Future Year Model Projections
Task 9a

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Abbreviations/Acronym List

Alpine	Alpine Geophysics, LLC
B20%	20% Clearest Days
Bext	Beta (or light) extinction
CAMx	Comprehensive Air quality Model with eXtensions
CMAQ	Community Multiscale Air Quality
CFR	Code of Federal Register
dv	Deciview
EC	Elemental carbon
EPA	United States Environmental Protection Agency
ERG	Eastern Research Group, Inc.
$f_s(RH)$	Monthly relative humidity function associated with small size distribution
$f_{ss}(RH)$	Monthly relative humidity function associated with sea salt
$f_L(RH)$	Monthly relative humidity function associated with large size distributions
I20%	20% Most Anthropogenically Impaired Days
IMPROVE	Interagency Monitoring of Protected Visual Environments
µg	micrograms
$\mu g/m^3$	micrograms per cubic meter
Mm^{-1}	Inverse Megameters
OM	Organic mass carbon
PM	Particulate matter
PM_{10}-PRI	Primary particulate matter ≤ 10 microns in aerodynamic diameter
$PM_{2.5}$-PRI	Primary particulate matter ≤2.5 microns in aerodynamic diameter
RHR	Regional Haze Rule
RPGs	Reasonable Progress Goals
RRF	Relative Response Factor
SESARM	Southeastern States Air Resource Managers, Inc.
SIPs	State Implementation Plans
SMAT-CE	Software for Model Attainment Test - Community Edition
URP	Uniform Rate of Progress
VISTAS	Visibility Improvement – State and Tribal Association of the Southeast

State Abbreviations

AL	Alabama
AR	Arkansas
CO	Colorado
FL	Florida
GA	Georgia
KY	Kentucky
LA	Louisiana
ME	Maine
MI	Michigan
MN	Minnesota
MO	Missouri
MT	Montana
NC	North Carolina
ND	North Dakota
NH	New Hampshire
NJ	New Jersey
NM	New Mexico
OK	Oklahoma
SC	South Carolina
SD	South Dakota
TN	Tennessee
TX	Texas
VA	Virginia
VT	Vermont
WV	West Virginia

1.0 INTRODUCTION

Southeastern States Air Resource Managers, Inc. (SESARM) has been designated by the United States Environmental Protection Agency (EPA) as the entity responsible for coordinating regional haze evaluations for the ten Southeastern states of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia. The Eastern Band of Cherokee Indians and the Knox County, Tennessee local air pollution control agency are also participating agencies. These parties are collaborating through the Regional Planning Organization known as Visibility Improvement - State and Tribal Association of the Southeast (VISTAS) in the technical analyses and planning activities associated with visibility and related regional air quality issues. VISTAS analyses will support the VISTAS states in their responsibility to develop, adopt, and implement their State Implementation Plans (SIPs) for regional haze.

The state and local air pollution control agencies in the Southeast are mandated to protect human health and the environment from the impacts of air pollutants. They are responsible for air quality planning and management efforts including the evaluation, development, adoption, and implementation of strategies controlling and managing all criteria air pollutants including fine particles and ozone as well as regional haze. This project will focus on regional haze and regional haze precursor emissions. Control of regional haze precursor emissions will have the additional benefit of reducing criteria pollutants as well.

The 1999 Regional Haze Rule (RHR) identified 18 Class I Federal areas (national parks greater than 6,000 acres and wilderness areas greater than 5,000 acres) in the VISTAS region. The 1999 RHR required states to define long-term strategies to improve visibility in Federal Class I national parks and wilderness areas. States were required to establish baseline visibility conditions for the period 2000-2004, natural visibility conditions in the absence of anthropogenic influences, and an expected rate of progress to reduce emissions and incrementally improve visibility to natural conditions by 2064. The original RHR required states to improve visibility on the 20% most impaired days and protect visibility on the 20% least impaired days.[1] The RHR

[1] RHR summary data is available at: http://vista.cira.colostate.edu/Improve/rhr-summary-data/

requires states to evaluate progress toward visibility improvement goals every five years and submit revised SIPs every ten years.

This report documents the steps taken by Alpine Geophysics, LLC (Alpine), under subcontract to Eastern Research Group, Inc. (ERG), in preparing the uniform rate of progress (URP) or "glidepath" visibility and light extinction values from the 2028elv5 modeling platform. Alpine prepared these datasets under ERG subcontract 4133.00.001/01.

2.0 RATE OF PROGRESS GOALS AND UNIFORM RATE OF PROGRESS

As required by the Regional Haze Rule (RHR), Reasonable Progress Goals (RPGs) must provide for an improvement in visibility for the 20 percent most anthropogenically impaired days (I20%) relative to baseline visibility conditions and ensure no degradation in visibility for the 20 percent clearest days (B20%) relative to baseline visibility conditions.[2] The baseline for each Class I area is the average visibility (in deciviews, dv) for the years 2000 through 2004. The visibility conditions in these years are the benchmark for the "provide for an improvement" and "no degradation" requirements. In addition, states are required to determine the rate of improvement in visibility needed to reach natural conditions by 2064 for the 20 percent most anthropogenically impaired days.[3]

A line drawn between the end of the 2000-2004 baseline period and 2064 is the uniform rate of progress (URP) or "glidepath" between these two points. The glidepath represents a linear or uniform rate of progress (dv/year)and can be used to determine visibility improvement needed in each implementation period to stay on target to reach natural conditions by 2064. The URP is a framework for consideration but there is no rule requirement to be on or below the glidepath. An example glidepath plot is shown in Figure 2-1.

[2] 40 CFR 51.308(f)(3)(i)-2
[3] 40 CFR 51.308(f)(1)

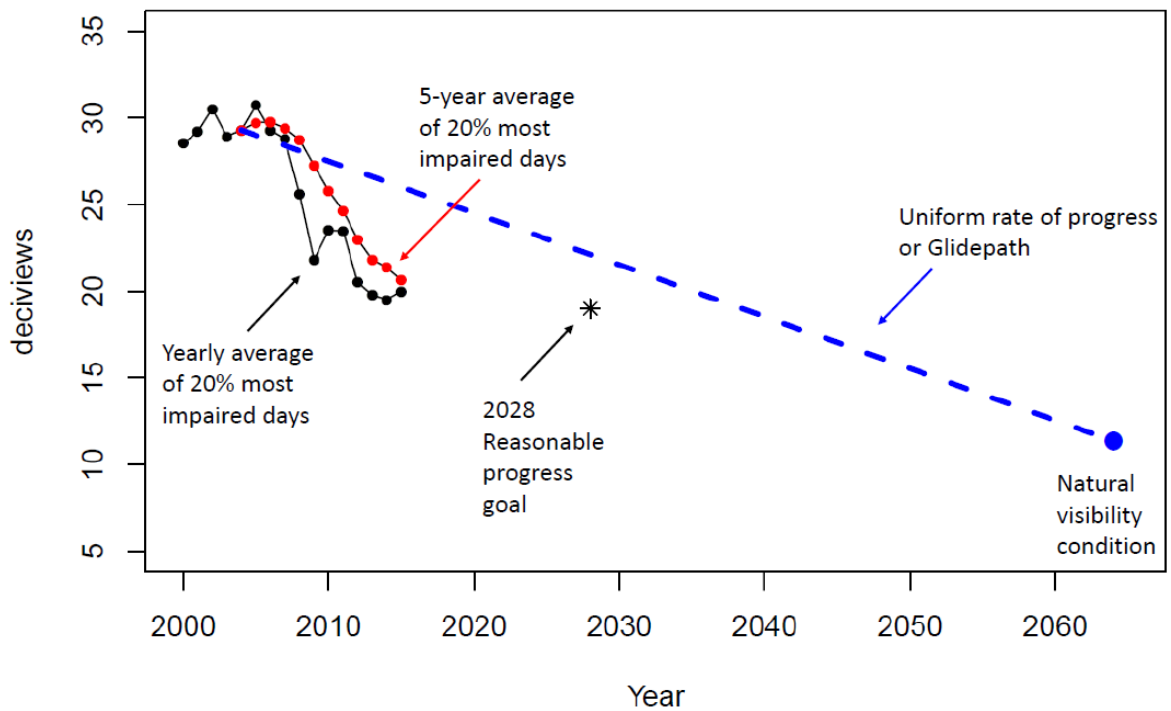

Figure 2-1. Example Glidepath Plot.

The RHR requires states to submit an implementation plan that evaluates and contains measures found necessary to make reasonable progress for implementation periods in approximately ten-year increments. The next regional haze SIP is due in July 2021, for the implementation period which ends in 2028. Therefore, modeling was used to project visibility to 2028 using a 2028 emissions inventory with "on-the-books" controls.[4] The EPA Software for Model Attainment Test - Community Edition (SMAT-CE) tool was used to calculate 2028 deciview values on the 20% most anthropogenically impaired and 20% clearest days at each Class I Area (IMPROVE site).[5] SMAT-CE[6] is an EPA software tool which implements the procedures in the SIP Modeling Guidance to project visibility to a future year.

