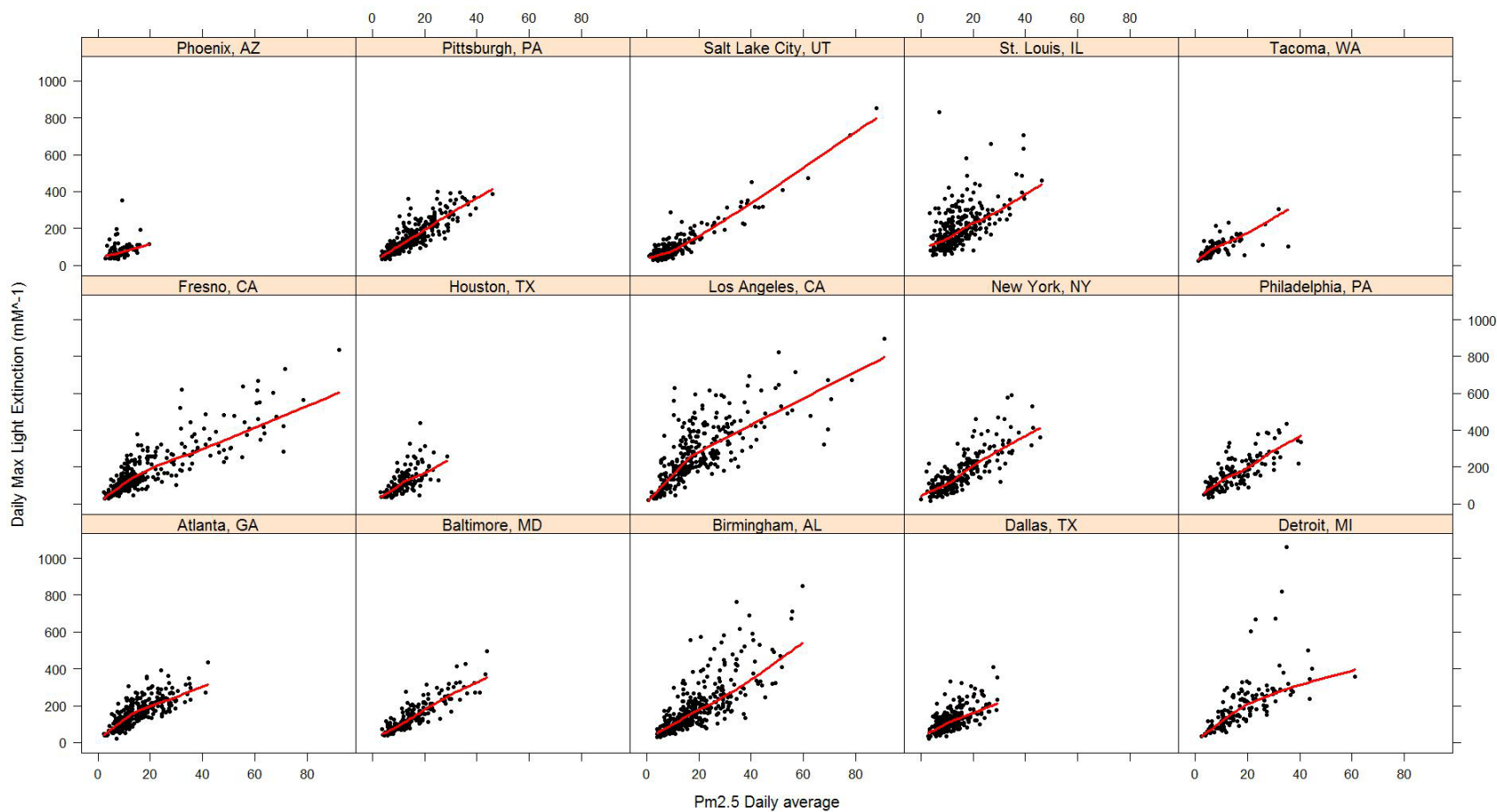
these plots is set at 40 to allow closer examination of the portion of the plot representing the bulk of the data; this prevents a very small number of daily maximum data points for a few study areas from appearing in Panel A and a very small percentage of 1-hour data points for a few study areas (Los 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 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.

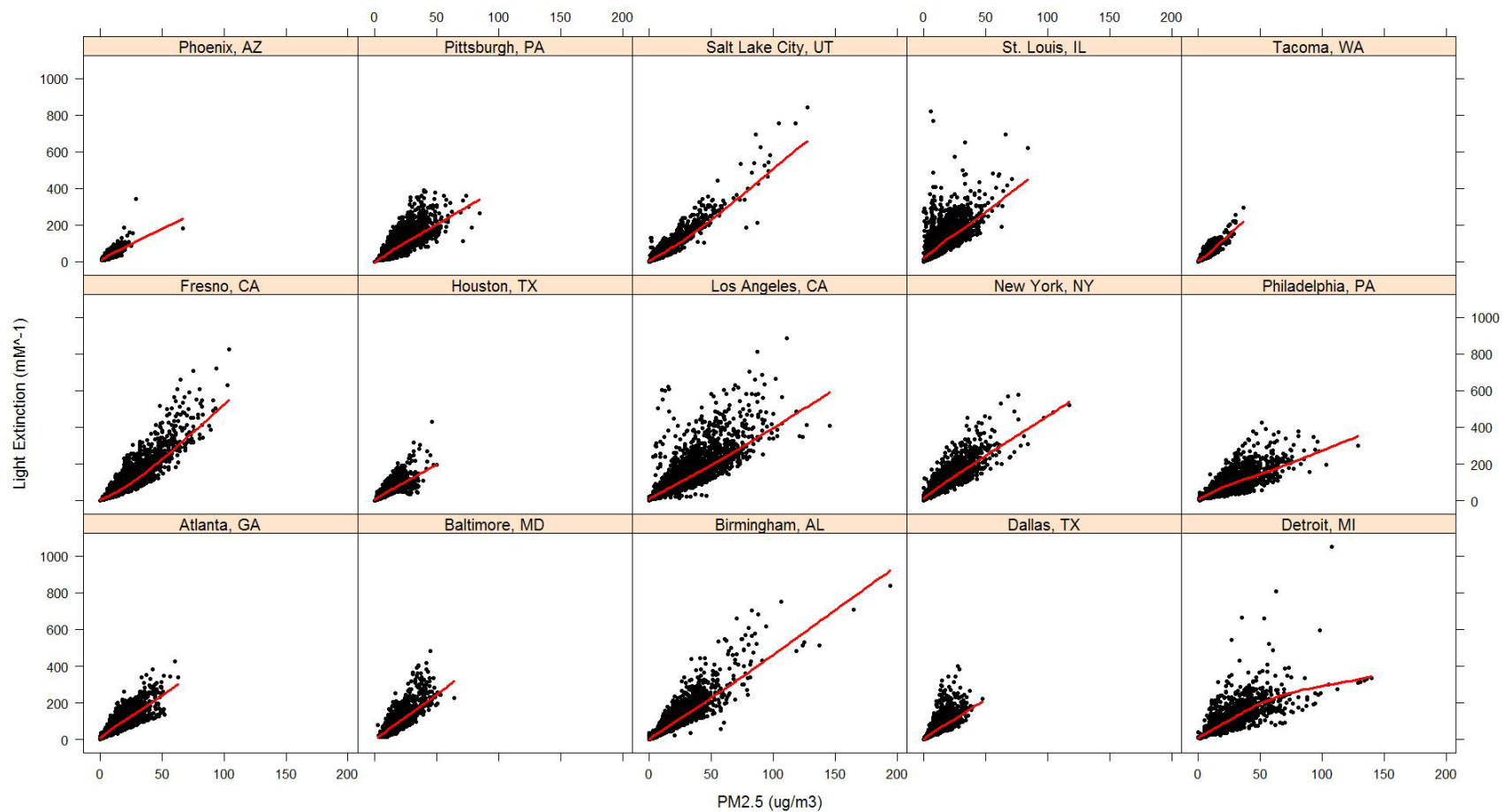
**Table D-1. Squared correlation coefficients between observed and LOESS  
model-predicted values of PM light extinction**

<b>Area</b>	<b>Figure D-1 24-hour PM<sub>2.5</sub> mass vs. daily maximum daylight 1- hour PM light extinction</b>	<b>Figure D-2 1-hour PM<sub>2.5</sub> mass vs. same- hour PM light extinction</b>	<b>Figure D-3 12-4 pm average PM<sub>2.5</sub> mass vs. 12-4 pm average PM light extinction</b>	<b>Figure D-4 12-4 pm average PM<sub>2.5</sub> mass vs. daily maximum daylight 1- hour PM light extinction</b>	<b>Figure D-5 8 am-12pm average PM<sub>2.5</sub> mass vs. daily maximum daylight 1- hour PM light extinction</b>
Tacoma	0.48	0.81	0.78	0.29	0.65
Fresno	0.76	0.83	0.9	0.69	0.83
Los Angeles	0.57	0.63	0.67	0.53	0.7
Phoenix	0.22	0.67	0.73	0.18	0.2
Salt Lake City	0.88	0.89	0.95	0.8	0.89
Dallas	0.45	0.59	0.53	0.2	0.35
Houston	0.46	0.61	0.62	0.2	0.3
St. Louis	0.40	0.43	0.2	0.18	0.36
Birmingham	0.61	0.81	0.78	0.34	0.44
Atlanta	0.54	0.72	0.8	0.4	0.7
Detroit	0.62	0.55	0.6	0.11	0.3
Pittsburgh	0.73	0.63	0.65	0.52	0.62
Baltimore	0.78	0.69	0.69	0.58	0.71
Philadelphia	0.60	0.6	0.57	0.38	0.49
New York	0.69	0.76	0.76	0.5	0.62
<b>AVERAGE</b>	<b>0.59</b>	<b>0.68</b>	<b>0.68</b>	<b>0.39</b>	<b>0.54</b>

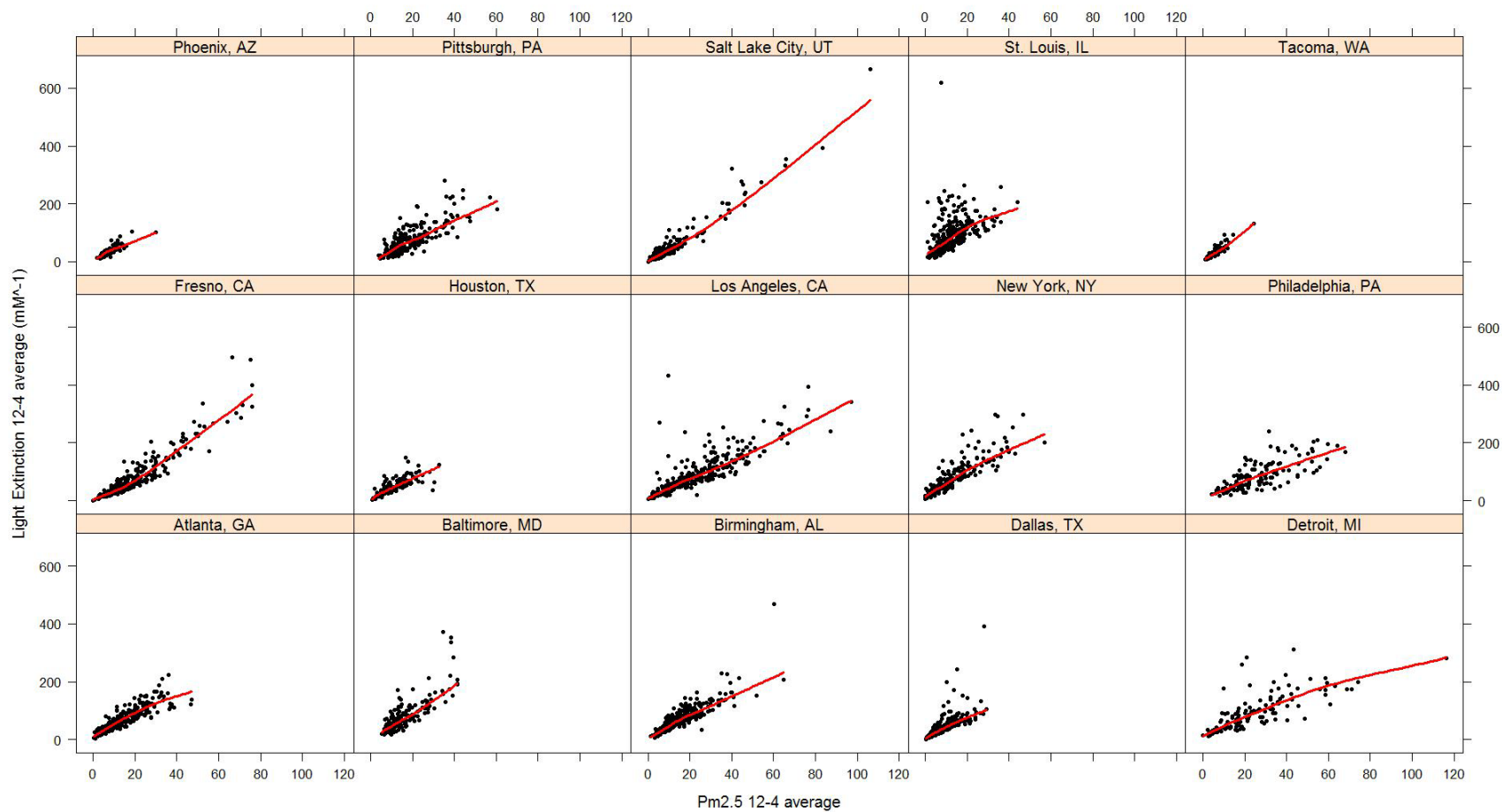
**Figure D-1. – Relationship between 24-hour PM<sub>2.5</sub> mass vs. daily maximum daylight 1-hour PM light extinction.**



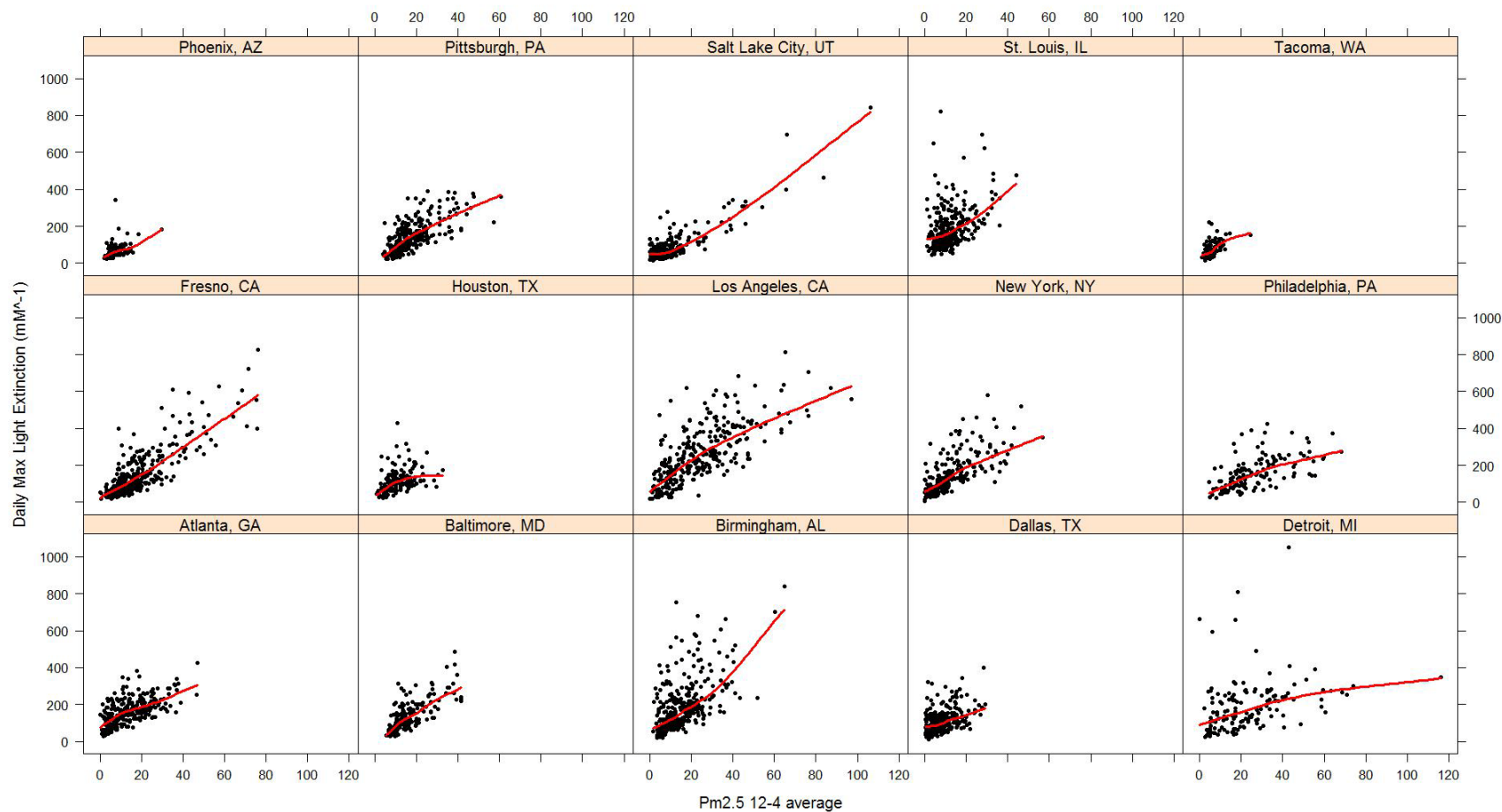
**Figure D-2. – Relationship between daylight 1-hour PM<sub>2.5</sub> mass vs. same-hour PM light extinction.**



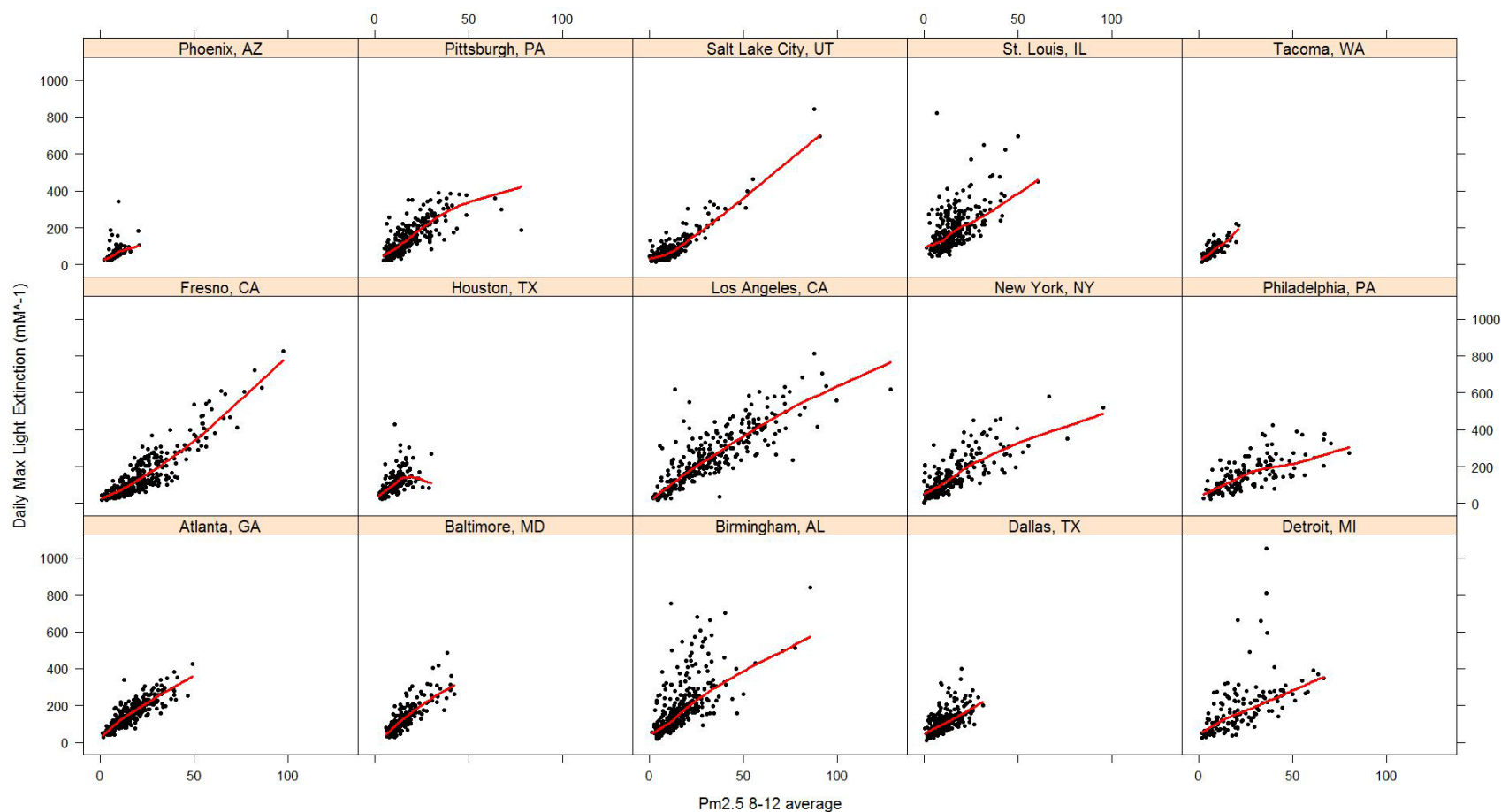
**Figure D-3. Relationship between 12-4 pm average PM<sub>2.5</sub> mass vs. 12-4 pm average PM light extinction.**



