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October 22, 2020

Andrew Wheeler, Administrator
U.S. Environmental Protection Agency
Mail Code 1101A
1200 Pennsylvania Ave., N.W.
Washington, D.C. 20460
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VIA ELECTRONIC AND U.S. MAIL

Re: Petition for Reconsideration of Air Quality Designation for Ector County, Texas for the 2010 Sulfur Dioxide (SO_2) Primary National Ambient Air Quality Standard – Round 3; Final Rule, EPA–HQ–OAR–2017–0003; FRL–9972–73–OAR

Dear Administrator Wheeler:

Pursuant to Sections 307(d)(7)(B) and 107(d)(3)(A) of the Clean Air Act, the Odessa, Texas Chapter of the National Association for the Advancement of Colored People (Odessa NAACP), Environmental Integrity Project, Environmental Defense Fund, the Lone Star Chapter of the Sierra Club, Texas Campaign for the Environment, Environment Texas, Public Citizen, Inc., and Earthworks ("Petitioners") hereby petition the Administrator of the Environmental Protection Agency ("EPA" or "Agency") to reconsider the decision to designate the Ector County, Texas area as unclassifiable/attainment for the Sulfur Dioxide Primary (Health-Based) National Ambient Air Quality Standard ("NAAQS"). 83 Fed. Reg. 1098 (Jan. 9, 2018).

As this Petition clearly demonstrates, air quality in and around the city of Odessa, in Ector County, Texas, is failing to meet EPA's primary, health-based, sulfur dioxide standard. Flaring at oil and gas production, gathering, and processing facilities in the Permian Basin is the main culprit for the dangerous levels of sulfur dioxide in the Odessa region's air. Flaring in the Permian Basin releases thousands of tons of excess illegal pollution, including toxics like benzene and hydrogen sulfide, and greenhouse gases including methane and carbon dioxide. In addition, the Permian Basin is a hotspot for sulfur dioxide flaring emissions. Sulfur dioxide is a potent air pollutant that harms the respiratory system even in brief exposures. As few as five minutes of breathing airborne SO_2 can cause coughing, tightness in the chest, and difficulty breathing that lasts for hours.

This Petition demonstrates that oil and gas flaring causes unsafe SO_2 levels in Ector County's air. In fact, based solely on "emission events," as that term is defined by the Texas Commission on Environmental Quality, these industry self-reported emissions cause levels of SO_2 in and around Odessa, Texas far in excess of the primary health-based NAAQS limit set by EPA. This pollution damages the health and disrupts the lives of the county's residents and visitors.

EPA created this Primary (also called the "1-hour," or "short-term exposure") Sulfur Dioxide national ambient standard in 2010 to protect people from the dangers posed by short-term exposure to SO_2. We urge EPA to reconsider its prior decision to classify Ector County, Texas as unclassifiable/attainment for the 2010 one-hour sulfur dioxide primary NAAQS, as determined in 83 Fed. Reg. 1098 (Jan. 9, 2018). EPA should instead propose and move to finalize a nonattainment designation for Ector County, based on the overwhelming evidence in this Petition demonstrating that the county's air quality fails to meet this minimum national standard. This important first step will put EPA, the State of Texas, and Ector County on the path toward achieving cleaner air in Odessa, Texas.

I. Air Quality in Ector County Fails to Meet the National Health-Based Ambient Standard for Sulfur Dioxide.

A. Modeling of Actual Sulfur Dioxide Emissions Shows Clear NAAQS Violations for Every Averaging Period From 2014-2019.

Industrial sources in Texas are required to self-report emission events, which are unauthorized upsets, startups, and shutdowns that release pollution above reportable quantities. Based solely on these industry self-reported emissions, levels of SO_2 are well above those likely to cause adverse health impacts and contribute to an unacceptable level of risk for local residents and visitors.

The attached air dispersion modeling study shows that even a fraction of Ector County's total sulfur dioxide emissions (i.e., merely a subset of industry-reported SO_2 emissions) cause violations of the 1-hour SO_2 NAAQS at multiple receptors.[1] The modeling study analyzes a subset

[1] H. Andrew Gray, Ph.D., Modeling the SO_2 Impacts From Intermittent Flare Events in Ector County, Texas (October 2020) Attachment 1.

of data comprised of reportable emission events, which Texas defines as "[a]ny emissions event that in any 24-hour period, results in an unauthorized emission from any emissions point equal to or in excess of the reportable quantity as defined in this section."[2] These unauthorized emission events are pollution releases distinct from routine emissions authorized by permit at these sources. Modeled sources include Ector County oil and gas facilities regulated by the Texas Commission on Environmental Quality ("TCEQ"), such as gas plants, tank batteries, compressor stations, booster stations, and storage units, as well as oil and gas exploration and drilling operations.

The study modeled hourly SO_2 concentrations at 961 gridded receptors placed every 1 mile based on emission event reports for these sources from 2014 through 2019. The results, as shown in the following Table, demonstrate that the 3-year average design value for the 1-hour SO_2 NAAQS – which corresponds to the 99th percentile, or 4th highest, maximum daily 1-hour SO_2 concentration –exceeded the acceptable standard of 196 µg/m3 (equivalent to 75 parts per billion) at between 164 and 252 receptors for each 3-year period during the six years.

Table 1. Modeled 3-Year Average Design Values for 1-Hour SO_2 NAAQS[3]

Modeled 3-Year Average	Maximum Receptor (µg/m3)	Grid Cells > 196 µg/m3	Grid Cells > 400 µg/m3
2014-2016	2,687.1	252	80
2015-2017	2,091.5	229	73
2016-2018	1,908.8	164	52
2017-2019	2,050.0	187	60

This means that for any given three year period, between 17% and 26% of Ector County, from 164 to 252 square miles, experienced air quality that violated the NAAQS. Even more disturbing, 52 to 80 receptors show design values more than twice the allowable concentration, and the maximum receptor exceeds that concentration by a factor of 10. These violations are most prevalent in the northern central part of the county, which is mostly rural and several miles west of Odessa, near the town of Goldsmith.

[2] 30 Tex. Admin. Code § 101.1(88).

[3] Table 3, H. Andrew Gray, Ph.D., Modeling the SO_2 Impacts From Intermittent Flare Events in Ector County, Texas (October 2020).

The following map of Ector County, taken from Fig. 23 of the modeling study, shows the extent of modeled SO_2 violations for the most recent averaging period, 2017-2019. The red overlay represents the area where modeled design value concentrations exceed the standard of 196 µg/m3.

Figure 1. Modeled SO_2 Concentrations Exceeding 196 µg/m^3, 2017-2019

In this map, 187 of 961 receptors, 187 square miles or approximately 19% of the total area of Ector County, show air quality that violates the SO_2 NAAQS. The town of Goldsmith lies entirely within the red violation area.

In addition to the gridded receptors, the study modeled SO_2 levels at 20 discrete receptors where people live, work, and worship, including residences, businesses and churches. Because much of Ector County is sparsely populated, these receptors were chosen to represent a geographically diverse set of locations where human exposure is highly likely. The study shows NAAQS violations at many of these receptors, demonstrating that people are being exposed to dangerous levels of SO_2 as a direct result of the modeled events.

Table 2. Modeled 3-Year Average Design Values for 1-Hour SO_2 NAAQS at Discrete Receptors (μg/m3)[4]

Location	2014-2016	2015-2017	2016-2018	2017-2019
Goldsmith Grocery, W Gulf Ave., Goldsmith	**731.2**	**902.8**	**845.2**	**583.5**
Odessa City Hall, W 8th St., Odessa	98.3	71.2	86.5	75.9
Residence, N Aster Ave., Gardendale	145.0	150.1	92.9	95.2
Western Skies RV Campground, Hwy 20, Penwell	143.1	140.3	62.9	64.6
Residence, Larchmont Pl., Odessa	160.8	155.0	101.1	118.3
Ranch, Boys Ranch Rd., west of Marion Flint	189.8	**205.7**	**207.2**	**197.4**
Goldsmith Community Church, N. Goldsmith Ave.	**818.5**	**975.8**	**823.7**	**530.7**
Residence, W 40th St., West Odessa	**224.8**	100.9	97.3	153.6
Residence, W Berry St., Odessa	80.8	56.8	51.8	57.7
University of Texas Permian Basin, Odessa	60.2	57.4	56.7	75.1
Ranch, Cottonwood Dr., west of Wire Line Rd.	187.8	179.8	158.3	177.9
Ranch, YT Ranch Rd., west of Chapel Hill Rd.	**293.2**	**241.5**	**210.9**	**325.2**
Residence, N Carter Ave., West Odessa	**201.6**	**215.0**	119.3	146.9
Ector College Prep Success Academy, Odessa	104.0	84.5	48.0	55.3
Faith Community Baptist Church, West Odessa	**217.0**	**199.8**	83.1	89.8
Residence, W Ivory St., Pleasant Farms	52.0	54.3	20.9	32.2
Odessa Meteor Crater Museum, Odessa	96.7	101.9	45.6	50.2
Ranch, YT Ranch Rd., east of James Lake	**452.3**	**512.5**	**448.5**	**524.4**
Residence, 3rd St., Notrees	165.6	159.5	104.5	118.1
Ranch, W Apple St., Pleasant Farms	37.4	34.0	15.5	31.3

As shown in the above table, 3-year average design value for the 1-hour SO_2 NAAQS, which corresponds to the 99th percentile (4th highest) maximum daily 1-hour SO_2 concentration, exceeds the standard of 196 μg/m3 (equivalent to 75 parts per billion) at between five and seven locations (out of the 20 modeled discrete receptor locations), depending on the three-year averaging period. Levels are highest in Goldsmith, Texas, which has a population of 277.[5] At both Goldsmith Grocery and Goldsmith Community Church, the 3-year average design value is more than double the health-based standard, and depending on the averaging period, it is as high as five times the health-based standard.

Modeling results unambiguously demonstrate that Ector County is not attaining the 1-hour SO_2 standard. This is especially concerning because the modeling study is based on only a subset of actual emissions in and around the county.

[4] Data from 2 and 5, H. Andrew Gray, Ph.D., Modeling the SO_2 Impacts From Intermittent Flare Events in Ector County, Texas (October 2020).
[5] United States Census Bureau, Population and Housing Unit Estimates, July 1, 2019.

B. The Modeling Study Follows EPA Guidelines.

The modeling study for this Petition was completed by H. Andrew Gray for Environmental Integrity Project. Dr. Gray received his Ph.D. in environmental engineering from the California Institute of Technology and has over 40 years of experience performing air dispersion modeling and related analyses. The modeling was conducted in AERMOD, with additional processing of weather and surface geographic data, which is EPA's preferred dispersion modeling tool for regulatory assessments of industrial point sources, including determinations of compliance with national ambient air quality standards like the SO_2 standard at issue here.[6]

The modeling protocol for the study followed EPA's modeling guidelines and the AERMOD implementation guide.[7] Emission information was obtained from industry self-reports of emission events, which sources submit to TCEQ through the State of Texas Environmental Electronic Reporting System ("STEERS"). Reports include information adequate to accurately model the emissions, including the location of the event, total amount of each pollutant released, start and end times of the event, and more. Additional source parameters, such as stack height and exit temperature, were obtained from publicly available TCEQ files, and conservative values were assumed where necessary data was unavailable.

C. The Modeling Study Conservatively Underrepresents Actual SO_2 Emissions.

The modeling study is conservative and underrepresents actual SO_2 concentrations because it models only a subset of emissions: reportable emission events from sources regulated by the TCEQ. As discussed above, these emission events are unauthorized pollution releases. Thus, this data does not include emissions from routine flaring or other combustion processes authorized by permit for the 173 modeled sources, which are a significant source of air pollution in Ector County. Nor does it contain unauthorized emission events below the reportable threshold. Further, the

[6] Factors to be used in determining whether areas are in violation of the 1-hour SO_2 NAAQS include: (1) Air quality characterization via ambient monitoring or dispersion modeling results; (2) emissions-related data; (3) meteorology; (4) geography and topography; and (5) jurisdictional boundaries. Air Quality Designations for the 2010 Sulfur Dioxide (SO2) Primary National Ambient Air Quality Standard—Round 2, 81 Fed. Reg. 45039 at 45043 (July 12, 2016) (citing Memorandum from Stephen D. Page, Director, U.S. EPA, Office of Air Quality Planning and Standards, to Air Division Directors, U.S. EPA Regions 1–10 (March 10, 2015)).

[7] U.S. Environmental Protection Agency. Guideline on Air Quality Models, 40 CFR Part 51, Appendix W. Published in the Federal Register, Vol. 70, No. 216, November 9, 2005; U.S. Environmental Protection Agency. AERMOD Implementation Guide. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. 2009.

modeling study does not take into account any background levels of SO_2, and does not include emissions from any other sources in or out of the county (with the exception of 5 sources in southern Andrews County), meaning that all modeled levels are incremental and attributable entirely to the modeled sources. As demonstrated in Map 1 below, there is significant flaring in the adjacent Permian Basin counties of Andrews, Martin, Midland, and Crane, which likely contributes to SO_2 concentrations in Ector County. None of these emissions are included in the modeling study.

Despite relying on only a limited subset of actual emissions, the study still shows much of Ector County in violation of the NAAQS. For residents of Ector County, these modeled levels of SO_2 correspond to real-world harm.

II. Sulfur Dioxide Levels in Ector County Are Harming People.

SO_2 is a potent air pollutant that harms the respiratory system and makes breathing difficult from exposures as short as a few minutes. Children, the elderly, and those who suffer from asthma are particularly vulnerable to the effects of SO_2. SO_2 also reacts with other pollutants in the atmosphere to form fine particulate matter, a distinct pollutant that can penetrate deep into the lungs and cause additional harm.

A. SO_2 Exposure Causes Adverse Health Effects.

In its in-depth review of SO_2 studies, including controlled human exposure, epidemiologic, and toxicological evidence, EPA found a causal relationship between respiratory morbidity and short-term exposure to SO_2.[8] A causal relationship is the most definitive finding the EPA can make regarding pollutant effects on human health. The immediate effect of SO_2 exposure to the respiratory system is bronchoconstriction, which then triggers mucus secretion, mucosal vasodilation, cough, and apnea followed by rapid shallow breathing.[9] The strongest evidence showed that short-term (5-minutes to 24-hours) exposure to ambient SO_2 caused respiratory morbidities including "lung function decrements, respiratory symptoms, hospital admissions, and emergency department visits."[10]

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[8] Environmental Protection Agency, Integrated Science Assessment ("ISA") for Sulfur Oxides – Health Criteria (September 2008) at 5-2.
[9] *Id.*
[10] Primary National Ambient Air Quality Standard for Sulfur Dioxide; Proposed Rule, 74 Fed. Reg. 64810 at 64816 (Dec. 8, 2009) (citing ISA).

For example, in numerous free-breathing chamber studies, asthmatic individuals exposed to SO_2 concentrations as low as 200–300 parts per billion ("ppb") for 5–10 minutes during exercise experienced moderate or greater bronchoconstriction, measurable loss of lung function, and respiratory effects including coughing, wheezing, chest tightness, and substernal irritation.[11] In the epidemiologic studies, SO_2-related effects on respiratory morbidity were observed in areas where the mean 24-hour average SO_2 levels ranged from 1 to 30 ppb, with maximum values ranging from 12 to 75 ppb.[12] EPA found that children, adults over 65 years old, and asthmatics are more sensitive to SO_2 exposure.[13] The strongest epidemiologic evidence of an association between short-term SO_2 concentrations and respiratory symptoms was in children. Asthmatics are also more sensitive to the effects of SO_2, likely resulting from preexisting inflammation associated with this disease.[14]

EPA found that the data supported a strong association between ambient SO_2 concentrations and emergency room visits and hospitalizations for all respiratory causes and asthma.[15] Further, the epidemiological evidence for short term SO_2 exposure suggested a causal relationship with all-cause (nonaccidental) and cardiopulmonary mortality.[16]

In addition to the studies reviewed for the ISA, the Agency stated that "measurable negative effects of air pollution on quality of life should be considered adverse."[17] EPA also accepted guidance from the American Thoracic Society in concluding that "exposure to air pollution that increases the risk of an adverse effect to the entire population is adverse, even though it may not increase the risk of any individual to an unacceptable level."[18] This is so because even if the pollution levels are not high enough to increase any individual's risk unacceptably, it nevertheless diminishes the reserve function of the population and increases their risk of being affected by other pollutants.

SO_2 pollution also contributes to the formation of secondary fine particulate matter, which causes additional adverse respiratory and cardiac health effects. A study of county-level emission

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[11] *Id.* at 64816 - 817.
[12] ISA at 5-9.
[13] Primary National Ambient Air Quality Standard for Sulfur Dioxide; Proposed Rule, 74 Fed. Reg. at 64820.
[14] ISA at 5-2.
[15] ISA at 3-21.
[16] ISA at 3-49.
[17] Primary National Ambient Air Quality Standard for Sulfur Dioxide; Proposed Rule, 74 Fed. Reg. at 64817 (quoting American Thoracic Society, *What constitutes an adverse health effect of air pollution?,* American Journal of Respir. Crit. Care Med, 161, at 665-67(200)).
[18] *Id.*

data calculated the health costs of primary and secondary particulate matter exposure from emission events in Ector County at over $10,000,000 for 2015 alone.[19]

More recent health studies of SO_2 confirm these risks and suggest that SO_2 may cause additional adverse effects. A study based on data from the nearby Eagle Ford Shale field in south Texas found that a high number of nightly flaring events in proximity to residences was associated with a 50% increase in the chances of preterm births and shorter gestation among Hispanic women.[20] And a study of 17 cities in China found that increased ambient SO_2 levels were associated with increased total, cardiovascular, and respiratory mortality.[21]

B. EPA Created the 1-hour SO_2 NAAQS Because Short-term Exposure Is Especially Dangerous.

The potency and alacrity of SO_2's adverse health effects led the EPA in 2010 to adopt the current 1-hour, 196 µg/m3 (75 ppb) standard and revoke the prior 24-hour and annual standards.[22] The Agency determined that this standard was necessary to adequately safeguard the health and safety of Americans, including "sensitive" populations such as asthmatics, children, and the elderly, with a margin for error.[23]

EPA adopted a 1-hour standard because SO_2 causes negative health effects from exposures as brief as five minutes. In this respect SO_2 exposure is very different from other criteria pollutants with longer duration standards. Pollutants like ozone, with an 8-hour standard, or particulate matter, with 24-hour and annual standards, require longer exposures to cause harm. In contrast, SO_2 can cause adverse symptoms from much shorter exposures, and those symptoms can last for hours after the exposure ends. This is important because a vast majority of the modeled violations are from short-duration, high-intensity flaring events that cause short-term spikes in SO_2 levels. These short-term spikes lead to the kind of exposure most likely to cause harm.

