Appendix D

Updated Visibility Statistics for the MANE-VU Region

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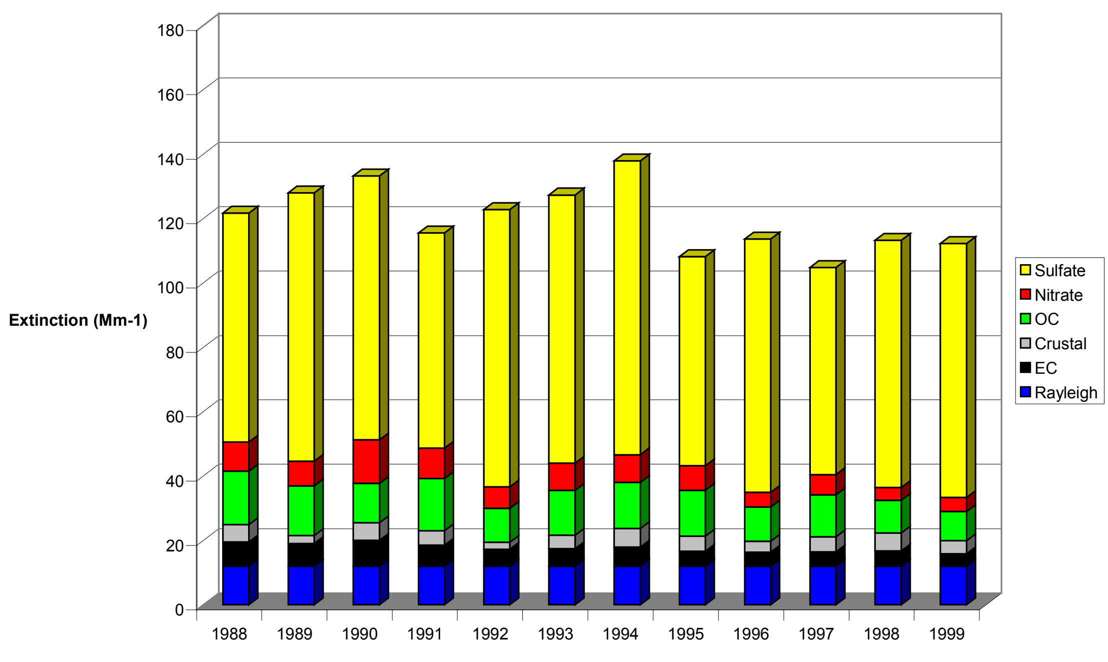
Technical Memorandum #1

Updated Visibility Statistics for the MANE-VU Region

Prepared by Northeast States for Coordinated Air Use Management (NESCAUM)

For the Mid-Atlantic/Northeast Visibility Union (MANE-VU) Regional Planning Organization

February 15, 2002



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Technical Memorandum #1

Updated Visibility Statistics for the MANE-VU Region

February 15, 2002

Submitted to the United States Environmental Protection Agency, Region III in partial fulfillment of requirements for EPA grant X-983384-01-0 to the Ozone Transport Commission

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Executive Summary

Under the U.S. Environmental Protection Agency's (USEPA) 1999 regional haze rule, states and tribes are required to submit implementation plans which must include calculations of current and estimated natural visibility conditions. Recent monitoring data from the Interagency Monitoring of Protected Visual Environments (IMPROVE) network has been used to examine visibility conditions in the Mid-Atlantic/Northeast Visibility Union (MANE-VU) region. These results suggest that across the MANE-VU region, visibility impairment on the 20 percent of days with the worst visibility in 1999 was reduced by approximately 2 dv relative to conditions in 1997 with the worst visibility conditions occurring further south and west. Further research is required to determine the cause of this improvement; however, meteorological conditions may have played a role. A slight decrease in nitrate composition appears to have occurred between 1995 and 2000, however, no substantive reductions in sulfate or organic material are apparent on the twenty percent worst visibility days during this same time period.

Recent guidance issued by USEPA for calculating visibility conditions suggests the use of climatological monthly mean values of the relative humidity adjustment factor to account for differences in scattering properties of fine particulate with increased relative humidity. An examination of relative humidity adjustment factor averaging time suggests that use of annual or monthly mean values may understate visibility conditions calculated using daily average relative humidity data where available. Comparison with optical data confirms that measured visibility conditions (i.e. transmissometer and nephelometer data) may be substantially different from those conditions obtained through USEPA recommended procedures. Further study is required to determine the impact these differences are likely to have on calculated rates of progress.

I. Introduction

States and tribes must submit implementation plans by December 31, 2008 outlining control measures needed over the subsequent ten years (2009-2018) in order to improve visibility conditions in Federal Class I areas within and near the MANE-VU region in compliance with the Environmental Protection Agency's (USEPA) regional haze rule. These plans must include calculations of baseline[1] and estimated natural visibility conditions. These plans must also estimate the necessary rate of progress for the 10-year compliance period needed to achieve the overall goal of natural visibility conditions by 2064. This document provides a survey of speciated fine particle and monitoring data from the Interagency Monitoring of Protected Visual Environments (IMPROVE) program and how it can be used in this process. This work builds upon a previous NESCAUM report (NESCAUM, 2001a) and is intended to update and expand upon the technical discussion presented in that document. New figures are presented which describe the nature and extent of visibility impairment in the region. Data used to generate each figure are presented in tabular form in Appendix A.

Two documents have recently been drafted by USEPA in order to guide states and tribes in performing reasonable progress and natural visibility calculations (USEPA 2001a, 2001b). While the methodology for calculating reconstructed light extinction used in this document is consistent with the approach taken in these guidance documents, NESCAUM has not rigorously applied the guidance recommendations for the substitution of missing values. When the proposed guidance documents are finalized, those aspects of the calculations presented here that differ from the guidance should be harmonized to provide a consistent assessment of current visibility conditions and trends in the MANE-VU region.

[1] Calculations of baseline conditions are based on monitored data from the years 2000 to 2004.

II. Data Sources and Methodologies

Data from the IMPROVE program represent a crucial input to state and tribal planning efforts under the 1999 regional haze rule. The National Park Service manages the IMPROVE program with the support of several contractors who perform specific data collection and analysis functions. These contractors include the University of California at Davis (site selection, filter management, gravimetric and elemental analyses and database management), the Desert Research Institute (elemental and organic carbon analyses), the Research Triangle Institute (ion analyses), Atmospheric Resource Specialists, Inc. (optical, scene, and meteorological data collection), and the Cooperative Institute for Research in the Atmosphere (data analysis and website support).

The IMPROVE web site provides speciated data for all sampling days at IMPROVE monitors.[2] Total particle light extinction can be calculated using this information and the methodology described below. Table 1 lists the particle species, formulae and assumptions used by IMPROVE to calculate particle concentrations. Ambient concentrations are in turn used to calculate reconstructed particle light extinction coefficients. The bracketed symbols in the second column of Table 1 correspond to species concentrations and to the labeling conventions used in the IMPROVE database. The labeling convention is:

[S]	= Elemental sulfur
[NO3]	= Nitrate
[EC#]	= Detailed elemental carbon species measured by thermal optical reflectance (TOR) with three bins (# = 1,2,3)
[OC#] & [OP]	= Detailed TOR organic species with bins (# = 1,2,3,4)
[AL]	= Aluminum
[SI]	= Silicon
[CA]	= Calcium
[FE]	= Iron
[TI]	= Titanium
[MT]	= Total mass (PM_{10})
[MF]	= Fine mass ($PM_{2.5}$)

[2] IMPROVE data are available via an ftp link located at the web address http://alta_vista.cira.colostate.edu/. The website is part of a cooperative program on visibility in Class I areas between the National Park Service Air Resources Division and the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University in Ft. Collins.

Table 1: Formulae and assumptions used with IMPROVE sampling measurements to derive reconstructed particle light extinction (adapted from Sisler and Malm, 2000).

Species	Formula	Assumptions
SULFATE	4.125[S]	All elemental S is from sulfate. All sulfate is from ammonium sulfate.
NITRATE	1.29[NO3]	Denuder efficiency is close to 100%. All nitrate is from ammonium nitrate.
LAC (Light absorbing carbon)	[EC1] + [EC2] + [EC3] – [OP]	All high temperature carbon is elemental.
OMC (Organic mass from carbon)	1.4{[OC1] + [OC2] + [OC3] + [OC4] + [OP]}	Average organic molecule is 71% carbon.
SOIL (Fine Soil)	2.2[AL] + 2.49[SI] + 1.63[CA] + 2.42[FE] + 1.94[TI]	[Soil K] = 0.6[Fe]. FeO and Fe_2O are equally abundant. A factor of 1.16 is used for MgO, Na_2O, H_2O, CO_2.
RCFM (Reconstructed fine mass)	[SULFATE] + [NITRATE] + [LAC] + [OMC] + [SOIL]	Represents dry ambient fine aerosol mass for continental sites.
CM (Coarse Mass)	[MT] – [MF]	Consists only of insoluble soil particles.

Total light extinction is a function of the individual light absorption and light scattering properties of particles present in the atmosphere. This total is frequently expressed as a light extinction coefficient (b_{ext}) in units of inverse length (such as Mm^{-1}). In simple terms, the light extinction coefficient is a measure of the proportion of light extinguished per unit of distance traveled through the atmosphere. The light extinction coefficient, b_{ext}, can be measured directly with a transmissometer or determined empirically by "reconstructing" extinction as the sum of the scattering and absorption coefficients of the relevant particle constituents, as indicated by the following equation.:[3,4]

[3] Absorption by nitrogen dioxide gas is not generally significant on a regional scale, though it can play a role in coherent pollution plumes (FLAG, 2000). Hence the discussion in this chapter considers elemental carbon as the only contributor to atmospheric light absorption.

$b_{ext} = b_{SO4} + b_{NO3} + b_{OrgC} + b_{Soil} + b_{Coarse} + b_{ElemC} + b_{Ray}$

Note that this equation includes Rayleigh scattering, b_{Ray}, which is a measure of scattering due to air molecules. The Federal Land Managers' Air Quality Related Values Workgroup (FLAG) uses a Rayleigh scattering value of 10 Mm^{-1} for the entire U.S. (FLAG, 2000). This value corresponds to Rayleigh conditions at about 1800 meters above sea level (Sisler and Malm, 2000). However, Rayleigh scattering varies with altitude and at sea level is estimated to be about 12 Mm^{-1} (Trijonis et al., 1990). To avoid understating "natural" background visibility impairment at coastal sites (which could result in setting unrealistic goals for haze reduction efforts), the analysis conducted here assumes a Rayleigh coefficient of 12 Mm^{-1} for the Acadia, Brigantine, Moosehorn, and Roosevelt Campobello Class I areas as well as the Washington D.C. and the James River Face IMPROVE sites. All of these sites have a mean altitude below 300 meters. This assumption reduces calculated background extinction levels by 2 Mm^{-1} but leads to a change of only 0.3 dv in estimated natural background conditions on the deciview scale.[5]

The calculation of extinction coefficients for each individual chemical species can be described by the following equations (FLAG, 2000):

$b_{SO4} = 3[(NH_4)_2SO_4]f(RH)$ [6]
$b_{NO3} = 3[NH_4NO_3]f(RH)$
$b_{OrgC} = 4[OrgC]$
$b_{Soil} = 1[Soil]$
$b_{Coarse} = 0.6[Coarse]$
$b_{ElemC} = 10[ElemC]$.

The bracketed quantities represent ambient air concentrations expressed in micrograms per cubic meter ($\mu g/m^3$). The numeric coefficients represent "dry" scattering efficiencies[7] (m^2/g), while the relative humidity adjustment factor f(RH) accounts for the hygroscopic properties of sulfate and nitrate (i.e., their tendency to absorb water in the atmosphere). As relative humidity increases this factor becomes larger, which in turn produces a higher coefficient of light extinction for the hygroscopic particles. Provided concentrations and humidity levels are known, the light extinction coefficients for individual particle constituents can be calculated and summed to estimate the overall light extinction coefficient, b_{ext}.

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[4] Particles in the atmosphere may exist as an internal mixture of several chemical species. IMPROVE assumes that the contribution of each particle constituent can be determined separately and summed to determine total light extinction.

[5] This assumption is in contrast to the recent USEPA guidance on this point which recommends using 10 Mm^{-1} consistently at all Class I areas, regardless of altitude (USEPA, 2001a).

[6] IMPROVE assumes that all sulfate is in the form ammonium sulfate ($(NH_4)_2SO_4$) and that all nitrate is in the form ammonium nitrate (NH_4NO_3). Other forms of these species exist in nature as detailed in Section D of this chapter. These differing forms may have different scattering efficiencies and relative humidity adjustment factors.

[7] Dry scattering efficiencies were determined for light at 550 nm (0.55 μm; green). There may be discrepancies between this value and those determined by integrating over the entire visible spectrum (400-700 nm).

It should be noted that a number of uncertainties are embedded in these calculations; hence, reconstruction of light extinction will not be accurate for every sample.[8] For example, the equations reflect simplified assumptions about the role of relative humidity and may not adequately account for the non-linear relationship between humidity and particle growth rate. Moreover, the relative humidity values traditionally used by IMPROVE represent an average over large geographic areas and long periods of time. Ideally, relative humidity should be recorded and stored with each concentration measurement so that an appropriate factor can be calculated for each observation. Second, different humidity adjustment factors should be used for the sulfate and nitrate fraction of aerosol particles given differences in the growth rates for these two constituents with increasing relative humidity. Third, the above equations assume that organic carbons are non-hygroscopic and do not require a relative humidity adjustment. In many instances little information is available about the specific constituents of secondary organic aerosol particles and of their potential affinity for water. Whether or not a relative humidity adjustment factor should be applied to the organic fraction is therefore an issue of current debate (Saxena et al., 1995). Finally, the IMPROVE calculations make an assumption that the particles are externally mixed as opposed to the more likely case that each particle is a homogenous (internal) mixture of the individual components. This difference will affect the physical properties of the particle and in turn how they impact visibility. The sensitivity of reconstructed light extinction to each of these assumptions is an area that warrants further investigation.[9] It should be noted that the IMPROVE program has taken efforts to quantify the precision of the techniques used for their calculations and has deemed it sufficient for the IMPROVE program objectives.

The recent guidance documents issued by USEPA (in draft form) discuss some of the uncertainty present in reconstructed light extinction, but do not resolve the issue by performing a detailed sensitivity analysis for each assumption. Section V of this report describes some comparisons of reconstructed light extinction with measured light extinction and attempts to quantify the discrepancy between the two techniques and thus provide a measure of the overall uncertainty.

The regional haze rule requires that visibility conditions be measured in deciview, a metric that is approximately linear with human perception of visibility impairment. The deciview is related to atmospheric extinction through the following relationship:

$$dv = 10\ ln(b_{ext}/10).$$

Extinction is used in this memorandum to explore the contribution of individual component of fine particulate to overall visibility impairment. The deciview is used to examine trends in visibility conditions.