**Figure D-4. Relationship between 12-4 pm average PM<sub>2.5</sub> mass vs. daily maximum daylight 1-hour PM light extinction.**

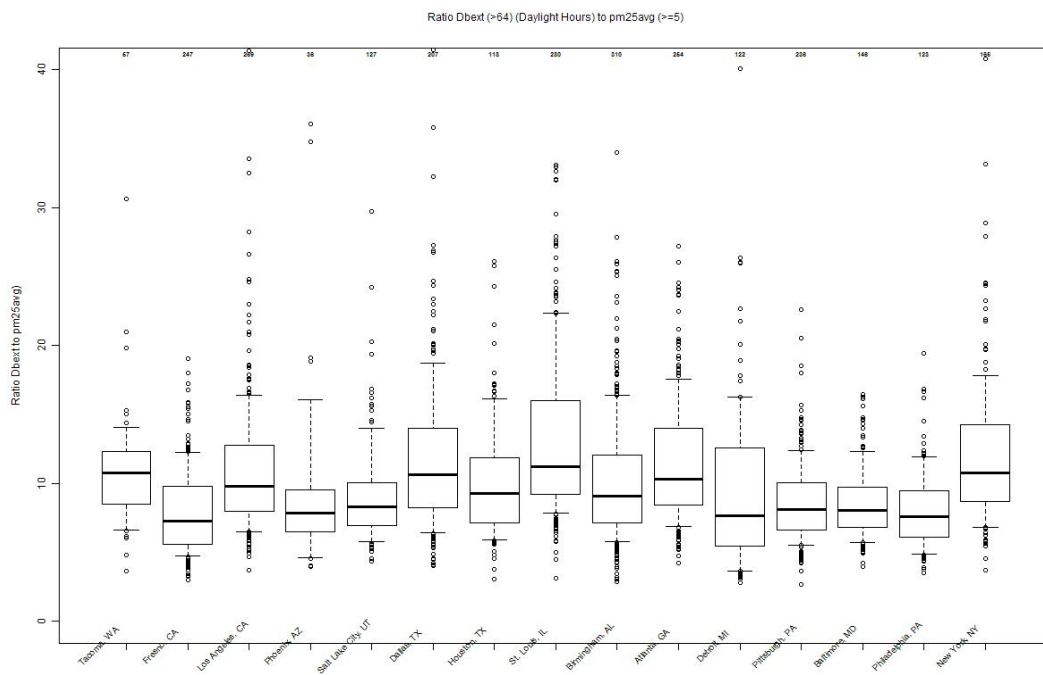


**Figure D-5. Relationship between 8 am-12pm average PM<sub>2.5</sub> mass vs. daily maximum daylight 1-hour PM light extinction**

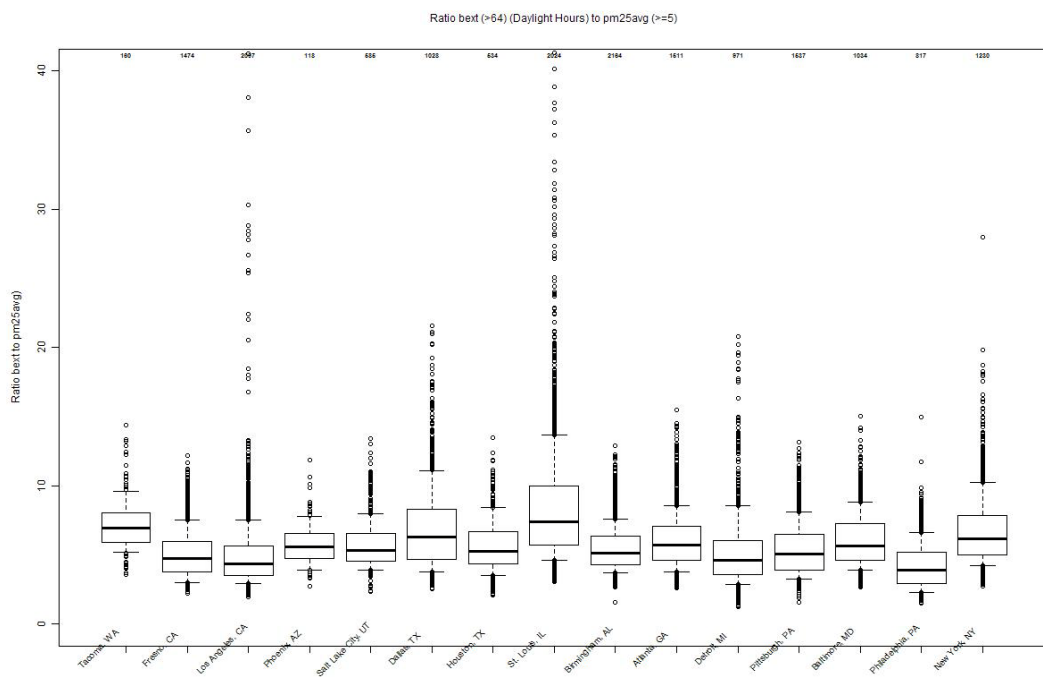


**Figure D-6. Distribution of ratios of 1-hour PM light extinction and PM<sub>2.5</sub> mass concentration.**

**A – Ratios of daily maximum daylight 1-hour PM light extinction to 24-hour average PM<sub>2.5</sub> concentration.**



**B – Ratios of daylight 1-hour PM light extinction to same-hour PM<sub>2.5</sub> concentration**





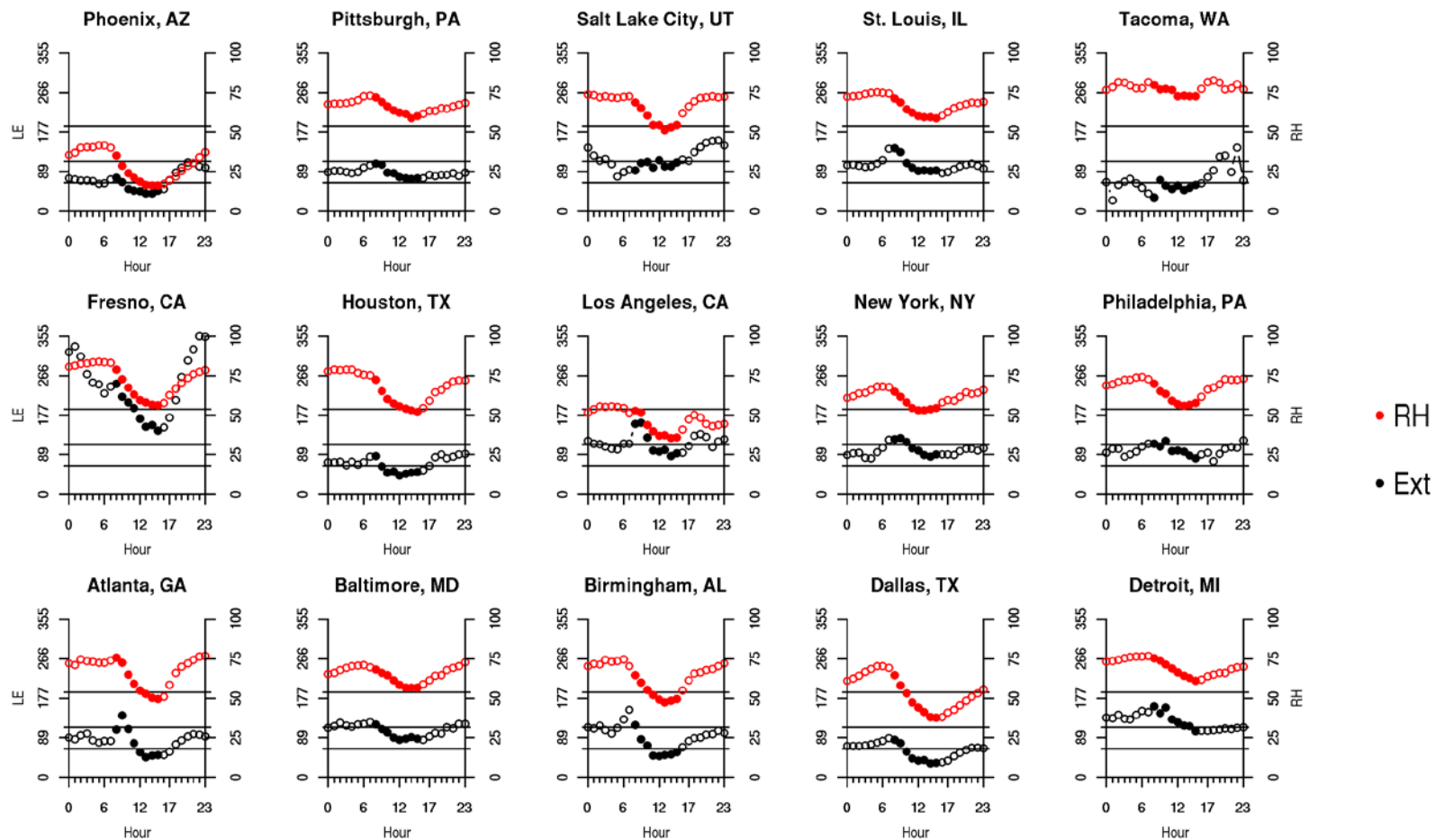
## **APPENDIX E - DIFFERENCES IN DAILY PATTERNS OF RELATIVE HUMIDITY AND PM LIGHT EXTINCTION BETWEEN AREAS AND SEASONS**

In the last review of the secondary PM NAAQS, the pattern of PM light extinction during the day was of particular interest. It was noted, using estimates of hourly PM light extinction based on a simpler approach than described for this analysis, that both (1) mid-day PM light extinction and (2) the slope of the relationship between PM light extinction and PM<sub>2.5</sub> concentration varied less among regions of the country than 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 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 light extinction generally is highest in the morning, corresponding to higher relative 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 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.

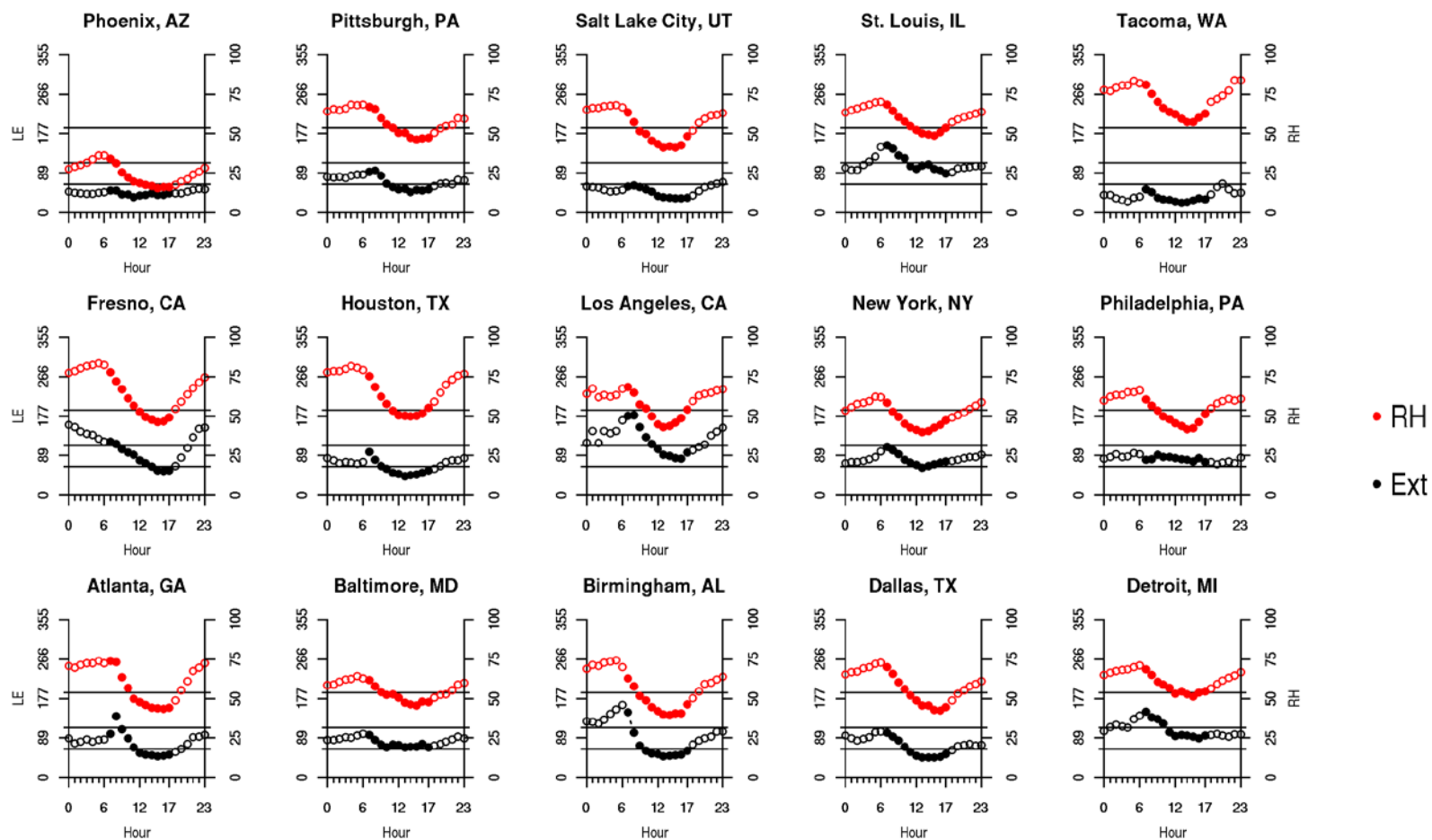
**Figure E-1. Diurnal and seasonal patterns of relative humidity (percent) and PM light extinction ( $\text{Mm}^{-1}$ ) for 2005-2007**

**(a) November-January**



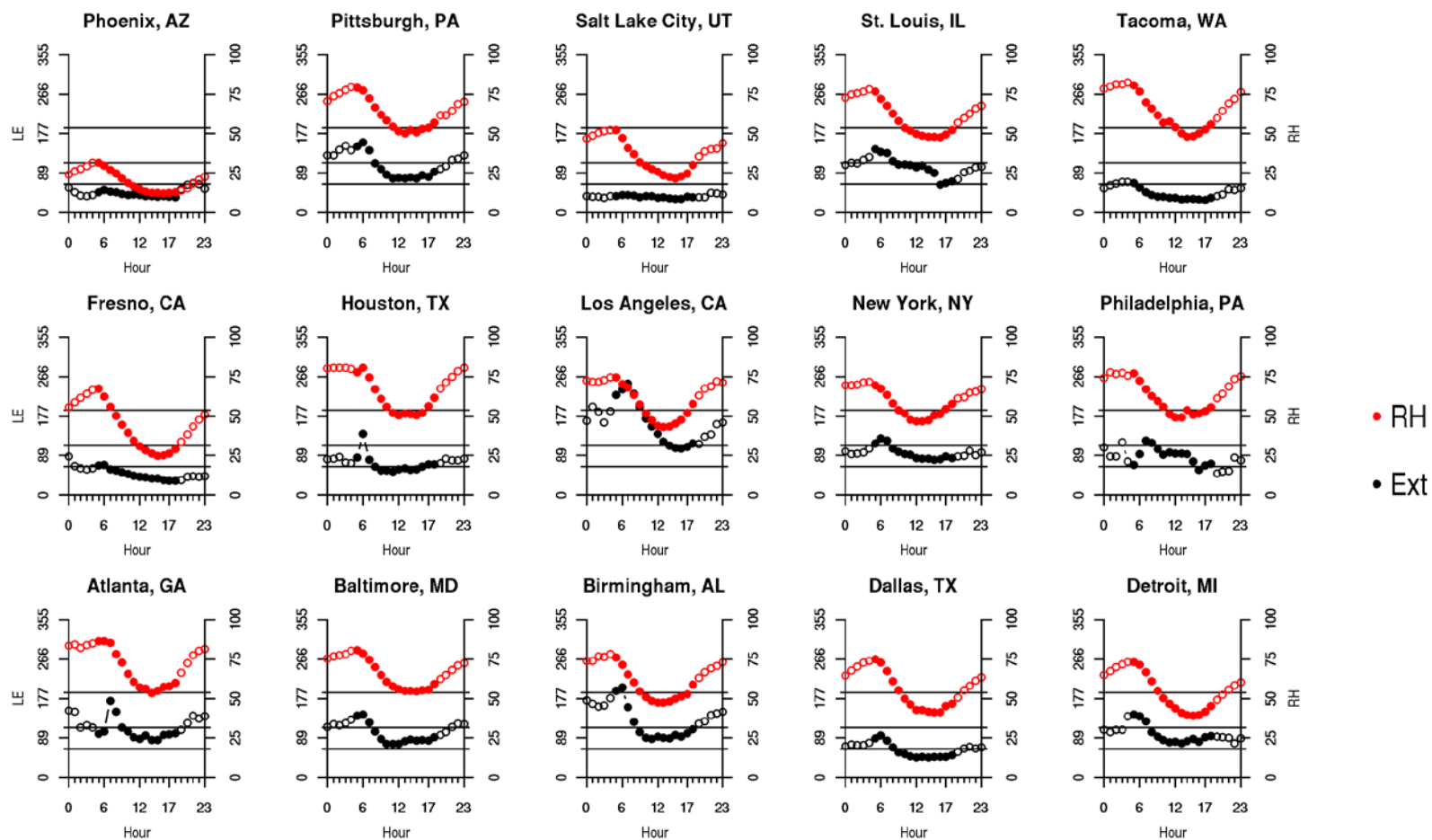
**Figure E-2. Diurnal and seasonal patterns of relative humidity (percent) and PM light extinction ( $\text{Mm}^{-1}$ ) for 2005-2007, continued**

