APPENDIX G

MODELING PROTOCOL

2021 REGIONAL HAZE STATE IMPLEMENTATION PLAN
REVISION

PROJECT NUMBER 2019-112-SIP-NR

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TABLE OF CONTENTS

List of Tables ii
List of Figures ii
Chapter 1: Photochemical Modeling Protocol 1
1.1 Introduction 1
1.2 Background 1
1.3 Participating Organizations 2
1.4 Schedule 3
1.5 Conceptual Model 3
1.5.1 Summary of Conceptual Models for Texas Class I Areas 3
1.5.2 Preliminary Conceptual Model - Causes of Haze in Big Bend National Park 4
1.5.3 Preliminary Conceptual Model - Causes of Haze in Guadalupe Mountains National Park 9
1.6 Episode Selection 14
1.7 Models Used 15
1.8 Model Inputs and Sources 15
1.8.1 Meteorological Modeling 15
1.8.2 Emissions Modeling 16
1.8.3 Photochemical Modeling 18
1.9 Modeling Domain Definition 19
1.10 Model Performance Evaluation 20
1.11 Future Year 21
1.12 Regional Haze Technical Analysis Framework 21
1.13 Documentation 22
References 23

LIST OF TABLES

Table 1-1: Schedule of Modeling Activities 3
Table 1-2: Planned Models for Regional Haze SIP Revision Modeling 15
Table 1-3: 2016 Base Case WRF Setup 16
Table 1-4: Summary of Base Case Point Source Emission Data Sources 16
Table 1-5: Summary of Base Case On-Road Mobile Source Emission Data Sources 16
Table 1-6: Summary of Base Case Non-Road Mobile, Off-Road, Area, Oil-and-Gas, and Biogenic Source Emission Data Sources 17
Table 1-7: Summary of Future Case Point Source Emission Data Sources 17
Table 1-8: Summary of Future Case On-Road Mobile Source Emission Data Sources 17
Table 1-9: Summary of Future Case Non-Road Mobile, Off-Road, Area, Oil-and-Gas, and Biogenic Source Emission Data Sources 18
Table 1-10: CAMx Model Configuration and Input Sources 19
Table 1-11: Model Domain Lambert Conformal Map Projection 19
Table 1-12: WRF Modeling Domain Definitions 20

LIST OF FIGURES

Figure 1-1: TCEQ Office of Air Organization Chart 2
Figure 1-2: Big Bend Terrain Map 4
Figure 1-3: Percent Contributions of Major Aerosol Components to Light Extinction on the 20% Most Impaired Days, 2001 through 2018 5
Figure 1-4: Number of Sampling Days in the 20% Most Impaired Days by Month at BIBE1 6
Figure 1-5: Average Contributions of Major Aerosol Chemical Components to Light Extinction During 20% Most Impaired Days in Each Year, 2001 through 2018, at BIBE1 7
Figure 1-6: Normalized Residence Time (Based on Data From 2012 through 2016) for Big Bend 8
Figure 1-7: Normalized Residence Times in 20% Most Impaired Days Weighed by Ammonium Sulfate During 2012 through 2016 for Big Bend 9
Figure 1-8: Terrain Map for Guadalupe Mountains 10
Figure 1-9: Percent Contributions of Major Aerosol Chemical Components to Light Extinction on the 20% Most Impaired Days at GUMO1, Average of 2000 through 2018 11
Figure 1-10: Average Contributions of Major Aerosol Chemical Components to Light Extinction on the 20% Most Impaired Days at GUMO1, Average for Each Year 2000 through 2018 11

Figure 1-11: Number of Sampling Days in the 20% Most Impaired Days in Each Month for GUMO1 12
Figure 1-12: Normalized Residence Time for GUMO1 (Based on Data From 2012 through 2016) 13
Figure 1-13: Normalized Residence Times in 20% Most Impaired Days Weighed by Ammonium Sulfate During 2012 through 2016 14
Figure 1-14: Monthly Distribution of the 20% Most Impaired Visibility Days at 14 Monitors In and Around Texas 15
Figure 1-15: IMPROVE Monitors In and Near Texas 21

CHAPTER 1: PHOTOCHEMICAL MODELING PROTOCOL

1.1 INTRODUCTION

The Texas Commission on Environmental Quality (TCEQ) will conduct modeling in support of the 2021 Regional Haze State Implementation Plan (SIP) Revision, hereafter referred to as the Regional Haze SIP Revision. The United States Environmental Protection Agency's (EPA) 2018 Modeling Guidance for Demonstrating Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze, hereafter referred to as 2018 modeling guidance, recommends that the following topics be core elements of any modeling protocol:

- Overview of the air quality issue being considered including historical background;
- List of the planned participants in the analysis and their expected roles;
- Schedule for completion of key steps in the analysis and final documentation;
- Description of the conceptual model for the area;
- Description of periods to be modeled, how they comport with the conceptual model, and why they are sufficient;
- Models to be used in the demonstration and why they are appropriate;
- Description of model inputs and their expected sources (e.g., emissions, meteorology, etc.);
- Description of the domain to be modeled (expanse and resolution);
- Process for evaluating base year model performance (meteorology, emissions, and air quality) and demonstrating that the model is an appropriate tool for the intended use;
- Description of the future years to be modeled and how projection inputs will be prepared;
- Description of the attainment test procedures and (if known) planned weight of evidence;
- Expected diagnostic or supplemental analyses needed to develop weight of evidence analyses; and
- Commitment to specific deliverables fully documenting the completed analysis.

This protocol will address each of these components for the modeling and data analysis in support of the Regional Haze SIP Revision following the 2018 modeling guidance.

1.2 BACKGROUND

The TCEQ will conduct photochemical grid modeling in support of the 2021 Regional Haze SIP Revision. This modeling will follow the EPA's modeling guidance.

The modeling guidance recommends several qualitative methods that acknowledge the limitations and uncertainties of photochemical models when used to project particulate matter concentrations into future years. First, the modeling guidance recommends using model results in a relative sense and applying the model response to the observed particulate matter concentration data and calculated visibility impairment. Second, the modeling guidance recommends using available air quality, meteorology, and emissions data to develop a conceptual model for visibility impairment and to use that analysis in episode selection. Third, the modeling guidance

recommends using other analyses, i.e., weight of evidence, to supplement and corroborate the model results.

1.3 PARTICIPATING ORGANIZATIONS

The TCEQ plans to conduct the meteorological modeling and portions of the photochemical modeling used in this Regional Haze SIP Revision on its own Linux computing clusters. TCEQ's Air Modeling and Data Analysis (AMDA) section has the responsibility for planning and conducting the SIP modeling. AMDA is part of the Air Quality Division of TCEQ's Office of Air. The Office of Air organization chart is shown in Figure 1-1: *TCEQ Office of Air Organization Chart.*

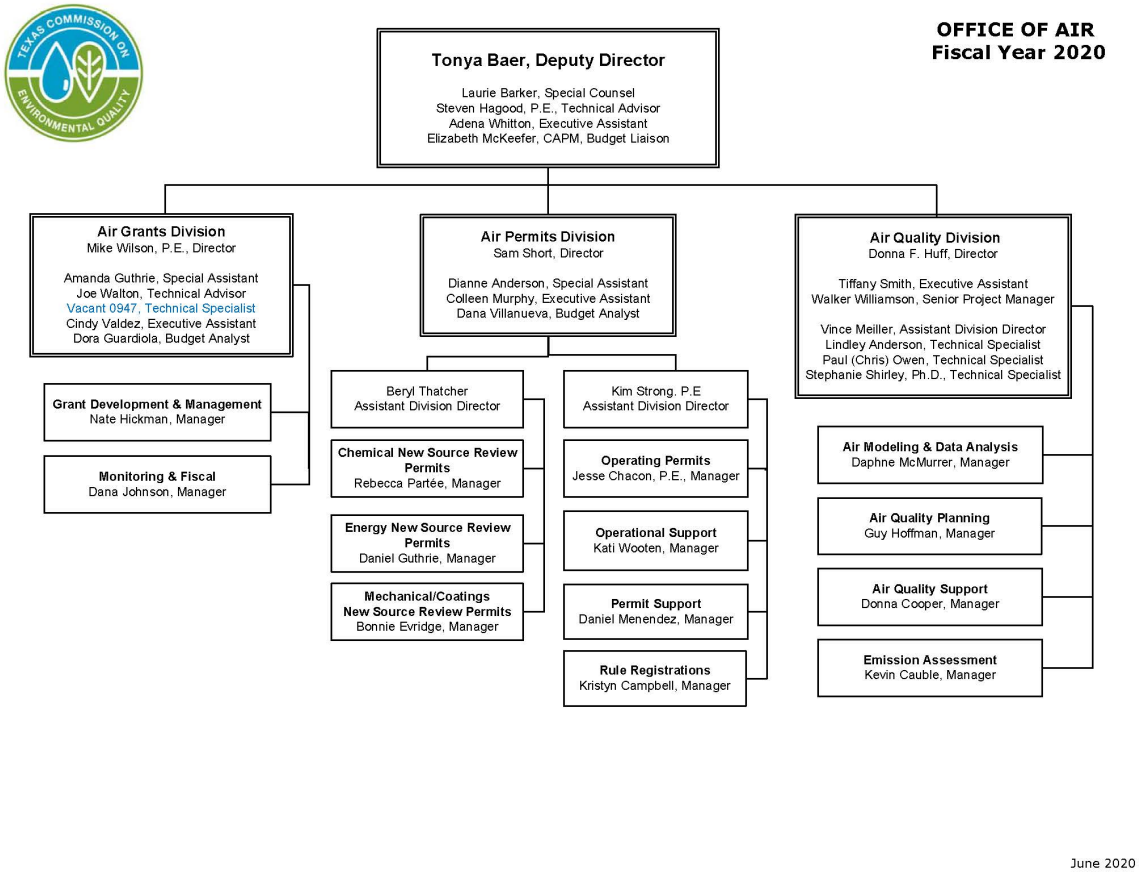

Figure 1-1: TCEQ Office of Air Organization Chart

The TCEQ is part of the 2016 National Emissions Collaborative and participated in the 2016 platform development along with the EPA, other states, and multi-jurisdiction air pollution control organization. In addition, the TCEQ is also part of the effort by EPA to conduct model performance evaluation for photochemical modeling using the 2016 National Emissions Collaborative platform. To aid in post-processing, the TCEQ will utilize contracting resources.

