# Technical Support Document for the Texas Regional Haze Second Planning Period State Implementation Plan Proposed Action

Regulations.gov Docket ID: EPA-R06-OAR-2021-0539

September 2024

EPA Region 6

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## 1. Introduction

This Technical Support Document (TSD) provides additional discussion and analysis of certain aspects of EPA's evaluation of Texas's second planning period Regional Haze plan (referred to in the preamble as "2021 Texas Regional Haze Plan"). Namely, this TSD provides additional information to support EPA's disapproval of Texas's source selection, identification of potential controls for petroleum coke calcining and carbon black plants, and an analysis of Texas's CAMx modeling and visibility metrics.

## 2. Source Selection

In order to select sources for evaluation using the four statutory factors, TCEQ defined geographic areas, or Areas of Influence (AOI), from which it then selected sources. Section IV.E.1.i. of our proposed rulemaking details the EPA's analysis of TCEQ's development of the AOIs for each impacted Class I area. The first step in conducting this analysis is to conduct a 72-hour back trajectory analysis. To do this, the TCEQ utilized the HYSPLIT model. From the NOAA web site:[1]

> *"HYSPLIT is a complete system for computing simple air parcel trajectories, as well as complex transport, dispersion, chemical transformation, and deposition simulations. HYSPLIT continues to be one of the most extensively used atmospheric transport and dispersion models in the atmospheric sciences community. A common application is a back trajectory analysis to determine the origin of air masses and establish source-receptor relationships. HYSPLIT has also been used in a variety of simulations describing the atmospheric transport, dispersion, and deposition of pollutants and hazardous materials. Some examples of the applications include tracking and forecasting the release of radioactive material, wildfire smoke, windblown dust, pollutants from various stationary and mobile emission sources, allergens and volcanic ash.*
>
> *The model calculation method is a hybrid between the Lagrangian approach, using a moving frame of reference for the advection and diffusion calculations as the trajectories or air parcels move from their initial location, and the Eulerian methodology, which uses a fixed three-dimensional grid as a frame of reference to compute pollutant air concentrations (The model name, no longer meant as an acronym, originally reflected this hybrid computational approach). HYSPLIT has evolved over more than 30 years, from estimating simplified single trajectories based on radiosonde observations to a system accounting for multiple interacting pollutants transported, dispersed, and deposited over local to global scales."*

It is important to understand what HYSPLIT back trajectories represent and their limitations. HYSPLIT back trajectory analyses use archived meteorological modeling that includes actual observed data (surface, upper air, airplane data, etc.) and modeled meteorological fields to estimate the most likely route of an air parcel transported from a particular location at a specified time. The method essentially follows a parcel of air backward in hourly steps for a specified length of time. HYSPLIT estimates the central path in both the vertical and horizontal planes. The HYSPLIT central path represents the centerline with the understanding that there are areas on each side horizontally and vertically that also contribute to the end point at the monitor. The horizontal and vertical areas from the centerline grow wider the further back in time the trajectory goes. Therefore, a HYSPLIT centerline does not have to pass directly over emissions sources or emission source areas, but merely relatively near emission source areas.

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[1] https://www.arl.noaa.gov/hysplit/.

While HYSPLIT modeling does have limitations, it can be useful in assessing data over a number of years and can be informative in an AOI analysis in identifying directionality of potential upwind sources. TCEQ conducted HYSPLIT modeling using the 20% most impaired days during 2012 to 2016 for each Class I area to determine the "frequency" of air parcels, plotted on a 32 x 32-degree hexagonal grid demarcated by geographic coordinates.[2] According to both the 2021 Texas Regional Haze Plan and a document provided to EPA during early engagement,[3] TCEQ conducted HYSPLIT model runs for the most impaired days with four start times per day (0600, 1200, 1800, and 2400) and three starting heights (100m, 500m, and 1000m).[4] TCEQ calculated the sum of the frequencies at each cell at all heights, and then the total frequencies across the entire 32x32 degree grid are calculated for each day. The daily probabilities at each cell were then calculated by dividing a given cell's frequency by the total frequency across the domain on a given day. These cell-specific and day-specific probabilities were then merged with the day-specific extinction values ($B_{ext}$) for ammonium nitrate and ammonium sulfate. The day-specific probabilities were multiplied by the day-specific light extinction. The product was summed across all days at each cell to give the extinction weighted probability at each cell in the domain. This is mathematically represented by the following formula:

$$EWRT_{ij} = \sum_{k=1}^{N} B_{ext_k} \tau_{ijk}$$

where $B_{ext_k}$ is the extinction coefficient attributed to the pollutant ($SO_4$ or $NO_3$) measured upon arrival of the $k^{th}$ trajectory at the IMPROVE site.

TCEQ stated, "the product of the frequency and the $B_{ext}$ at each cell was divided by the product of the frequency and the $B_{ext}$ across the entire domain for all the days and all the heights," meaning that TCEQ scaled the EWRTs to the total of the domain.[5] However, the description in the early engagement document included the following text: "Prior to plotting the AOIs, the weighted probabilities were scaled to 1 by dividing the weighted probabilities in each cell by the maximum value in a cell in the domain." As an initial matter, and as noted in our proposed rulemaking, these two methodologies are inconsistent. TCEQ scaled to the maximum based on a review of the data analyses provided in early engagement. Furthermore, the AOIs included in the 2021 Texas Regional Haze Plan are identical to the AOIs contained in the early engagement document, confirming Texas did not change its analyses between early engagement and its submitted Plan.

To assess the methodology used by Texas, EPA reviewed similar analyses performed by the Regional Planning Organizations (RPOs), CenSARA and WRAP,[6] in support of their member states' regional haze SIPs. CenSARA used IMPROVE data from 2012-2016 and WRAP used IMPROVE data from 2014-2018. We note that the WRAP EWRT maps are not entirely equivalent given the different baseline period evaluated, however, we provide them here as additional information. According to the report prepared

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[2] *See* 2021 Texas Regional Haze Plan, p. 7-6 through 7-8.

[3] *See* README.AOIdevelopmentFor2021RHSIP_Response_to_EPArequest.20Nov2020update.pdf included in the docket for this action.

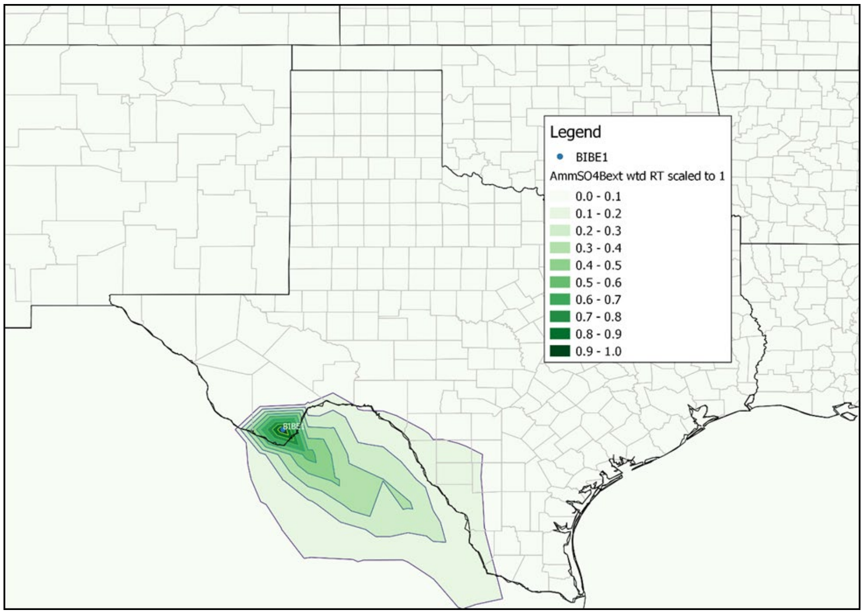
[4] *See* 2021 Texas Regional Haze Plan, p. 7-6.

[5] See 2021 Texas Regional Haze Plan, p. 7-7.

[6] CenSARA is the Central States Air Resource Agencies, and WRAP is the Western Regional Air Partnership.

by Ramboll on behalf of CenSARA[7] and the WRAP Technical Support System web site,[8] the gridded EWRT values are normalized to display the percentage of the domain total EWRT. By way of example, below are AOIs for the 20% most impaired days weighed by ammonium sulfate generated by Texas, CenSARA, and WRAP for Salt Creek Wilderness Area and Big Bend National Park. We have included additional comparisons of AOIs generated for Class I areas impacted by Texas emissions in the docket for this action.

**Figure 2.1. Texas AOI for BIBE: Normalized Residence Times in 20% Most Impaired Days Weighed by Ammonium Sulfate During 2012 through 2016.**



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[7] See "Determining Areas of Influence – CenSARA Round Two Regional Haze, Final Report." Prepared by Ramboll, November 2018 included in the docket for this action.

[8] www.views.cira.colostate.edu/tssv2/WEP-AOI/.

**Figure 2.2. Texas AOI for SACR: Normalized Residence Times in 20% Most Impaired Days Weighed by Ammonium Sulfate During 2012 through 2016 for Big Bend.**[9]

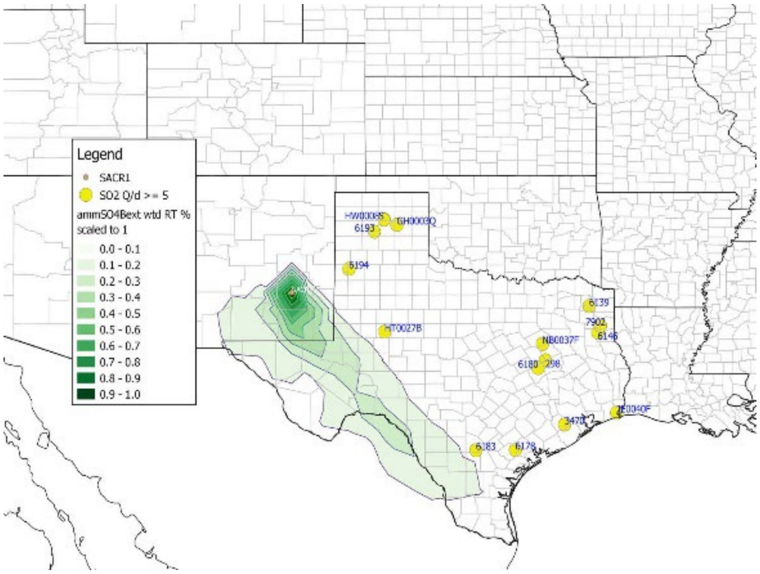
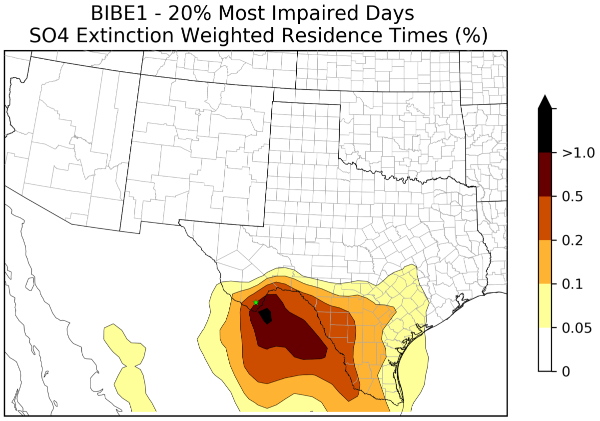


**Figure 2.3. Big Bend 20% Most Impaired Days Sulfate Extinction Weighted Residence Times (%) During 2012 through 2016 (CenSARA).**


BIBE1 - 20% Most Impaired Days
SO4 Extinction Weighted Residence Times (%)

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[9] 2021 Texas Regional Haze Plan, Appendix G, p. G-9, Figure 1-7.

**Figure 2.4. Salt Creek 20% Most Impaired Days Sulfate Extinction Weighted Residence Times (%) During 2012 through 2016 (CenSARA).**

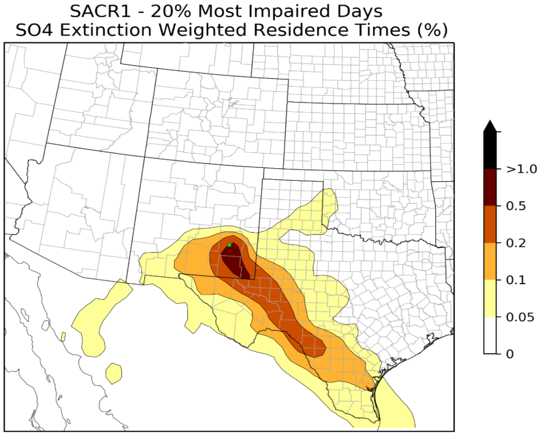


**Figure 2.5. Big Bend 20% Most Impaired Days Sulfate Extinction Weighted Residence Times (%) During 2014 through 2018 (WRAP).**

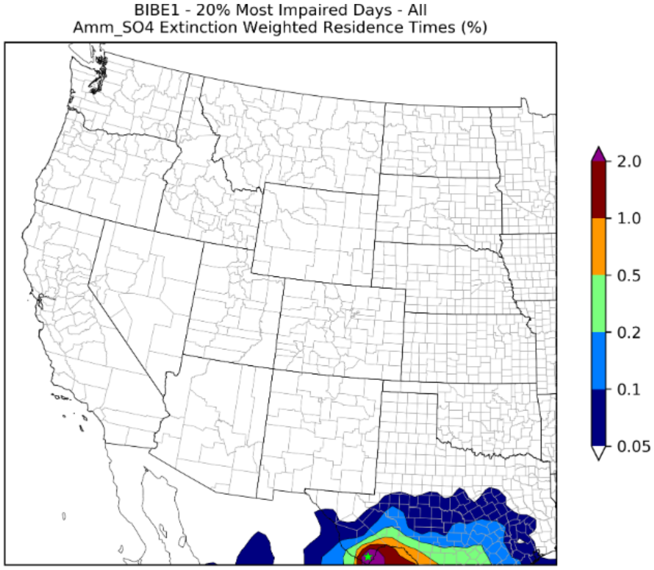
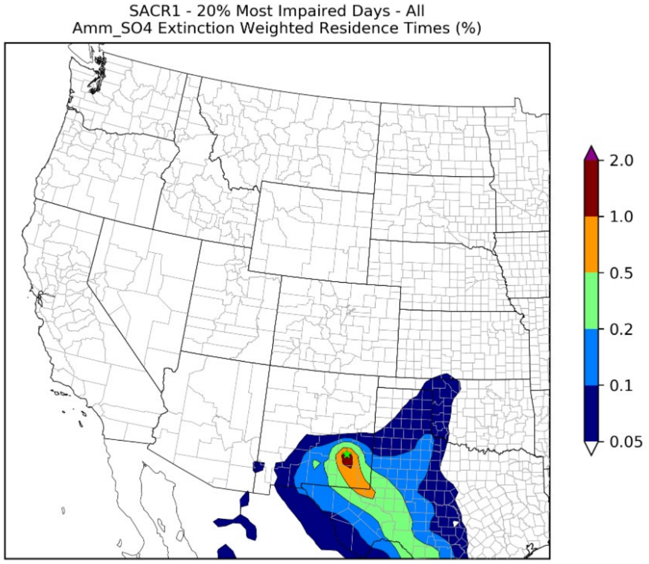


**Figure 2.6. Salt Creek 20% Most Impaired Days Sulfate Extinction Weighted Residence Times (%) During 2014 through 2018 (WRAP).**



The EPA calculated its own AOIs using the methodology TCEQ described in its SIP, scaling to the domain total. We used EWRT data provided by TCEQ during early engagement, consistent with the final conclusions Texas stated in its 2021 Texas Regional Haze Plan,[10] and plotted the EWRTs falling within the range of 0.01 to greater than 1, capturing the whole range of calculated values. As demonstrated below with the examples provided, the AOIs generated by the EPA encompass a significantly larger geographic area than those provided by TCEQ in its SIP. This difference confirms first that Texas did not follow the methodology described in its SIP.

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[10] The EPA notes that TCEQ did not provide the information shared with the EPA to the public during TCEQ's public comment period.

**Figure 2.7. Big Bend: Sulfate Extinction Weighted Residence Times in 20% Most Impaired Days During 2012 through 2016 (%, Normalized to Domain Total).**

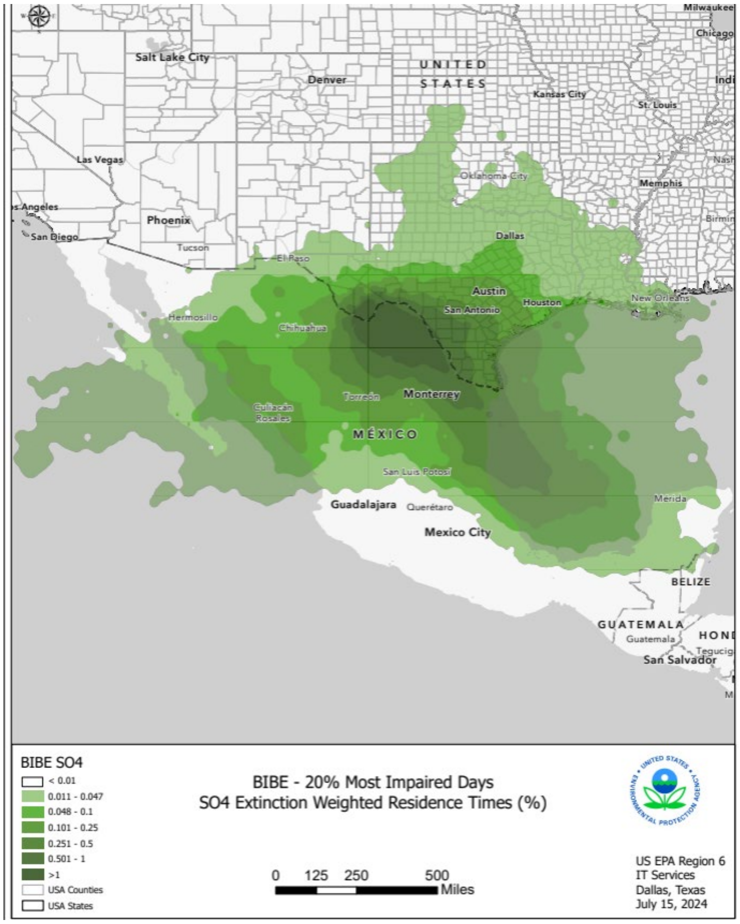
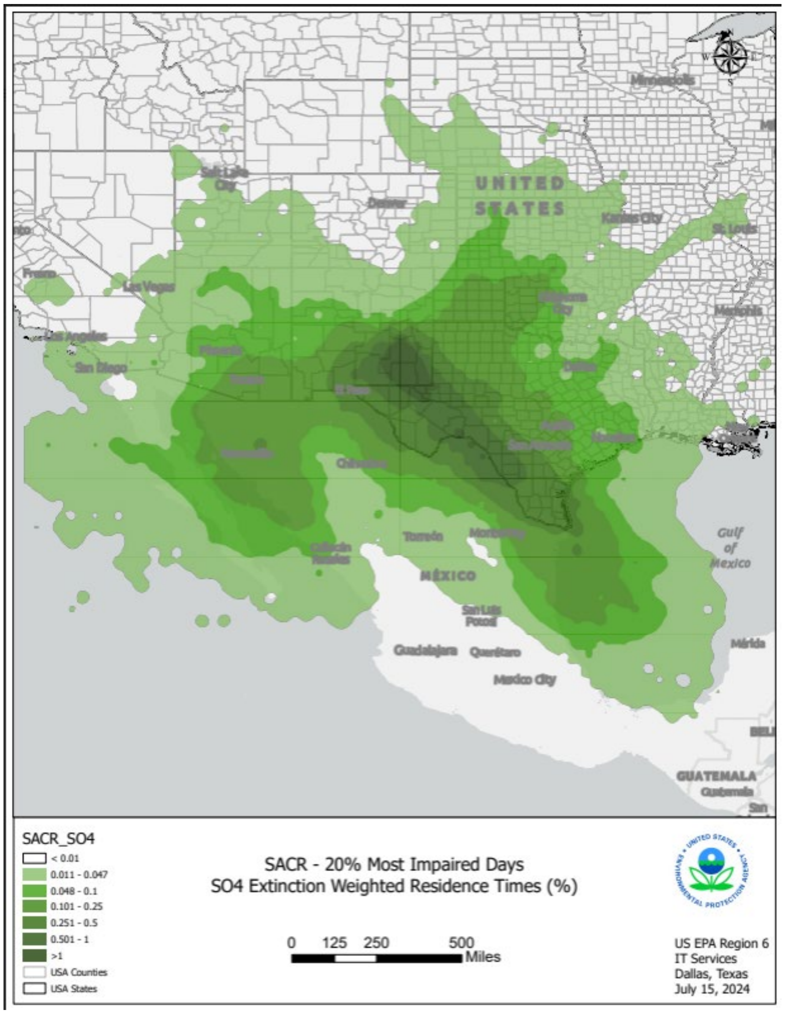


**Figure 2.8. Salt Creek: Sulfate Extinction Weighted Residence Times in 20% Most Impaired Days During 2012 through 2016 (%, Normalized to Domain Total).**



As discussed in our proposed rulemaking, TCEQ applied a threshold of 0.1 or 10% of the maximum EWRT value to define the boundary of the AOI for the first step in their source selection.[11] The effect of choosing a threshold that is dependent on the maximum value is that the threshold can limit the extent of the AOI simply because a large number of back trajectories travel through one particular area near the Class I area, even if those trajectories come from a wide range or areas. For example, if there is Class I area that has a high maximum, 10 percent of that number would be a large number. The AOI would be cutoff below this large number or, in other words, any value below the large number would not be plotted. In this example, by not plotting the values below the cutoff (larger number), the boundary of the AOI will be narrowed and may not capture areas that have meaningful contribution to visibility impairment at the Class I area. Thus, the AOI will not be representative of all sources that meaningfully impact visibility at that Class I area and can result in sources with Q/ds greater than or equal to 5 falling outside of an AOI. Texas did not justify their choice of threshold or evaluate whether the selected threshold provided for AOIs that included a sufficiently large area to capture the sources of influence. By using a threshold dependent on the maximum value, the percentage of the contributing areas captured

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[11] The second step being application of Q/d > 5 for sources that fell within the boundary.

by the AOI varied from Class I area to Class I area. In contrast, the CenSARA analysis that was developed to support the source selection efforts in the member states, created AOI maps utilizing EWRT scaled to the total value. This created AOI maps whose values represented the percentage contribution to the total EWRT value across the area, and thresholds then represented a minimal value of contribution from that area to the total. CenSARA plotted these AOIs for the Class I areas with isopleths of 0.05% and 0.1% to illustrate the potential AOIs for the Class I areas. By using a threshold that is a percentage of the total, the threshold selected represents a contribution to the total. In this way, for example, a threshold of 0.1% ensures that areas with contributions greater than 0.1% of the overall total EWRT value is included in the AOI. When we compare the AOIs and the source selection to those developed by CenSARA we observe large differences in the extent of the AOIs and the sources selected for further analysis.