**(b) February-April**



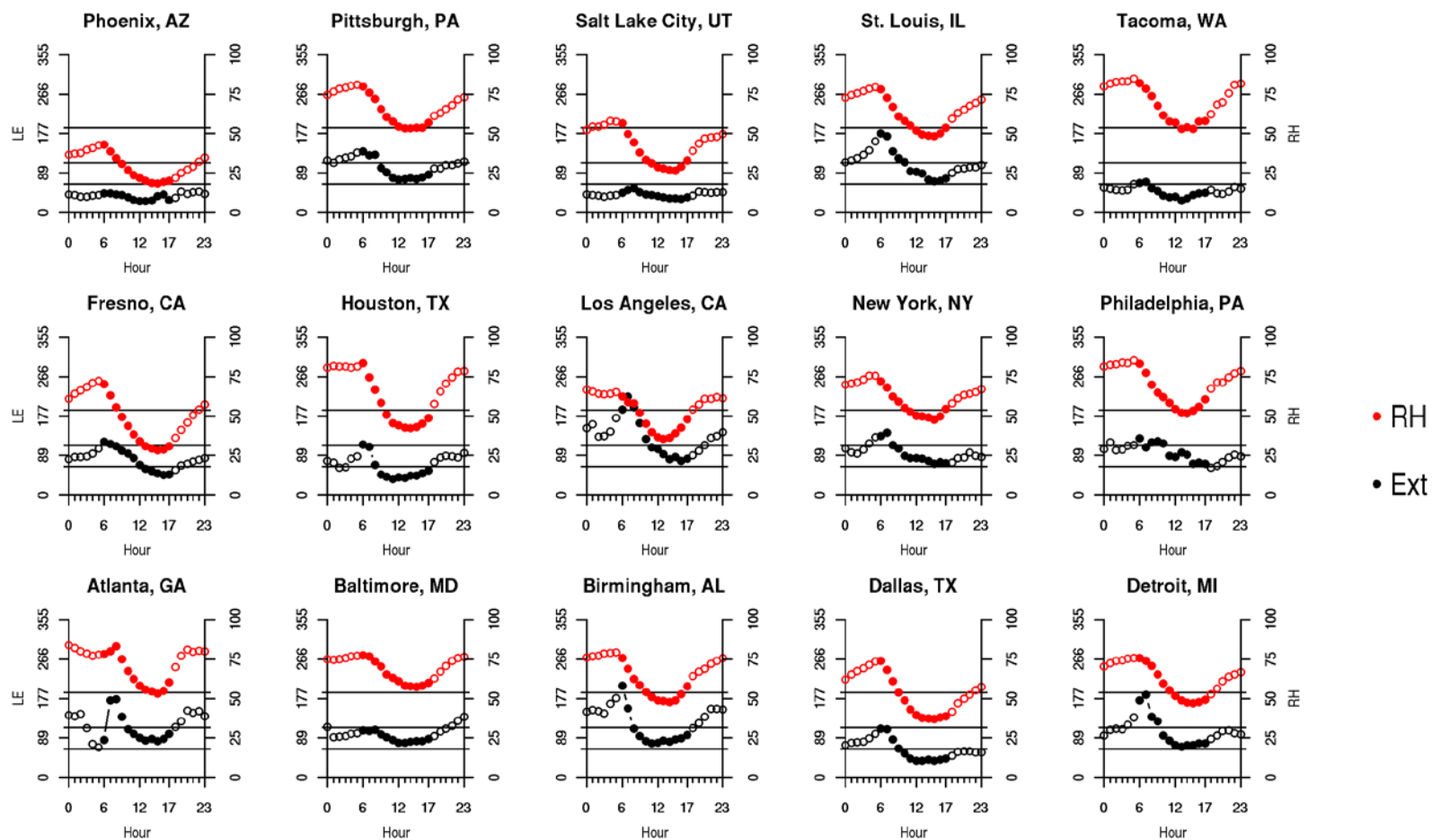
**Figure E-3. Diurnal and seasonal patterns of relative humidity (percent) and PM light extinction ( $\text{Mm}^{-1}$ ) for 2005-2007, continued**

**(c) May-July**



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

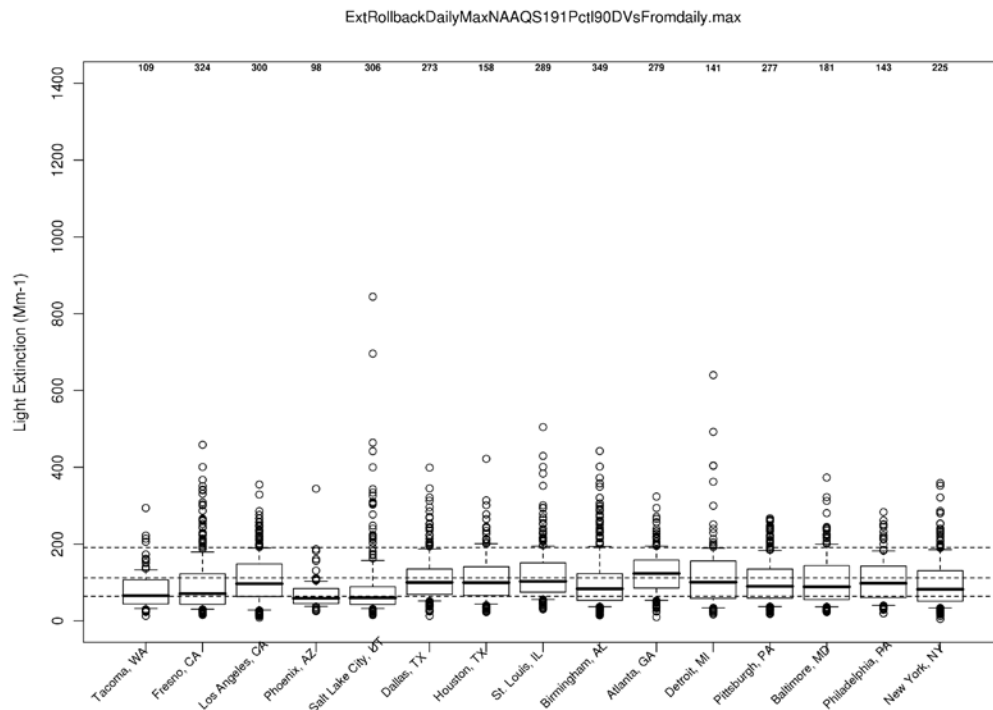
**(d) August-October**



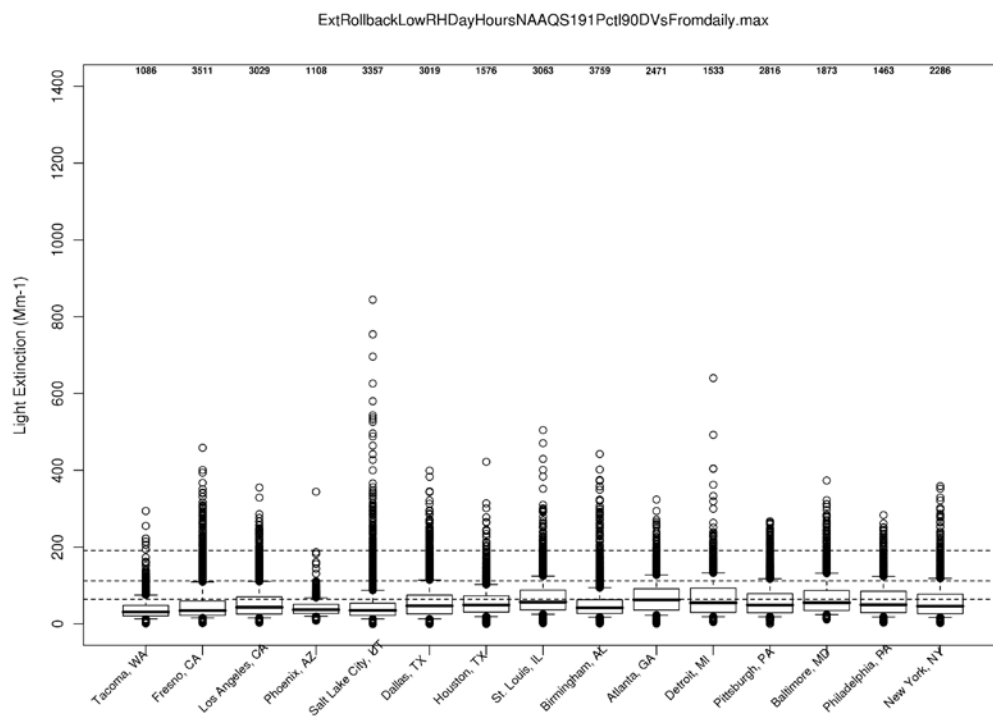
**APPENDIX F - DISTRIBUTIONS OF MAXIMUM DAILY  
AND HOURLY DAYLIGHT PM LIGHT EXTINCTION -  
UNDER “JUST MEET” CONDITIONS**

(a) NAAQS Scenario  
 Daily Max  
 $191 \text{ Mm}^{-1}$   
 90<sup>th</sup> percentile

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



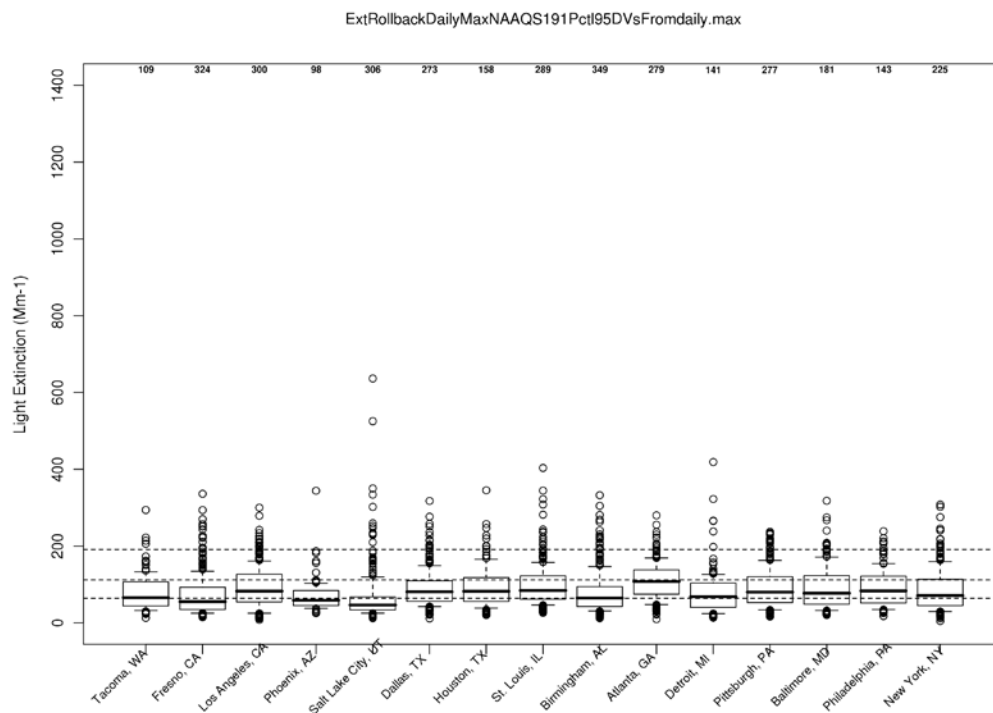
Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)



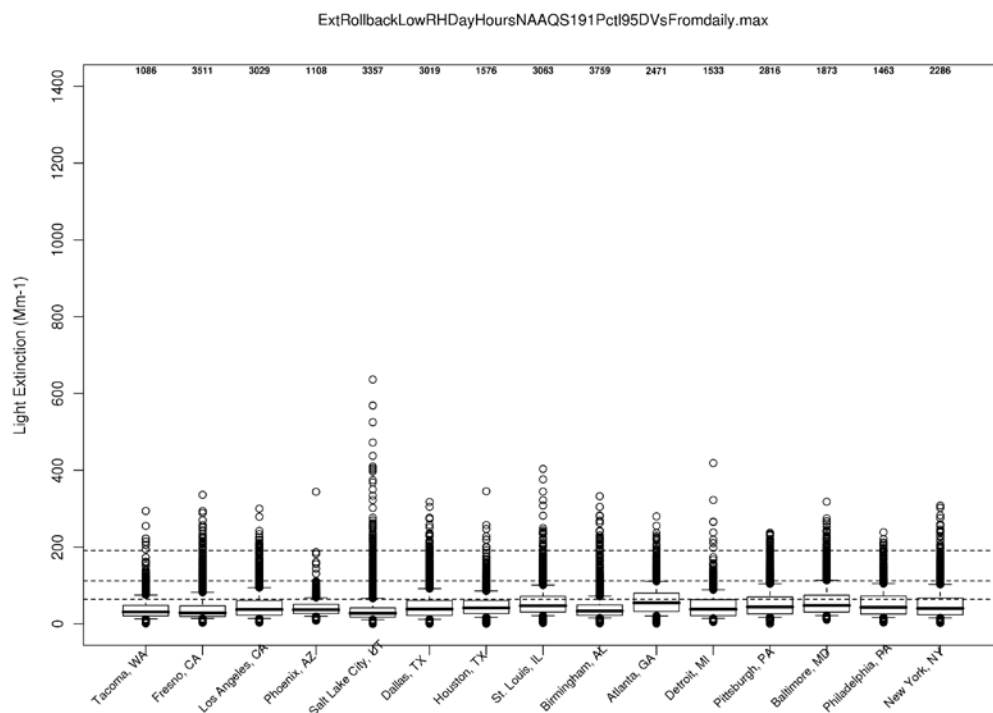


(b) NAAQS Scenario  
 Daily Max  
 $191 \text{ Mm}^{-1}$   
 95<sup>th</sup> percentile

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

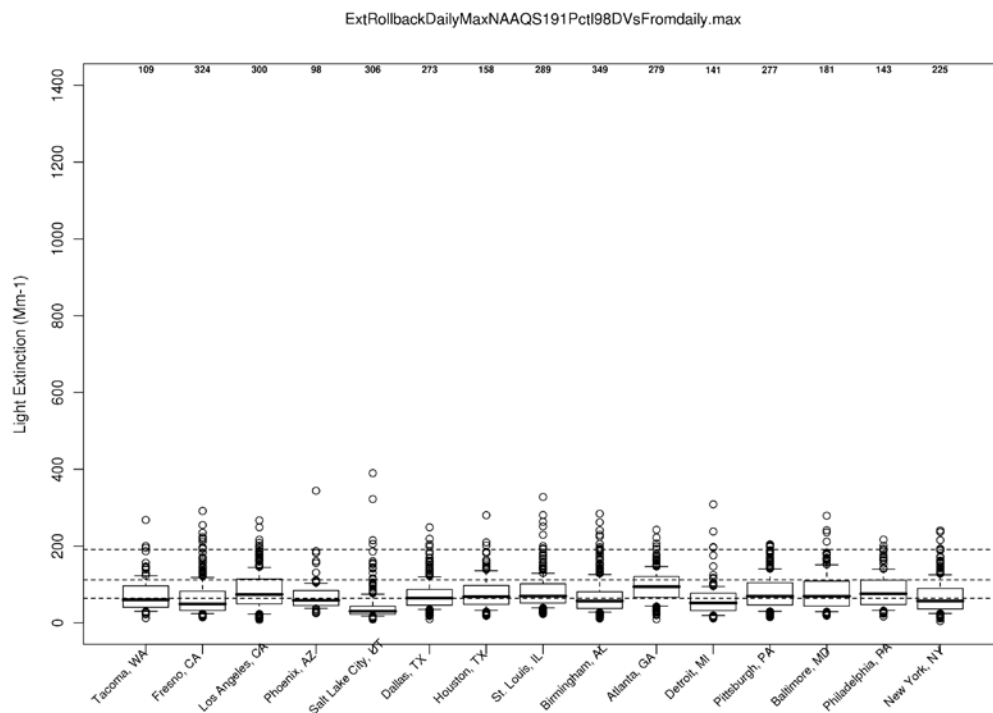


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

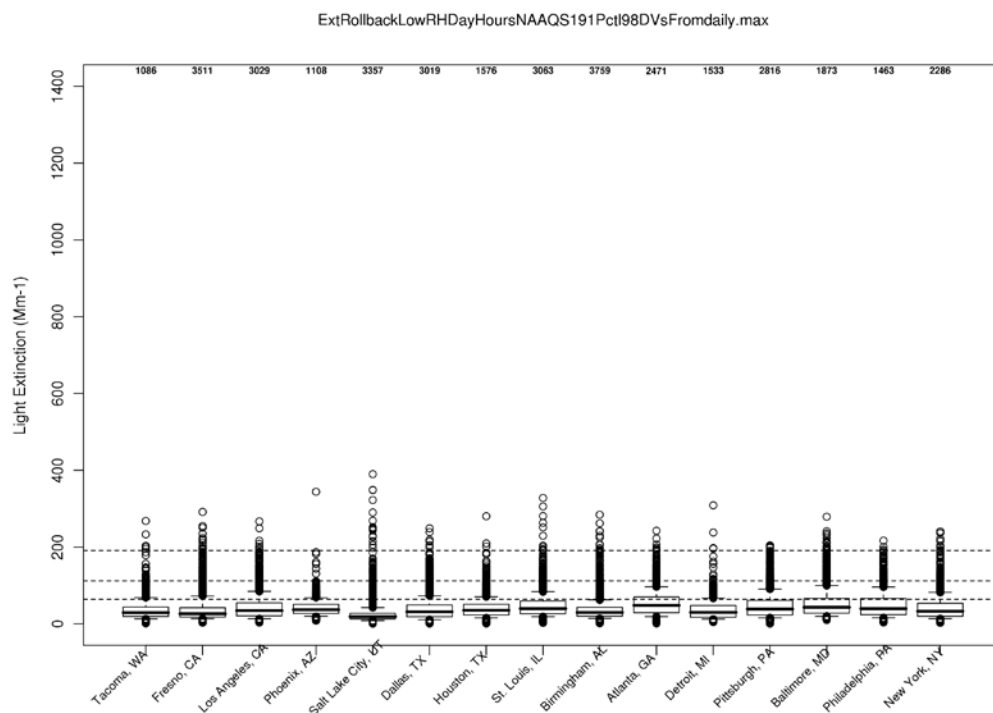


(c) NAAQS Scenario  
 Daily Max  
 $191 \text{ Mm}^{-1}$   
 98<sup>th</sup> percentile