1.4 SCHEDULE

The schedule of activities for completing modeling activities for the Regional Haze SIP Revision is shown below in Table 1-1: *Schedule of Modeling Activities.*

Table 1-1: Schedule of Modeling Activities

Modeling Activity	Time Frame
Base Case • Develop base case emissions • Evaluate meteorological modeling • Conduct emissions modeling and processing • Conduct base case photochemical modeling • Conduct model performance evaluations	2018 – Fall 2019
Future Case • Develop future base emissions with applicable growth and current controls • Conduct future base modeling and source apportionment • Project future visibility impairment at all Class I area monitors • Estimate international anthropogenic emissions contribution to adjust 2064 endpoint • Evaluate source apportionment results	Fall 2019 – Spring 2020

1.5 CONCEPTUAL MODEL

1.5.1 Summary of Conceptual Models for Texas Class I Areas

The goal of the Regional Haze Rule is to prevent future and remedy existing anthropogenic visibility impairment in Class I areas. The Interagency Monitoring of Protected Visual Environments (IMPROVE) program was initiated in 1985[1] and implemented a long-term monitoring program to track changes in visibility and determine causes of visibility impairment in the National Parks and Wilderness Areas. There are two Class I areas in Texas: Big Bend National Park and Guadalupe Mountains National Park. Texas Class I areas are impacted by both anthropogenic and natural emissions including ammonium sulfate and ammonium nitrate, which are primarily formed from anthropogenic emissions of SO_2 and NO_X, as well as naturally occurring dust and fire emissions. Ammonium sulfate transported from the southeast of these two locations and from northeastern Mexico are major causes of haze at Big Bend and Guadalupe Mountains National Parks. In addition, dust from areas near the Mexico, New Mexico and Arizona border in the spring are important sources of haze at both areas. Organics associated with fires in the spring and dust transported from northern Africa in the summer also have important contributions to regional haze during those episodes[2,3].

[1] http://vista.cira.colostate.edu/Improve/
[2] Western Regional Air Partnership Causes of Haze Assessment https://www.air-resource.net/COHA/
[3] Big Bend Regional Aerosol and Visibility Observational Study (BRAVO) https://vista.cira.colostate.edu/Improve/big-bend-regional-aerosol-and-visibility-observational-bravo/

1.5.2 Preliminary Conceptual Model - Causes of Haze in Big Bend National Park

Ammonium sulfate transported from the eastern United States and from point sources in the northeastern Mexico, as well as dust from west of the monitoring site along the Mexico, New Mexico, and Arizona border in the spring are major causes of haze at the Big Bend National Park. Organics associated with fires in the spring and dust transported from northern Africa in the summer also have important contributions to regional haze during those episodes.

The Big Bend monitoring site (BIBE1) is located ~4 kilometers (km) (2.5 miles) southeast of Panther Junction, within Big Bend National Park, at a site elevation of 1,075 meters (3,526 feet). As shown in Figure 1-2: *Big Bend Terrain Map*, the average non-Rayleigh light extinction (Bext) on the 20% most impaired days is 36.3 inverse megameters (Mm^{-1}) (deciview ~12.9, visual range ~66.8 miles). The average contributions of the major aerosol components to Big Bend National Park haze are ammonium sulfate 67%, ammonium nitrate 4%, organic matter 13%, elemental carbon 5%, fine soil 3%, and coarse mass 9%.

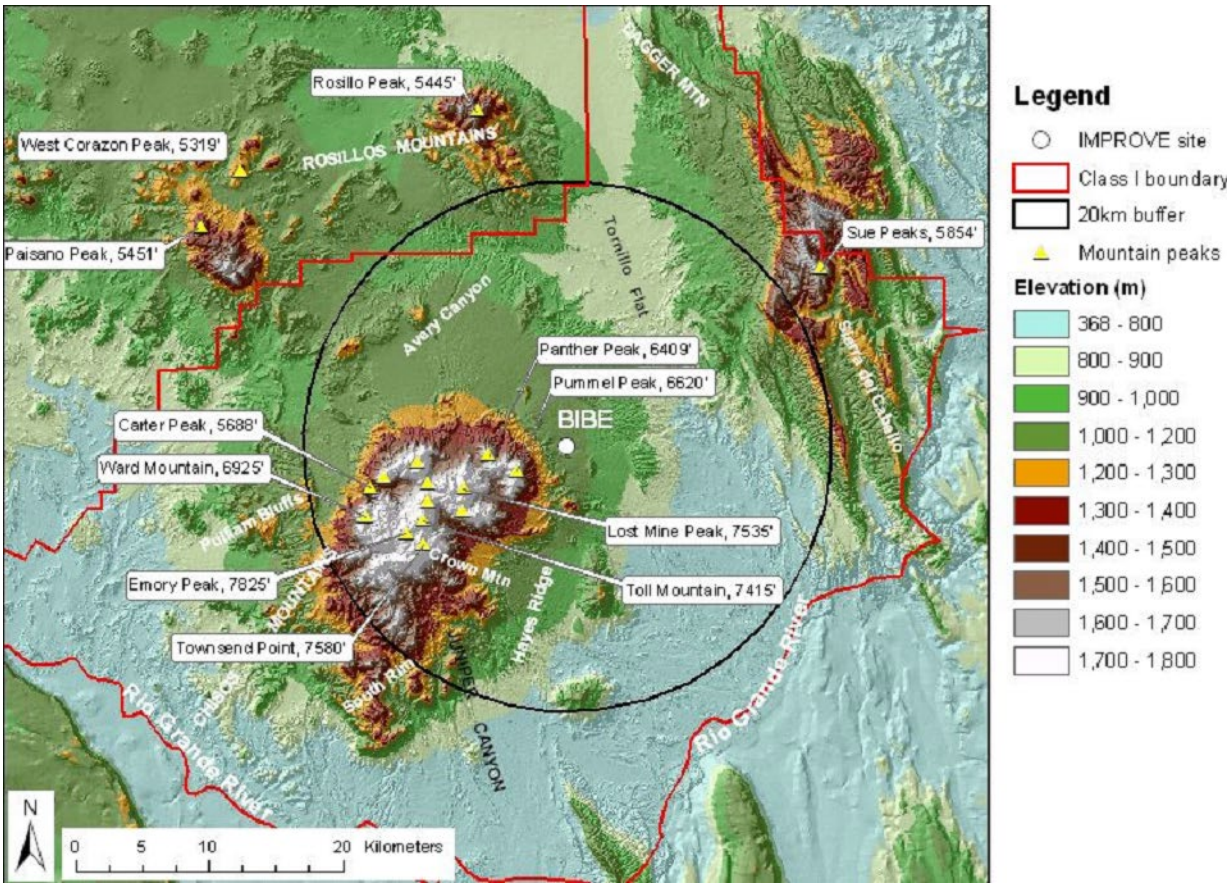

Figure 1-2: Big Bend Terrain Map

Figure 1-3: *Percent Contributions of Major Aerosol Components to Light Extinction on the 20% Most Impaired Days, 2001 through 2018* shows the percentage contributions of major aerosol components to light extinction on the 20% most impaired days (based

on data available from 2001 through 2018)[4]. The BIBE monitor did not achieve data completeness for the year 2000.

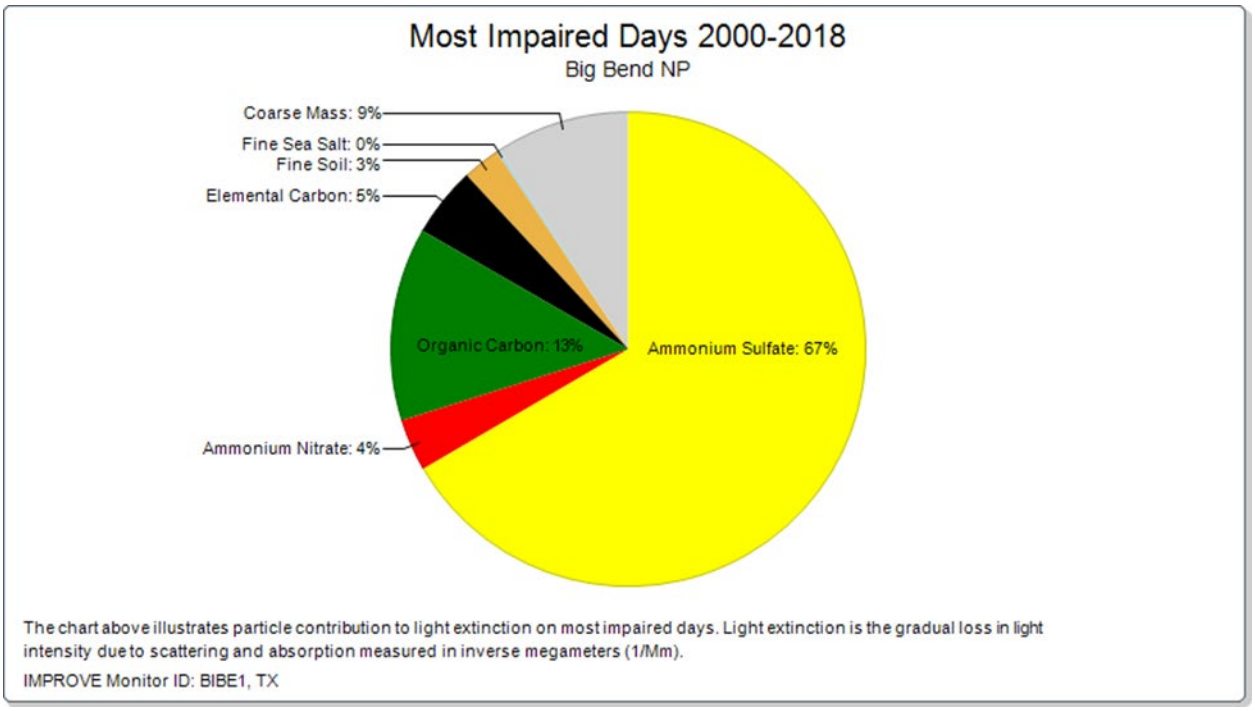

Figure 1-3: Percent Contributions of Major Aerosol Components to Light Extinction on the 20% Most Impaired Days, 2001 through 2018

Figure 1-4: *Number of Sampling Days in the 20% Most Impaired Days by Month at BIBE1*[5] shows the monthly distribution of sample days in the 20% most impaired category. The highest occurrence of the 20% most impaired days occurred in August and September when 62 and 63, respectively, of the most impaired days in 2001 through 2018 were observed.