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[8] In fact, reconstructed light extinction is not expected to be accurate for every sample as it was designed to provide a consistent and replicable process for approximating light extinction based on observed relationships.

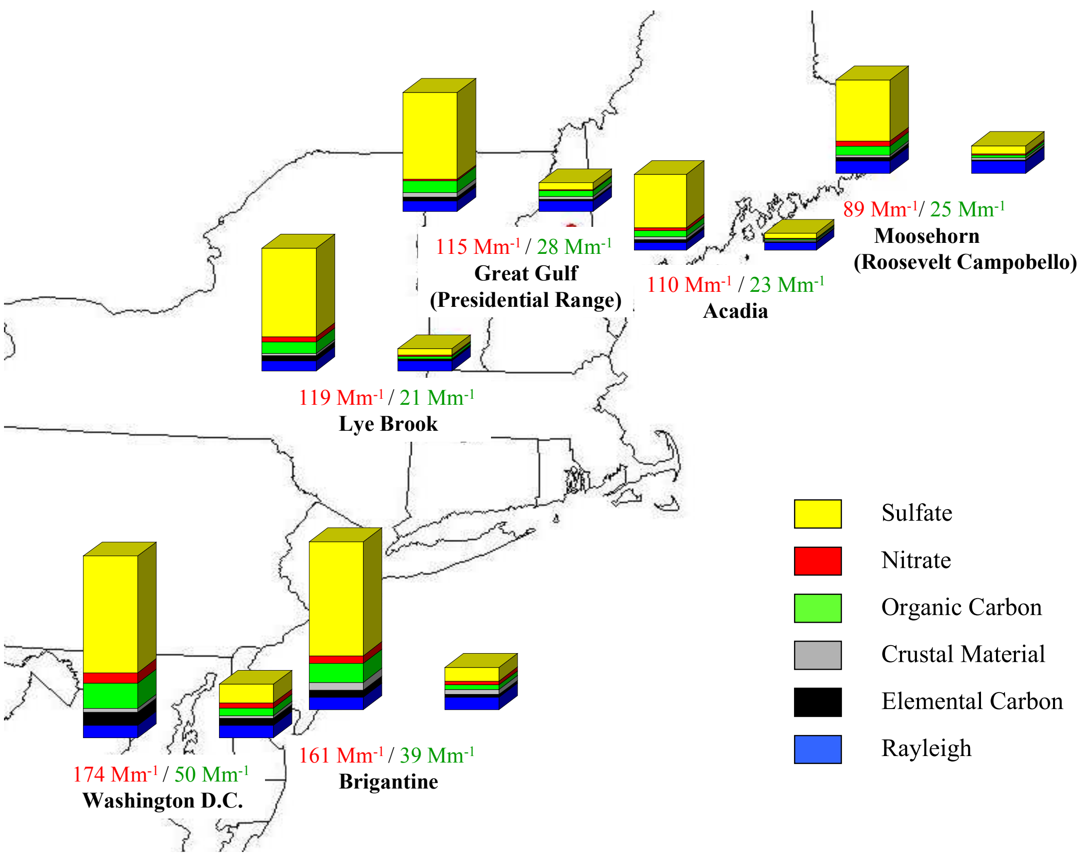
[9] The sensitivity of reconstructed light extinction to relative humidity adjustment factor averaging time is explored in Section IV. The FLAG (FLAG, 2000) has suggested that annually-averaged adjustment factors are adequate for screening analyses; however, the recent USEPA guidance (USEPA, 2001a) has recommended monthly average factors be used for SIP work.

III. Visibility Across the Northeastern U.S. –1999

A. MANE-VU Class I Areas

The regional haze rule calls for a steady improvement of visibility on the 20 percent of days with the worst visibility and the prevention of deterioration in visibility on the 20 percent of days with the best visibility at Federal Class I areas across the country. In 1999, visibility experienced at MANE-VU Class I areas was somewhat better than that which has been documented previously for 1997 (NESCAUM, 2001a). As Figure 1 shows, the 20 percent of days with the worst visibility[10] (left bars; based on calculations of reconstructed light extinction) range from 89 to 174 Mm^{-1} of total light

Figure 1: Speciated contribution to total atmospheric light extinction in or near Class I Areas in the Northeast and Mid-Atlantic states on 20 percent of days with the worst (left bar) and best (right bar) visibility conditions during 1999.



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[10] The terms "worst" or "best" visibility as well as "20 percent worst" or "20 percent best" visibility conditions are defined throughout this report as the simple average of the upper or lower 20 percentile of a cumulative frequency distribution of reconstructed light extinction for days in which all particle species were successfully measured, respectively.

extinction (particle light extinction plus Rayleigh scattering).[11] This corresponds to 22-29 dv and is approximately 2 dv lower than visibility conditions on the worst days in 1997. Visibility impairment is not, however, uniform across the region, with the worst visibility conditions occurring further south and west.

The majority of this visibility impairment can be attributed to sulfate aerosol, which was responsible for over two-thirds of the extinction on the days with the worst twenty percent visibility at most sites. Organic Carbon (OC) is formed from the byproducts of literally hundreds of precursor organic molecules including Volatile Organic Compounds (VOCs) and biogenically emitted species. After sulfate, organic carbon is responsible for the greatest atmospheric extinction on the days with the worst and best visibility days. Nitrate, elemental carbon (or soot) and crustal material (i.e. dust and soil) are responsible for the remaining particle extinction. Rayleigh scattering, due to natural scattering of air molecules, is shown in blue.

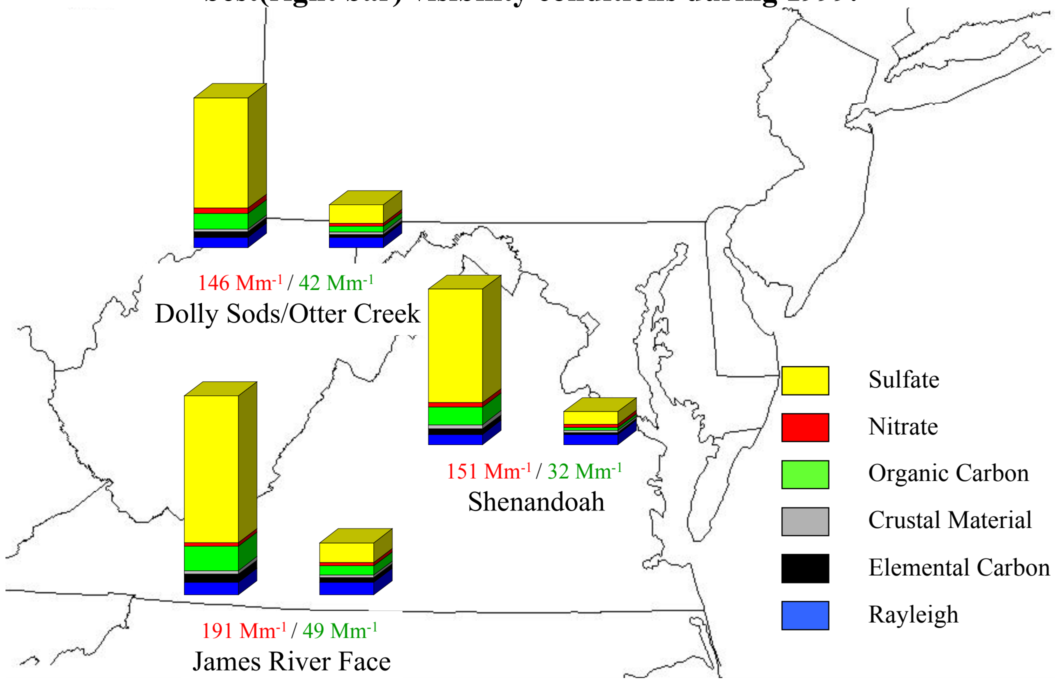
Substantially lower levels of visibility impairment are present on the 20 percent of days with the best visibility conditions (see right bars in Figure 1) relative to the worst days. However, it should be noted that some areas (especially those further south and west) still have significant visibility impairment relative to natural conditions, estimated to be approximately 21-24 Mm^{-1} or 8-9 dv (NESCAUM, 2001a).

B. Nearby Areas

Areas just to the south of the MANE-VU region also saw improved visibility conditions in 1999 over what has been reported previously for 1997. Figure 2 shows average reconstructed light extinction for the 20 percent of days with the worst and best visibility conditions at IMPROVE monitors at Class I areas in Virginia and West Virginia. These values represent, on average, a 3 dv improvement in the worst 20 percent of visibility conditions in 1999 relative to 1997 values. Similar to the MANE-VU Class I areas, an analysis of the 2000 data will be required to know whether or not the trend has continued.

[11] These calculations use a climatological monthly mean relative humidity adjustment factor consistent with recent USEPA guidance on the subject. Discussion of how these factors differ from alternatives is presented in section IV of this memorandum.

Figure 2: Speciated contribution to total atmospheric light extinction in or near Class I areas in Virginia and West Virginia on 20 percent of days with the worst (left bar) and best(right bar) visibility conditions during 1999.



IV. Visibility Trends

As discussed in the last section, 1999 visibility conditions appear to have been better than those of other recent years. We caution the reader, however, that an analysis of the meteorological conditions in 1999 and earlier years should be performed before concluding that a significant improvement in visibility conditions (on the order of 2 dv) has occurred as a result of reductions in anthropogenic emissions. The one-in-three day data collection schedule of the IMPROVE program may have also contributed, in part, to an improved trend if the worst visibility days happened to occur mostly on days when no sampling was taking place. The trend charts shown in this report (see Figure 3-12 later in this section) reflect the improved visibility relative to prior years, but additional years of data will be required to determine if this trend is sustained or whether the improvement was temporary.

Determining what role meteorology plays in year to year variation of average visibility conditions is complicated. Individual terms in the equation for reconstructed light extinction are proportional to the fine particle mass as well as the relative humidity correction factor and, therefore, reconstructed extinction will be sensitive to year-to-year variation in both of these factors.[12] In simplified terms, ambient fine particle mass is a function of emissions, transport, photochemistry, and deposition, which vary in time.

Relative humidity also varies year-to-year, but recent guidance on tracking reasonable progress (USEPA, 2001a) suggests a method for removing this variability. By using climatological mean relative humidity adjustment factors, the sensitivity of reconstructed light extinction to interannual changes in relative humidity is removed completely. Essentially, the same humidity conditions are assumed to be experienced every year and thus any difference in visibility conditions is due to emissions or other meteorological factors. The advantage is that we can remove one confounding factor for verification of a regional haze control. The disadvantage is that we are not calculating precise visibility conditions in any given year.

A. Comparison of Timescales for Averaging Relative Humidity

In order to understand the differences between the use of climatological annual, climatological monthly or day-specific relative humidity adjustment factors, we have calculated reconstructed light extinction in three different ways. Consistent with previous NESCAUM reports and recommendations presented in the FLAG report, annual average relative humidity adjustment factors[13] have been used to calculate average visibility (in

[12] Terms are also proportional to the dry scattering efficiency of the particular material, but this is a physical characteristic of each component and not subject to temporal variation.

[13] FLAG recommend the use of annual average relative humidity adjustment factor for screening analysis only. For detailed analyses, the use of daily average factors is preferred, when such data is available. The FLAG final report (FLAG, 2000) presents seasonal average factors for use when daily humidity data is unavailable. It should be noted that the annual and seasonal average factors presented in the FLAG final

deciviews) on the twenty percent of days with the worst and best visibility conditions.[14] These calculations have been repeated using monthly site-specific adjustment factors developed and recommended by USEPA in their recent guidance on tracking progress under the regional haze rule (USEPA, 2001a). In addition, daily relative humidity adjustment factors (based on actual humidity data as opposed to climatological means) were used to calculate reconstructed extinction values. All three techniques are compared in the following series of charts showing trends in the best and worst visibility at IMPROVE sites throughout the Northeast and Mid-Atlantic States (presented from northeast to southwest).

All of the values shown in these charts represent the simple average of visibility values (in dv) from the twenty percent of days with the worst and best visibility conditions each year. The difference between the two (or sometimes three) curves shown for worst visibility conditions at each site has to do with the averaging time used for relative humidity adjustment factor. For the blue curves, a single site-specific annual mean value for the relative humidity adjustment factor was used for the whole year. These values were obtained from the final Phase I Report of the Federal Land managers' Air quality related values workGroup (FLAG, 2000). For the red curves, 12 site-specific climatological monthly mean values were used for days in the corresponding month. These values were provided by the USEPA contractor (SAIC, personal communication) and were the basis for relative humidity adjustment factors listed in the recent USEPA guidance document (USEPA, 2001a). When measured daily relative humidity data was available (see Acadia and Camp Dodge Charts) the calculations were repeated using these data directly (green curves). Reconstructed light extinction was then calculated, converted to deciviews, and ranked from greatest to least. The twenty percent of days with the highest and lowest deciview values were usually the same, but not always. There were some instances when the use of a monthly (or daily) average relative humidity adjustment factor elevated a day (or dropped a day) into (or out of) the top twenty percent of the ranking. Appendix A contains a table of annual and monthly climatological mean values for relative humidity and the appropriate adjustment factors which were used for these calculations. Note that the FLAG reports do not list an annual correction factor nor relative humidity values for Washington, D.C. We have assumed that relative humidity and the associated correction factor for the Washington, D.C. IMPROVE monitor would be relatively close to values estimated for Shenandoah National Park and have used 3.0 for the annual value of the relative humidity correction factor for these calculations.

Results differ between sites. At most sites, visibility impairment is consistently underestimated on the worst days and overestimated on the best days using the annually-averaged factors relative to the values derived using monthly factors. However, the degree of difference is relatively small and at many sites (e.g. Lye Brook, Brigantine and

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phase I report differ substantially from those presented in the draft phase I report (FLAG, 1999) and subsequently used by NESCAUM in earlier assessments of visibility conditions in the Northeast and Mid-Atlantic region. The factors presented in the final phase I report are used here and are compared to the earlier values in Table A.1 and A.2 in Appendix A.

[14] See footnote 10 for a specific definitions of 20 percent worst and best conditions.

Washington D.C.) the two methods produce very similar results on the worst days. The two methods are in strong agreement at virtually all sites on the best visibility days (exceptions being Washington D.C. and James River Face). The two sites for which daily humidity data were available show that use of a daily factor produces values that are significantly higher (in dv) than those calculated using other methods. These results show that averaging humidity across a month or a year will tend to moderate the influence of hygroscopic aerosol in calculations of extinction. However, such a relationship has not been observed elsewhere (USEPA, 2001a, pg. 6-4) and is worthy of additional investigation.