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

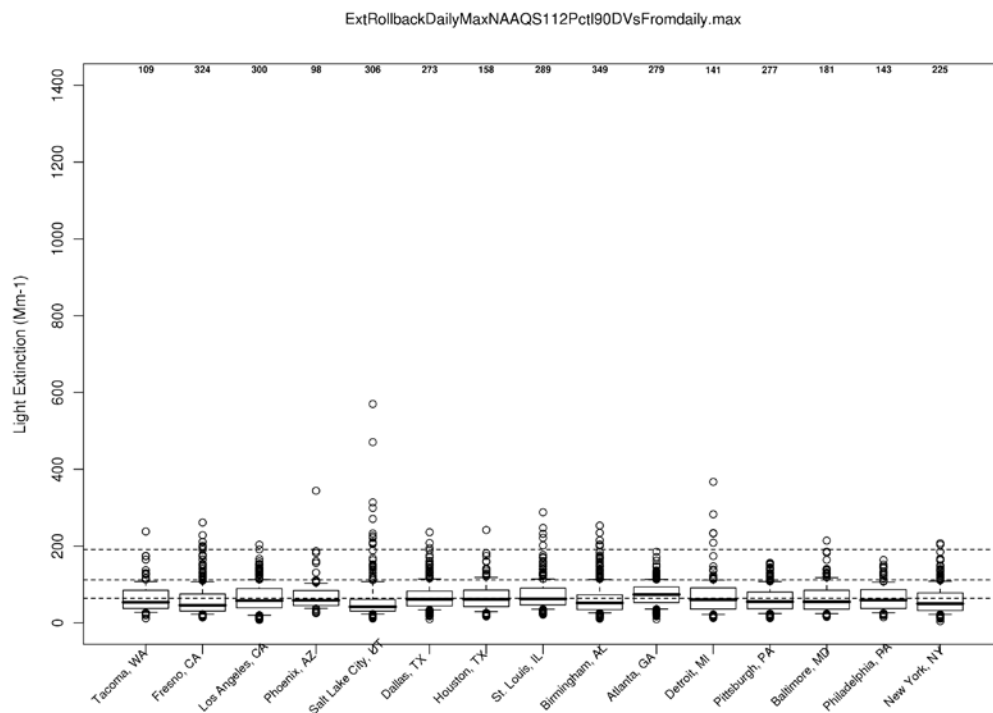


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

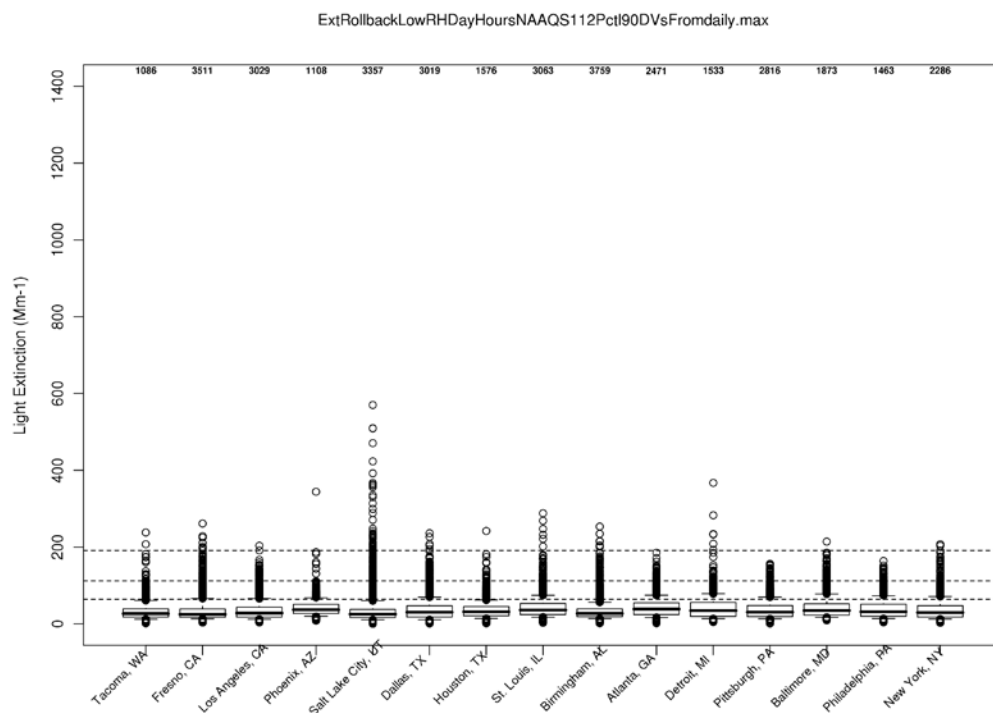


(d) NAAQS Scenario  
Daily Max  
112 Mm<sup>-1</sup>  
90<sup>th</sup> percentile

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

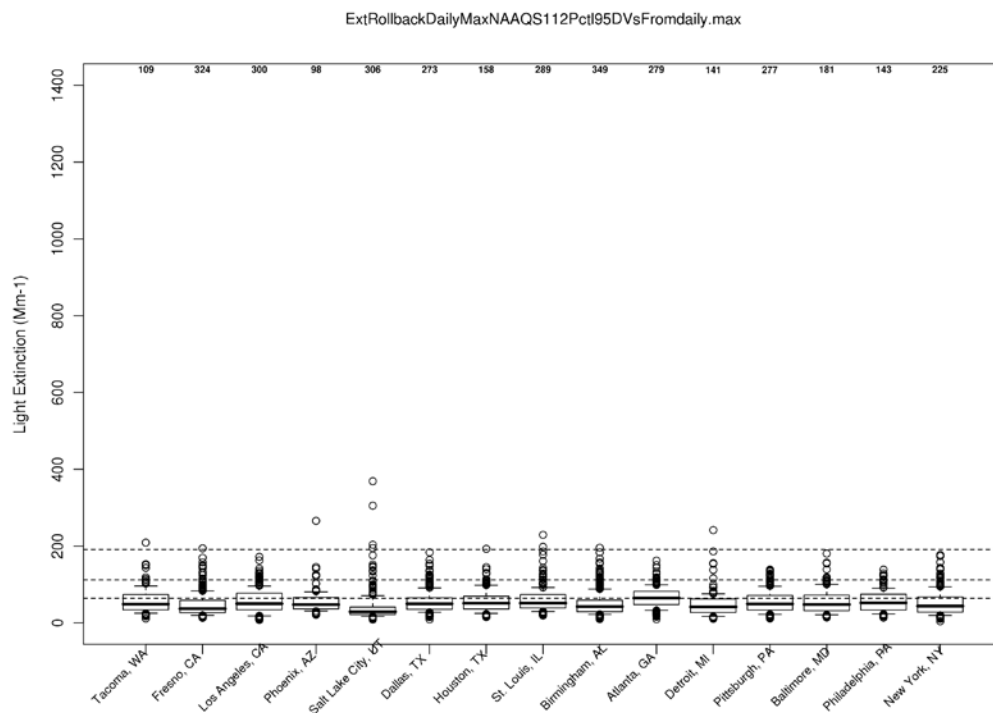


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

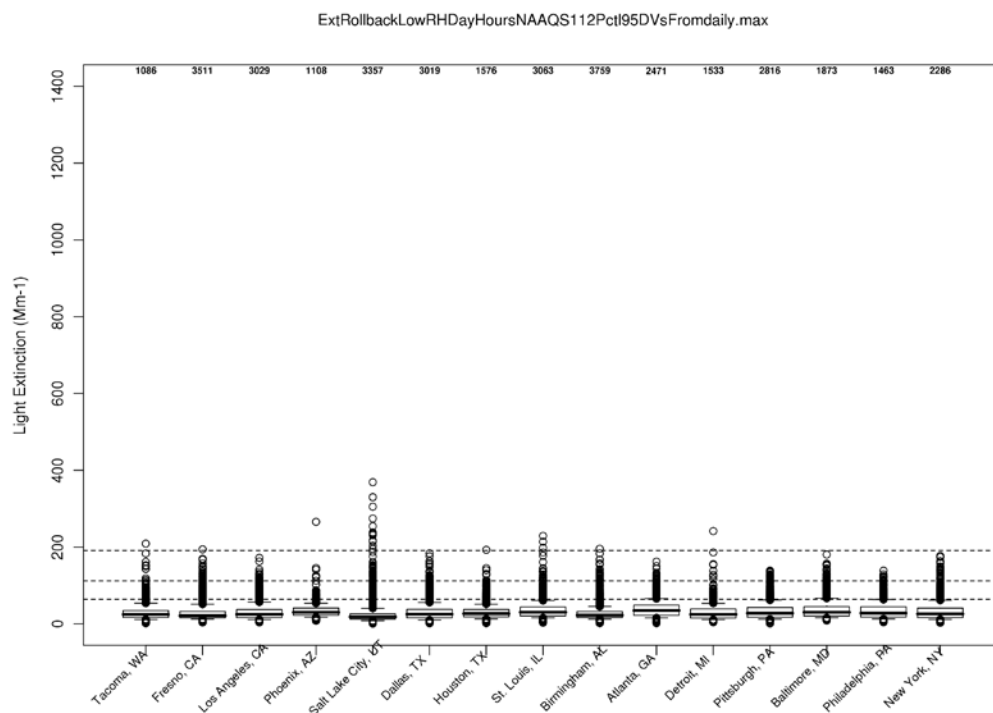


(e) NAAQS Scenario  
 Daily Max  
 112 Mm<sup>-1</sup>  
 95<sup>th</sup> percentile