4 "Regional Haze Modeling for Southeastern VISTAS II Regional Haze Analysis Project Final Modeling Protocol, Update and Addendum to the Approved Modeling Protocol for Task 6.1 (June 2018)." August 31, 2020.

5 The base year (2009-2013) IMPROVE data for the 20% most impaired and 20% clearest days was calculated based on the EPA recommended method described in "Technical Guidance for the Second Implementation Period of the Regional Haze Rule." (December 2018).

6 SMAT-CE is available here: https://www.epa.gov/scram/photochemical-modeling-tools

3.0 CALCULATION OF 2028 VISIBILITY

The visibility projections follow the procedures in section 5 of the SIP Modeling Guidance.[7] Based on the recommendation in the modeling guidance, the observed base period visibility data is linked to the base modeling year. This is the 5-year ambient data base period centered about the base modeling year. In this case, for a base modeling year of 2011, the ambient IMPROVE data should be from the 2009-2013 period.[8]

The visibility calculations use the "revised" IMPROVE equation, which has been used in most regional haze SIPs over the last 10 years. The IMPROVE equation (or algorithm) uses particulate matter (PM) species concentrations and relative humidity data to calculate visibility impairment or beta extinction (bext) in units of inverse megameters (Mm-1) as follows:

bext = 2.2 x f_s(RH) x [Small Sulfate] + 4.8 x f_L(RH) x [Large Sulfate]
+ 2.4 x f_s(RH) x [Small Nitrate] + 5.1 x f_L(RH) x [Large Nitrate]
+ 2.8 x {Small Organic Mass] + 6.1 x [Large Organic Mass]
+ 10 x [Elemental Carbon]
+ 1 x [Fine Soil]
+ 1.7 x f_{ss}(RH) x [Sea Salt]
+ 0.6 x [Coarse Mass]
+ Rayleigh Scattering (site specific)

The total sulfate, nitrate, and organic mass concentrations are each split into two fractions, representing small and large size distributions of those components. Site-specific Rayleigh scattering is calculated based on the elevation and annual average temperature of each IMPROVE monitoring site.

The 2028 future year visibility on the I20% and B20% days at each Class I area is estimated by using the observed IMPROVE data (2009-2013) and the relative percent modeled change in PM species between 2011 and 2028. The process is described in the following six steps (see the SIP Modeling Guidance for a more detailed description and examples).

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7 https://www3.epa.gov/ttn/scram/guidance/guide/O3-PM-RH-Modeling_Guidance-2018.pdf.

8 The baseline period for the regional haze program continues to be 2000-2004, and the uniform rate of progress is calculated using that historical data. However, the modeled visibility projections should use ambient data from a 5-year base period that corresponds to the modeled base year meteorological and emissions data. Also, unlike the ozone and $PM_{2.5}$ attainment tests, the ambient data averaging calculation is a 5-year mean, where each year counts equally (unlike the 5-year weighted average values recommended for the ozone and $PM_{2.5}$ attainment test).

- Step 1 - For each Class I area (i.e., IMPROVE site), estimate anthropogenic impairment (Mm^{-1}) on each day using observed speciated $PM_{2.5}$ data plus PM_{10} data (and other information) for each of the 5 years comprising the base period (2009-2013) and rank the days on this indicator.[9] This ranking will determine the 20 percent most anthropogenically impaired days. For each Class I area, also rank observed visibility (in deciviews) on each day using observed speciated $PM_{2.5}$ data plus PM_{10} data for each of the 5 years comprising the base period. This ranking will determine the 20 percent clearest days.
- Step 2 - For each of the 5 years comprising the base period, calculate the mean deciviews for the I20% and B20% days. For each Class I area, calculate the 5-year mean deciviews for most impaired and clearest days from the 5 year-specific values.
- Step 3 - Use an air quality model to simulate air quality with base period (2011) emissions and future year (2028) emissions. Use the resulting information to develop site-specific relative response factors (RRFs) for each component of PM[10] identified in the "revised" IMPROVE equation. The RRFs are an average percent change in species concentrations based on the measured I20% and B20% days from 2011 (the calendar days from 2011 identified from the IMPROVE data above are matched by day to the modeled days).
- Step 4 - Multiply the species-specific RRFs by the measured daily species concentration data during the 2009-2013 base period (for each day in the measured I20% day set and each day in the B20% day set), for each site. This results in daily future year 2028 PM species concentration data.
- Step 5 - Using the results in Step 4 and the IMPROVE algorithm, calculate the future daily extinction coefficients for the previously identified I20% days and B20% days in each of the five base years.
- Step 6 - Calculate daily deciview values (from total daily extinction) and then compute the future year (2028) average mean deciviews for the I20% days and B20% days for each year. Average the five years together to get the final future mean deciview values for the I20% and B20% days.

The SMAT-CE tool outputs individual year and 5-year average base year and future year deciview values on the I20% and B20% days. Additional SMAT output variables include the results of intermediate calculations such as species-specific extinction values (both base and future year) and species specific RRFs (on the I20% and B20% days). Table 3-1 details the settings used for the SMAT runs to generate the 2028 future year deciview projections.

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9 The EPA recommended methodology for determining the most anthropogenically impaired days (which includes the explanation of how anthropogenic vs. natural daily light extinction was determined) can be found in Technical Guidance on Tracking Visibility Progress for the Second Implementation Period of the Regional Haze Program.

10 Relative response factors (RRFs) are calculated separately for sulfate, nitrate, organic carbon mass, elemental carbon, fine soil mass, and coarse mass. Since observed sea salt is primarily from natural sources which are not expected to be year-sensitive, and the modeled sea salt is uncertain, the sea salt RRF for all sites is assumed to be 1.0.

In cases within VISTAS states where an IMPROVE monitor is not located within a Class I area, surrogate IMPROVE monitors are assigned to establish baseline visibility values for modeling. When this occurs, the 5-year average base year visibility from the surrogate location is used with modeled concentrations from the actual Class I area modeled grid cell to calculate future year RRFs and visibility results. In Class I areas outside of the VISTAS states, surrogate monitor baseline data and RRFs are used to project future year visibility.

Table 3-1. SMAT Settings for 2028 Visibility Calculations.

SMAT Option	Setting or File Used
IMPROVE algorithm	Use new version
Grid cells at monitor or Class I area centroid?	Use grid cells at monitor
IMPROVE data file	ClassIareas_NEWIMPROVEALG_2000to2017_2019_feb 11_IMPAIRMENT.csv[11]
Baseline file	2011el_cb6r4_v6_11g.ag.vistas12.vistas12.PM.mats.tileFULL.csv
Forecast file	2028elv5_cb6r4_v6_11g.ag.vistas12.vistas12.PM.mats.tileFULL.csv
Temporal adjustment at monitor	3 x 3
Start monitor year	2009
End monitor year	2013
Base model year	2011
Minimum years required for a valid monitor	1

Table 3-2 shows the base and future year deciview values on the B20% and I20% days at each Class I area for the base model period (2009-2013) and future year (2028).[12]

[11] The IMPROVE ambient data file has the 20% most impaired days identified as "group 90" days and 20% clearest days identified as "group 10" days. The definition of the most impaired days uses the EPA recommended methodology from Technical Guidance on Tracking Visibility Progress for the Second Implementation Period of the Regional Haze Program. The IMPROVE data file used for this analysis included patched and/or substituted data.

[12] The 2028 results are calculated for Class I areas with the VISTAS_12 modeling domain which are represented by 45 IMPROVE sites. Results are not shown for Class I areas which are outside of this domain and for Class I areas which did not have complete IMPROVE data in 2011.

Table 3-2. Base and Future Year Deciview Values on the 20% Clearest and 20% Most Anthropogenically Impaired Days at Each Class I Area for the Base Model Period (2009-2013) and Future Year (2028) in the VISTAS 12 Modeling Domain

Class I Area Site ID	Class I Area Name	IMPROVE Site ID	Base Year (2009-2013) 20% Clearest Days (dv)	Future Year (2028) 20% Clearest Days (dv)	Base Year (2009-2013) 20% Most Anthropogenically Impaired Days (dv)	Future Year (2028) 20% Most Anthropogenically Impaired Days (dv)
SIPS	Sipsey Wilderness	SIPS1	12.84	11.11	21.67	16.62
CACR	Caney Creek Wilderness	CACR1	9.74	8.79	20.87	18.32
UPBU	Upper Buffalo Wilderness	UPBU1	9.95	8.93	20.52	17.82
GRSA	Great Sand Dunes NM	GRSA1	3.81	3.68	8.78	8.29
MOZI	Mount Zirkel Wilderness	MOZI1	0.44	0.23	6.05	5.49
RAWA	Rawah Wilderness	MOZI1	0.44	0.23	6.05	5.49
ROMO	Rocky Mountain NP	ROMO1	1.60	1.47	9.21	8.39
CHAS	Chassahowitzka	CHAS1	13.76	12.54	19.94	16.79
EVER	Everglades NP	EVER1	11.23	10.64	16.30	15.52
SAMA	St. Marks	SAMA1	13.33	11.59	20.11	16.43
COHU	Cohutta Wilderness	COHU1	10.94	9.15	21.19	14.90
OKEF	Okefenokee	OKEF1	13.34	11.58	20.70	16.90
WOLF	Wolf Island	OKEF1	13.34	11.55	20.70	16.75
MACA	Mammoth Cave NP	MACA1	13.69	11.66	24.04	19.27
BRET2	Breton Wilderness	BRIS1[13]	13.81	12.13	22.49	18.39

[13] The BRIS1 IMPROVE monitor is used for Breton Wilderness as the original monitor (BRET1) was decommissioned in 2005 after Hurricane Katrina.