[19] Zirogiannis et. al., *Understanding Excess Emissions from Industrial Facilities: Evidence from Texas*, Environ. Sci. Technol. (Jan. 27, 2020).
[20] Cushing et. al., *Flaring from Unconventional Oil and Gas Development and Birth Outcomes in the Eagle Ford Shale in South Texas*, Environmental Health Perspectives (July 2020).
[21] Chen et. al., *Short-term exposure to sulfur dioxide and daily mortality in 17 Chinese cities: The China air pollution and health effects study (CAPES)*, Environmental Research 118 (2012).
[22] Primary National Ambient Air Quality Standard for Sulfur Dioxide, 75 Fed. Reg. 35520 (June 22, 2010).
[23] *Id.* at 35526.

Unfortunately, as shown in the modeling study, dangerous spikes of SO_2 occur in Ector County, including in areas where people live, work, worship, and recreate. SO_2 levels exceed the health-based standard in multiple locations for every three-year averaging period in the six years analyzed. Many receptors—including at places inhabited by people—show three-year average design values over double the safe limit, and the worst receptors show three-year average design values over ten times the safe limit.

These modeled levels are well above the NAAQS, and firmly in the range at which SO_2 can and will cause adverse health effects. People who live, work, and travel in Ector County are being placed at an unacceptable risk of respiratory harm due to SO_2 emissions from the ongoing flaring from oil and gas facilities. Ector County's current attainment designation is incorrect, and fails to protect the 166,223 women, men, and children who live there.[24] The county desperately needs federally-enforceable program of emissions reductions to achieve compliance with the NAAQS.

C. Ector County Residents Experience Adverse Health Effects From SO_2.

The modeled NAAQS violations are consistent with the lived experiences of local residents during the frequent air pollution episodes in Ector County. During these episodes, residents are prevented from enjoying even brief periods outside their homes due to SO_2-laden air that causes a host of respiratory problems. Residents regularly see flares and smell the acrid odor indicative of SO_2, and experience negative health effects associated with SO_2 exposure, including shortness of breath, tightness in their chests, coughing, difficulty breathing, nausea, irritation of the eyes, and irritation of the throat and lungs. The adverse respiratory effects of even a short exposure can persist for hours. Many residents have been forced to take steps to reduce their exposure to air pollution by, for example, avoiding spending time outside their homes, or closing the windows and vents in their car while driving. The pollution is pervasive and frequently interferes with their lives. SO_2 pollution and its adverse health effects prevent people from gardening, enjoying a cup of coffee on the porch, grilling in the backyard, and a host of other activities that most of us take for granted. We submit this Petition in the hope that EPA will take steps to remedy this unsustainable situation.

[24] U.S. Census Bureau, Population Estimates Program, July 1, 2019.

III. Additional Evidence of Poor Air Quality in Ector County

Ector County's designation merits reconsideration on the strength of the above modeling demonstration alone. In addition to that clear evidence of NAAQS violations, this section contains further evidence that systematically under-reported emissions from oil and gas activity in the Permian Basin are causing ongoing violations of SO_2 NAAQS.

A. Ector County Residents Experience Elevated Levels of Asthma.

Ector County residents experience increased incidence of asthma, putting them at greater risk of harm from SO_2. Texas Tech University Health Sciences Center estimates that 20% of school children in Ector County have asthma, and that asthma symptoms are the leading cause of school absences here.[25] This is far above national average for childhood (age <18) asthma of 11.6%.[26]

The three year moving average for 2013-2015 for adults (age 18+) in Ector County who have ever been diagnosed with asthma was 13.5% compared to the statewide average of 11.8%.[27] Between 2013 and 2017, lifetime asthma prevalence rates in adults in Ector County increased at a rate greater than the statewide rate. In 2015-2017, the moving average for adults in Ector County who have been diagnosed with asthma increased to 15.7%, while the state-wide average increased to 12.1%.[28] For 2015-2017, the most recent period for which accurate data is available, Ector County's adult asthma rate exceeded the statewide average by 29.8%.[29]

As discussed above, people with asthma are among the most vulnerable to the adverse health impacts of breathing SO_2. They are more likely to experience respiratory symptoms from even short exposures, and their lungs are less able to cope with those symptoms, including difficulty breathing, coughing, wheezing, and irritation of the airways. The 75ppb standard was developed with such sensitive populations in mind. With both childhood and adult asthma rates

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[25] Odessa American, Open house set for renovated Texas Tech pediatric clinic (May 30, 2018) (citing Texas Tech University Health Sciences Center News Release).
[26] Centers for Disease Control and Prevention, 2018 National Health Interview Survey (NHIS) Data, Table 2-1 Lifetime Asthma Prevalence Percents by Age, United States: National Health Interview Survey, 2018 (available at https://www.cdc.gov/asthma/nhis/2018/table2-1.htm).
[27] Community Hospital Consulting, Medical Center Hospital Community Health Needs Assessment and Implementation Plan (August 2019) (citing CARES Engagement Network, Health Indicator Report: logged in and filtered for Ector County, TX, https://engagementnetwork.org/; data accessed April 9, 2019; Texas Behavioral Risk Factor Surveillance System, Center for Health Statistics, Texas Department of State Health Services; data accessed April 9, 2019).
[28] *Id.*
[29] *Id.*

significantly higher than state and national averages, Ector County residents are especially vulnerable to the NAAQS violations modeled in the study.

B. EPA Lacked Adequate Data to Classify Ector County as attainment.

Ector County was designated Unclassifiable/Attainment in the absence of any air quality data supporting that designation. Ector County lacks any single source large enough to require classification under 42 USC § 51.120. Because of this, the State of Texas did not gather ambient monitoring data or conduct any modeling to support its attainment recommendation to the EPA.[30] But modeling of expected SO_2 exposures based on a limited subset of emissions data demonstrates that Ector County regularly experiences dangerous levels of SO_2, due primarily to 173 smaller sources which collectively cause and contribute to significant SO_2 NAAQS violations.

C. The Nearest SO_2 Monitor Shows Levels Exceeding the NAAQS.

For the period covered in the study, there was no SO_2 monitor present in Ector County; the nearest monitor was in Big Spring, Texas, approximately 54 miles from Ector County's eastern border.[31] This monitor began collecting data in December 2016, and almost immediately began recording measurements above the 75ppb standard. The following table shows the dates on which the Big Spring monitor recorded an hourly concentration of SO_2 in excess of 75ppb.

Table 3. Dates of Hourly SO_2 Concentration Exceedances in Excess of 75ppb at the Big Spring Monitoring Site (2017-2020)

Date	Ambient SO_2 (ppb)
1/11/2017	78.2
1/24/2017	98.1
6/27/2017	88.3
7/24/2017	86.6
11/18/2017	84.7
11/20/2017	79.7
11/24/2017	117.3
12/23/2017	107.3
1/7/2018	77.4
1/10/2018	76.2

[30] Environmental Protection Agency, Technical Support Document: Chapter 39 - Intended Round 3 Area Designations for the 2010 1-Hour SO2 Primary National Ambient Air Quality Standard for Texas at 1.
[31] EPA Site Number: 482271072, CAMS: 107, located at 1218 N. Midway Rd, Big Spring TX,79720 (data available at: https://www17.tceq.texas.gov/tamis/index.cfm?fuseaction=report.view_site&siteAQS=482271072).

1/19/2018	133.6
1/31/2018	76.0
2/15/2018	99.7
2/16/2018	99.4
3/9/2018	460.1
3/20/2018	81.1
11/17/2018	91.7
8/2/2019	79.9
8/3/2019	108.7
8/9/2019	91.9
8/13/2019	79.6
2/27/2020	110.5
3/1/2020	81.9
3/11/2020	93.5
4/19/2020	399.8

The Big Spring monitor data represents the closest data available to Ector County, and shows a pattern SO_2 NAAQS violations, including spikes in excess of five times the standard in 2018 and 2020.

D. TCEQ Receives Frequent Complaints of SO_2 Odors in Ector County.

As the agency tasked with protecting Texas' environment, TCEQ receives and investigates environmental complaints. Since January 2014, TCEQ received 249 complaints related to air quality in Ector Country.[32] Of those, 140 complaints specifically describe odors. People in Ector County consistently complain about foul, rotten-egg, sulfur odors that cause difficulty breathing and other health issues. Many complaints identify specific oil and gas facilities as the suspected source of the pollution. These complaints are further evidence that SO_2 emissions are having direct, negative impacts on the health and quality of life of Ector County residents.

E. Oil and Gas Flares Emit Roughly Double the Emissions of Sulfur Dioxide Reported to the State's Emission Inventory.

The National Emissions Inventory and the Texas Emissions Inventory fail to include significant flaring emissions and woefully undercount the actual levels of emissions from oil and gas activity. In Texas, two state agencies have overlapping, and sometimes conflicting, jurisdiction

[32] TCEQ Complaint Status, sorted for Ector County, January 1, 2014 through October 15, 2020, available at https://www2.tceq.texas.gov/oce/waci/index.cfm.

over oil and gas flares: The Texas Railroad Commission regulates oil and gas drilling and also authorizes flaring at oil and gas wells; whereas, the Texas Commission on Environmental Quality is responsible for air permitting for all sources.

The TCEQ requires some, but not all operators to report their annual point source emissions inventories. Oil and gas drillers who are regulated by the Railroad Commission do not report routine emissions directly to the TCEQ. They report to TCEQ only unauthorized emission events for which emissions exceed reportable quantities. For routine emissions, oil and gas drillers instead report the annual amount of gas that is vented or flared at each oil and gas lease to the Railroad Commission, and then TCEQ obtains this data and uses it to develop area source emission estimates. These emissions are required to be included in the State's Emissions Inventory, and are also included in the State Implementation Plan for achieving and maintaining the national ambient air quality standards. The Texas Emission Inventory woefully undercounts oil and gas emissions.

Emissions from oil and gas production that are found in the Texas Emission Inventory come from two sources. For larger oil and gas sites that meet the emissions reporting thresholds in 30 Tex. Admin. Code Section 101.10, the owners or operators of the sites estimate the emissions and report them to the TCEQ annually in their point source emissions inventories. For smaller sites that do not meet the reporting thresholds found in 30 Tex. Admin. Code Section 101.10, the TCEQ estimates the emissions as non-point (or area) source emissions. These are county-level estimates based on production data obtained from the Texas Railroad Commission ("RRC"), such as the active number of oil and gas wells and the annual amount of crude oil and natural gas production.

Area source oil and gas emissions have been estimated using several methods. Reports that detail these methods, as well as the estimated annual emissions that have been included in the Texas SIP include:[33]

- *Characterization of Oil and Gas Production Equipment and Develop a Methodology to Estimate Statewide Emissions* (2010).[34]

[33] These and additional studies since 2001, detailing all of TCEQ's oil and gas production emission estimates found in the Texas SIP are available here: https://www.tceq.texas.gov/airquality/airmod/project/pj_report_ei.html

[34] This report is available on the TCEQ's Air Quality Research and Contract Reports website at: https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/ei/5820784003FY1026-20101124-ergi-oilGasEmissionsInventory.pdf .

- *Condensate Tank Oil and Gas Activities* (2012)
- *Upstream Oil and Gas Heaters and Boilers* (2013)
- *Specified Oil and Gas Well Activities Emissions Inventory Update* (2014)

None of these studies, nor any of Texas's or EPA's regulatory actions that relied on the emissions estimates found in these studies, adequately account for all actual oil and gas flare emissions.

The TCEQ develops area source emissions inventories every three years and submits them to the EPA for the National Emissions Inventory ("NEI"). The most recent NEI was developed for calendar year 2017 per federal reporting requirements. 2017 Texas statewide SO_2 emissions from area source oil wellhead flaring were estimated to be 19,092 tpy. 2017 Texas statewide SO_2 emissions from area source gas wellhead flaring were estimated to be 4,233 tpy.

To demonstrate the magnitude of the oil and gas well flaring emissions that TCEQ and EPA have failed to consider, we reviewed the most recent available Texas Railroad Commission flare data, which covered the period from October 2018 through September 2019,[35] for the Railroad Commission's District 8 (which covers a portion of the Permian Basin including Ector and Midland Counties). We relied on the Railroad Commission's Hydrogen Sulfide Fields Concentrations Listings for an average hydrogen sulfide concentration per field.[36] We assumed 98% conversion of hydrogen sulfide to sulfur dioxide, which is a common industry practice, although we acknowledge that 100% destruction of hydrogen sulfide is typically expected.

We used the following standard engineering calculations to determine how much hydrogen sulfide and sulfur dioxide oil and gas drillers emitted in the Railroad Commission District 8 over the one-year study period:

Flared Calculations:[37]

$$\boldsymbol{tons\ H_2S} = \frac{field\ concentration\ H_2S\ ppm}{1{,}000{,}000\ ppmv} \times Volume\ Vented\ (MCF) \times 1{,}000\ \left(\frac{scf}{MCF}\right) \times \frac{34.1\ molar\ weight\ H_2S\ \frac{lb}{lb-mol}}{379.3\,\frac{scf}{mol}} \times \frac{ton}{2{,}000\ lb} \times 0.02\ (gas\ not\ combusted)$$

[35] TX RRC Production Report Queries. Available at http://webapps.rrc.texas.gov/PR/publicQueriesMainAction.do.
[36] TX RRC Hydrogen Sulfide (H2S) Fields & Concentrations Listings. Available at https://www.rrc.state.tx.us/oil-gas/research-and-statistics/field-data/h2s/.
[37] *Id.*

$$\textbf{tons } \boldsymbol{SO_2} = \frac{field\ concentration\ H_2S\ ppm}{1{,}000{,}000\ ppmv} \times Volume\ Vented\ (MCF) \times 1{,}000\ \left(\frac{scf}{MCF}\right) \times \frac{34.1\ molar\ weight\ H_2S\ \frac{lb}{lb-mol}}{379.3\ \frac{scf}{mol}} \times \frac{64.1\ molar\ weight\ SO_2\ \frac{lb}{lb-mol}}{34.1\ molar\ weight\ H_2S\ \frac{lb}{lb-mol}} \times \frac{ton}{2{,}000\ lb} \times 0.98\ (gas\ combusted)$$

Vented Calculation:[38]

$$\textbf{tons } \boldsymbol{H_2S} = \frac{field\ concentration\ H_2S\ ppm}{1{,}000{,}000\ ppmv} \times Volume\ Vented\ (MCF) \times 1{,}000\ \left(\frac{scf}{MCF}\right) \times \frac{34.1\ molar\ weight\ H_2S\ \frac{lb}{lb-mol}}{379.3\ \frac{scf}{mol}} \times \frac{ton}{2{,}000\ lb}$$

Based on available data, oil and gas operators in RRC District 8 flared roughly 141 BCF of gas between October 2018 and September 2019, and vented about 3,213 thousand cubic feet during that period. Flaring this much gas, much of it high in hydrogen sulfide content, would have resulted in an estimated 48,459 tons of SO_2 and 1,466 tons of H_2S. Venting and flaring on oil and gas leases located in Martin and Howard counties likely resulted in the highest estimated emissions of SO_2 and H_2S.

Our results by county are shown in the following table:

Table 4. Estimated tons of SO_2 and H_2S from wellhead flaring In RRC District 8, Q4 2018-Q3 2019

County	Total SO_2 (tons)	Total H_2S (tons)
Martin	11,309	966
Howard	11,158	121
Midland	5,373	83
Reeves	4,542	52
Andrews	3,547	70
Ector	2,675	33
Glasscock	2,520	30
Pecos	2,005	31
Crane	1,795	25
Loving	1,037	11

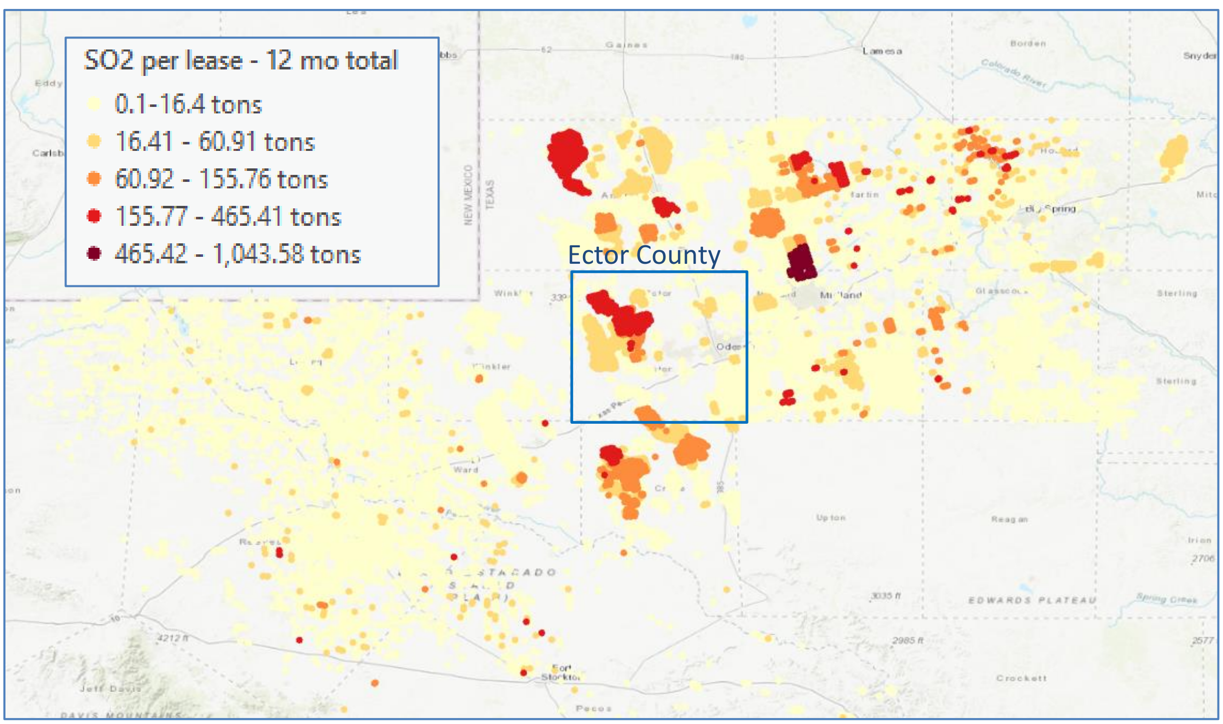
[38] Texas Commission on Environmental Quality, Air Permits Division. New Source Review (NSR) Emission Calculations. Available at: https://www.tceq.texas.gov/assets/public/permitting/air/Guidance/NewSourceReview/emiss_calc_flares.pdf.

Ward	886	27
Culberson	551	6
Winkler	525	6
Mitchell	45	0
Sterling	7	0
Unknown	484	5
Total	**48,459**	**1,466**

As demonstrated above, Permian Basin area flares at sources regulated by the Texas Railroad Commission emitted 48,459 tons of sulfur dioxide in the most recent year, over double the state-wide total of 23,325 tons found in TCEQ's annual Emission Inventory. This difference holds for Ector County, where flares emitted at least 2,575 tons of sulfur dioxide compared to the Emission Inventory total of 1,028 tons.