Figure 3: Worst (top) and best (bottom) visibility trends at Moosehorn Wilderness Area

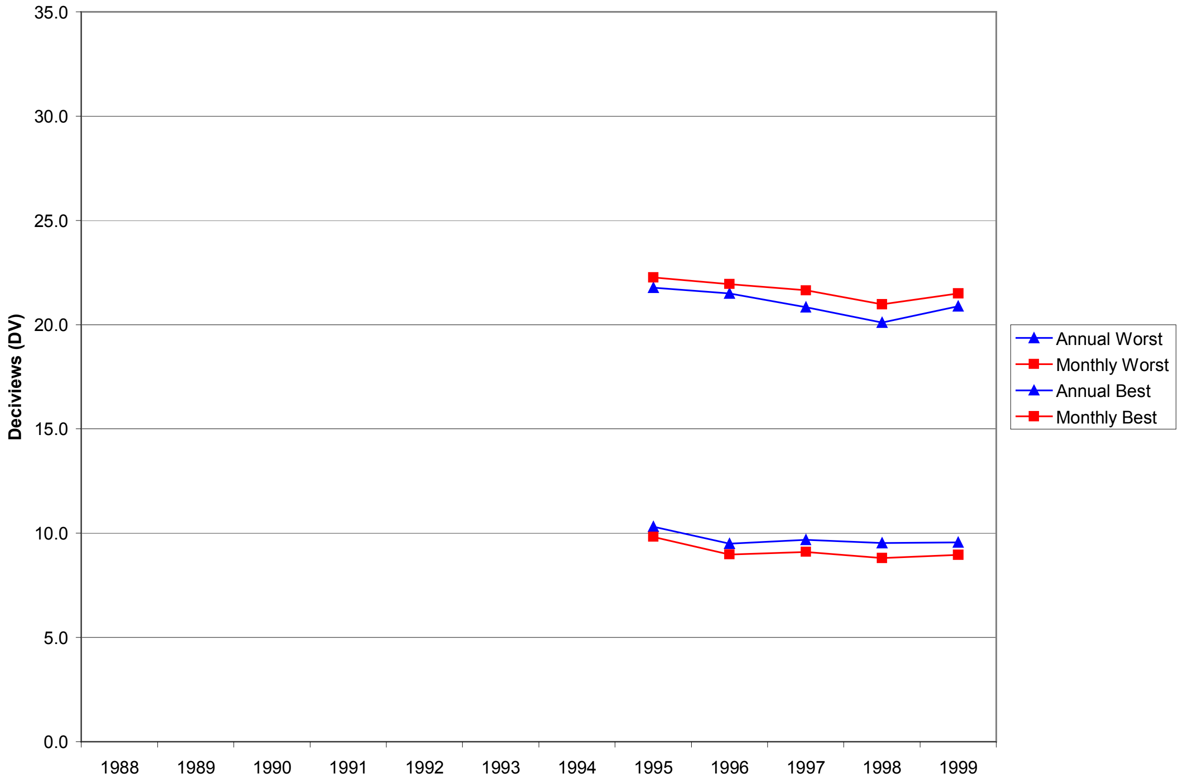


Figure 4: Worst (top) and best (bottom) visibility trends at Acadia National Park

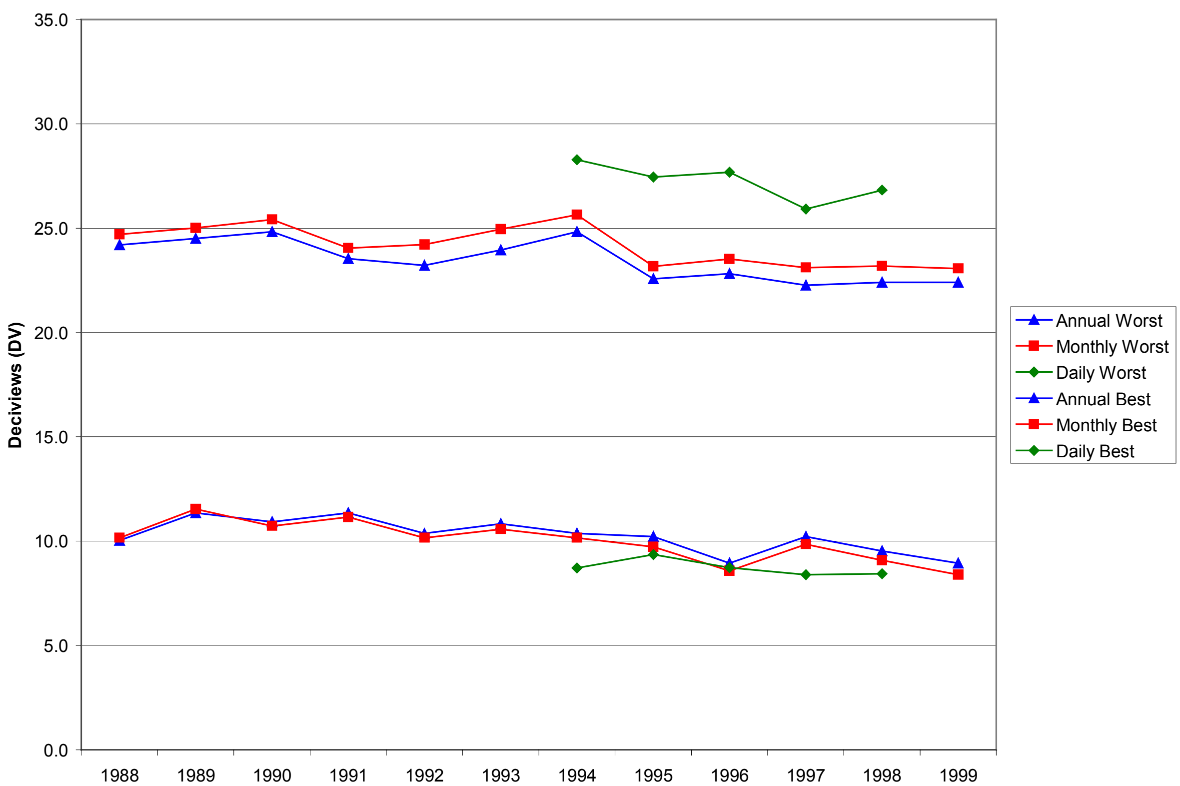
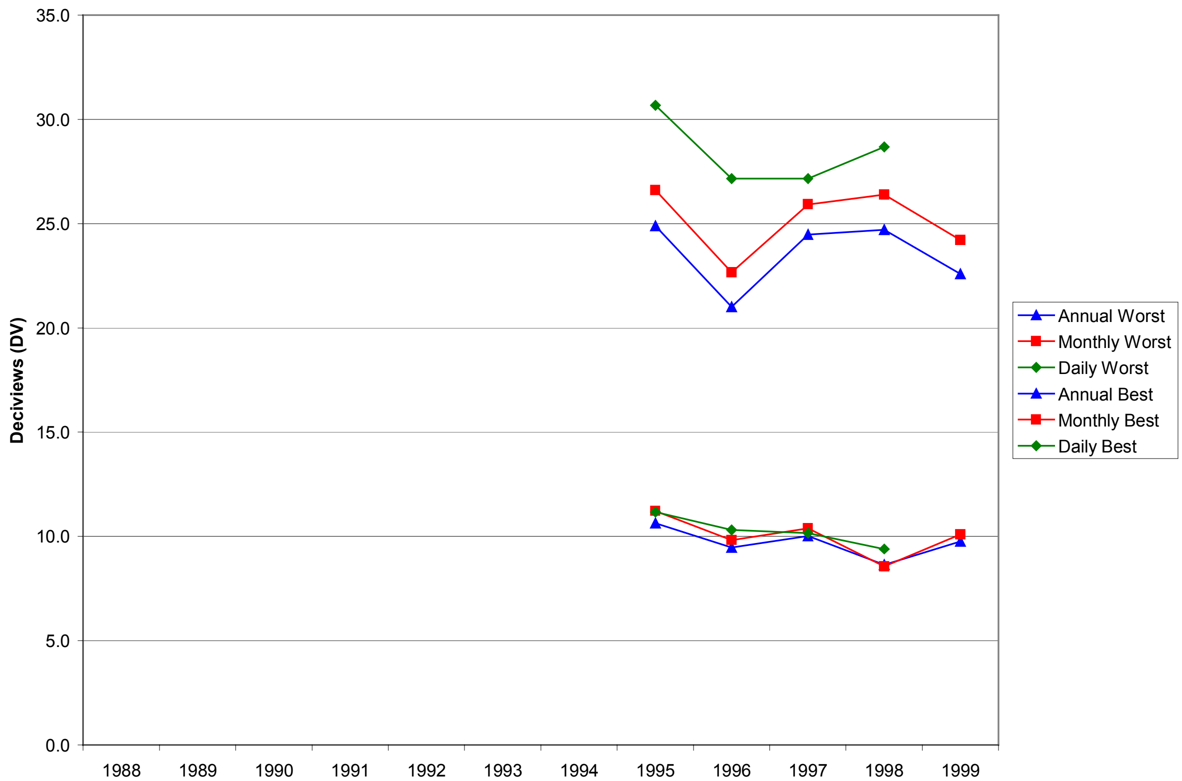


Figure 5: Worst (top) and best (bottom) visibility trends at Camp Dodge (IMPROVE monitor near Great Gulf and Presidential Range – Dry River Wilderness Areas)



note: The Camp Dodge IMPROVE monitor collects data in summertime only.

Figure 6: Worst (top) and best (bottom) visibility trends at Lye Brook Wilderness Area

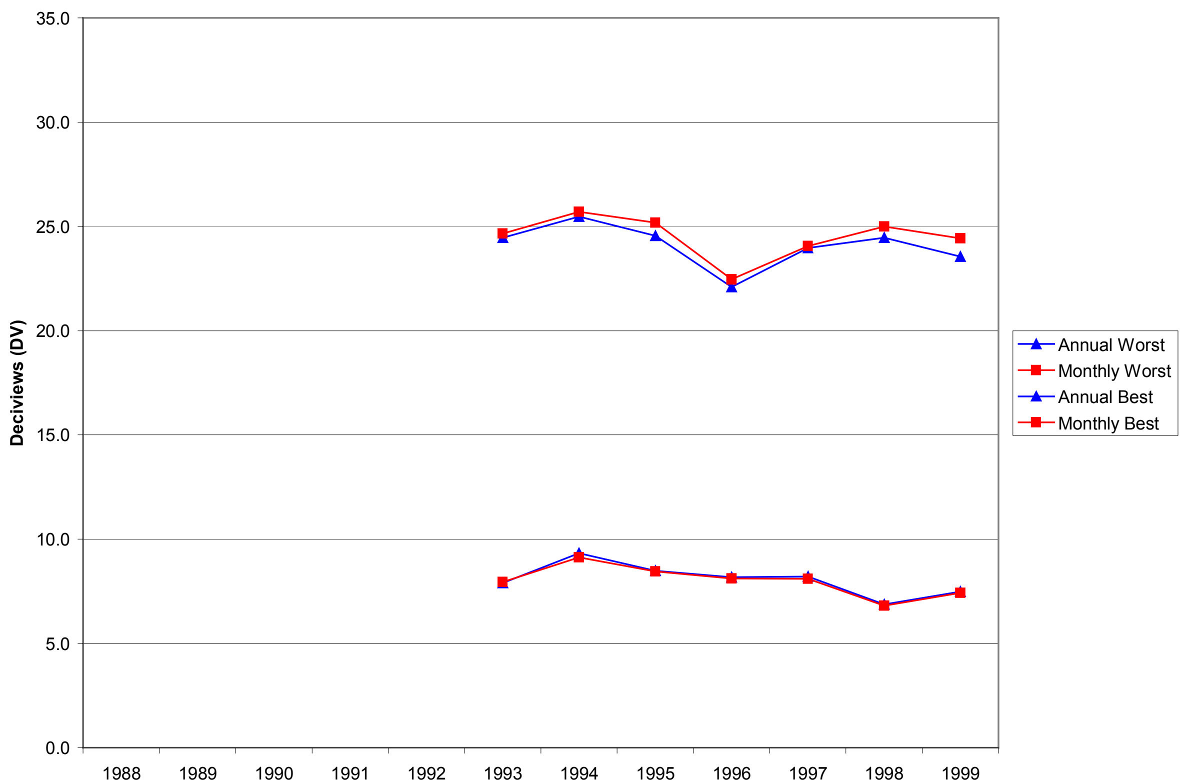


Figure 7: Worst (top) and best (bottom) visibility trends at Brigantine Wilderness Area

