Visibility

SAMI VISIBILITY ASSESSMENT OBJECTIVES

- Summarize visibility and air quality trends for SAMI Class I areas based on IMPROVE data
- Assess methods used to calculate light scattering from measured or modeled air quality
- Use SAMI air quality model results to project future air quality and visibility in response to SAMI strategies
- Provide visibility estimates to support SAMI socioeconomic analyses
- Provide electronic software tools to archive and display SAMI visibility results
- Relate SAMI assessment to EPA guidance for the regional haze rule

[INSERT GRAPHIC 5.1: LOOK ROCK VISIBILITY]

WHAT IS VISIBILITY?

Visibility is a term that refers to human perception of a scenic vista. The term addresses our ability to distinguish the color, contrast, and outline of objects viewed in a landscape. Fine particles and gases in the atmosphere scatter or absorb light and reduce the clarity of the view and the distance that can be discerned by the human eye. As visibility is reduced, colors appear washed out and less vivid, and landscape features become less clear, or may disappear altogether.

Light energy is transmitted through the atmosphere (Malm, 1999). The passage of light in the atmosphere can be altered in three ways:

- Light is scattered out of the sight path between the viewer and the image. Particles in the size range closest to the wavelengths of visible light (particles between 0.3 and 0.7 microns) are the most efficient in scattering light.

- Light can also be removed from the sight path by NO2 and black carbon particles.

- Light is scattered into the sight path from sunlight or from light reflected off the ground or other objects in a landscape.

Visibility is also affected by the angle of the sun. When the sun is overhead, light encounters few particles in the vertical sight path to our eye and little light is scattered. We perceive the sun as white. When the sun is nearer the horizon, more of the sight path likely to be affected by particles and gases in the atmosphere. At sunrise or sunset, blue light is scattered out of the sight path and we perceive the sun and sky as red. There are also other issues among the viewer, target, and sun that affect perception. Viewer-target separation, if that distance is small relative to the overall visual range, the sensitivity to changes in visibility impairment will be small. Visibility is best when angel of incidence equals the angle of reflection (when the dawn sun

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comes over your shoulder and hits the target and bounces back to you horizontally). Sun angle also affects the perceived color of target.

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[INSERT GRAPHIC 5.2: SAMI RELEVANCE TO REGIONAL HAZE]

WHAT CAUSES HAZE?

Particles and gases in the atmosphere scatter or absorb light and impair visibility. **Fine particles** are those less than 2.5 microns, while **coarse particles** are those particles between 2.5 and 10 microns. Fine particles are either emitted directly or secondary byproducts formed in the atmosphere from emissions of gases.

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Fine particles include sulfate, nitrate, organic, and soil particles. [Note: We don't know that. Recent research suggest considerable man-made contribution. Also, source attribution should not be here.] Organic particles reflect blue light and cause a bluish haze. The Great Smoky Mountains and Blue Ridge Mountains were named for the natural bluish haze and misty clouds common to these mountains.

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Sulfate particles are formed from sulfur dioxide emissions, primarily from coal combustion. As illustrated in Figure Visibility 1, sulfate particles occur in the atmosphere as sulfuric acid (one sulfate molecule associated with two hydrogen ions), as ammonium bisulfate (one sulfate molecule associated with one hydrogen ion and one ammonium ion), or as ammonium sulfate (one sulfate molecule associated with two ammonium ions). Sulfate particles scatter light of all colors and cause a whitish or gray haze. Ammonia gas is emitted primarily from livestock and fertilizer applications.

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[INSERT FIGURE 5.1: ILLUSTRATION OF MOLECULES OF SO4 WITH H AND NH4, NO3 GAS WITH NH4 TO FORM NH4NO3 PARTICLE]

Ammonium nitrate particles are formed from nitric acid gas and ammonia gas. Nitric acid gas is formed from nitrogen oxide emissions from combustion of fossil fuels (coal, natural gas, gasoline, and diesel). Ammonia gas reacts with nitric acid gas to form the ammonium nitrate particles. Because ammonia gas preferentially binds with sulfate, little ammonium nitrate particles will be formed until all sulfate particles are fully neutralized (ratio of ammonium to sulfate ions of 2.0). For most of the year in the southeastern United States, sulfate particles are not fully neutralized by ammonium, and nitrate particles concentrations are low (IMPROVE).