Table 3-2. Base and Future Year Deciview Values on the 20% Clearest and 20% Most Anthropogenically Impaired Days at Each Class I Area for the Base Model Period (2009-2013) and Future Year (2028) in the VISTAS 12 Modeling Domain

Class I Area Site ID	Class I Area Name	IMPROVE Site ID	Base Year (2009-2013) 20% Clearest Days (dv)	Future Year (2028) 20% Clearest Days (dv)	Base Year (2009-2013) 20% Most Anthropogenically Impaired Days (dv)	Future Year (2028) 20% Most Anthropogenically Impaired Days (dv)
ACAD	Acadia NP	ACAD1	7.02	6.70	16.84	14.67
MOOS	Moosehorn	MOOS1	6.71	6.61	15.80	14.14
ROCA	Roosevelt Campobello International Park	MOOS1	6.71	6.61	15.80	14.14
ISLE	Isle Royale NP	ISLE1	5.40	5.25	17.63	15.12
SENE	Seney	SENE1	5.51	5.34	19.84	16.87
BOWA	Boundary Waters Canoe Area	BOWA1	4.86	4.76	16.43	13.99
HEGL	Hercules-Glades Wilderness	HEGL1	10.96	9.75	21.63	18.80
MING	Mingo	MING1	12.47	11.14	22.70	19.69
MELA	Medicine Lake	MELA1	6.56	6.30	16.59	15.79
ULBE	UL Bend	ULBE1	4.03	3.86	11.90	11.37
LIGO	Linville Gorge Wilderness	LIGO1	9.70	8.21	20.39	14.25
SHRO	Shining Rock	SHRO1[a]	5.36	4.54	19.05	13.31
SWAN	Swanquarter	SWAN1	11.76	10.77	19.76	15.27
THRO	Theodore Roosevelt NP	THRO1	6.38	6.11	15.71	14.67
GRGU	Great Gulf Wilderness	GRGU1	5.87	5.40	15.43	12.30

Table 3-2. Base and Future Year Deciview Values on the 20% Clearest and 20% Most Anthropogenically Impaired Days at Each Class I Area for the Base Model Period (2009-2013) and Future Year (2028) in the VISTAS 12 Modeling Domain

Class I Area Site ID	Class I Area Name	IMPROVE Site ID	Base Year (2009-2013) 20% Clearest Days (dv)	Future Year (2028) 20% Clearest Days (dv)	Base Year (2009-2013) 20% Most Anthropogenically Impaired Days (dv)	Future Year (2028) 20% Most Anthropogenically Impaired Days (dv)
PRRA	Presidential Range-Dry River Wilderness	GRGU1	5.87	5.40	15.43	12.30
BRIG	Brigantine	BRIG1	12.25	11.07	22.26	18.40
BAND	Bandelier NM	BAND1	3.99	3.99	9.17	8.96
BOAP	Bosque del Apache	BOAP1	5.72	5.71	11.19	10.96
PECO	Pecos Wilderness	WHPE1	0.57	0.57	6.96	6.57
SACR	Salt Creek	SACR1	7.37	7.73	15.31	15.00
SAPE	San Pedro Parks Wilderness	SAPE1	1.22	1.16	6.82	6.52
WHIT	White Mountain Wilderness	WHIT1	3.34	3.33	10.58	10.14
WHPE	Wheeler Peak Wilderness	WHPE1	0.57	0.57	6.96	6.57
WIMO	Wichita Mountains	WIMO1	9.22	8.56	20.32	18.10
ROMA	Cape Romain	ROMA1	13.59	12.11	21.48	16.64
BADL	Badlands NP	BADL1	5.78	5.54	14.33	12.95
WICA	Wind Cave NP	WICA1	3.99	3.78	12.31	11.20
GRSM	Great Smoky Mountains NP	GRSM1	10.63	8.96	21.39	15.03

Table 3-2. Base and Future Year Deciview Values on the 20% Clearest and 20% Most Anthropogenically Impaired Days at Each Class I Area for the Base Model Period (2009-2013) and Future Year (2028) in the VISTAS 12 Modeling Domain

Class I Area Site ID	Class I Area Name	IMPROVE Site ID	Base Year (2009-2013) 20% Clearest Days (dv)	Future Year (2028) 20% Clearest Days (dv)	Base Year (2009-2013) 20% Most Anthropogenically Impaired Days (dv)	Future Year (2028) 20% Most Anthropogenically Impaired Days (dv)
JOYC	Joyce-Kilmer-Slickrock Wilderness	GRSM1	10.63	8.97	21.39	14.88
BIBE	Big Bend NP	BIBE1	5.65	5.60	14.37	13.94
CAVE	Carlsbad Caverns NP	GUMO1	5.25	5.03	12.81	12.07
GUMO	Guadalupe Mountains NP	GUMO1	5.25	5.03	12.81	12.07
JARI	James River Face Wilderness	JARI1	11.79	9.80	21.37	15.87
SHEN	Shenandoah NP	SHEN1	8.60	7.27	20.72	14.47
LYBR2	Lye Brook Wilderness	LYEB1	4.89	4.22	18.06	14.14
DOSO	Dolly Sods Wilderness	DOSO1	9.03	7.55	21.59	15.29
OTCR	Otter Creek Wilderness	DOSO1	9.03	7.55	21.59	15.26

[a] The base year model period dv value for the 20% clearest and most impaired days at Shining Rock was calculated using a 3-year average of 2009, 2012, and 2013 (IMPROVE data) for both the 20% clearest and most impaired days. These values from the base year were then applied to the RRF from the LIGO site calculate the adjusted future year dvs.

Figure 3-1 shows the predicted change in deciviews at each Class I area (IMPROVE site) on the I20% days between 2011 and 2028 (2028 deciviews minus 2011 deciviews). The visibility improvement in the east is generally large, in the range of a 2-6 deciview improvement. Most sites in the west show a relatively small deciview improvement of less than 2 deciviews.