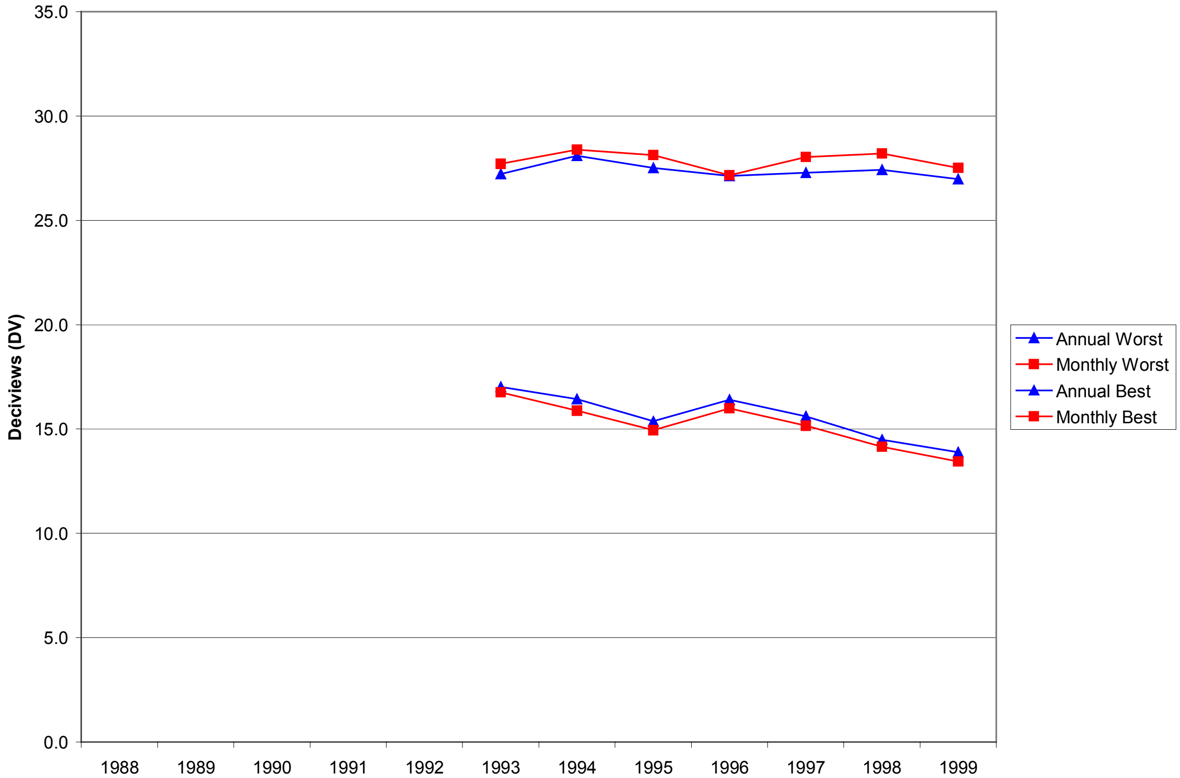
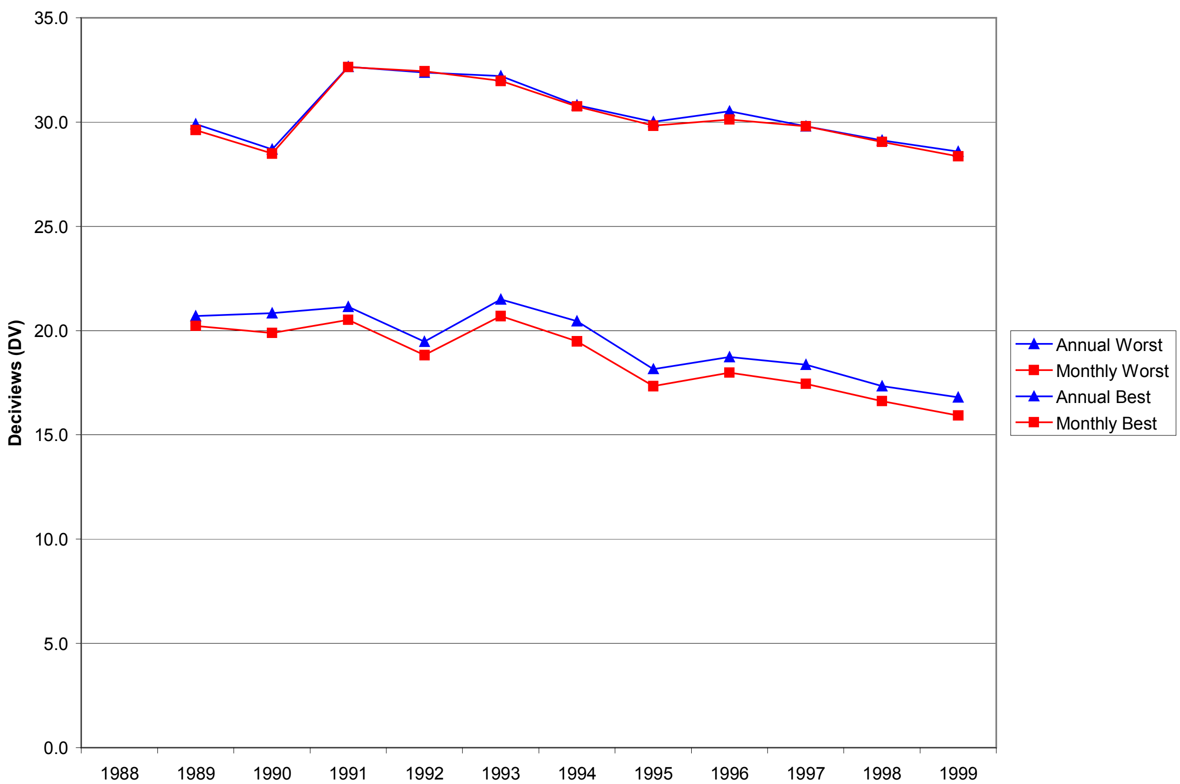


Figure 8: Worst (top) and best (bottom) visibility trends at Washington D.C.



note: The Washington D.C. IMPROVE data reflect urban conditions

Figure 9: Worst (top) and best (bottom) visibility trends at Shenandoah National Park

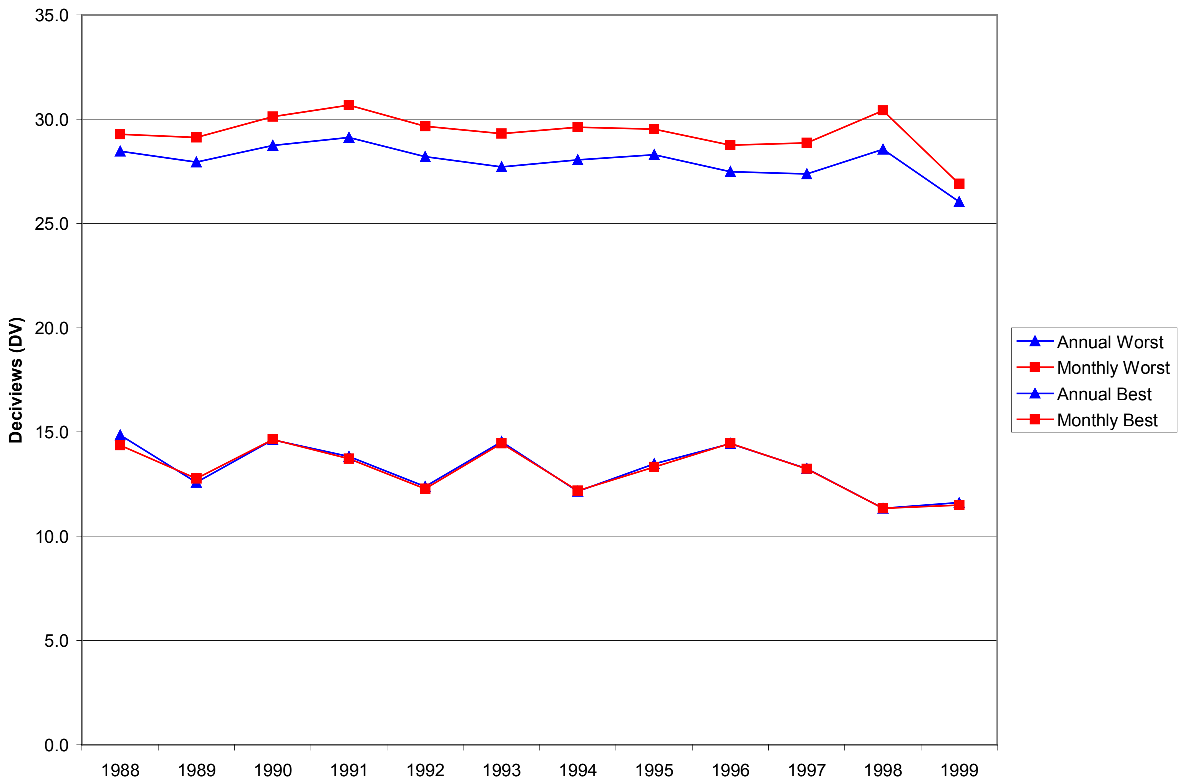


Figure 10: Worst (top) and best (bottom) visibility trends at Dolly Sods Wilderness Area

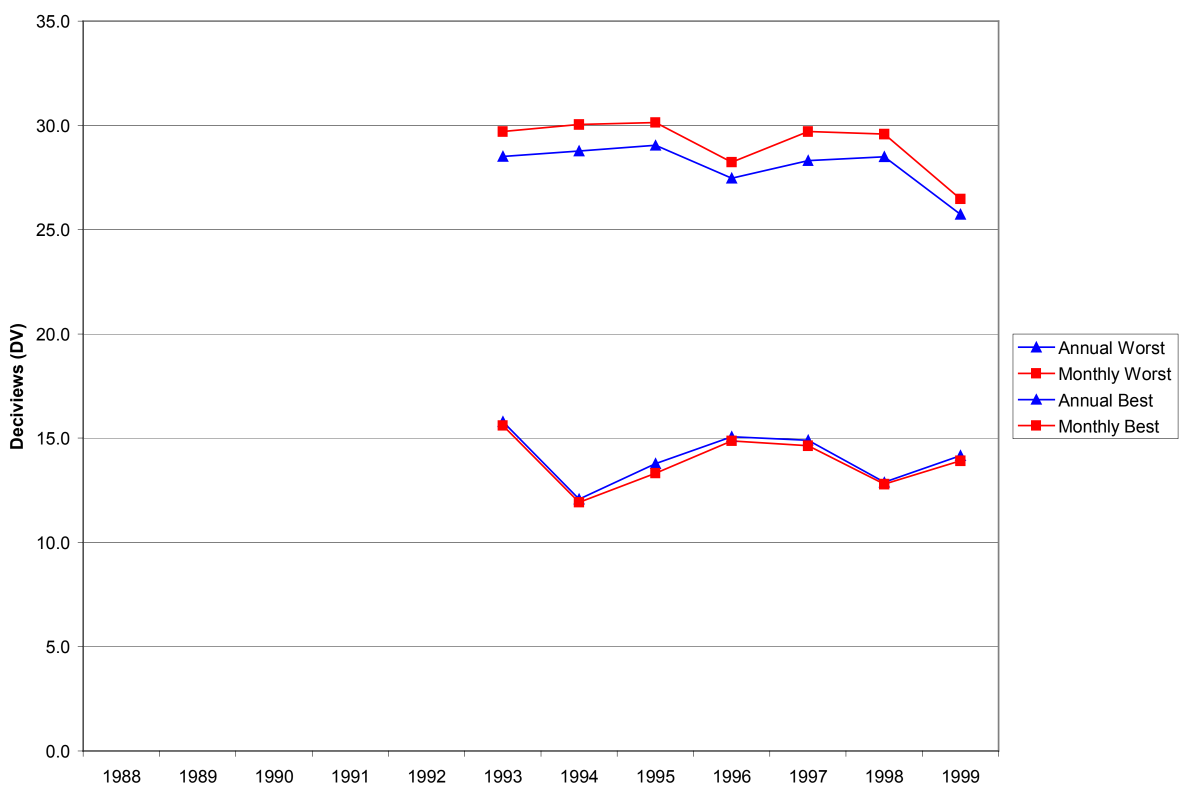


Figure 11: Worst (top) and best (bottom) visibility trends at James River Face Wilderness Area

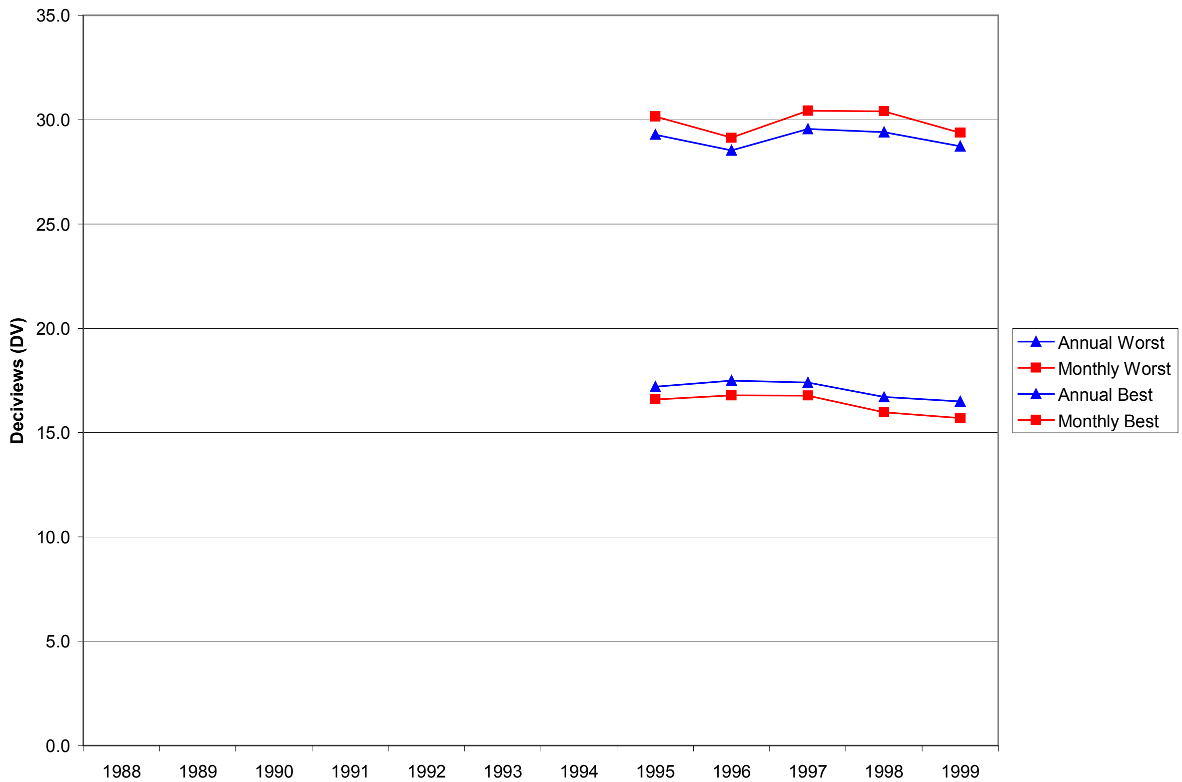
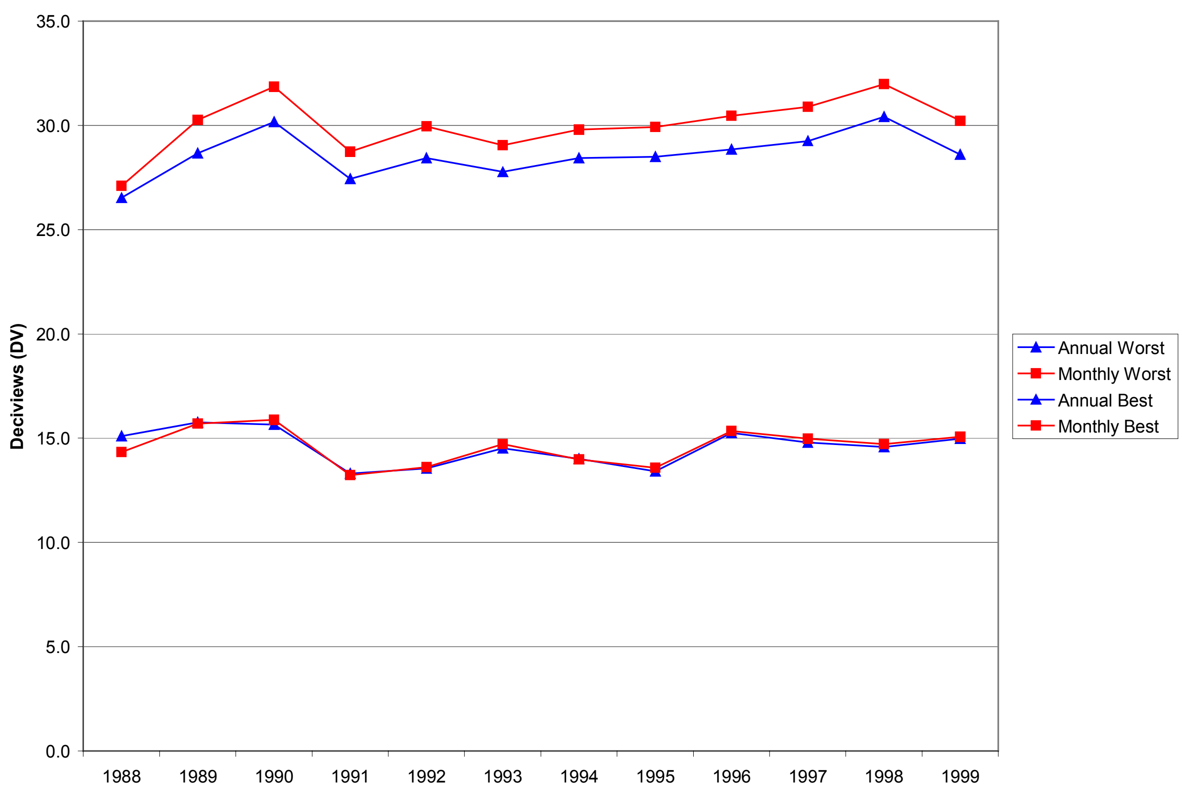


Figure 12: Worst (top) and best (bottom) visibility trends at Great Smoky Mountain National Park



B. Five-year average trends

USEPA's *Draft Guidance on Tracking Progress Under the Regional Haze Rule* (USEPA, 2001a) specifically requires the use of five-year averages for determining success with visibility goals in State Implementation Plans. As opposed to the trends shown in the preceding section, trends in five-year averages are more difficult to discern as each point represents five years worth of data, and thus any interannual variability is smoothed to a much greater degree.