[4] http://views.cira.colostate.edu/fed/
[5] *Id*

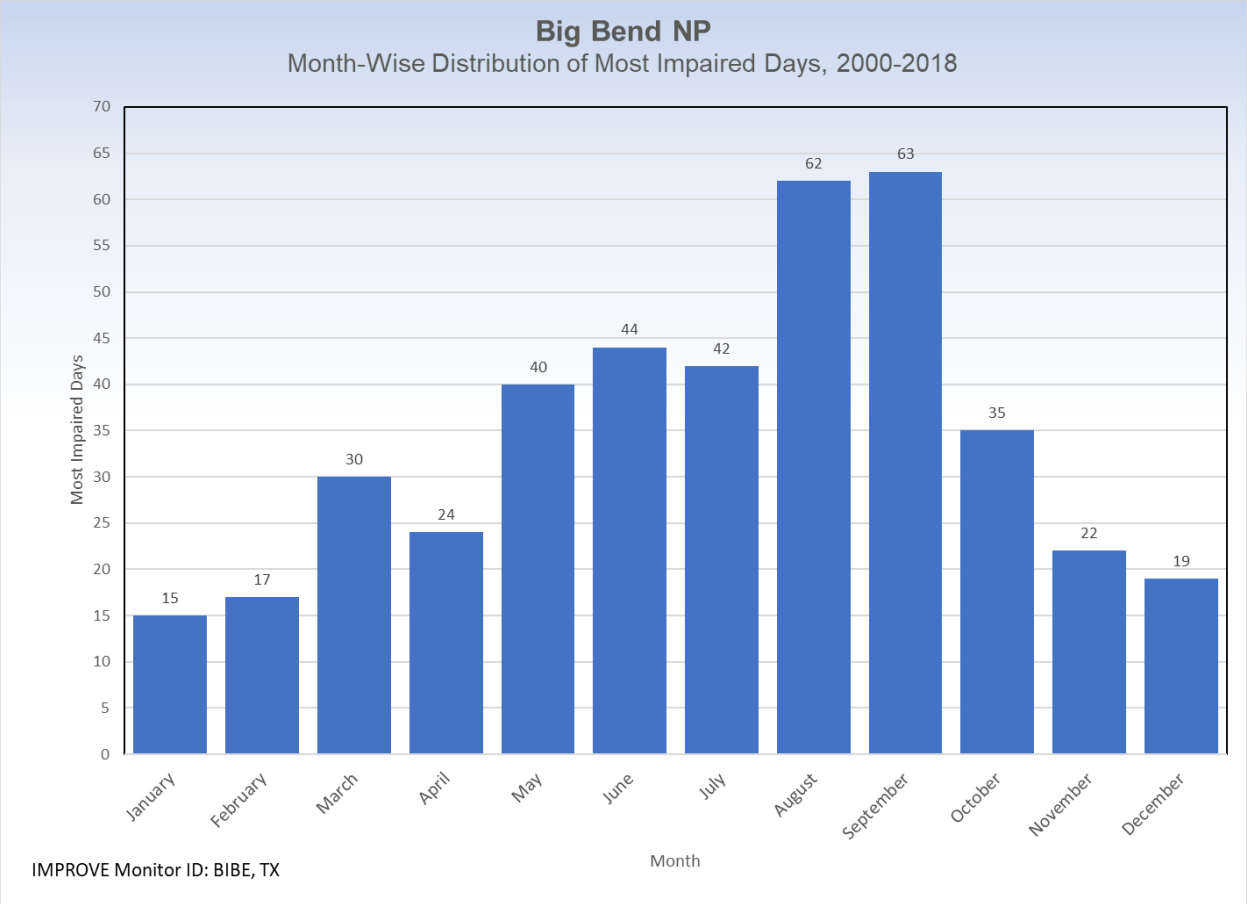

Figure 1-4: Number of Sampling Days in the 20% Most Impaired Days by Month at BIBE1

As shown in Figure 1-3 for all years and Figure 1-5: *Average Contributions of Major Aerosol Chemical Components to Light Extinction During 20% Most Impaired Days in Each Year, 2001 through 2018, at BIBE1*[6], ammonium sulfate is the largest aerosol contributor to haze in the 20% most impaired days throughout the 2001 through 2018 time period and that ammonium sulfate has decreased during this period.

[6] http://views.cira.colostate.edu/fed/

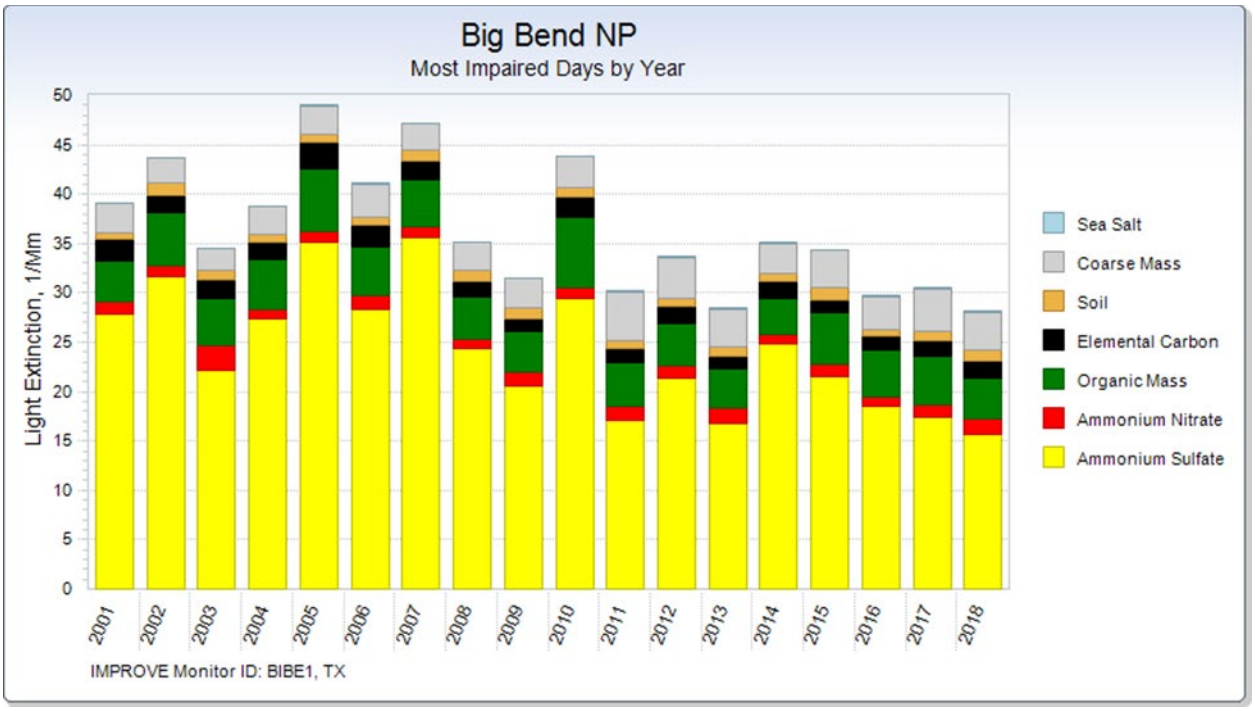

Figure 1-5: Average Contributions of Major Aerosol Chemical Components to Light Extinction During 20% Most Impaired Days in Each Year, 2001 through 2018, at BIBE1

From individual trajectories, generated using the Hybrid Single Particle Lagrangian Integrated Trajectory Model, residence time fields were calculated for a 32 by 32 grid surrounding the Class I area with approximately one-degree latitude by one-degree longitude grid cells. Residence time analysis computes the amount of time an air parcel is in a horizontal grid cell. Plotted on a map, residence time is shown as percent of total hours in each grid cell across the domain, thus allowing an interpretation of general air flow patterns for a given Class I area. The residence time fields for the 20% most anthropogenically impaired days were selected for the analysis to highlight the emissions sources that may be contributing to visibility impairment during those specific periods. Figure 1-6: *Normalized Residence Time (Based on Data From 2012 through 2016) for Big Bend* shows that the main flow direction is from the southeast.