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

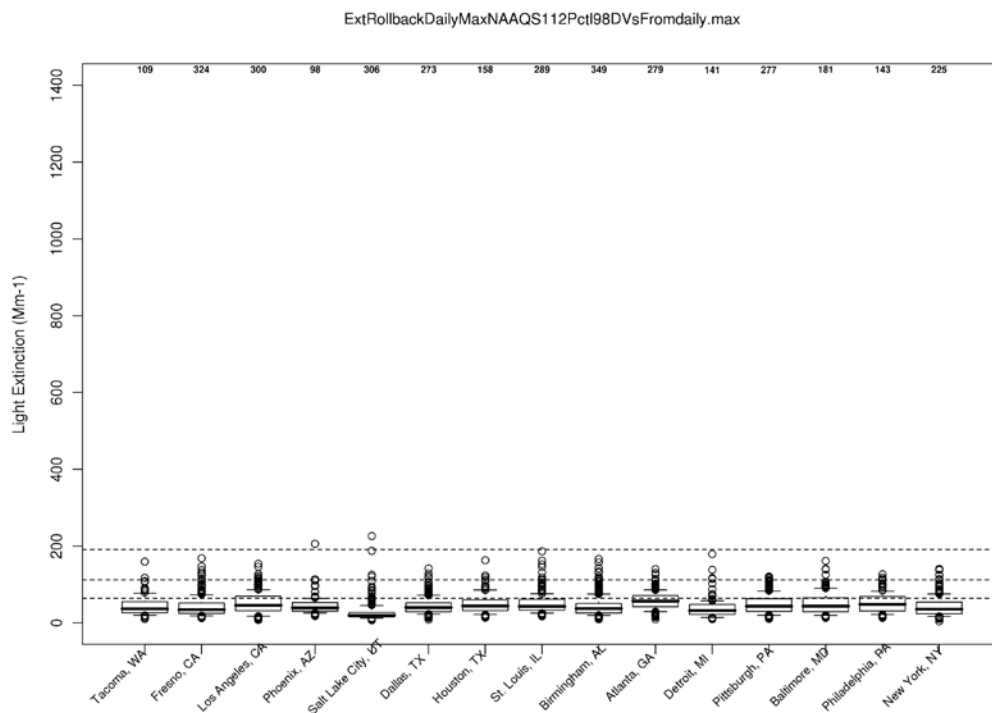


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

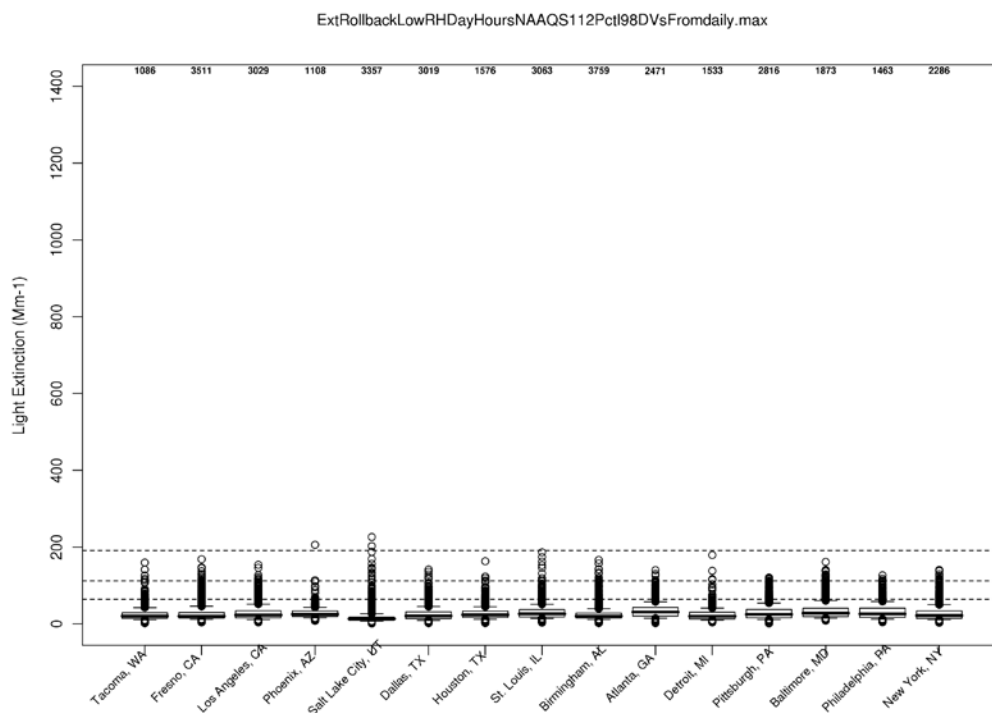


**(f) NAAQS Scenario**  
**Daily Max**  
**112 Mm<sup>-1</sup>**  
**98<sup>th</sup> percentile**

**Displayed: Daily Max Daylight Light Extinction (excluding hours >90% RH)**

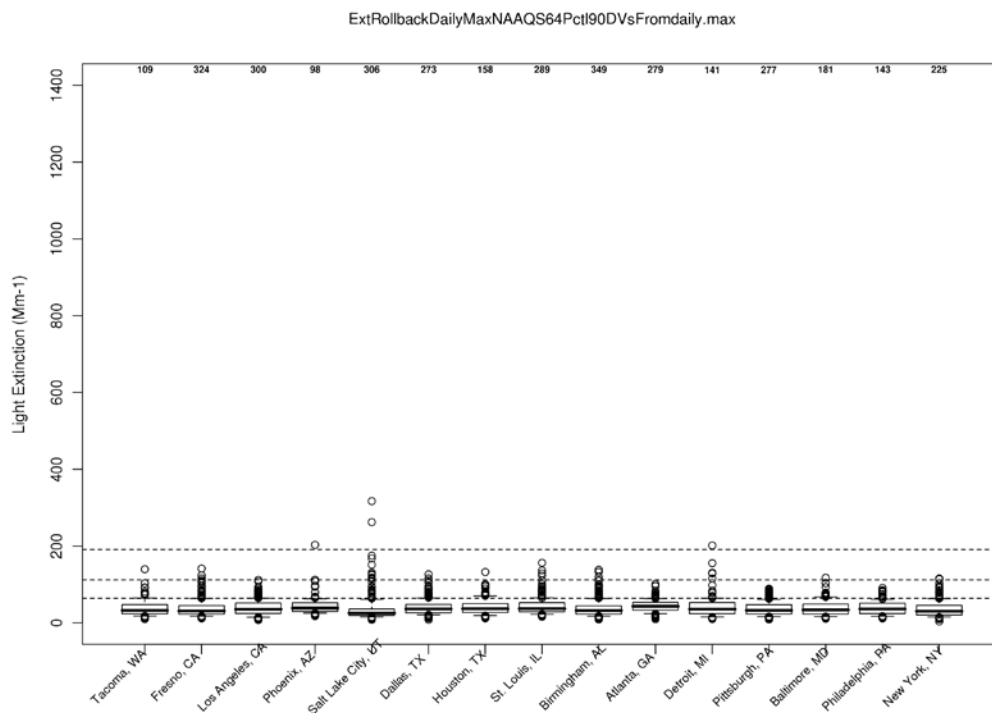


**Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)**

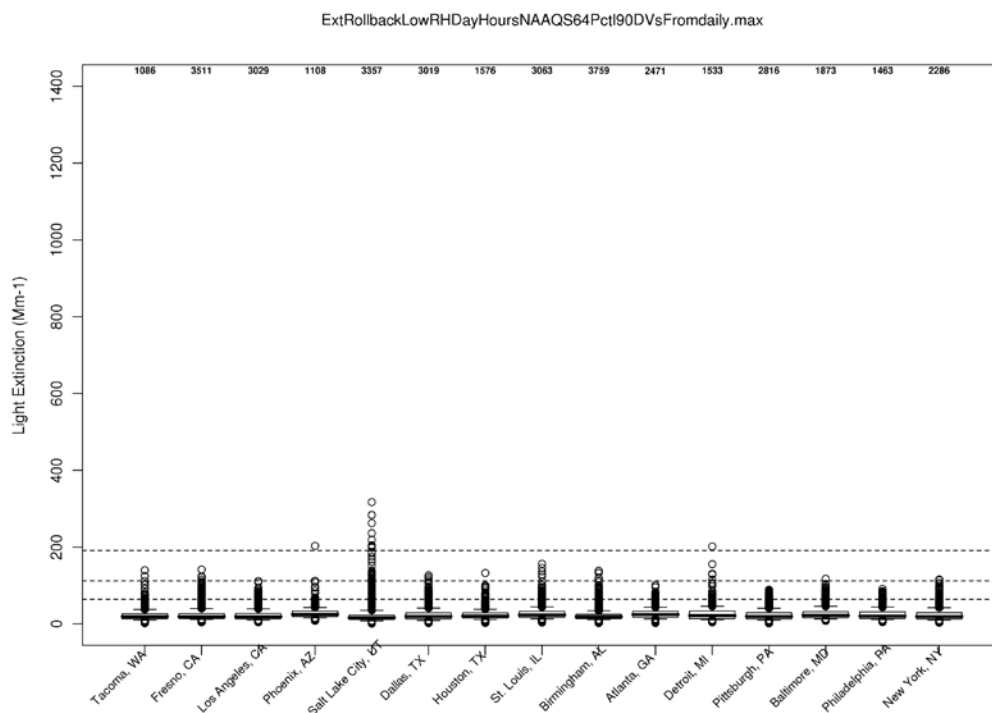


(g) NAAQS Scenario  
Daily Max  
64 Mm<sup>-1</sup>  
90<sup>th</sup> percentile

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

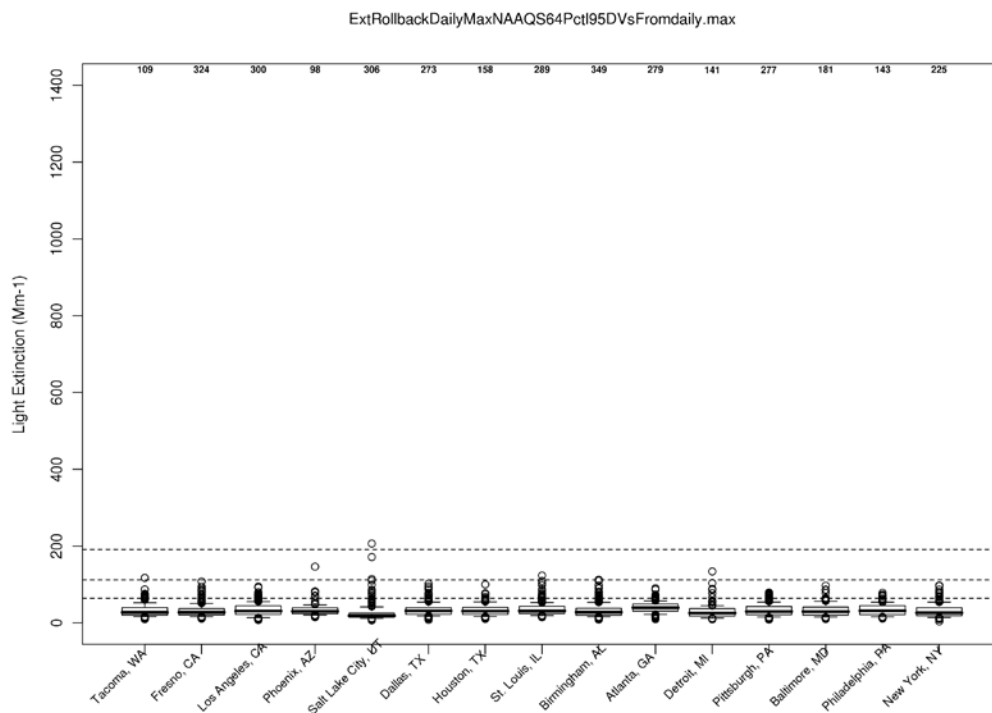


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

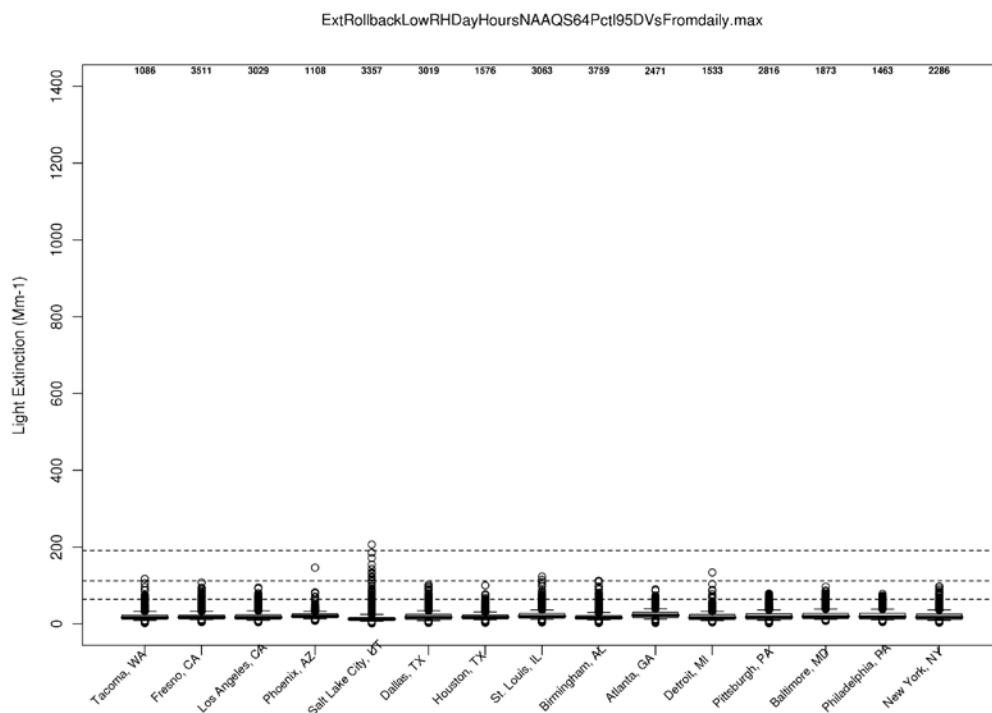


(h) NAAQS Scenario  
Daily Max  
64 Mm<sup>-1</sup>  
95<sup>th</sup> percentile

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

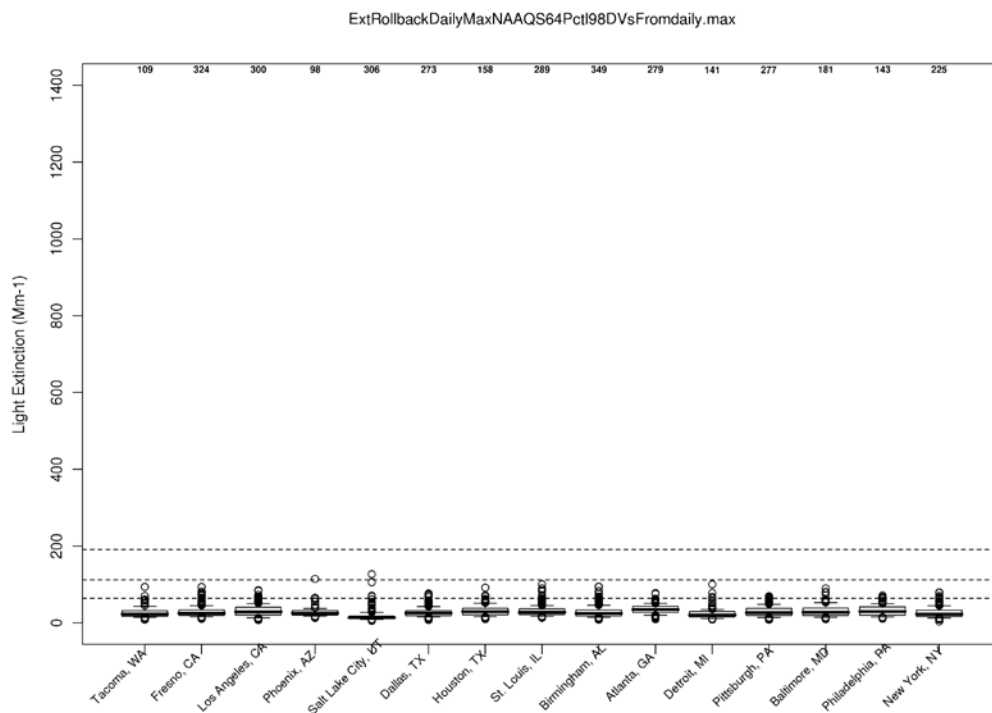


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

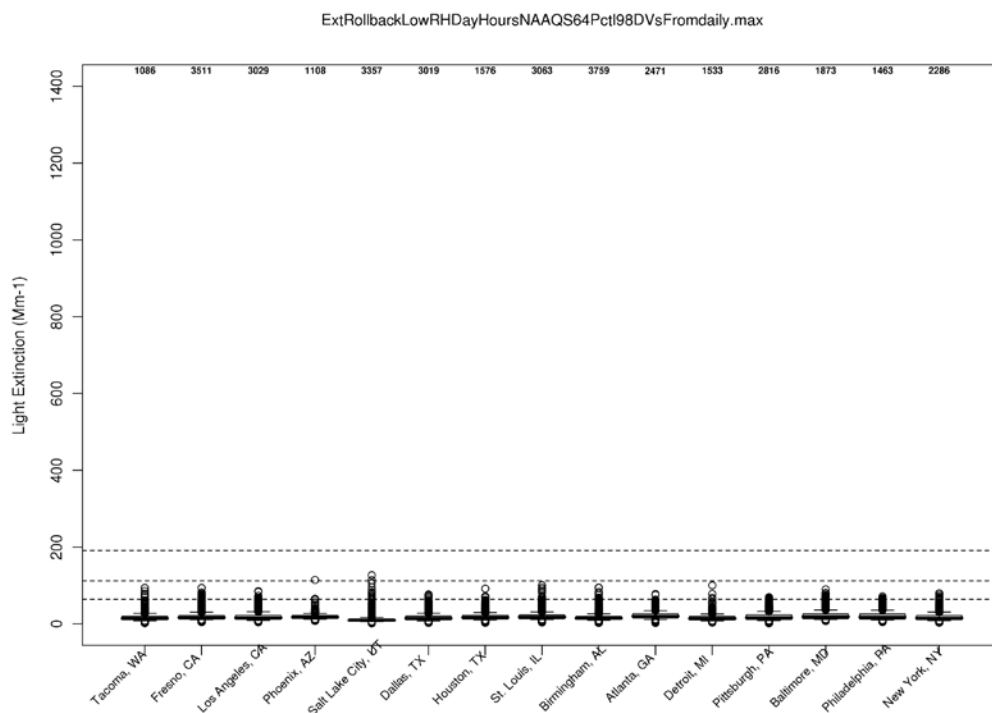


(i) NAAQS Scenario  
Daily Max  
64 Mm<sup>-1</sup>  
98<sup>th</sup> percentile

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



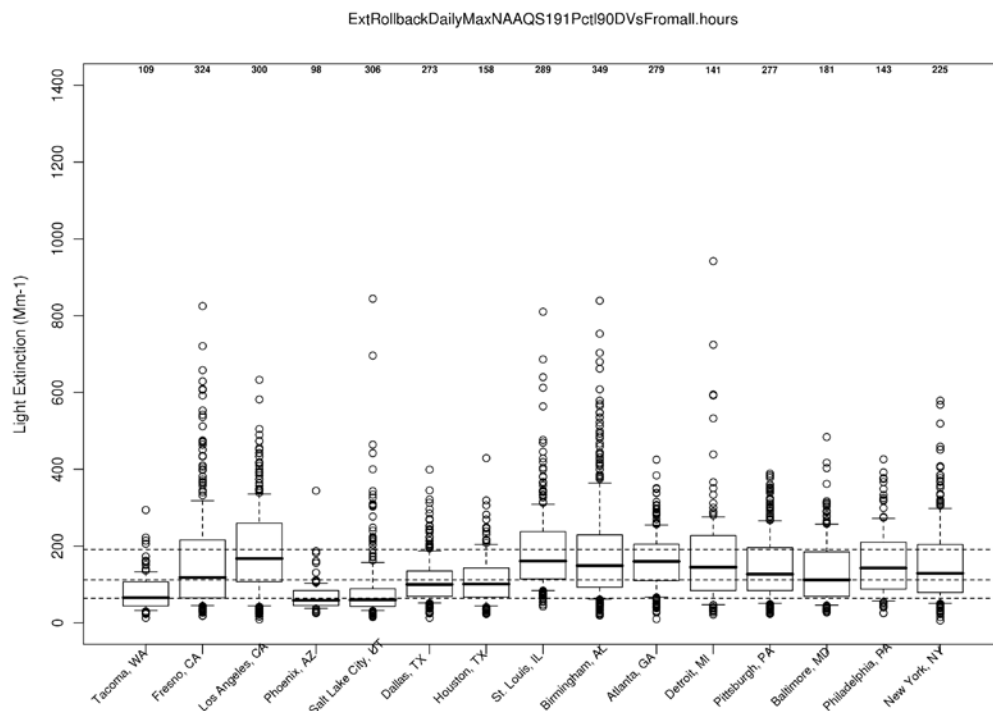
Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)



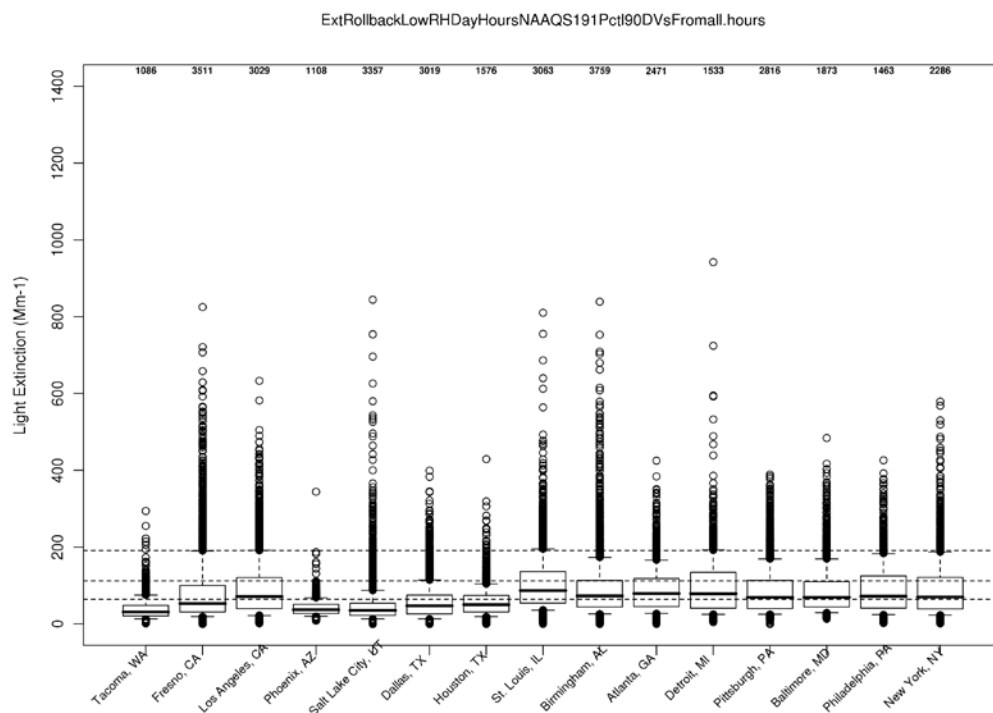


(j) NAAQS Scenario  
All hours  
191 Mm<sup>-1</sup>  
90<sup>th</sup> percentile

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

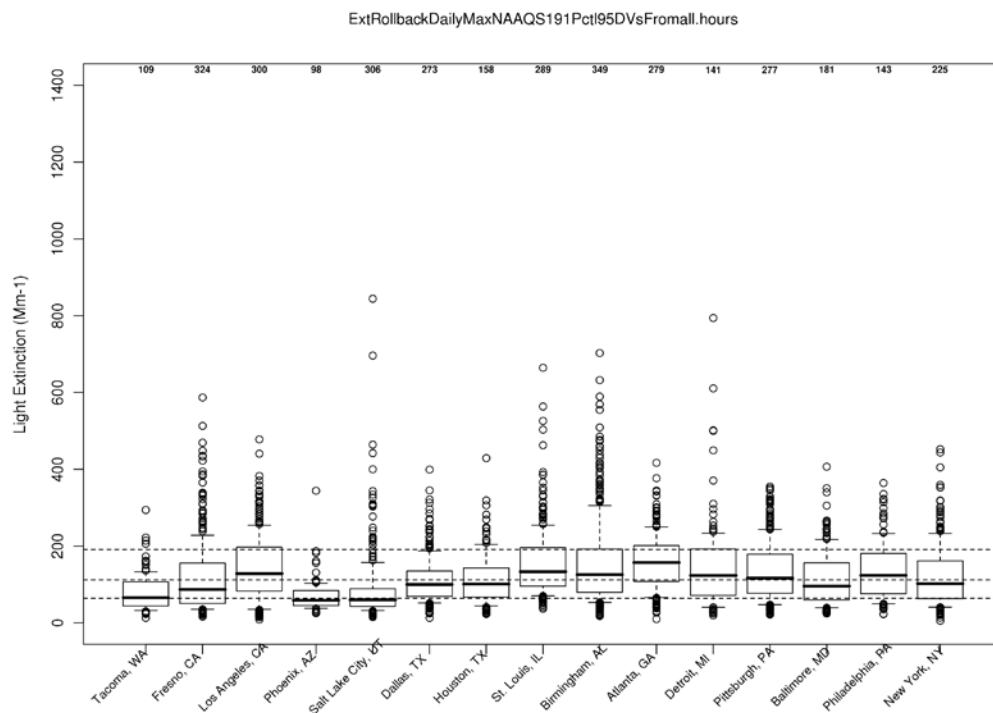


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

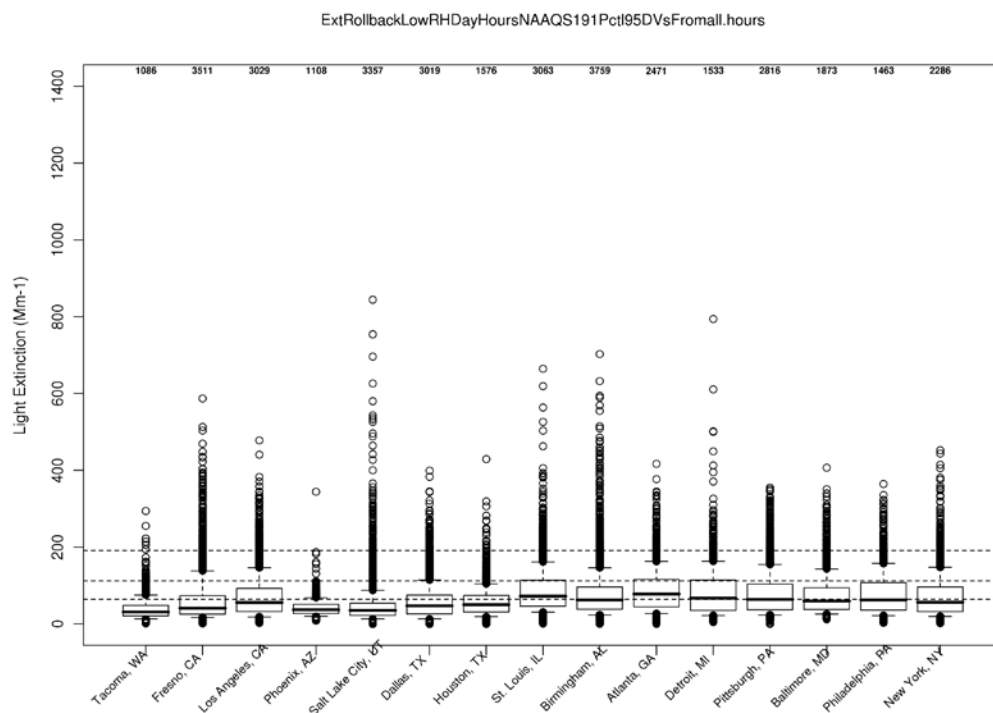


(k) NAAQS Scenario  
 All hours  
 $191 \text{ Mm}^{-1}$   
 95<sup>th</sup> percentile

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

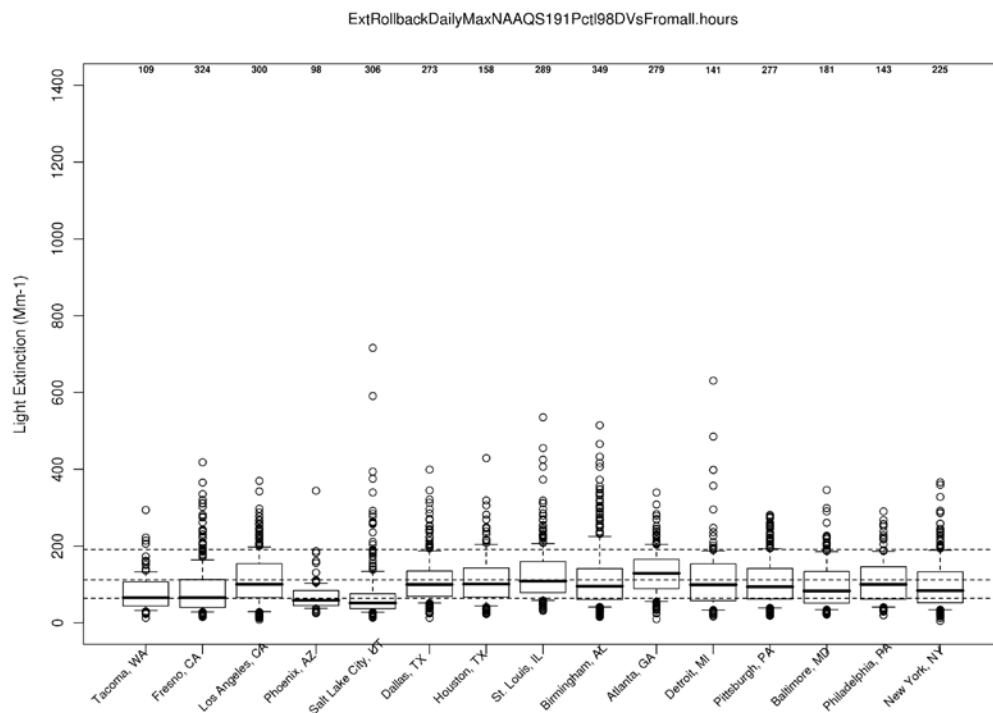


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

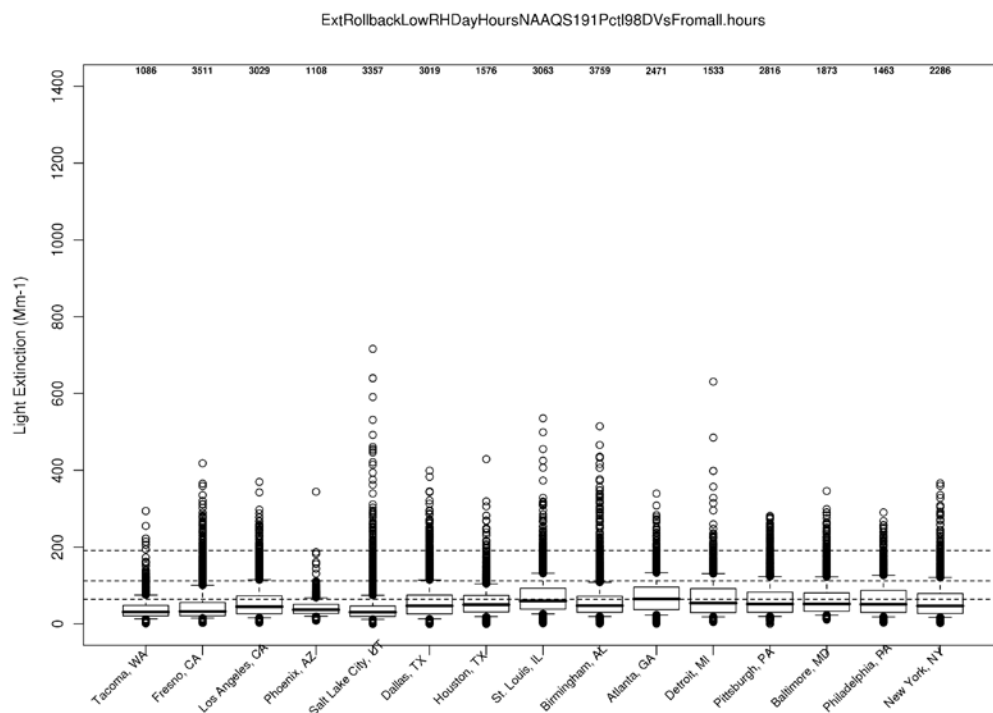


(I) NAAQS Scenario  
 All hours  
 191 Mm<sup>-1</sup>  
 98<sup>th</sup> percentile