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Fine soil particles are primarily from construction, agricultural, and road sources. Fine soil particles scatter less light than sulfate, nitrate, and organic particles.

Elemental carbon is emitted from forest fires and other combustion sources. Elemental carbon absorbs light and removes light from the sight path. Nitrogen dioxide gas (NO2) absorbs blue light and thus we perceive a reddish brown haze. This is particularly notable above urban areas with high densities of nitrogen oxides emissions.

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HOW IS VISIBILITY MEASURED?

Visibility is measured using visual observations, optical instruments, or calculated from fine particle mass.

Visual range is a common measure of visibility that describes the distance that can be viewed and is reported in miles or kilometers (Figure 5.2). [Note: At night, this visual range is near zero. Why do we use 24 hour averages of mass and light extinction?] Visual range is not a good measure of the clarity of an image. Visual range can be measured using observations of objects at fixed distances from an observation point. Visual range can also be calculated from light extinction.

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[INSERT FIGURE 5.2: MEASUREMENT SCALES FOR VISUAL RANGE, EXTINCTION, AND DECIVIEW; INSERT SCALE FROM MALM, 1999, PAGE 35]

Light extinction is an optical measure of both the absorption and scattering of light in a sight path and is reported as inverse megameters. The higher the extinction value, the poorer the visibility. Light extinction measures atmospheric conditions but does not address how people perceive visibility. Light extinction is measured using optical instruments (called transmissometers or nephalometers) or calculated based on measured mass of fine particle components.

Deciview is a measure of visibility that is based on the same concept as decibels, which measure hearing. A deciview measures an equivalent incremental change in visibility whether the atmosphere is clear or hazy. [Note: Cite and qualify the citation or delete.] Deciview is calculated from light extinction using a logrithmic scale. The higher the deciview value the poorer the visibility.

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Photographic images are commonly used to illustrate visibility. In recording a view, cameras function similarly to the human eye. The aperture of a camera controls the amount of light entering the camera in much the same manner that the iris of the eye controls the light reaching the retina. The retina of the eye detects the relative differences in brightness and contrast between objects and the background. Photographs capture the clarity, contrast, and the colors of objects in an image that the film makers wants you to see. Because photographs cannot record as much detail as the human eye, they are imperfect images of how we perceive a vista.

Photographs of clear vistas in the SAMI Class I areas have been recorded as computer images using a computer software tool called WINHAZE (*reference* ARS,). These images represent visibility on the 3% (*check*) best visibility days at these sites. The computer images can be adjusted to visualize how a view changes in response to changes in light extinction. These photographs of Shining Rock Wilderness Area, NC, illustrate the range of visibility from clear to hazy days. [Note: Delete or modify this paragraph. The tool to visually display adjusted photographs for SAMI was never delivered.]

[*Illustrate range of visibility conditions in Shining Rock Wilderness Area, NC using either WINHAZE photos here or inserting photos of actual modeled days after text describing episode selection and just reference those photos here. [Note: Prefer the latter.]*]

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CALCULATING LIGHT EXTINCTION

Light extinction can be calculated using assumptions about particle mass, extinction efficiency, and the amount of water vapor in the air, or relative humidity. SAMI used the equation below to calculate light extinction from the measured components of particle mass and changes in light extinction in response to the aggregated changes in the components of particle mass under SAMI strategies. For simplicity this equation ignores the effects of different particle sizes and shapes on light extinction and assumes that particles behave the same way in mixtures as they do when all particles are the same chemical component.

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Δ bext = E_{idry} x f_i (RH) x ΔC_i

[Note: This equation is missing the summation over all species i.]

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Where: Δ bext = change in light extinction

E_{idry} = dry extinction efficiency of fine particle species i

f_i (RH) = effect of relative humidity on extinction efficiency of fine particle species i

ΔC_I = change in concentration of fine particle species i

[NOTE: Why equations here while nowhere else. Change to words.]