After determining the AOIs for each Class I area for each pollutant, Texas then applied the Q/d threshold of greater than or equal to five within the boundaries of the AOIs to identify sources for further evaluation using the four factors. For existing EGUs, TCEQ used data from ERTAC to estimate EGU projections for 2028 for $NO_X$ and $SO_2$. For non-EGUs, Texas estimated 2028 future year emissions from 2016 reported emissions from the State of Texas Air Reporting System (STARS) coupled with growth factors developed by the consulting firm, Eastern Research Group, Inc. (ERG). These projected emissions were used as the “Q” in the Q/d analysis. While Texas’s SIP was not clear on how the State determined the distance (d) from sources to respective Class I areas, Texas included distance values in a spreadsheet that was made available during its public comment period.

Because the Q/d was only considered after and independently of the AOIs, several sources with large Q/d values were not considered for further analysis. Meaning, Texas did not consider a source, regardless of the size of its emissions, if it was not first within the geographic area defined by the AOIs. The EWRT is essentially a depiction of air flow patterns irrespective of emissions concentrations. However, emissions from large sources with elevated stacks can travel large distances that may not be represented by predominant wind flow patterns. Therefore, their visibility impairing potential will not necessarily be represented by Texas’s AOI.

By way of example, W A Parish was just outside the 10% threshold of the maximum EWRT value for the Caney Creek and Wichita Mountains ammonium sulfate AOI that Texas used. Tolk Generating Station was also outside the 10% threshold of the maximum EWRT value for Salt Creek. These sources had Q/d values well above Texas’s threshold of 5. W A Parish, for example, had a Q/d of 32.2 for Caney Creek and 28.2 for Wichita Mountains and 25.1 for Big Bend.[12] Tolk Generating Station had a Q/d value over 84 for Salt Creek.[13] Given the large emissions, it is very likely that these sources are contributing to visibility impairment even if they happen to fall just outside of the Texas AOIs. Had Texas selected these sources for further evaluation under the four-factors, Texas may have found cost-effective controls available based on its analysis of other coal-fired EGUs with no controls or underperforming controls.

In comparison, CenSARA also created maps using a combined EWRT x Q/d to better identify sources that are contributing to visibility impairment on the 20% most impaired days.[14] As shown in the figures

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[12] *See* EPA Q_d Spreadsheet.xlsx available in the docket for this action. The information included in the EPA’s spreadsheet used information from the “Texas EWRT AMDA Pivot final.xlsx” spreadsheet. Texas’s spreadsheet is also available in the docket for this action.

[13] *See* EPA Q_d Spreadsheet.xlsx available in the docket for this action. The information included in the EPA’s spreadsheet used information from a spreadsheet created by TCEQ titled “Texas EWRT AMDA spreadsheet.xlsx”. Texas’s spreadsheet is also available in the docket for this action.

[14] https://www.censara.org/ftpfiles/Ramboll/.

below, there are a number of sources in Texas that are located outside of the AOI but, because they have a large Q/d, are significant contributors to visibility impairment. By using the EWRT AOI as a bright line cutoff, irrespective of specific source emissions, Texas did not capture these sources for evaluation of control measures using the four factors, despite their otherwise significant contributions to visibility impairment.

**Figure 2.9. CenSARA EWRT x Q/d AOI for Sulfates at Big Bend (2016).**

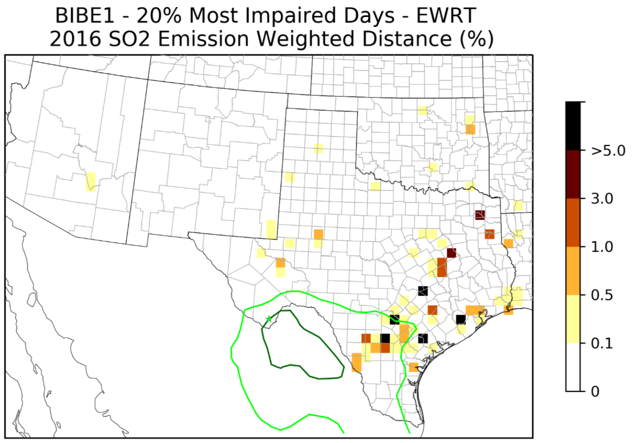


**Figure 2.10. CenSARA EWRT x Q/d AOI for Sulfates at Salt Creek (2016).**

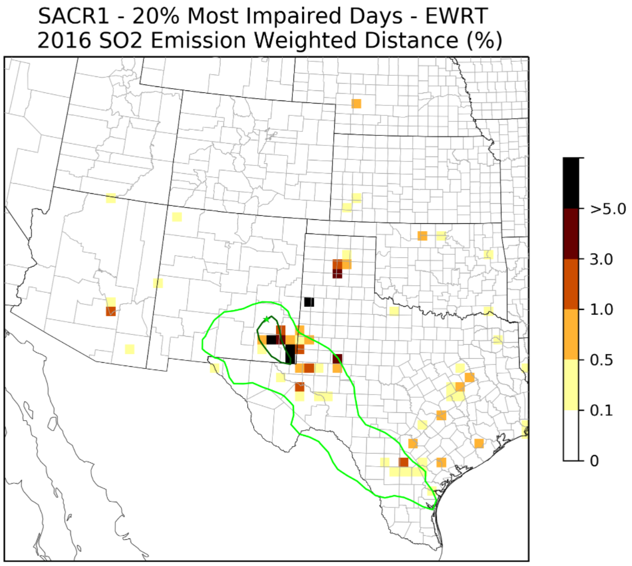


Figure 2.11. **CenSARA EWRT x Q/d AOI for Sulfates at Big Bend (2028).**

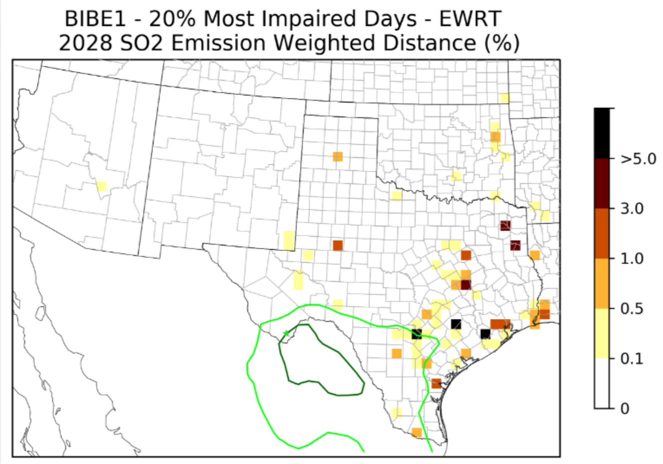
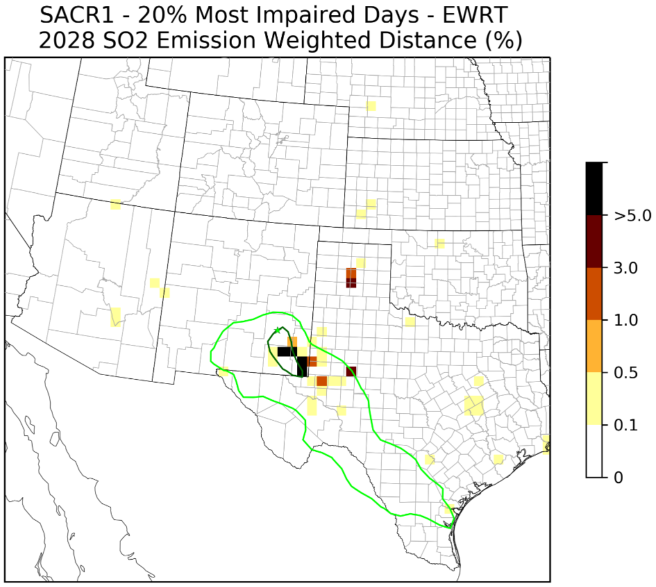


**Figure 2.12. CenSARA EWRT x Q/d AOI for Sulfates at Salt Creek (2028).**



## 3. Identification of Potential Controls for Petroleum Coke Calcining Facilities

As discussed in Section IV.E.2.a of our notice of proposed rulemaking, Texas determined that there were no technically feasible $SO_2$ controls available for petroleum coke calcining facilities. We explain in our notice of proposed rulemaking why we find that determination to be unreasonable. In this section of the TSD, we include additional information regarding the feasibility of controls at petroleum coke calcining facilities.

The coke calcining source category consists of processes that heat petroleum coke to high temperatures in the absence of air or oxygen for the purpose of removing impurities or volatile substances in the petroleum coke feedstock.[15] The coke calcining source category includes, but is not limited to, rotary kilns used to calcine petroleum coke. Based on information from a 2022 EPA TSD, there are an estimated 5 operating coke calcining companies in the US with approximately 15 operating facilities with 29 coke calcining process units.[16] Oxbow and Rain Industries are two of the largest calcined petroleum coke companies, with worldwide production capacity of 2.1 million tons/year and estimated US production capacity of approximately 1.8 million tons/yr.[17] Most of the petroleum calcining coke facilities in the United States are located along the Texas and Louisiana coast. The EPA is aware of three petroleum coke facilities in Louisiana (Rain CII facilities in Lake Charles, Norco, and Chalmette) that currently have controls installed and operating to reduce $SO_2$ emissions.[18] In addition, the EPA is aware of a Rain facility in India that also has controls in place to reduce $SO_2$ emissions. The following paragraphs provide additional information regarding the controls at these facilities based on information available to EPA.

Rain CII Carbon LLC – Chalmette Calcining Plant

Rain CII Carbon LLC owns and operates the Chalmette Calcining Plant located in Chalmette, Louisiana. According to their Title V Permit No. 2500-00006-V3, the Chalmette Calcining Plant installed an $SO_2$ scrubber on the waste heat boiler/baghouse system as required by compliance order dated June 20, 2013. The $SO_2$ scrubber was operational as of August 3, 2015, and the emission limits associated with operation of the scrubber were authorized in the permit on October 27, 2017. The scrubbing system resulted in permitted $SO_2$ emissions reduction at Chalmette from 7008.01 tpy to 2625.78 tpy for a reduction of 4382.23 tpy. According to Rain's website, the system resulted in up to a 65% reduction in $SO_2$ emissions.[19]

Rain CII Carbon LLC - Lake Charles Calcining Plant

Rain CII Carbon LLC owns and operates the Lake Charles Calcining Plant located in Sulphur, Louisiana. According to a "Request for Authorization to Construct and Operate, Title V Permit Number 0520-00048-V1" dated December 21, 2010, Rain CII initiated a Waste Heat Recovery Project which consisted of the installation of a waste heat boiler and a baghouse system. The baghouse system includes lime injection and "reactors" in the ductwork to provide turbulence and residence time to allow for $SO_2$ emissions reduction. The design is purported to allow for a reduction in $SO_2$ emissions from 3960 lb/hr to 1600 lb/hr.

Rain CII provides additional information on the web site and in their 2022 Sustainability Report on their facility operations and $SO_2$ control systems. According to information on Rain's web site, the system at the Lake Charles Calcining Plant has the potential to reduce $SO_2$ emissions by up to 60%.[20]

The Rain CII Carbon LLC - Norco Calcining Plant

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[15] https://www.epa.gov/ghgreporting/subpart-ww-coke-calciners.

[16] Technical Support Document for Coke Calcining: Proposed Rule for the Greenhouse Gas Reporting Program, Office of Air and Radiation, U.S. Environmental Protection Agency (Jan. 2022). Available in the docket for this action as well as in docket EPA-HQ-OAR-2019-0424-0110.

[17] Technical Support Document for Coke Calcining: Proposed Rule for the Greenhouse Gas Reporting Program, Office of Air and Radiation, U.S. Environmental Protection Agency (Jan. 2022). Available in the docket for this action as well as in docket EPA-HQ-OAR-2019-0424-0110.

[18] https://www.raincarbon.com/sustainability/sustainability-activities/environment/sustaining-ecosystems.

[19] https://www.raincarbon.com/sustainability/sustainability-activities/environment/sustaining-ecosystems.

[20] https://www.raincarbon.com/sustainability/sustainability-activities/environment/sustaining-ecosystems.

Rain CII Carbon LLC owns and operates the Norco Calcining Plant, an existing coke calcining facility located in St. Charles Parish near Norco, Louisiana. In August 2017, Rain CII submitted an application to modify its Title V and PSD permit to "redefine Best Available Control Technology (BACT) for emissions of sulfur dioxide from the Pyroscrubber/HRB…Rain CII proposes to establish $SO_2$ BACT as the use of a lime baghouse with upgraded process control systems." The $SO_2$ control system consists of a lime baghouse system with an automated lime screw drive tied via a control loop to the $SO_2$ continuous emissions monitoring system to allow lime to be fed to the system automatically. These controls and associated emission limits were authorized in PSD-LA-582(M-5) and Title V Permit No. 2520-00003-V4 on August 7, 2018. The $SO_2$ control system reduced $SO_2$ emissions from 3886.84 tpy to 2936.21 tpy (-950.63 tpy).

Rain CII provides additional information on the web site and in their 2022 Sustainability Report on their facility operations and $SO_2$ control systems. According to information on Rain's web site, the system at the Norco facility has the potential to reduce emissions by up to 40%.[21]

The Rain CII Carbon LLC facility in India

Rain CII Carbon Vizag Limited (RCCVL) operates a petroleum coke calcining plant at Visakhapatnam ("Vizag") in Andhra Pradesh, India. RCCVL is part of Rain Carbon Inc.

The plant has two 68 m long rotary kilns and features an extensive waste heat recovery and flue gas treatment system that generates electrical power from surplus heat. According to Rain's sustainability report, the plant has operated a high-efficiency, lime-based FGD system since its commissioning in 1998.[22] Based on available literature prepared by Rain, the plant uses dry scrubbing technology and requires continuous injection of hydrated lime into the scrubber reactor.[23] The cooled flue gas enters at the bottom of the scrubber and water is injected along with lime to maintain an exit flue gas temperature of around 85°C which is necessary for efficient removal of $SO_2$ via reaction to form $CaSO_3/CaSO_4$.[24] After the scrubber, the flue gas passes through a set of cyclones to remove part of the lime. The lime is recycled back to the scrubber for further reaction and to reduce overall lime consumption.[25]

Carbon Black Facilities

As discussed in Section IV.E.2.a of our notice of proposed rulemaking, Texas determined that there were no technically feasible $SO_2$ controls available for carbon black facilities. We explain in our notice of proposed rulemaking why we find that determination to be unreasonable. In this section of the TSD, we are providing additional information regarding the requirement for carbon black facilities to install and

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[21] https://www.raincarbon.com/sustainability/sustainability-activities/environment/sustaining-ecosystems.

[22] Sustainable CPC Production at the Vizag Calciner, Les Edwards, Maria Hunt, Pankaj Verma, Peter Weyell, and Julia Koop, Proceedings of the 38th International ICSOBA Conference, (Nov. 2020) available at https://raincarbon.com/Upload/Content_Files/rain-carbon-inc-sustainability-report-cy2022.pdf.

[23] Sustainable CPC Production at the Vizag Calciner, Les Edwards, Maria Hunt, Pankaj Verma, Peter Weyell, and Julia Koop, Proceedings of the 38th International ICSOBA Conference, (Nov. 2020) available at https://raincarbon.com/Upload/Content_Files/rain-carbon-inc-sustainability-report-cy2022.pdf.https://www.raincarbon.com/Upload/PDF/2020-icsoba-sustainable-cpc-production-at-the-vizag-calciner.pdf.

[24] Sustainable CPC Production at the Vizag Calciner, Les Edwards, Maria Hunt, Pankaj Verma, Peter Weyell, and Julia Koop, Proceedings of the 38th International ICSOBA Conference, (Nov. 2020) available at https://raincarbon.com/Upload/Content_Files/rain-carbon-inc-sustainability-report-cy2022.pdf.

[25] Sustainable CPC Production at the Vizag Calciner, Les Edwards, Maria Hunt, Pankaj Verma, Peter Weyell, and Julia Koop, Proceedings of the 38th International ICSOBA Conference, (Nov. 2020) available at https://raincarbon.com/Upload/Content_Files/rain-carbon-inc-sustainability-report-cy2022.pdf.

operate $SO_2$ controls. These requirements were part of consent decrees entered into between the facility and EPA and were in place at the time Texas was developing its second planning period SIP. Specifically, the EPA entered into consent decrees with several carbon black manufacturing companies (Columbian Chemicals,[26] Sid Richardson,[27] Continental Carbon,[28] Orion,[29] and Cabot[30]) that required control of $SO_2$ emissions using scrubbing technology or an alternative technology that was equal to at least 95% control efficiency.

### 4. Cost of Scrubber Upgrades

As discussed in Section IV.E.2.b of the notice of proposed rulemaking, Texas used an assumption of $139/kW to calculate the capital costs of scrubber upgrades. This $139/kW assumption is the highest capital cost $/kW value out of several scrubber upgrades cost estimates for EGUs compiled from a National Park Service (NPS) spreadsheet from 2010 found on the Western Regional Air Partnership (WRAP) legacy website and relied upon by Texas.[31] Figure 4.1 below presents the capital costs in $/kW for the scrubber upgrades included in the 2010 NPS spreadsheet. As can be seen, the $139/kW assumption is an outlier value, which corresponds to upgrades at the Coal Creek Power Plant in North Dakota. The costs for upgrades at this facility included additional project elements other than upgrades to the existing scrubber, such as coal drying.[32] The next highest capital cost $/kW value included in the spreadsheet is an upgrade project that was estimated to cost $52.39/kW.[33] The average $/kW capital costs provided in the spreadsheet, even including the $139/kW outlier is approximately $38/kW, with costs as low as $4/kW for some units.[34] The average cost if we exclude the outlier cost for Coal Creek units is $19.52/kW. Scrubber upgrade costs are site-specific, depending on existing scrubber design and available upgrades.[35] Therefore, it is inappropriate to rely on cost assumptions that are based on outliers, especially absent any discussion of why the higher cost is more reflective of upgrades necessary at a particular source, because they are not representative of the anticipated cost of scrubber upgrades at these units. Had Texas instead relied on the average capital cost found in the spreadsheet, and presented as the example calculation in its SIP, the capital costs contained in the SIP would have been significantly lower.

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[26] Case 6:17-cv-01661-UDJ-CBW entered June 1, 2018, available at https://www.epa.gov/enforcement/columbian-chemicals-company-clean-air-act-settlement.

[27] Case 3:17-cv-01792-SDD-RLB entered December 22, 2017, available at https://www.epa.gov/enforcement/sid-richardson-carbon-and-energy-company-clean-air-act-settlement.

[28] Case 5:15-cv-00290-F entered March 23, 2015, modified December 22, 2017, available at https://www.epa.gov/enforcement/continental-carbon-company-clean-air-act-settlement.

[29] Case 6:17-cv-01660 entered December 22, 2017, available at https://www.epa.gov/enforcement/orion-engineered-carbons-llc-clean-air-act-settlement.

[30] Case 6:13-cv-03095-RFD-PJH entered November 19, 2013, modified May 5, 2017, and December 22, 2017, available in the docket for this action.

[31] *See* "scrubber upgrades.xlsx"; *see also* "2010 NPS EGUs with Proposed BART SO2 Controls Spreadsheet.xlsx." Both documents are available in the docket for this action.

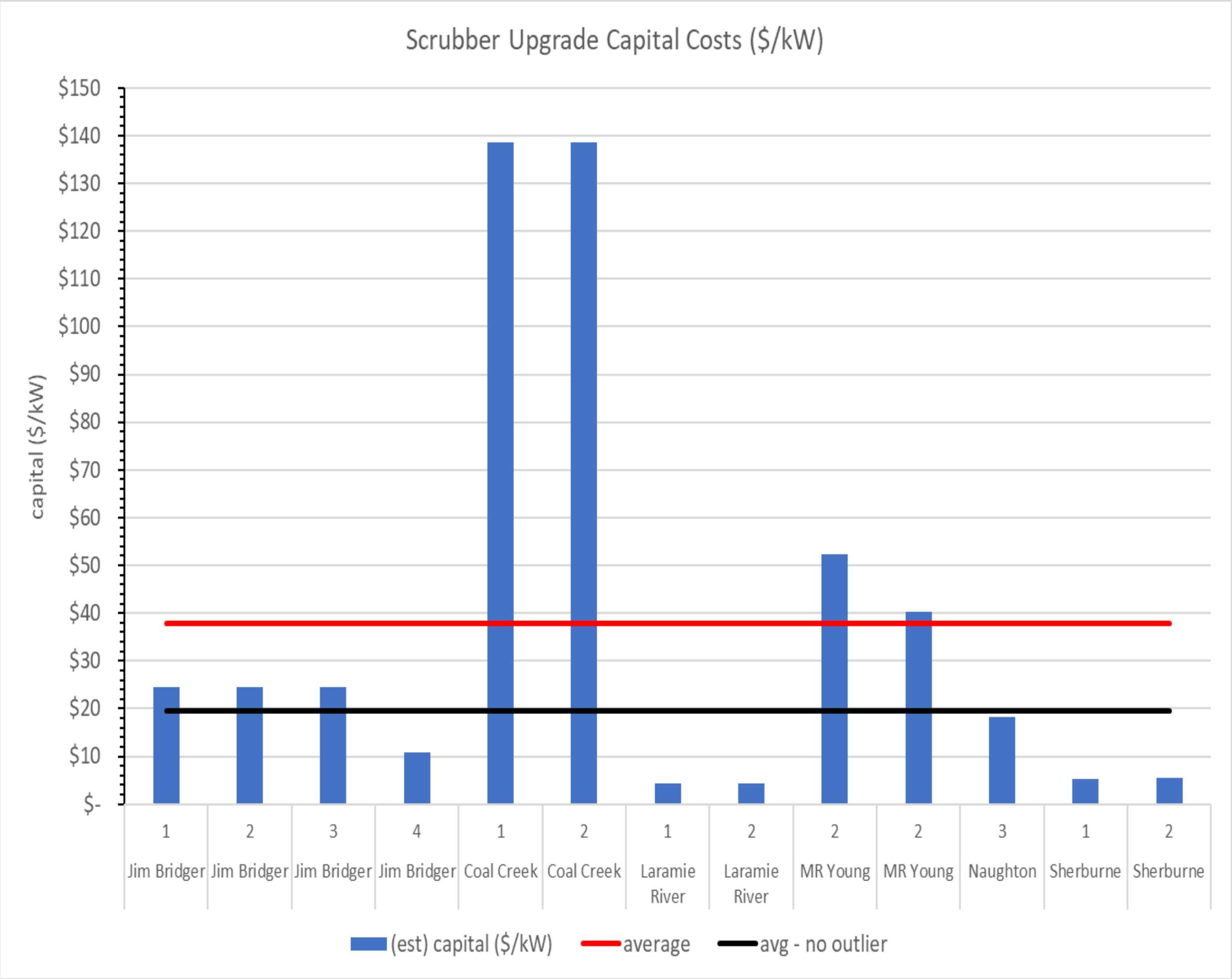
[32] *See* Great River Energy Coal Creek BART Emission Control Cost Analysis. The report is available in the docket for this action.

[33] *See* scrubber upgrades.xlsx.

[34] *See* scrubber upgrades.xlsx.

[35] For example, costs to upgrade scrubber performance from 94-95% at San Miguel might only require increased reagent use, whereas scrubber upgrades at less efficient units may require more significant equipment upgrades or elimination of scrubber bypasses, as demonstrated by the range in costs in the 2010 NPS spreadsheet.