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

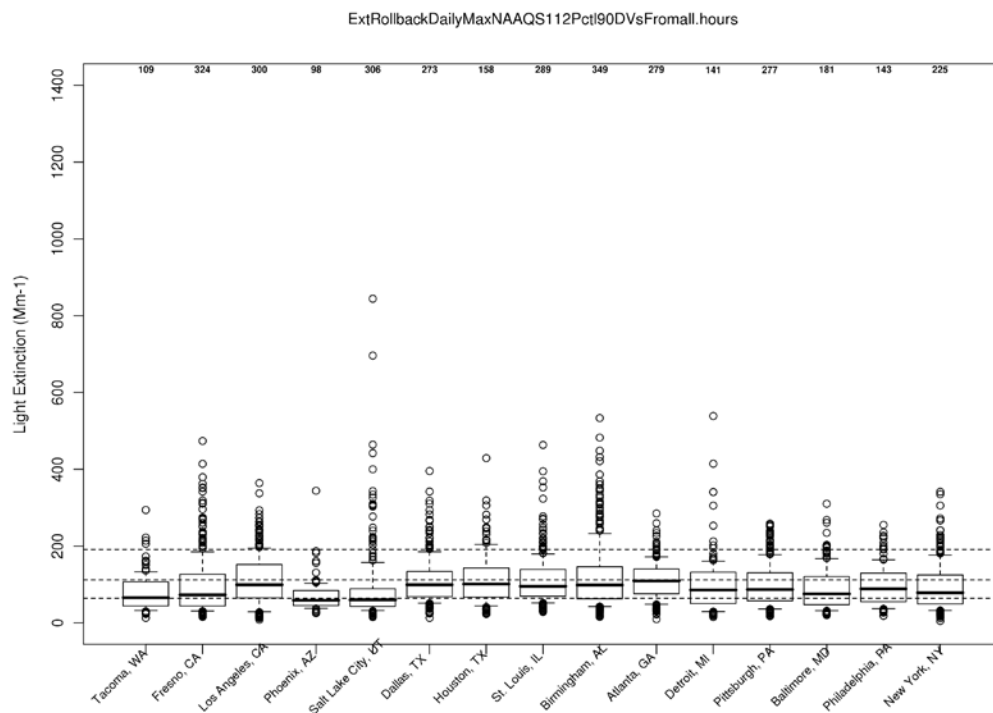


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

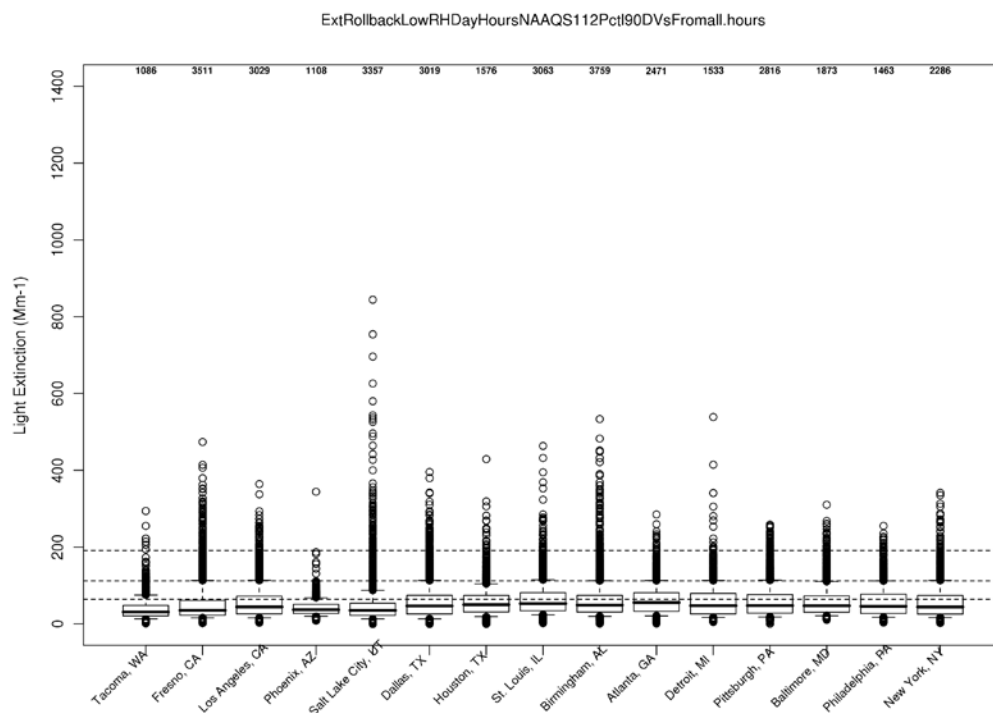


(m) NAAQS Scenario  
 All hours  
 112 Mm<sup>-1</sup>  
 90<sup>th</sup> percentile

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

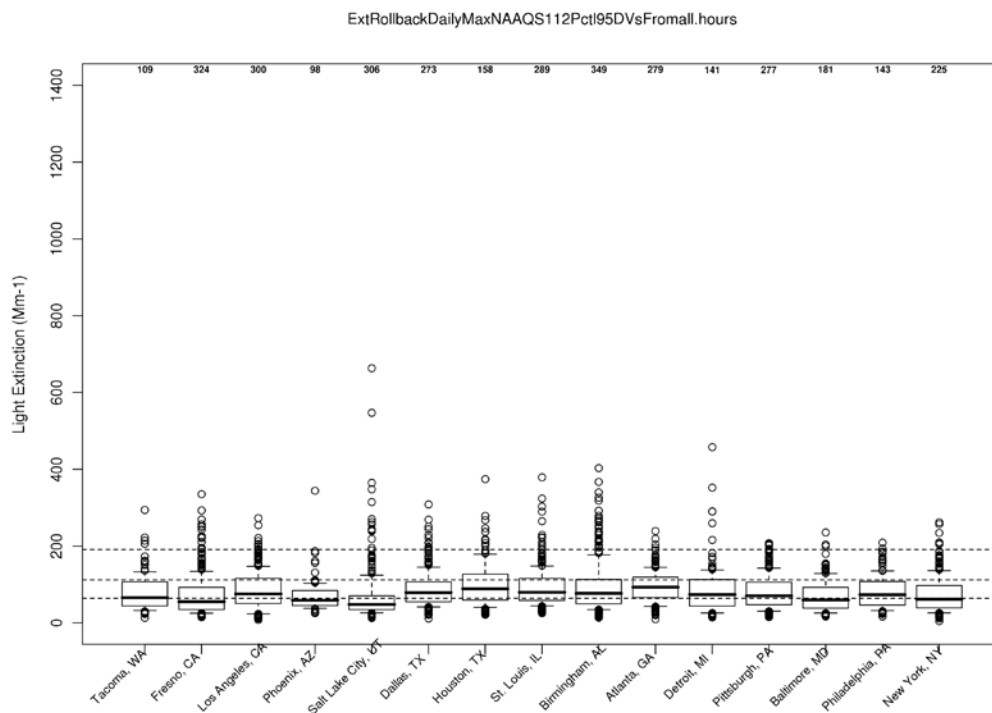


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

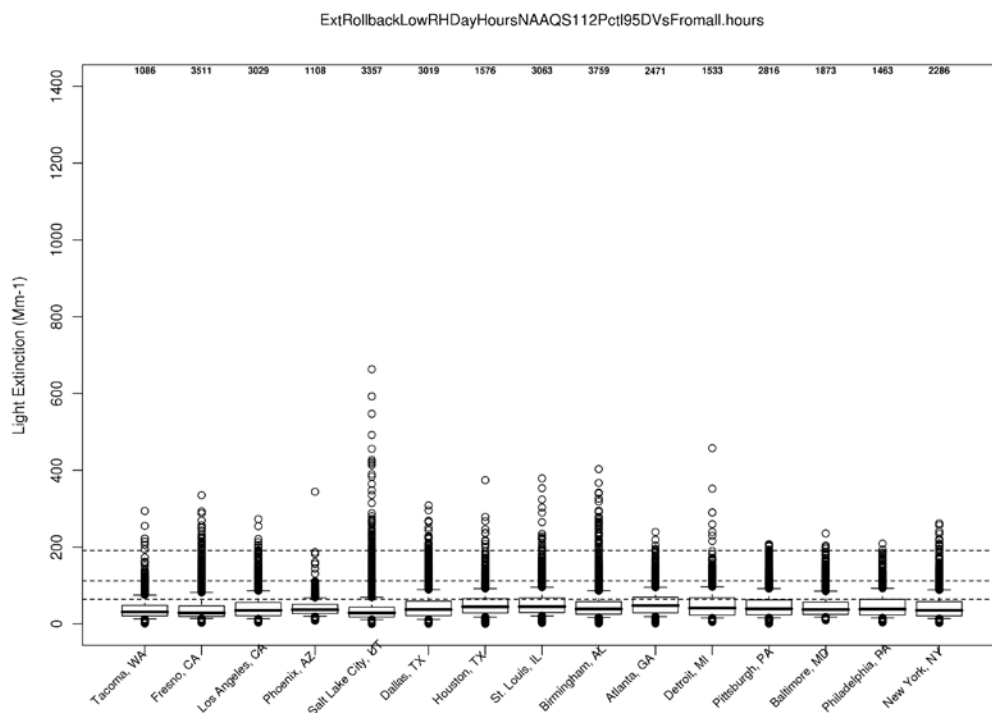


(n) NAAQS Scenario  
 All hours  
 112 Mm<sup>-1</sup>  
 95<sup>th</sup> percentile

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

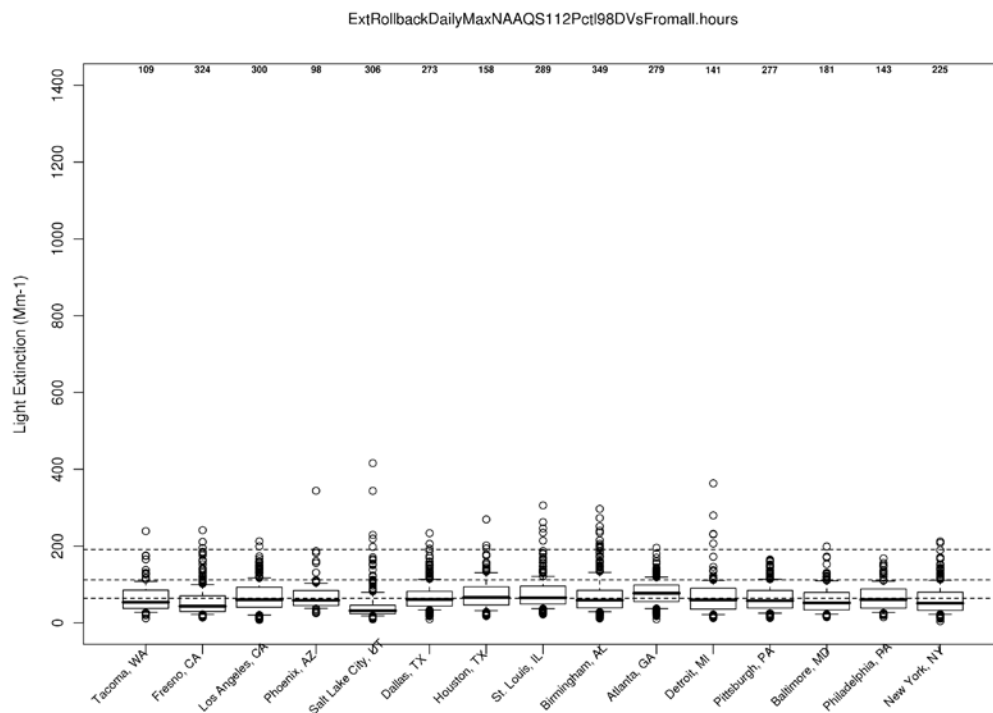


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

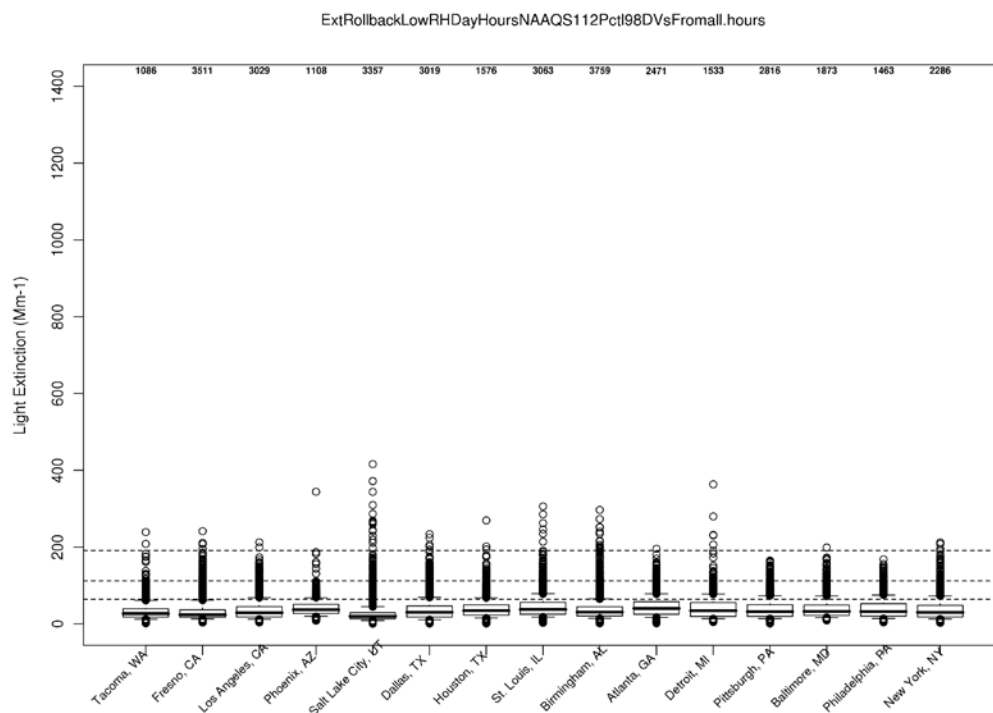


(o) NAAQS Scenario  
 All hours  
 112 Mm<sup>-1</sup>  
 98<sup>th</sup> percentile

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

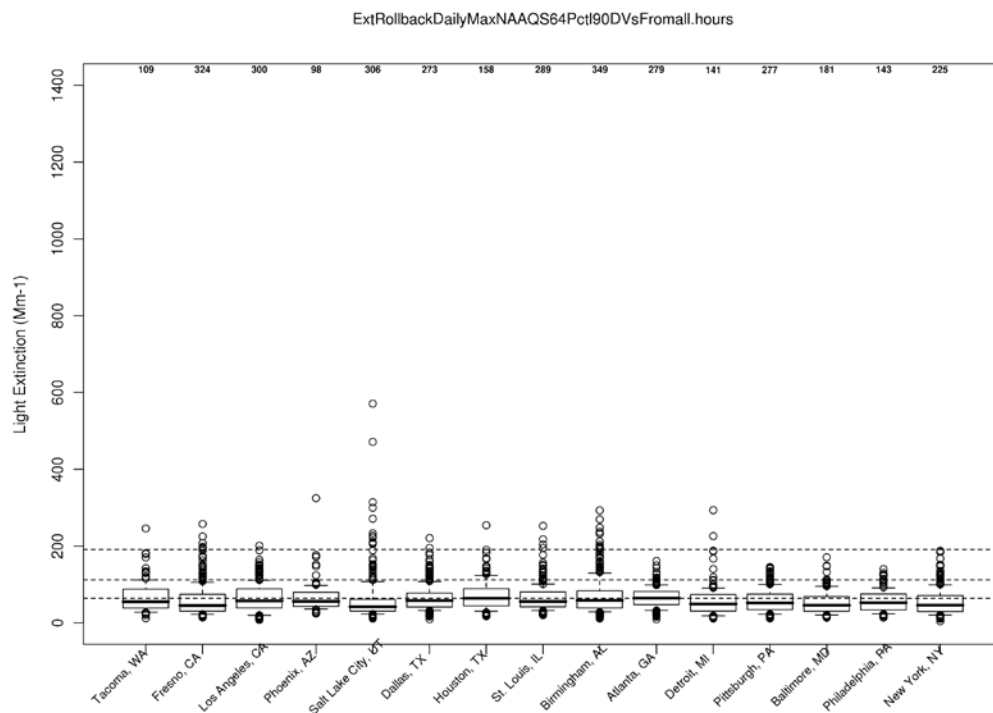


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

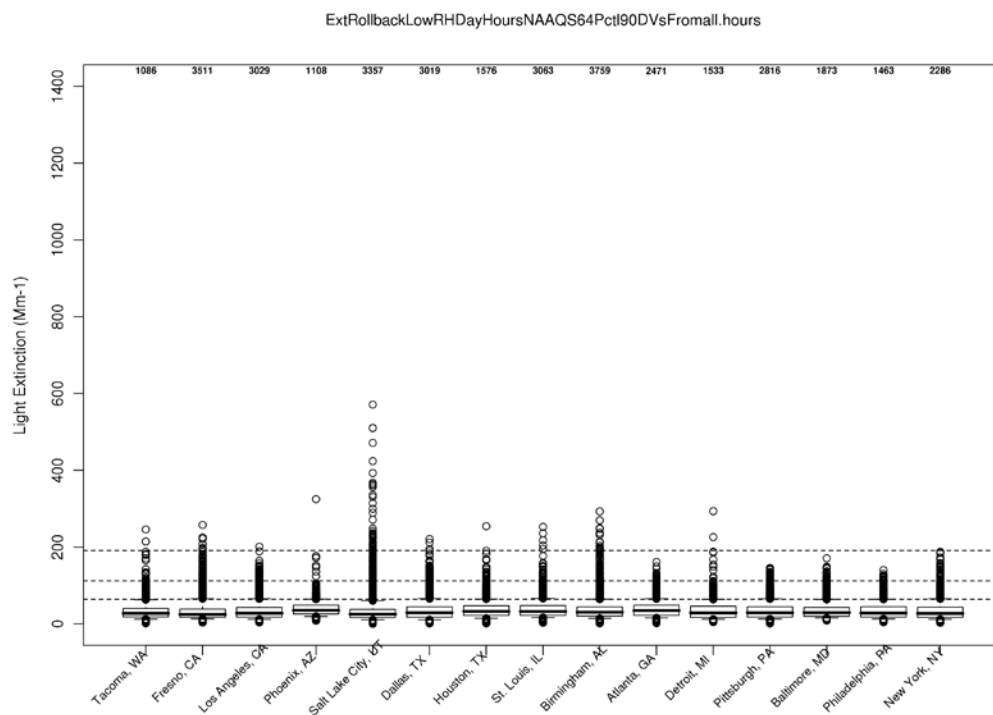


(p) NAAQS Scenario  
 All hours  
 64 Mm<sup>-1</sup>  
 90<sup>th</sup> percentile