Fine particles are more efficient in scattering light than coarse particles and play a greater role in visibility impairment. Organic particles scatter light more efficiently than sulfate and nitrate particles, and all three components scatter more efficiently than soil and coarse particles. Elemental carbon absorbs light. To calculate light extinction, a factor to account for the efficiency of light scattering or light absorption is assigned to each fine particle species and to coarse particles. This efficiency factor is multiplied by the measured mass of each species, as defined in the equation below.

b_{ext} = 3.0 x f(RH) x [Ammonium Sulfate]
+ 3.0 x f(RH) x [Ammonium Nitrate]
+ 4.0 x [organics]

+ 1.0 x [soil]
+ 10.0 x [Elemental Carbon]
+ 0.6 x [Coarse Mass]
+ 10 [light scattering in clear air]

[NOTE: Why equations here while nowhere else. Change to words.]

The calculation of light extinction includes a term that accounts for relative humidity. Sulfate and nitrate particles, and to an uncertain extent, organic particles absorb water vapor. With added water vapor, sulfate particles grow to larger particle sizes that are more efficient at

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scattering light. Some particles can also grow out of the size range most efficient to scattering light. Acidic sulfate particles absorb more water vapor and scatter more light than ammoniated sulfate particles. At higher relative humidity (greater than 75%) sulfate and nitrate particles can scatter (*what factor*?) as much light as at lower relative humidity (35% or below) (reference)

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WHAT IS NATURAL VISIBILITY?

In the absence of human emissions, natural background visibility is effected by the scattering by air molecules, by water vapor, and naturally occurring levels of elemental carbon, sulfate, nitrate, and soil particles of organic particles formed from gaseous emissions from vegetation. Natural background visibility in the eastern United States is estimated as 93 miles[Note: Unless one can cite the averaging time (i.e., annual average, worst case, average of worst case) this statement is meaningless and subject to individual interpretation. It does not communicate well. Delete or clarify.] plus or minus 30 miles (Trijones, et. al. 1990). Natural visibility is lower in the summer than in the winter in the southeastern US, because both relative humidity and natural production of secondary particles are higher in the summer than in the winter.

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VISIBILITY MONITORING IN SAMI CLASS I AREAS

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The Interagency Monitoring of Protected Visual Environments (IMPROVE) network has measured fine and coarse particles at national parks and wilderness areas beginning in the late 1980s. By 2002, the network includes ____ sites nationally, and 8 sites in the SAMI region (Figure 5.3). Great Smoky Mountains and Shenandoah National Parks have the most complete IMPROVE data sets in the SAMI region (Table 5.1).

[INSERT FIGURE 5.3: MAP OF SAMI REGION AND LOCATIONS OF IMPROVE MONITORS IN SAMI CLASS I AREAS.]

METHODS

[Note: This section needs to clearly state that this is a summary of IMPROVE methods and assumptions, NOT SAMI's. There are places where SAMI made different, better assumptions. There are also places where we would disagree with IMRPOVE (e.g., that all the "unmeasured mass" is due to water vapor).]

The IMPROVE network collects particles on teflon or quartz filters (*check*, add reference) over a 24-hour period, for two days per week (prior to 2000, every Wednesday and Saturday, since 2000, every 3rd day). [Description of IMPROVE mass may need to move to air quality modeling section with discussion of model performance.] Average daily particle mass is measured directly for sulfate, nitrate, soil, and elemental carbon. Ammonium mass is not routinely measured by IMPROVE. Sulfate mass is reported as the mass of ammonium sulfate assuming that sulfate is fully neutralized (ratio of ammonium to sulfate ions is 2.0). Nitrate is reported as the mass of ammonium nitrate.

Only a fraction of the total organic particles are captured on the filter. moreover, to account for the non-carbon material found in organic particles, IMPROVE multiplies the measured carbon in organic PM mass by a factor of 1.4 to report total mass in OC.

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Total measured PM2.5 mass is often larger than the sum of the measured individual species: sulfate, nitrate, organics, soils, and elemental carbon. The composition of the unmeasured mass is unknown but commonly attributed by NPS to water vapor associated with the fine particles.