**Figure 4.1. Scrubber Upgrade Capital Costs ($/kw).**



To illustrate this point, the EPA recalculated the scrubber upgrade costs for Martin Lake, San Miguel, and Pirkey using the average capital cost[36] as well as the average operation and maintenance costs (O/M) contained in Texas's Excel spreadsheet and identified in their example calculation in Appendix B of the 2021 Texas Regional Haze Plan (see Appendix A to this TSD).[37] EPA focused on these three sources as these were the scrubber upgrades that Texas identified as meeting its cost-effectiveness threshold of $5,000/ton. We also recalculated these costs using the calculated average capital costs and average O/M when the outlier costs for Coal Creek are excluded (see Appendix B to this TSD).[38] Figures 4.2 and 4.3 below compares the calculated total annual costs and cost-effectiveness for scrubber upgrades at these units estimated by TCEQ to those calculated using the average costs (Avg) and the average costs without

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[36] By providing this illustration, the EPA is not necessarily endorsing the use of the average capital cost to calculate the cost of scrubber upgrades at a source. Given the site-specific nature of scrubber upgrades, the use of the average capital cost of several scrubber upgrades may not accurately reflect the cost to upgrade any particular scrubber.

[37] *See* "EPA modified RH-2021-Summary Emissions, Cost Table.xlsx" and "EPA modified-scrubber upgrades.xlsx" spreadsheets. Available in the docket for this action.

[38] *See* "EPA modified RH-2021-Summary Emissions, Cost Table.xlsx" and "EPA modified-scrubber upgrades.xlsx" spreadsheets. Available in the docket for this action.

the outlier values for Coal Creek (Avg – no outlier). We also include estimated costs for scrubber upgrades for the Limestone units as discussed below.

**Figure 4.2. Comparison of Total Annual Costs.**

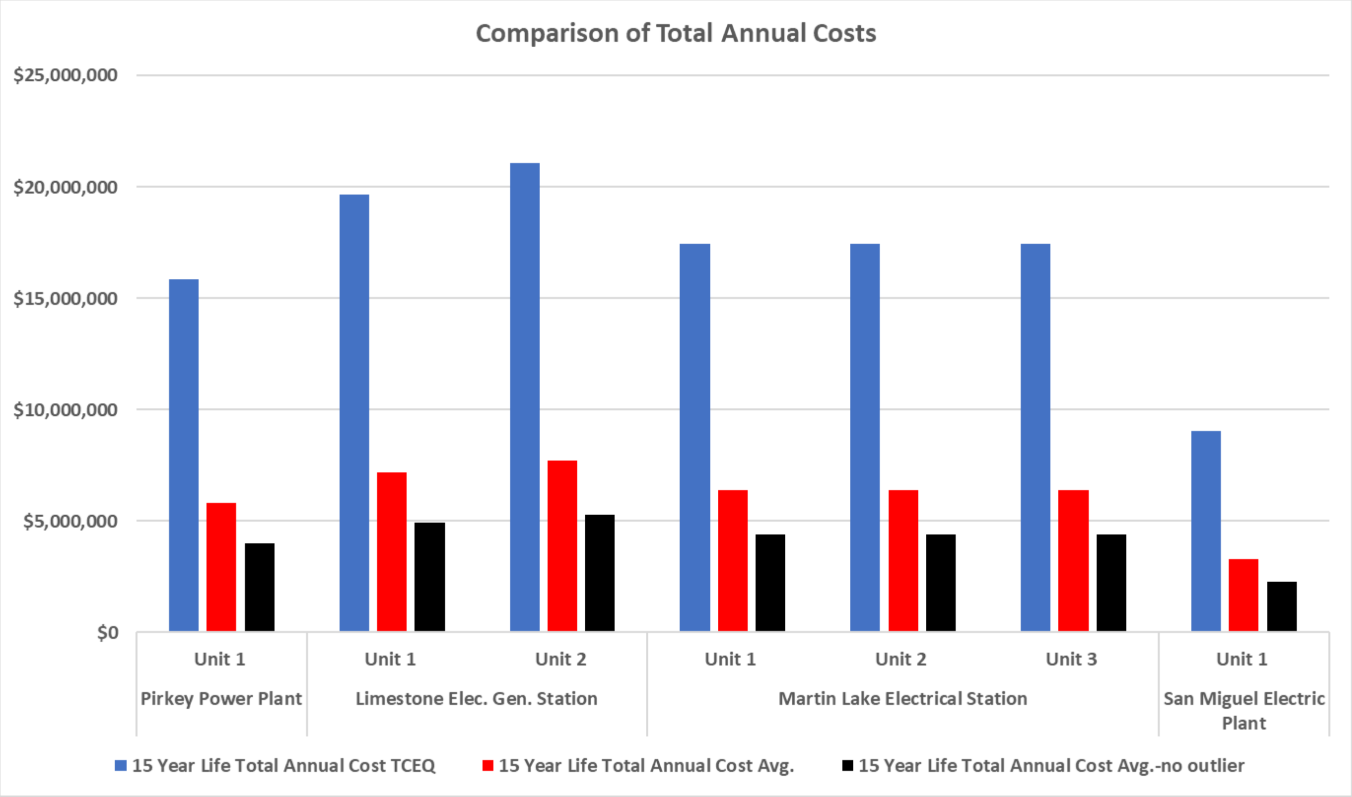
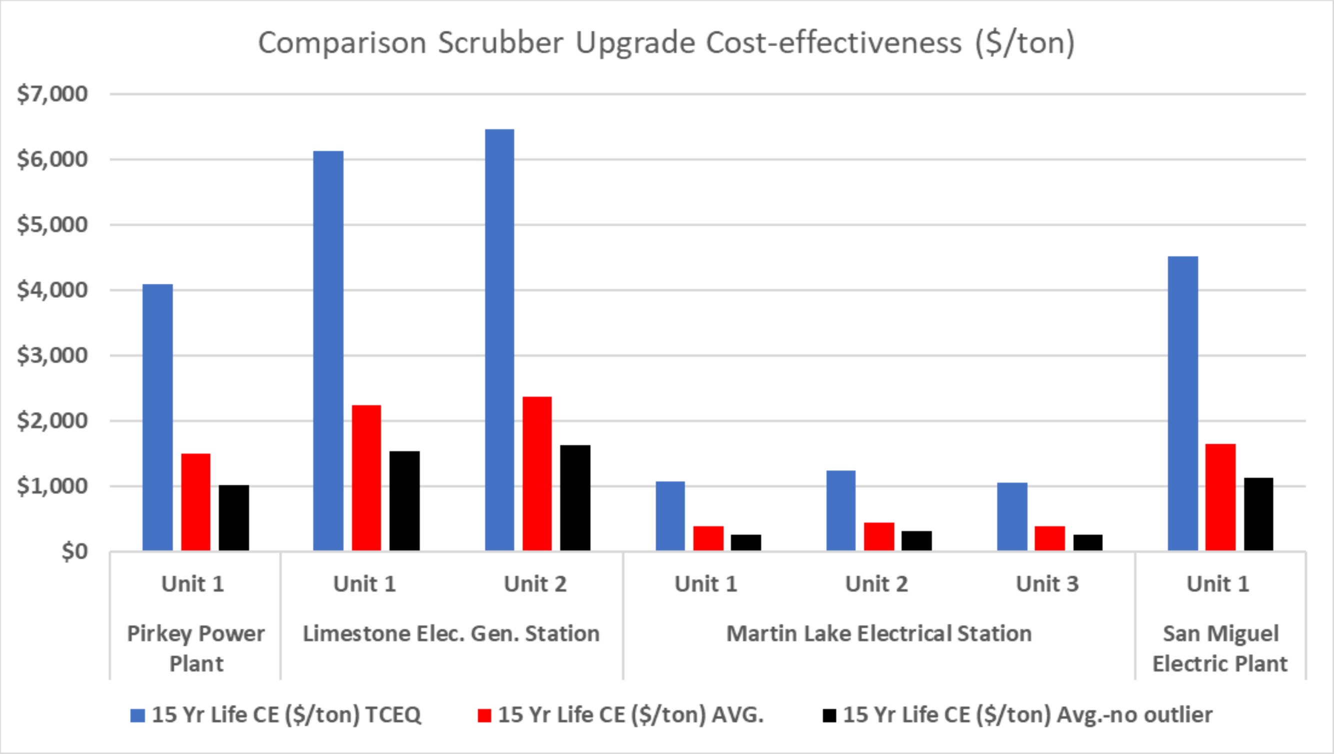


**Figure 4.3. Comparison of Scrubber Upgrade Cost-Effectiveness ($/ton).**



Using the average values of $37.84/kW for capital costs and $3.08/kW for O/M for the scrubber upgrades, the 15-year total annual costs are reduced from $77,293,916 to $28,320,403, a reduction in annual costs of $48,973,513. Noting that Limestone was not included in the TCEQ's aggregate cost analysis or sensitivity modeling for total visibility benefits because the cost of controls were above the TCEQ's threshold of $5000/ton, we calculate that, using the average cost of $37.84/kW for capital costs and $3.08/kW for O/M for the scrubber upgrades, Limestone controls would have a cost-effectiveness of less than $2,500/ton and would add about $15 million to the total annual cost and an additional reduction in emissions of about 6,500 tons.

Using the average values of $19.52/kW for capital costs and $2.97/kW for O/M for the scrubber upgrades when the outlier costs for Coal Creek units are excluded, the 15-year total annual costs are reduced from $77,293,916 to $19,416,130, a reduction in annual costs of $ $57,877,786. We calculate that Limestone controls would have a cost-effectiveness of less than $1,650/ton and add about $10 million to the total annual cost and an additional reduction in emissions of about 6,500 tons.

## 5. Chemical Transport Modeling Performed By TCEQ

### 5.1. Background

As part of Texas's Regional Haze Plan for second planning period, Texas had to establish a reasonable progress goal (RPG) in deciviews that reflects the visibility conditions that are projected to be achieved by 2028 for this planning period as part of the long-term strategy (LTS). The RPGs must provide for improvement of visibility for the most impaired days (MID) since the baseline period and ensure no degradation of visibility for the clearest days since the baseline period. Texas performed chemical transport modeling using the Comprehensive Air Quality Model with Extensions (CAMx) model to project future visibility conditions and evaluate the impact of emission reductions on visibility. The CAMx

Particulate Source Apportionment Technology (PSAT) was used to estimate the effect of emissions from emission sectors and regions on visibility impairment at Class I areas.

## 5.2. Overview of TCEQ's Modeling

Appendix G of the 2021 Texas Regional Haze Plan includes the Modeling Protocol and ancillary documents including preliminary modeling work Ramboll U.S. Corporation (Ramboll) provided for TCEQ in August 2019, "Regional Haze Modeling Final Report" (Ramboll Report 1) and Ramboll's June 2020, "Regional Haze Modeling to Evaluate Progress in Improving Visibility in and near Texas, Final Report" (Ramboll Report 2).[39] TCEQ's overview of their modeling is documented Chapter 8.3 of their 2021 Regional Haze Plan. Additional modeling details are provided in Appendices D, E, F, and G of their 2021 Regional Haze Plan. Chapter 8.3 of the 2021 Texas Regional Haze Plan also refers to Ramboll's June 2020 report for the model evaluation that was performed; we discuss this in subsections 5.3 and 5.5 of this TSD.

TCEQ performed CAMx modeling for this SIP with the assistance of Ramboll, which assisted TCEQ with evaluating model performance, post-processing model outputs, Particulate Source Apportionment (PSAT) modeling, and other technical assistance. In this TSD, EPA will give a brief overview of the modeling performed and included in Texas's 2021 Regional Haze Plan and we refer the reader to TCEQ's 2021 Regional Haze Plan for more details.[40] TCEQ's modeling included one base case model run, two future year modeling runs, one source apportionment (PSAT) run, and three sensitivity runs.

### *5.2.1. Episode Selection and Base Case Modeling*

EPA's Modeling Guidance for Demonstrating Air Quality Goals for Ozone, PM2.5, and Regional Haze[41] (EPA 2018 Modeling Guidance) and previous versions of EPA's modeling guidance documents provides guidance to states, tribes, and local authorities on the recommended steps to develop base period and future year modeling, as well as how to develop future year modeled projections as part of a regional haze SIP submittal.

The TCEQ considered the EPA 2018 Modeling Guidance criteria and the availability of modeling platforms for this application. TCEQ describes the modeling episode selection in section 8.3.3.1 of the 2021 Regional Haze Plan. TCEQ utilized the 2016 National Emissions Inventory Collaborative (NEIC) modeling platform.[42] The 2016 NEIC modeling platform was developed by the EPA, states (including Texas), local areas, and other groups collaboratively to generate a North American emission inventory for 2016. A Base Year Selection Workgroup was created, with TCEQ participation, to evaluate and select the base year for the collaborative modeling platform. [43] After a year of research and analysis on regulatory

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[39] Both Ramboll reports are available in the docket for this action. See FN 40.

[40] 2021 Texas Regional Haze Plan, and Appendices. Also two TCEQ contracted Ramboll modeling reports: "Regional Haze Modeling Final Report", August 15, 2019, included in the docket as "582199153301-20190815-ramboll-RegionalHazeModeling.pdf", to be further referenced as "Ramboll Report 1"; "Regional Haze Modeling to Evaluate Progress in Improving Visibility in and near Texas Final Report", June 25, 2020, included in the docket as "Ramboll-RegionalHazeModelingEvaluateProgressVisibility.pdf", to be further referenced as "Ramboll Report 2".

[41] EPA 2018 Modeling Guidance for Demonstrating Air Quality Goals for Ozone, PM2.5, and Regional Haze, https://www.epa.gov/sites/production/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf, November 2018.

[42] NEIC, 2020. National Emissions Inventory Collaborative Wiki, http://views.cira.colostate.edu/wiki/wiki/9169, accessed May 7, 2020.

[43] National Emissions Inventory Collaborative (NEIC), 2017. NEIC Base Year Selection Workgroup Final Report, https://drive.google.com/open?id=1o0e75dlliyjDZOmBDOPxIdMUhUTeph4Y, April 2017.

timelines, meteorological conditions, and emission inventories, 2016 was chosen as the preferred year. A coordination committee was formed with EPA and state representatives to select the workgroups and their co-leads, plan data releases, and report out the 2016 modeling platform development to the modeling community.[44] The TCEQ was involved in the overall coordination of the platform development as well as participating in many of the workgroups that created the 2016 emission inventories. Based in part on the availability of emissions inventory data from the collaborative modeling platform, as well as to provide consistency with modeling efforts by the EPA, other states, and regional planning organizations, the TCEQ chose the base case regional haze modeling year of 2016.

For their base case, TCEQ modeled January 1, 2016, through December 31, 2016, with a 15-day ramp-up period beginning on December 16, 2015.

The TCEQ used lateral and top boundary conditions (BC) for the CAMx 36-kilometer (km) resolution domain from the global 3-D model of atmospheric chemistry driven by meteorological input from the Goddard Earth Observing System (GEOS) of the National Aeronautics and Space Agency (NASA) Global Modeling and Assimilation Office, known as GEOS-Chem.[45]

The CAMx particulate matter calculation option the TCEQ used, coarse/fine (CF), tracks chemically inert particles in two sizes: coarse and fine. The cutoff size between the categories is a diameter of 2.5 micrometers (µm). The complete list of inorganic particulate matter species modeled in the CAMx CF aerosol option is shown in Table 5.1 which replicates 2021 Texas Regional Haze Plan Table 8-1.

**Table 5.1. 2021 Texas Regional Haze Plan Table 8-1: List of Inorganic PM Species for the CAMx CF Aerosol Option.**

| CAMx Label | Name |
|---|---|
| PSO4 | Particulate Sulfate |
| PNO3 | Particulate Nitrate |
| PNH4 | Particulate Ammonium |
| PEC | Primary Elemental Carbon |
| FPRM | Fine Other Primary (diameter ≤ 2.5 µm) |
| FCRS | Fine Crustal (diameter ≤2.5 µm) |
| CPRM | Coarse Other Primary |
| CCRS | Coarse Crustal |
| PH20 | Aerosol Water Content |
| NA | Sodium |
| PCL | Particulate Chloride |

CAMx calculates secondary organic aerosols (SOA) produced from chemical reactions of primary emissions. TCEQ used the secondary organic aerosol processor (SOAP) scheme with updated terpene chemistry SOAP version 2.2 (SOAP2.2), that computes, and partitions SOA into six species: SOA1, SOA2, SOA3, SOA4, SOPA, and SOPB. CAMx also tracks directly emitted and non-chemically evolving organic aerosols as primary organic aerosols (POA). The anthropogenic SOA species SOA1 and SOA2 are partitioned based on chemical volatility, as are the biogenic SOA species SOA3 and SOA4. The non-

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[44] "Base Year Selection Workgroup Final Report", April 5, 2017; Base_Year_Selection_Report_V1.1.pdf, https://drive.google.com/file/d/1o0e75dIliyjDZOmBDOPxIdMUhUTeph4Y/view.

[45] See 2021 Texas Reginal Haze Plan, page 8-3.

volatile anthropogenic aerosols are tracked as SOPA, and non-volatile aerosols condensed from biogenic sources are tracked as SOPB.

When calculating light extinction, the CAMx species used needs to be mapped onto the PM species measured at the Interagency Monitoring of Protected Visual Environments (IMPROVE) monitors. Table 5.2 is 2021 Texas Regional Haze Plan Table 8-2 that is replicated here and shows the mapping.

**Table 5.2. 2021 Texas Regional Haze Plan Table 8-2: CAMx to IMPROVE Particulate Matter Species Cross Reference.**

| IMPROVE PM Species | Short Name | CAMx Species |
|---|---|---|
| Ammonium Sulfate | AmmSO4 | 1.375 x PSO4 |
| Ammonium Nitrate | AmmNO3 | 1.290 x PNO3 |
| Organic Aerosol | OA or OMC | POA + SOA1 + SOA2 + SOPA + SOA3 + SOA4 + SOPB |
| Elemental Carbon | EC | PEC |
| Crustal Material | Soil | FPRM + FCRS |
| Sea salt | Sea salt | NA + PCL |
| Coarse Mass | CM | CPRM + CCRS |

In the 2021 Texas Regional Haze Plan, “Equation 8-1: IMPROVE Equation,” (2021 Texas Regional Haze Plan pages 8-4 and 8-5) describes how these modeled PM species concentrations and relative humidity data are used to calculate visibility impairment or beta extinction ($B_{ext}$) in units of inverse megameters ($Mm^{-1}$).

### *5.2.2. Future Case Modeling*

Simulations for 2028 used meteorology inputs from 2016 with estimates of 2028 emissions as described in 2021 Texas Regional Haze Plan Section 8.3.6: *2028 Future Case Emissions*.

Versions of the 2028 future year modeled:

1. 2028 base case;
2. 2028 simulation with all anthropogenic emissions outside the United States set to zero, used to determine the international anthropogenic contributions to visibility impairment at IMPROVE monitors for use in a glidepath adjustment;
3. 2028 source apportionment run. (See additional discussion in section 5.6 of this TSD);
4. TCEQ also evaluated three potential control scenario runs discussed in section 5.7.

## 5.3. Meteorological Modeling

TCEQ used version 3.8.1 of the WRF model to generate the meteorological inputs for the photochemical modeling. The WRF modeling system was developed by a broad user community, including the Air Force Weather Agency, national laboratories, and academia.

The WRF modeling was conducted for the 48-state Continental United States and certain surrounding areas (CONUS). WRF modeling period starts December 16, 2015, and ends December 31st, 2016WRF was configured for a single 12 km grid covering almost all North America. For details on the WRF modeling setup, inputs, and model performance evaluation (MPE), we refer the reader to the 2021 Texas Regional Haze Plan, Section 8.3.4 and Appendix D: Meteorological Modeling. EPA did not identify any major concerns with Texas's WRF setup or model performance evaluation and find that, overall, it was acceptable to use for this SIP.

## 5.4. Chemical Transport (CAMx) Modeling

### *5.4.1. Base Case Modeling Emissions*

TCEQ documented their emission inventory development for the different types of emission sources in Section 8.3.5 and Appendix E of its 2021 Regional Haze Plan.[46] We refer the reader to those documents for details on the base case emission inventory used in the chemical transport grid modeling.

TCEQ developed an emission inventory of both anthropogenic, biogenic, fire related and natural emissions for the base year 2016 (inventory was for December 16, 2015 through December 31st 2016).

For Texas point sources emissions for the base case modeling, the TCEQ designated 2018 as the base year for Texas EGUs with emissions from the EPA's AMPD, and 2016 as the base year for all other stationary point sources (non-EGUs) with emissions recorded in the STARS database (annual emissions data reported pursuant to the reporting requirements of 30 Texas Administrative Code (TAC) §101.10).

For the non-Texas North American portion of the modeling domain, the TCEQ used 2016 NEIC platform for the point sources. For the non-Texas U.S. portion of the modeling domain, hourly $NO_x$ emissions for major EGUs were obtained from the EPA Air Markets Program Database (AMPD) for each day of the 2016 base case year. Canadian and Mexican point source emissions were also obtained from the 2016 NEIC platform. Emissions for point sources in the Gulf of Mexico (e.g., oil-and-gas production platforms) were obtained from the 2014 Gulfwide Emissions Inventory (GWEI, 2014) provided by the U.S. Bureau of Ocean Energy Management (BOEM).

### *5.4.2. 2028 Future Case Emissions*

TCEQ documented their 2028 future year emission inventory development for the different types of emission sources in the 2021 Regional Haze Plan Section 8.3.6 and in Appendix E: Emission Modeling.[47] We refer the reader to those documents for details on the future case emission inventory used in the chemical transport grid modeling.

For the future case 2028 point source emissions for the non-Texas U.S. portion of the modeling domain, hourly $NO_x$ emissions for major EGUs were obtained from the Eastern Regional Technical Advisory Committee (ERTAC) projection model.[48] Canadian and Mexican point source emissions, and emissions for non-EGU point sources in states beyond Texas were obtained from the 2016 NEIC platform (v 2028fg). Emissions for point sources in the Gulf of Mexico were set equal to the base case.

The 2028 future year non-EGU point source emissions for Texas sources were projected from the 2016 STARS data considering the effect of all applicable rules, regulations, and expected growth.

The 2028 future case EGU emission estimates within Texas were based on the 2018 AMPD data. Texas states the projected emissions also account for the reasonable progress Best Available Retrofit Technology (BART) Federal Implementation Plan (FIP) for specific EGU $SO_2$ emissions, and the Cross-State Air Pollution Rule (CSAPR) Update for EGU $NO_X$ emissions. Future case EGU emission estimates

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[46] TCEQ SIP Appendix E Emission Modeling.

[47] 2021 Regional Haze Plan, Appendix E Emission Modeling.

[48] https://marama.org/technical-center/ertac-egu-projection-tool/.

accounted for retirements as well as newly permitted EGUs. More details regarding Texas EGU point sources, the BART FIP, and CSAPR can be found in Appendix E of the 2021 Texas Regional Haze Plan.

### *5.4.3. Modeling Domains and Configuration*

For the chemical transport modeling, TCEQ used two nested CAMx modeling grids. Figure 5.1 replicates 2021 Texas Regional Haze Plan Figure 8 16: CAMx Modeling Grids and shows the 36-km North American grid (na_36km) in red, and a smaller 12-km U.S. grid (us_12km), shown in blue. The 36 km grid has 172 cells east-to-west and 148 cells south-to-north. The 12 km grid has 398 cells east-to-west, and 248 cells south-to-north.