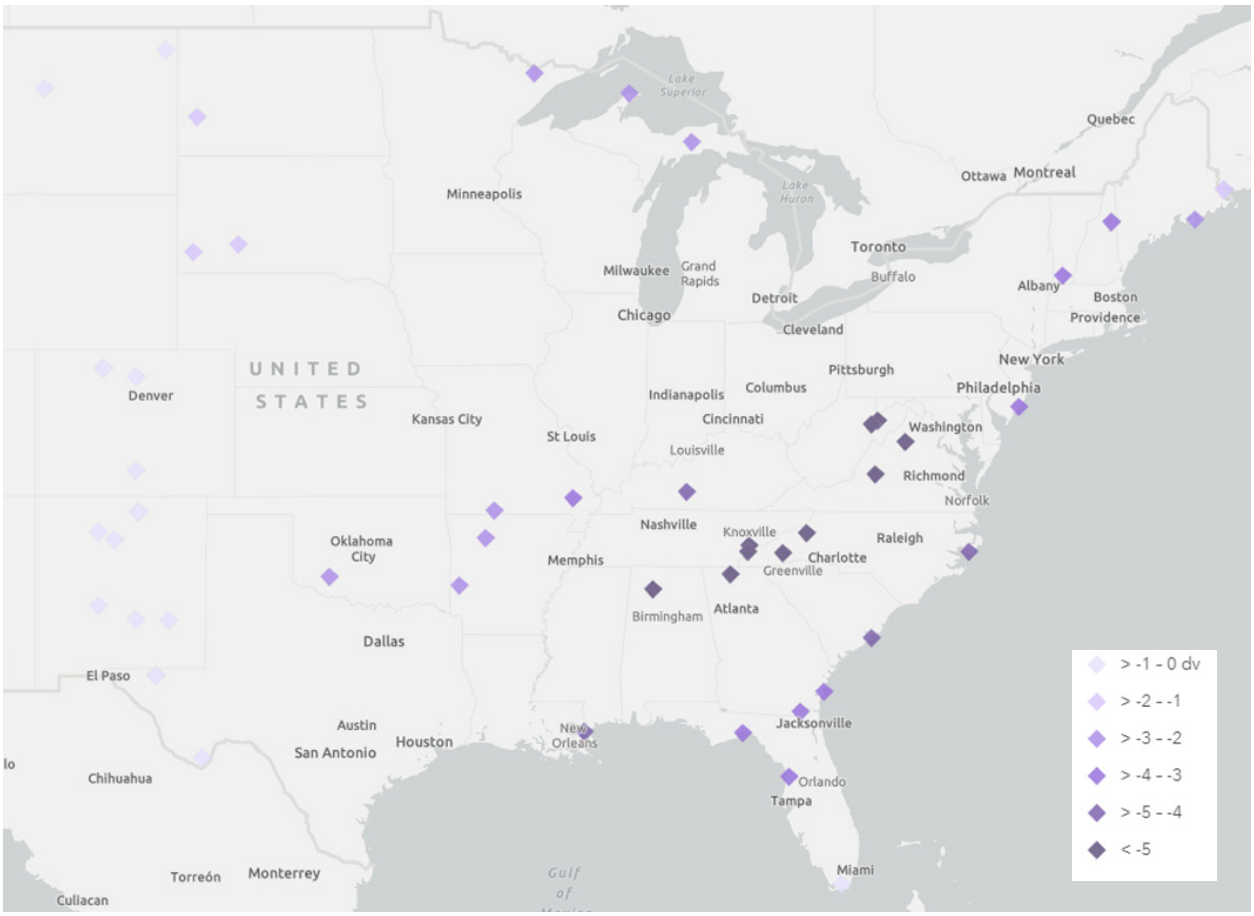


Figure 3-1. Projected Change in Deciviews (dv) at IMPROVE Sites in VISTAS_12 Domain on the 20% Most Impaired Days Between 2011 and 2028 (2028 – 2011).

4.0 COMPARISON TO REGIONAL HAZE "GLIDEPATH"

The future year 2028 deciview projections can be compared to the visibility "glidepaths" at each Class I area. The unadjusted "glidepath" represents the amount of visibility improvement needed in each implementation period, starting from the baseline 2000-2004 period, to stay on a linear path to natural visibility conditions by 2064. The adjusted "glidepath" accounts for international anthropogenic impacts on visibility at each Class I area.

Visibility on the I20% days is compared to the relevant value of the glidepath, in this case for a future year of 2028. Since the glidepath is a linear path between 2004 and 2064, a glidepath value (in deciviews) can be calculated for any future year, using a simple equation. The following formula was used to calculate the 2028 unadjusted glidepath value:

$$Glidepath2028 = Baseline\ Avg\ Deciview - \left(\frac{Baseline\ Avg\ Deciview - Natural\ Conditions}{60}\right) * 24$$

Where:

Baseline avg deciview = average observed deciview value on the I20% days for 2000-2004 (in dv)

Natural conditions = Natural conditions on the I20% days at the Class I area (in dv)

Visibility at Class I areas is impacted not only by natural and anthropogenic emissions from within the U.S., but also by natural and anthropogenic *international* emissions. Due to the fact that international anthropogenic emissions are beyond the control of states preparing regional haze SIPs, the Regional Haze Rule allows states to optionally propose an adjustment of the 2064 URP endpoint to account for international anthropogenic impacts, if the adjustment has been developed using scientifically valid data and methods.[14] The URP can be adjusted by adding an estimate of the visibility impact of international anthropogenic sources to the value of the natural visibility conditions to get an adjusted 2064 endpoint. See the Technical Guidance on Tracking Visibility Progress[15] for more details. This is referred to as the "Default Adjusted" glideslope and natural conditions calculation.

The regional haze rule also allows for an optional adjustment to the URP relating to certain prescribed fires. Specifically, the rule also allows states to optionally propose an adjustment of the 2064 URP endpoint to account for impacts from certain wildland prescribed fires.

[14] See 40 CFR 51.308(f)(1)(vi)
[15] https://www.epa.gov/visibility/technical-guidance-tracking-visibility-progress-second-implementation-period-regional

The EPA modeling calculates estimated Class I area (IMPROVE site) contributions from international anthropogenic and prescribed fire emissions using a combination of hemispheric scale CMAQ zero-out model runs and regional scale CAMx source apportionment modeling.

Table 4-1 shows the 2028 glidepath values (in dv) at each Class I area, including the data needed to calculate the glidepath (natural conditions and the 2000-2004 baseline deciview values).[16] The observed 2009-2013 values and projected 2028 values are also included, which are repeated from Table 3-2.

In cases where an IMPROVE monitor is not located within a Class I area, surrogate IMPROVE monitors are assigned to establish a glidepath.

[16] The values for the 20% most impaired and clearest days and natural conditions are calculated according to the draft recommended method in the draft EPA guidance document "Draft Guidance for the Second Implementation Period of the Regional Haze Rule" posted at https://www.epa.gov/visibility/regional-haze-guidance-technical-support-document-and-data-file.

Table 4-1. Natural and Default-Adjusted Natural Conditions, 2000-2004 Baseline Visibility, Observed 2009-2013 Visibility, 2028 Projected Visibility, 2028 Unadjusted and Default-Adjusted Glidepath Values for the 20% Most Anthropogenically Impaired Days.

Class I Area ID	Class I Area Name	State	IMPROVE Site ID	Natural Conditions 20% Most Impaired Days (dv)	Default Adjusted Natural Conditions 20% Most Impaired Days (dv)	Observed 00-04 Baseline 20% Most Impaired Days (dv)	Observed 09-13 Impairment 20% Most Impaired Days (dv)	Projected 2028 Impairment 20% Most Impaired Days (dv)	2028 Unadjusted Glidepath 20% Most Impaired Days (dv)	2028 Default Adjusted Glidepath 20% Most Impaired Days (dv)
SIPS	Sipsey Wilderness	AL	SIPS1	9.55	11.35	27.71	21.67	16.62	20.45	21.16
CACR	Caney Creek Wilderness	AR	CACR1	9.47	11.21	23.99	20.87	18.32	18.18	18.88
UPBU	Upper Buffalo Wilderness	AR	UPBU1	9.43	11.84	24.25	20.52	17.82	18.32	19.29
GRSA	Great Sand Dunes NM	CO	GRSA1	4.45	6.57	9.66	8.78	8.29	7.58	8.42
MOZI	Mount Zirkel Wilderness	CO	MOZI1	3.16	5.26	7.29	6.05	5.49	5.64	6.48
RAWA	Rawah Wilderness	CO	MOZI1	3.16	5.26	7.29	6.05	5.49	5.64	6.48
ROMO	Rocky Mountain NP	CO	ROMO1	4.93	6.87	11.12	9.21	8.39	8.64	9.42
CHAS	Chassahowitzka	FL	CHAS1	8.97	11.40	24.62	19.96	16.79	18.36	19.27
EVER	Everglades NP	FL	EVER1	8.34	11.25	19.54	16.30	15.52	15.06	16.22
SAMA	St. Marks	FL	SAMA1	9.19	11.49	24.30	20.11	16.43	18.26	19.36
COHU	Cohutta Wilderness	GA	COHU1	9.52	11.55	28.85	21.19	14.90	21.12	22.09
OKEF	Okefenokee	GA	OKEF1	9.47	12.41	25.34	20.70	16.90	18.99	20.17
WOLF	Wolf Island	GA	OKEF1	9.47	12.41	25.34	20.70	16.75	18.99	20.17
MACA	Mammoth Cave NP	KY	MACA1	9.79	12.11	29.83	24.04	19.27	21.81	22.74
BRET2	Breton Wilderness	LA	BRIS1	9.28	12.71			18.39		20.03
ACAD	Acadia NP	ME	ACAD1	10.39	13.10	22.01	16.84	14.67	17.36	18.45
MOOS	Moosehorn	ME	MOOS1	9.97	13.42	20.66	15.80	14.14	16.38	17.76

Table 4-1. Natural and Default-Adjusted Natural Conditions, 2000-2004 Baseline Visibility, Observed 2009-2013 Visibility, 2028 Projected Visibility, 2028 Unadjusted and Default-Adjusted Glidepath Values for the 20% Most Anthropogenically Impaired Days.