The following map illustrates the SO_2 "hot spots" based on our analysis of the RRC flaring data described above, and shows high concentrations of SO_2 flaring emissions in Ector and surrounding counties:

Figure 2. SO_2 Flaring Emissions Per Lease, 2017



IV. The Administrator Must Convene a Proceeding for Reconsideration in Accordance With § 307(d)(7)(B) of the Clean Air Act.

Petitioners present this information pursuant to § 307(d)(7)(B) of the Clean Air Act, which provides an opportunity for the public to object to an Agency designation even after the public comment period closes, provided that: 1) the grounds for such objection arose after the period for public comment and 2) the objection is of central relevance to the outcome of the rule.[39] If these requirements are satisfied, the "Administrator shall convene a proceeding for reconsideration of the rule and provide the same procedural rights as would have been afforded had the information been available at the time the rule was proposed."[40]

A. The Grounds for This Petition Arose After the Comment Period.

As discussed above, grounds for this Petition arose after the comment period, which closed in 2017. The modeling study analyzed all Ector County emission events from 2014 through the end of 2019, and was completed in October 2020. This newly available air quality information shows widespread NAAQS violations across the county and is the grounds for this objection to Ector County's attainment designation. This new information arose after the close of the comment period, and so EPA must convene a rulemaking proceeding to reconsider the erroneous designation of unclassifiable/attainment for the 2010 SO_2 Primary NAAQS for Ector County.

B. The Information in This Petition Is of Central Relevance to Ector County's Attainment Classification.

This Petition is of central relevance to the county's designation because it is evidence of severe and pervasive air quality issues that negatively impact the residents of Ector County and violate state and federal law. This Petition is based on the first and only modeling of air pollution data for the area, which shows frequent exceedances of the 1-hour SO_2 NAAQS despite modeling only a fraction of actual emissions. Had this information been available at the time the rule was proposed, Ector County would have been properly designated nonattainment.

Because the grounds for this Petition arose after the period for public comment and this objection is of central relevance to the outcome of the rule, the Administrator must convene a

[39] 42 U.S.C. § 7607(d)(7)(B).
[40] Id.

proceeding for reconsideration. Petitioners urge EPA to issue a final nonattainment designation for Ector County based on the overwhelming evidence that demonstrates that rampant flaring in the Permian Basin has caused and will continue to cause exceedances of the SO_2 NAAQS absent a comprehensive program of emissions reductions.

V. Conclusion

Excessive flaring at oil and gas facilities is poisoning the air in Ector County. Levels of sulfur dioxide exceed the health-based standard established by the EPA across large areas of the County, including areas where people live, work, pray, and recreate. These dangerous levels of air pollution harm local residents and reduce the quality of life for the entire region. Without effective regulation to bring flaring under control, West Texans will continue to breathe air that fails to meet Clean Air Act standards. To redress this harm, EPA should designate Ector County as nonattainment for the primary (one-hour) SO_2 NAAQS.

Respectfully Submitted,

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VIA ELECTRONIC MAIL

Modeling the SO_2 Impacts From Intermittent Flare Events in Ector County, Texas

H. Andrew Gray
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October 2020

Report prepared for
Environmental Integrity Project
Austin, Texas

INTRODUCTION

Scope of Work

I have been retained by the Environmental Integrity Project to address, from the perspective of an atmospheric scientist, the issue of whether sulfur dioxide (SO_2) emissions from intermittent flare releases from oil and gas facilities have substantially contributed to elevated levels of air pollution in Ector County, Texas. Using incident reports filed by these facilities as part of the State of Texas Environmental Electronic Reporting System and obtained from the Texas Commission on Environmental Quality, for the six-year period between 2014 and 2019, I evaluated the air quality impacts (SO_2 concentrations) that occurred throughout Ector County, Texas due to emissions from intermittent flare events at numerous oil and gas facilities. I address in this report the question of whether these emissions likely caused violations of the primary (health-based) national ambient air quality standards (NAAQS) for SO_2.

Methodology

Based upon my education and professional experience as an atmospheric scientist, I conducted an air dispersion modeling analysis to determine the SO_2 air quality impacts in the surrounding area due to intermittent emission events from oil and gas flares in Ector County, Texas. I compiled the necessary information to describe the SO_2 emissions between 2014 and 2019. I used this information as input to the AERMOD dispersion model which simulated the dispersion of the SO_2 into the surrounding community for every hour during the entire six-year period.

Conclusions

Based on the emission data and modeling analysis that I conducted, I conclude that SO_2 emissions from the oil and gas flares did, in fact, substantially contribute to elevated levels of SO_2 in the ambient air over a large area within Ector County. The model estimates that the 1-hour Primary NAAQS for SO_2 was violated at numerous locations throughout the county.

Qualifications

I am an environmental engineer and atmospheric scientist with over 40 years of professional experience performing air quality dispersion modeling and related analyses. I received my Bachelor of Science (BS) in civil engineering / engineering and public policy from Carnegie-Mellon University in 1979. I earned a Master of Science (MS) and a Ph.D. in environmental engineering science from the California Institute of

Technology (Caltech), with a minor emphasis in numerical methods. My doctoral thesis, on the control of atmospheric carbon particles in the Los Angeles region, includes a number of analyses that have been relied upon and cited repeatedly by atmospheric modelers, researchers, and government planners during the last thirty years.

I have developed, evaluated, and applied air pollution dispersion models in academic, regulatory and consulting environments. I developed and applied the methodologies for assessing particulate matter and visibility that were used by the South Coast Air Quality Management District (Southern California) for their air quality management plans during the 1980s and 1990s. I managed a team of researchers that evaluated the MESOPUFF model (the precursor to CALPUFF) for the US Interagency Workgroup on Air Quality Modeling (IWAQM).

As a consultant, I have modeled the air quality impacts of thousands of emission sources, using a variety of air quality models (including AERMOD, CALPUFF, CAMx, CMB, etc.) for various clients, including industry (e.g., diesel engine manufacturers and the off-shore container shipping industry), government (e.g., US EPA and US Dept. of Justice), and environmental organizations (including Sierra Club and National Parks Conservation Association).

I have authored hundreds of technical reports, many of which have been published in peer-reviewed journals and symposia. I have provided expert testimony regarding air dispersion modeling analyses at numerous hearings, depositions, and at trial. In April 2014, I was invited by the Royal Institute of International Affairs to participate in the “Balancing Global Energy Policy Objectives: A High-Level Roundtable” meeting.

I have expertise in air quality monitoring, statistical analyses, atmospheric chemistry, meteorology, particle processes, atmospheric transport and deposition, numerical methods, computer modeling, air quality control strategy design, and environmental public policy. An integral part of my research has involved developing, applying, and evaluating computer modeling tools to determine the air quality impacts of emission sources in the areas surrounding those sources. My experience and qualifications are described in detail in the attached resume (Attachment A).

MODEL APPLICATION

Model Selection

The AERMOD air quality model was used to determine the increase in ambient SO_2 concentrations in Ector County due to intermittent emissions from 173 oil and gas facilities located around Odessa, Texas, mainly in Ector County. AERMOD[1,2,3] is a steady-state plume model that considers atmospheric dispersion based on the planetary boundary layer turbulence structure and scaling concepts. AERMOD has been adopted in federal rule by the US Environmental Protection Agency (EPA) as the preferred near-field dispersion model for regulatory assessments of industrial point sources, including determinations of compliance with the National Ambient Air Quality Standards (NAAQS), and evaluations of proposed new source emission.[4]

In addition to the AERMOD dispersion model, the AERMOD modeling system includes AERMET, a meteorological data preprocessor. The protocol that I used for this modeling analysis follows the guidance for AERMOD and AERMET applications established in US EPA's modeling guidelines[5] and the AERMOD implementation guide.[6]

This report describes the modeling exercise that I conducted using the AERMOD model to evaluate the impact of intermittent oil and gas flare emissions on ambient SO_2 concentrations in Ector County. The necessary input data including emission rates, receptor and meteorological data, and modeling options, are described below, followed by a summary of the model results.

Source Data

SO_2 is emitted from the oil and gas facilities from various emission points throughout Ector County. The Texas Commission on Environmental Quality (TCEQ) maintains records of Emissions Events, which are essentially unauthorized emissions from upsets and unplanned maintenance events, and these are the intermittent emission incidents I modeled in this study. The Incident Reports obtained from TCEQ include information such as the location of the facilities, the start date and time, end date and time, and amount of SO_2 (lbs) released during each emission event. Incident Reports for 2014 through 2019 were obtained from TCEQ for use in this study.[7] For modeling purposes,

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[1] U.S. Environmental Protection Agency. AERMOD: Description of Model Formulation. EPA-454/R-03-004. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. September 2004.
[2] U.S. Environmental Protection Agency. Addendum: User's Guide for the AMS/EPA Regulatory Model – AERMOD. EPA-454/B-03-001. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711, March 2011.
[3] U.S. Environmental Protection Agency. User's Guide for the AMS/EPA Regulatory Model – AERMOD. EPA-454/B-16-011. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. December 2016.
[4] U.S. Environmental Protection Agency. Guideline on Air Quality Models, 40 CFR Part 51, Appendix W. Published in the Federal Register, Vol. 70, No. 216, November 9, 2005.
[5] Ibid.
[6] U.S. Environmental Protection Agency. AERMOD Implementation Guide. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. 2009. http://www.epa.gov/ttn/scram/7thconf/aermod/aermod_implmtn_guide_19March2009.pdf
[7] TCEQ's Emission Event Report Database, https://www2.tceq.texas.gov/oce/eer/

it was assumed that the SO_2 emissions were released at a constant rate between the start date/time and end date/time.

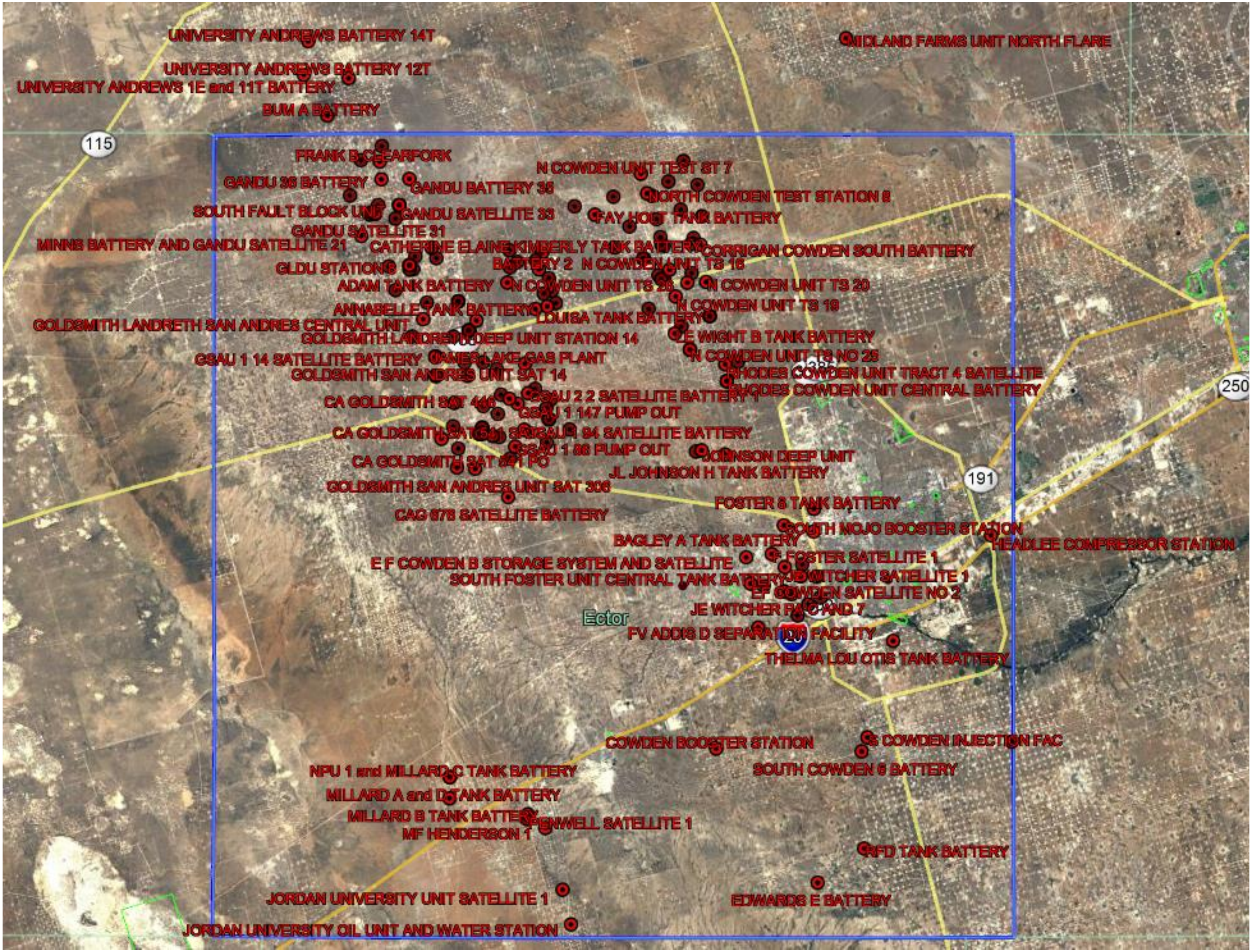
Source information required by the AERMOD model for point sources includes the location of each emission release, the height (above ground) of release, the stack diameter, stack gas temperature, exit velocity, and the pollutant emission rate.[8] Source parameters, including release height, stack diameter, exit velocity, and exit gas temperature, were obtained from publicly available TCEQ files, including TCEQ's point source database and facility-specific permit and application files. Stack heights were obtained for 48 facilities, stack diameters were obtained for 42 facilities, exit velocities were obtained for 20 facilities, and exit temperatures were obtained for 30 facilities.

The locations (UTM coordinates[9]) were estimated using information contained in permit files or the TCEQ Incident Reports, along with Google Earth maps and aerial images. Figure 1 shows the locations of the modeled emission releases.[10]

For those facilities that did not have reliable stack parameter data, conservative default values were used in the modeling (default stack height: 13.72 m, default stack diameter: 0.30 m, default exit velocity: 20.0 m/s, default exit temperature: 1273 K). It should be noted that these default stack parameter values produced higher than average plume rise for each of these sources, which resulted in somewhat lower (conservative) concentration impacts than would be expected if the actual stack parameter data (if known) had been used. The modeled locations and stack parameters for all 173 facilities are shown in Appendix A.

[8] "Pollutant emission rate" is the mass of pollutant released into the atmosphere per unit time (lb/hour).
[9] UTM (Universal Transverse Mercator) coordinates (meters) are located in UTM Zone 13.
[10] A few of the modeled emission releases affecting air quality in Ector County were located in southern Andrews County, to the north of Ector County.

Figure 1. Modeled Sources



In total, 4,347 incidents were modeled. SO_2 was emitted from all 4,347 incidents during 305,836 different source-hours between 2014 and 2019, accounting for a total duration of 301,652.5 hours. The total duration is equivalent to 5.7 "sources" running full-time for all six years. The total SO_2 emitted from incidents from all 173 sources for all six years was 46,244,565 lb (23,122 tons). Incident information by year is presented in Table 1, below.

Table 1. Number, Total Duration and Total Emissions from Modeled Incidents

Year	# of Incidents	Total Hours	SO_2 Emitted (tons)
2014	495	53,494.0	5,059
2015	669	53,511.5	4,350
2016	568	36,669.9	3,194
2017	832	36,490.7	2,669
2018	948	47,515.6	2,849
2019	835	73,970.9	5,003
Total 2014-2019	4,347	301,652.5	23,122

Overall, the average incident lasted 69.4 hours and emitted 10,638 lb, however both the incident duration and total emissions varied widely, as shown in Figures 2-13, below. The overall average emission rate for all incidents was 153.3 lb/hr (with a wide variation).

The maximum incident duration was 2,659 hours (110.8 days). 8 incidents had durations exceeding 1,000 hours.

The maximum incident total SO_2 emissions was 1,066,993 lb (533.5 tons), which began in late November 2016 and lasted for 15.5 days. 64 incidents had total SO_2 emissions exceeding 100,000 lb, or 50 tons.

The maximum incident emission rate was 39,561 lb/hr, which occurred during a two-hour period in December 2016. 424 incidents had SO_2 emission rates that exceeded 1,000 lb/hr; 37 incidents had emission rates that exceeded 10,000 lb/hr, or 5 tons/hour.