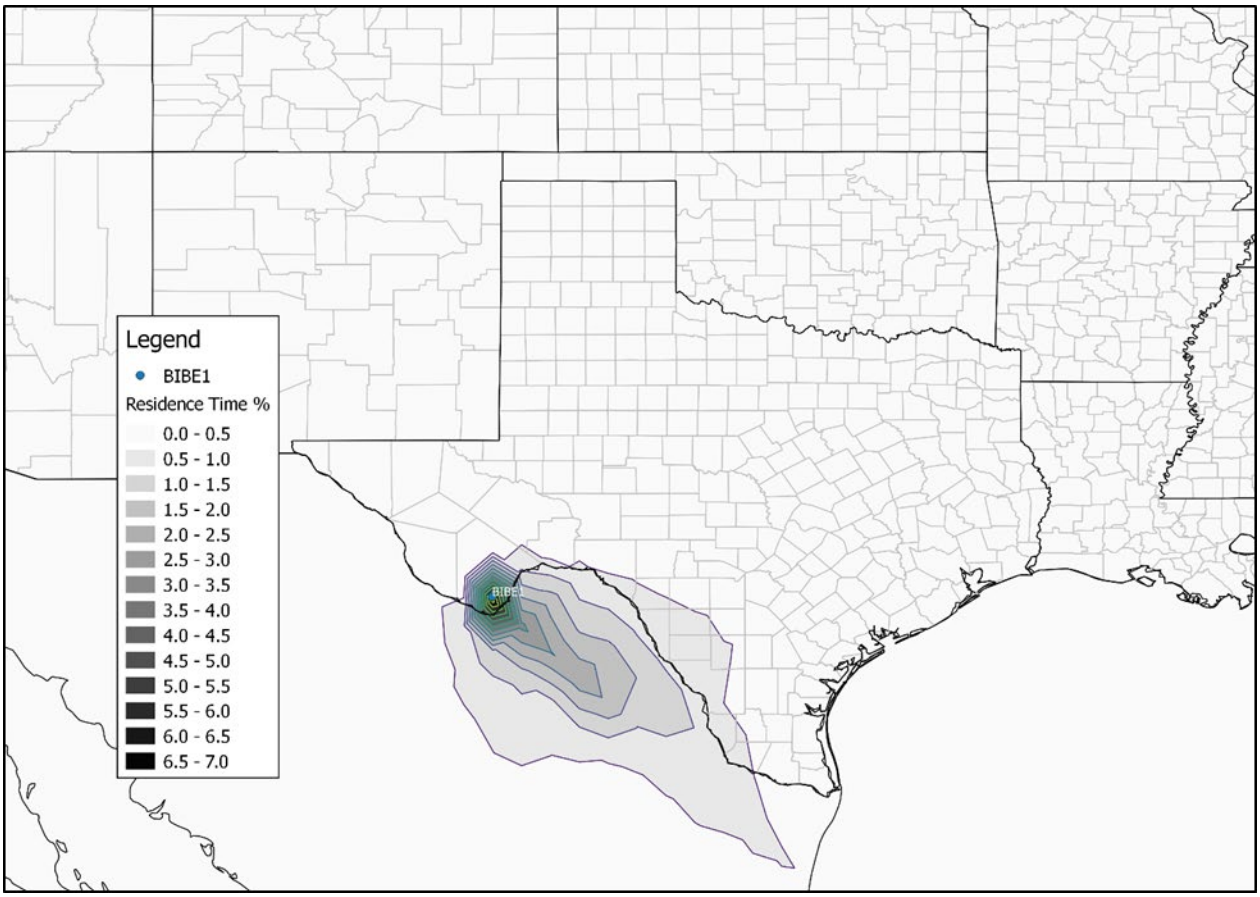

Figure 1-6: Normalized Residence Time (Based on Data From 2012 through 2016) for Big Bend

Ammonium sulfate is the largest contributor to aerosol light extinction on the 20% most impaired days, with a mean contribution of 67% during the 2000 through 2018 time period. Figure 1-7: *Normalized Residence Times in 20% Most Impaired Days Weighed by Ammonium Sulfate During 2012 through 2016 for Big Bend* suggests that ammonium sulfate is mainly transported from northern Mexico on the 20% most impaired days. There are some important point sources such as the Carbon I and II coal-fired power plants located in northern Mexico, about 275 km (170 mi) southeast from the monitoring site. These power plants are among the largest SO_2 point sources and may contribute to the ammonium sulfate loadings at the Big Bend National Park year-round.

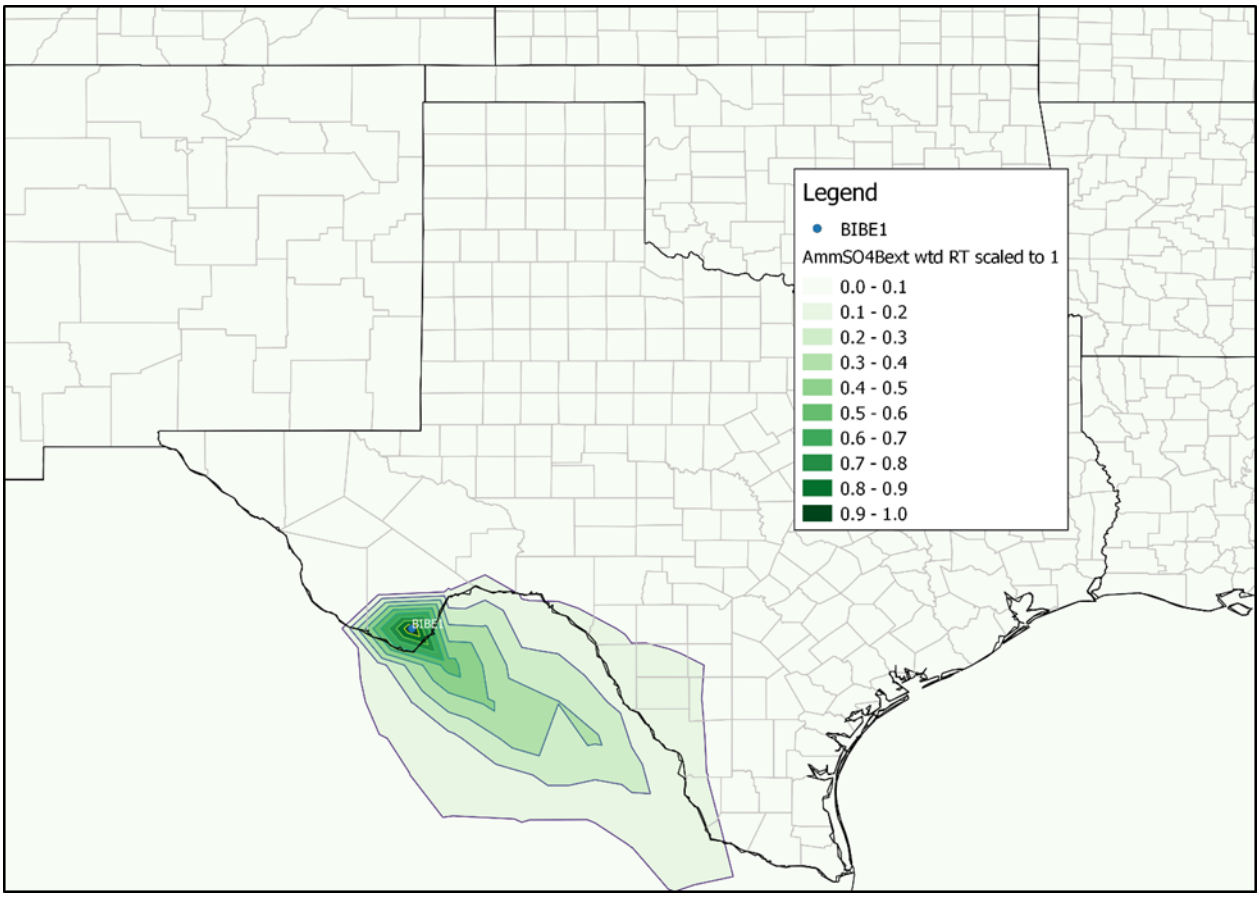

Figure 1-7: Normalized Residence Times in 20% Most Impaired Days Weighed by Ammonium Sulfate During 2012 through 2016 for Big Bend

1.5.3 Preliminary Conceptual Model - Causes of Haze in Guadalupe Mountains National Park

Ammonium sulfate from the southeastern United States and from point sources in the northeastern Mexico in the summer, as well as dust from western Texas and northern Mexico, and southeastern Texas in the spring are the major causes of haze at the Guadalupe Mountains National Park[7].

The Guadalupe Mountains IMPROVE monitoring site (GUMO1) shown in Figure 1-8: *Terrain Map for Guadalupe Mountains* is located 8 km (5 mi) southeast of Guadalupe Peak. The monitoring site is outside of the Guadalupe Mountains National Park Class I area at an elevation of 1,674 meters (5,492 feet). The site is located near the top of the northwest-to-southeast oriented Delaware Mountain Range. It has good exposure to regional scale winds. The site may be influenced by wind-blown dust from the dry lakes (bare ground) west of the site, as well as from the Mexican dry/barren region to the southwest. The average non-Rayleigh light extinction (Bext) is 31.4 Mm^{-1} (deciview ~11.4, visual range ~77.18 miles) for the 2000 through 2018 time period. On average, ammonium sulfate is the largest contributor to haze, with a contribution of 55%.

[7]Western Regional Air Partnership Causes of Haze Assessment https://www.air-resource.net/COHA/