Class I Area ID	Class I Area Name	State	IMPROVE Site ID	Natural Conditions 20% Most Impaired Days (dv)	Default Adjusted Natural Conditions 20% Most Impaired Days (dv)	Observed 00-04 Baseline 20% Most Impaired Days (dv)	Observed 09-13 Impairment 20% Most Impaired Days (dv)	Projected 2028 Impairment 20% Most Impaired Days (dv)	2028 Unadjusted Glidepath 20% Most Impaired Days (dv)	2028 Default Adjusted Glidepath 20% Most Impaired Days (dv)
ROCA	Roosevelt Campobello International Park	ME	MOOS1	9.97	13.42	20.66	15.80	14.14	16.38	17.76
ISLE	Isle Royale NP	MI	ISLE1	10.15	12.99	19.53	17.63	15.12	15.78	16.91
SENE	Seney	MI	SENE1	11.11	14.07	23.62	19.84	16.87	18.62	19.80
BOWA	Boundary Waters Canoe Area	MN	BOWA1	9.11	12.12	18.95	16.43	13.99	15.01	15.83
HEGL	Hercules-Glades Wilderness	MO	HEGL1	9.30	11.32	25.17	21.63	18.80	18.82	19.63
MING	Mingo	MO	MING1	9.28	11.09	26.60	22.59	19.69	19.67	20.22
MELA	Medicine Lake	MT	MELA1	5.95	13.21	16.63	16.59	15.79	12.36	15.26
ULBE	UL Bend	MT	ULBE1	5.87	11.79	12.76	11.90	11.37	10.00	12.37
LIGO	Linville Gorge Wilderness	NC	LIGO1	9.70	11.14	28.05	20.39	14.25	20.71	21.29
SHRO	Shining Rock	NC	SHRO1	9.70	11.78	28.05	19.05	13.31	20.71	21.50
SWAN	Swanquarter	NC	SWAN1	9.79	11.44	24.40	19.76	15.27	18.56	18.80
THRO	Theodore Roosevelt NP	ND	THRO1	5.96	10.56	16.35	15.71	14.67	12.19	14.04
GRGU	Great Gulf Wilderness	NH	GRGU1	9.78	12.66	21.93	15.43	12.30	17.07	18.22
PRRA	Presidential Range-Dry River Wilderness	NH	GRGU1	9.78	12.66	21.93	15.43	12.30	17.07	18.22
BRIG	Brigantine	NJ	BRIG1	10.69	12.72	27.43	22.20	18.40	20.73	21.55
BAND	Bandelier NM	NM	BAND1	4.59	6.73	9.70	9.17	8.96	7.66	8.51
BOAP	Bosque del Apache	NM	BOAP1	5.36	7.52	11.61	11.19	10.96	9.11	9.97

Table 4-1. Natural and Default-Adjusted Natural Conditions, 2000-2004 Baseline Visibility, Observed 2009-2013 Visibility, 2028 Projected Visibility, 2028 Unadjusted and Default-Adjusted Glidepath Values for the 20% Most Anthropogenically Impaired Days.

Class I Area ID	Class I Area Name	State	IMPROVE Site ID	Natural Conditions 20% Most Impaired Days (dv)	Default Adjusted Natural Conditions 20% Most Impaired Days (dv)	Observed 00-04 Baseline 20% Most Impaired Days (dv)	Observed 09-13 Impairment 20% Most Impaired Days (dv)	Projected 2028 Impairment 20% Most Impaired Days (dv)	2028 Unadjusted Glidepath 20% Most Impaired Days (dv)	2028 Default Adjusted Glidepath 20% Most Impaired Days (dv)
PECO	Pecos Wilderness	NM	WHPE1	3.53		7.35	6.96	6.57	5.82	
SACR	Salt Creek	NM	SACR1	5.50	9.69	16.54	15.26	15.00	12.12	13.80
SAPE	San Pedro Parks Wilderness	NM	SAPE1	3.36	5.61	7.66	6.81	6.52	5.94	6.84
WHIT	White Mountain Wilderness	NM	WHIT1	4.89	8.53	11.31	10.58	10.14	8.74	10.20
WHPE	Wheeler Peak Wilderness	NM	WHPE1	3.53		7.35	6.96	6.57	5.82	
WIMO	Wichita Mountains	OK	WIMO1	6.92	10.19	22.15	20.32	18.10	16.06	17.36
ROMA	Cape Romain	SC	ROMA1	9.79	11.89	25.25	21.48	16.64	19.07	19.91
BADL	Badlands NP	SD	BADL1	6.09	9.67	14.98	14.33	12.95	11.42	12.86
WICA	Wind Cave NP	SD	WICA1	5.64	8.38	13.09	12.31	11.20	10.11	11.21
GRSM	Great Smoky Mountains NP	TN	GRSM1	10.05	11.68	29.16	21.39	15.03	21.52	22.17
JOYC	Joyce-Kilmer-Slickrock Wilderness	TN	GRSM1	10.05	11.68	29.16	21.39	14.88	21.52	22.17
BIBE	Big Bend NP	TX	BIBE1	5.33	12.34	15.57	14.37	13.94	11.47	14.28
CAVE	Carlsbad Caverns NP	TX	GUMO1	4.83	10.57	14.60	12.81	12.07	10.69	12.99
GUMO	Guadalupe Mountains NP	TX	GUMO1	4.83	10.57	14.60	12.81	12.07	10.69	12.99
JARI	James River Face Wilderness	VA	JARI1	9.48	11.25	28.08	21.37	15.87	20.64	21.35
SHEN	Shenandoah NP	VA	SHEN1	9.52	11.19	28.32	20.72	14.47	20.80	21.47

Table 4-1. Natural and Default-Adjusted Natural Conditions, 2000-2004 Baseline Visibility, Observed 2009-2013 Visibility, 2028 Projected Visibility, 2028 Unadjusted and Default-Adjusted Glidepath Values for the 20% Most Anthropogenically Impaired Days.

Class I Area ID	Class I Area Name	State	IMPROVE Site ID	Natural Conditions 20% Most Impaired Days (dv)	Default Adjusted Natural Conditions 20% Most Impaired Days (dv)	Observed 00-04 Baseline 20% Most Impaired Days (dv)	Observed 09-13 Impairment 20% Most Impaired Days (dv)	Projected 2028 Impairment 20% Most Impaired Days (dv)	2028 Unadjusted Glidepath 20% Most Impaired Days (dv)	2028 Default Adjusted Glidepath 20% Most Impaired Days (dv)
LYBR2	Lye Brook Wilderness	VT	LYEB1		12.78			14.14		19.25
DOSO	Dolly Sods Wilderness	WV	DOSO1	8.92	10.78	28.29	21.59	15.29	20.54	21.29
OTCR	Otter Creek Wilderness	WV	DOSO1	8.92	10.78	28.29	21.59	15.26	20.54	21.29

The 2028 future year projected deciview values can be compared to the unadjusted glidepath for 2028. While the RHR requires future year projected visibility impairment be compared to the glidepath, it does not require the RPGs be on or below the glidepath. However, the rule has different requirements depending on whether the projected value (RPG) is above or below the glidepath.[17]

Figure 4-1 shows the difference between the 2028 projected visibility impairment (in deciviews at each IMPROVE site on the I20% days) and the 2028 unadjusted glidepath (2028 projected minus 2028 unadjusted glidepath). Negative values are below the unadjusted glidepath and positive values are above the unadjusted glidepath.

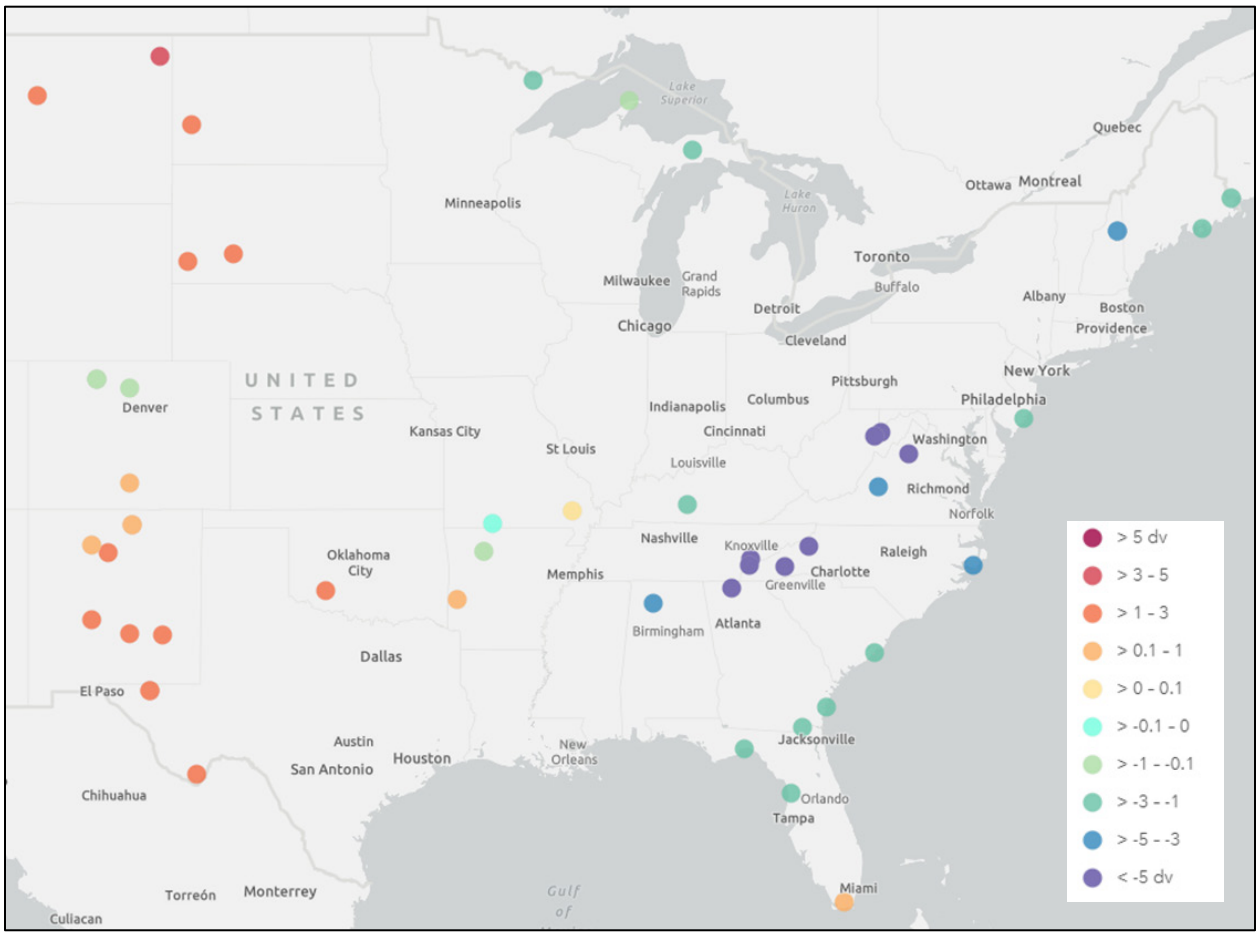


Figure 4-1. Map of Deviations from the 2028 Unadjusted Glidepath at IMPROVE Sites in the VISTAS 12 Domain.