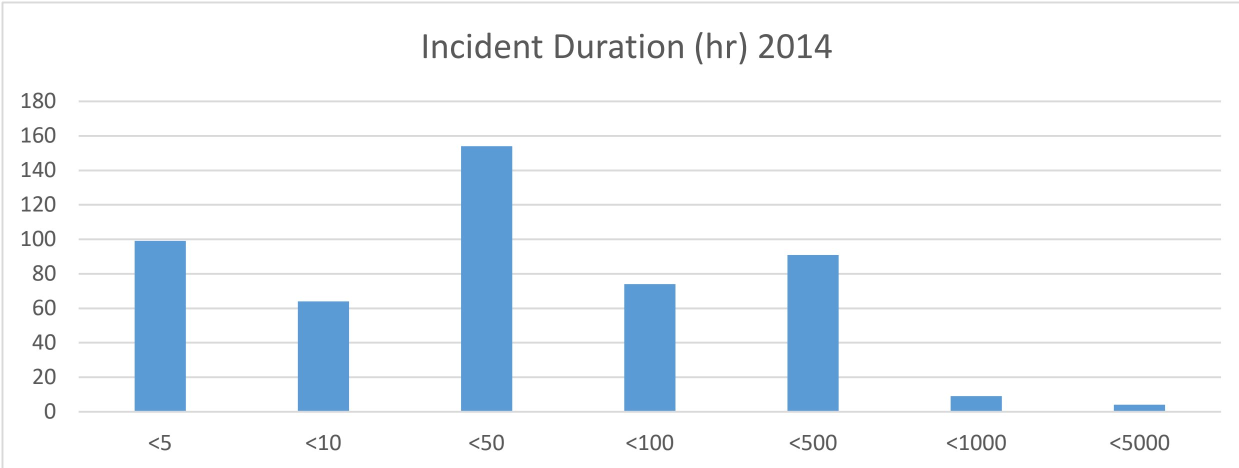


Figure 2. Incident Duration, 2014

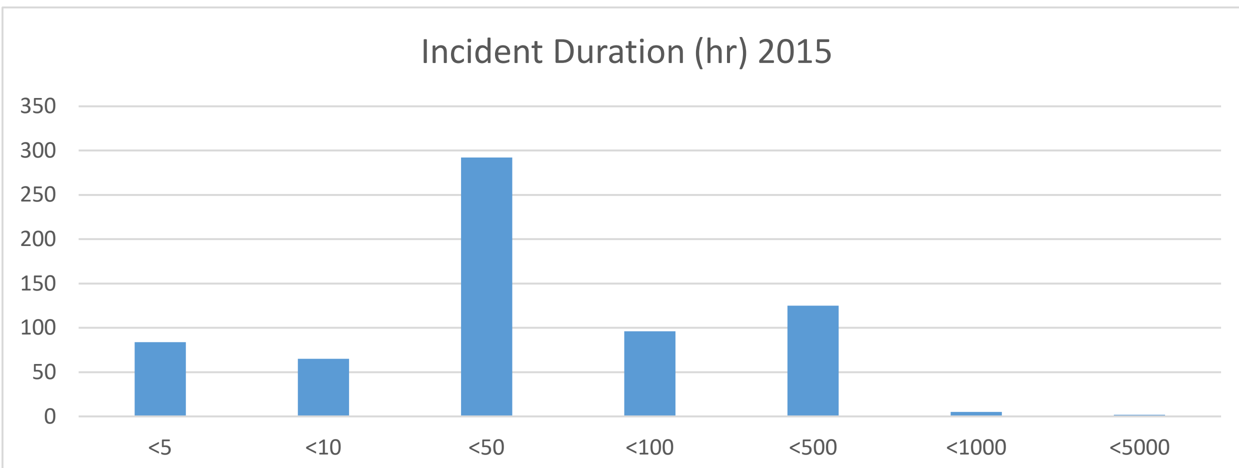


Figure 3. Incident Duration, 2015

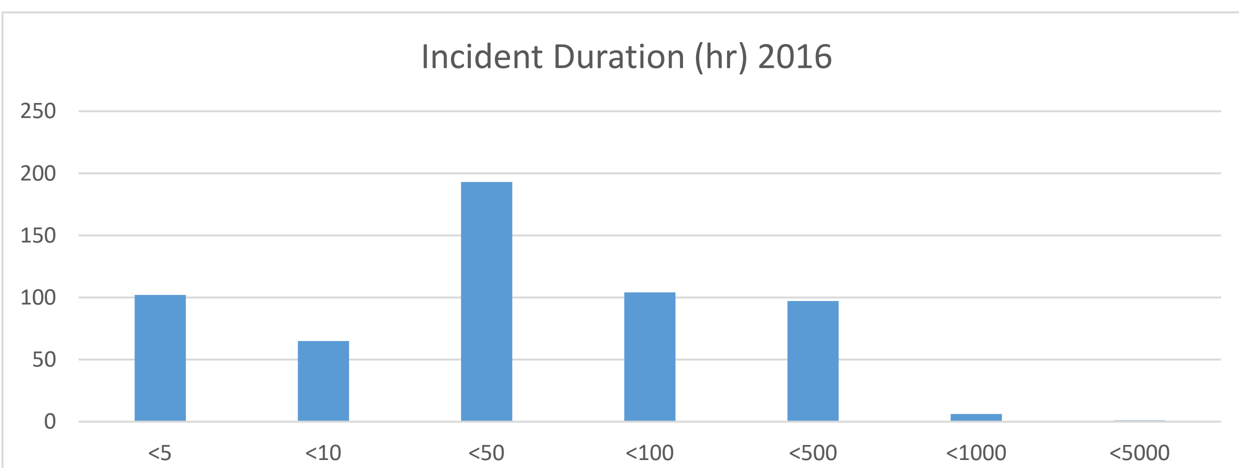


Figure 4. Incident Duration, 2016

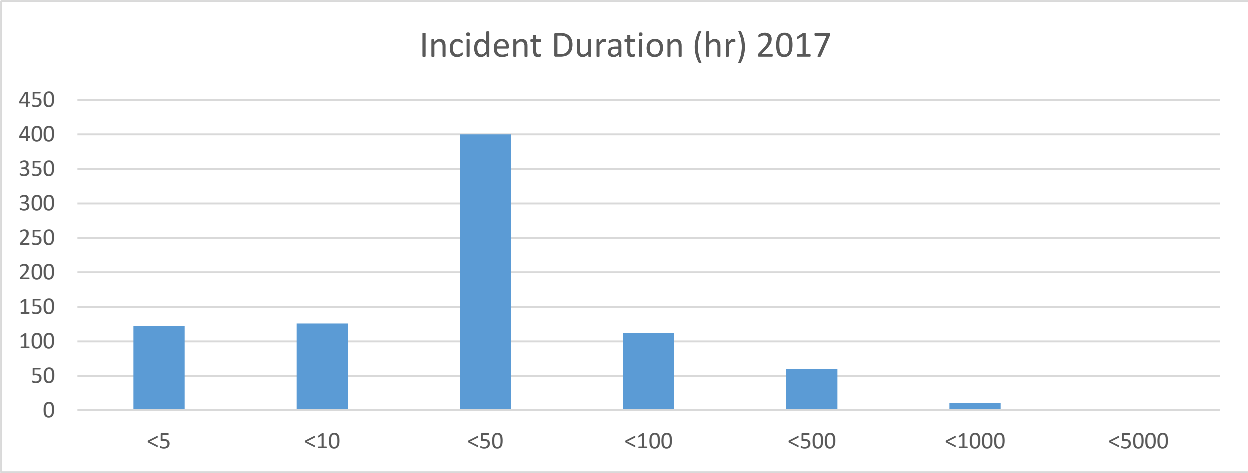


Figure 5. Incident Duration, 2017

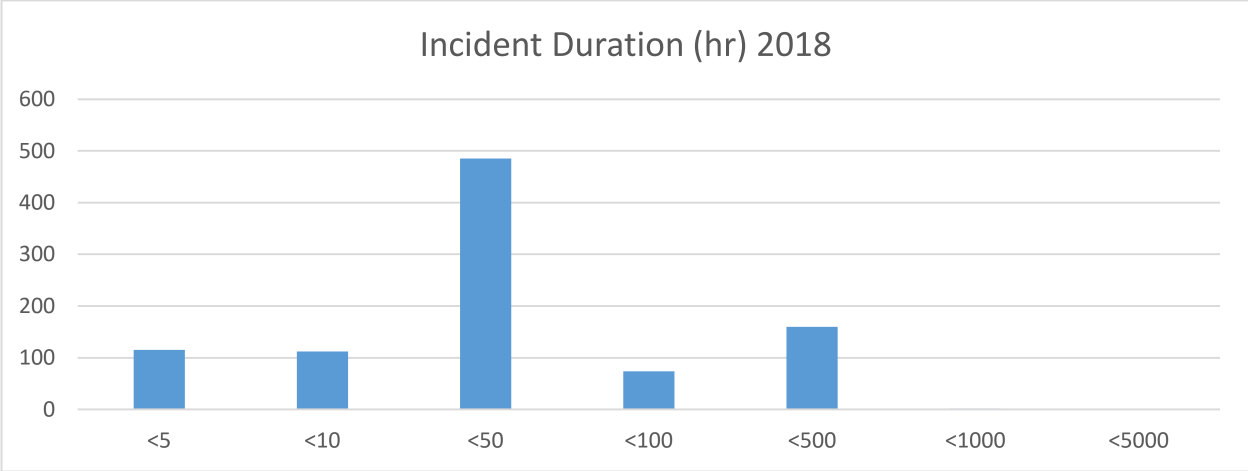


Figure 6. Incident Duration, 2018

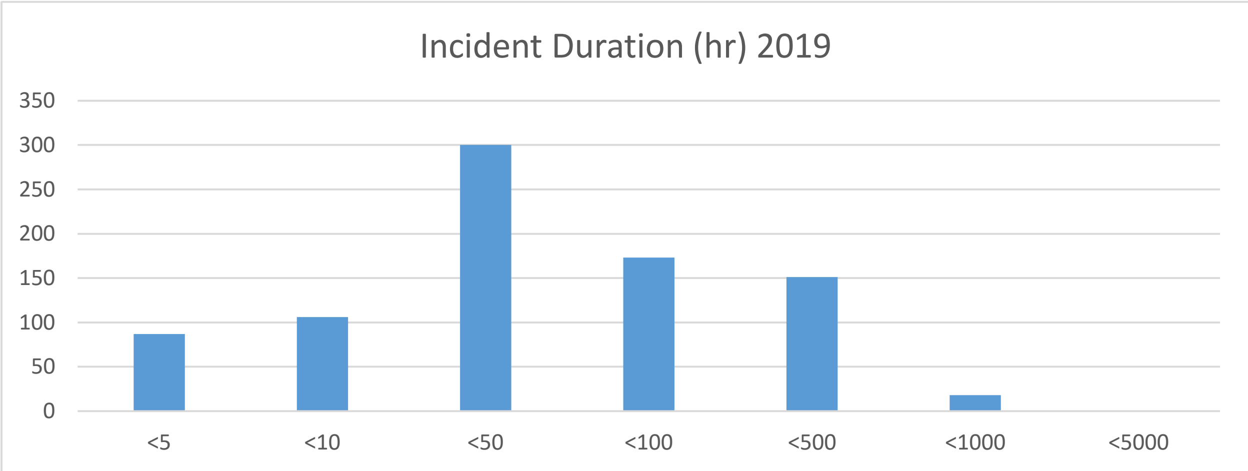


Figure 7. Incident Duration, 2019

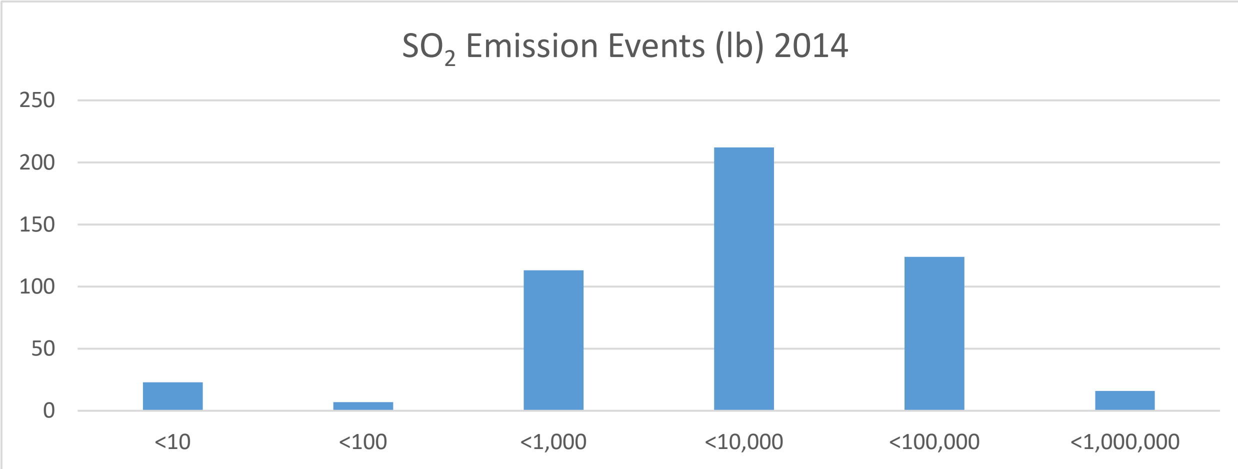


Figure 8. Emissions Events (lb), 2014

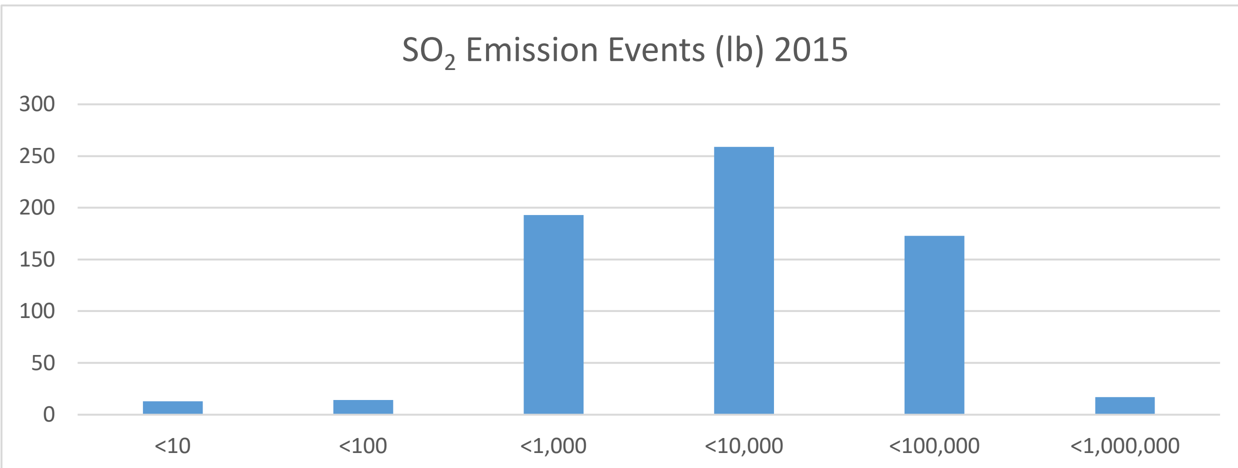


Figure 9. Emissions Events (lb), 2015

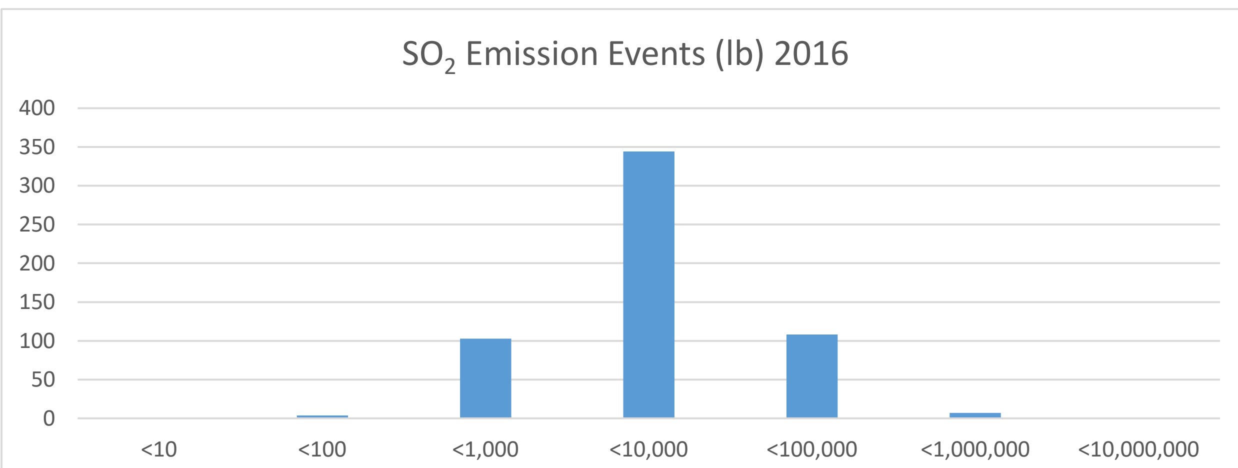


Figure 10. Emissions Events (lb), 2016

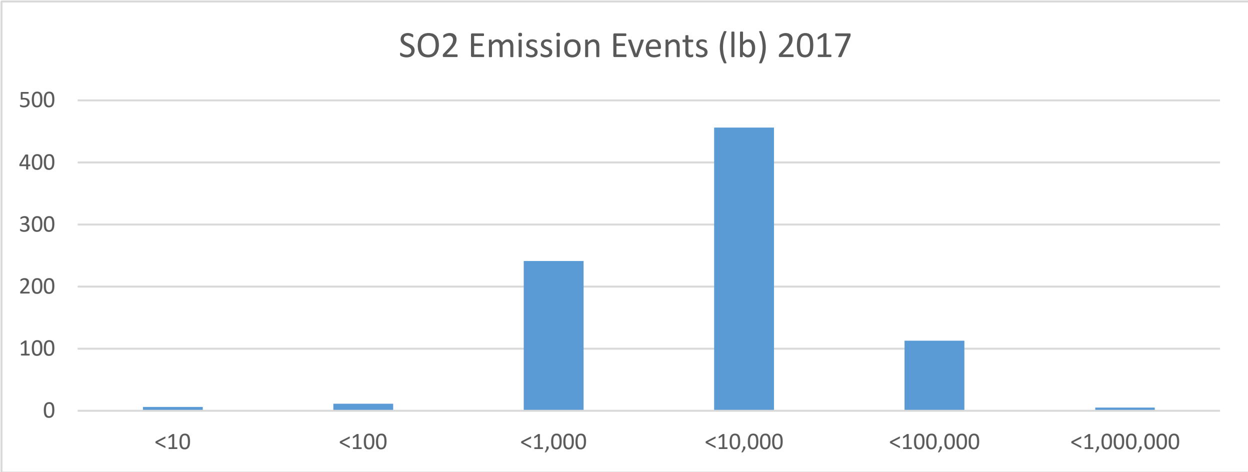


Figure 11. Emissions Events (lb), 2017

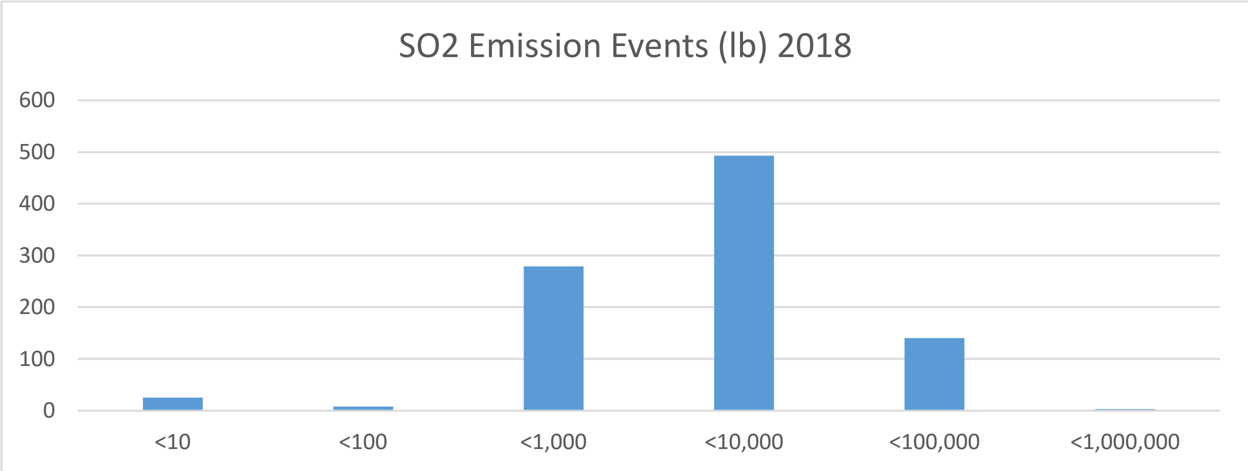


Figure 12. Emissions Events (lb), 2018

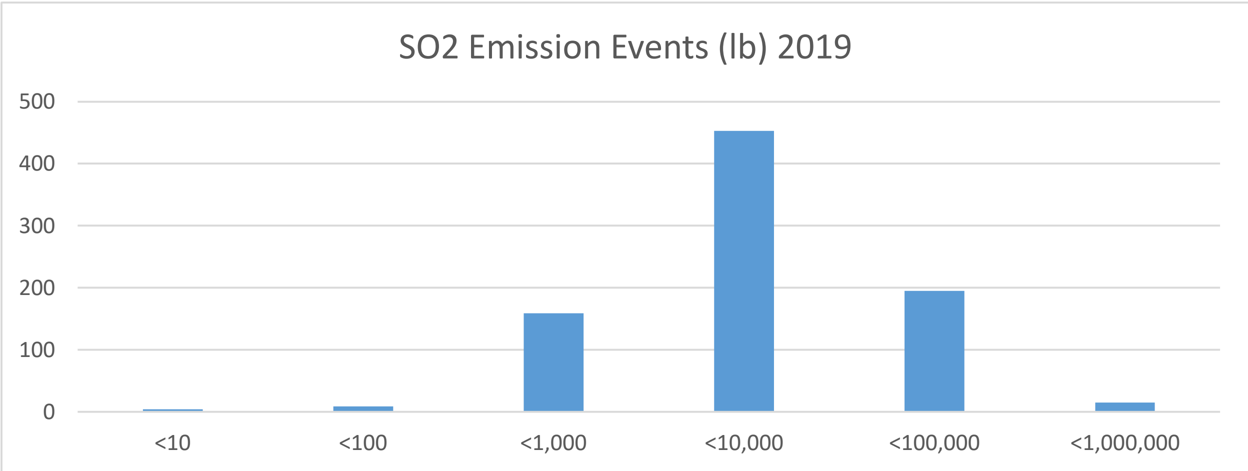


Figure 13. Emissions Events (lb), 2019

Receptor Data

The AERMOD model is designed to estimate pollutant concentrations at a specified set of locations within the modeling domain, which are referred to as the modeled "receptors". For the current AERMOD application, I defined a set of gridded modeled receptors within Ector County (30 mi x 30 mi square), as shown in Figure 14. Receptors were placed every 1 mile, accounting for 961 gridded receptors (31 N/S x 31 E/W).