The CAMx and WRF model domains are defined on the LCC map projection with parameters shown in Texas SIP Table 8-28. The vertical structure of the CAMx model includes 29 layers extending from the surface to 18,250 m. The layer depth increases from 34 m at the surface to 3,611 m for the top layer, as shown in Table 8-28: CAMx Vertical Structure with Layer Dimensions and Boundaries.

The TCEQ used the latest public-release version of CAMx, version 6.5. Several tests were performed to examine how different model configurations affect model performance, including 1) using SOAP v2.2, 2) adding lightning NO$_X$, and 3) adjusting surface resistance of ammonia in the dry deposition scheme. The best performing model configuration was selected and is summarized in Table 5.3, which is Table 8-29: CAMx Model Configuration in the 2021 Texas Regional Haze Plan.

**Figure 5.1. 2021 Texas Regional Haze Plan Figure 8-16: CAMx Modeling Grids.**

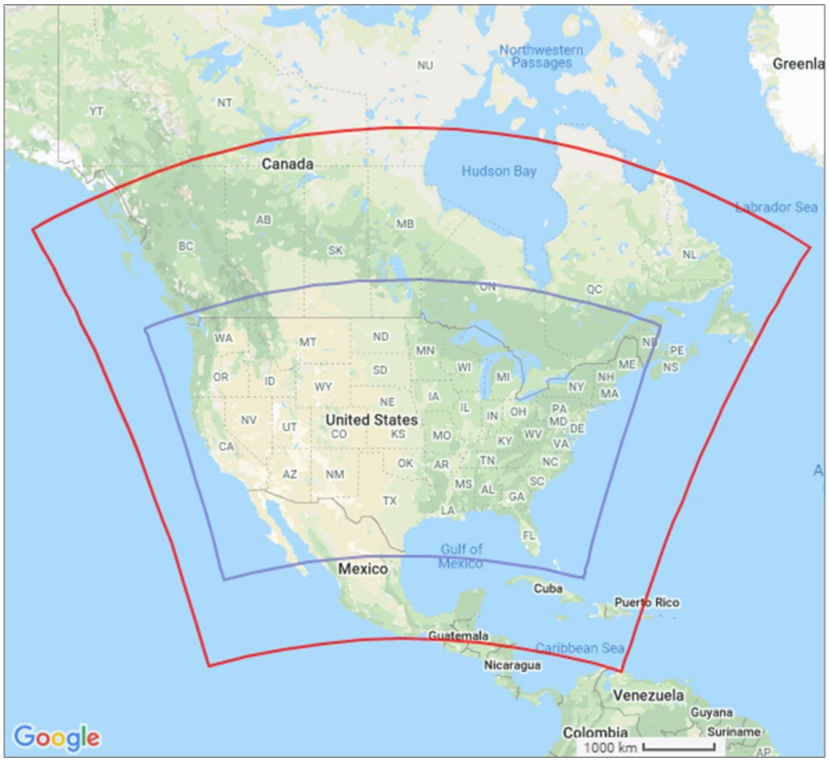

**Table 5.3. 2021 Texas Regional Haze Plan Table 8-29: CAMx Model Configuration.**

| CAMx Option | Choice Used |
|---|---|
| Version | Version 6.50 |
| Horizontal Grids | 36 km with nested 12 km |
| Vertical Grid | 29 Layers |
| Time Zone | Coordinated Universal Time (UTC) |
| Chemistry Mechanism | Carbon Bond 6r4 gas-phase mechanism and coarse/fine particulate matter scheme |
| Photolysis Mechanism | Tropospheric Ultraviolet and Visible (TUV) radiative transfer model, version 4.8, with Total Ozone Mapping Spectrometer (TOMS) ozone column data |
| Chemistry Solver | Euler-Backward Iterative (EBI) |
| Secondary Aerosol | Secondary Organic Aerosol Processor (SOAP) v2.2 that will be standard in CAMx Version 7.0 |
| Meteorology | WRF model v3.8.1. See Section 8.3.4.2 for configuration. |
| Advection Scheme | Piecewise Parabolic Method (PPM) |
| Planetary Boundary Layer (PBL) Mixing | K-theory |
| Dry Deposition Scheme | Wesley. Default surface resistance for ammonia (R scale = 1) |
| Lightning $NO_x$ | CAMx preprocessor |
| Wind-Blown Dust | CAMx preprocessor |
| Iodine Emissions | Oceanic iodine emissions computed from saltwater masks |

EPA has reviewed TCEQ's CAMx modeling configuration and domains and finds them acceptable.

## 5.5. Model Performance Evaluation (MPE)

TCEQ and its contractor, Ramboll, conducted Model Performance Evaluations (MPE) to compare the model-predicted values with the monitored (IMPROVE) values at the CIAs. Chapter 8.3 of Texas's 2021 Regional Haze Plan contains descriptions of the models used, including the Weather Research and Forecasting (WRF) meteorological model and CAMx model used.

The MPE for the meteorological modeling results is provided in Section 8.3.4.3 of the 2021 Texas Regional Haze Plan. More extensive MPE (including monthly MPE) is provided in Appendix D of the TCEQ's 2021 Regional Haze Plan and Ramboll Reports 1 and 2. TCEQ concluded that across the south-central U.S., which includes the Class I areas of Texas and surrounding states, the meteorological modeling performance "was consistently acceptable with few outliers."[49] Graphics and statistics were provided in the 2021 Regional Haze Plan, Appendix D and Ramboll Reports 1 and 2. In our review of the information, the discussions and technical arguments appear to support that meteorological model performance was generally adequate and reasonable to rely upon.

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[49] 2021 Texas Regional Haze Plan, Appendix D Meteorological Modeling, page D-90.

We also evaluated TCEQ's Model Performance Evaluation (MPE). TCEQ's goals in their base case modeling were to predict visibility levels at individual Class I areas (represented by Interagency Monitoring of Protected Visual Environments (IMPROVE) and Chemical Speciation Network (CSN)[50] monitoring sites) in 2016 and to estimate emissions contributions to 2016 particulate matter (PM) species concentrations using 2016 meteorology. The predicted 2016 PM species concentrations were first converted to light extinction coefficients then to deciviews and used as the base case for TCEQ's visibility analysis to support the 2021 Regional Haze Plan. TCEQ tracked culpability for modeled visibility impairment by emissions sectors and geographic regions using the CAMx Particulate Source Apportionment Technology (PSAT).[51] The model performance and visibility analysis followed the procedures of EPA's 2018 modeling guidance for SIP modeling[52] and 2019 memo Availability of Modeling Data and Associated Technical Support Document (EPA 2019 Modeling TSD).[53]

Texas's 2021 Regional Haze Plan, Section 8.3.7.4 provides a general summary of the CAMx MPE with the more detailed MPE included in Appendix F, Section 1.1 of the 2021 Regional Haze Plan. TCEQ analyzed total PM2.5 model performance, individual PM2.5 species ($SO_4$, $NO_3$, Organic Aerosols (OA), Elemental Carbon (EC), Soil, Sea Salt (SS) and Coarse Mass) and total extinction/visibility performance. The Normalized Mean Bias (NMB) and Normalized Mean Error (NME) are compared to numerical "goals" and less stringent "criteria" benchmarks recommended by Emery et al. (2016).[54] Fractional Bias (FB) and Fractional Error (FE) are also compared to benchmarks established by the U.S. Regional Planning Organizations (RPOs) based on (Boylan and Russell, 2006).[55] In general, the $SO_4$ and $NO_3$ model performance was better than for the other species, which is good, since most of the anthropogenic extinction and visibility impairment is typically from ammonium sulfates and ammonium nitrates. Included in our review of the 2021 Texas Regional Haze Plan MPE discussion were Tables 8-30, 8-32, 8-33, and 8-34 that we have replicated here.[56] Table 5.4 replicates the 2021 Texas Regional Haze Plan Table 8-30 that indicates the performance benchmark criteria and performance benchmark goals that TCEQ used in the evaluation of model performance. Model performance metrics (quarterly and annual) for $PM_{2.5}$, $SO_4$, and $NO_3$ are included as Tables 5.5, 5.6, and 5.7 from 2021 Texas Regional Haze Plan Tables 8-32, 8-33, and 8-44.

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[50] https://www.epa.gov/amtic/chemical-speciation-network-csn.

[51] CAMx Users Guide_v7.30 available in the docket for this action.

[52] Modeling Guidance for Demonstrating Air Quality Goals for Ozone, PM2.5, and Regional Haze, https://www.epa.gov/sites/default/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf, EPA, November 2018.

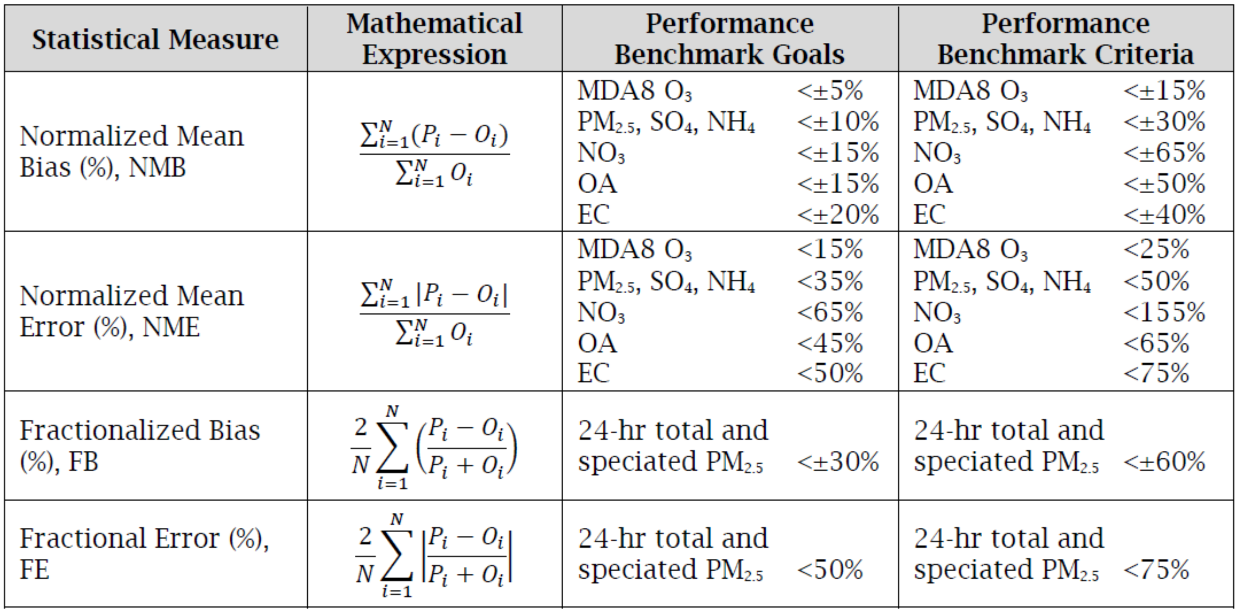
[53] Updated EPA 2028 Regional Haze Modeling - Technical Support Document, https://www.epa.gov/sites/production/files/2019-10/documents/updated_2028_regional_haze_modeling-tsd-2019_0.pdf, EPA, September 2019.

[54] Emery, C., Liu, Z., Russell, A.G., Odman, M.T., Yarwood, G. and Kumar, N., 2017. Recommendations on statistics and benchmarks to assess photochemical model performance. Journal of the Air & Waste Management Association, 67(5), pp.582-598.

[55] Boylan, J.W. and A.G. Russell, 2006. PM and Light Extinction Model Performance Metrics, Goals and Criteria for Three-Dimensional Air Quality Models. Atmos. Env. 40:4946-4959.

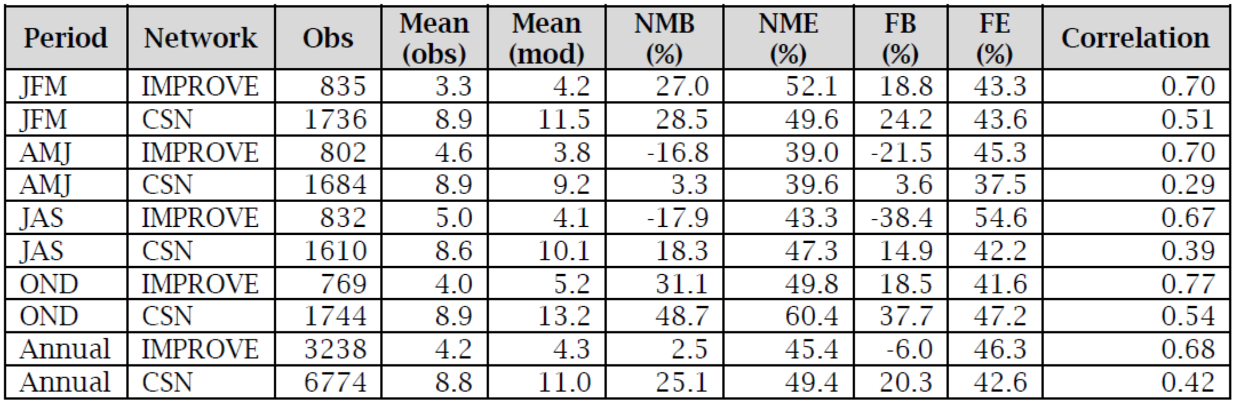
[56] 2021 Texas Regional Haze Plan Tables 8-32, 8-33, and 8-34 (pages 8-36 thru 8-39).

**Table 5.4. 2021 Texas Regional Haze Plan Table 8-30: Definitions of Statistical Performance Measures and Performance Benchmarks.**



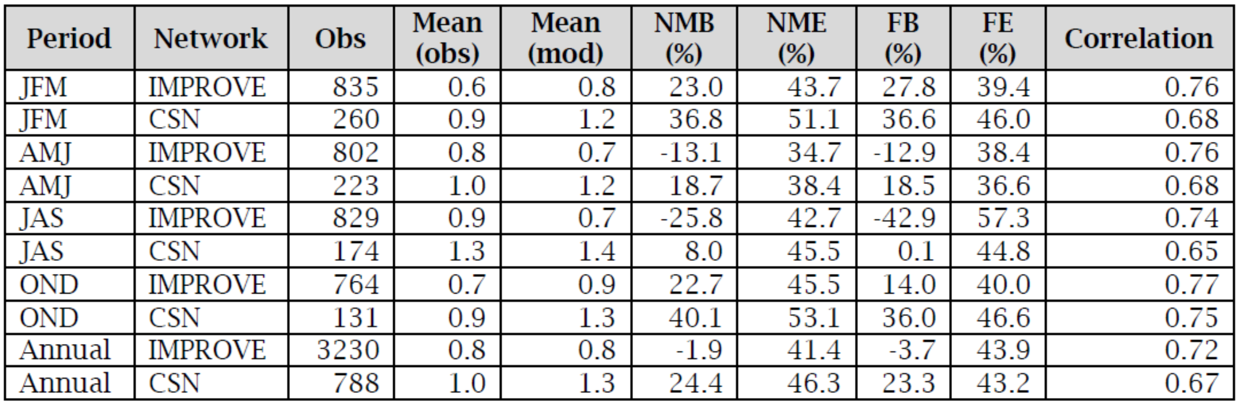
| Statistical Measure | Mathematical Expression | Performance Benchmark Goals | Performance Benchmark Criteria |
|---|---|---|---|
| Normalized Mean Bias (%), NMB | $\frac{\sum_{i=1}^{N}(P_i - O_i)}{\sum_{i=1}^{N} O_i}$ | MDA8 $O_3$ <±5%<br>$PM_{2.5}$, $SO_4$, $NH_4$ <±10%<br>$NO_3$ <±15%<br>OA <±15%<br>EC <±20% | MDA8 $O_3$ <±15%<br>$PM_{2.5}$, $SO_4$, $NH_4$ <±30%<br>$NO_3$ <±65%<br>OA <±50%<br>EC <±40% |
| Normalized Mean Error (%), NME | $\frac{\sum_{i=1}^{N}\lvert P_i - O_i\rvert}{\sum_{i=1}^{N} O_i}$ | MDA8 $O_3$ <15%<br>$PM_{2.5}$, $SO_4$, $NH_4$ <35%<br>$NO_3$ <65%<br>OA <45%<br>EC <50% | MDA8 $O_3$ <25%<br>$PM_{2.5}$, $SO_4$, $NH_4$ <50%<br>$NO_3$ <155%<br>OA <65%<br>EC <75% |
| Fractionalized Bias (%), FB | $\frac{2}{N}\sum_{i=1}^{N}\left(\frac{P_i - O_i}{P_i + O_i}\right)$ | 24-hr total and speciated $PM_{2.5}$ <±30% | 24-hr total and speciated $PM_{2.5}$ <±60% |
| Fractional Error (%), FE | $\frac{2}{N}\sum_{i=1}^{N}\left\lvert\frac{P_i - O_i}{P_i + O_i}\right\rvert$ | 24-hr total and speciated $PM_{2.5}$ <50% | 24-hr total and speciated $PM_{2.5}$ <75% |

**Table 5.5. 2021 Texas Regional Haze Plan Table 8-32: Model Performance Metrics for PM2.5 at IMPROVE and CSN Sites.**



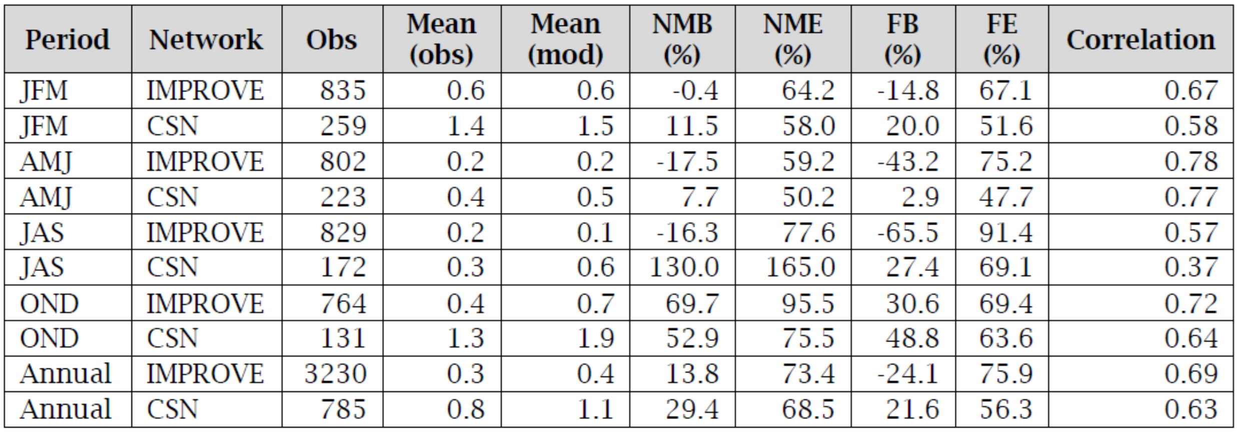
| Period | Network | Obs | Mean (obs) | Mean (mod) | NMB (%) | NME (%) | FB (%) | FE (%) | Correlation |
|---|---|---|---|---|---|---|---|---|---|
| JFM | IMPROVE | 835 | 3.3 | 4.2 | 27.0 | 52.1 | 18.8 | 43.3 | 0.70 |
| JFM | CSN | 1736 | 8.9 | 11.5 | 28.5 | 49.6 | 24.2 | 43.6 | 0.51 |
| AMJ | IMPROVE | 802 | 4.6 | 3.8 | -16.8 | 39.0 | -21.5 | 45.3 | 0.70 |
| AMJ | CSN | 1684 | 8.9 | 9.2 | 3.3 | 39.6 | 3.6 | 37.5 | 0.29 |
| JAS | IMPROVE | 832 | 5.0 | 4.1 | -17.9 | 43.3 | -38.4 | 54.6 | 0.67 |
| JAS | CSN | 1610 | 8.6 | 10.1 | 18.3 | 47.3 | 14.9 | 42.2 | 0.39 |
| OND | IMPROVE | 769 | 4.0 | 5.2 | 31.1 | 49.8 | 18.5 | 41.6 | 0.77 |
| OND | CSN | 1744 | 8.9 | 13.2 | 48.7 | 60.4 | 37.7 | 47.2 | 0.54 |
| Annual | IMPROVE | 3238 | 4.2 | 4.3 | 2.5 | 45.4 | -6.0 | 46.3 | 0.68 |
| Annual | CSN | 6774 | 8.8 | 11.0 | 25.1 | 49.4 | 20.3 | 42.6 | 0.42 |

**Table 5.6. 2021 Texas Regional Haze Plan Table 8-33: Model Performance Metrics for Particulate Sulfate at IMPROVE and CSN Sites.**



| Period | Network | Obs | Mean (obs) | Mean (mod) | NMB (%) | NME (%) | FB (%) | FE (%) | Correlation |
|---|---|---|---|---|---|---|---|---|---|
| JFM | IMPROVE | 835 | 0.6 | 0.8 | 23.0 | 43.7 | 27.8 | 39.4 | 0.76 |
| JFM | CSN | 260 | 0.9 | 1.2 | 36.8 | 51.1 | 36.6 | 46.0 | 0.68 |
| AMJ | IMPROVE | 802 | 0.8 | 0.7 | -13.1 | 34.7 | -12.9 | 38.4 | 0.76 |
| AMJ | CSN | 223 | 1.0 | 1.2 | 18.7 | 38.4 | 18.5 | 36.6 | 0.68 |
| JAS | IMPROVE | 829 | 0.9 | 0.7 | -25.8 | 42.7 | -42.9 | 57.3 | 0.74 |
| JAS | CSN | 174 | 1.3 | 1.4 | 8.0 | 45.5 | 0.1 | 44.8 | 0.65 |
| OND | IMPROVE | 764 | 0.7 | 0.9 | 22.7 | 45.5 | 14.0 | 40.0 | 0.77 |
| OND | CSN | 131 | 0.9 | 1.3 | 40.1 | 53.1 | 36.0 | 46.6 | 0.75 |
| Annual | IMPROVE | 3230 | 0.8 | 0.8 | -1.9 | 41.4 | -3.7 | 43.9 | 0.72 |
| Annual | CSN | 788 | 1.0 | 1.3 | 24.4 | 46.3 | 23.3 | 43.2 | 0.67 |

**Table 5.7. 2021 Texas Regional Haze Plan Table 8-34: Model Performance Metrics for Particulate Nitrate at IMPROVE and CSN Sites.**



| Period | Network | Obs | Mean (obs) | Mean (mod) | NMB (%) | NME (%) | FB (%) | FE (%) | Correlation |
|---|---|---|---|---|---|---|---|---|---|
| JFM | IMPROVE | 835 | 0.6 | 0.6 | -0.4 | 64.2 | -14.8 | 67.1 | 0.67 |
| JFM | CSN | 259 | 1.4 | 1.5 | 11.5 | 58.0 | 20.0 | 51.6 | 0.58 |
| AMJ | IMPROVE | 802 | 0.2 | 0.2 | -17.5 | 59.2 | -43.2 | 75.2 | 0.78 |
| AMJ | CSN | 223 | 0.4 | 0.5 | 7.7 | 50.2 | 2.9 | 47.7 | 0.77 |
| JAS | IMPROVE | 829 | 0.2 | 0.1 | -16.3 | 77.6 | -65.5 | 91.4 | 0.57 |
| JAS | CSN | 172 | 0.3 | 0.6 | 130.0 | 165.0 | 27.4 | 69.1 | 0.37 |
| OND | IMPROVE | 764 | 0.4 | 0.7 | 69.7 | 95.5 | 30.6 | 69.4 | 0.72 |
| OND | CSN | 131 | 1.3 | 1.9 | 52.9 | 75.5 | 48.8 | 63.6 | 0.64 |
| Annual | IMPROVE | 3230 | 0.3 | 0.4 | 13.8 | 73.4 | -24.1 | 75.9 | 0.69 |
| Annual | CSN | 785 | 0.8 | 1.1 | 29.4 | 68.5 | 21.6 | 56.3 | 0.63 |

In general, model performance metrics and the performance benchmark criteria are not judged on a pass/fail basis, but overall, it is preferable that the criteria are met most of the time for the more important species/pollutants. Referring to Table 5.5, given the criteria and goals of Table 5.4, TCEQ indicated that $PM_{2.5}$ had some overestimation and some underestimation of $PM_{2.5}$ mass. Quarterly normalized mean bias (NMB) met the NMB bias performance criteria for three of the four quarters. Quarterly normalized mean error (NME) met the criteria for three of the four quarters for the IMPROVE sites (1st Quarter was slightly over at 52.1%) and met the criteria for three of the four quarters for the CSN sites (4th Quarter was 60.4%). Quarterly fractionalized bias (FB) and fractional error (FE) criteria were met for all quarters and the goals were met for three of the four quarters for the IMPROVE and CSN sites. TCEQ also indicated that despite some overprediction of soil impacts, the annual NMB was 2.5% for the IMPROVE sites (well within the goal of <±10%) and 25.1% at the CSN sites (within the criteria of <±30%); annual NME was 45.4% and 49.4% (within the <±50% criteria); annual FB and FE were both within the criteria and goals as well.