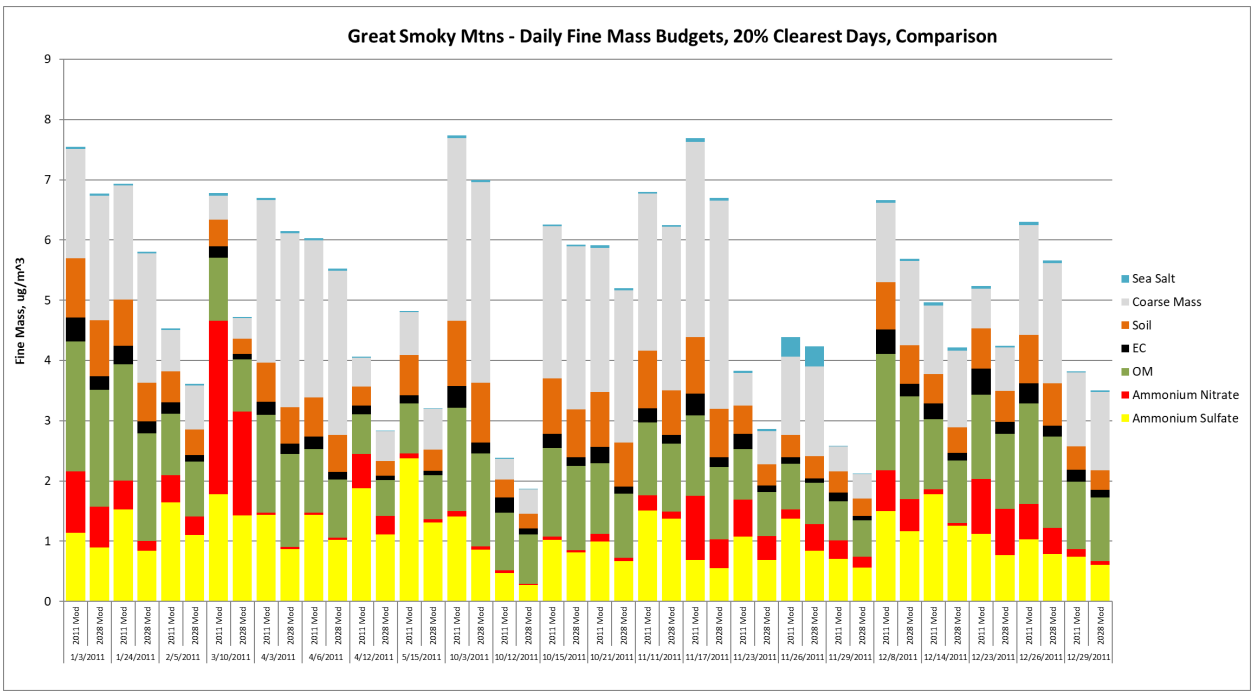
[17] See 40 CFR 51.308(f)(3)(ii) and (iii)

There are two major features that can be seen in Figure 4-1. First, all Class I areas in the VISTAS states, except for Everglades, are significantly below the unadjusted glidepath. Second, the majority of Class I areas west of the Mississippi River are above the unadjusted glidepath.

5.0 $PM_{2.5}$ COMPOSITION AND CONTRIBUTIONS TO LIGHT EXTINCTION

Day-by-day stacked bar charts detailing the composition of $PM_{2.5}$ on each of the 20% clearest and 20% most impaired days for both 2011 and 2028 modeled concentration ($\mu g/m^3$) and light extinction (Mm^{-1}) were developed for each IMPROVE monitoring site in the VISTAS_12 modeling domain. These plots display the amount of total particle mass using concentrations of coarse mass, crustal (soil), ammonium nitrate, ammonium sulfate, elemental carbon (EC), organic mass carbon (OM), and sea salt. Charts for each of the VISTAS_12 modeling domain's Class I areas can be generated using the provided Excel file titled "APP_A_ag_v6_40.2028elv5.vistas_12_SESARM (4 Sept 2020).xlsx" in Appendix A.

Figure 5-1 below presents the daily mass budgets for each of the 20% clearest (top) and 20% most anthropogenically impaired (bottom) days at the Great Smoky Mountains National Park. Values identified as "2011 Mod" represent the 2011 modeled concentrations and values identified as "2028 Mod" represent the 2028 modeled concentrations. The amount of light extinction due to each species is displayed in Figure 5-2 below. Rayleigh scattering in the extinction plots is site specific Rayleigh scattering for that site, which does not vary by day (not modeled or observed).



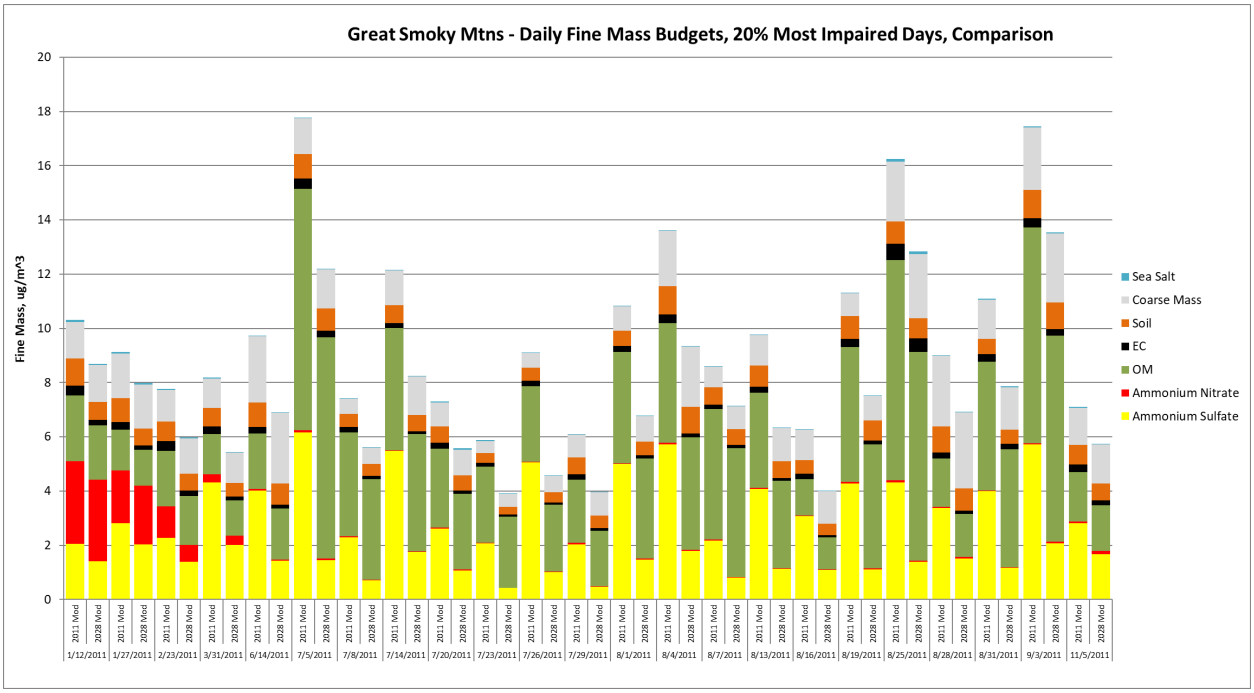
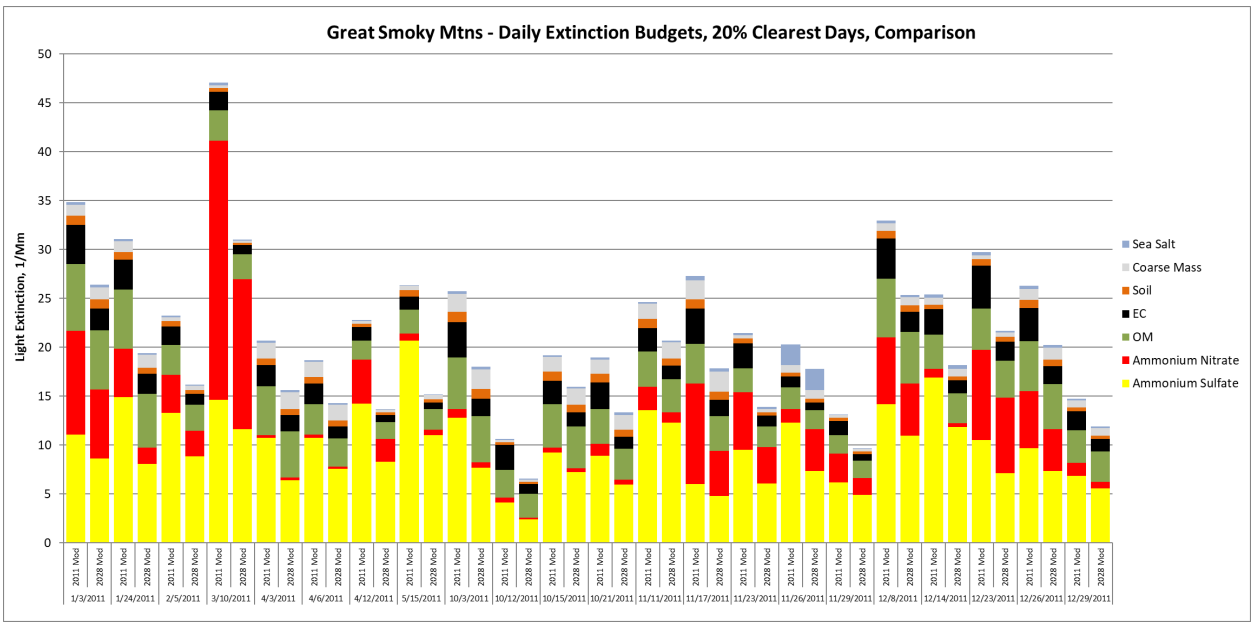