The AERMOD model calculated the SO_2 concentration (µg/m^3) at each of the 961 receptor locations for every hour of the six-year model simulation (52,584 hours). The modeled concentrations at each receptor location are assumed to be representative of the surrounding 1 mi x 1 mi grid cell.[11]

In addition to the gridded receptors, a set of 20 discrete receptors, located at residences, ranches, churches, places of business, etc., were placed throughout Ector County, as shown In Table 2, below. The locations of the discrete receptors are also shown on the map in Figure 15.

Table 2. Discrete Receptors

Receptor	Type	Location
R1	business	SE corner of Gulf Ave (HWY 158) & S. Scharbauer St., Goldsmith
R2	urban center	Intersection of W 8th St. & N Washington Ave., Odessa
R3	residential	N Aster Ave., between E Larkspur Ln. and E Goldenrod Dr., Gardendale
R4	campground	Western Skies RV Campground, HWY 20, Penwell
R5	residential	Larchmont Pl., north Odessa
R6	ranch	Boys Ranch Rd., 0.9 km west of Marion Flint (Rte 26)
R7	church	Goldsmith Community Church, S Goldsmith Ave & Avenue E, Goldsmith
R8	residential	5200 block of W 40th St., west Odessa
R9	residential	2300 block of W Berry St., south Odessa
R10	school	University of Texas of the Permian Basin, east Odessa
R11	ranch	Cottonwood Dr, 0.5 km west of Wire Line Rd.
R12	ranch	YT Ranch Rd., 3.9 km west of Chapel Hill Rd. (Rte 1936)
R13	residential	6900 block of N Carter Ave, West Odessa
R14	school	Ector College Prep Success Academy, south Odessa
R15	church	Faith Community Baptist Church, West Odessa
R16	residential	Intersection of W Ivory St. & S Beryl Ave., Pleasant Farms
R17	museum	Odessa Meteor Crater Museum, SW Odessa
R18	ranch	YT Ranch Rd., 2.9 km east of James Lake (Rte 866)
R19	residential	3rd St., Notrees
R20	ranch	NE corner of W Apple St. & S Klondyke Ave., Pleasant Farms

[11] The gridded receptors are located at the center of each 1 mi x 1 mi grid cell.

Figure 14. Ector County AERMOD modeling domain (30 mi x 30 mi)

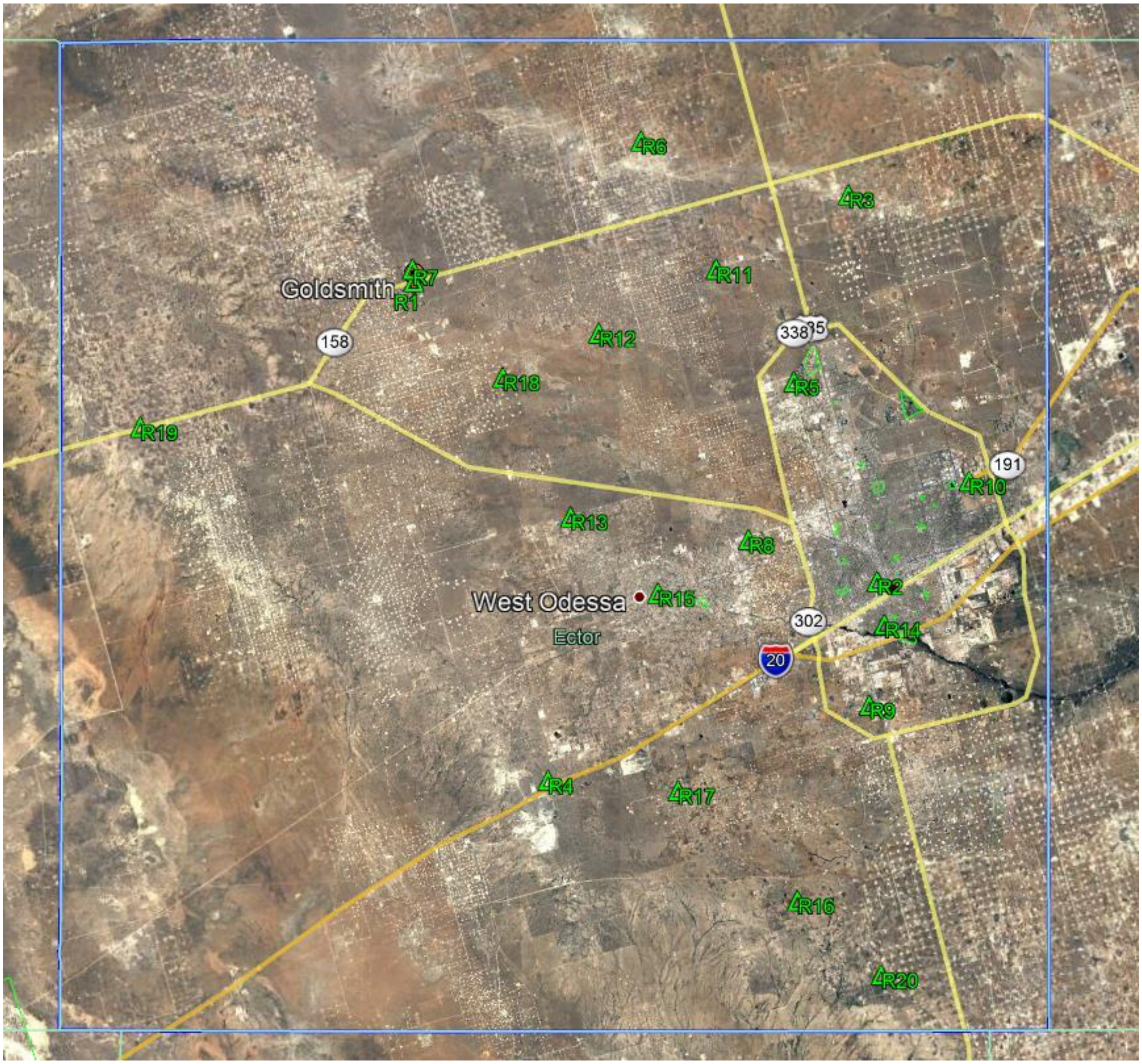


Figure 15. Modeling Domain Showing Locations of Discrete Receptors

Meteorological Data

I assembled meteorological data for 2014-2019 for input to the AERMOD model. The model requires continuous records of surface and upper air meteorological data (including wind speeds and directions, temperatures, ambient air pressures, precipitation, etc.). These data were obtained from airport measurements. The surface data included (1) hourly Integrated Surface Data (ISD) from the Odessa Schleymeyer

Field Airport (ODO),[12] and (2) 1-minute Automated Surface Observing System (ASOS) wind data from ODO.[13] The upper air data consisted of morning radiosonde measurements (soundings) recorded each day at 1200 GMT at Midland International Airport (MAF),[14] located about 8 km east of Ector County.

AERMOD ignores hours with variable wind (i.e., undefined wind direction) or calm (low wind speed) conditions, resulting in zero concentrations for those hours, which can lead to an underestimation of long-term average concentrations. To address the issue of calm and variable winds associated with the hourly averaged surface wind data that is typically input to AERMOD, US EPA developed the AERMINUTE preprocessor.[15] AERMINUTE processes 1-minute ASOS wind data, resulting in significantly fewer hours with calm and missing winds. I used AERMINUTE (Version 15272) to reduce the number of calm wind conditions (zero wind speed) within the hourly Odessa surface data for 2014-2019 from 1,595 to 220 (out of 52,584 total modeled hours).

AERSURFACE,[16] a non-regulatory component of the AERMOD modeling system, was used to develop the surface characteristics at ODO, as required by AERMET. I obtained land cover/land use data from the US Geological Survey (USGS) National Land Cover Database (NLCD)[17] and processed the data using AERSURFACE (Version 13016) in order to determine the required micrometeorological parameters (noon-time albedo, daytime Bowen ratio, and surface roughness length) at ODO using twelve 30-degree sectors for each month. Average surface moisture was assumed for the Odessa Airport location.[18]

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[12] National Climatic Data Center, Integrated Surface Data (ISD) for ODO (USAF: 722648; WBAN: 03031) 2014-2019, National Oceanic and Atmospheric Administration (NOAA). ftp://ftp.ncdc.noaa.gov/pub/data/noaa/readme.txt

[13] National Centers for Environmental Information (NCEI), Automated Surface Observing System (ASOS) Data for Odessa, TX (ODO), 2014-2019. National Oceanic and Atmospheric Administration (NOAA). https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/automated-surface-observing-system-asos

[14] Earth System Research Laboratory (ESRL), ESRL Radiosonde Database, FSL Data for MAF (WBAN: 23023) 2014-2019. National Oceanic and Atmospheric Administration (NOAA). https://ruc.noaa.gov/raobs/General_Information.html

[15] U.S. Environmental Protection Agency. AERMINUTE User's Guide. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. 2011. http://www.epa.gov/ttn/scram/7thconf/aermod/aerminute_v11059.zip

[16] U.S. Environmental Protection Agency. AERSURFACE User's Guide. EPA-454/B-08-001. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. 2008. (http://www.epa.gov/ttn/scram/7thconf/aermod/aersurface_userguide.pdf)

[17] Multi-Resolution Land Characteristics Consortium (MRLC). https://www.mrlc.gov/

[18] According to Climate Data for US Cities (http://www.usclimatedata.com/climate/odessa/texas/united-states/ustx2587), the average precipitation for Odessa, TX is 15 inches. According to the Average Annual Precipitation by City in the United States (https://www.currentresults.com/Weather/US/average-annual-precipitation-by-city.php), the average annual precipitation for Austin, Dallas, and San Antonio, are 34.2, 37.6, and 32.3 inches, respectively. AERSURFACE guidelines recommend using the wet surface moisture option for locations in the top 30 percent of annual precipitation (greater than about 45 inches), and dry surface moisture for locations in the bottom 30 percentile.

I used the AERMET meteorological preprocessor (Version 16216)[19] to merge the hourly surface and upper air data, and to estimate a number of required boundary layer parameters using the meteorological data and surface characteristics.

Modeling Options

A number of control options must be specified in order to execute the AERMOD model. For this application, regulatory default options were used, which include the use of stack-tip downwash (for point releases), and the calms and missing data processing as set forth in US EPA's modeling guidelines.[20] There are almost no topological features in Ector County, so the model was run in "flat" mode (i.e., no terrain effects). The model's averaging time was set to one hour and default flagpole receptor heights were assumed to be 1.5 m. The majority of Ector County is sparsely populated, so the "Rural" modeling option was selected within AERMOD.[21]

I used the most recent version of AERMOD (Version 16216r) to estimate the SO_2 concentration impacts due to emissions from the intermittent flares at each of the 173 modeled facilities. No background concentrations were added to the modeled impacts, therefore the modeled concentrations represent the incremental impact to the surrounding community from the modeled incidents.

MODEL RESULTS

The AERMOD model was used to estimate the average SO_2 concentration due to emissions from the 173 modeled facilities for every hour of the six-year (2014-2019) modeling period at every gridded and discrete receptor location. The current Primary National Ambient Air Quality Standard (NAAQS) for SO_2[22] requires that the 99th percentile of 1-hour daily maximum SO_2 concentrations, averaged over 3 years, is below 75 ppb (equivalent to 196 ug/m3). The modeled 99th percentile (4th highest) maximum daily 1-hour SO_2 concentrations for each year are shown in Table 3, below, for the gridded receptors. Three-year averages of the modeled 99th percentile maximum daily 1-hour SO_2 concentrations for the gridded receptors are shown in Table 4.

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[19] U.S. Environmental Protection Agency. User's Guide to the AERMOD Meteorological Preprocessor (AERMET). EPA-454/R-03-003. U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. 2004. http://www.epa.gov/ttn/scram/7thconf/aermod/aermet_userguide.zip
[20] U.S. Environmental Protection Agency. Guideline on Air Quality Models, 40 CFR Part 51, Appendix W. Published in the Federal Register, Vol. 70, No. 216, November 9, 2005.
[21] The "URBAN" modeling option would incorporate the effects of increased surface heating from an urban area on pollutant dispersion under stable nighttime atmospheric conditions.
[22] https://www.epa.gov/criteria-air-pollutants/naaqs-table

A shown in Tables 3 and 4, the 1-hour SO_2 NAAQS level was exceeded during each model year, and for each three-year averaging period, at numerous locations throughout Ector County.

Table 3. Annual Modeled Design Values for 1-Hour SO_2 NAAQS[23]

Model Year	Maximum Receptor (µg/m3)	Grid Cells > 196 µg/m3	Grid Cells > 400 µg/m3
2014	4,624.6	170	72
2015	3,333.6	352	111
2016	2,992.5	229	80
2017	2,161.2	128	34
2018	3,022.2	159	47
2019	4,996.8	279	82
6-year avg	1,714.2	209	67
6-year max	4,996.8	461	166

Table 4. Modeled 3-Year Average Design Values for 1-Hour SO_2 NAAQS

Modeled 3-Year Average	Maximum Receptor (µg/m3)	Grid Cells > 196 µg/m3	Grid Cells > 400 µg/m3
2014-2016	2,687.1	252	80
2015-2017	2,091.5	229	73
2016-2018	1,908.8	164	52
2017-2019	2,050.0	187	60

Figures 16-23 show the modeled three-year average SO_2 design value concentration impacts due to emissions from the 173 facilities.[24] The modeled three-year average 99th percentile daily maximum hourly SO_2 concentration (NAAQS design value) exceeded the allowable NAAQS level (196 µg/m^3) across a large area of the modeling domain (the red areas shown in Figures 16-23): 252 square miles in 2014-2017, 229 square miles in 2015-2017, 164 square miles in 2016-2018, and 187 square miles in 2017-2019 (one square mile is equivalent to 2.59 km^2).

[23] Design values correspond to the 99th percentile (4th highest) maximum daily 1-hour SO_2 concentration.
[24] Contours are shown in Figures 16, 18, 20, and 22 for concentrations up to 196 µg/m^3. The red areas represent design value concentrations that exceed 196 µg/m^3.