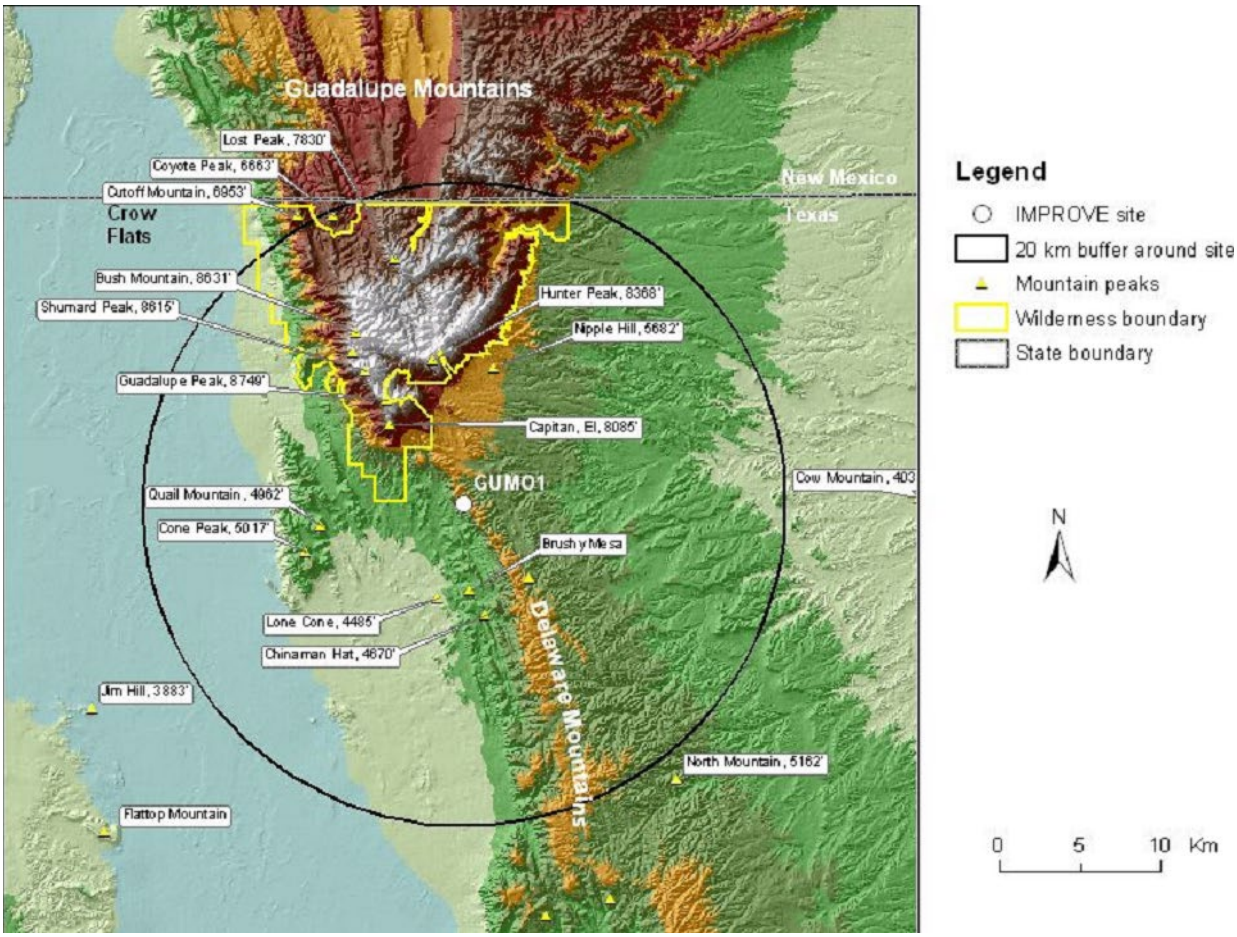

Figure 1-8: Terrain Map for Guadalupe Mountains

Figure 1-9: *Percent Contributions of Major Aerosol Chemical Components to Light Extinction on the 20% Most Impaired Days at GUMO1, Average of 2000 through 2018* shows the percentage aerosol components contribute to light extinction at GUMO1 based on data available from 2000 through 2018[8] and Figure 1-10: *Average Contributions of Major Aerosol Chemical Components to Light Extinction on the 20% Most Impaired Days at GUMO1, Average for Each Year 2000 through 2018* shows how the ammonium sulfate contribution has been generally declining between 2000 and 2018[9].

[8] http://views.cira.colostate.edu/fed/
[9] *Id.*

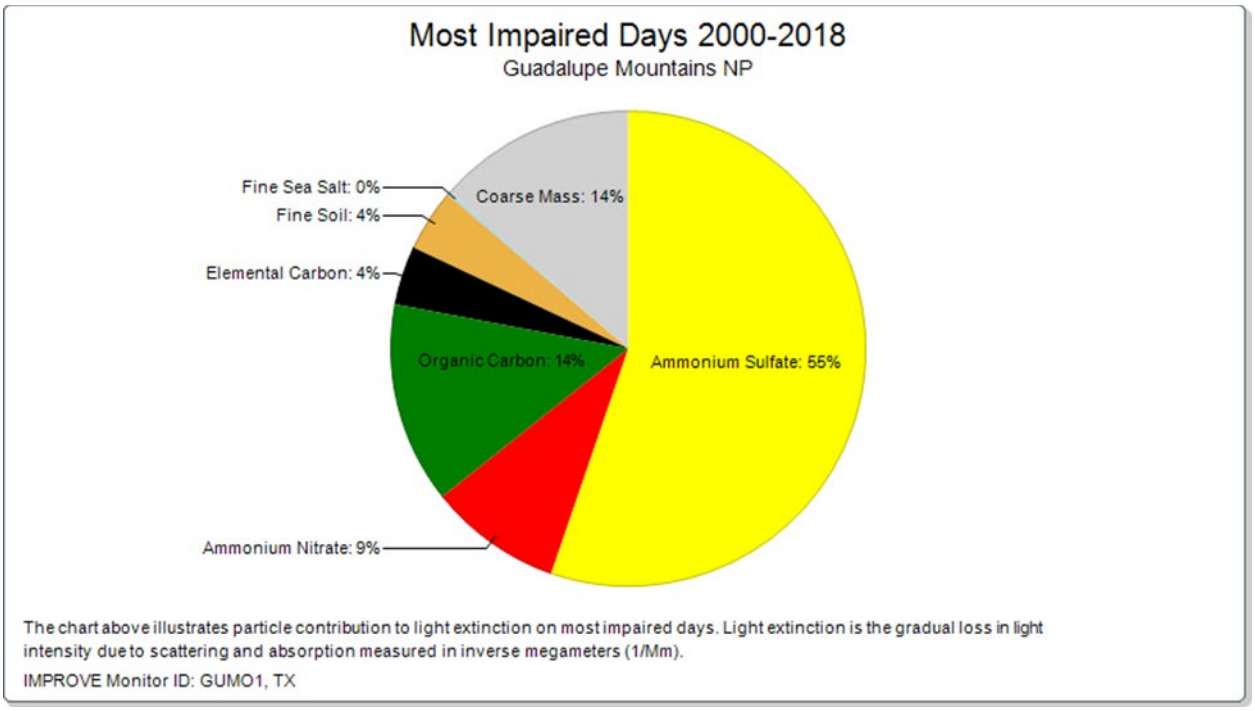

Figure 1-9: Percent Contributions of Major Aerosol Chemical Components to Light Extinction on the 20% Most Impaired Days at GUMO1, Average of 2000 through 2018

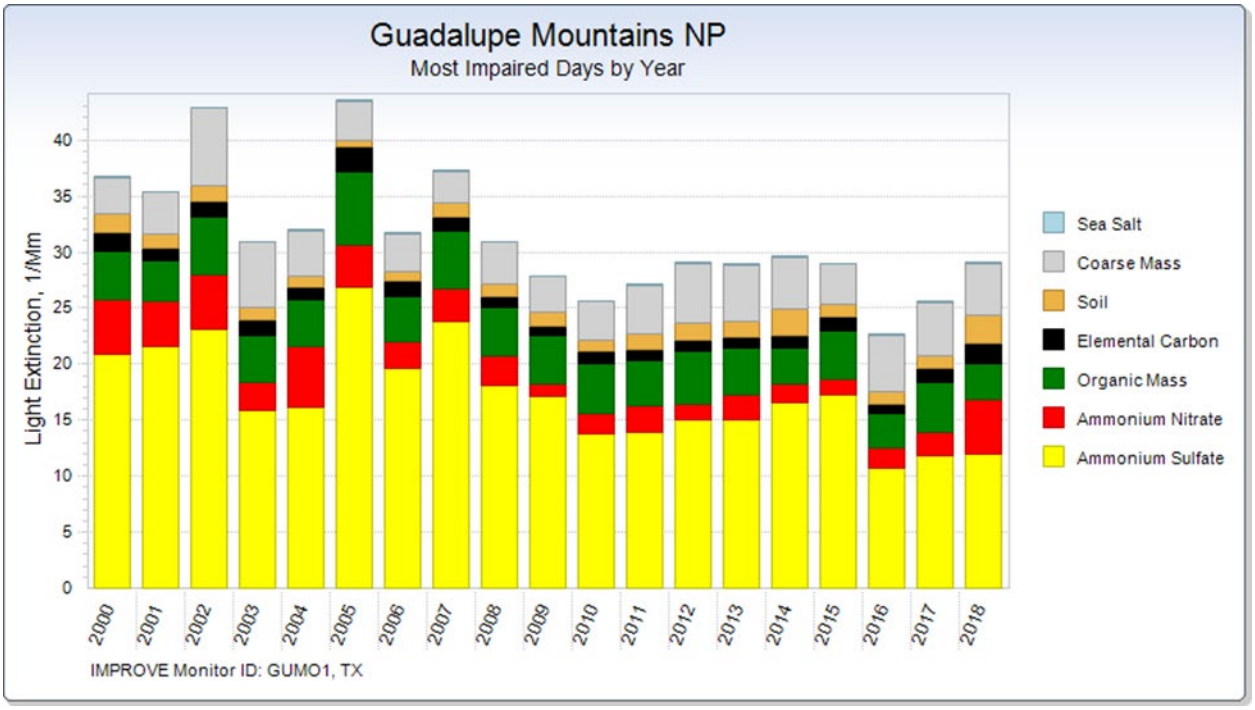

Figure 1-10: Average Contributions of Major Aerosol Chemical Components to Light Extinction on the 20% Most Impaired Days at GUMO1, Average for Each Year 2000 through 2018

Figure 1-11: *Number of Sampling Days in the 20% Most Impaired Days in Each Month for GUMO1*[10] shows that from 2000 through 2018 the highest occurrence of the 20% most impaired days happened in August, in which 93 of the sampling days were observed. As shown in Figure 1-9, ammonium sulfate is the largest aerosol contributor to haze, with a contribution of 55% on the 20% most impaired days. Organic carbon and coarse mass are the next largest aerosol components of haze at Guadalupe Mountains National Park, each with 13% contribution on the most impaired days. Fine soil and elemental carbon each contribute 4% during the 20% most impaired days during the 2000 through 2018 time period.