Light extinction and relative humidity are currently measured by IMPROVE at Great Smoky Mountains, TN; James River Face, VA; and Shenandoah, VA; Light extinction and relative humidity were measured at Dolly Sods, WV, from 1991 to and at Shining Rock, NC, from 1993 to ____ . These measurements have been discontinued (Table 5.1).

Table 5.1. IMPROVE monitoring at Class I areas in SAMI region.
[Note: this table needs a lot of work. First, it is misplaced. It should be in the section that describes SAMI's methods for data source and substitution. Second, the entries are confusing.]

Class I area	Date IMPROVE particle monitoring initiated	source of particle data for SAMI analyses (1991-1995)	Date Relative Humidity Initiated and RH Source for SAMI analyses	
Sipsey Wilderness Area, AL,	1991	Borrow July 1991 episode from Great Smoky Mtns.	None, use modeled RH for episodes	
Cohutta Wilderness Area, GA,	2000	Borrow 1991-1995 episodes from Great Smoky Mtns	2002, use modeled RH for episodes	
Great Smoky Mountains National Park, TN	1988	Use Great Smoky Mtns. data	1991 – current, use measured hourly RH	
Joyce Kilmer-Slickrock Wilderness Area, NC	None, IMPROVEuses Great Smoky Mtns.	Use Great Smoky Mtns. data	None, use Great Smoky Mtns. RH	
Shining Rock Wilderness Area, NC	1993	Borrow data for 4 episodes 1991-1993 from Great Smoky Mtns, use on-site data for 5 episodes.	1993-check, use modeled RH for episodes with on-site measured RH	
Linville Gorge Wilderness Area, NC	2000	Borrow data for 1991-93 episodes from Great Smoky Mtns. and 1994-1995 episodes from Shining Rock	None, use modeled RH	
James River Face Wilderness Area, VA	1993	Borrow data for 1991-1993 episodes from Shenandoah;	2000?, use modeled RH for episodes	

		use on-site data for 5 episodes		
Shenandoah National Park, VA	1988	Use Shenandoah data	1991 to current, use measured hourly RH	
Dolly Sods Wilderness Area, WV	1991	Borrow July 1991 episode from Shenandoah; use on site data for 8 episodes	1991- , use modeled RH for July 1991 episode, measured hourly RH for episodes	
Otter Creek Wilderness Area, WV	None IMPROVE uses Dolly Sods	Use Dolly Sods data	Use same RH data as Dolly Sods	

TRENDS

Based on the IMPROVE data, there has been no clear trend in annual median visual range (Figure 5.4) over the past decade at SAMI Class I areas (IMPROVE, 2002). There are greater differences in annual median visibility between Class I areas than between years at any one site. Summer days tend to be hazier than the annual average. [Note: Since we are not sure what the 93 represents (i.e., annual average, worst case, average of worst case), we cannot make this statement.]

Deleted: Compared to natural background of 93 miles, current annual median visibility at Shenandoah National Park is ____ miles and at Great Smoky Mountains is _____ miles.

[INSERT FIGURE 5.4: VISUAL RANGE AT SAMI CLASS I AREA BASED ON IMPROVE DATA]

[Note: The following section is not relevant to trends.]

For annual average conditions at SAMI Class I areas, ammonium (Note: or ammoniated if that's a word) sulfate particles are the largest contributors to fine particle mass and visibility impairment.. Organic particles are the second largest contributors to fine particle mass. Nitrate particles contribute more to light extinction than to fine particle mass. Nitrate particles have lower mass than organic particles at all sites (5 to 10 % of fine particle mass on annual average) but similar or slightly larger contributions to light extinction than organic particles (Adlhoch, 2002). However, this finding is subject to revision because it assumes organic particles are not hygroscopic. This assumption is not reasonable. Some of the particles are hygroscopic and, therefore, organic particles are likely to be a larger contributor to extinction than nitrate. On most days elemental carbon and soils are minor contributors to fine particle mass and visibility impairment . On the 20% haziest days, ammonium or ammoniated sulfate particles contribute greater than 70% (*check*) of total light extinction. On the 20% clearest days, ammonium or ammoniated sulfate contributes roughly 50% (*check*) of light extinction and organics, nitrate, soils, and elemental carbon have larger contributions to light extinction than on hazier days (IMPROVE, 2002).