Figure 16. Modeled Design Value SO_2 concentrations (μg/m^3), 2014-2016

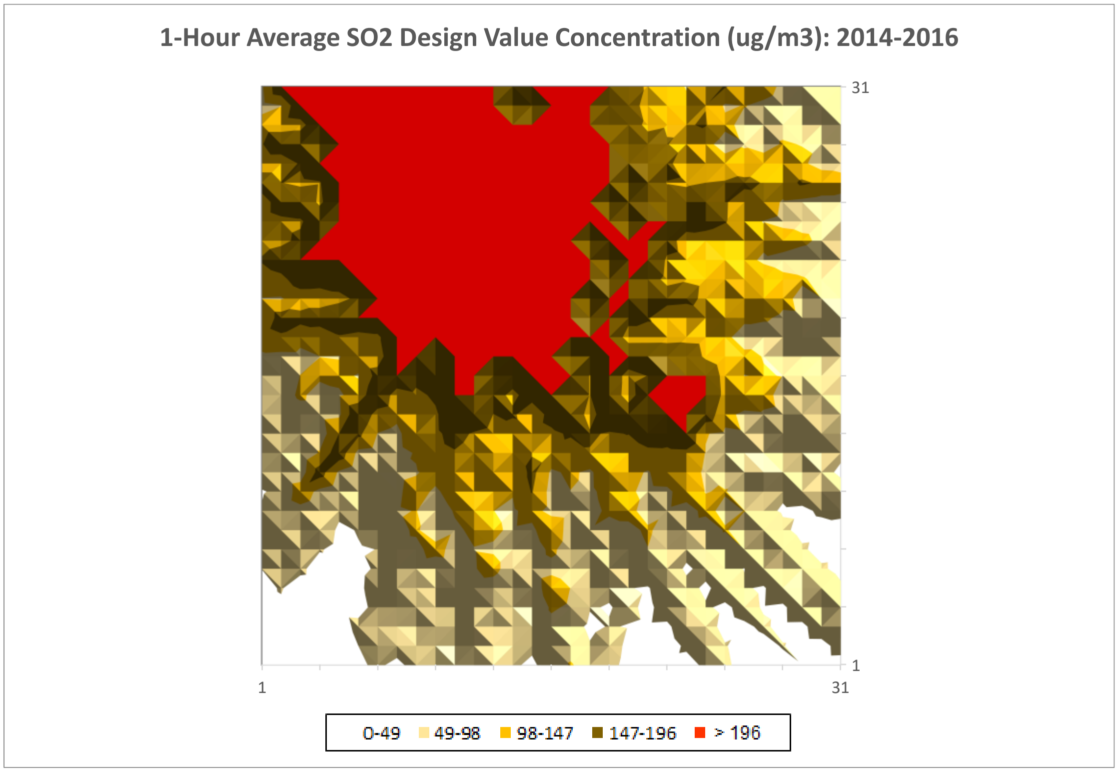

Figure 17. Modeled SO_2 concentrations exceeding 196 μg/m^3, 2014-2016

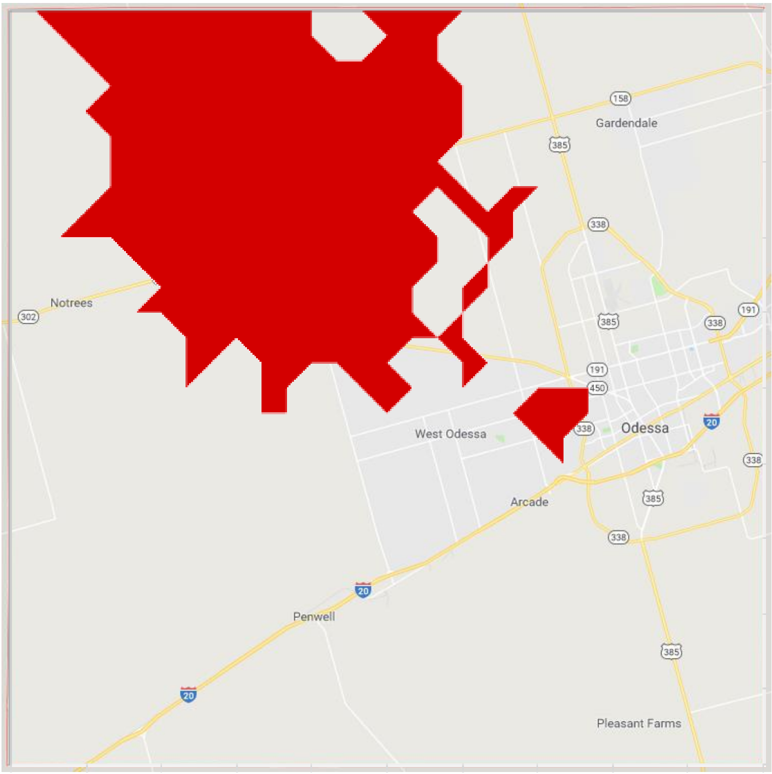

Figure 18. Modeled Design Value SO_2 concentrations (µg/m^3), 2015-2017

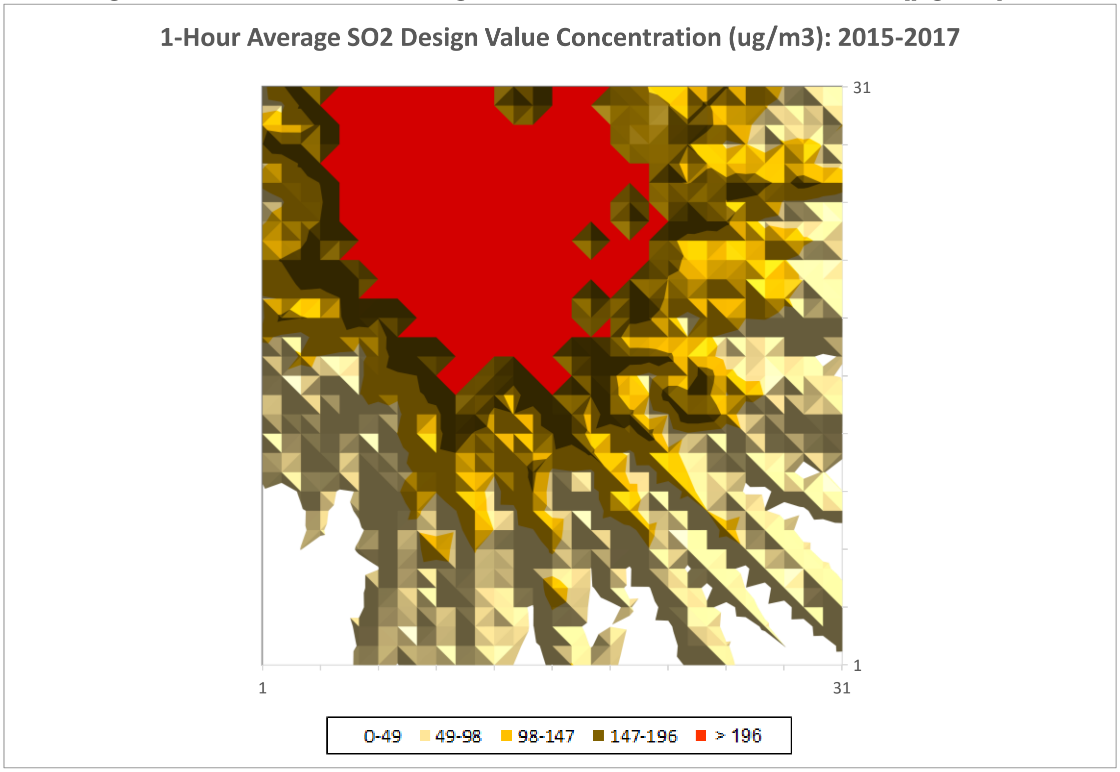

Figure 19. Modeled SO_2 concentrations exceeding 196 µg/m^3, 2015-2017

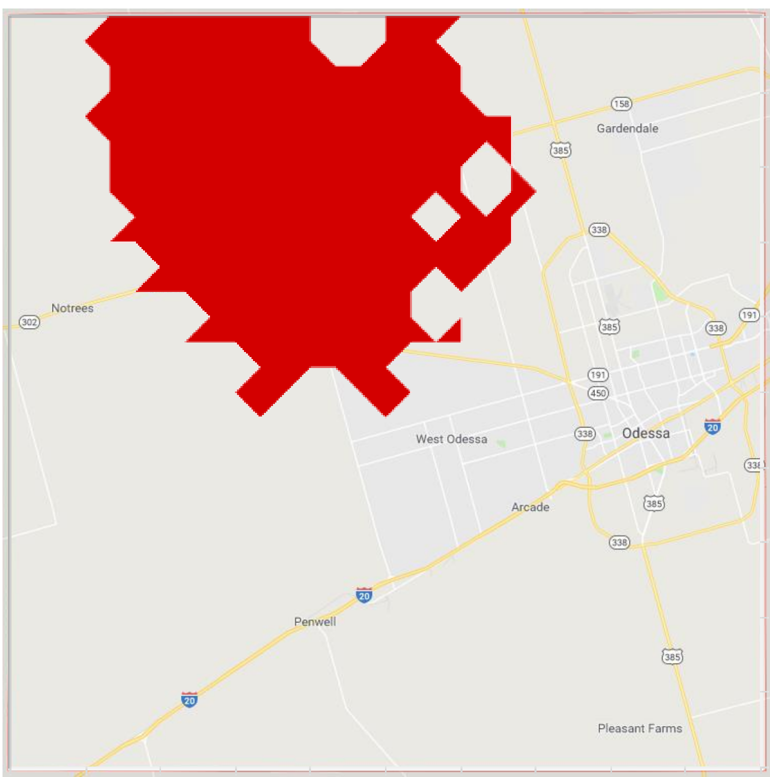

Figure 20. Modeled Design Value SO_2 concentrations (μg/m^3), 2016-2018

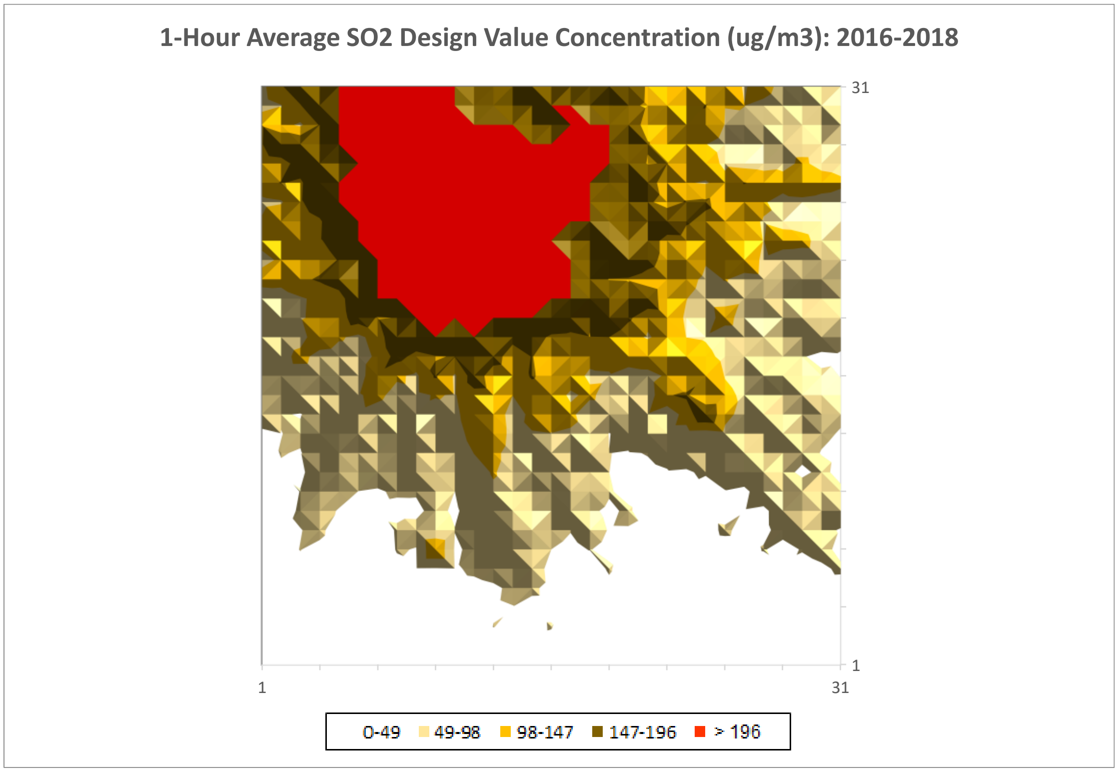

Figure 21. Modeled SO_2 concentrations exceeding 196 μg/m^3, 2016-2018

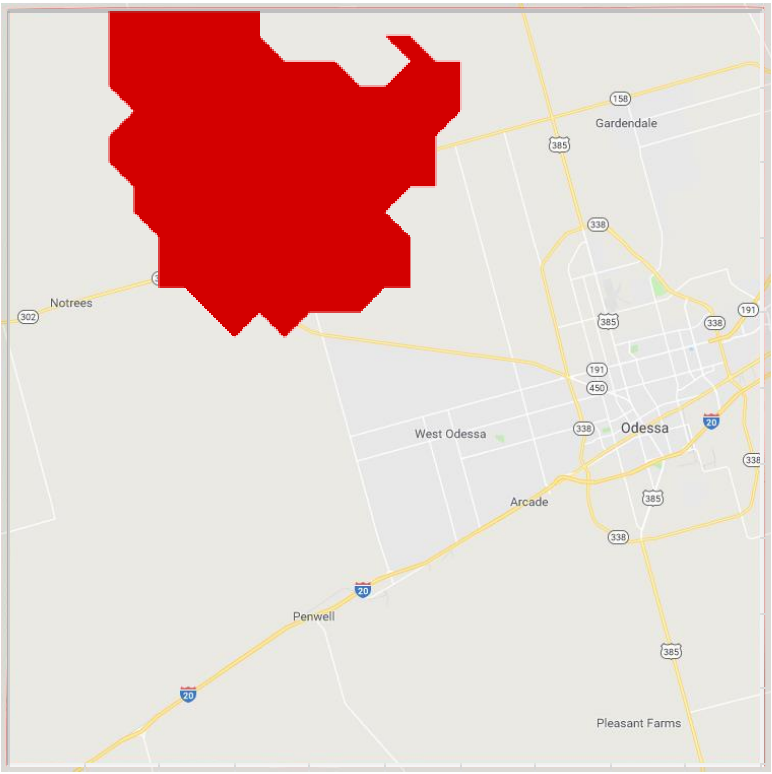

Figure 22. Modeled Design Value SO_2 concentrations (µg/m^3), 2017-2019

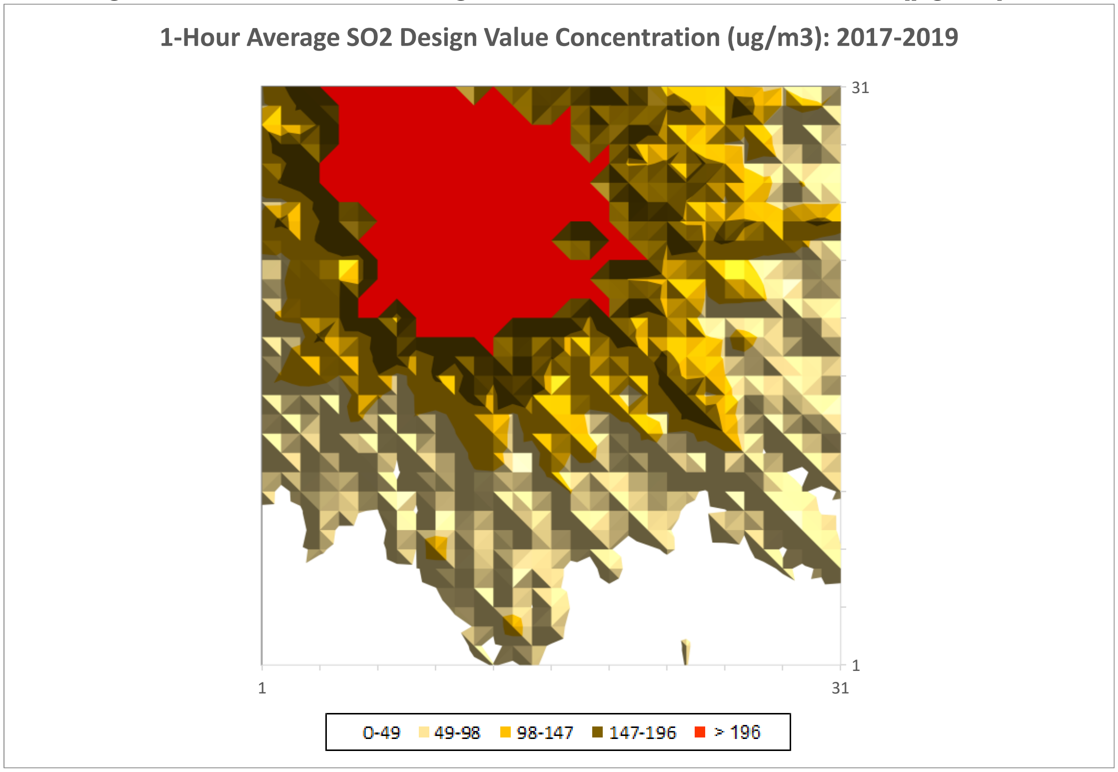

Figure 23. Modeled SO_2 concentrations exceeding 196 µg/m^3, 2017-2019

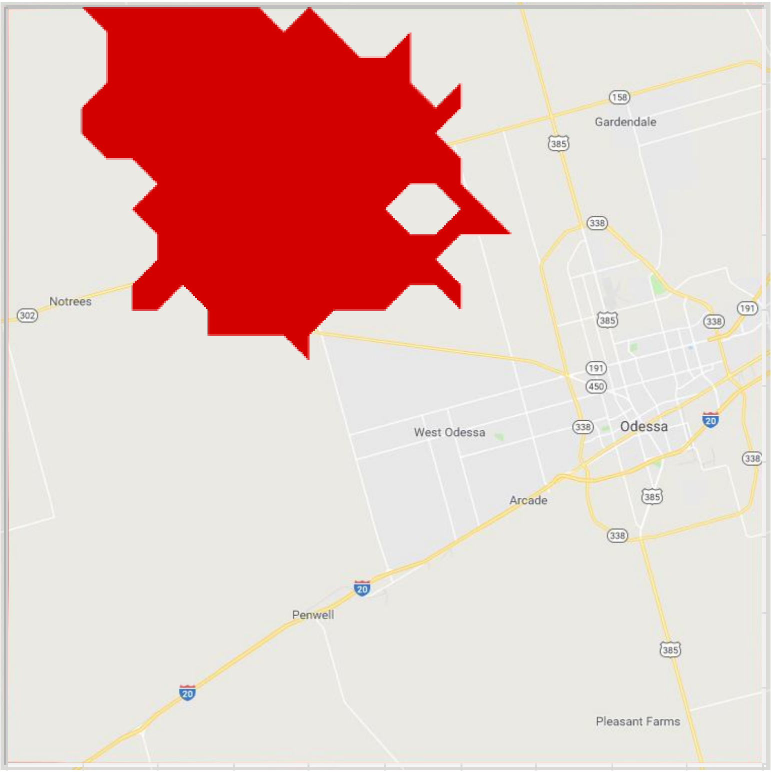

Table 5 shows the modeled design values (99th percentile daily maximum hourly SO_2 concentration) for each model year at each of the 20 discrete receptor locations. The modeled annual design values exceeded the allowable NAAQS level (196 μg/m^3) at numerous locations throughout Ector County (between 4 and 12 discrete locations, depending on the year, accounting for 14 of the 20 discrete receptor locations), as shown in red in the table.

Table 5. Modeled Design Values for 1-Hour SO_2 NAAQS at Discrete Receptors

Receptor	UTMx (m)	UTMy (m)	2014	2015	2016	2017	2018	2019	6-yr AVG	6-yr MAX
R1	725335	3540778	**330.7**	**623.1**	**1,239.8**	**845.6**	**450.1**	**454.7**	**657.3**	**1,239.8**
R2	748320	3526688	121.7	87.7	85.5	40.4	133.7	53.7	87.1	133.7
R3	746500	3545500	73.4	**241.4**	120.1	88.6	70.1	127.0	120.1	**241.4**
R4	732420	3516640	47.1	**320.3**	61.8	38.6	88.2	67.0	103.9	**320.3**
R5	744025	3536317	125.2	**245.2**	112.0	107.9	83.3	163.6	139.5	**245.2**
R6	736288	3547888	155.5	175.9	**238.2**	**203.0**	180.5	**208.9**	193.6	**238.2**
R7	725253	3541377	**267.4**	**845.0**	**1,343.1**	**739.3**	**388.8**	**464.1**	**674.6**	**1,343.1**
R8	741970	3528581	**428.6**	178.2	67.5	56.9	167.3	**236.7**	189.2	**428.6**
R9	748072	3520648	98.4	80.6	63.5	26.3	65.4	81.4	69.3	98.4
R10	752720	3531690	55.3	62.5	62.7	47.0	60.4	117.9	67.6	117.9
R11	740100	3541720	125.6	**221.2**	**216.7**	101.6	156.6	**275.5**	182.9	**275.5**
R12	734425	3538475	**284.3**	**334.2**	**261.2**	129.1	**242.5**	**604.0**	**309.2**	**604.0**
R13	733250	3529500	85.4	**433.5**	86.0	125.6	146.3	168.7	174.3	**433.5**
R14	748720	3524600	106.8	148.9	56.4	48.3	39.5	78.2	79.7	148.9
R15	737600	3525880	79.4	**451.9**	119.7	28.0	101.8	139.6	153.4	**451.9**
R16	744760	3511055	23.8	112.9	19.4	30.7	12.6	53.2	42.1	112.9
R17	738795	3516280	41.6	**203.5**	45.1	57.3	34.5	58.7	73.4	**203.5**
R18	729780	3536216	**244.1**	**611.1**	**501.6**	**424.6**	**419.3**	**729.3**	**488.3**	**729.3**
R19	712136	3533400	146.3	**227.6**	123.0	128.0	62.6	163.8	141.9	**227.6**
R20	748950	3507500	33.0	67.0	12.3	22.6	11.6	59.8	34.4	67.0

Table 6. Modeled 3-Year Average Design Values for 1-Hour SO_2 NAAQS at Discrete Receptors

Receptor	UTMx (m)	UTMy (m)	2014-2016	2015-2017	2016-2018	2017-2019
R1	725335	3540778	**731.2**	**902.8**	**845.2**	**583.5**
R2	748320	3526688	98.3	71.2	86.5	75.9
R3	746500	3545500	145.0	150.1	92.9	95.2
R4	732420	3516640	143.1	140.3	62.9	64.6
R5	744025	3536317	160.8	155.0	101.1	118.3
R6	736288	3547888	189.8	**205.7**	**207.2**	**197.4**
R7	725253	3541377	**818.5**	**975.8**	**823.7**	**530.7**
R8	741970	3528581	**224.8**	100.9	97.3	153.6
R9	748072	3520648	80.8	56.8	51.8	57.7
R10	752720	3531690	60.2	57.4	56.7	75.1
R11	740100	3541720	187.8	179.8	158.3	177.9
R12	734425	3538475	**293.2**	**241.5**	**210.9**	**325.2**
R13	733250	3529500	**201.6**	**215.0**	119.3	146.9
R14	748720	3524600	104.0	84.5	48.0	55.3
R15	737600	3525880	**217.0**	**199.8**	83.1	89.8
R16	744760	3511055	52.0	54.3	20.9	32.2
R17	738795	3516280	96.7	101.9	45.6	50.2
R18	729780	3536216	**452.3**	**512.5**	**448.5**	**524.4**
R19	712136	3533400	165.6	159.5	104.5	118.1
R20	748950	3507500	37.4	34.0	15.5	31.3

As shown in Table 6, the modeled three-year average 99th percentile daily maximum hourly SO_2 concentration (NAAQS design value) exceeded the allowable NAAQS level (196 $\mu g/m^3$) at between five and seven locations (out of the 20 modeled discrete receptor locations), depending on the three-year averaging period. NAAQS exceedances (as shown in red) were observed at eight different discrete receptors: R1 (business, Goldsmith), R6 (ranch, Boys Ranch Rd.), R7 (church, Goldsmith), R8 (residence, west Odessa), R12 (ranch, YT Ranch Rd.), R13 (residence, west Odessa), R15 (church, west Odessa), and R18 (ranch, YT Ranch Rd.).