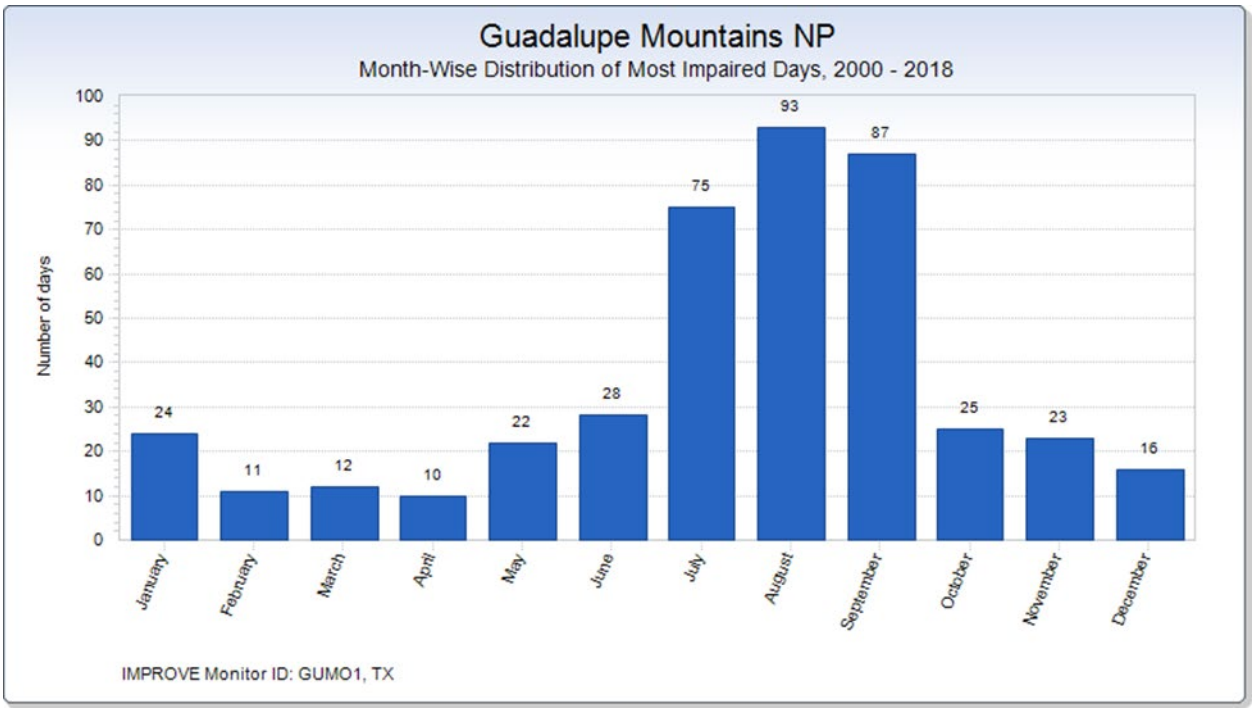

Figure 1-11: Number of Sampling Days in the 20% Most Impaired Days in Each Month for GUMO1

Figure 1-12: *Normalized Residence Time for GUMO1 (Based on Data From 2012 through 2016)* shows that winds from the southeast are dominant on the 20% most impaired days during the 2012 through 2016 time period.

[10] http://views.cira.colostate.edu/fed/

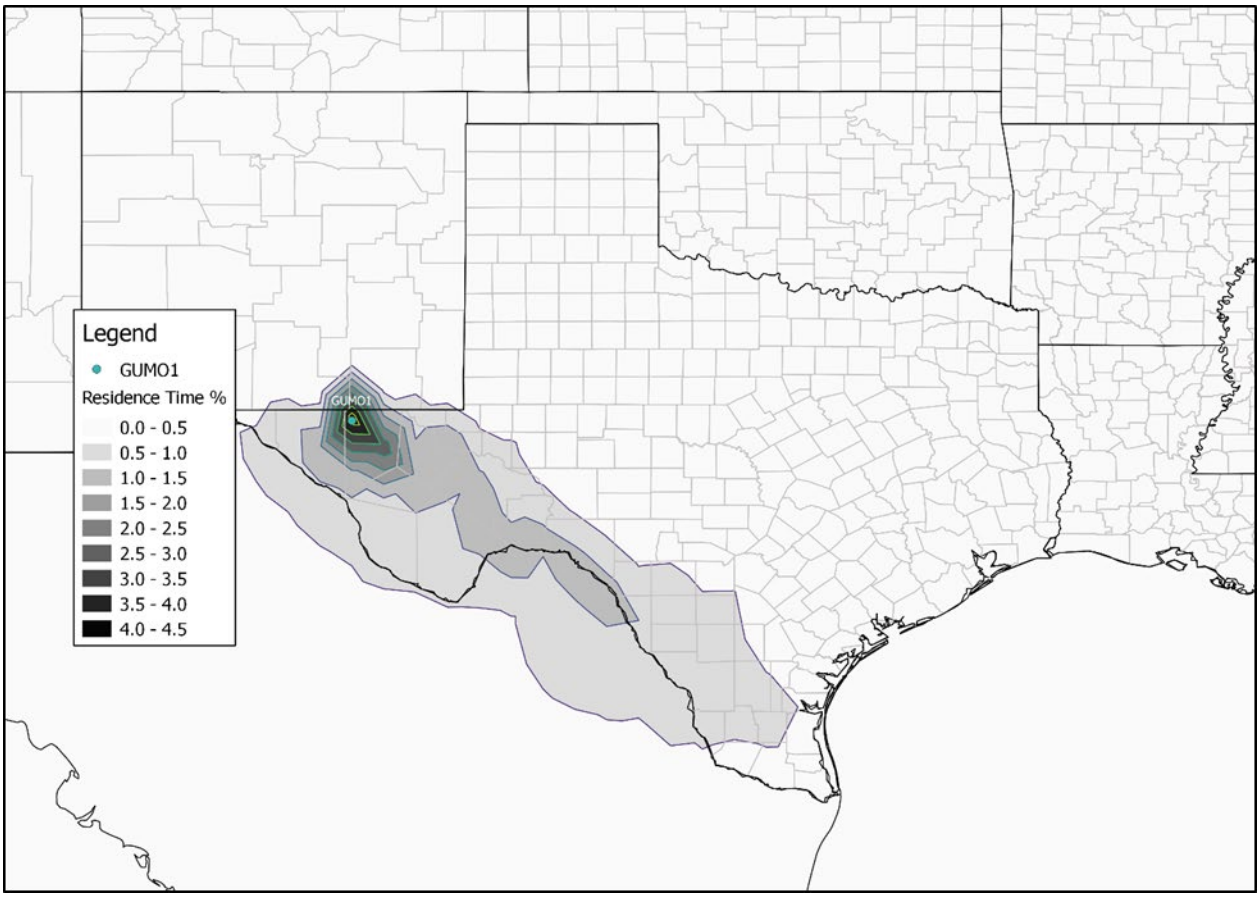

Figure 1-12: Normalized Residence Time for GUMO1 (Based on Data From 2012 through 2016)

Ammonium sulfate is the largest contributor to aerosol light extinction on the 20% most impaired days. Figure 1-13: *Normalized Residence Times in 20% Most Impaired Days Weighed by Ammonium Sulfate During 2012 through 2016* suggests that ammonium sulfate is mainly transported from south and southwest Texas and northern Mexico. There are some important point sources such as the Carbon I and II coal-fired power plants located in northern Mexico. These power plants are among the largest SO_2 point sources and may contribute to the ammonium sulfate loadings at the GUMO1 monitor year-round.

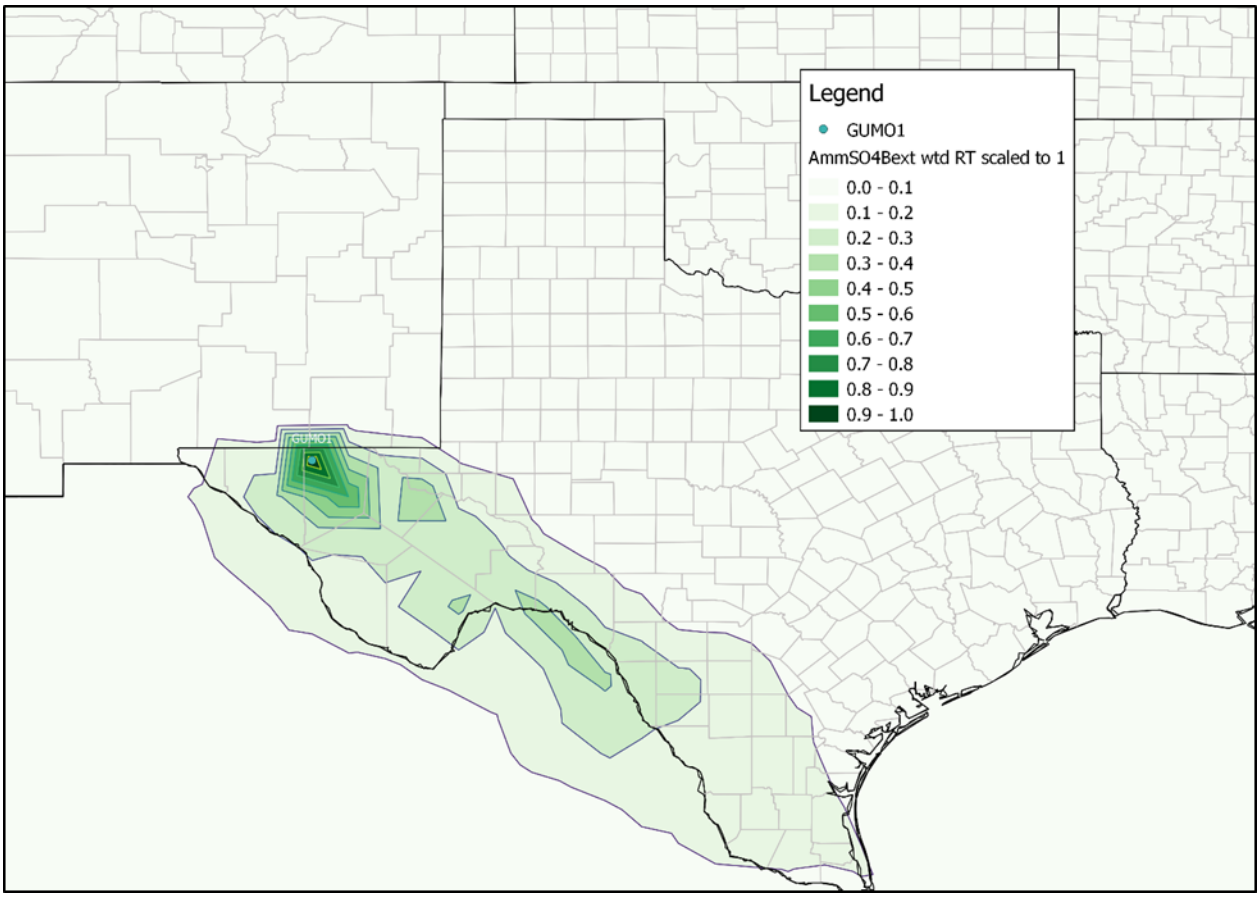

Figure 1-13: Normalized Residence Times in 20% Most Impaired Days Weighed by Ammonium Sulfate During 2012 through 2016

1.6 EPISODE SELECTION

The EPA, states (including Texas), local areas, and other groups collaboratively developed a North American emission inventory for a calendar year 2016 episode. A Base Year Selection Workgroup was created, with TCEQ participation, to evaluate and select the base year for the collaborative modeling platform (NEIC, 2017). After a year of research and analysis on regulatory 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. 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. The annual 2016 episode was selected for this regional haze modeling because of the availability of emission inventory data from the collaborative modeling platform and consistency with modeling efforts by the EPA, other States, and Regional Planning Organizations.