Figure 13 shows trend lines for the twenty percent worst visibility days calculated using climatological mean monthly relative humidity adjustment factors as advocated in the guidance document. The year specified on the x-axis represents the middle year of the five used for each data point. Thus the data record ends with 1997 which is based on data from the years 1995-1999. Trends for the twenty percent best days have also been calculated using five-year averages and are shown in Figure 14. In general, we see that visibility has remained unchanged or improved at most IMPROVE monitoring sites on the best and worst visibility days. The exception is Great Smoky Mountain National Park where significant degradation of visibility conditions is apparent.

Figure 13: Worst day visibility trends based on five-year average values of visibility (dv) for MANE-VU and nearby Class I areas.

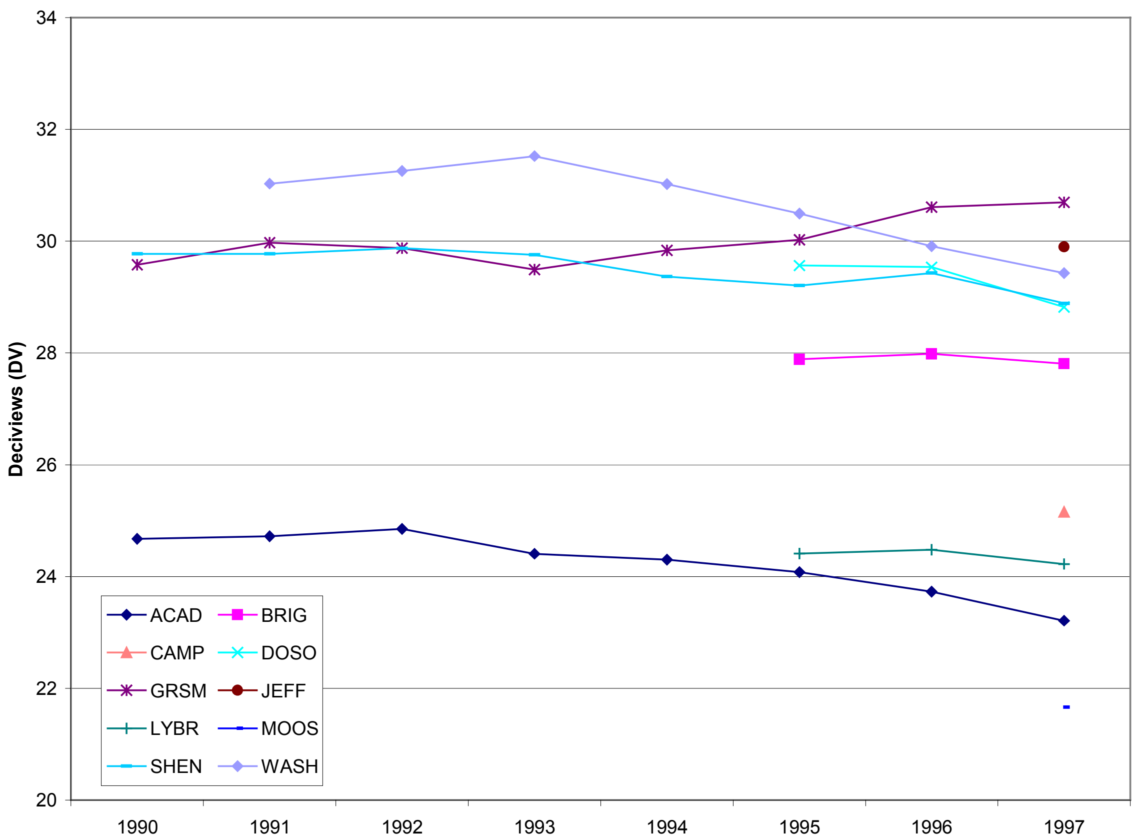
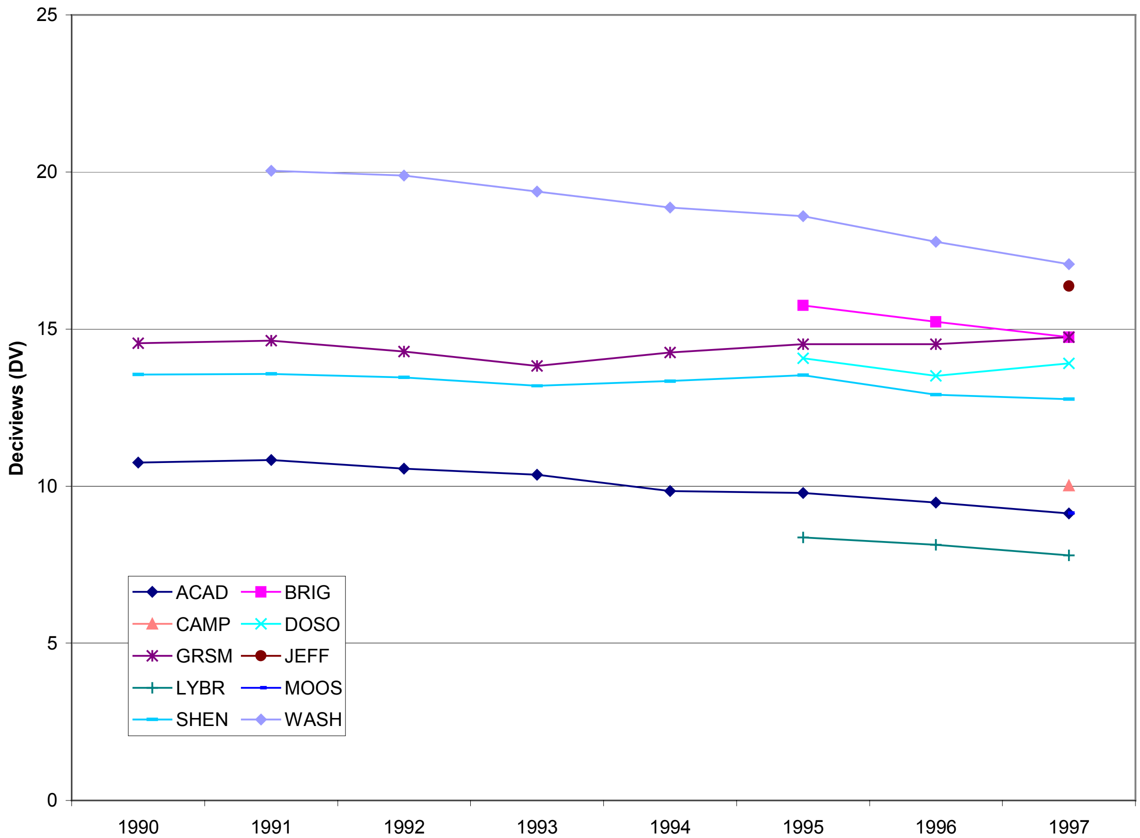


Figure 14: Best day visibility trends based on five-year average values of visibility (dv) for MANE-VU and nearby Class I areas.



C. Trends in Composition on the Best and Worst Visibility Days

In addition to looking at trends in overall visibility conditions, it is interesting to look at trends in extinction from individual components of fine particles. Figures 13-18 show speciated contribution to extinction for three IMPROVE sites in the MANE-VU region across years for which data was available. The three sites shown are Acadia National Park, Lye Brook Wilderness Area, and Brigantine Wilderness Area. Climatological monthly mean relative humidity adjustment factors were used for these calculations of species specific atmospheric extinction.

On the best visibility days, a slight reduction in the extinction due to sulfates and nitrates is evident.[15] No apparent trends are evident in organic carbon or crustal material; however, crustal material does exhibit a significant amount of variability. This variability in what is ostensibly a natural phenomenon, may be indicative of meteorological

[15] This finding is further supported by EPA's *1999 Emissions and Air Quality Trends Report* which found visibility trends in sulfate and nitrate levels were decreasing on the best and "middle" twenty percent of days.

variability. Elemental carbon may have decreased slightly at Acadia over the 1988-99 time period.

There appears to be a slight reduction in nitrate extinction on the worst days, but trends in sulfate – the principal contributor to visibility impairment at all sites – are difficult to discern. The second largest contributor to extinction at all three sites, organic material, has remained relatively unchanged during the period.

Figure 13: Speciated contribution to extinction observed at Acadia National Park on the 20 percent of days with the worst visibility between 1988 and 1999.

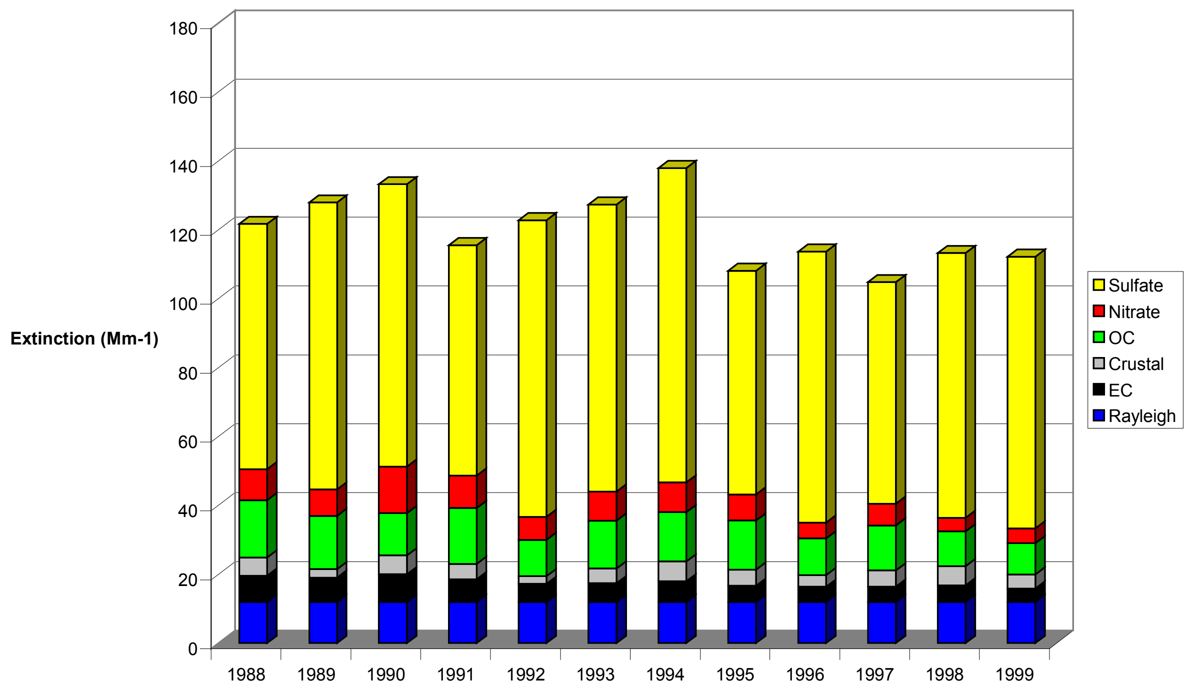


Figure 14: Speciated contribution to extinction observed at Acadia National Park on the 20 percent of days with the best visibility (note difference in scale) between 1988 and 1999.

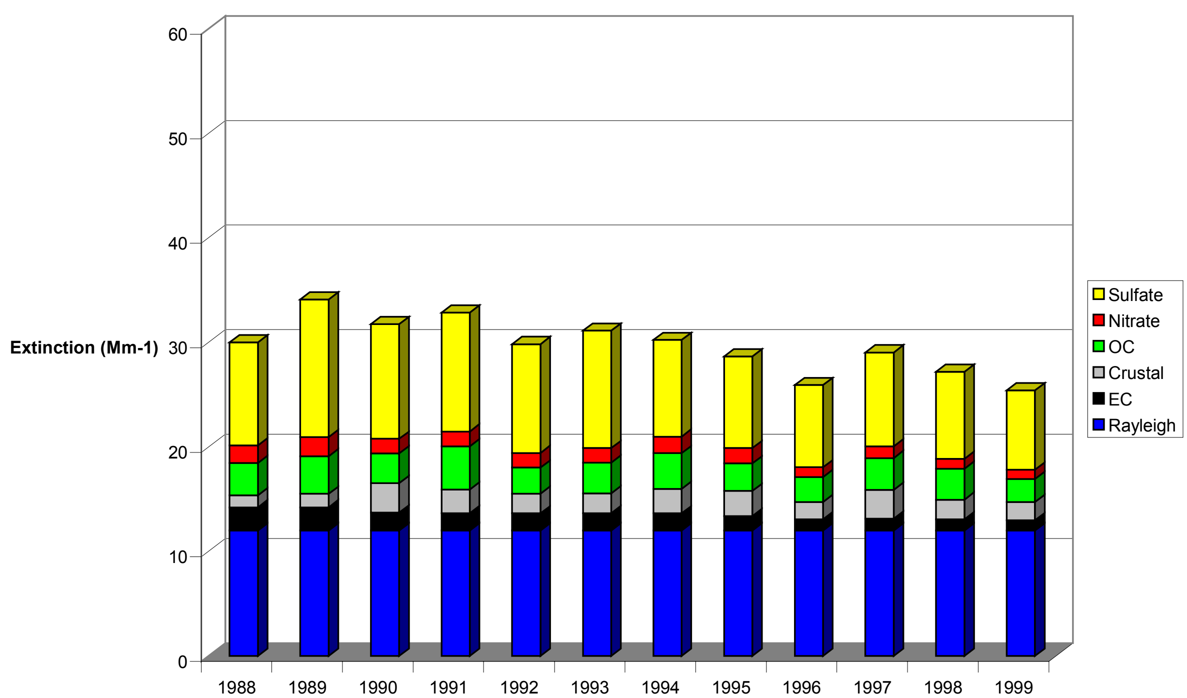


Figure 15: Speciated contribution to extinction observed at Lye Brook Wilderness Area on the 20 percent of days with the worst visibility between 1993 and 1999.