Referring to Table 5.6, TCEQ indicated that particulate sulfate had some overestimation and some underestimation. Quarterly NMB met bias performance criteria for all the IMPROVE quarters and for two of the four CSN quarters. Quarterly NME met bias performance criteria for the IMPROVE sites and for CSN sites the NME bias performance criteria were met for two of the four quarters and nearly met for the other two quarters.  Quarterly FB and FE criteria were met for all quarters. FB goals were met for three of the four quarters for the IMPROVE and two of the four quarters for CSN sites, and FE goals were met for all quarters at CSN sites and for all but one quarter at IMPROVE sites. TCEQ also reported that the annual NMB was -1.9% for the IMPROVE sites (well within the goal of <±10%) and 24.4% at the CSN sites (within the criteria of <±30%); annual NME was 41.4% and 46.3% (within the <±50% criteria); annual FB and FE were both within the criteria and goals.

Referring to Table 5.7, TCEQ indicated that particulate nitrate model error was more than sulfate because of the more complicated nitrogen chemistry.  The benchmark criteria and goals for nitrate also have wider acceptance levels, as most models have difficulty with nitrate performance.  NMB met bias performance criteria for three of the four quarters for the IMPROVE and CSN sites. The CSN sites met the NMB goals for two of the quarters, and the IMPROVE sites met the NMB goals for one of the quarters as well as the annual goal. NME met the error criteria for all quarters and the goal for two of the four quarters. NME met the error criteria for three of the four quarters and met the goal for two quarters for the CSN sites. FB criteria were met for all quarters for CSN sites and three quarters at IMPROVE sites, and the goals were met or nearly met for two quarters at IMPROVE sites and met for three quarters for CSN sites.  FE criteria was met or nearly met for three quarters at IMPROVE sites and was met for four quarters at CSN sites. The annual NMB was 13.8% for the IMPROVE sites (within the goal of <±15%) and 29.4% at the CSN sites (within the criteria of <±65%); annual NME was 73.4% and 68.5% and within the criteria and slightly exceeding the goal of <±65%; annual FB was within the goal for both IMPROVE and CSN sites; and FE was within the criteria for CSN sites and just over for the IMPROVE sites with 75.9% versus the criteria of <±75%.

TCEQ also evaluated model performance comparing predicted and observed light extinction calculated from PM 2.5 species concentrations at the IMPROVE monitors for the 20% most impaired and clearest days.  See Figures 8-18 and 8-19 of the 2021 Texas Regional Haze Plan. TCEQ concluded that their visibility modeling performance was generally comparable to EPA's 2016 base case model performance (EPA's Updated 2028 Regional Haze Modeling)[57] and was better at predicting particulate nitrate at a number of Class I areas and worse for coarse mass when compared to EPA's 2016 model performance and observations. Texas decided that model performance was adequate for the modeling to be used for their Regional Haze SIP. EPA's evaluation of TCEQ's MPE statistics generally found that it had adequate model performance. EPA's review of these and other MPE analyses concurs that TCEQ's model performance was adequate.

## 5.6. Particulate Matter Source Apportionment (PSAT)

Texas used the CAMx model which includes a Particulate Matter Source Apportionment (PSAT) analysis tool that tracks emissions from user-defined source groups and model-generated emissions to determine their influence on modeled particulate matter concentrations. The TCEQ used PSAT to analyze source contributions from different emission sectors and geographical regions to modeled PM concentrations at IMPROVE monitors for Class I areas in Texas and other nearby states. CAMx version 6.5 can apportion the following classes of particulate matter:

- Particulate Sulfate (PSO4)

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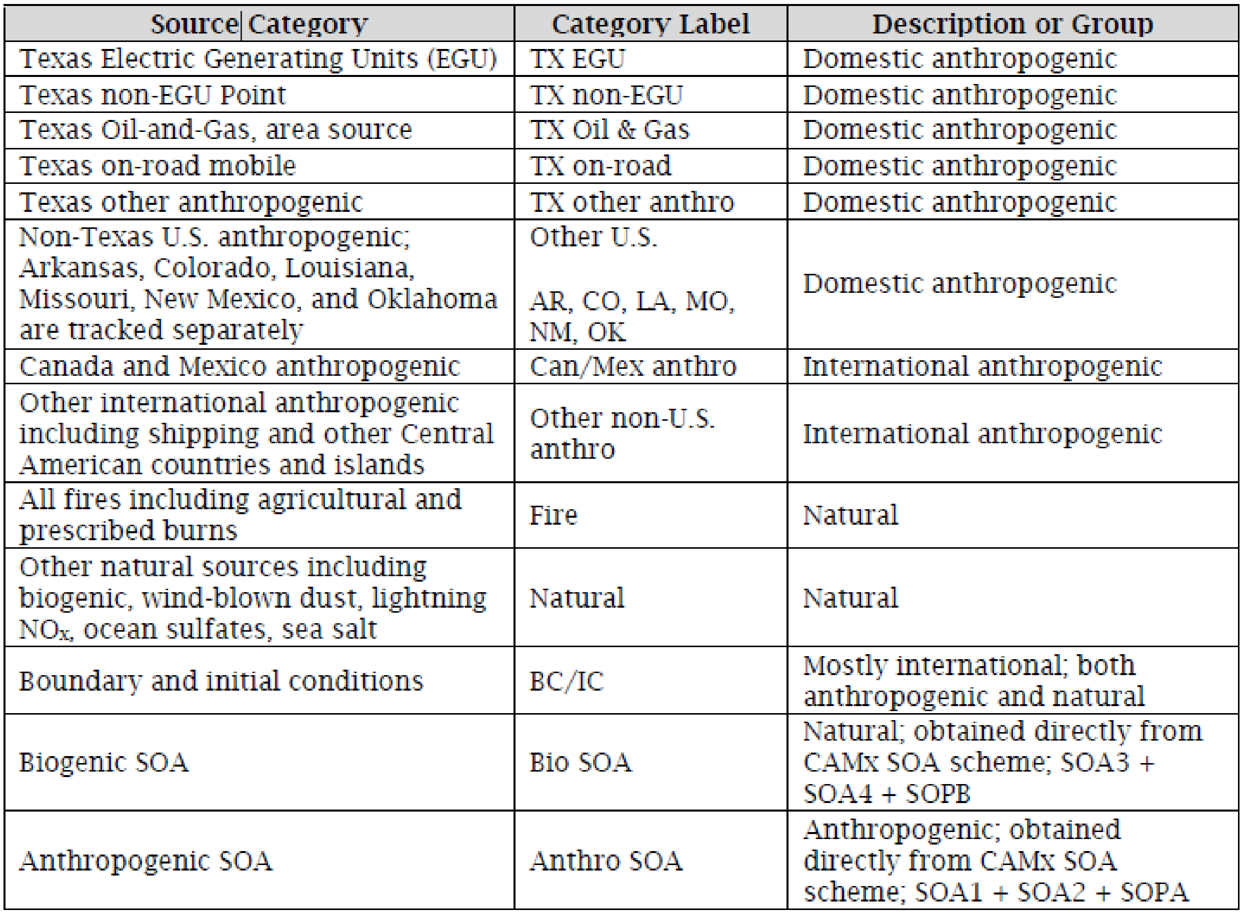
[57] TSD for EPA'S Updated 2028 Regional Haze Modeling: https://www.epa.gov/sites/production/files/2019-10/documents/updated_2028_regional_haze_modeling-tsd-2019_0.pdf, EPA, September 2019.

- Particulate Nitrate (PNO3)
- Particulate Ammonium (PNH4)
- Primary PM (PEC, POA, FCRS, FPRM, CCRS, and CPRM)

Secondary organic aerosol formed from anthropogenic (e.g., aromatics) and biogenic VOC precursors (e.g., isoprene, monoterpene) were obtained directly from CAMx outputs. The anthropogenic SOA is the sum of CAMx species SOA1, SOA2, and SOPA. The biogenic SOA is the sum of CAMx species SOA3, SOA4, and SOPB.

To determine the influence of emissions of interest originating in Texas, neighboring states, and other areas within the modeling grid or boundary conditions, the TCEQ chose the PSAT source categories listed in Table 5.8 which is a replication of Texas SIP Table 8-39: PSAT Emission Source Categories of the 2021 Regional Haze Plan (reproduced below). Industrial sectors in Texas were grouped by type, whereas the rest of the anthropogenic and natural sources in the United States (U.S.) and other areas were grouped by region. Natural sources were kept together across the model domain.

**Table 5.8. 2021 Texas Regional Haze Plan Table 8-39: PSAT Emission Source Categories.**



| Source Category | Category Label | Description or Group |
|---|---|---|
| Texas Electric Generating Units (EGU) | TX EGU | Domestic anthropogenic |
| Texas non-EGU Point | TX non-EGU | Domestic anthropogenic |
| Texas Oil-and-Gas, area source | TX Oil & Gas | Domestic anthropogenic |
| Texas on-road mobile | TX on-road | Domestic anthropogenic |
| Texas other anthropogenic | TX other anthro | Domestic anthropogenic |
| Non-Texas U.S. anthropogenic;<br>Arkansas, Colorado, Louisiana, Missouri, New Mexico, and Oklahoma are tracked separately | Other U.S.<br>AR, CO, LA, MO, NM, OK | Domestic anthropogenic |
| Canada and Mexico anthropogenic | Can/Mex anthro | International anthropogenic |
| Other international anthropogenic including shipping and other Central American countries and islands | Other non-U.S. anthro | International anthropogenic |
| All fires including agricultural and prescribed burns | Fire | Natural |
| Other natural sources including biogenic, wind-blown dust, lightning $NO_x$, ocean sulfates, sea salt | Natural | Natural |
| Boundary and initial conditions | BC/IC | Mostly international; both anthropogenic and natural |
| Biogenic SOA | Bio SOA | Natural; obtained directly from CAMx SOA scheme; SOA3 + SOA4 + SOPB |
| Anthropogenic SOA | Anthro SOA | Anthropogenic; obtained directly from CAMx SOA scheme; SOA1 + SOA2 + SOPA |

In Ramboll Report 2, Ramboll discusses the process of using the CAMx PSAT related modeling files for 2016 and 2028 how the 2028 PSAT results were generated for 2028 source groups in a contract report for TCEQ.[58] Ramboll Report 2 gives a general description of the process that Ramboll followed and explains that they used EPA's Software for the Model Attainment Test (SMAT) in processing the modeling files to generate PSAT results. Ramboll Report 2 summarized the steps as follows (Section 3.4 of Ramboll Report 2 page 28-29):

> 1. Run SMAT using the 2016 and base case 2028 simulations. This creates 2028 projections from species specific RRFs multiplied by baseline observations at each IMPROVE monitor (the same as Step 1 in Section 3.3)
>
> 2. Create "sector tag" SMAT input files as the difference between the base case 2028 total concentrations and the concentration from each sector tag group (e.g., 2028 base case minus 2028 sector tag concentrations).
>
> 3. Run SMAT using the base case 2028 and each 2028 sector tag SMAT input file. This creates sector tag species specific RRFs that are multiplied by the 2028 forecast extinction from Step 1. Ramboll - Regional Haze Modeling to Evaluate Progress in Improving Visibility in and near Texas
>
> 4. Impairment sector contributions are calculated as the differences between Step 3 and Step 1.
>
> 5. Calculate percent contributions of each sector to the total modeled impairment in 2028.

Ramboll indicated that they followed EPA's methodology and refer to EPA's more fully documented step-by step procedures in Appendix C – PSAT Post-Processing Details of EPA's 2019 Modeling TSD.[59]

The Ramboll Report 2 included Table 3-5 (replicated here) that summarizes source contributions (Texas different anthropogenic source groups contributions were grouped together) for the 20% most impaired days.

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[58] "Regional Haze Modeling to Evaluate Progress in Improving visibility in and near Texas Final Report"; Ramboll US Corporation; June 25, 2020 (further referred to as "Ramboll Report 2"). Included in this docket as "Ramboll-RegionalHazeModelingEvaluateProgressVisibility.pdf."

[59] In the docket for this action "EPA 2019 Modeling TSD.pdf."

**Table 5.9. Replication of Ramboll Report 2 Table 3-5.**

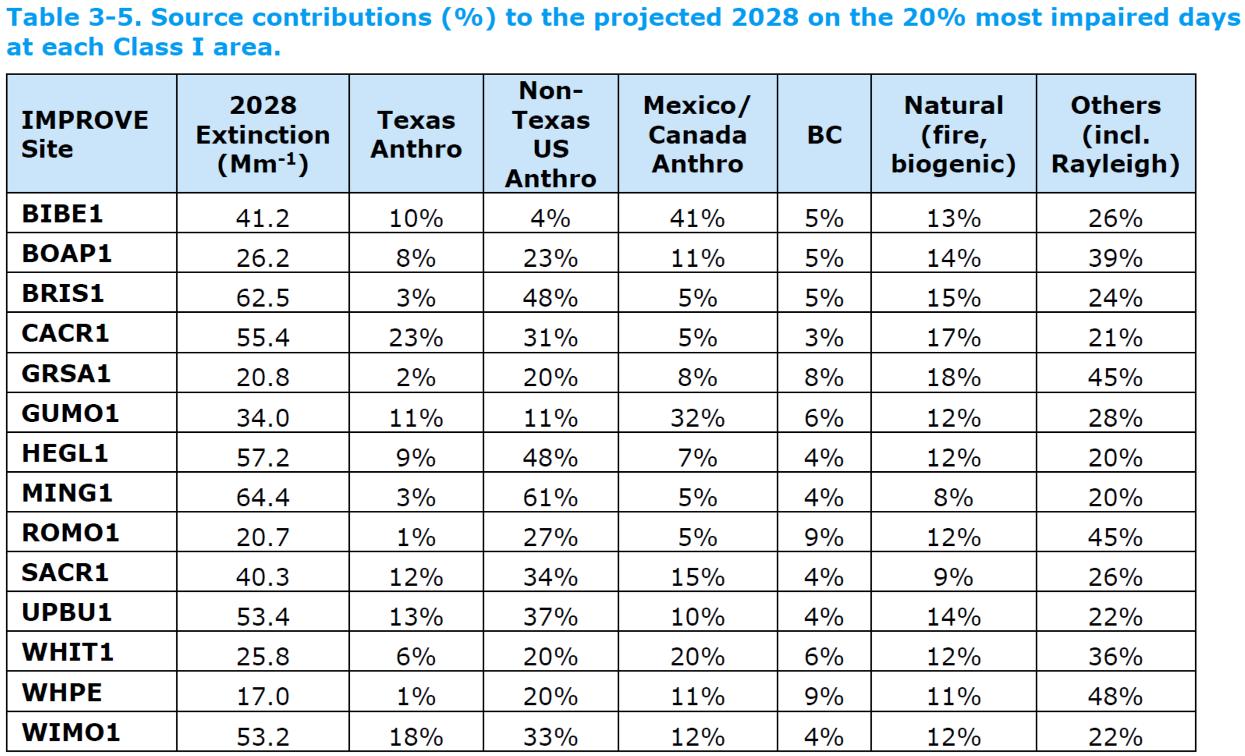

**Table 3-5. Source contributions (%) to the projected 2028 on the 20% most impaired days at each Class I area.**

| IMPROVE Site | 2028 Extinction ($Mm^{-1}$) | Texas Anthro | Non-Texas US Anthro | Mexico/ Canada Anthro | BC | Natural (fire, biogenic) | Others (incl. Rayleigh) |
|---|---|---|---|---|---|---|---|
| **BIBE1** | 41.2 | 10% | 4% | 41% | 5% | 13% | 26% |
| **BOAP1** | 26.2 | 8% | 23% | 11% | 5% | 14% | 39% |
| **BRIS1** | 62.5 | 3% | 48% | 5% | 5% | 15% | 24% |
| **CACR1** | 55.4 | 23% | 31% | 5% | 3% | 17% | 21% |
| **GRSA1** | 20.8 | 2% | 20% | 8% | 8% | 18% | 45% |
| **GUMO1** | 34.0 | 11% | 11% | 32% | 6% | 12% | 28% |
| **HEGL1** | 57.2 | 9% | 48% | 7% | 4% | 12% | 20% |
| **MING1** | 64.4 | 3% | 61% | 5% | 4% | 8% | 20% |
| **ROMO1** | 20.7 | 1% | 27% | 5% | 9% | 12% | 45% |
| **SACR1** | 40.3 | 12% | 34% | 15% | 4% | 9% | 26% |
| **UPBU1** | 53.4 | 13% | 37% | 10% | 4% | 14% | 22% |
| **WHIT1** | 25.8 | 6% | 20% | 20% | 6% | 12% | 36% |
| **WHPE** | 17.0 | 1% | 20% | 11% | 9% | 11% | 48% |
| **WIMO1** | 53.2 | 18% | 33% | 12% | 4% | 12% | 22% |

Ramboll Report 2 included figures with the PSAT results and glidepaths for each Class I area they analyzed. EPA is including figures related to Big Bend and Salt Creek in this TSD. Figures for other Class I areas are available in Ramboll Report 2 and related spreadsheets. The spreadsheet Glidepath_PSAT_Phase1_2014_2017.tz.BG.xlsm and individual spreadsheets for each Class I area[60] (available in the docket for this action), were included in additional documentation the EPA obtained during early engagement in the Fall of 2020. These spreadsheets contain additional information on the PSAT modeling results and analysis, as well as the underlying data used to generate the charts and tables in the 2021 Texas Regional Haze Plan.

### *5.6.1. Big Bend*

As discussed in the notice of proposed rulemaking, the TCEQ's PSAT model results indicate that emissions from Texas anthropogenic sources account for over 10% (4.24 $Mm^{-1}$) of the total light extinction at Big Bend, and 67% of the light extinction due to U.S. anthropogenic emissions. The influence from Texas sources on light extinction at Big Bend is approximately double the influence from anthropogenic sources in the rest of the U.S. combined. The contribution from Texas EGU sources alone (3.4%, 1.4 $Mm^{-1}$) is almost as large as the impairment due to all non-Texas U.S. anthropogenic sources combined (4%, 1.84 $Mm^{-1}$). Figure 5.2 below (Figure 8-21 of the 2021 Texas Regional Haze Plan) shows the PSAT model results for each emission source category in terms of percentage of the total light extinction. Figure 5.3 (Figure 1-51 of the 2021 Texas Regional Haze Plan, Appendix F) shows that visibility

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[60] BIBE.xlsx, SACR.xlsx, BOAP.xlsx, BRIS.xlsx, CACR.xlsx, GRSA.xlsx, GUMO.xlsx, HEGL.xlsx, MING.xlsx, ROMO.xlsx, UPBU.xlsx, WHIT.xlsx, WHPE.xlsx, and WIMO.xlsx are available in the docket.

impairment at Big Bend is primarily due to sulfate (62% of the non-Rayleigh extinction).