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LINKING SAMI AIR QUALITY MODEL AND VISIBILITY EFFECTS ASSESSMENT

IMPROVE fine particle and relative humidity data from 1991 to 1995 at Look Rock, TN, in Great Smoky Mountains National Park and at Big Meadows, VA, in Shenandoah National Park was used to select episode days for air quality modeling (SAI, 1998, Timin, 2002). All IMPROVE days were assigned to one of five classes based on the combined fine particle mass of sulfate, nitrate, organics, and soil (Table 5.2). Class 1 days are the days with the lowest 20% of fine particle mass. Class 4 plus Class 5 days together represent the 20% highest mass days in the 1991-1995 record. Class 5 alone address the days with 3% highest mass.

Table 5.2. Adapt from SAI Episode Selection Report (include columns for summer vs winter?)

Visbility Class	Combined Fine Particle Mass (SO4, NO3, organics, and soils, µg/m3)	Frequency of Days	Number of modeled days with IMPROVE data- Great Smoky Mtns.	Number of modeled days with IMPROVE data- Shenandoah
1	0 - 5.0	0 -20%		
2	5.1 - 9.1	21-50%		
3	9.1 – 15.8	51-80%		
4	15.8 – 24.9	81-97%		
5	24.9 – 41.5	98-100%		

[Note: There needs to be a separate episode selection section. Then this section can be brief and speak to those days used. This same comment applies to Ozone and Acid Deposition.]

Deleted: Sixty-nine days in nine episodes in 1991-1995 were selected to represent annual average fine particles, annual average wet deposition, and growing season ozone. Air quality on these 69 days was modeled using the Urban to Regional Multiscale (URM) model. URM is an integrated, one-atmosphere model for fine particles, ozone, and acid deposition (see Chapter ___ Air Quality Modeling). URM was first run using emissions specific to the 69 days in 1991-1995. SAMI emissions inventories for 2010 and 2040 (see Chapter ____ Emissions Inventory) were then used to project future air quality on the modeled days.

The 69 modeled days include 22 days when IMPROVE monitoring data are available for model performance evaluation (Figure 5.5). Weights are assigned to each of these 22 days to account for the frequency of occurrence during 1991-1995 of meteorology similar to that on the modeled days. These weights of these 22 days are used to reconstruct fine particle mass and visibility for annual average, summer average, and class average conditions.

[INSERT FIGURE 5.5: FINE PARTICLE MASS AT GREAT SMOKY MOUNTAINS FOR EXAMPLE MODELED DAYS IN EACH OF 5 VISIBILITY CLASSES (FROM IMPROVE ON LEFT AND URM MODELED ON RIGHT)]

IMPROVE monitoring data was used as the basis for projecting future changes in visibility in response to SAMI strategies. The modeled percentage change in the components of fine particle mass from the 1991-1995 reference year to 2010 or 2040 was used to adjust the monitored components of the fine particle mass. The modeled percentage change is called the relative reduction factor. If modeled mass of a chemical component varied from measured mass on a modeled day by more than a factor of two, then the relative reduction factor was not accepted. Instead the average relative reduction factor from days with good model performance was substituted.

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Where IMPROVE monitoring data was not available, data was borrowed from nearest IMPROVE site (see Table 5.1; Adlhoch, 2002). If relative humidity was not measured at the sites for the modeled days, then modeled hourly RH was used for visibility calculations.