SUMMARY AND CONCLUSIONS

I compiled the necessary information in order to characterize the oil and gas flare SO_2 emission incidents from 173 facilities during the period between 2014 and 2019. I also constructed the required hourly meteorological data representing the six-year period 2014-2019. The source and meteorological data were input to the AERMOD dispersion model which was used to estimate the SO_2 air quality impacts throughout Ector County. The model results indicate that SO_2 emissions from the intermittent flare releases had a significant effect on SO_2 air quality in Ector County. The model estimated that the oil and gas flare incidents were responsible for exceedances of the 1-hour SO_2 Primary NAAQS between 2014 and 2019 over an area of between 164 and 252 square miles within Ector County, depending on the three-year period. The 1-hour SO_2 Primary NAAQS was exceeded at eight of the twenty modeled discrete receptor locations (residences, businesses, ranches, churches, etc.) during the six-year modeling period (2014-2019).

APPENDIX A. Modeled Sources

Customer Name (CN)	RN Number	Facility	LAT	LON	stack height (m)	stack diameter (m)	exit velocity (m/s)	temperature (K)
OXY USA WTP LP	RN102199759	RHODES COWDEN UNIT CENTRAL BATTERY	31.953700	-102.470000	13.72	0.30	20.00	1273.00
(CN600125827)	RN102414307	JOHNSON GBSA UNIT CB	31.915537	-102.489732	7.62	0.30	20.00	1273.00
	RN102665148	RHODES COWDEN UNIT TRACT 3 SATELLITE	31.964300	-102.462900	13.72	0.30	20.00	1273.00
	RN104428909	RHODES COWDEN UNIT TRACT 4 SATELLITE	31.962800	-102.471000	13.72	0.30	20.00	1273.00
	RN102298460	BAGLEY A TANK BATTERY	31.872200	-102.414600	13.72	0.30	20.00	1273.00
	RN105609424	DORA ROBERTS RANCH UNIT TRACT 19 CTB	31.758055	-102.288055	13.72	0.30	20.00	1273.00
Citation Oil & Gas Corp.	RN110599032	JORDAN UNIVERSITY OIL UNIT AND WATER STATION	31.659100	-102.569450	6.10	0.30	20.00	1273.00
(CN600126536)	RN110573565	JORDAN UNIVERSITY UNIT SATELLITE 1	31.677950	-102.574800	6.10	0.11	20.00	1274.82
Devon Energy Production	RN105780795	RFD TANK BATTERY	31.700300	-102.382400	13.72	0.30	20.00	1273.00
Company, L.P.	RN102500782	MF HENDERSON 1	31.711500	-102.585800	13.72	0.30	20.00	1273.00
(CN600132344)	RN105780837	THELMA LOU OTIS TANK BATTERY	31.812900	-102.363800	13.72	0.30	20.00	1273.00
	RN106426786	MCELROY F BATTERY	31.523200	-102.285300	13.72	0.30	20.00	1273.00
	RN106426943	MCELROY H BATTERY	31.478500	-102.267700	13.72	0.30	20.00	1273.00
	RN106426976	MCELROY F 25 BATTERY	31.504300	-102.296600	13.72	0.30	20.00	1273.00
Oxy USA Inc. (CN600268296)	RN102516168	JL JOHNSON H TANK BATTERY	31.913900	-102.471100	13.72	0.30	20.00	1273.00
XTO Energy Inc.	RN106893795	CA GOLDSMITH SAT 541 SAT	31.922222	-102.652222	13.72	0.30	20.00	1273.00
(CN600601348)	RN102303211	GSAU CENTRAL BATTERY	31.925000	-102.627900	13.72	0.30	20.00	1273.00
	RN102304755	GOLDSMITH CAG CENTRAL TB	31.925000	-102.627900	13.72	0.30	20.00	1273.00
	RN103914248	CAG 731 TANK BATTERY	31.940000	-102.625600	6.10	0.30	20.00	1273.00
	RN103914354	CAG 437 SATELLITE BATTERY	31.911600	-102.608300	6.10	0.30	20.00	1273.00
	RN103914438	GSAU 2 2 SATELLITE BATTERY 1	31.947100	-102.597000	13.72	0.30	20.00	1273.00
	RN103914461	CAG CENTRAL BATTERY NO 448	31.935800	-102.616300	7.62	0.10	20.00	1273.00
	RN103914495	CAG 480 SATELLITE BATTERY	31.963700	-102.625800	13.72	0.30	20.00	1273.00
	RN104149414	GSAU 1 138 PUMP OUT	31.963600	-102.637500	13.72	0.30	20.00	1273.00
	RN104149430	GSAU 2 2 BATTERY	31.960000	-102.617000	6.10	0.10	0.91	1273.00
	RN104149844	GSAU 1 147 PUMP OUT	31.941300	-102.603600	13.72	0.30	20.00	1273.00
	RN104149927	GSAU 1 296 SATELLITE BATTERY	31.928300	-102.626300	13.72	0.30	20.00	1273.00
	RN105716047	GOLDSMITH C02 PILOT PHASE II FACILITY	31.923800	-102.619400	24.38	0.30	12.80	1273.00
	RN106893753	CA GOLDSMITH SAT 446	31.944000	-102.608900	13.72	0.30	20.00	1273.00
	RN106894330	CA GOLDSMITH SAT 511	31.929000	-102.644800	13.72	0.30	20.00	1273.00
	RN106902265	GOLDSMITH SAN ANDRES UNIT SAT 14	31.966649	-102.656325	13.72	0.30	20.00	1273.00
	RN106904238	GOLDSMITH SAN ANDRES UNIT SAT 120	31.956400	-102.635600	13.72	0.30	20.00	1273.00
	RN108344706	CAG 266 SATELLITE BATTERY	31.941700	-102.644040	9.14	0.30	20.00	1273.00
	RN103914453	GSAU 2 2 SATELLITE BATTERY 2	31.949440	-102.592500	13.72	0.30	20.00	1273.00
	RN106894603	CA GOLDSMITH SAT 541 PO	31.906740	-102.642246	13.72	0.30	20.00	1273.00
	RN104149463	GSAU 1 94 SATELLITE BATTERY	31.927220	-102.599400	13.72	0.30	20.00	1273.00
	RN104149968	GSAU 1 94 PUMP OUT 2	31.923330	-102.615300	13.72	0.30	20.00	1273.00
	RN106900889	GOLDSMITH SAN ANDRES UNIT SAT 296	31.928363	-102.626263	13.72	0.30	20.00	1273.00
	RN106894140	CA GOLDSMITH SAT 497	31.956338	-102.655869	13.72	0.30	20.00	1273.00
	RN106900921	GOLDSMITH SAN ANDRES UNIT SAT 1 47	31.946200	-102.614300	13.72	0.30	20.00	1273.00
	RN106901077	GOLDSMITH SAN ANDRES UNIT SAT 306	31.906090	-102.630646	13.72	0.30	20.00	1273.00
	RN102298643	GSAU 1 306 CO2 RECOMPRESSION FACILITY	31.917000	-102.641500	13.72	0.30	20.00	1273.00
	RN103914701	CAG 676 SATELLITE BATTERY	31.890800	-102.609600	13.72	0.30	20.00	1273.00
	RN104149471	GSAU 1 86 PUMP OUT	31.918100	-102.605200	13.72	0.30	20.00	1273.00
	RN104149919	GSAU 1 14 SATELLITE BATTERY	31.966900	-102.656100	13.72	0.30	20.00	1273.00
Occidental Permian Ltd.	RN102292885	RHODES A CENTRAL BATTERY	31.953700	-102.470000	13.72	0.30	20.00	1273.00
(CN600755086)	RN102412046	N COWDEN UNIT TS 16	32.014000	-102.506700	13.72	0.30	20.00	1273.00
	RN102412137	N COWDEN UNIT TEST STN 1	32.072900	-102.497800	13.72	0.30	20.00	1273.00
	RN102413135	OB HOLT R LEASE TB 1	32.061800	-102.507400	13.72	0.30	20.00	1273.00
	RN102413655	N COWDEN UNIT TS NO 25	31.970700	-102.493600	13.72	0.30	20.00	1273.00
	RN102413903	N COWDEN UNIT TS 26	32.007000	-102.495300	13.72	0.30	20.00	1273.00
	RN102414083	NORTH COWDEN UNIT SOUTH CENTRAL TANK BATTERY	32.009444	-102.510277	13.72	0.30	20.00	1273.00
	RN102416013	GSMITH LANDRETH DEEP ST12	31.996666	-102.641666	9.14	1.83	20.00	1255.37
	RN102416344	GLDU STATION 4	32.020100	-102.655700	13.72	0.30	20.00	1273.00
	RN102416476	GLDU STATION 9	32.025700	-102.658800	13.72	0.30	20.00	1273.00
	RN102417698	GOLDSMITH LANDRETH DEEP UNIT STATION 14	31.986300	-102.630000	9.14	0.30	20.00	810.93
	RN102418381	OB HOLT S TANK BATTERY	32.054000	-102.518000	13.72	0.30	20.00	1273.00
	RN102419959	FOSTER COOP STORAGE SYSTEM AND WATER INJECTION STATION	31.842800	-102.446500	6.10	0.05	18.29	294.26
	RN102420601	BH BLAKENEY A AND B LSE 1	32.026000	-102.541800	13.72	0.30	20.00	1273.00
	RN102421344	NORTH COWDEN CO2 INJECTION FACILITY	31.970700	-102.493600	13.72	0.30	20.00	1273.00
	RN102421369	N COWDEN UNIT TS 22	31.988900	-102.481000	13.72	0.30	20.00	1273.00
	RN102421625	N COWDEN UNIT TS 21	31.988900	-102.481000	13.72	0.30	20.00	1273.00
	RN102421716	GLDU STATION 8	32.016200	-102.672800	13.72	0.30	20.00	1273.00
	RN102421773	N COWDEN UNIT TS 15	32.043000	-102.486000	13.72	0.30	20.00	1273.00
	RN102421922	N COWDEN UNIT TS 20	32.007400	-102.483300	13.72	0.30	20.00	1273.00
	RN102422185	N COWDEN UNIT TS 19	31.999500	-102.502800	13.72	0.30	20.00	1273.00
	RN102422326	N COWDEN UNIT TS 18	31.992800	-102.520000	13.72	0.30	20.00	1273.00
	RN102517935	N COWDEN UNIT TEST STA 4	32.060000	-102.488800	13.72	0.30	20.00	1273.00
	RN102520467	GOLDSMITH LANDRETH DEEP UNIT STATION 3	32.015555	-102.686111	9.14	0.15	20.00	1273.00
	RN102530706	GOLDSMITH LANDRETH DEEP UNIT STATION 5	31.977600	-102.644700	9.14	0.15	20.00	1273.00
	RN102533965	N COWDEN UNIT TEST STN 3	32.031200	-102.491300	13.72	0.30	20.00	1273.00
	RN102590338	SOUTH FOSTER UNIT CENTRAL TANK BATTERY	31.847900	-102.422800	6.71	0.05	1.16	1255.37
	RN102598810	GOLDSMITH LANDRETH DEEP UNIT STATION 10	32.014000	-102.670500	9.14	0.30	20.00	810.93
	RN102751856	N COWDEN UNIT TEST STA 9	32.046600	-102.499500	13.72	0.30	20.00	1273.00
	RN102752920	GOLDSMITH LANDRETH DEEP UNIT STATION 6	31.996666	-102.641666	9.14	0.15	20.00	1273.00
	RN102817673	NORTH COWDEN TEST STATION 8	32.055400	-102.521000	13.72	0.30	20.00	1273.00
	RN102874062	N COWDEN UNIT TEST STA 10	32.041400	-102.514900	13.72	0.30	20.00	1273.00
	RN102898624	N COWDEN UNIT TEST STA 6	32.053500	-102.542600	13.72	0.30	20.00	1273.00
	RN102995461	N COWDEN UNIT TEST SATELLITE 11	32.037400	-102.532300	13.72	0.30	20.00	1273.00
	RN102995479	N COWDEN UNIT TEST SATELLITE 14	32.027600	-102.511900	13.72	0.30	20.00	1273.00
	RN102996055	N COWDEN UNIT TEST STA 23	31.983300	-102.499000	13.72	0.30	20.00	1273.00
	RN102996071	GOLDSMITH LANDRETH DEEP UNIT CTB AND SATELLITE 11	31.996000	-102.661700	7.32	0.09	20.00	1273.00
	RN103024170	GOLDSMITH LANDRETH DEEP UNIT STATION 1	32.016200	-102.672800	9.14	0.05	1.52	810.93
	RN102756756	N COWDEN UNIT TEST SAT 13	32.027000	-102.510300	13.72	0.30	20.00	1273.00