**Figure 5.2. 2021 Texas Regional Haze Plan Figure 8-21: PSAT Light Extinction Influence at Big Bend National Park in Texas.**

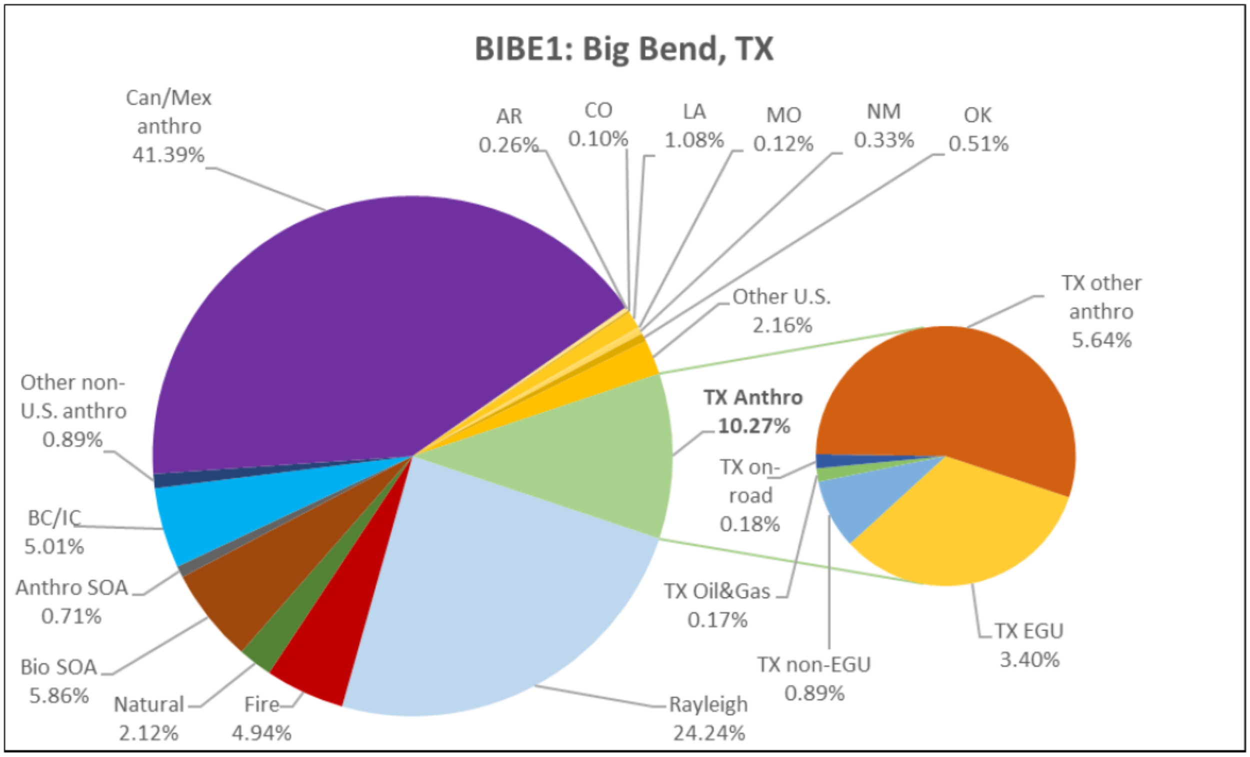


Figure 8-21: PSAT Light Extinction Influence at Big Bend National Park in Texas

**Figure 5.3. 2021 Texas Regional Haze Plan Appendix F Figure 1-51: PSAT Light Extinction Influence at Big Bend National Park in Texas.**

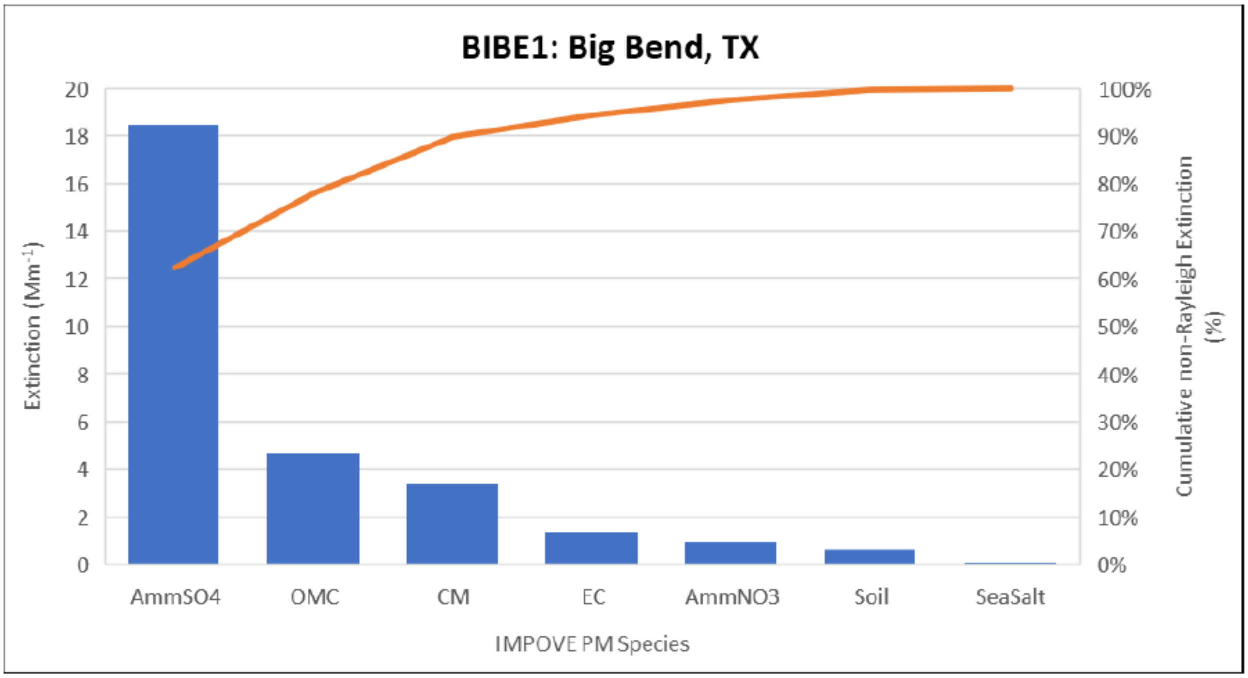


**Figure 1-51: Extinction by Ranked PM Species on the 20% Most Impaired Days at Big Bend**

The influence of Texas sources on sulfate and nitrate concentrations at Big Bend (see Figures 5.4 and 5.5 below) shows that emissions from Texas sources are projected to account for approximately 65.4% of the particulate sulfate concentration and 59.3% of the nitrate concentration due to U.S. anthropogenic emissions. The vast majority (93.9%) of the Texas influence on particulate sulfate concentrations at Big Bend can be attributed to Texas anthropogenic emissions from EGU point (77% of Texas influence) and non-EGU point sources (17% of Texas influence).

**Figure 5.4. Big Bend Particulate Sulfate PSAT contributions (from spreadsheet BIBE.xlsx).**

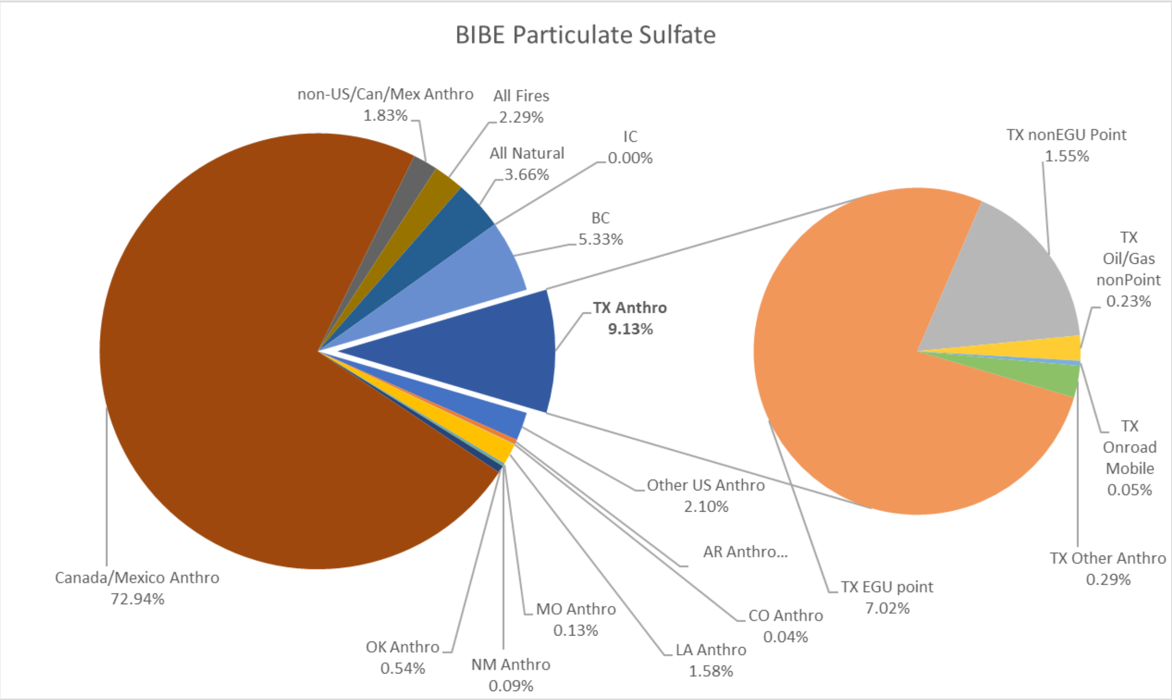


**Figure 5.5. Big Bend Particulate Nitrate PSAT contributions (from spreadsheet BIBE.xlsx).**

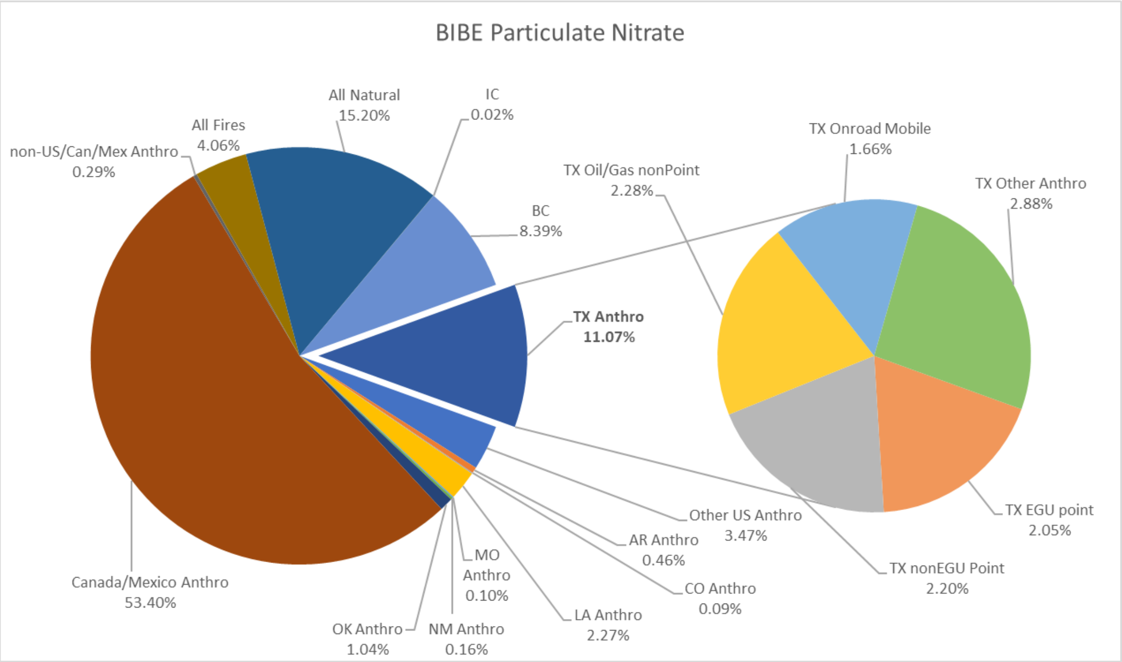


**Figure 5.6. Figure C-1 from Appendix C of Ramboll Report 2.**

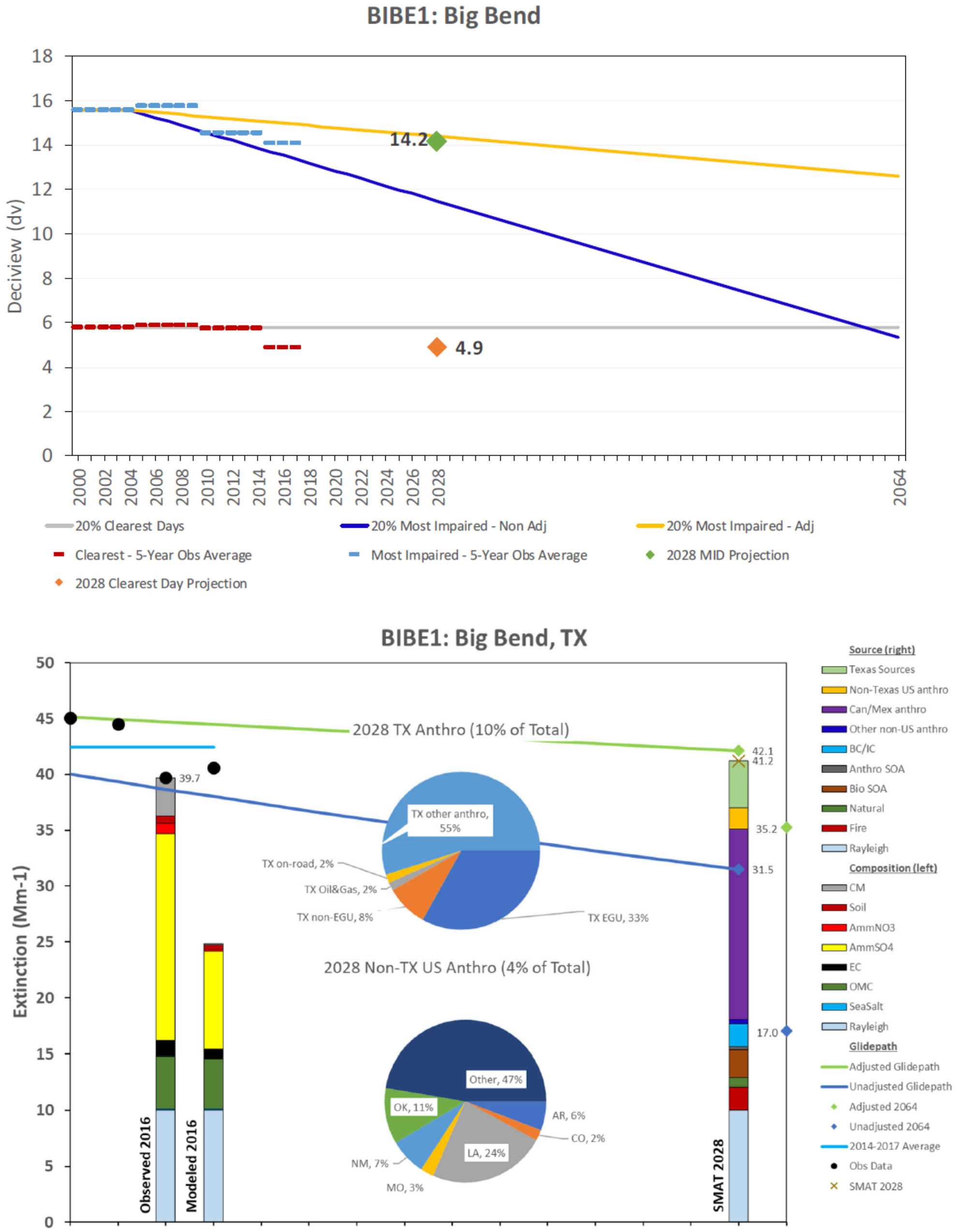


**Figure C-1. Glidepaths in deciview (top) and visibility extinction (bottom) with 2028 sector contributions at BIBE1.**

### *5.6.2. Salt Creek*

Figure 5.8 below shows the PSAT model results for each emission source category in terms of percentage of the total light extinction. Texas's PSAT modeling show that Texas sources account for almost 12% (4.84 $Mm^{-1}$) of the light extinction at Salt Creek. Over half (61%) of the Texas contribution to light extinction is due to Texas EGU (38%) and Texas non-EGU (23%) point sources. Figure 5.7 (Figure 1-60 of the 2021 Texas Regional Haze Plan, Appendix F) shows that visibility impairment at Salt Creek is primarily due to sulfate (32% of the non-Rayleigh extinction) followed by nitrate (24%) and coarse mass (21%).

**Figure 5.7. 2021 Texas Regional Haze Plan Appendix F Figure 1-60: PSAT Light Extinction Influence at Salt Creek Wilderness Area in New Mexico.**

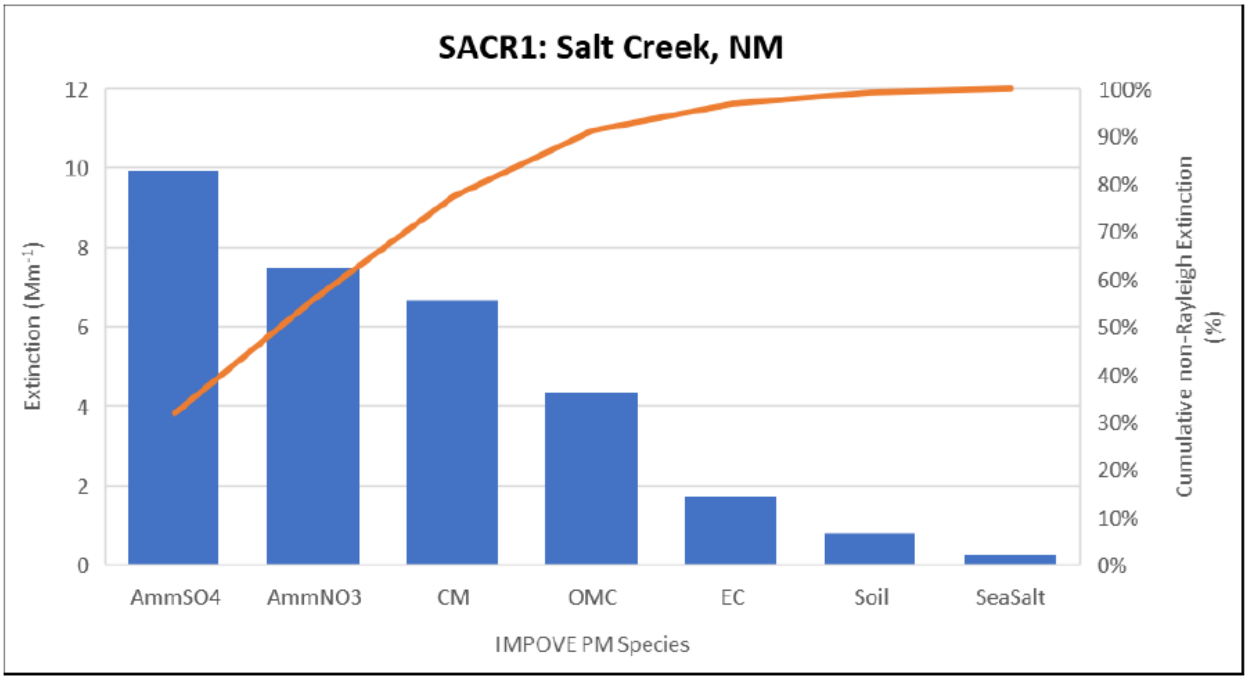
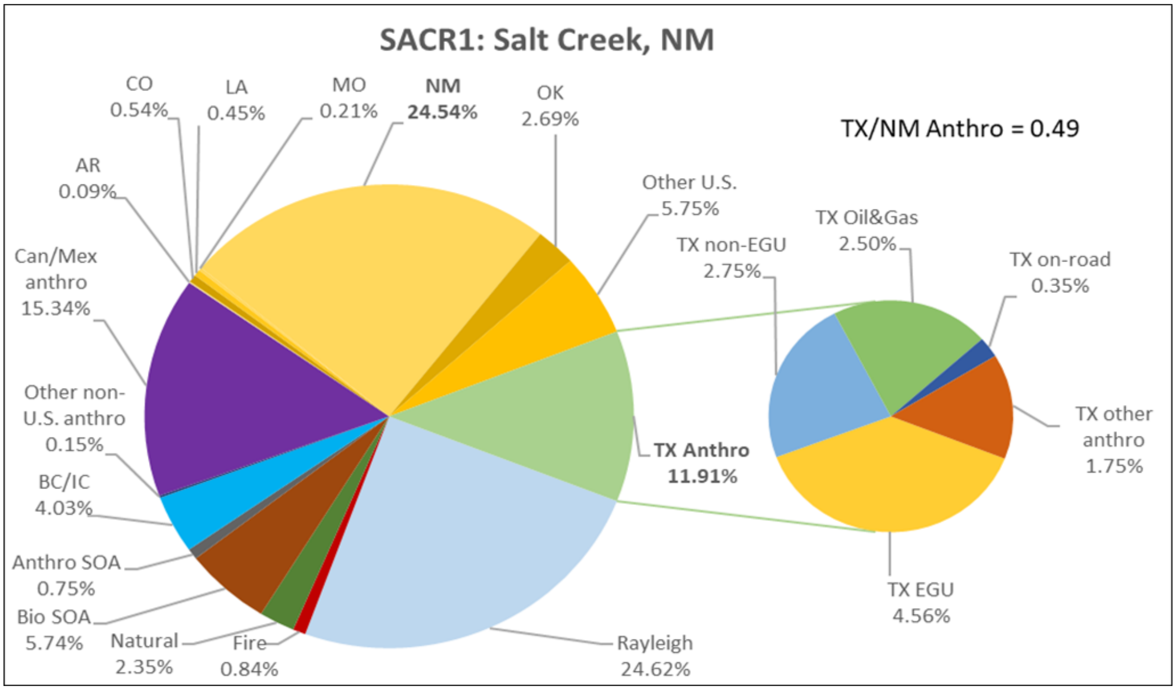


Figure 1-60: Extinction by Ranked PM Species on the 20% Most Impaired Days at Salt Creek

**Figure 5.8. Salt Creek PSAT Contributions (from spreadsheet Glidepath_PSAT_PhaseI_2014-2017.xlsx).**



The influence of Texas sources on sulfate and nitrate concentrations at Salt Creek are shown below (see Figures 5.9 and 5.10 below). Focusing on modeled U.S. anthropogenic impacts alone, Texas anthropogenic sources account for approximately 51.3% of the particulate sulfate concentrations at Salt Creek. The influence from Texas's point sources on particulate sulfate concentrations at Salt Creek is more than double the amount of New Mexico's total (point source, non-point source, and mobile source) influence on particulate sulfate concentrations at Salt Creek. Meaning, $SO_2$ emissions from Texas sources contribute more to visibility impairment at Salt Creek than $SO_2$ emissions from New Mexico sources. The majority (80%) of the Texas influence on particulate sulfate concentrations at Salt Creek can be attributed to Texas anthropogenic emissions from EGU point (52% of Texas influence) and non-EGU point sources (28% of Texas influence).

Focusing on modeled U.S. anthropogenic impacts alone, Texas anthropogenic sources account for approximately 37.8% of the particulate nitrate concentrations at Salt Creek.

Figure 5.9. Salt Creek Particulate Sulfate PSAT Contributions (from spreadsheet SACR.xlsx).

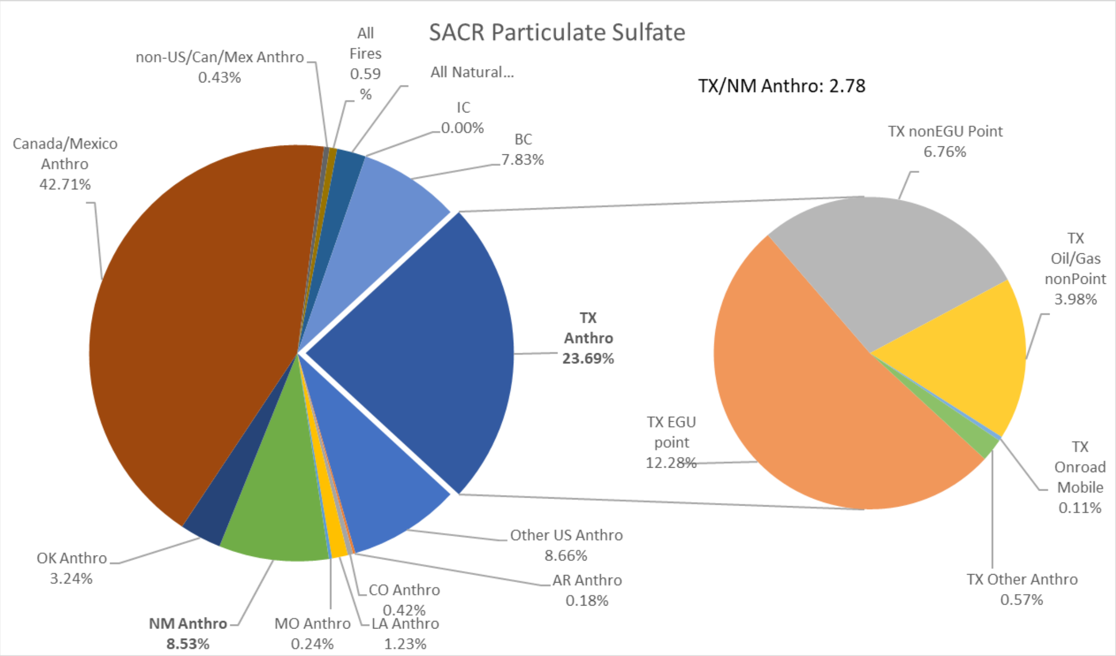


Figure 5.10. Salt Creek Particulate Nitrate PSAT Contributions (from spreadsheet SACR.xlsx).