EVALUATING ASSUMPTIONS FOR CALCULATING LIGHT EXTINCTION

SAMI investigated the sensitivity of light extinction calculations to the assumptions used in the extinction equation. SAMI tested the effects of the following assumptions on calculated light extinction:

- increase the multiplier used with measured organic mass to calculate total organic mass from 1.4 (value assumed by IMPROVE) to 1.7 or 2.0.
- assume that 15% of total organic mass asborbs water vapor (IMPROVE assumes organics do not absorb water)
- combine the effect of two assumptions above (increase multiplier and assume 15% of increased mass absorbs water
- vary the acidity of sulfate fine particles ratio of ammonium to sulfate ions from 0.5 to 2.0 (value assumed by IMPROVE).
- vary the scattering efficiency of coarse mass from 0.4, 0.6 (value assumed by IMPROVE), 0.8, to 1.5 (upper limit)
- vary the data source for relative humidity (using measured hourly, modeled hourly, or monthly average relative humidity)

In all cases, the standard IMPROVE assumptions gave lower light extinction values than the alternatives tested. The acidity of sulfate particles and the source of relative humidity data were the two assumptions that had the greatest effect of calculated light extinction. All other assumptions showed negligible or small increases in extinction (relative to the IMPROVE assumptions) and were not considered in SAMI's strategy analyses.

[NOTE: WE NEED A PARAGRAPH THAT DISTIGUISHES THE EFFECT OF THE ASSUMPTIONS ON THE CALCULATION OF EXTINCTION AND THE EFFECT ON THE CHANGE IN EXTINCTION. WHILE WE WERE ABLE TO LOOK SOMEWHAT AT THE EFFECT ON CHANGE, WE COULD NOT REALLY ASSESS THE EFFECT OF THE CARBON ASSUMPTIONS (I.E.,SCALING FACTOR AND HYGROSCOPICITY) BECAUSE THE SAMI STRATEGIES DID NOT CHANGE CARBON EMISSIONS MUCH.]

IMPROVE does not routinely measure ammonium but assumes that measured sulfate particles are fully neutralized (ratio of ammonium to sulfate ions of 2.0). Since 1997, ammonium has been measured from the filters at three IMPROVE sites in the SAMI region: Great Smoky Mountains National Park in eastern Tennessee, Shenandoah National Park in Virginia, and Dolly Sods Wilderness Area in West Virginia (reference IMPROVE). These ammonium measurements and those from other studies (Saxena, SEARCH) indicate that on many days sulfate particles are not fully neutralized. On a daily basis, that ratio may be below 1.0, especially in the summertime. At ammonium to sulfate ratios below 1.0, sulfate is more efficient at scattering light than when the ratio is in the range 1.5 – 2.0. These ammonium measurements suggest that, at least in the southeastern US, light extinction by sulfate may be underestimated on some days. SAMI chose to use the monthly average measured ratio of ammonium to sulfate (Figure 5.6) to calculate light extinction in 1991-1995 and in 2010 and 2040 in response to SAMI strategies. [Note: This section should add a discussion about the effect on changes in extinction. For example, using IMPROVE all changes are as ammonium sulfate. Under SAMI assumptions change can include a change in form as well as amount. Changing form from sulfuric acid to ammonium sulfate will be much different than from ammonium sulfate to sulfuric acid.]

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[INSERT FIGURE 5.6: MONTHLY AVERAGE RATIO OF AMMONIUM TO SULFATE IONS MEASURED AT IMPROVE MONITORING SITES AT GREAT SMOKY MOUNTAINS, SHENANDOAH, AND DOLLY SODS FROM 1997 TO 1999.]

The selection of data source for relative humidity had the greatest effect on calculated light extinction. Because relative humidity effects how much light is scattered by fine particles, days with the lowest particle mass are not necessarily the days with the clearest visibility. Across the seasons, relative humidity is generally higher in the summer than in the winter. The highest relative humidity generally occurs in the hours before and after dawn and the lowest relative humidity at mid-day.

The Environmental Protection Agency recommends using monthly average relative humidity data for the purpose of evaluating visibility trends over time (reference Regional Haze guidance). However, in the case of assessing the effectiveness of strategies, actual relative humidity is more appropriate. To the extent available, SAMI used relative humidity measured at the same site as air quality was measured. If measured hourly relative humidity data was not available, modeled hourly relative humidity data were used (Table Visibility 1).

Deleted: For air quality modeling, SAMI used the same relative humidity data to model current and future emissions.