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

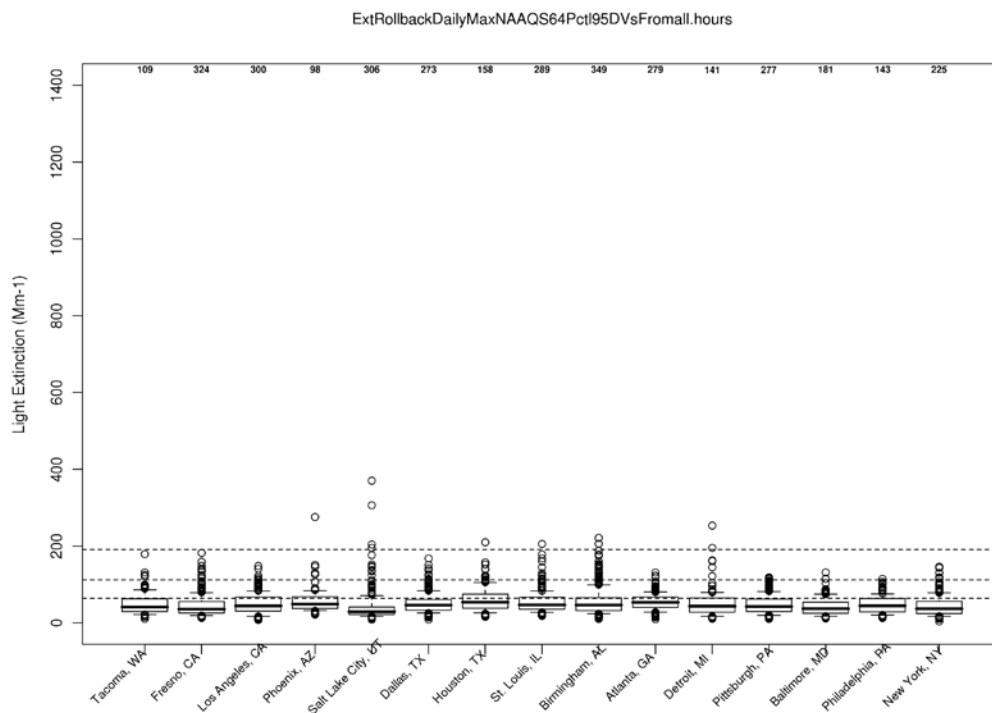


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

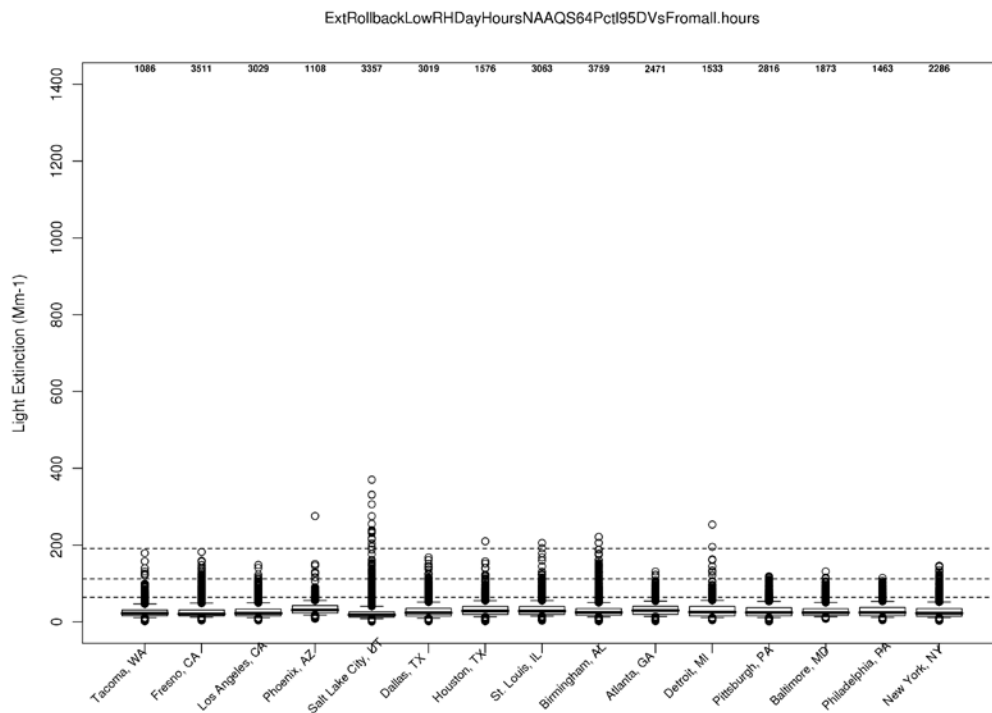


(q) NAAQS Scenario  
 All hours  
 64 Mm<sup>-1</sup>  
 95<sup>th</sup> percentile

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



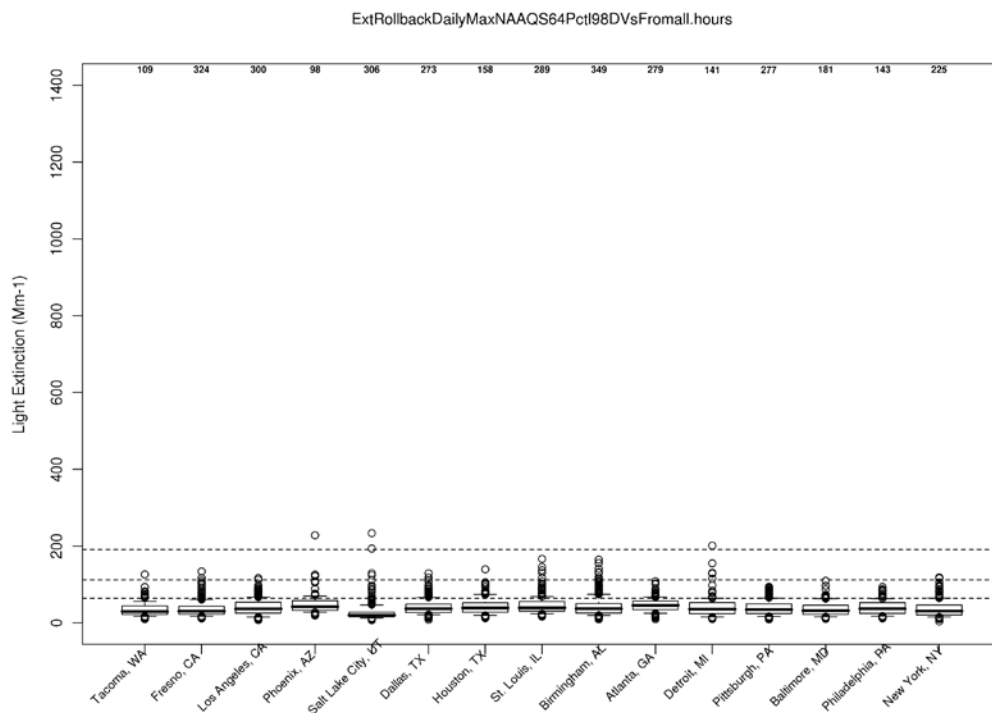
Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)



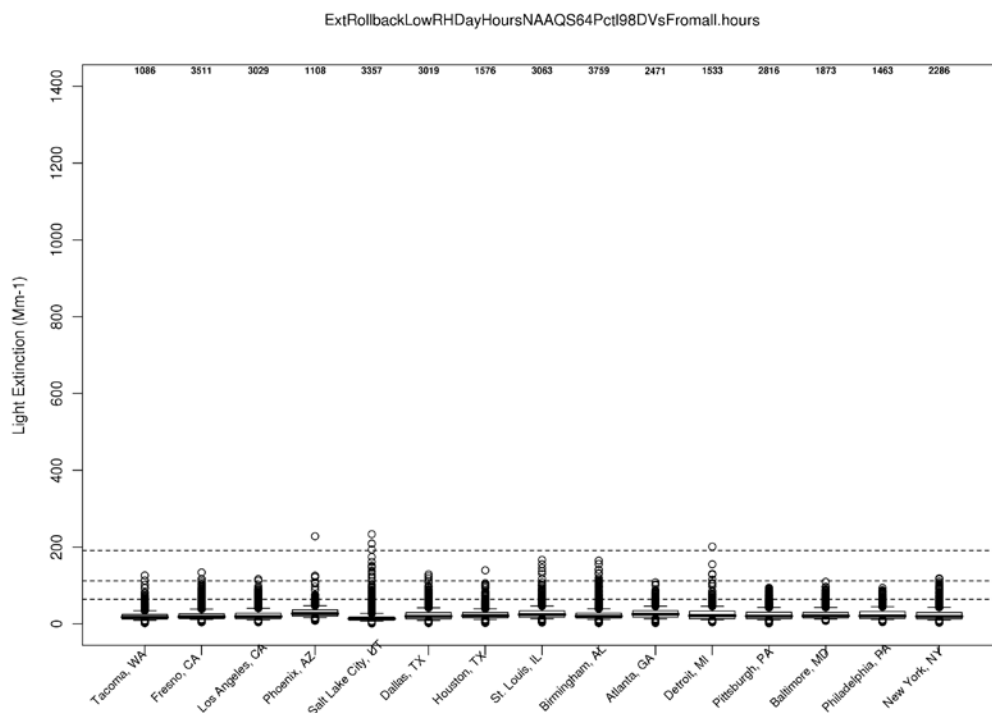


(r) NAAQS Scenario  
 All hours  
 64 Mm<sup>-1</sup>  
 98<sup>th</sup> percentile

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

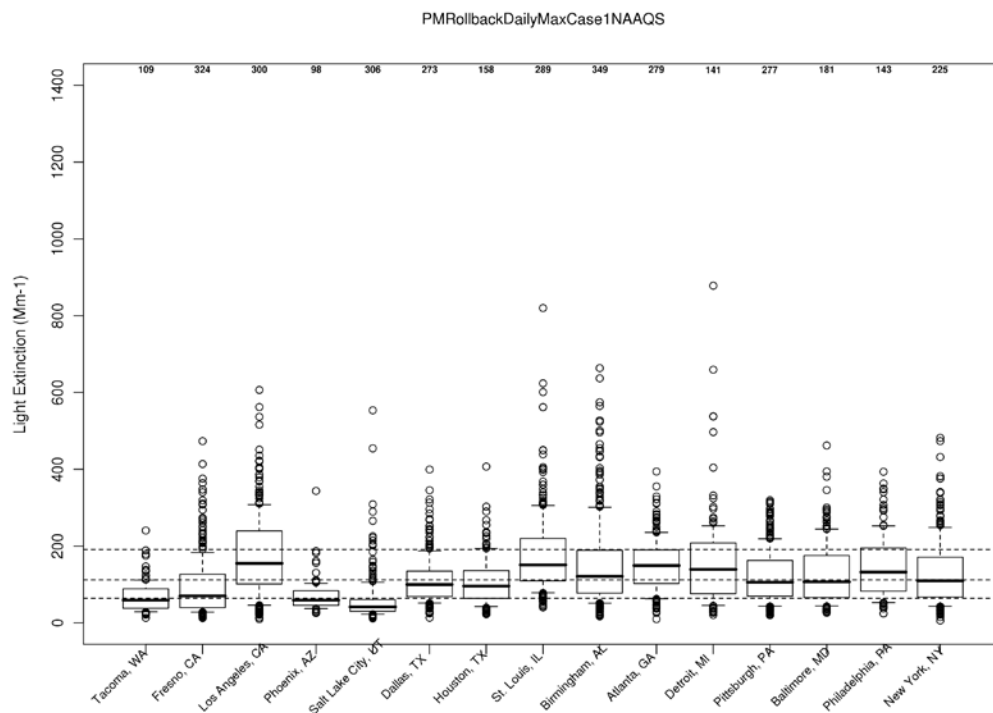


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)

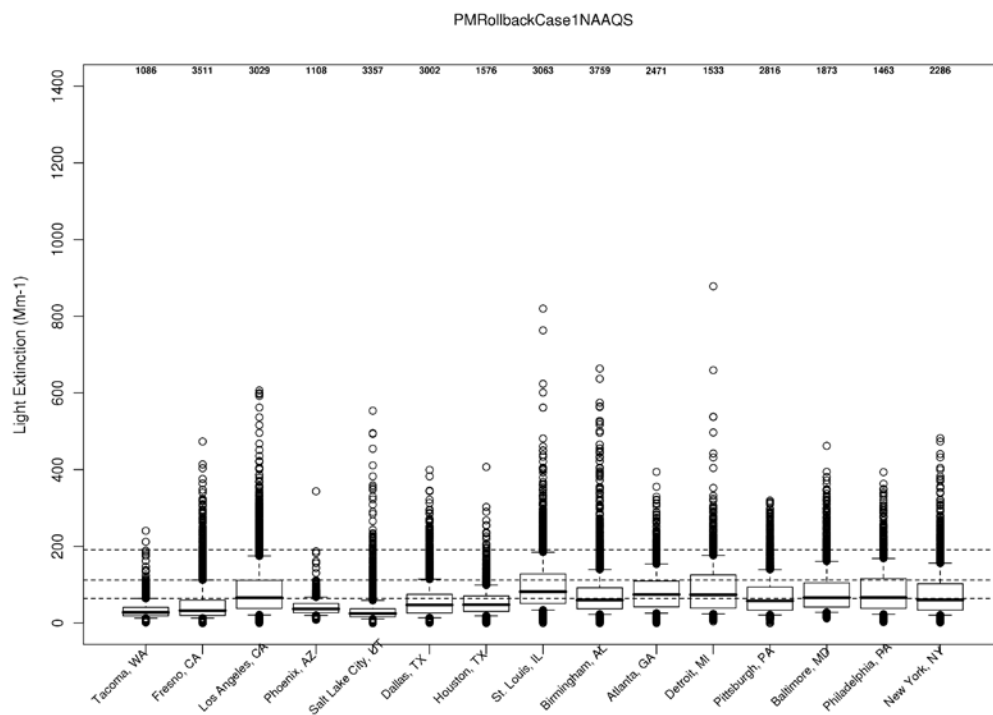


(s) NAAQS Scenario  
 15  $\mu\text{g}/\text{m}^3$  annual  
 35  $\mu\text{g}/\text{m}^3$  24-hour

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

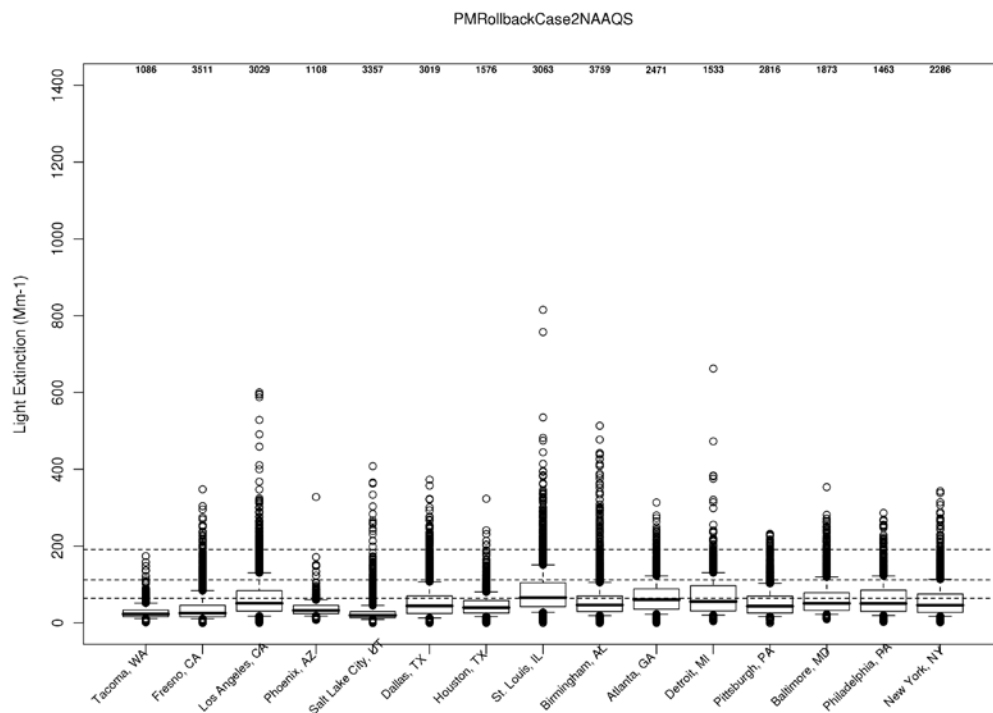


Displayed: Hourly Daylight Light Extinction (excluding hours >90% RH)



(t) NAAQS Scenario  
 12  $\mu\text{g}/\text{m}^3$  annual  
 25  $\mu\text{g}/\text{m}^3$  24-hour

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



## **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 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 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).

Table G-1 shows how many estimates of 1-hour daylight PM 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 relative 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 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 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 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 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 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

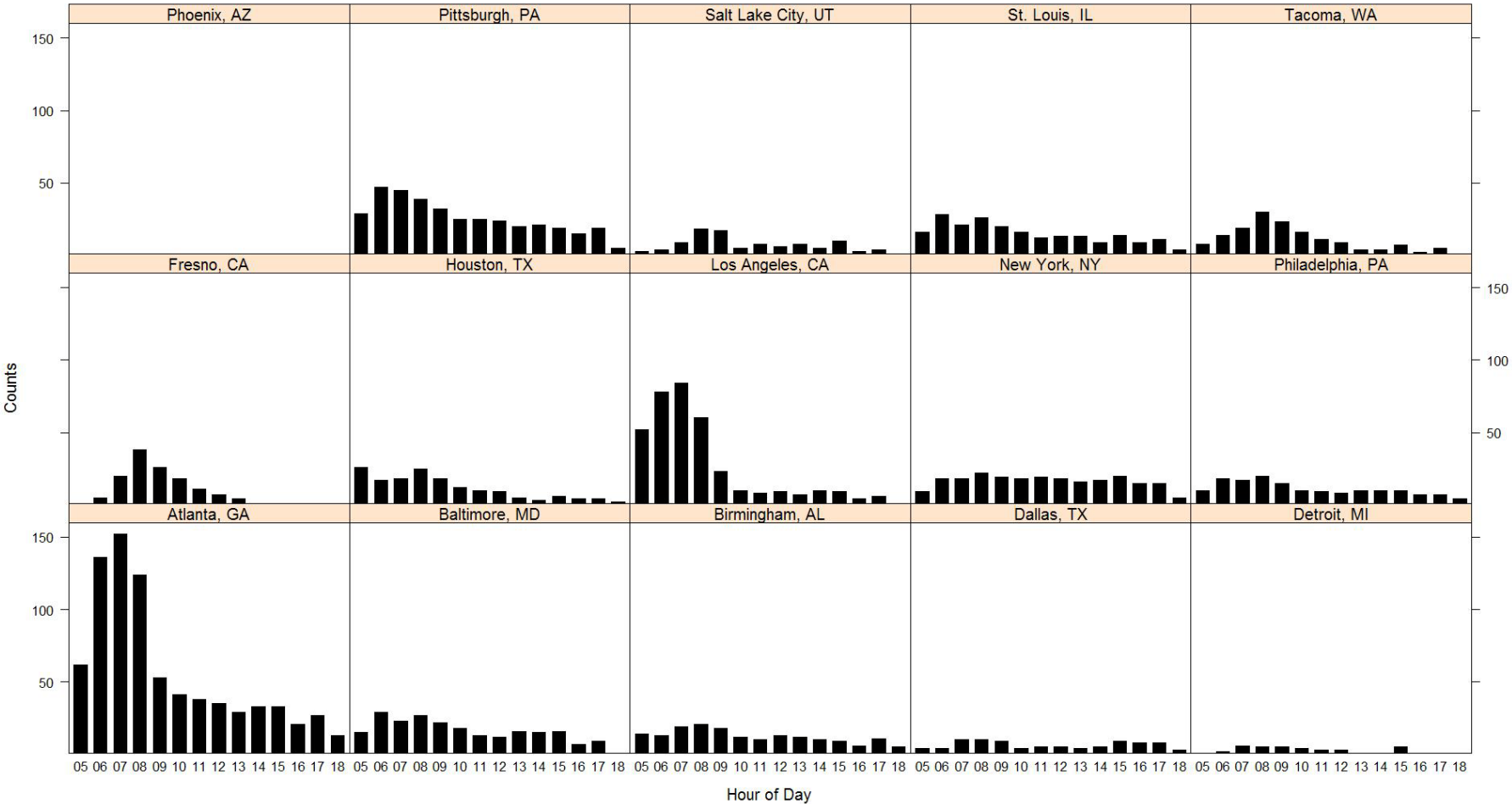
light extinction are notably lower after exclusion, on both a daily maximum basis and individual hour basis, indicating that PM concentrations in some of the excluded hours are fairly high. If only low-PM hours were excluded by the relative humidity screen, the highest values of light extinction would not have been affected.