Figure 5-1. Predicted (CAMx) Concentrations (µg/m^3) Great Smoky Mountains National Park on the Modeled 20% Clearest (Top) and 20% Most Anthropogenically Impaired (Bottom) Days.



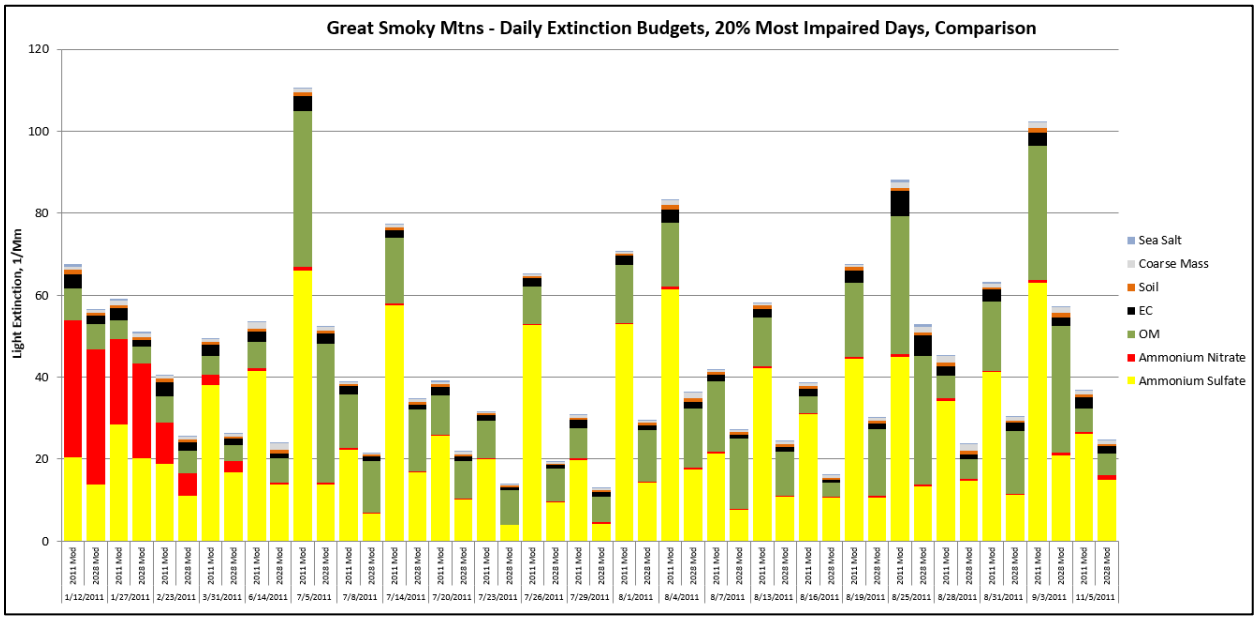


Figure 5-2. Predicted (CAMx) Light Extinctions (Mm^{-1}) Great Smoky Mountains National Park on the Modeled 20% Clearest (Top) and 20% Most Anthropogenically Impaired (Bottom) Days.

Average stacked bar charts detailing the composition of $PM_{2.5}$ on each of the 20% clearest and 20% most impaired days for both 2011 and 2028 SMAT concentration ($\mu g/m^3$) and light extinction (Mm^{-1}) were developed for each IMPROVE monitoring site in the VISTAS_12 modeling domain. These plots display the amount of total particle mass using concentrations of

coarse mass, crustal (soil), ammonium nitrate, ammonium sulfate, elemental carbon (EC), organic mass carbon (OM), and sea salt. Charts for each of the VISTAS_12 modeling domain's Class I areas can be generated using the provided Excel file titled "StackedBarCharts.xlsx" in Appendix B.

Figure 5-3 below presents the average mass budgets for the 20% clearest (right) and 20% most anthropogenically impaired (left) days at the Great Smoky Mountains National Park. Values identified as "2011 SMAT" represent the 2009-2013 average observed concentrations and values identified as "2028 SMAT" represent the 2028 SMAT output concentrations. The amount of light extinction due to each species is displayed in Figure 5-4 below. Rayleigh scattering in the extinction plots is site specific Rayleigh scattering for that site, which does not vary by day (not modeled or observed).

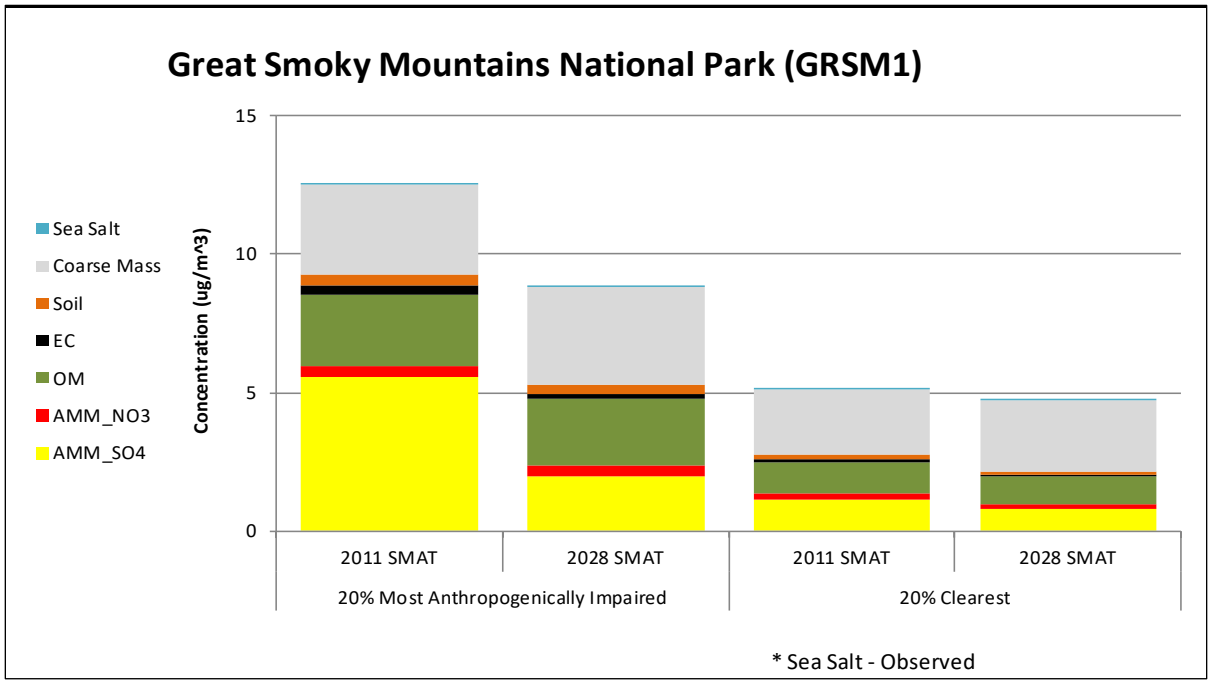


Figure 5-3. SMAT Concentrations (µg/m^3) Great Smoky Mountains National Park on the Modeled 20% Clearest (Right) and 20% Most Anthropogenically Impaired (Left) Days.