APPENDIX A. Modeled Sources

Customer Name (CN)	RN Number	Facility	LAT	LON	stack height (m)	stack diameter (m)	exit velocity (m/s)	temperature (K)
	RN102413416	N COWDEN UNIT TS 24	32.010982	-102.513793	13.72	0.30	20.00	1273.00
	RN105093835	NORTH COWDEN UNIT REINJECTON COMPRESSION FACILITY	32.020000	-102.523611	13.72	0.91	9.59	1273.00
	RN102995503	N COWDEN UNIT TEST ST 7	32.066000	-102.525000	13.72	0.30	20.00	1273.00
	RN102415163	GOLDSMITH BLAKENEY ANDRES	31.956300	-102.655900	13.72	0.30	20.00	1273.00
	RN102771995	GOLDSMITH LANDRETH DEEP UNIT STATION 1	32.016200	-102.672800	13.72	0.30	20.00	1273.00
	RN102412145	JE WITCHER SATELLITE 4	31.838250	-102.428670	6.10	0.10	0.29	1088.71
	RN102413796	F FOSTER SATELLITE 1	31.860000	-102.441300	13.72	0.30	20.00	1273.00
	RN102418761	JE WITCHER SATELLITE 1	31.852940	-102.432980	6.10	0.05	7.32	294.26
	RN102419686	GLDU STATION 13	31.977600	-102.671100	13.72	0.30	20.00	1273.00
	RN102420239	S FOSTER UNIT SAT A TB	31.854400	-102.421900	13.72	0.30	20.00	1273.00
	RN102421427	SOUTH FOSTER SATELLITE F	31.832700	-102.418000	7.62	0.61	20.00	1273.00
	RN102421856	GLDU STN NO 7	32.002730	-102.681720	13.72	0.30	20.00	1273.00
	RN102757184	SOUTH FOSTER UNIT SATELLITE G	31.836388	-102.410277	7.62	0.06	20.00	1273.00
	RN102877255	SOUTH FOSTER UNIT SAT D	31.847800	-102.412600	7.62	0.61	20.00	1273.00
	RN102943214	LAGUNA A STORAGE SYSTEM	31.826700	-102.424800	13.72	0.30	20.00	1273.00
	RN102416146	E F COWDEN B STORAGE SYSTEM AND SATELLITE	31.858251	-102.457686	13.72	0.30	20.00	1273.00
	RN106441454	FOSTER 8 TANK BATTERY	31.884500	-102.414360	13.72	0.30	20.00	1273.00
	RN108398405	NORTH COWDEN REINJECTION COMPRESSOR FACILITY	32.020000	-102.523000	13.72	0.30	20.00	1273.00
	RN108734252	GOLDSMITH LANDRETH DEEP UNTI NORTH CTB	32.021100	-102.669200	13.72	0.30	20.00	1273.00
	RN102419926	EF COWDEN SATELLITE NO 2	31.844000	-102.454900	13.72	0.30	20.00	1273.00
	RN102420189	FV ADDIS D SEPARATION FACILITY	31.820200	-102.450000	13.72	0.30	20.00	1273.00
	RN102309374	BP AMERICA NORTH COWDEN GASOLINE PLT	32.012200	-102.492500	13.72	0.30	20.00	1273.00
	RN102418589	JE WITCHER PA C AND 7	31.839800	-102.433500	13.72	0.30	20.00	1273.00
	RN105236426	MIDLAND FARMS UNIT NORTH FLARE	32.139600	-102.393500	13.72	0.30	20.00	1273.00
	RN108586108	GOLDSMITH LANDRETH DEEP UNIT NORTH CTB	32.013800	-102.672800	13.72	0.30	20.00	1273.00
DCP Operating Company, LP (CN601229917)	RN100209436	ANDECTOR BOOSTER STATION	32.041500	-102.681900	9.75	0.30	12.80	672.04
	RN100211549	DUKE ENERGY JUDKINS BOOSTER	31.716300	-102.597500	28.35	0.20	20.00	1255.37
	RN100222330	GOLDSMITH GAS PLANT	31.980900	-102.634400	30.48	0.40	65.53	1273.15
	RN102419421	CHAPEL HILL BOOSTER	32.031666	-102.512500	30.48	0.34	20.00	1088.71
	RN106320153	WIGHT BOOSTER STATION	31.924800	-102.626400	12.19	0.30	20.00	1273.00
DCP Midstream, LP (CN601229917)	RN100210954	COWDEN BOOSTER STATION	31.754600	-102.476900	13.72	0.30	20.00	1273.00
Four Star Oil & Gas Company (CN601284219)	RN100218890	HEADLEE COMPRESSOR STATION	31.870000	-102.301111	13.72	0.30	20.00	1273.00
ConocoPhillips Company (CN601674351)	RN102186830	GANDU 36 BATTERY	32.062700	-102.690900	7.62	0.15	20.00	1033.15
	RN102195955	CLYDE COWDEN BATTERY 1	31.933000	-102.583600	13.72	0.15	2.84	1033.15
	RN102881521	SOUTH FAULT BLOCK UNIT	32.048611	-102.679444	7.62	0.15	20.00	1033.15
	RN105969943	CLYDE COWDEN BATTERY 5	31.933000	-102.583700	13.72	0.15	11.90	810.93
	RN106153463	UNIVERSITY ANDREWS 1E and 11T BATTERY	32.117500	-102.712000	13.72	0.15	27.98	1033.15
	RN106248347	UNIVERSITY ANDREWS BATTERY 14T	32.137500	-102.738000	7.62	0.15	20.00	1033.15
	RN106262827	EMBAR 2 AND 6 BATTERY	32.080700	-102.690700	13.72	0.15	20.00	1033.15
	RN106274418	UNIVERSITY ANDREWS BATTERY 12T	32.119300	-102.740800	13.72	0.09	20.00	1033.15
	RN106336712	BUM A BATTERY	32.097200	-102.725600	7.62	0.15	20.00	1033.15
	RN106338825	MCENTIRE CENTRAL TANK BATTERY	32.048800	-102.693000	7.62	0.15	20.00	1033.15
	RN106503253	NPU 1 and MILLARD C TANK BATTERY	31.739000	-102.646800	13.72	0.30	20.00	1273.00
	RN106503261	CLYDE COWDEN SATELLITE 4	31.939000	-102.585400	13.72	0.30	20.00	1273.00
	RN106564750	CLYDE COWDEN BATTERY 2	31.920400	-102.585000	13.72	0.30	20.00	1273.00
	RN106597891	GANDU 26 FRANK B BATTERY	32.073070	-102.704100	13.72	0.30	20.00	1273.00
	RN106636236	CLYDE COWDEN BATTERY 7	31.943500	-102.582700	13.72	0.15	3.18	1033.15
	RN106833478	CLYDE COWDEN BATTERY 6	31.927463	-102.570541	13.72	0.15	7.29	1033.15
	RN107712127	GANDU SATELLITE 33	32.048800	-102.679500	13.72	0.15	20.00	1033.15
	RN107712135	GANDU SATELLITE 31	32.044300	-102.694700	13.72	0.15	20.00	1033.15
	RN108320300	FRANK B CLEARFORK	32.072380	-102.692000	13.72	0.30	20.00	1273.00
	RN108320508	GANDU SATELLITE 19	32.053900	-102.711000	13.72	0.30	20.00	1273.00
	RN108726639	MINNS BATTERY AND GANDU SATELLITE 21	32.031933	-102.703700	13.72	0.15	14.42	1033.15
	RN108790296	GANDU BATTERY 34	31.981000	-102.635000	13.72	0.30	20.00	1273.00
	RN109215442	EMBAR 2 - WCAB	32.048800	-102.679500	6.10	0.91	20.00	1273.00
	RN102194826	GANDU 25 BATTERY	32.043600	-102.698500	13.72	0.30	20.00	1273.00
	RN106264724	MILLARD A and D TANK BATTERY	31.739000	-102.646800	13.72	0.30	20.00	1273.00
	RN102295524	S COWDEN INJECTION FAC	31.760600	-102.380300	13.72	0.30	20.00	1273.00
	RN102198181	SOUTH COWDEN 6 BATTERY	31.753000	-102.384000	13.72	0.30	20.00	1273.00
	RN105778476	FRANK A BATTERY	32.043800	-102.695100	13.72	0.30	20.00	1273.00
	RN108790403	GANDU BATTERY 8	31.981000	-102.635000	13.72	0.30	20.00	1273.00
	RN106335573	EDWARDS E BATTERY	31.681800	-102.412100	13.72	0.30	20.00	1273.00
	RN105797880	GANDU CENTRAL TANK BATTERY	32.044700	-102.697700	13.72	0.30	20.00	1273.00
	RN106336316	MILLARD B TANK BATTERY	31.727500	-102.647000	13.72	0.30	20.00	1273.00
Burlington Resources Oil & Gas Company LP (CN602989436)	RN109961052	GANDU BATTERY 35	32.063000	-102.673100	13.72	0.30	20.00	1273.00
Chevron MidContinent, L.P. (CN603028317)	RN101931897	NORTH COWDEN CENTRAL TANK BATTERY	32.008800	-102.512000	13.72	0.30	20.00	1273.00
Kinder Morgan Production Company LLC (CN603227380)	RN105979363	GOLDSMITH LANDRETH SAN ANDRES CENTRAL UNIT	31.987000	-102.664000	15.24	0.08	20.00	1273.00
Linn Operating, LLC (CN603395690)	RN107097164	PATE TANK BATTERY	32.018100	-102.603960	13.72	0.30	20.00	1273.00
	RN107097289	RICHARD TANK BATTERY	32.002500	-102.582000	13.72	0.30	20.00	1273.00
	RN107098436	TRIPP JAMES TANK BATTERY	32.009300	-102.583800	13.72	0.30	20.00	1273.00
	RN107098741	JONAH TANK BATTERY	32.015130	-102.608640	13.72	0.30	20.00	1273.00
	RN107100224	ALLISON TANK BATTERY	32.019000	-102.592200	13.72	0.30	20.00	1273.00
	RN107096695	ANNABELLE TANK BATTERY	31.994000	-102.584800	13.72	0.30	20.00	1273.00
	RN107097693	HENRY CENTRAL TANK BATTERY	31.995840	-102.579300	13.72	0.30	20.00	1273.00
	RN107099079	CATHERINE ELAINE KIMBERLY TANK BATTERY	32.023200	-102.588100	13.72	0.30	20.00	1273.00

APPENDIX A. Modeled Sources

Customer Name (CN)	RN Number	Facility	LAT	LON	stack height (m)	stack diameter (m)	exit velocity (m/s)	temperature (K)
	RN107099806	GIDEON AND ELIZABETH TANK BATTERY	32.001000	-102.587000	13.72	0.30	20.00	1273.00
	RN107100182	ADAM TANK BATTERY	32.006900	-102.610300	13.72	0.30	20.00	1273.00
Cross Timbers Energy, LLC (CN604493007)	RN102305406	PENWELL SATELLITE 1	31.718900	-102.597000	13.72	0.30	20.00	1273.00
JAMES LAKE MIDSTREAM LLC (CN604509893)	RN107088759	JAMES LAKE GAS PLANT	31.963000	-102.599000	39.62	0.30	19.99	1273.15
OXY USA Inc. (CN604677401)	RN101949733	BLAKENEY OA TANK BATTERY	32.048300	-102.567400	13.72	0.30	20.00	1273.00
	RN102496916	JOHNSON DEEP UNIT	31.916200	-102.486100	13.72	0.30	20.00	1273.00
	RN102508215	LE WIGHT B TANK BATTERY	31.979400	-102.503300	13.72	0.30	20.00	1273.00
	RN102515202	CORRIGAN COWDEN UNIT TB	32.028000	-102.492900	13.72	0.30	20.00	1273.00
	RN104282645	SOUTH MOJO BOOSTER STATION	31.875555	-102.433611	27.43	0.91	20.00	1272.59
	RN110238953	CORRIGAN COWDEN SOUTH BATTERY	32.027600	-102.486900	13.72	0.30	20.00	1273.00
	RN101987022	FAY HOLT TANK BATTERY	32.043800	-102.554400	13.72	0.30	20.00	1273.00
Scout Energy Management LLC (CN605147479)	RN107098196	BATTERY 2	32.014000	-102.590100	13.72	0.30	20.00	1273.00
	RN107098931	SAMANTHA TANK BATTERY	32.024410	-102.609000	13.72	0.30	20.00	1273.00
	RN107099830	LOUISA TANK BATTERY	31.992600	-102.592400	13.72	0.30	20.00	1273.00

H. ANDREW GRAY

EDUCATION

Ph.D. environmental engineering science, California Institute of Technology, Pasadena, California, 1986

M.S. environmental engineering science, California Institute of Technology, Pasadena, California, 1980

B.S. civil engineering/engineering and public policy, Carnegie-Mellon University, Pittsburgh, Pennsylvania, 1979

EXPERIENCE

Dr. H. Andrew Gray has been performing research in air pollution for over 35 years, within academic, governmental, and consulting environments. He has made significant contributions in the areas of airborne particles and visibility, including the development and application of computer-based air quality models. His areas of expertise are air pollution control strategy design and evaluation, computer modeling of the atmosphere (including AERMOD, CALPUFF, CAMx, etc.), characterization of ambient air quality and air pollutant source emissions, aerosol monitoring and modeling, visibility analysis, receptor modeling, statistical data analysis, mathematical programming, numerical methods, and analysis of environmental public policy. Dr. Gray is currently an independent contractor focusing on particulate matter and visibility related research issues. Previous Gray Sky Solutions projects include assessment of Clean Air Act and other regulations on visibility in Class I (park and wilderness) areas, development of air pollution control plans and emission inventories for tribal lands, review and development of guidelines for modeling long-range transport impacts using the CALPUFF model, evaluation of particulate air quality impacts associated with diesel exhaust emissions, air quality management plan modeling protocol review, a critical review of Clean Air Mercury Rule (CAMR) documents, and assessment of the regional air quality impacts of power plant emissions. Dr. Gray has performed dispersion modeling studies to determine the impacts associated with mercury emissions in the Chesapeake Bay region, and has evaluated the air quality, visibility and health impacts of numerous electric generating facilities, industrial sources, and container ship traffic. Recently, Dr. Gray worked with a team of researchers to evaluate the health effects due to coal-fired power plant emissions throughout China. Dr. Gray was invited by the Royal Institute of International Affairs to participate in the "Balancing Global Energy Policy Objectives: A High-Level Roundtable" meeting in April 2014.

Before starting Gray Sky Solutions, Dr. Gray was the manager of the PM_{10} and Visibility Program at Systems Applications International (SAI / ICF Inc.). At SAI, Dr. Gray conducted and managed a number of varied air pollution research projects. In the early 1990s, Dr. Gray directed a large (over $1 million) air-quality modeling program to determine the impact of SO_2 emissions from a large coal-fired power plant on Grand Canyon sulfate and visibility levels. He managed projects to develop carbon particle emission data for the Denver area, designed a PM_{10} monitoring and modeling program for the El Paso area, determined the appropriate tradeoffs between direct PM_{10} emissions and emissions of PM_{10} precursors, estimated the visibility effects in federal Class I areas due to the 1990 Clean Air Act Amendments (results of which were incorporated into EPA's 1993 Report to Congress on the expected visibility consequences of the 1990 Clean Air Act Amendments), and provided assistance to EPA Region VIII's tribal air programs. Other projects include emission inventory development for Sacramento and carbon monoxide modeling of Phoenix, Arizona to support federal and regional implementation plans in those regions, systematic evaluation of the Interagency Workgroup on Air Quality Modeling (IWAQM) recommendations for the use of MESOPUFF II, a critical assessment of exposures to particulate diesel exhaust in California, and an evaluation of $PM_{2.5}$ and PM_{10} air quality data in support of EPA's review of the federal particulate matter air quality standards. Later projects included a study of micrometeorology and modeling of low wind speed stable conditions in the San Joaquin Valley (CA), an assessment of the reductions in nationwide ambient particulate nitrate exposures due to mobile source NO_X emission reductions, an evaluation of visibility conditions in the Southern Appalachian Mountains region, a review of cotton ginning emission factors, and a critical review and assessment of the PM_{10} Attainment Demonstration Plan for the San Joaquin Valley. Dr. Gray was a member of the modeling subcommittee of the technical committee of the Grand Canyon Visibility Transport Commission.

Previous to his tenure at SAI, Dr. Gray was responsible for the PM_{10} and visibility programs at the South Coast Air Quality Management District which involved directing monitoring, analysis, and modeling efforts to support the design of air pollution control strategies for the South Coast Air Basin of California. He developed and applied the methodologies for assessing PM_{10} concentrations that were used by the District through numerous subsequent air quality management plan revisions. Dr. Gray authored portions of the 1989 Air Quality Management Plan issued by the District that describe the results of modeling and data analyses used to evaluate particulate matter control strategies. Dr. Gray was instrumental in promoting the development and application of state-of-science models for predicting particulate matter concentrations. His responsibilities included direction and oversight of numerous aerosol-related contracts, including development of the SEQUILIB and SAFER models, construction of an ammonia emission database, and development of sulfate, nitrate and organic chemical mechanisms. In addition, Dr. Gray was responsible for initiating the District's visibility control program.

In research performed at the California Institute of Technology, Dr. Gray studied control of atmospheric fine primary carbon particle concentrations and performed computer programming tasks for acquisition and analysis of real-time experimental data. He designed, constructed, and operated the first long-term fine particle monitoring network in Southern California in the early 1980s. He also developed and applied deterministic models to predict source contributions to fine primary carbon particle concentrations and constructed objective optimization procedures for control strategy design. In research carried out for the Department of Mechanical Engineering at Carnegie-Mellon University, Dr. Gray developed fuel use data for input to an emission simulation model for the northeastern United States.

Specialized Professional Competence

- Air pollution control strategy design
- Atmospheric air quality characterization
- Aerosols and visibility
- Computer modeling and data analysis
- Dispersion modeling for particulate matter and visibility

- Receptor modeling including Chemical Mass Balance (CMB) and factor analysis
- Analysis of environmental public policy

Professional Experience

- Systems Applications International (SAI/ICF)—PM_{10} and visibility program manager—participated in and managed numerous air quality modeling and analysis projects for public and private sector clients, with emphasis on particulate matter and visibility research
- South Coast Air Quality Management District, El Monte, California—air quality specialist—developed and applied air quality modeling analyses to support air pollution control strategy design for the South Coast Air Basin of California
- California Institute of Technology, Pasadena, California—research assistant—Ph.D. candidate in environmental engineering science. Thesis: Control of atmospheric fine primary carbon particle concentrations (thesis advisors: Dr. Glen Cass, Dr. John Seinfeld, and Dr. Richard Flagan)
- California Institute of Technology, Pasadena, California—laboratory assistant—performed computer programming tasks for acquisition and analysis of real-time experimental data
- Department of Mechanical Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania—research assistant—developed fuel use data for an emissions simulation model for the northeastern United States. Grant from the U.S. Department of Energy for evaluation of national energy policy
- Department of Civil Engineering, Carnegie-Mellon University, Pittsburgh, Pennsylvania—consultant—analyzed structural retrofit design for Ferrari Dino import automobile for United States five mph crash test

HONORS AND AWARDS

Harold Allen Thomas Scholarship Award, Carnegie-Mellon University

University Honors, Carnegie-Mellon University

PROFESSIONAL AFFILIATIONS

Air and Waste Management Association

American Association for Aerosol Research

SELECTED PUBLICATIONS AND PRESENTATIONS

The Deposition of Airborne Mercury within the Chesapeake Bay Region from Coal-fired Power Plant Emission in Pennsylvania, in press (2012)

Peer Review of the Interagency Workgroup On Air Quality Modeling Phase 2 Summary Report And Recommendations For Modeling Long Range Transport Impacts (with others), Report compiled by: John S. Irwin, Air Policy Support Branch, Atmospheric Sciences Modeling Division, U.S. Environmental Protection Agency Research Triangle Park, NC 27711 (1999)

Source Contributions to Atmospheric Fine Carbon Particle Concentrations (with G.R. Cass), *Atmospheric Environment*, 32:3805-3825 (1998)

"Monitoring and Analysis of the Surface Layer at Low Wind Speeds in Stable PBL's in the Southern San Joaquin Valley of California" (with others), presented at the American Meteorological Society's 12th Symposium on Boundary Layers and Turbulence, Vancouver, British Columbia (July 1997)

"Estimation of Current and Future Year NOx to Nitrate Conversion for Various Regions of the United States" (with A. Kuklin), presented at the 90th Meeting of the Air and Waste Management Association, Toronto, Ontario (June 1997)

Integrated Monitoring Study (IMS) 1995: Characterization of Micrometeorological Phenomena: Mixing and Diffusion in Low Wind Speed Stable Conditions: Study Design and Preliminary Results (with others), in *Measurement of Toxic and Related Air Pollutants*, Air and Waste Management Association, Pittsburgh, Pennsylvania, pp. 484-500 (1996)

Regional Emissions and Atmospheric Concentrations of Diesel Engine Particulate Matter: Los Angeles as a Case Study (with G.R. Cass), in *Diesel Exhaust: A Critical Analysis of Emissions, Exposure, and Health Effects*, Health Effects Institute, Cambridge, Massachusetts, pp. 125-137 (1995)

"Assessment of the Effects of the 1990 Clean Air Act Amendments on Visibility in Class I Areas", presented at the 86th Annual Meeting & Exhibition of the Air and Waste Management Association, Denver, Colorado (June 1993)

"Source Contributions to Atmospheric Carbon Particle Concentrations" (with others), presented at the Southern California Air Quality Study Data Analysis Conference, Los Angeles, California (July 1992)

"Modeling Wintertime Sulfate Production in the Southwestern United States" (with M. Ligocki), presented at the AWMA/EPA International Specialty Conference on PM10 Standards and Nontraditional Particulate Source Controls, Scottsdale, Arizona (January 1992)

"Deterministic Modeling for the Navajo Generating Station Visibility Impairment Study: An Overview," presented at the 84th Meeting of the Air and Waste Management Association, Vancouver, British Columbia (June 1991)

"Receptor and Dispersion Modeling of Aluminum Smelter Contributions to Elevated PM10 Concentrations" (with R. G. Ireson and A. B. Hudischewskyj), presented at the 84th Meeting of the Air and Waste Management Association, Vancouver, British Columbia (June 1991)

Visibility and PM-10 in the South Coast Air Basin of California (with J.C. Marlia), in *Visibility and Fine Particles,* Air and Waste Management Association, Pittsburgh, Pennsylvania, pp. 468-477 (1990)

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EMPLOYMENT HISTORY

Systems Applications International	Manager, PM_{10} and Visibility Program	1989–1997
South Coast Air Quality Management District	Air Quality Specialist	1985–1989
California Institute of Technology, Pasadena, California	Research Assistant Laboratory Assistant	1979–1985 1979
Carnegie-Mellon University, Dept. of Mechanical Engineering Pittsburgh, Pennsylvania	Research Assistant	1978–1979