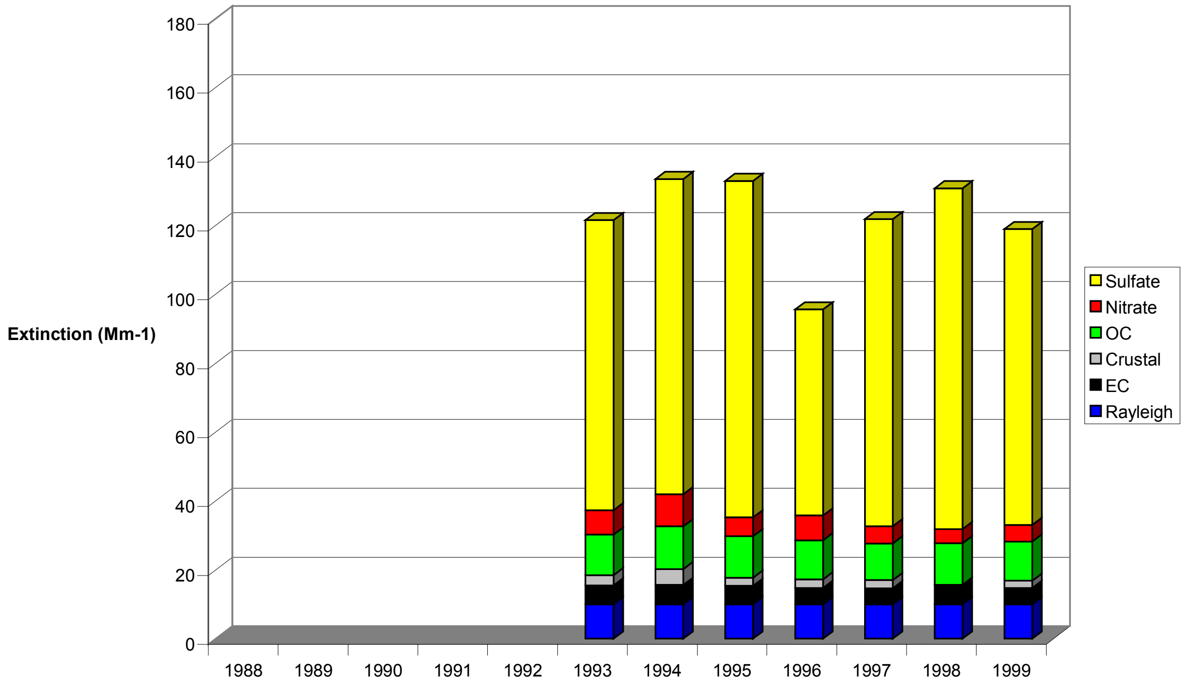


Figure 16: Speciated contribution to extinction observed at Lye Brook Wilderness Area on the 20 percent of days with the best visibility (note difference in scale) between 1993 and 1999.

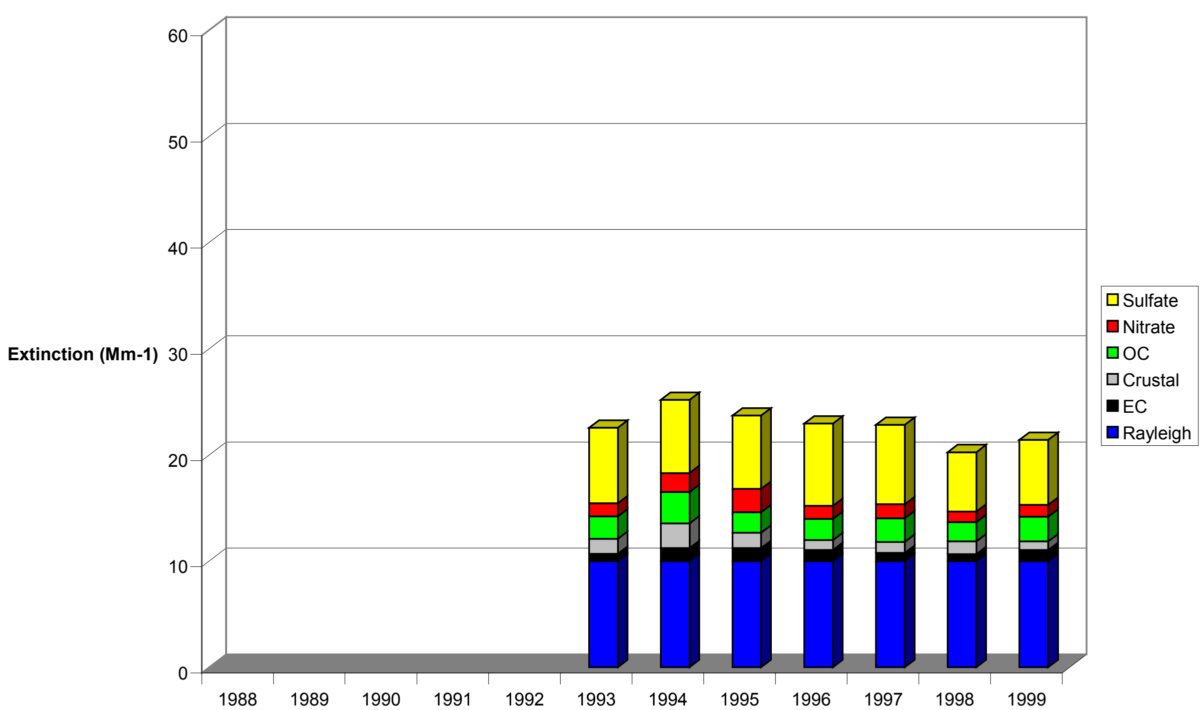


Figure 17: Speciated contribution to extinction observed at Brigantine Wilderness Area on the 20 percent of days with the worst visibility between 1993 and 1999.

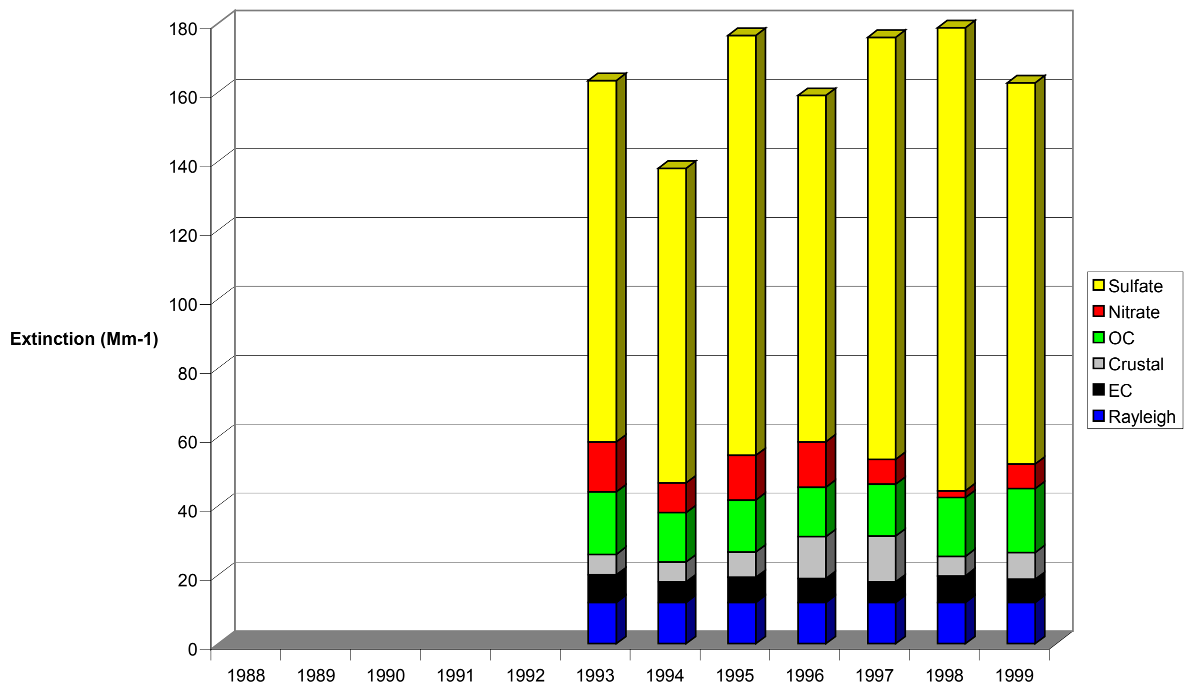
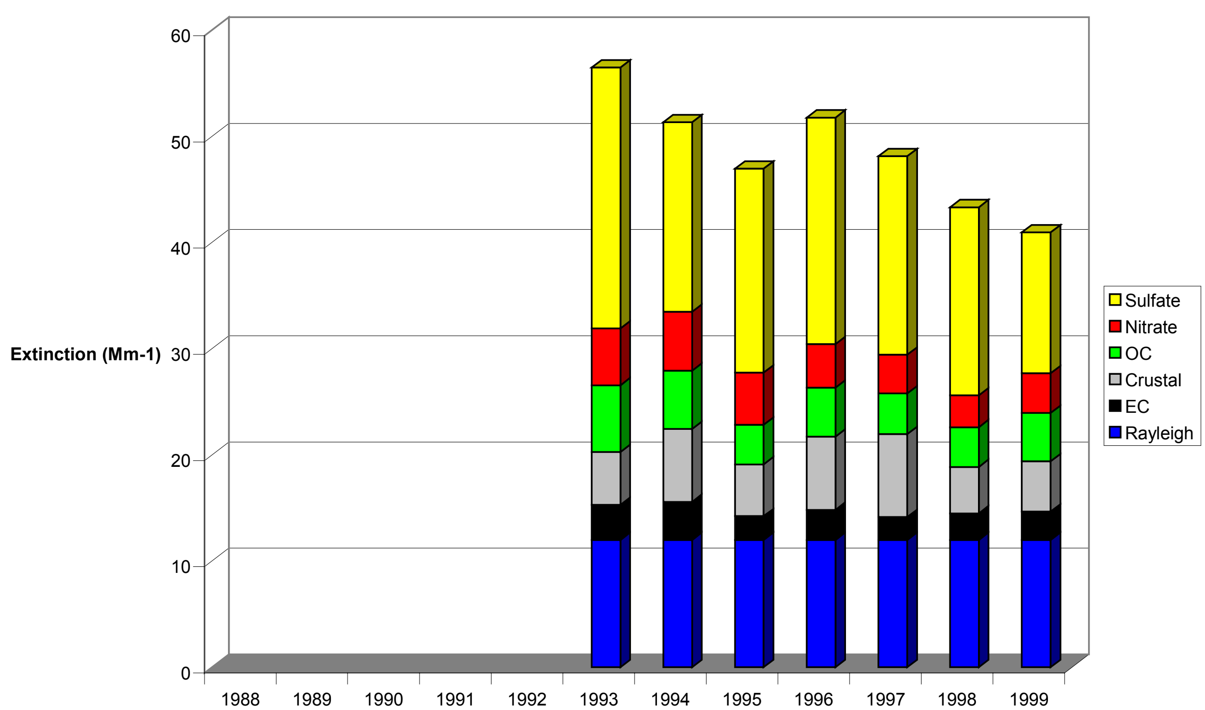


Figure 18: Speciated contribution to extinction observed at Brigantine Wilderness Area on the 20 percent of days with the best visibility (note difference in scale) between 1993 and 1999.



V. Comparing Optical vs. Aerosol Monitoring Techniques

The transmissometer and nephelometer are the most common instruments used for optical monitoring. Transmissometers operate over an open path of 1 km to 10 km and measure total light extinction (b_{ext}) by determining the loss of light (due to scattering and absorption of the intervening atmosphere) from an artificial light source of known luminescence at a fixed distance. Nephelometers measure light scattering (b_{scat}), which is responsible for most light extinction in rural areas of the eastern U.S. Nephelometers operate over a very short open path (few inches) and are easier to install and maintain than transmissometers. However, they measure only a portion (albeit a large majority) of total light extinction. Light absorption (b_{abs}) can be measured continuously by aethalometers and other instruments, which measure the amount of light absorbed by particles collected on a filter. Absorption is typically estimated from the concentration of elemental carbon collected on IMPROVE filters or by subtracting nephelometer data (b_{scat}) from transmissometer data (b_{ext}). Relatively few aethalometers have been deployed in the field.

Reconstructed light extinction obtained from aerosol monitoring techniques compares fairly well with light attenuation as measured by transmissometers and nephelometers; however, the level of agreement is dependant on how relative humidity is treated in the calculation (Malm, 2000). In order to understand the differences between optical and aerosol techniques, reconstructed light extinction was compared to measured extinction obtained by the IMPROVE program.

Figure 19 shows reconstructed light extinction plotted against measured extinction derived from transmissometer data at Acadia National Park between 1988 and 1993. The reconstructed extinction values plotted in Figure 19 are based on calculations using climatological monthly mean relative humidity factors. Significantly more data were available for this type of comparison from the Shenandoah National Park IMPROVE monitor. Figure 20 shows similar data for this more southerly location during 1999 only. A review of the data indicates that some values which would be considered among the twenty percent worst based on reconstructed light extinction would not qualify among the twenty percent worst days based on measured light extinction and vice versa. While this conclusion can not be definitively drawn due the high number of unpaired values, it does point to a potential inaccuracy incurred by the use of reconstructed light extinction.[16]

[16] It should be noted that perfect agreement between reconstructed light extinction based on aerosol measurements and light extinction measured directly by a transmissometer are not expected to give perfect agreement since aerosol measurments are collected at a single ground-level site, whereas a transmissometer provides the integrated visibility conditions across a line of site, usually somewhat above the surface.

Figure 19: Comparison of measured extinction (transmissometer data) to reconstructed light extinction (b_{ext}; calculated using climatological mean monthly relative humidity adjustment factors) at Acadia National Park between 1988 and 1993.