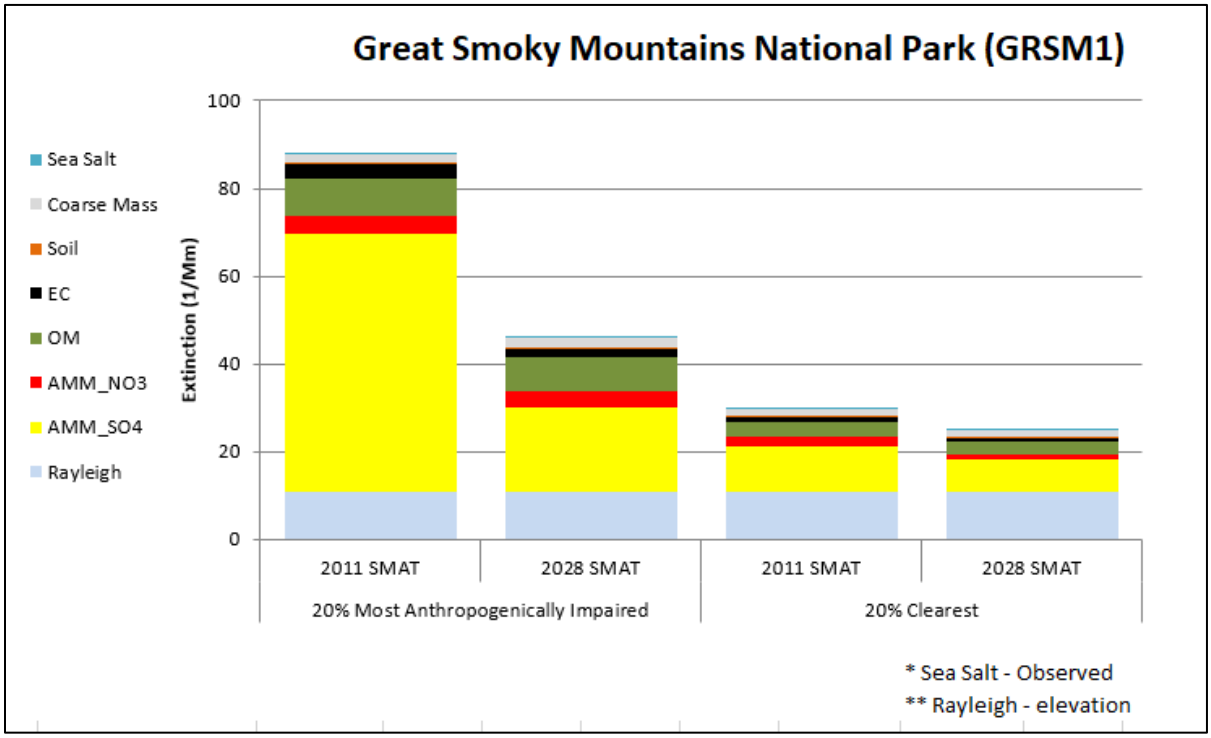


Figure 5-4. SMAT Light Extinctions (Mm-1) Great Smoky Mountains National Park on the Modeled 20% Clearest (Right) and 20% Most Anthropogenically Impaired (Left) Days.

6.0 REGIONAL HAZE SITE SUMMARIES

Figure 6-1 provides an example of relevant observational and modeling data available at each IMPROVE station in the VISTAS_12 modeling domain. Charts for each of the VISTAS_12 modeling domain's Class I areas can be generated by the provided Excel file titled "APP_C_SESARM_2028elv5_URP_20200903.xlsx" in Appendix C.

- The 2009-2013 observed annual average visibility (deciviews) and light extinction values (Mm^{-1}) on the 20% most impaired days are shown as (up to 5) black dots and (for comparison) additional recent observations for 2014-2017 are shown as green dots.
- The red diamonds represent the modeled 2011 (left) and 2028 (right) visibility or light extinction values on the 20% most anthropogenically impaired days.
- The dashed blue line and the dashed orange line represent different versions of the URP glidepath.
- The dashed blue line (Glidepath) is the unadjusted glidepath that runs from the 2000-2004 baseline value to natural conditions in 2064.
- The dashed orange line (Adj Glidepath) is the default adjusted glidepath that runs from the 2000-2004 baseline value to the default adjusted 2064 endpoint.
- The short solid blue line on the right side of the plot represents the unadjusted 2064 endpoint (ambient natural conditions).

- The short solid orange line on the right side of the plot represents the default adjusted 2064 endpoint.

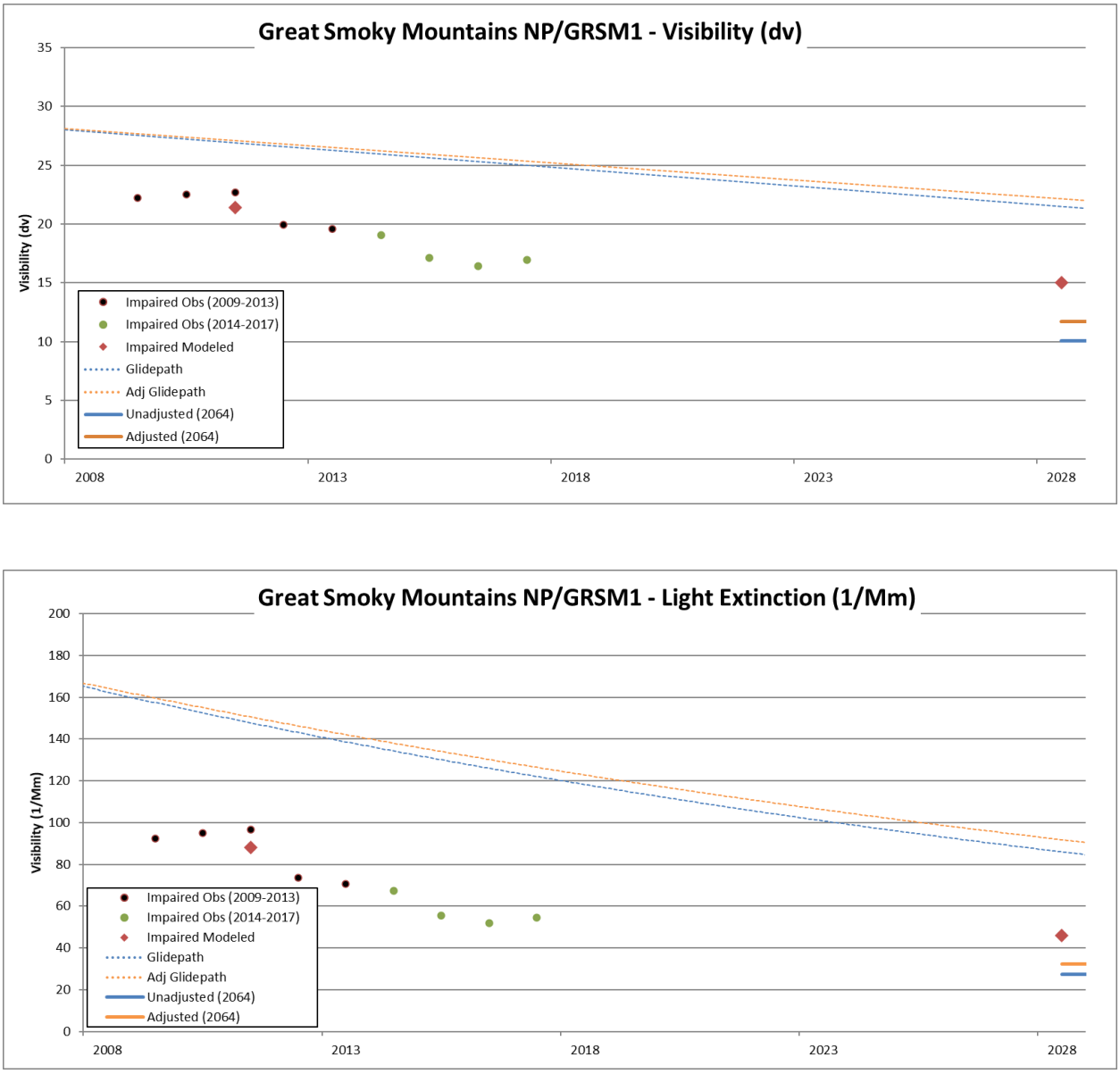


Figure 6-1. 2009-2017 IMPROVE Observations, 2011 and 2028 CAMx Model Predictions, and Unadjusted and Default-Adjusted Glidepaths for Visibility (Top) and Light Extinction (Bottom) at GRSM1.

Appendix A.

Daily Mass Concentration and Light Extinction Stacked Bar Charts for Each Class I Area

(see "APP_A_ag_v6_40.2028elv5.vistas_12_SESARM (4 Sept 2020).xlsx")

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Appendix B.

Uniform Rate of Progress Graphs for Each Class I Area

(see "APP_B_StackedBarCharts.xlsx")

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Appendix C.

Uniform Rate of Progress Graphs for Each Class I Area

(see "APP_C_SESARM_2028elv5_URP_20200903.xlsx")

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