Finally, Table G-2 contrasts PM light extinction design values before and after the exclusion, for the 90<sup>th</sup> and 95<sup>th</sup> percentile forms based on daily maximum daylight 1-hour PM light extinction, for current conditions. (A similar comparison for the 98<sup>th</sup> 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 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**

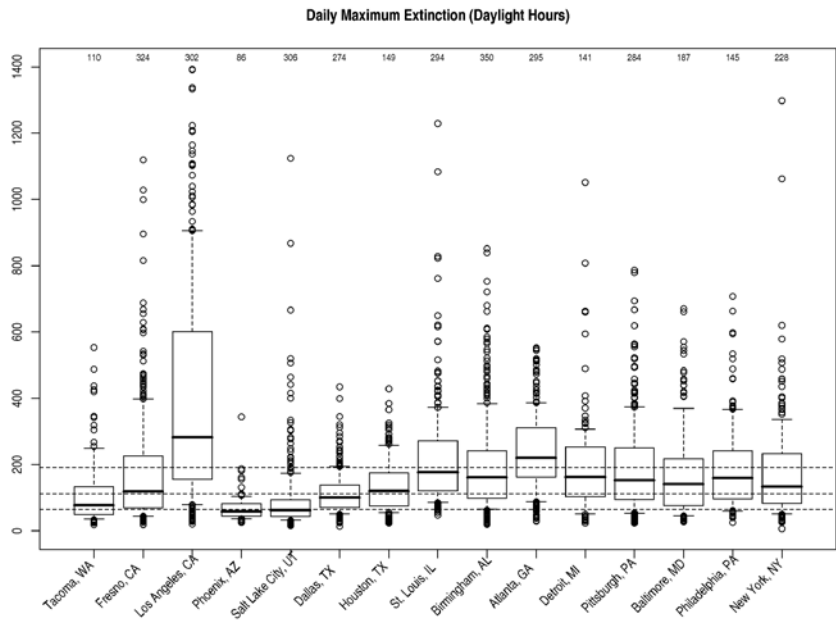
<b>Study Areas</b>	<b>Percent of Daylight Hours Excluded</b>	<b>Percent of Days with at Least One Daylight Hour Excluded</b>
Tacoma	12.3	49.1
Fresno	3.6	15.7
Los Angeles	10.6	49.7
Phoenix	0.0	0.0
Salt Lake City	2.9	13.7
Dallas	2.8	12.8
Houston	9.6	40.9
St. Louis	6.4	21.1
Birmingham	4.4	19.1
Atlanta	24.1	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.**

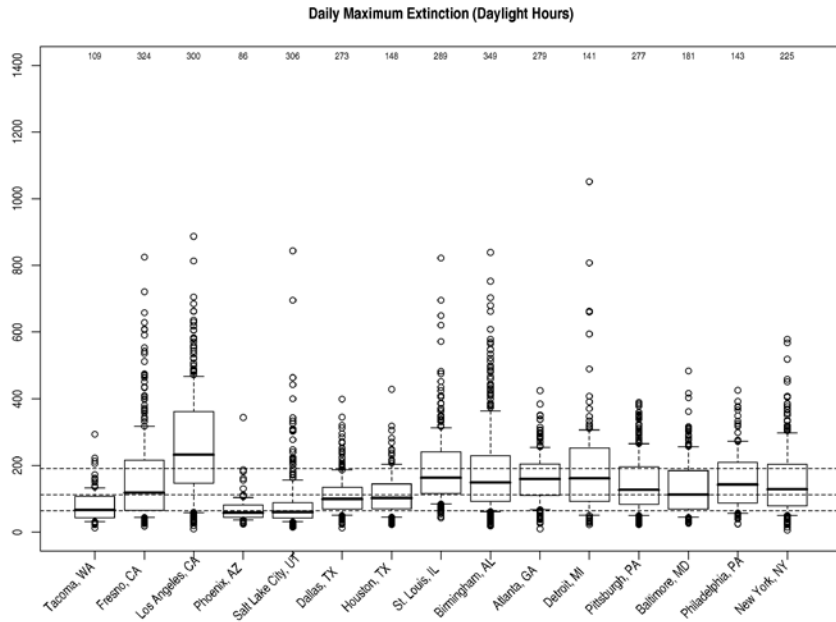


**Figure G-2. Comparison of distributions of estimated daylight 1-hour PM light extinction and maximum daily daylight 1-hour PM light extinction across the 2005-2007 period for current conditions, by study area, before and after elimination of hours with relative humidity greater than 90 percent.**

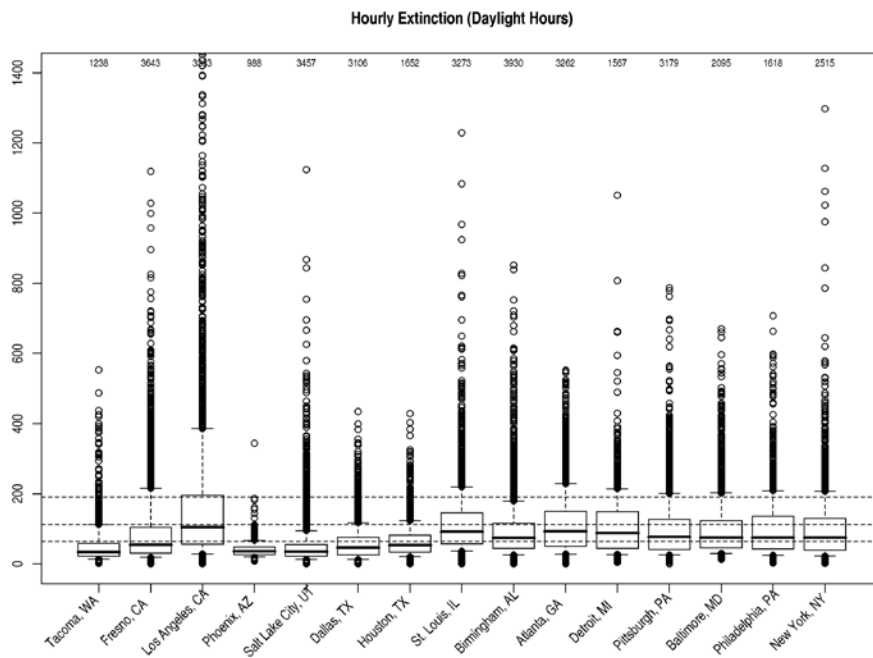
**(a) Maximum daily values**  
**Before Elimination**



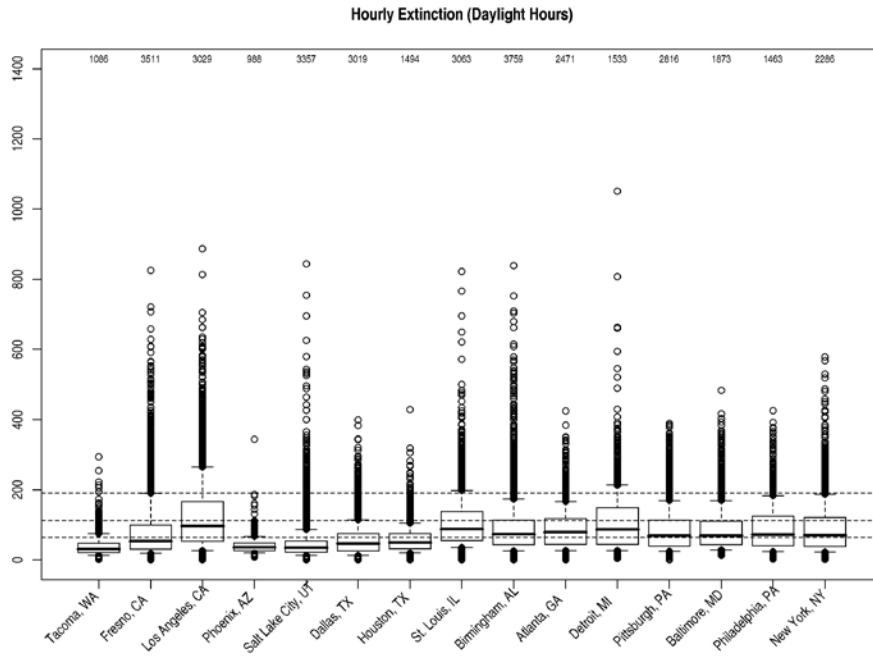
**After Elimination**



**(b) Individual 1-hour values**  
**Before Elimination**



**After Elimination**





**Table G-2. Comparison of 90<sup>th</sup> and 95<sup>th</sup> percentile PM light extinction design values for the 2005-2007 period for current conditions based on maximum daily 1-hour daylight PM light extinction, before and after elimination of hours with relative humidity greater than 90 percent**

Study Areas	PM 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

## **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 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 90<sup>th</sup> percentile form for both the daily maximum and all hours approaches.

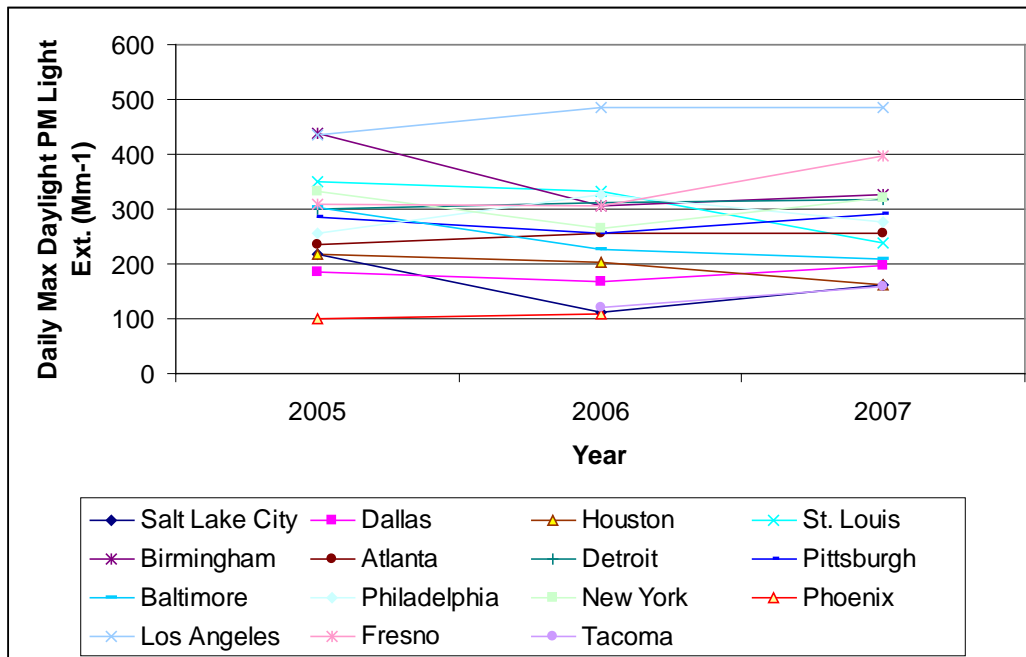
**Table H-1. Year-specific percentile values of PM light extinction for 2005, 2006, and**

**2007**

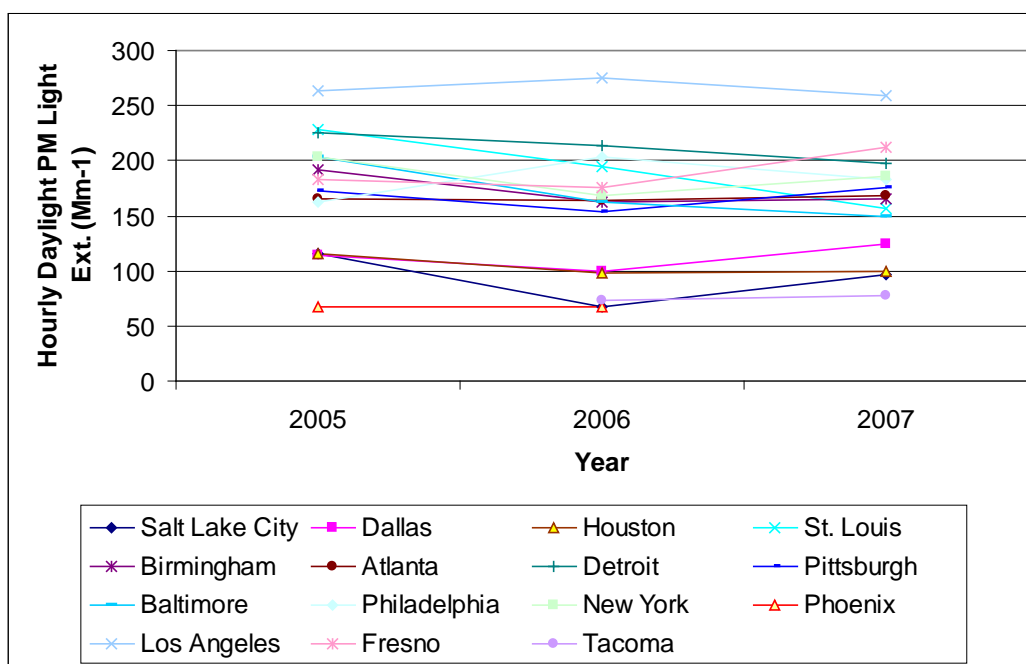
Study Areas	90 <sup>th</sup> Percentile Form				95 <sup>th</sup> Percentile Form				98 <sup>th</sup> Percentile Form			
	2005	2006	2007	2005-2007 Average	2005	2006	2007	2005-2007 Average	2005	2006	2007	2005-2007 Average
	Based on Daily Maximum 1-Hour Daylight PM Light Extinction (Excluding hours with relative humidity greater than 90%)											
Tacoma	NA	121	158	140	NA	140	173	157	NA	214	206	210
Fresno	308	307	398	338	553	364	472	463	658	400	542	533
Los Angeles	435	485	486	469	507	535	619	554	606	605	662	624
Phoenix	100	110	NA	105	156	131	NA	144	344	187	NA	266
Salt Lake City	217	112	163	164	310	141	306	252	343	191	696	410
Dallas	184	169	197	183	252	223	242	239	313	321	271	302
Houston	217	204	161	194	269	238	196	234	306	319	248	291
St. Louis	350	331	239	307	434	405	303	381	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	318	310	347	408	663	473	391	489	1051	644
Pittsburgh	284	257	292	278	347	272	320	313	360	350	383	364
Baltimore	303	227	208	246	362	258	239	286	417	308	260	328
Philadelphia	257	325	276	286	333	367	318	339	426	376	377	393
New York	333	265	320	306	405	275	384	355	568	352	451	457
	Based on 1-Hour Daylight PM Light Extinction (All Hours) (Excluding hours with relative humidity greater than 90%)											
Tacoma	NA	73	78	76	NA	102	109	106	NA	120	151	136
Fresno	183	175	212	190	257	262	278	266	395	332	391	373
Los Angeles	263	275	259	266	325	362	359	349	408	458	486	451
Phoenix	67	68	NA	68	79	78	NA	79	92	96	NA	94
Salt Lake City	115	67	96	93	194	83	148	142	255	116	303	225
Dallas	114	100	125	113	145	126	158	143	184	176	204	188
Houston	116	98	100	105	143	122	119	128	191	174	148	171
St. Louis	229	195	157	194	277	239	188	235	334	309	226	290
Birmingham	191	162	166	173	251	204	226	227	340	267	319	309
Atlanta	166	164	169	166	188	194	202	195	233	233	248	238
Detroit	226	213	198	212	267	253	234	251	320	312	314	315
Pittsburgh	173	153	176	167	217	193	218	209	284	236	272	264
Baltimore	203	163	150	172	290	194	196	227	345	225	225	265
Philadelphia	163	204	183	183	209	234	224	222	280	298	258	279
New York	204	169	186	186	265	222	244	244	313	267	320	300

**Figure H-1. Inter-year variability in 90th percentile 1-hour daylight PM 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 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.

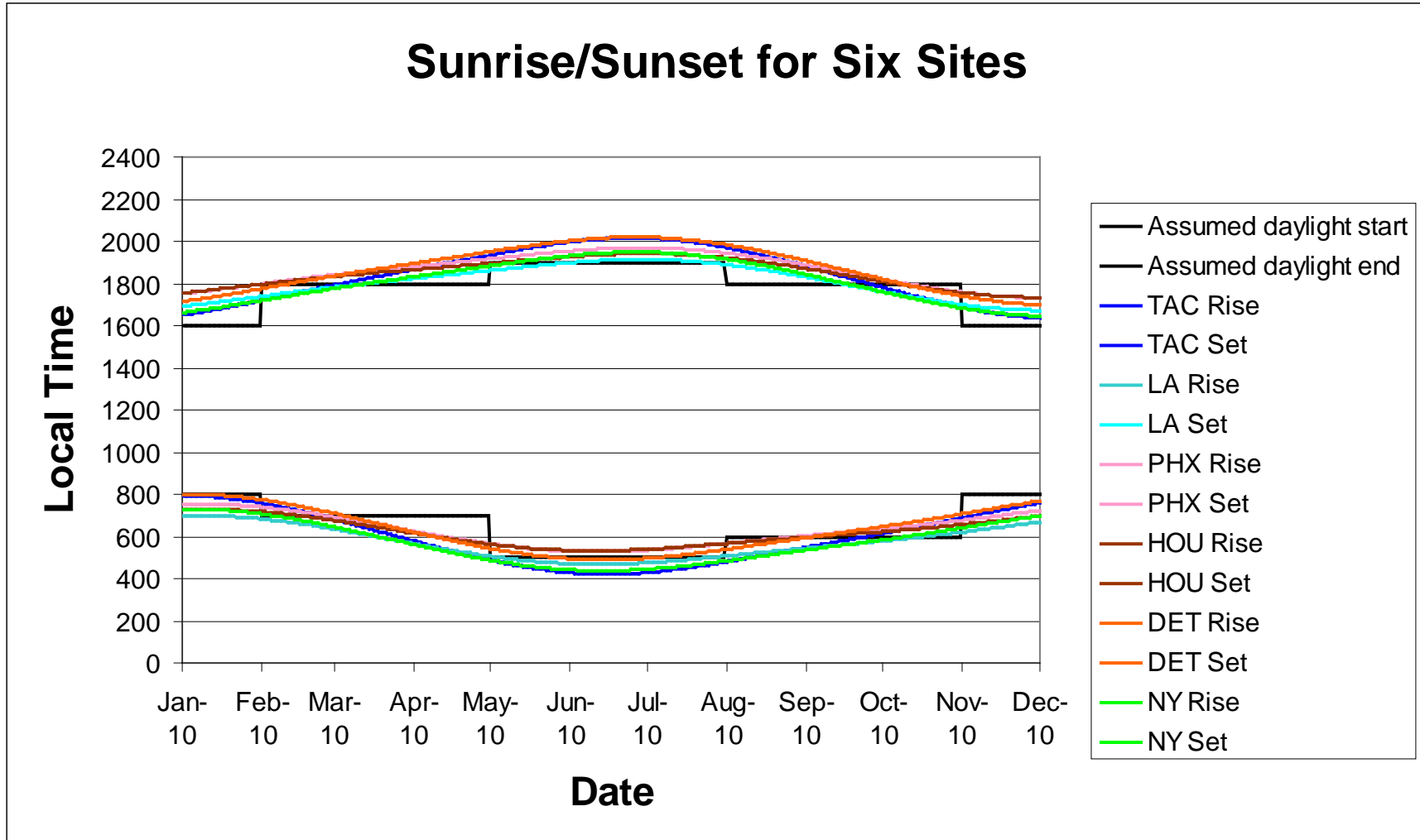
Figure I-1 shows the relationship between these sunrise and sunset times and the simple scheme used to denote hours as fully daylight. The vertical scale is in hours with zero corresponding to local noon. The smooth curves represent the actual times of sunrise (top of figure) and sunset (bottom of figure). 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 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**

<b>Study Area</b>	<b>February (AM and PM)</b>	<b>April (AM)</b>	<b>June-July (PM)</b>	<b>October (AM and PM)</b>
<b>Tacoma</b>	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%.
<b>Los Angeles</b>	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%.
<b>Phoenix</b>	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.
<b>Houston</b>	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.
<b>Detroit</b>	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.
<b>New York</b>	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%.





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