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IMPROVE assumes that the multiplier for measured organic mass to calculate total organic mass is 1.4. More recent measurements (Turpin, et. al.,) suggest that in the southeastern US, a multiplier for measured mass of 1.6 to 2.2 might be more appropriate. Increasing the multiplier to 2.0 changed visibility by more than 1 deciview on less than 6% of all days in 1991-1995 at Great Smoky Mountains and Shenandoah. [Note: Where did this come from? Also, this refers to effect on the calculation of extinction not on the change in extinction. Need to say effect of change is not known because it couldn't be assessed from SAMI strategies which have little change in carbon.] The response to changes in the assumed multiplier for organic mass might be larger at sites where organic compounds have a larger contribution to visibility than is the case at the SAMI Class I areas or if there were larger changes in projected OC.

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VISIBILITY RESPONSES TO SAMI STRATEGIES

Annual average SO2 and NOx emissions in 2010 and 2040 will be reduced under SAMI emissions strategies. Ammonia gas emissions are projected to increase in the A2 and B1 strategies and decrease in the B3 strategy (assuming 75% reductions in NH3 emissions from livestock). Changes in emissions of volatile Organic Compounds, elemental carbon, and soils are small (Figure 5.7, Chapter___, Emissions Inventory).

INSERT FIGURE 5.7: ANNUAL EMISSIONS IN 8 SAMI STATES (ALSO IN EI CHAPTER]

KEY FINDINGS

Fine particle responses to SAMI strategies are illustrated in Figures 5.8 and 5.9 for Great Smoky Mountains and Shenandoah National Parks. These trends are representative of those at the other SAMI Class I areas. In 1991-1995 at Great Smoky Mountains, ammonium or ammoniated sulfate particles account for 68 % of annual average reconstructed fine particle mass and 72 % of annual average light extinction. In 2010, annual average SO4 fine particles are projected to decrease by 12, 26, and 50% under SAMI's A2, B1, and B3 strategies, respectively, compared to 1991-1995. Annual average visibility at Great Smoky Mountains is projected to increase from 23 miles in 1991-1995 to 24, 27, and 36 miles in 2010 under the SAMI A2, B1, and B3 strategies.

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[INSERT FIGURE 5.8: ANNUAL AVERAGE FINE PARTICLE MASS AT GREAT SMOKY MOUNTAINS AND SHENANDOAH NATIONAL PARKS IN 1991-1995 AND IN 2010 AND 2040 IN RESPONSE TO SAMI STRATEGIES.]

[INSERT FIGURE 5.9: ANNUAL AVERAGE LIGHT EXTINCTION AT GREAT SMOKY MOUNTAINS AND SHENANDOAH NATIONAL PARKS IN 1991-1995 AND IN 2010 AND 2040 IN RESPONSE TO SAMI STRATEGIES.]

The largest improvements in visibility are projected to occur in response to SO2 reductions. Sulfate contributions to fine particle mass and light extinction are projected to decrease under all SAMI strategies. The URM model projects little change in visibility in the SAMI Class I areas in response to changes in human-made organic compounds. This latter results is due to small changes in carbon emissions embedded in the SAMI strategies and the fact that the model assumes most of the OC comes from natural sources, an assumption that may not be correct based on recent evidence showing significant man-made OC at GSMNP. [Note to PFB: this last edit needs to be checked with Roger Tanner.]

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On some days, nitrate particles are projected to increase in response to SAMI strategies. On these days, sulfate particles are reduced while ammonia gas increases. When all sulfate particles are fully neutralized, nitrate particles are formed. The increases in nitrate particles are much smaller than the decreases in sulfate particles projected on these days, so visibility is still projected to improve, but less than would be expected based solely on sulfate reductions.

The largest improvements in visibility in response to SAMI emissions strategies are projected to occur on days with the highest fine particle mass (Figure 5.10 a and b).