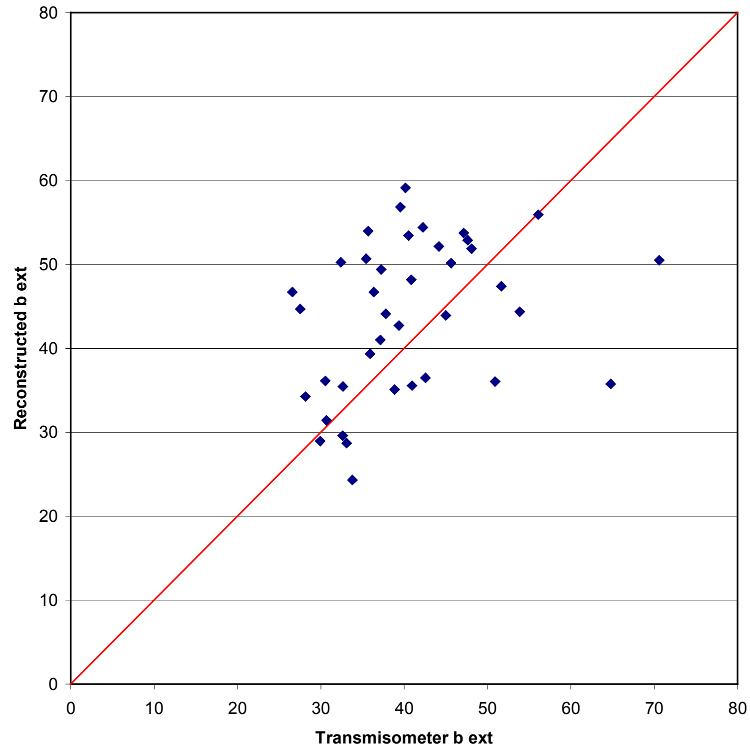
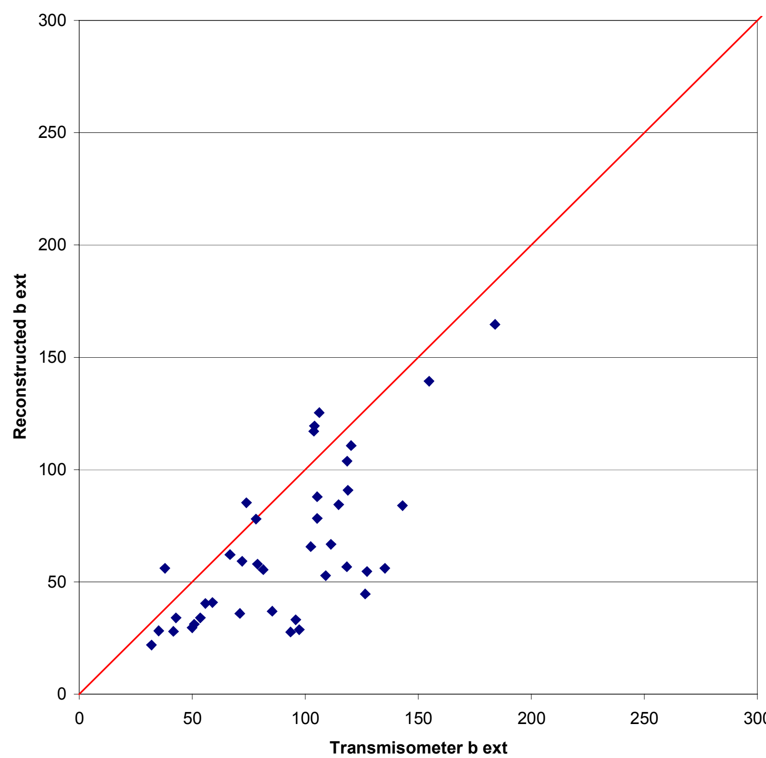


Figure 20: Comparison of measured extinction (transmissometer data) to reconstructed light extinction (b_{ext}; calculated using climatological mean monthly relative humidity adjustment factors) at Shenandoah National Park during 1999.



Some IMPROVE sites also have nephelometers deployed which measure total scattering (b_{scat}). Figure 21 compares the reconstructed scattering coefficient calculated using climatological mean monthly relative humidity adjustment factors with measured scattering coefficients derived from nephelometer data collected at Acadia during 1997. Figure 22 shows the same figure, with reconstructed scattering coefficients that have been calculated using actual relative humidity data measured at Acadia. This figure shows that the agreement is clearly much better when actual data is used, and suggests that the use of monthly average factors may bias the reconstructed scattering values high.

The issues that these figures raise with respect to the use of climatological mean monthly factors are complex. By using climatological monthly values, any year to year variation in visibility which can be attibuted to interannual relative humidity variation is removed. Hence, reasonable progress calculations based on climatological mean factors will specifically track that portion of any visibility improvement which is due to emissions reductions of haze contributing pollutants. If climatological mean values are used consistently for the baseline period and for future calculations of visibility conditions, then any bias due to the use of monthly average factors on reconstructed extinction values is likely to be consistent across both time periods (i.e. extinction calculated for the baseline period and for out years are both likely to be off in the same direction). Given that the deciview is the metric upon which "rate of progress" calculations are based, and it is logarithmically related to extinction, the difference between two equally biased extinction values, will not necessarily translate into two equally biased deciview values. Therefore, further study is required to understand the effect that these potential biases may introduce in "rate of progress" calculations for setting visibility goals.

Figure 21: Comparison of measured scattering (nephelometer data) to reconstructed scattering (b_{scat}; calculated using climatological mean monthly relative humidity adjustment factors) at Acadia National Park during 1997.

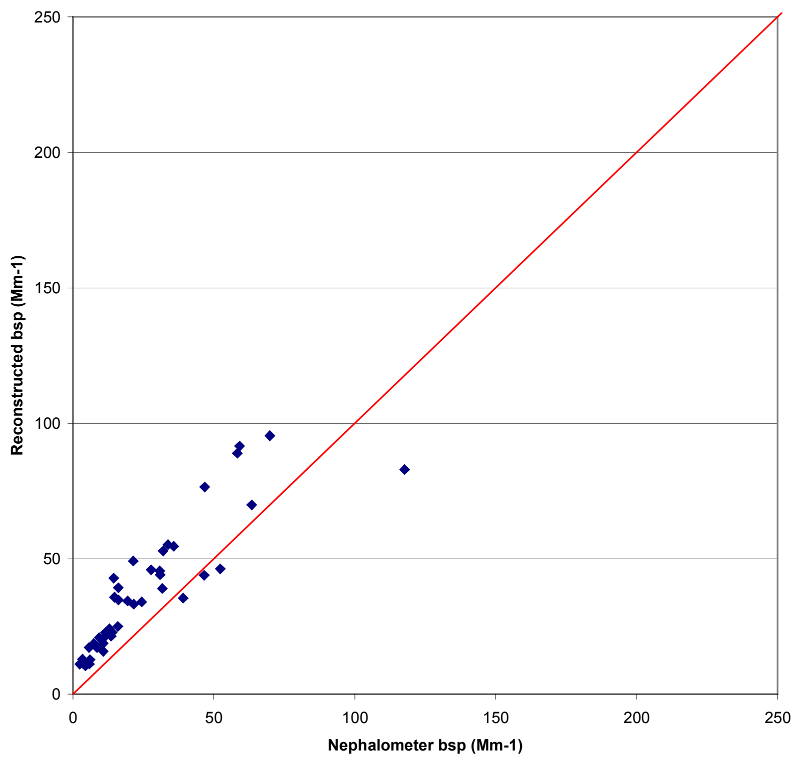
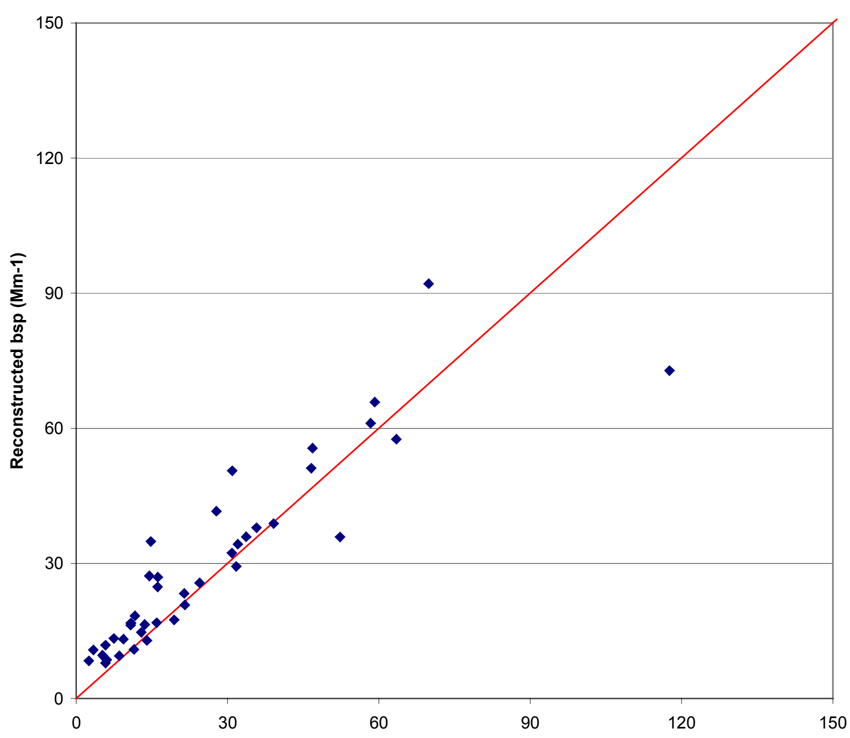


Figure 22: Comparison of measured scattering (nephelometer data) to reconstructed scattering (b_{scat}; calculated using daily relative humidity adjustment factors) at Acadia National Park during 1997.



VI. Summary

The IMPROVE network has generated a significant quantity of data for the MANE-VU Class I areas and those nearby. Analysis of these data continues to be an important source of information on baseline visibility conditions and year-to-year variability. The latest IMPROVE results indicate that MANE-VU Class I areas experienced significantly improved visibility in 1999 over 1997, the most recent year previously assessed by MANE-VU. The reasons for this improvement are not known definitively; however, meteorological variability and the IMPROVE sampling schedule may have played a role in addition to changes in anthropogenic emissions. Analysis of data from subsequent years will be required to determine if a statistically significant trend has been established or whether 1999 was a temporary improvement.

Differences in annual average visibility conditions (calculated in deciviews) are apparent depending on how relative humidity adjustment factors are handled in the calculations. Annual and monthly climatological mean values of the relative humidity adjustment factor have been compared against factors calculated for daily average relative humidity measured at two sites. This limited analysis of the data indicates that climatological mean values may underestimate visibility conditions on the worst days, however, other studies have not supported this conclusion.

While overall trends in visibility have shown marginal improvements, trends in some of the individual components of fine particulate matter measured at IMPROVE sites in the MANE-VU region have not been observed. Continued analysis of IMPROVE data from the regional haze baseline period (2000-2004) should help in identifying any trends in specific components of fine particulate if they exist. Ideally, such analysis should attempt to account for variations in meteorology not accounted for by the use of climatological relative humidity adjustment factors.

Finally, a comparison of measured and reconstructed light extinction has shown reasonable agreement between these techniques at some locations. Further study is required to fully understand the sensitivity of calculated rates of progress to the use of climatological mean values of relative humidity adjustment factors versus daily averages of observed humidity.

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Appendix A – Site specific, climatologically averaged relative humidity and relative humidity adjustment factors and other visibility statistics

Table A.1 – Site specific, climatological average relative humidity (data listed in percent)

Site	FLAG 1999	FLAG 2000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ACAD	87	82	69	66	64	64	65	66	71	74	74	73	72	72
BRIG	88	82	67	64	64	62	66	69	72	74	74	71	67	68
CAMP	88	82	68	65	63	63	64	68	71	73	74	71	70	69
DOSO	89	83	69	66	65	61	67	70	72	74	74	69	68	71
GRSM	85	84	70	66	64	62	70	77	76	77	76	72	70	71
JEFF	83	82	66	63	62	59	67	71	72	74	73	68	65	68
LYBR	87	82	68	65	64	62	64	67	70	73	74	70	69	69
MOOS	88	82	70	66	63	64	64	67	70	73	74	72	72	72
SHEN	87	82	67	64	63	60	66	71	73	75	74	69	65	68
WASH	N/A	N/A	65	61	62	61	67	68	69	71	71	70	65	65

Notes: Annual Data based on FLAG draft phase I report (1999) and final report in 2000. Monthly data provided by SAIC under contract to USEPA (see USEPA, 2001a). Note that significant differences exist between the draft and final FLAG annual estimates. Additionally, large differences exist between annual FLAG and the monthly USEPA estimates of relative humidity. However, the differences between FLAG and USEPA correction factors (Table A.2) are much smaller suggesting different relationships were used for calculating correction factors from relative humidity data.

Table A.2 – Site specific, climatological average relative humidity adjustment factor (unitless)

Site	FLAG 1999	FLAG 2000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ACAD	3.8	3.0	3.26	2.94	2.84	3.37	3.11	2.98	3.41	3.83	4.04	3.82	3.56	3.53
BRIG	3.9	3.0	2.83	2.64	2.73	2.6	3.03	3.16	3.44	3.72	3.64	3.34	2.85	2.83
CAMP	3.9	3.0	2.78	2.56	2.58	2.77	2.93	3.22	3.49	3.81	3.98	3.42	3.06	2.92
DOSO	4.3	3.1	2.98	2.79	2.81	2.56	3.12	3.39	3.54	3.87	3.85	3.27	2.97	3.1
GRSM	3.4	3.2	3.31	3.04	2.91	2.7	3.17	3.86	3.82	3.96	4.24	3.77	3.29	3.44
JEFF	3.1	3.0	2.83	2.64	2.66	2.43	2.98	3.28	3.39	3.67	3.64	3.15	2.81	2.96
LYBR	3.8	3.0	2.74	2.56	2.61	2.59	2.82	3.03	3.27	3.56	3.66	3.25	2.93	2.83
MOOS	3.9	3.0	2.97	2.69	2.66	3.01	2.96	3.1	3.41	3.8	3.91	3.54	3.24	3.2
SHEN	3.8	3.0	3.07	2.83	2.79	2.53	3.05	3.41	3.54	3.93	3.85	3.21	2.95	3.07
WASH	N/A	N/A	2.74	2.47	2.62	2.42	3.03	2.89	2.98	3.05	3.31	3.14	2.69	2.64

Notes: Annual Data based on FLAG draft phase I report (1999) and final report (2000). Monthly data provided by SAIC under contract to USEPA (see USEPA, 2001a). Note that significant differences exist between the draft and final FLAG annual estimates. Additionally, large differences exist between annual FLAG and monthly USEPA estimates of relative humidity (Table A.1). As shown here, the FLAG and USEPA correction factors are in much better agreement suggesting different relationships were used for calculating correction factors from relative humidity data.

Table A.3 – Speciated contribution to atmospheric light extinction in or near Class I Areas in the Northeast and Mid-Atlantic states on 20% of days with the worst visibility conditions in 1999.