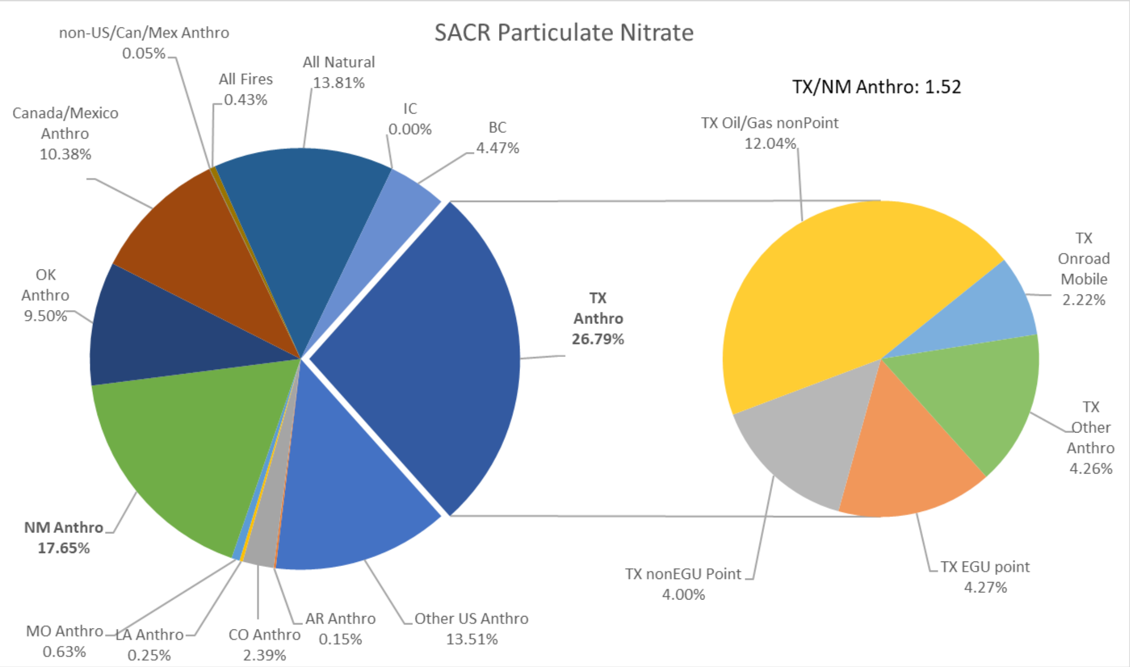


**Figure 5.11. Figure C-10 from Appendix C of Ramboll Report 2.**

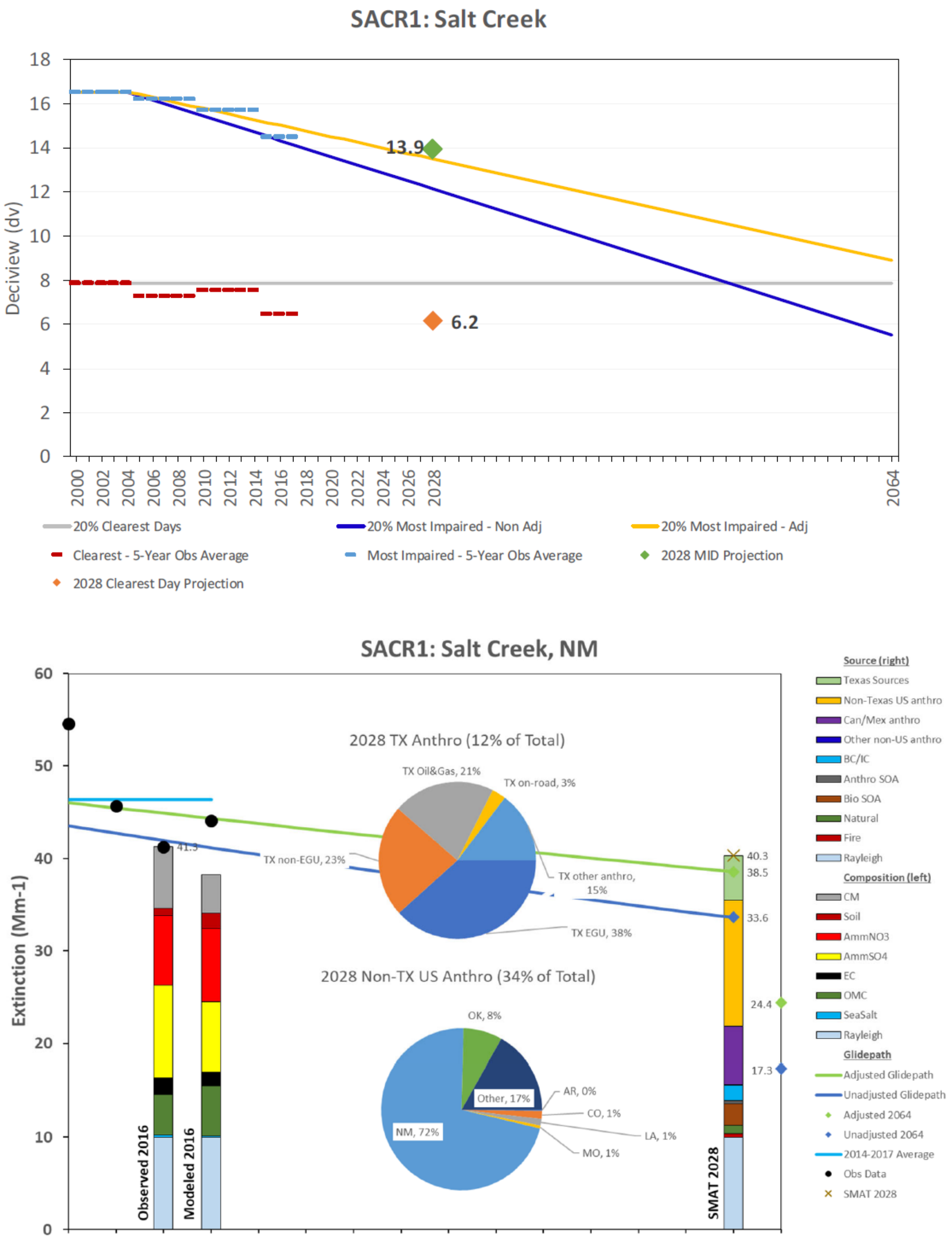


**Figure C-10. Glidepaths in deciview (top) and visibility extinction (bottom) with 2028 sector contributions at SACR1.**

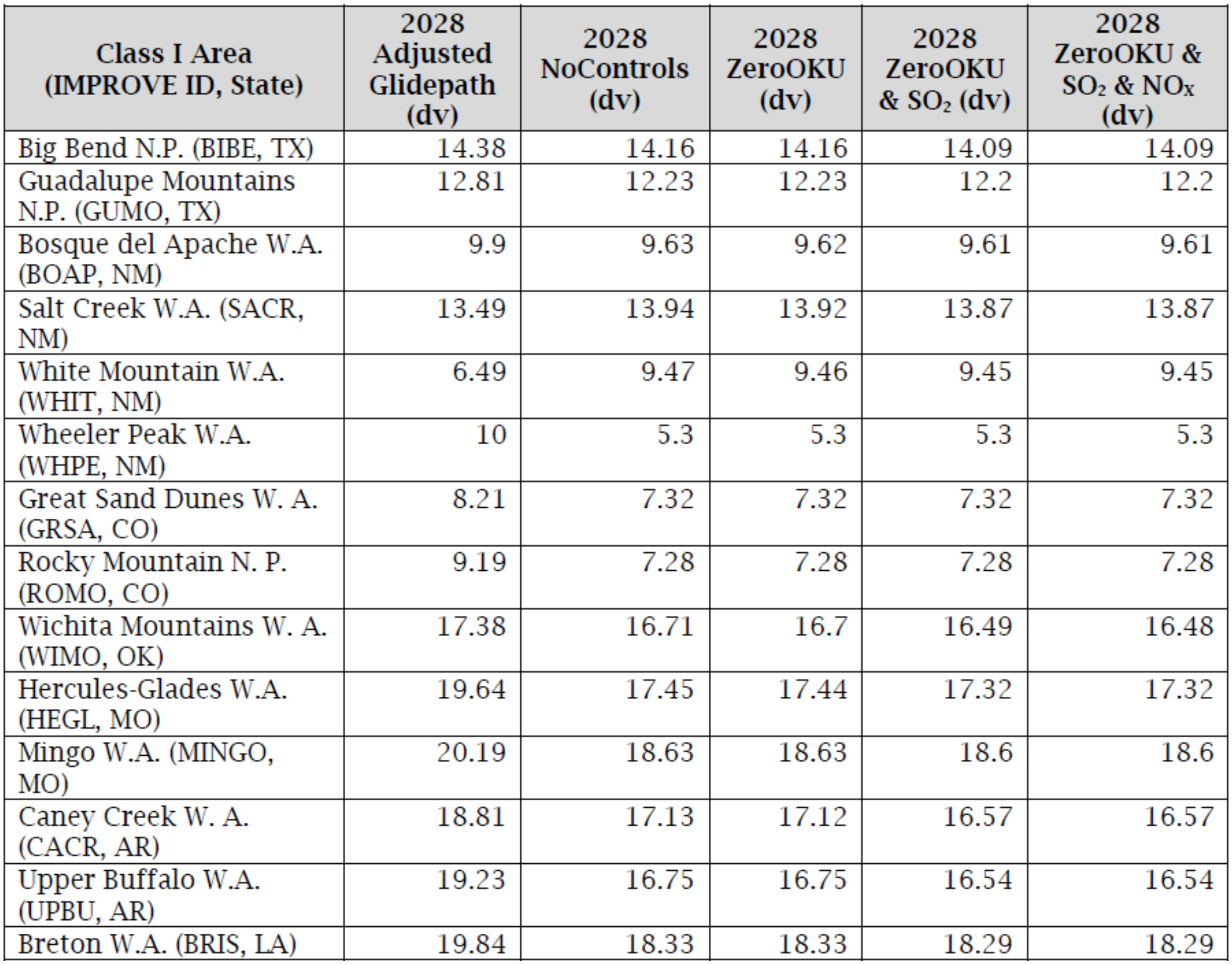
## 5.7. Sensitivity Scenarios

TCEQ performed additional modeling for three sensitivity analysis scenarios to estimate the impact of potential $NO_X$ and $SO_2$ reductions (from potential control measures considered as part of its four-factor analysis) on visibility at Class I areas. The three sensitivity control scenarios were conducted by reducing $NO_X$ and/or $SO_2$ emissions at specific EGU and non-EGU sources based on TCEQ's source selection and four-factor analysis.

- Scenario 1: Removal of the Oklaunion Power. This scenario is labeled ZeroOKU.
- Scenario 2: In addition to Scenario 1, SO2 reductions at the sources that Texas identified as having $SO_2$ control measures meeting its $5,000/ton cost-effectiveness threshold. This scenario is labeled ZeroOKU&SO2.
- Scenario 3: In addition to Scenario 2, NOX reductions at the sources that Texas identified as having $NO_X$ control measures meeting its $5,000/ton cost-effectiveness threshold. This scenario is labeled ZeroOKU&SO2&NOX.

Texas evaluated the difference in projected visibility between these three scenarios and the 2028 base case that represents the on-the-books emission levels. The results of this analysis for the 20% most impaired days are summarized in the Table 5.10 below (Table 8-46 from the 2021 Texas Regional Haze Plan). See the 2021 Texas Regional Haze Plan Section 8.5 and Appendix F, Section 1.3 for additional information. The spreadsheet Base_Control-comparison_2014-2017.tz_BG.xlsx (available in the docket for this action), included as part of additional documentation the EPA obtained during early engagement in the Fall of 2020, contains additional information on the sensitivity scenario modeling results and analysis.

**Table 5.10. 2021 Texas Regional Haze Plan Table 8-46: Sensitivity Run 2028 Visibility Impairment on 20% Most Impaired Days and Adjusted Glidepath.**



| Class I Area (IMPROVE ID, State) | 2028 Adjusted Glidepath (dv) | 2028 NoControls (dv) | 2028 ZeroOKU (dv) | 2028 ZeroOKU & $SO_2$ (dv) | 2028 ZeroOKU & $SO_2$ & $NO_x$ (dv) |
|---|---|---|---|---|---|
| Big Bend N.P. (BIBE, TX) | 14.38 | 14.16 | 14.16 | 14.09 | 14.09 |
| Guadalupe Mountains N.P. (GUMO, TX) | 12.81 | 12.23 | 12.23 | 12.2 | 12.2 |
| Bosque del Apache W.A. (BOAP, NM) | 9.9 | 9.63 | 9.62 | 9.61 | 9.61 |
| Salt Creek W.A. (SACR, NM) | 13.49 | 13.94 | 13.92 | 13.87 | 13.87 |
| White Mountain W.A. (WHIT, NM) | 6.49 | 9.47 | 9.46 | 9.45 | 9.45 |
| Wheeler Peak W.A. (WHPE, NM) | 10 | 5.3 | 5.3 | 5.3 | 5.3 |
| Great Sand Dunes W. A. (GRSA, CO) | 8.21 | 7.32 | 7.32 | 7.32 | 7.32 |
| Rocky Mountain N. P. (ROMO, CO) | 9.19 | 7.28 | 7.28 | 7.28 | 7.28 |
| Wichita Mountains W. A. (WIMO, OK) | 17.38 | 16.71 | 16.7 | 16.49 | 16.48 |
| Hercules-Glades W.A. (HEGL, MO) | 19.64 | 17.45 | 17.44 | 17.32 | 17.32 |
| Mingo W.A. (MINGO, MO) | 20.19 | 18.63 | 18.63 | 18.6 | 18.6 |
| Caney Creek W. A. (CACR, AR) | 18.81 | 17.13 | 17.12 | 16.57 | 16.57 |
| Upper Buffalo W.A. (UPBU, AR) | 19.23 | 16.75 | 16.75 | 16.54 | 16.54 |
| Breton W.A. (BRIS, LA) | 19.84 | 18.33 | 18.33 | 18.29 | 18.29 |

** We note that the 2028 adjusted glidepath dv numbers presented for White Mountain W.A. and Wheeler Peak W.A. were transposed in 2021 Texas Regional Haze Plan Table 8-46. White Mountain W.A. should be 10 dv and Wheeler Peak W.A. should be 6.49 dv.

Figure 5.12 replicates Figure 8-30 in the 2021 Texas Regional Haze Plan which shows the modeled deciview benefit from the shutdown of Oklaunion, with the largest benefits at SACR, WIMO, BOAP, and WHIT and some benefit at all the Class I areas analyzed.

**Figure 5.12. 2021 Texas Regional Haze Plan Figure 8-30: Total Visibility Impairment Change Between the ZeroOKU Sensitivity and 2028NoControls Case.**

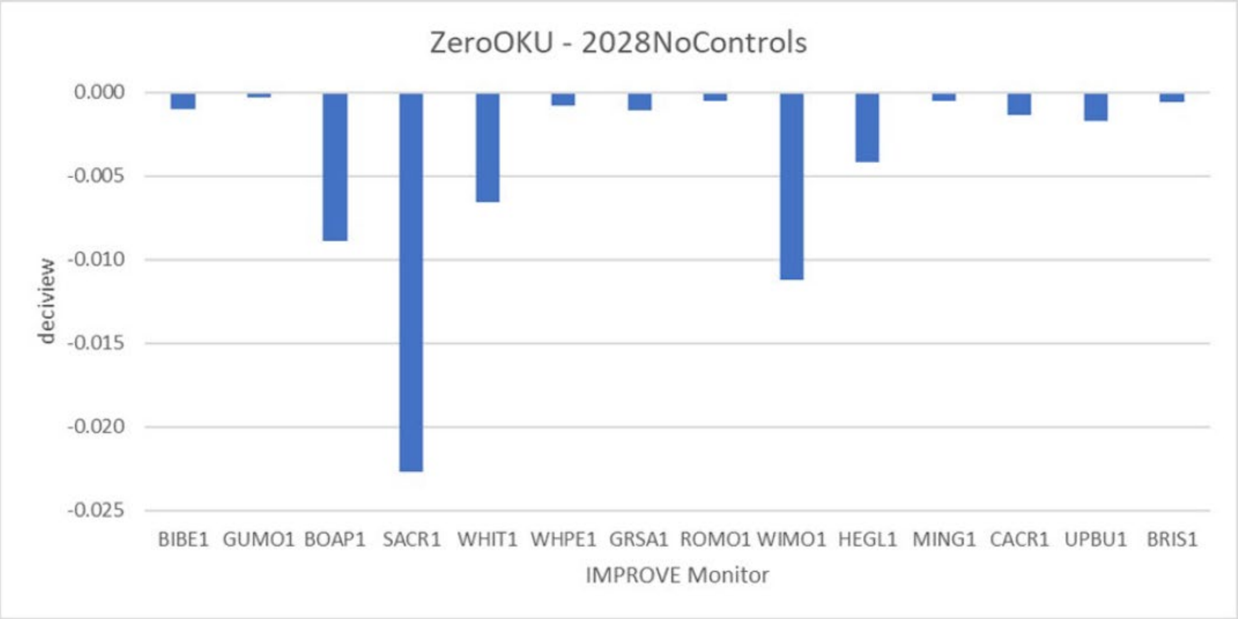


**Figure 8-30: Total Visibility Impairment Change Between the ZeroOKU Sensitivity and the 2028NoControls Case**

Figure 5.13 replicates 2021 Texas Regional Haze Plan Figure 8-33 which shows the modeled deciview benefit from all three control scenarios. The ZeroOKU&SO2 scenario shows a deciview benefit (20%MIDs) at all Class I areas analyzed including at BIBE and SACR. The additional $NO_X$ controls in the ZeroOKU&SO2&NOx control sensitivity provides relatively small deciview benefits compared to the benefits of $SO_2$ controls at facilities other than Oklaunion.

**Figure 5.12. 2021 Texas Regional Haze Plan Figure 8-33: Visibility Impairment Reduction for ZeroOKU, ZeroOKU&SO2, and ZeroOKU&SO2&NOx Sensitivities.**

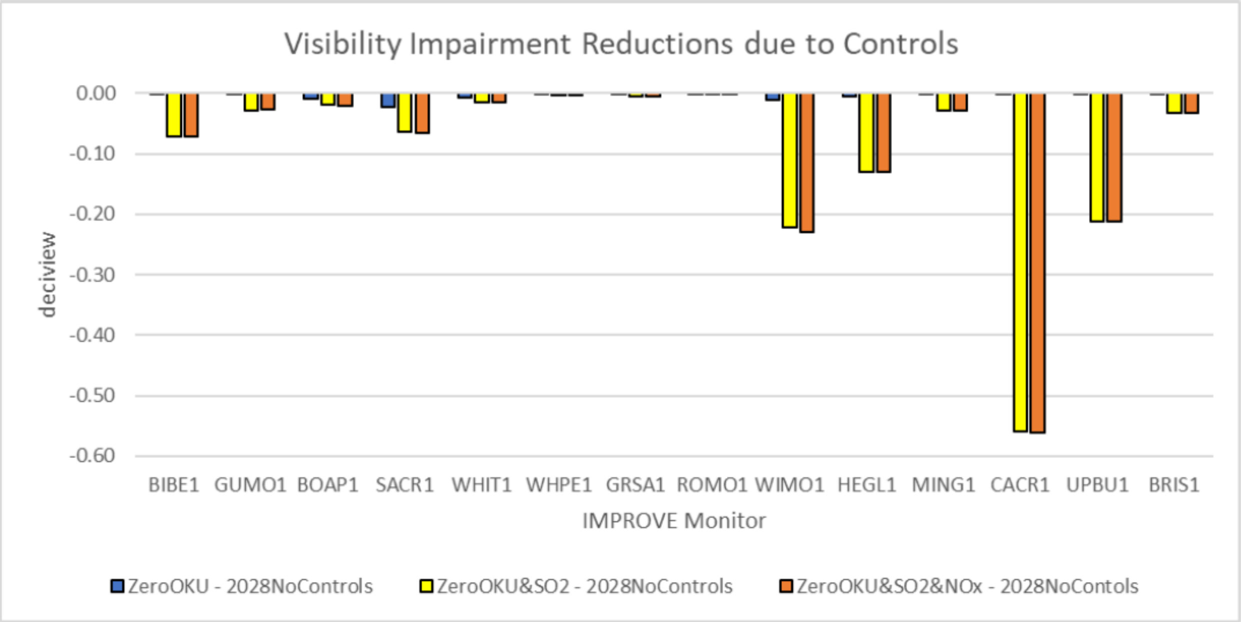


**Figure 8-33: Visibility Impairment Reduction for ZeroOKU, ZeroOKU&SO2, and ZeroOKU&SO2&NOx Sensitivities**

**Figure 5.13. Light Extinction reductions (from Base_Control-comparison_2014-2017.tz_BG.xlsx).**

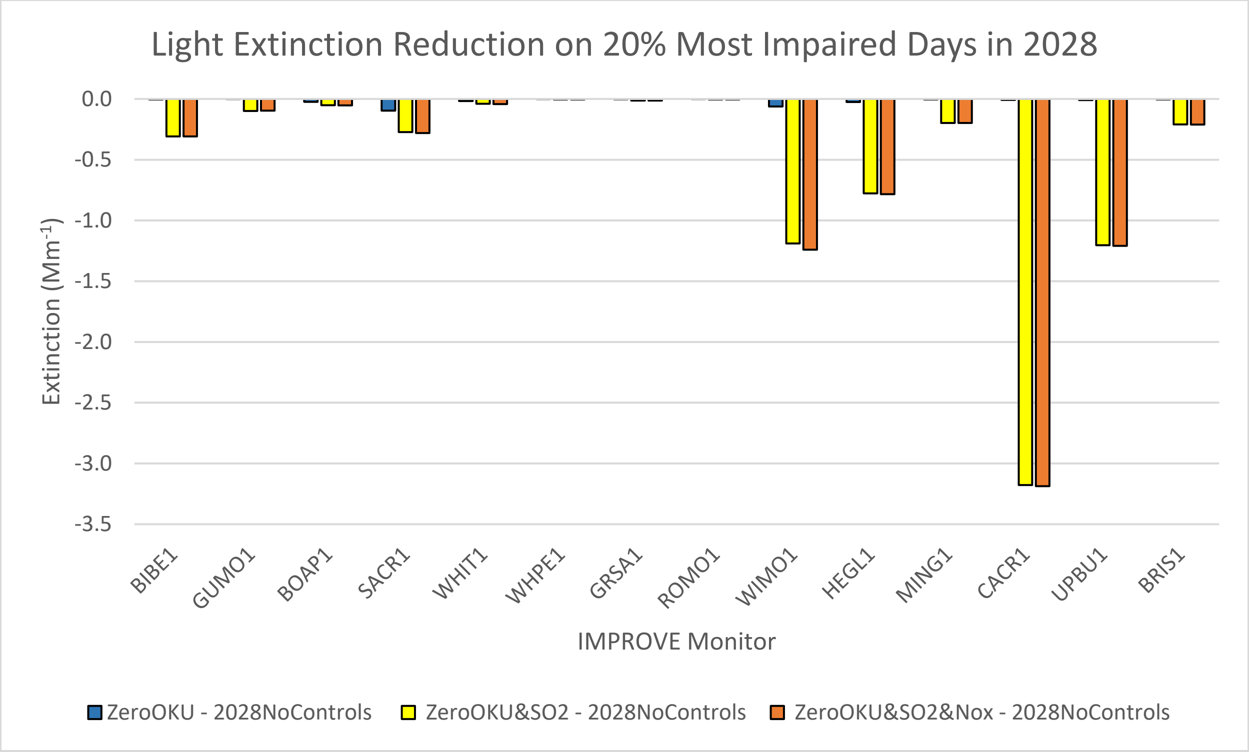


**Table 5.11. Light Extinction ($Mm^{-1}$) Results of Sensitivity Scenarios (from Base_Control-comparison_2014-2017.tz_BG.xlsx).**

| IMPROVE Monitor | 2028 NoControls | ZeroOKU | ZeroOKU - 2028NoControls | ZeroOKU& SO2 | ZeroOKU& SO2 - 2028NoControls | ZeroOKU&SO2 &Nox | ZeroOKU&SO2 &Nox - 2028NoControls |
|---|---|---|---|---|---|---|---|
| BIBE1 | 41.95 | 41.94 | 0.00 | 41.64 | -0.31 | 41.64 | -0.31 |
| GUMO1 | 34.60 | 34.60 | 0.00 | 34.51 | -0.10 | 34.51 | -0.10 |
| BOAP1 | 26.48 | 26.46 | -0.02 | 26.43 | -0.05 | 26.43 | -0.05 |
| SACR1 | 41.31 | 41.21 | -0.10 | 41.03 | -0.27 | 41.03 | -0.28 |
| WHIT1 | 26.52 | 26.50 | -0.02 | 26.48 | -0.04 | 26.48 | -0.04 |
| WHPE1 | 17.30 | 17.30 | 0.00 | 17.30 | 0.00 | 17.30 | 0.00 |
| GRSA1 | 21.06 | 21.06 | 0.00 | 21.05 | -0.01 | 21.05 | -0.01 |
| ROMO1 | 21.34 | 21.33 | 0.00 | 21.33 | 0.00 | 21.33 | 0.00 |
| WIMO1 | 54.58 | 54.51 | -0.06 | 53.39 | -1.19 | 53.33 | -1.24 |
| HEGL1 | 59.17 | 59.15 | -0.03 | 58.39 | -0.78 | 58.39 | -0.78 |
| MING1 | 66.96 | 66.95 | 0.00 | 66.76 | -0.20 | 66.76 | -0.20 |
| CACR1 | 56.94 | 56.94 | -0.01 | 53.77 | -3.18 | 53.76 | -3.19 |
| UPBU1 | 55.12 | 55.11 | -0.01 | 53.91 | -1.20 | 53.91 | -1.21 |
| BRIS1 | 64.57 | 64.57 | 0.00 | 64.36 | -0.21 | 64.36 | -0.21 |