During the 2016 episode, the 14 monitors in and around Texas recorded their 20% most anthropogenically impaired days as shown in Figure 1-14: Monthly *Distribution of the 20% Most Impaired Visibility Days at 14 Monitors in and Around Texas.*

Anthropogenic visibility impairment occurred most frequently in September, followed by July and January, a bimodal distribution with summer and winter peaks.

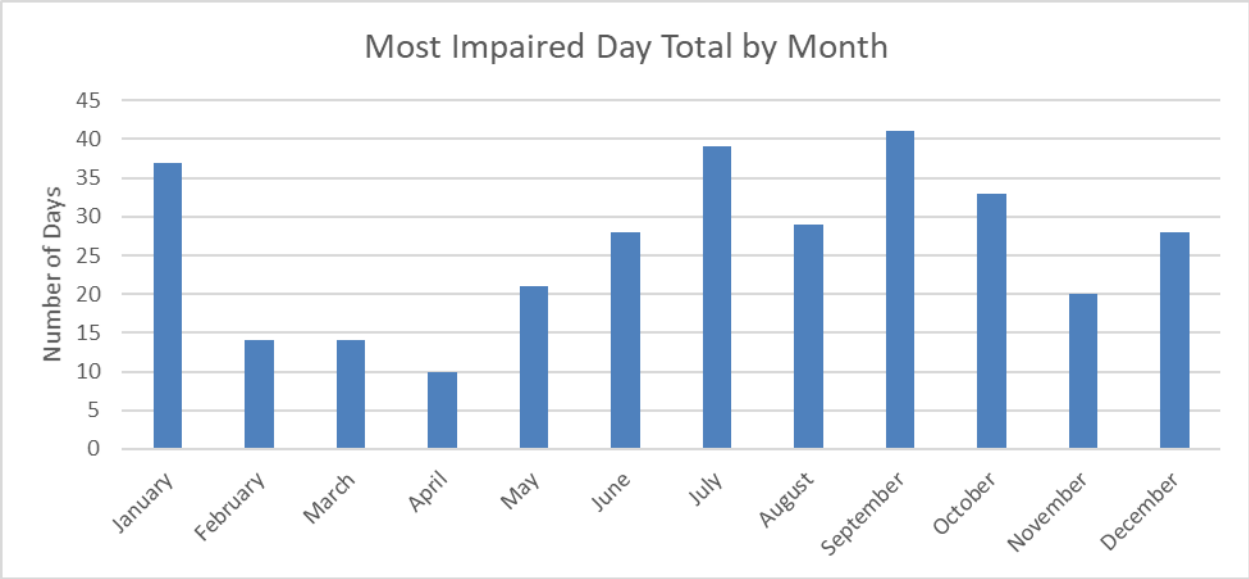

Figure 1-14: Monthly Distribution of the 20% Most Impaired Visibility Days at 14 Monitors In and Around Texas

1.7 MODELS USED

The TCEQ plans to use the models detailed in Table 1-2: *Planned Models for Regional Haze SIP Revision Modeling* in developing the Regional Haze SIP Revision.

Table 1-2: Planned Models for Regional Haze SIP Revision Modeling

Type	Model	Version
Photochemical	Comprehensive Air Quality Model with extensions (CAMx)	6.5
Meteorological	Weather Research and Forecasting (WRF) model	3.8.1
Emissions Processing	Emissions Processing System	3.22 or later
Biogenic	Biogenic Emission Inventory System (BEIS)	3.61
Initial and Boundary Conditions	The global atmospheric chemistry model driven by assimilated meteorological observations from the Goddard Earth Observing System (GEOS-Chem)	11-02rc

1.8 MODEL INPUTS AND SOURCES

1.8.1 Meteorological Modeling

Table 1-3: *2016 Base Case WRF Setup*. The WRF model inputs will be developed and the model will be run for 2016. Details of the WRF inputs, outputs, and model performance evaluation will be provided in the Meteorological Modeling appendix submitted with the regional haze documentation.

Table 1-3: 2016 Base Case WRF Setup

Grid	Nudging Type	PBL	Cumulus	Radiation	Land-Surface	Microphysics
12 km	3-D Analysis	ACM2	Kain-Fritsch	RRTM / Dudhia	Pleim-Xiu	Morrison

km = kilometer; PBL = Planetary Boundary Layer; ACM2 = Asymmetric Convective Model, version 2; RRTM = Rapid Radiative Transfer Model

1.8.2 Emissions Modeling

The 2018 modeling guidance recommends using the model results in a relative sense. This relative approach is based on how the model responds to the change in emissions between a base and a future year. Therefore, three modeling emissions data sets will be developed for this Regional Haze SIP Revision:

- 2016 base case emissions;
- 2028 future year emissions; and
- 2028 future year sensitivity analyses.

Summaries of the primary data sources for the development of the base case modeling emissions are provided in Table 1-4: *Summary of Base Case Point Source Emission Data Sources*, Table 1-5: *Summary of Base Case On-Road Mobile Source Emission Data Sources*, and Table 1-6: *Summary of Base Case Non-Road Mobile, Off-Road, Area, Oil-and-Gas, and Biogenic Source Emission Data Sources*.

Table 1-4: Summary of Base Case Point Source Emission Data Sources

Region	Data Source
Texas	2016 State of Texas Air Reporting System (STARS) for non-Electric Generating Units (non-EGU)
Other U.S. States	2016 National Emissions Inventory Collaborative (NEIC) platform Beta version (vβ) for non-EGUs
All U.S. States	2016 EPA's Air Markets Program Data (AMPD) hourly data for EGUs
Offshore	2014 Bureau of Ocean Energy Management (BOEM) Gulf-Wide Emission Inventory (GWEI) platforms of western Gulf of Mexico
Mexico and Canada	2016 NEIC platform vβ
Other Countries	2010 Emissions Database for Global Atmospheric Research (EDGAR) v4.2
U.S. Fires	2016 Fire Inventory from the National Center for Atmospheric Research (FINN)

Table 1-5: Summary of Base Case On-Road Mobile Source Emission Data Sources

Region	Data Source
HGB and DFW	2016 based on Motor Vehicle Emission Simulator (MOVES2014a) emission rates and Highway Performance Monitoring System (HPMS) for vehicle miles traveled (VMT) activity estimates
Other Texas	2016 based on MOVES2014a emission rates and HPMS for VMT activity estimates
Other U.S. States	2016 NEIC platform vβ

Note: Houston-Galveston-Brazoria (HGB) and Dallas-Ft. Worth (DFW) nonattainment areas

Table 1-6: Summary of Base Case Non-Road Mobile, Off-Road, Area, Oil-and-Gas, and Biogenic Source Emission Data Sources

Region	Non-Road Mobile Sources	Area Sources	Off-Road Sources	Oil-and-Gas Sources	Biogenic Sources
Texas	2016 run of Texas NONROAD model, version 2 (TexN2)	2016 NEIC platform vβ and version one (v1)	2016 NEIC platform vβ and v1	Railroad Commission of Texas data and equipment-specific emission rates	BEIS 3.61
Other U.S. States	2016 NEIC platform vβ	2016 NEIC platform vβ and v1	2016 NEIC platform vβ and v1	2016 NEIC platform vβ	BEIS 3.61
Canada	2016 NEIC platform vβ	2016 NEIC platform vβ and v1	2016 NEIC platform vβ	2016 NEIC platform vβ	BEIS 3.61
Mexico	2016 NEIC platform vβ	2016 NEIC platform vβ and v1	2016 NEIC platform vβ	2016 NEIC platform vβ	BEIS 3.61

Summaries of the primary data sources for the development of the future case modeling emissions are provided in Table 1-7: *Summary of Future Case Point Source Emission Data Sources*, Table 1-8: *Summary of Future Case On-Road Mobile Source Emission Data Sources*, and Table 1-9: *Summary of Future Case Non-Road Mobile, Off-Road, Area, Oil-and-Gas, and Biogenic Source Emission Data Sources.*

Table 1-7: Summary of Future Case Point Source Emission Data Sources

Region	Data Source
Texas	2016 STARS for non-EGUs; 2018 AMPD hourly data for EGUs
Other U.S. States	2028 from 2016 NEIC platform vβ for non-EGUs; Eastern Regional Technical Advisory Committee 2028 Projection for EGUs
Offshore	2014 BOEM GWEI platforms of western Gulf of Mexico
Mexico and Canada	2028 from 2016 NEIC platform vβ
Other Countries	2010 EDGAR v4.2
U.S. Fires	2016 FINN