[INSERT FIGURES 5.10 A AND B: CHANGES IN VISIBILITY IN 2010 IN RESPONSE TO SAMI STRATEGIES FOR MODELED DAYS IN FIVE CLASSES BASED ON FINE PARTICLE MASS AT (A) GREAT SMOKY MOUNTAINS AND (B) SHENANDOAH]

Annual average visual range in 1991-1995 varied from 10-25 miles across the 10 SAMI Class I areas (Figure 5.11). The poorest annual visibility occurred at Dolly Sods in WV and Sipsey in northern AL. The best annual visibility occurred at Great Smoky Mountains in eastern TN. Across the 10 SAMI Class I areas, annual average visual range in 2010 is projected to increase by less than 2 miles under the A2 strategy, by 1-6 miles under the B1 strategy, and by 4-15 miles under the B3 strategies.

[INSERT FIGURE 5.11: CHANGES IN ANNUAL AVERAGE VISIBILITY BETWEEN 1991-1995 AND 2010 AT 10 CLASS I AREAS IN RESPONSE TO SAMI STRATEGIES]

The greatest improvements in annual average visibility are projected for those Class I areas that are mostly influenced by emissions from the SAMI states: Cohutta, GA; Great Smoky Mountains, TN; Joyce Kilmer, NC; Shining Rock, NC; and Linville Gorge, NC (see Chapter ___, Air Quality Modeling, also Boylan, et. al., 2002). Sipsey Wilderness Area in north AL, and the Class I areas in WV and VA receive greater contributions from states outside the SAMI region. Because emissions for sources in the non-SAMI states were held at the same levels in the B1 and B3 strategies as the A2 strategy, annual average visibility at these Class I areas did not improve as much as for the Class I areas in GA, TN, and NC.

Visibility improved more for the summer average days than the annual average visibility. At most sites, visibility for the 20% highest mass days also improved more than annual average visibility (Adloch). Visibility improved more on the 20% highest mass modeled days than on the 20% lowest mass

[Note: We have never seen this analysis and we know that it will be very difficult to come to consensus on how to make these calculations.]

[INSERT FIGURE 5.12: CHANGES IN VISIBILITY BETWEEN 1991-1995 AND 2010 FOR THE 20% HIGHEST MASS DAYS AT 10 CLASS I AREAS IN RESPONSE TO SAMI STRATEGIES]

LINK TO SOCIOECONOMIC ANALYSES

[SECTION UNDER DEVELOPMENT] [NOTE: WHEN WILL WE SEE THIS SECTION?]

UNCERTAINTIES

Deleted: Under the regional haze rules, states are to set reasonable progress goals for the rate of improvement in visibility, using deciview as the unit of measure. For the 20% highest mass days in the SAMI analyses, the rate of improvement in the 15 years between 1991-1995 and 2010 for the A2 strategy varied across the SAMI Class I areas from ___to ____deciviews (Figure 5.12). This is equivalent to _ to ___deciviews per decade by 2010 for the A2 strategy. The rate of improvement between 1991-1995 and 2010 would be ___ to ____ deciviews per decade for the B1 and ____ to _____ deciviews per decade for the B3 strategy. Between 2010 and 2040 the rate of improvement on the 20% highest mass days would be ___ to ____ deciviews per decade for the A2 strategy, ___to____ for the B1 strategy, and ___ to ___ for the B3 strategy.¶

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[SECTION UNDER DEVELOPMENT, DRAFT ITEMS BELOW] [NOTE: WHEN WILL WE SEE THIS SECTION?]

- Cumulative results carried from emissions inventory and atmospheric model contribute largest uncertaintyConfidence is highest for SO4 aerosols, intermediate for organics, soil, and EC, and lowest for NH4 and NO3 Other, smaller, sources of error from:
- Using modeled days to represent all other days
- Using relative reduction method to calculate change in response to SAMI strategies
- Assumptions used to calculate visibility
- Borrowing IMPROVE monitoring data for sites without monitors
- Uncertainties in IMPROVE monitoring methods

LESSONS LEARNED [NOTE: DELETE. COVERED ELSEWHERE.]

[SECTION UNDER DEVELOPMENT] [NOTE: WHEN WILL WE SEE THIS SECTION?]

CONCLUSIONS

[SECTION UNDER DEVELOPMENT] [NOTE: WHEN WILL WE SEE THIS SECTION?] [NOTE: USE THE LAST SUBCOMMITTEE AGREED UPON BULLETS AND STICK WITH THOSE].