## 6. <u>Visibility Metrics</u>

Consistent with the CAA, "regional haze" is defined at 40 CFR 51.300 as "visibility impairment that is caused by the emission of air pollutants from numerous anthropogenic sources located over a wide geographic area. Such sources include, but are not limited to, major and minor stationary sources, mobile sources, and area sources." This visibility impairment is a result of anthropogenic particles and gases in the atmosphere that scatter and absorb (i.e., extinguish) light, thus acting to reduce overall visibility. The primary cause of regional haze is light extinction by particulate matter (PM). For purposes of the Regional Haze Rule, light extinction is estimated from measurements of PM and its chemical components (sulfate, nitrate, organic mass by carbon (OMC), light absorbing carbon (LAC), fine soil (FS), sea salt, and coarse material (CM)), assumptions about relative humidity at the monitoring site, and the use of a commonly accepted algorithm, the "revised" IMPROVE equation.[61] These estimates of light extinction are logarithmically transformed to deciview units.

The IMPROVE Equation, uses PM species concentrations and relative humidity data to calculate visibility impairment or beta extinction ($B_{ext}$) in units of inverse megameters ($Mm^{-1}$).
Revised IMPROVE equation:

$$\begin{aligned} B_{ext} = \; & 2.2 * fs(RH) * [small\ sulfate] + 4.8 * fL(RH) * [large\ sulfate] \\ & + 2.4 * fs(RH) * [small\ nitrate] + 5.1 * fL(RH) * [large\ nitrate] \end{aligned}$$

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[61] Pitchford, M. L., W. C. Malm, B. A. Schichtel, N. Kumar, D. Lowenthal and J. L. Hand, Revised algorithm for estimating light extinction from IMPROVE particle speciation data, Journal of the Air & Waste Management Association, 57, 1326-1336, 2007.

*+ 2.8 * [small organic mass] + 6.1 * [large organic mass]*
*+ 10 * [elemental carbon]*
*+ 1 * [fine soil]*
*+ 1.7 * fss(RH) * [sea salt]*
*+ 0.6 * [coarse mass]*
*+ Rayleigh scattering (site-specific)* and

fs(RH) = the unitless site-specific water growth factor for small particles as a function of relative humidity (RH),

fL(RH) = the site-specific water growth for large particles,

fss(RH) = the water growth factor for sea salt,

[ ] = particulate matter concentrations in μg/m$^3$, and each particle type has a numeric dry mass extinction efficiency factor in units of (m$^2$/g).

Sulfate is assumed to be all "large sulfate" if total sulfate is over 20 μg/m$^3$, otherwise its fraction of the total is assumed to increase uniformly between 0 and 1 when the total is in the range between 0 and 20 (i.e. large sulfate = (total sulfate/20)*total). A similar definition applies for nitrate and for organic mass. The organic mass is assumed to be 1.8 times the organic carbon mass that is measured by IMPROVE monitors. Sea salt is estimated as 1.8 * [chloride] (or chlorine if chloride not available). The $f_S$, $f_L$, $f_{SS}$ are water growth factors for small ("S") and large ("L") fractions of sulfate and nitrate, and for sea salt ("SS"). Their values depend on relative humidity, ranging from 1 at low humidity to over 5 at 95% humidity.

Rayleigh scattering is the light extinction due to scattering from interaction of light with molecules of the air itself with no pollutants. It is site-specific because it depends on average atmospheric pressure at the site.

The deciview index is then calculated as:

Deciview index = $10 \ln (B_{ext}/10\ Mm^{-1})$

The difference in deciview values or delta deciview is then calculated from the change in extinction using the following equation:

$\Delta dv = 10 \ln((B_{background}+\Delta B_{ext})/ B_{background})$,

where B is extinction ($Mm^{-1}$), $\Delta B_{ext}$ is the change in extinction due to a change in emissions from a source or group of sources, and Δdv is the delta-deciview visibility impact.

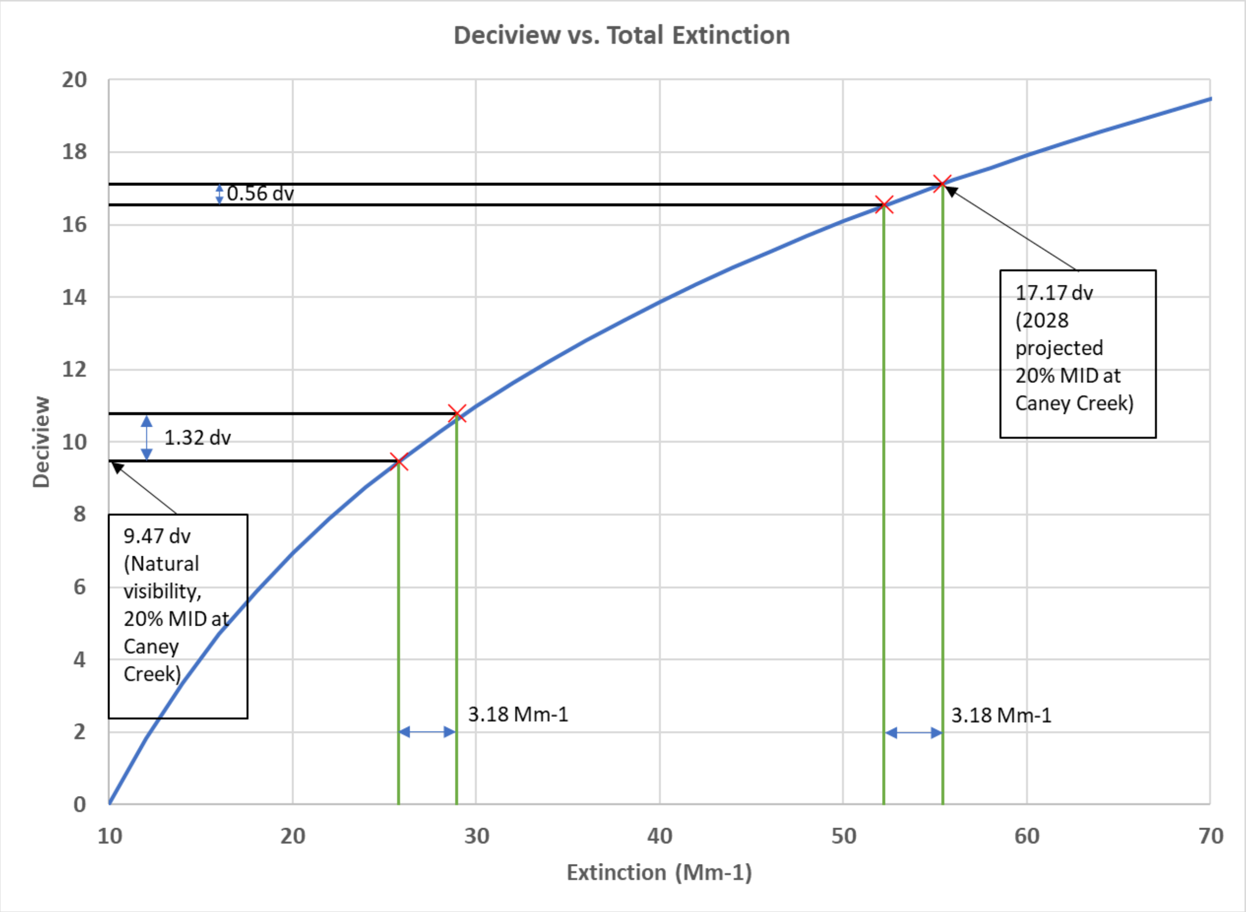
In our 2019 Guidance, we define delta deciview as:

> The difference in the deciview index for two different ambient conditions. This difference can express the visibility impact of a source or the visibility benefit of an emission control measure. For example, the daily visibility impact of a source in delta deciview units is the difference between the deciview index value that would exist if the source were the only anthropogenic source, added to the natural background, and the daily visibility that would exist due to the natural background alone. Because of the logarithmic nature of the deciview scale, the delta deciview value between two ambient conditions with a certain difference in light extinction values depends on the value of the overall light extinction of the less polluted condition and not only on the difference in light extinction.

The 2019 Guidance recommends the use of light extinction units to express visibility impacts and visibility benefits instead of the use of delta deciviews because of how the delta deciview calculation is impacted by the overall light extinction.

Due to the logarithmic relationship between deciviews and extinction, the del-dv (or delta deciview) is dependent upon the point on the deciview-extinction curve where the analysis is completed. For example, see Figure 6.1 which shows the logarithmic relationship and the calculated del-dv change due to a 3.18 ($Mm^{-1}$) change at both the 2028 projected extinction level and the natural visibility conditions extinction level for Caney Creek. For example, see Figure 6.1 which shows the logarithmic relationship and the calculated del-dv change due to a 3.18 $Mm^{-1}$ change at both the 2028 projected extinction level and the natural visibility conditions extinction level for Caney Creek. As discussed elsewhere, Texas's sensitivity modeling estimates that the Scenario 2 control scenario would result in a reduction in extinction at Caney Creek of 3.18 $Mm^{-1}$. In the 'dirty background' case, the 3.18 $Mm^{-1}$ yields a 0.56 del-dv visibility improvement, whereas in the 'clean background' case the same 3.18 $Mm^{-1}$ yields a 1.32 del-dv improvement. In this example, the 'clean background' situation yields a del-dv improvement more than two times greater than the 'dirty background' for the same level of extinction improvement. In the context of evaluating Texas's control scenarios, looking at visibility improvement on a 'clean background' is also important since any emission reductions from controls will continue to provide benefits as other pollutant concentrations decrease in the Class I area atmosphere. This results in further reductions in the calculated extinction levels) and therefore yielding more del-dv benefit over time as the area continues to make progress towards natural condition levels.

**Figure 6.1. Logarithmic Relationship between Deciview versus Total Extinction.**



The ‘clean’ vs. ‘dirty’ background issue can be conceptualized in an analogy by realizing that the deciview scale of visibility is similar to the decibel scale of sound. If a pin is dropped on a table in a quiet room (analogous to a clean background), it can be easily heard. If on the other hand, the same pin is dropped on the same table in a noisy room (analogous to a dirty background), it will not seem as loud in a relative sense. In both cases, the dropped pin makes the same sound (analogous to extinction level), but in the latter case, that sound is partially obscured by the noisy room.

The concern about using existing or “degraded” background conditions in analyzing visibility impacts goes back to EPA’s 2005 BART Rule. In that rule we explained that:

> Using existing conditions as the baseline for single source visibility impact determinations would create the following paradox: the dirtier the existing air, the less likely it would be that any control is required. This is true because of the nonlinear nature of visibility impairment. In other words, as a Class I area becomes more polluted, any individual source's contribution to changes in impairment becomes geometrically less. Therefore, the more polluted the Class I area would become, the less control would seem to be needed from an individual source. We agree that this kind of calculation would essentially raise the "cause or contribute" applicability threshold to a level that would never allow enough emission control to significantly improve visibility. Such a reading would render the visibility provisions meaningless, as EPA and the States would

> be prevented from assuring "reasonable progress" and fulfilling the statutorily-defined goals of the visibility program. Conversely, measuring improvement against clean conditions would ensure reasonable progress toward those clean conditions.[62]

In evaluating benefits of potential controls, Texas considered estimated deciview improvements based on the difference between two different projected 2028 total extinction levels. As discussed above, since Texas's analysis is based on a full photochemical grid model that includes modeling all emissions in the modeling domain, the model results in deciviews are inherently a degraded background analysis and the calculated deciview results are impacted/lowered by emissions from other sources in the analysis. In other words, the overall projected visibility condition from all emission sources impacts the calculated deciview visibility benefit from the evaluated control scenario. The deciview improvement based on the projected 2028 background conditions provides an estimate of the amount of benefit that can be anticipated in 2028 and the impact a control scenario and associated emission reductions may have on the visibility conditions for 2028. However, this estimate based on degraded or "dirty" background conditions underestimates the visibility improvement that would be realized for the control options under consideration. Because of the non-linear nature of the deciview metric, as a Class I area becomes more polluted the visibility impairment from an individual or group of sources in terms of deciviews becomes geometrically less. Relying solely on a quantification of visibility benefits relative to "dirty background,"[63] as Texas did in its 2021 Regional Haze Plan (i.e., conditions with greater impairment than natural background visibility conditions), obscures the full potential benefits of control measures and makes it less likely that a measure, or measures, would appear reasonable from a visibility benefit perspective.[64] Thus, this approach to considering visibility benefit serves to *maintain* the current impairment at Class I areas, which is inconsistent with the statutory goal of the CAA §169A(a)(1) to eliminate future, and remedy existing manmade visibility impairment.

Texas's own modeling results show that had Texas considered the visibility improvement associated with the control scenarios it modeled relative to natural background, the visibility improvement would have been considerably larger. For example, under control Scenario 2, the visibility improvement at Caney Creek would be considerably larger (1.32 deciviews) than the values documented by Texas (0.56 deciview). The right most column of Table 6.1 shows Texas's modeled visibility benefits calculated relative to natural visibility conditions using the 20% most impaired natural visibility conditions.[65] Because Texas's consideration of projected visibility benefits was limited to a dirty background basis, Texas did not consider the full potential benefits associated with each control scenario it evaluated.

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[62] 70 FR 39104, 39124 (July 6, 2005).

[63] *North Dakota v. EPA*, 730 F.3d 750, 764-766 (8th Cir. 2013) ("Although the State was free to employ its own visibility model and to consider visibility improvement in its reasonable progress determinations, it was not free to do so in a manner that was inconsistent with the CAA. Because the goal of § 169A is to attain natural visibility conditions in mandatory Class I Federal areas, see 42 U.S.C. § 7491(a)(1), and EPA has demonstrated that the visibility model used by the State would serve instead to maintain current degraded conditions, we cannot say that EPA acted in a manner that was arbitrary, capricious, or an abuse of discretion by disapproving the State's reasonable progress determination based upon its cumulative source visibility modeling.").

[64] *See* 2019 Guidance at 16, 36.

[65] Natural visibility values obtained from TCEQ spreadsheet Glidepath_PSAT_Phase1_2014_2017.tz.BG.xlsm, "Results Table." The values are also available in "Recommendation for the Use of Patched and Substituted Data and Clarification of Data Completeness for Tracking Visibility Progress for the Second Implementation Period of the Regional Haze Program," https://www.epa.gov/visibility/memo-and-technical-addendum-ambient-data-usage-and-completeness-regional-haze-program. The EPA Office of Air Quality Planning and Standards, Research Triangle Park (June 3, 2020).

**Table 6.1. Visibility Benefit of Texas's Control Scenario 2.**[66]

| Class I Area | IMPROVE Monitor | 2028 Extinction ($Mm^{-1}$) | Texas Anthro | Non-Texas U.S. Anthro | Total US Anthro ($Mm^{-1}$) | Total Anthro from Texas ($Mm^{-1}$) | Texas % of total US anthropogenic impairment | Scenario 2 extinction reduction ($Mm^{-1}$) | Scenario 2 reduction of total US anthropogenic | Scenario 2 reduction of Texas anthropogenic contribution | Scenario 2 extinction reduction (dv) | Scenario 2 extinction reduction compared to Natural conditions (dv) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Caney Creek | CACR1 | 55.4 | 23% | 31% | 29.92 | 12.74 | 43% | -3.18 | ***-10.60%*** | ***-25.00%*** | -0.56 | -1.32 |
| Big Bend | BIBE1 | 41.2 | 10% | 5% | 6.18 | 4.12 | 67% | -0.31 | ***-5.00%*** | ***-7.50%*** | -0.07 | -0.18 |
| Upper Buffalo | UPBU1 | 53.4 | 13% | 38% | 27.23 | 6.94 | 25% | -1.2 | ***-4.40%*** | ***-17.30%*** | -0.21 | -0.48 |
| Wichita Mountains | WIMO1 | 53.2 | 18% | 33% | 27.13 | 9.58 | 35% | -1.19 | ***-4.40%*** | ***-12.40%*** | -0.22 | -0.61 |
| Hercules-Glades | HEGL1 | 57.2 | 9% | 48% | 32.60 | 5.15 | 16% | -0.78 | ***-2.40%*** | ***-15.20%*** | -0.13 | -0.31 |
| Salt Creek | SACR1 | 40.3 | 12% | 34% | 18.54 | 4.84 | 26% | -0.27 | -1.50% | -5.60% | -0.06 | -0.16 |
| Guadalupe Mountains | GUMO1 | 34 | 11% | 11% | 7.48 | 3.74 | 50% | -0.1 | -1.30% | -2.70% | -0.03 | -0.06 |

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[66] See EPA TX contributions to Class I areas.xlsx available in the docket for this action.

# APPENDICES

## Appendix A. Comparison of TCEQ Estimated Scrubber Upgrade Costs to EPA Calculated Costs Using Average Capital and O/M Costs.

| Company/Site Name | Unit | 2018 EIA Electric Capacity/2016 EI Capacity or Engine Rating | Capital Costs | | 15 Year Life Total Annual Cost | | Emissions Removed (tpy) | 15 Year Life Cost Effectiveness ($/ton) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | TCEQ | Avg. | TCEQ | Avg. | | TCEQ | AVG. |
| American Electric Power/Pirkey Power Plant | Unit 1 | 721 MW | $99,921,030 | $27,279,969 | $15,877,183 | $5,817,383 | 3,874 | $4,098 | $1,502 |
| NRG Energy/Limestone Elec. Gen. Station | Unit 1 | 893 MW | $123,757,947 | $33,787,812 | $19,664,805 | $7,205,163 | 3,212 | $6,123 | $2,244 |
| | Unit 2 | 957 MW | $132,627,498 | $36,209,335 | $21,074,153 | $7,721,546 | 3,259 | $6,467 | $2,370 |
| Vistra Energy/Martin Lake Electrical Station | Unit 1 | 793 MW | $109,899,275 | $30,004,182 | $17,462,700 | $6,398,313 | 16,172 | $1,080 | $396 |
| | Unit 2 | 793 MW | $109,899,275 | $30,004,182 | $17,462,700 | $6,398,313 | 14,101 | $1,238 | $454 |
| | Unit 3 | 793 MW | $109,899,275 | $30,004,182 | $17,462,700 | $6,398,313 | 16,458 | $1,061 | $389 |
| San Miguel Electric Cooperative/San Miguel Electric Plant | Unit 1 | 410 MW | $56,820,558 | $15,512,881 | $9,028,634 | $3,308,081 | 2,001 | $4,512 | $1,653 |

**Appendix B**. **Comparison of TCEQ Estimated Scrubber Upgrade Costs to EPA Calculated Costs Using Average Capital and O/M Costs (Excluding Coal Creek Outlier).**

| Company/Site Name | Unit | 2018 EIA Electric Capacity/2016 EI Capacity or Engine Rating | Capital Costs | | 15 Year Life Total Annual Cost | | Emissions Removed (tpy) | 15 Year Life Cost Effectiveness ($/ton) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | TCEQ | Avg.-no outlier | TCEQ | Avg.-no outlier | | TCEQ | Avg.-no outlier |
| American Electric Power/Pirkey Power Plant | Unit 1 | 721 MW | $99,921,030 | $14,072,503 | $15,877,183 | $3,988,328 | 3,874 | $4,098 | $1,029 |
| NRG Energy/Limestone Elec. Gen. Station | Unit 1 | 893 MW | $123,757,947 | $17,429,605 | $19,664,805 | $4,939,773 | 3,212 | $6,123 | $1,538 |
| | Unit 2 | 957 MW | $132,627,498 | $18,678,760 | $21,074,153 | $5,293,800 | 3,259 | $6,467 | $1,625 |
| Vistra Energy/Martin Lake Electrical Station | Unit 1 | 793 MW | $109,899,275 | $15,477,802 | $17,462,700 | $4,386,607 | 16,172 | $1,080 | $271 |
| | Unit 2 | 793 MW | $109,899,275 | $15,477,802 | $17,462,700 | $4,386,607 | 14,101 | $1,238 | $311 |
| | Unit 3 | 793 MW | $109,899,275 | $15,477,802 | $17,462,700 | $4,386,607 | 16,458 | $1,061 | $267 |
| San Miguel Electric Cooperative/San Miguel Electric Plant | Unit 1 | 410 MW | $56,820,558 | $8,002,394 | $9,028,634 | $2,267,981 | 2,001 | $4,512 | $1,133 |