Table 1-8: Summary of Future Case On-Road Mobile Source Emission Data Sources

Region	Data Source
HGB and DFW	2028 based on MOVES2014a emission rates and HPMS for VMT activity estimates
Other Texas	2028 based on MOVES2014a emission rates and HPMS for VMT activity estimates
Other U.S. States	2028 from 2016 NEIC platform

Table 1-9: Summary of Future Case Non-Road Mobile, Off-Road, Area, Oil-and-Gas, and Biogenic Source Emission Data Sources

Region	Non-Road Mobile Sources	Area Sources	Off-Road Sources	Oil-and-Gas Sources	Biogenic Sources
Texas	2028 run of TexN2	2028 from 2016 NEIC platform vβ	2028 from 2016 NEIC platform vβ and v1	Railroad Commission of Texas data and equipment-specific emission rates	BEIS 3.61
Other U.S. States	2028 from 2016 NEIC platform vβ	2028 from 2016 NEIC platform vβ	2028 from 2016 NEIC platform vβ and v1	2028 from 2016 NEIC platform vβ	BEIS 3.61
Canada	2028 from 2016 NEIC platform vβ	2028 from 2016 NEIC platform vβ	2028 from 2016 NEIC platform vβ and v1	2028 from 2016 NEIC platform vβ	BEIS 3.61
Mexico	2028 from 2016 NEIC platform vβ	2028 from 2016 NEIC platform vβ	2028 from 2016 NEIC platform vβ and v1	2028 2016 NEIC platform vβ	BEIS 3.61

The details on the development of modeling emissions for annual episode base and future years for point sources, on-road, non-road, and off-road mobile sources, area sources, and biogenic sources will be provided in Section 8.3.5: *2016 Base Case Modeling Emissions* of the Regional Haze SIP Revision documentation as well as the accompanying appendix, Appendix 8-2: *Emissions Modeling*. The emission inventory files will be made available at TCEQ modeling file transfer protocol (FTP) site.

1.8.3 Photochemical Modeling

The TCEQ will use the latest public-release version of CAMx, version 6.5. Several sensitivity tests will be performed to examine how different model configurations affect model performance, including 1) using the secondary organic aerosol processor (SOAP) scheme with updated terpene chemistry, version 2.2, 2) adding lightning NO_x, and 3) adjusting surface resistance of ammonia in the dry deposition scheme. The anticipated model configuration is summarized in Table 1-10: *CAMx Model Configuration and Input Sources*.

Table 1-10: CAMx Model Configuration and Input Sources

CAMx Option, Input Source	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	SOAP, version 2.2 that will be standard in CAMx Version 7.0
Meteorology	WRF, version 3.8.1
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

Details of the photochemical modeling and any updates made will be discussed in the Regional Haze SIP Revision documentation.

1.9 MODELING DOMAIN DEFINITION

The CAMx and WRF modeling domains will use the map projection described in Table 1-11: *Model Domain Lambert Conformal Map Projection*.

Table 1-11: Model Domain Lambert Conformal Map Projection

Projection Parameter	Value
First True Latitude (Alpha)	33°N
Second True Latitude (Beta)	45°N
Central Longitude (Gamma)	97°W
Projection Origin	97°W, 40°N
Spheroid	Perfect Sphere, Radius = 6370 km

The CAMx modeling domain will use two concentric grids; a 36 km grid with 172 cells west-to-east and 148 cells south-to-north, and a 12 km grid with 398 cells west-to-east, and 248 cells south-to-north. The vertical structure of the CAMx model will include 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.

The WRF modeling domain is described in Table 1-12: *WRF Modeling Domain Definitions*.

Table 1-12: WRF Modeling Domain Definitions

Domain	Easting Range (km)	Northing Range (km)	East/West Grid Points	North/South Grid Points
12 km	-3492 to 3492	-1324 to 3024	583	505

The WRF vertical structure will contain 43 layers and extend from the surface to 20,581 m. The WRF and CAMx modeling domains will be described in greater detail in Section 8.3.4: *Weather Research and Forecasting (WRF) Modeling*, and Section 8.3.7: *Photochemical Modeling* of the regional haze SIP documentation.

1.10 MODEL PERFORMANCE EVALUATION

Performance evaluation of emissions models is inherently difficult except for highly controlled experimental settings. Evaluation of emissions using ambient concentrations usually requires a model to account for atmospheric dispersion, advection, and chemistry, so it is best to evaluate the combined emissions-photochemical modeling setup together. Emissions model outputs can, however, be visualized using graphical routines so that they can be compared with knowledge of the sources' spatiotemporal characteristics. The TCEQ plans to conduct extensive model performance evaluation (MPE) of both the WRF and CAMx modeling used in the Regional Haze SIP Revision.

MPE of the CAMx modeling will be described in detail in Section 8.3.7.4: *Model Performance Evaluation* of the 2021 Regional Haze SIP Revision documentation, while MPE of WRF will be provided in Appendix 8-1: *Meteorological Modeling*. Visibility impairment will be compared with observations at the IMPROVE monitoring sites located within the area shown in Figure 1-15: *IMPROVE Monitors In and Near Texas*.

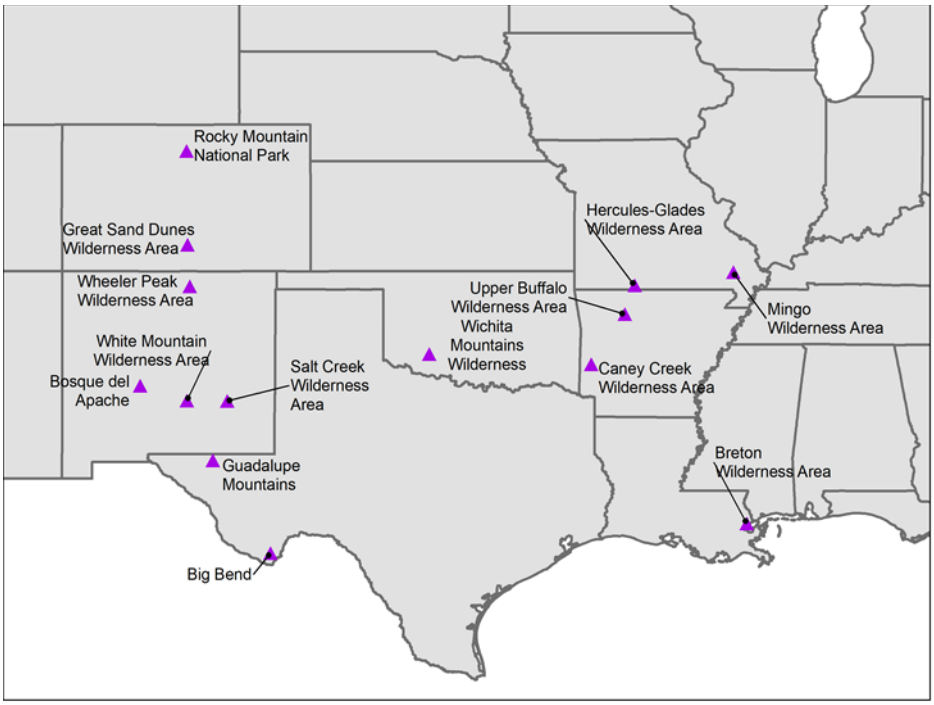

Figure 1-15: IMPROVE Monitors In and Near Texas

1.11 FUTURE YEAR

The future year of 2028 will be modeled since it is the end of the second planning period under the Regional Haze Rule. Anthropogenic emissions source categories for 2028 will be created by applying growth and control factors to base year emissions. Boundary conditions from a 2028 GEOS-Chem model run will be used.

Since biogenic emissions are dependent upon the meteorological conditions on a given day, the same episode-specific emissions used in the base case modeling will be used in the future year modeling. Since future year wildfires cannot be predicted, the wildfire emissions inventory developed for the base case modeling will also be used in the future year modeling.

1.12 REGIONAL HAZE TECHNICAL ANALYSIS FRAMEWORK

The TCEQ will project visibility impairment at IMPROVE monitors serving individual Class I areas in 2028 and estimate emissions contributions to 2028 particulate matter (PM) species concentrations using 2016 meteorology. The projected 2028 PM species concentrations will be converted to light extinction coefficients and then to deciviews and used to evaluate visibility progress as of 2028. Culpability for visibility impairment by emissions sectors and geographic regions will be estimated using the CAMx Particulate Source Apportionment Technology. Geographical regions include individual states and foreign countries (international contributions). The visibility analysis will follow the same procedures described in EPA's technical guidance (EPA, 2018) and the EPA's technical supporting document (TSD; EPA, 2019).

1.13 DOCUMENTATION

The modeling guidance recommends including the following elements of documentation as part of a SIP revision:

- Executive summary that provides an overview of the analysis and the key conclusions;
- Reference to the modeling protocol noting any major deviations from the original plans;
- List of the institutional participants in the attainment demonstration and their roles;
- Description of air quality in the area and how that shaped the analysis;
- Justification for the model, episodes, domain, and grid(s) used in the analysis;
- Description of the development of the emissions inputs used in the base year modeling, including tabular summaries by state/county, as appropriate;
- Description of the development of meteorological inputs used in the base year modeling;
- Description of all other base year modeling inputs;
- Evaluation of base year model performance (meteorology, emissions, and air quality), including a description of the observational database used in the evaluation and any diagnostic or sensitivity tests used to improve the model;
- Description of the strategy used to estimate international anthropogenic emissions contribution to future year design values;
- Description of any supplemental analyses designed to bolster the results; and
- Detailed summary of the entire analysis that leads to the conclusion that the State of Texas will fulfill its obligations under the Regional Haze Rule.

The TCEQ will include the above-listed elements in the submitted 2021 Regional Haze SIP Revision.

REFERENCES

EPA, 2018. Modeling Guidance for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze, https://www3.epa.gov/ttn/scram/guidance/guide/O3-PM-RH-Modeling_Guidance-2018.pdf, November 2018.

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National Emissions Inventory Collaborative (NEIC), 2017. Base Year Selection Workgroup Final Report, https://drive.google.com/file/d/1o0e75dIliyjDZOmBDOPxIdMUhUTeph4Y/view, April 2017.

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