	Contribution to Extinction from						Total Extinction (Mm^{-1})	Total Extinction (dv)
	Sulfate (Mm^{-1})	Nitrate (Mm^{-1})	Organic Carbon (Mm^{-1})	Crustal Material (Mm^{-1})	Elemental Carbon (Mm^{-1})	Rayleigh Scattering (Mm^{-1})		
Acadia National Park, ME	78.9	4.3	9.1	4.1	3.9	12.0	112.2	24.2
Brigantine Wildlife Refuge, NJ	110.6	7.2	18.5	7.7	6.7	12.0	162.7	27. 9
Dolly Sodds /Otter Creek Wilderness, WV	107.2	5.2	15.3	2.4	5.4	10.0	145.5	26.8
Great Gulf Wilderness Area, NH	84.2	1.4	11.6	4.3	3.8	10.0	115.2	24.4
Great Smoky Mountains National Park, NC	168.2	2.0	19.4	5.4	5.3	10.0	210.2	30.5
Jefferson/James River Face Wilderness Area, VA	142.7	3.5	23.7	3.3	8.2	12.0	193.5	29.6
Lye Brook Wilderness Area, VT	85.9	4.8	11.3	2.1	4.8	10.0	118.9	24.8
Moosehorn Wildlife Refuge, ME	59.5	4.6	8.7	2.2	3.5	12.0	90.5	22.0
Shenandoah National Park, VA	110.5	4.1	17.3	4.1	5.3	10.0	151.2	27.2
Washington, DC	113.2	10.1	24.5	3.7	12.8	12.0	176.3	28.7

Table A.4 – Speciated contribution to atmospheric light extinction in or near Class I Areas in the Northeast and Mid-Atlantic states on 20% of days with the best visibility conditions in 1999.

	Contribution to Extinction from						Total Extinction (Mm^{-1})	Total Extinction (dv)
	Sulfate (Mm^{-1})	Nitrate (Mm^{-1})	Organic Carbon (Mm^{-1})	Crustal Material (Mm^{-1})	Elemental Carbon (Mm^{-1})	Rayleigh Scattering (Mm^{-1})		
Acadia National Park, ME	7.6	0.9	2.2	1.7	1.0	12.0	25.4	9.3
Brigantine Wildlife Refuge, NJ	13.3	3.7	4.6	4.8	2.7	12.0	41.0	14.1
Dolly Sodds /Otter Creek Wilderness, WV	18.0	3.0	5.4	2.7	2.4	10.0	41.6	14.3
Great Gulf Wilderness Area, NH	6.8	0.7	5.5	3.0	1.5	10.0	27.6	10.1
Great Smoky Mountains National Park, NC	19.8	2.2	6.9	3.5	3.1	10.0	45.6	15.2
Jefferson/James River Face Wilderness Area, VA	19.2	3.2	9.0	2.7	4.6	12.0	50.6	16.2
Lye Brook Wilderness Area, VT	6.1	1.1	2.3	0.8	1.0	10.0	21.4	7.6
Moosehorn Wildlife Refuge, ME	7.7	1.5	2.4	2.1	1.0	12.0	26.8	9.8
Shenandoah National Park, VA	12.3	3.1	3.0	1.9	1.8	10.0	32.1	11.7
Washington, DC	18.2	5.0	7.1	2.8	6.8	12.0	52.0	16.5

Table A.5 – Worst and best visibility trends at Acadia National Park, ME (Total extinction in deciviews)

	Humidity Factor	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Annual	24.2	24.5	24.8	23.5	23.2	24.0	24.8	22.6	22.8	22.3	22.4	22.4
	Monthly	24.7	25.0	25.4	24.1	24.2	24.9	25.7	23.2	23.5	23.1	23.2	23.1
	Daily							28.3	27.4	27.7	25.9	26.8	
Best	Annual	10.0	11.4	10.9	11.4	10.4	10.8	10.4	10.2	8.9	10.2	9.5	8.9
	Monthly	10.2	11.5	10.7	11.2	10.2	10.6	10.2	9.7	8.6	9.9	9.1	8.4
	Daily							8.7	9.4	8.7	8.4	8.4	

Table A.6 – Worst and best visibility trends at Brigantine Wildlife Refuge, NJ (Total extinction in deciviews)

	Humidity Factor	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Annual						27.2	28.1	27.5	27.1	27.3	27.4	27.0
	Monthly						27.7	28.4	28.1	27.2	28.0	28.2	27.5
Best	Annual						17.0	16.4	15.4	16.4	15.6	14.5	13.9
	Monthly						16.8	15.9	14.9	16.0	15.2	14.1	13.4

Table A.7 – Worst and best visibility trends at Dolly Sodds/Otter Creek Wilderness, WV (Total extinction in deciviews)

	Humidity Factor	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Annual						28.5	28.8	29.0	27.5	28.3	28.5	25.7
	Monthly						29.7	30.0	30.1	28.2	29.7	29.6	26.5
Best	Annual						15.8	12.1	13.8	15.1	14.9	12.9	14.2
	Monthly						15.6	11.9	13.3	14.9	14.6	12.8	13.9

Table A.8 – Worst and best visibility trends at Great Gulf Wilderness, NH (Total extinction in deciviews, summer only)

	Humidity Factor	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Annual								24.9	21.0	24.5	24.7	22.6
	Monthly								26.6	22.7	25.9	26.4	24.2
	Daily								30.7	27.2	27.2	28.7	
Best	Annual								10.6	9.5	10.0	8.6	9.8
	Monthly								11.2	9.8	10.4	8.6	10.1
	Daily								11.2	10.3	10.2	9.4	

Table A.9 – Worst and best visibility trends at Great Smoky Mountains National Park, NC (Total extinction in deciviews)

	Humidity Factor	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Annual	26.5	28.7	30.2	27.4	28.4	27.8	28.4	28.5	28.8	29.3	30.4	28.6
	Monthly	27.1	30.3	31.8	28.7	30.0	29.1	29.8	29.9	30.5	30.9	32.0	30.2
Best	Annual	15.1	15.8	15.7	13.3	13.6	14.5	14.0	13.4	15.3	14.8	14.6	15.0
	Monthly	14.3	15.7	15.9	13.2	13.6	14.7	14.0	13.6	15.4	15.0	14.7	15.1

Table A.10 – Worst and best visibility trends at Jefferson/James River Face Wilderness, VA (Total extinction in deciviews)

	Humidity Factor	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Annual								29.3	28.5	29.5	29.4	28.7
	Monthly								30.1	29.1	30.4	30.4	29.4
Best	Annual								17.2	17.5	17.4	16.7	16.5
	Monthly								16.6	16.8	16.8	16.0	15.7

Table A.11 – Worst and best visibility trends at Lye Brook Wilderness, VT (Total extinction in deciviews)

	Humidity Factor	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Annual						24.5	25.5	24.5	22.1	24.0	24.5	23.6
	Monthly						24.7	25.7	25.2	22.5	24.1	25.0	24.4
Best	Annual						7.9	9.3	8.5	8.2	8.2	6.9	7.5
	Monthly						8.0	9.1	8.5	8.1	8.1	6.8	7.4

Table A.12 – Worst and best visibility trends at Moosehorn Wildlife Refuge, ME (Total extinction in deciviews)

	Humidity Factor	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Annual								21.8	21.5	20.8	20.1	20.9
	Monthly								22.3	21.9	21.6	21.0	21.5
Best	Annual								10.3	9.5	9.7	9.5	9.6
	Monthly								9.8	9.0	9.1	8.8	9.0

Table A.13 –Worst and best visibility trends at Shenandoah National Park, VA (Total extinction in deciviews)

	Humidity Factor	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Annual	28.5	27.9	28.7	29.1	28.2	27.7	28.1	28.3	27.5	27.4	28.6	26.0
	Monthly	29.3	29.1	30.1	30.7	29.7	29.3	29.6	29.5	28.8	28.9	30.4	26.9
Best	Annual	14.9	12.6	14.6	13.8	12.4	14.5	12.2	13.5	14.4	13.2	11.4	11.6
	Monthly	14.4	12.8	14.6	13.7	12.3	14.5	12.2	13.3	14.5	13.2	11.3	11.5

Table A.14 – Worst and best visibility trends at Washington, DC (Total extinction in deciviews)

	Humidity Factor	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Annual		29.9	28.7	32.6	32.4	32.2	30.8	30.0	30.5	29.8	29.1	28.6
	Monthly		29.6	28.5	32.6	32.4	32.0	30.8	29.8	30.1	29.8	29.1	28.4
Best	Annual		20.7	20.8	21.1	19.5	21.5	20.5	18.2	18.7	18.4	17.3	16.8
	Monthly		20.2	19.9	20.5	18.8	20.7	19.5	17.3	18.0	17.5	16.6	15.9

Table A.15 – Worst visibility trends based on five-year average (Total extinction in deciviews)

Site	1988-1992	1989-1993	1990-1994	1991-1995	1992-1996	1993-1997	1994-1998	1995-1999
Acadia National Park, ME	24.68	24.73	24.86	24.41	24.30	24.08	23.73	23.21
Brigantine Wildlife Refuge, NJ						27.89	27.98	27.81
Dolly Sodds /Otter Creek Wilderness, WV								25.16
Great Gulf Wilderness Area, NH						29.56	29.54	28.82
Great Smoky Mountains National Park, NC	29.58	29.97	29.88	29.49	29.84	30.03	30.61	30.70
Jefferson/James River Face Wilderness Area, VA								29.90
Lye Brook Wilderness Area, VT						24.42	24.48	24.23
Moosehorn Wildlife Refuge, ME								21.66
Shenandoah National Park, VA	29.77	29.78	29.88	29.76	29.37	29.21	29.43	28.89
Washington, DC		31.03	31.26	31.53	31.02	30.50	29.91	29.43

Table A.16 – Best visibility trends based on five-year average (Total extinction in deciviews)

Site	1988-1992	1989-1993	1990-1994	1991-1995	1992-1996	1993-1997	1994-1998	1995-1999
Acadia National Park, ME	10.75	10.84	10.56	10.36	9.84	9.78	9.48	9.13
Brigantine Wildlife Refuge, NJ						15.75	15.22	14.74
Dolly Sodds /Otter Creek Wilderness, WV								10.02
Great Gulf Wilderness Area, NH						14.07	13.51	13.91
Great Smoky Mountains National Park, NC	14.55	14.63	14.29	13.83	14.25	14.52	14.52	14.74
Jefferson/James River Face Wilderness Area, VA								16.37
Lye Brook Wilderness Area, VT						8.36	8.13	7.79
Moosehorn Wildlife Refuge, ME								9.14
Shenandoah National Park, VA	13.55	13.57	13.46	13.19	13.34	13.53	12.91	12.77
Washington, DC		20.03	19.88	19.37	18.87	18.59	17.78	17.07

Table A.17 – Speciated contribution to extinction observed at Acadia National Park, ME on the 20 percent of days with the worst and best visibility using monthly relative humidity factors (Mm^{-1})

		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Sulfate	71.1	83.3	82.0	66.8	86.1	83.3	91.2	64.9	78.7	64.3	76.9	78.9
	Nitrate	9.0	7.6	13.5	9.5	6.7	8.5	8.7	7.6	4.5	6.3	3.9	4.3
	Organic Carbon	16.6	15.5	12.3	16.2	10.6	13.8	14.3	14.2	10.7	13.1	10.1	9.1
	Crustal Matter	5.3	2.5	5.5	4.5	2.2	4.2	5.7	4.7	3.4	4.7	5.6	4.1
	Elemental Carbon	7.6	7.1	8.0	6.6	5.2	5.4	6.0	4.7	4.4	4.4	4.8	3.9
	Rayleigh Scattering	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	Total Extinction	121.7	127.9	133.3	115.5	122.8	127.3	137.9	108.1	113.7	104.8	113.3	112.2
Best	Sulfate	9.9	13.2	11.0	11.4	10.4	11.2	9.2	8.8	7.9	9.0	8.3	7.6
	Nitrate	1.7	1.8	1.4	1.4	1.4	1.4	1.6	1.5	0.9	1.1	1.0	0.9
	Organic Carbon	3.1	3.6	2.8	4.1	2.5	2.9	3.4	2.6	2.4	3.1	3.0	2.2
	Crustal Matter	1.2	1.3	2.8	2.3	1.9	1.9	2.3	2.4	1.7	2.8	1.9	1.7
	Elemental Carbon	2.2	2.2	1.7	1.7	1.6	1.7	1.6	1.4	1.1	1.1	1.1	1.0
	Rayleigh Scattering	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
	Total Extinction	28.0	32.1	29.7	30.8	27.8	29.1	28.2	26.7	23.9	27.0	25.2	23.4

Table A.18 – Speciated contribution to extinction observed at Lye Brook Wilderness, VT on the 20 percent of days with the worst and best visibility using monthly relative humidity factors (Mm^{-1})

		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Sulfate						84.2	91.5	97.7	59.8	89.1	98.9	85.9
	Nitrate						7.1	9.3	5.5	7.2	5.1	4.2	4.8
	Organic Carbon						11.8	12.4	12.0	11.3	10.6	12.0	11.3
	Crustal Matter						3.0	4.7	2.3	2.5	2.4	0.0	2.1
	Elemental Carbon						5.5	5.6	5.4	4.8	4.6	5.7	4.8
	Rayleigh Scattering						10.0	10.0	10.0	10.0	10.0	10.0	10.0
	Total Extinction						121.5	133.5	132.9	95.6	121.8	130.8	118.9
Best	Sulfate						7.1	6.9	6.9	7.8	7.5	5.6	6.1
	Nitrate						1.2	1.8	2.2	1.2	1.3	1.0	1.1
	Organic Carbon						2.1	3.0	1.9	2.0	2.2	1.8	2.3
	Crustal Matter						1.4	2.3	1.4	0.9	1.0	1.2	0.8
	Elemental Carbon						0.7	1.2	1.2	1.1	0.8	0.7	1.0
	Rayleigh Scattering						10.0	10.0	10.0	10.0	10.0	10.0	10.0
	Total Extinction						22.6	25.2	23.7	23.0	22.8	20.3	21.4

Table A.19 – Speciated contribution to extinction observed at Brigantine Wildlife Refuge, NJ on the 20 percent of days with the worst and best visibility using monthly relative humidity factors (Mm^{-1})

		1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Worst	Sulfate						104.8	91.2	121.7	100.5	122.4	134.3	110.6
	Nitrate						14.5	8.7	13.0	13.2	7.2	2.0	7.2
	Organic Carbon						18.1	14.3	15.1	14.3	15.1	17.1	18.5
	Crustal Matter						5.9	5.7	7.4	12.1	13.2	5.6	7.7
	Elemental Carbon						8.0	6.0	7.3	7.0	6.0	7.7	6.7
	Rayleigh Scattering						12.0	12.0	12.0	12.0	12.0	12.0	12.0
	Total Extinction						163.4	137.9	176.4	159.1	175.9	178.7	162.7
Best	Sulfate						24.6	17.8	19.2	21.3	18.7	17.7	13.3
	Nitrate						5.4	5.5	4.9	4.1	3.6	3.0	3.7
	Organic Carbon						6.3	5.5	3.7	4.6	3.8	3.7	4.6
	Crustal Matter						5.0	6.9	4.9	6.9	7.8	4.4	4.8
	Elemental Carbon						3.3	3.6	2.2	2.8	2.1	2.5	2.7
	Rayleigh Scattering						12.0	12.0	12.0	12.0	12.0	12.0	12.0
	Total Extinction						54.5	49.3	45.0	49.8	46.1	41.3	39.0